VCI2016 - The 14th Vienna Conference on Instrumentation

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Book of Abstracts
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Plenary 1 / 449

New Opportunities for the Time Projection Chamber in its Fourth Decade

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Now in its fourth decade, the Time Projection Chamber (TPC) idea continues to find new and novel applications in nuclear and particle physics, rare longevity in the arsenal of experimental techniques. I examine some of the recent implementations as exemplars of the scientific aspirations, with focus on a bizarre idea to exploit single molecule fluorescent imaging as a means to identify the birth of the barium daughter in double-beta decays of 136Xe. Efficient 'tagging' of the barium daughter would eliminate essentially all backgrounds due to radioactivity, opening a path to the realization of a true ton-scale 'Discovery Class' experiment based on a modular high-pressure xenon gas TPC concept.

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Dark Matter Detectors

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Recent Developments in Silicon Detectors

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The talk will give a (selective) overview of developments in recent years on silicon detectors, in particular those developments which are challenged by new demands on particle tracking and vertexing from coming-up new experiments and upgrades.

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The ultralight DEPFET Pixel Detector of the Belle II Experiment

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An upgrade of the existing Japanese flavor factory (KEKB in Tsukuba, Japan) is under construction, and foreseen for commissioning by the end of 2017. This new $e^+e^-$ machine (SuperKEKB) will deliver an instantaneous luminosity 40 times higher than the world record set by KEKB.

In order to be able to fully exploit the increased number of events and provide high precision measurements of the decay vertex of the B meson systems in such a harsh environment, the Belle detector will be upgraded (Belle II) and a new silicon vertex detector, based on the DEPFET technology, will be designed and constructed. The new pixel detector, close to the interaction point, will consist on two layers of DEPFET active pixel sensors. This technology combines the detection together with the in-pixel amplification by the integration, on every pixel, of a field effect transistor into a fully depleted silicon bulk. In Belle II, DEPFET sensors thinned down to 75 μm with low power consumption and low intrinsic noise will be used. The first large thin multichip production modules have been produced and the characterization results will be presented in this contribution.

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The upgraded Pixel Detector of the ATLAS experiment for Run-2 at the Large Hadron collider.

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Run-2 of the LHC is providing new challenges to track and vertex reconstruction with higher energies, denser jets and higher rates. Therefore the ATLAS experiment has constructed the first 4-layer Pixel detector in HEP, installing a new Pixel layer, also called Insertable B-Layer (IBL).

IBL is a fourth layer of pixel detectors, and has been installed in May 2014 at a radius of 3.3 cm between the existing Pixel Detector and a new smaller radius beam-pipe. The new detector, built to cope with high radiation and expected occupancy, is the first large scale application of 3D detectors and CMOS 130nm technology. In addition the Pixel detector was refurbished with a new service
quarter panel to recover about 3% of defective modules lost during run-1 and a new optical readout system to readout the data at higher speed while reducing the occupancy when running with increased luminosity.

The commissioning and performance of the 4-layer Pixel Detector, in particular the IBL, will be presented, using collision data.

**primary experiment:**

**ATLAS Summary:**

The IBL detector construction was achieved within about two years starting from mid-2012 to the May 2014 installation in ATLAS, a very tight schedule to meet the ATLAS installation and detector closure before starting the Run2 in Spring 2015.

The key features and challenges met during the IBL project were:

- Industrialisation and integration of two sensor technologies (Planar and 3D) on one single stave layout.
- Bump-bonding of thin front-end electronics and sensors. This requirement was met by gluing a sapphire glass substrate to the FEI4 wafer for all the processing steps and later detached it by laser debonding technique after the flip-chip, before the module delivery for further assembly.
- Largest FE area design and process in 130 nm technology for a tracker in high energy physics. Thanks to its large area it was possible to maximise the active area and reduce the bump bonding cost.
- Global IBL envelope of less than 10mm between the Pixel Detector and the beam pipe that led to optimise the mechanics, the services, and the fitting. Consequently this was a challenge for integration, installation and the beam pipe bake-out.
- Minimisation of the stave material budget. This constraint requested to have the service bus tightly integrated with the stave. A mix of two aluminium power layers and four copper layers for service lines like clock, command, data, HV and, DCS was developed.
- Development of the Type 1 electrical services for power and long (~4 m) data transmission wires. The high density pin connectors had to be designed and fabricated on purpose to match the limited space for integration.
- Module thermo-mechanical interface with the local stave support considering the following main requirements: interface reliability and reproducibility, radiation hardness and, replaceability of a module without damaging the neighbouring ones, the stave and the service flex wings integrity.
- Design, development and qualification of cooling pipe connections and electrical insulation for the grounding and shielding.
- Servicing the cooling in the detector region with respect to the space and thermal insulation requirements. It requested R&D design and fabrication of flexible vacuum transfer lines that could not be transferred to industry for time reasons and had to be produced in-house.
- Sealing and high level of requirement for low dew point temperature inside the detector volume with CO2 cooling down to freezing point (-55 C)
- Installation of the cooling plant and the long vacuum transfer line (~100 m) to the junction box and a dummy load installed close to the IBL and inside the Muon detector. Two cooling plants with 3kW capacity each have been installed and independently controlled such that they could run either in complementary operational mode, standby while the other one is running, or in parallel which was mainly used during the bake-out. The latter operational mode allows reinforcing the cooling power capability almost doubling the flow and the safety level in case of failure of one of the plants.

During the two years of production and integration two major issues affected the schedule which led to several months of break for understanding, reworking and improving the production and the integrated components. The first one is related to the bump bonding yield issue which happened at the beginning of the production and was found only for few batches. The major problem observed was related to merge and open bumps, which was fixed by changing the tacking method and the flip-chip machine.
The second one is related to wire bonding corrosion which was accidentally discovered on most of the already produced staves at the middle of the production. The conclusions of all investigations is to recommend to protect the wire bond foot with encapsulation or potting against water immersion which was not possible to implement on the IBL detector due to schedule constrains and given the required time for implementing and qualifying the technique. The final and reviewed decision was to leave the IBL detector with unprotected wire bonds and to guarantee at all stages of the integration, installation and operation phases a safe level of dryness. During commissioning, it was found that the particularities of the IBL mechanical structures lead to deformation of the structure due to mechanical constrains induced by the low temperature. A larger than expected thermally-induced $r$-$\phi$ "twisting" of IBL staves was observed at the level of few $\mu$m/K that was mapped out with large cosmic rays samples. It required refinements of operating procedures, but no impact on data quality is presently foreseen. This effect is currently managed via a careful temperature control at the level of $\sim 0.2$ K as recently measured.

To summarise, the challenges helped the IBL community to focus and excel in the technology and engineering field of competence with a very positive and constructive result. The main issues met and reported above were very instructive and allowed the community to make the relevant effort to correct and improve the detector production and operation. All of this was an excellent lesson for the future work to consider a next generation of pixel detectors.

Plenary 2 / 250

How can Moore’s Law help making better detectors?

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A prophetic and risky prediction made more than half a century ago in the then obscure field of “integrated electronics” has changed profoundly every manufacturing, computing and communication technology that we can imagine.

Also in experimental physics, microelectronics has changed not only the speed at which we can read and manipulate data from detectors, but has also allowed designers to sense smaller signals, measure shorter time intervals, improve spatial resolution of detectors, and all this at much lower power consumption than ever before.

Commercial applications of this technology continue to push the performance of innumerable devices that are built based on it. The latest innovations offered by this technology are likely to have an impact on the design of future detectors and experiments that will be as dramatic as those of the last 20 years. This presentation will give a glimpse on what these coming technologies might be and hint at how they could be adapted beneficially to instrumentation for particle and nuclear detectors.

primary experiment:

LHC

Plenary 2 / 1

Development of Ultra Fast Silicon Detector for 4D tracking

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Development of Ultra Fast Silicon Detector for 4D tracking

In this contribution I will review the progress towards the development of a new type of silicon detectors suited for picosecond tracking, the so called Ultra-Fast Silicon Detectors, designed to obtained concurrent precisions of ~ 10 picoseconds and ~ 30 microns with a 50 micron thick sensor. UFSD are based on the concept of Low-Gain Avalanche Detectors, which are silicon detectors with an internal multiplication mechanism so that they exhibit a signal which is a factor of ~ 10 larger than standard silicon detectors. This increased signal makes LGAD ideal for many applications, ranging from experiments requiring very low material budgets, to very high radiation environment, to applications that need very precise timing.

The basic design of UFSD consists of a thin silicon sensor with moderate internal gain and pixelated electrodes coupled to full custom VLSI chips. An ultra-fast thin silicon sensor represents a new frontier in silicon sensor design and the development of a thin sensor combined with charge multiplication presents a major challenge.

UFSD detectors are now considered in the proposal of the CT-PPS for the forward CMS tracker and for the upgrade of the ATLAS forward calorimeter.

I will report on first sensor measurements, the plan for future productions and the initial progress towards the development of the read-out electronics.

Plenary 2 / 32

Level-1 track trigger for CMS in HL-LHC

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The High Luminosity LHC (HL-LHC) is expected to deliver luminosities of $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$, with an average number of overlapping proton-proton collisions per bunch crossing of up to 200. However, a higher number of particle interactions per bunch crossing presents huge challenge to the experiments, as their trigger systems are not designed to accommodate the anticipated rates. For luminosity levels expected after the HL-LHC upgrade of the accelerator, the solution to the problem is to use silicon tracker data at a very early stage of triggering. A key component of the CMS upgrade for HL-LHC is a track trigger system which would identify tracks with transverse momentum above 2 GeV/c already at the first-level trigger. However, due to high bunch-crossing rates, as well as the size and high occupancy of the detectors, there is an enormous challenge in implementing a track trigger. Three different proposals for implementing Level-1 tracking at CMS are presented. The proposed architectures are discussed along with the status of current hardware prototypes and anticipated performance from simulation. Plans for the future development are also outlined.

Art and History of Vienna / 450

Art and History of Vienna

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The city of Vienna was essentially founded by the ancient Romans. In the late middle ages, it became the capital of the Habsburg Empire, and consequently grew in size and importance. Even though
there are some Roman excavations, most of the architectural heritage originates from the monarchy. In particular, the turn of the 19th to 20th centuries was undoubtedly a peak in many aspects of arts and culture, and even the population of Vienna was then higher than today. Nonetheless, the monarchy terminated almost hundred years ago and gave way to modernism. All periods of fine arts are represented in Vienna, by architecture as well as in museums. In addition, performing arts and classical music are offered in various places. This presentation will provide an overview of the history of Vienna, the periods of art and where to spot them, with a particular focus on the locations where social events will take place during this conference.

Plenary 3 / 446

Recent Progress in Photodetectors

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The paper will review recent progress in photodetectors: vacuum based detectors (PMTs, MCP PMTs), solid state detectors (SiPMs, APDs) and hybrid detectors (HPD, HAPDs). It will discuss advances in photon detection efficiency, timing properties, as well as improvements in radiation hardness, resistance against ageing and suppression of internal noise. As a motivation for these improvements it will also discuss several applications that drive this progress in the fields of experimental particle physics (in particular RICH and DIRC type counters, and calorimeters) and in detectors for medical imaging (TOF PET).

Plenary 3 / 17

SciFi - A large Scintillating Fibre Tracker for LHCb

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The LHCb detector will be upgraded during the Long Shutdown 2 (LS2) of the LHC in order to cope with higher instantaneous luminosities and to read out the data at 40MHz using a trigger-less readout system. All front-end electronics will be replaced and several sub-detectors must be redesigned to cope with higher occupancy. The current tracking detectors downstream of the LHCb dipole magnet will be replaced by the Scintillating Fibre (SciFi) Tracker. Concept, design and operational parameters are driven by the challenging LHC environment including significant ionising and neutron radiation levels. Over a total active surface of 360 m² the SciFi Tracker will use scintillating fibres (Ø 0.25 mm) read out by Silicon Photomultipliers (SiPMs). State-of-the-art multi-channel SiPM arrays are being developed to read out the fibres and a custom ASIC will be used to digitise the signals from the SiPMs. The project is now at the transition from R&D to series production. We will present the evolution of the design and the latest lab and test beam results.

primary experiment: LHCb

Summary:

The LHCb SciFi tracker [1] is designed to replace the current Outer Tracker (based on gas drift tubes) and the Inner Tracker (silicon microstrips). It consists of 3 tracking stations with 4 independent planes each (X-U-V-X, stereo angle ±5°) and extends over 6 m in width and 4.8 m in height (see Fig. 1). Blue emitting scintillating plastic fibres of type SCSF-78MJ from Kuraray with 250 μm diameter are arranged in a staggered close-packed geometry to 6-layer fibre mats. The mats are 2.4 m long and mirrors applied to the non-read end. The scintillation light exiting at the other end is detected by linear arrays of SiPM
detectors (128 channels of $0.25 \times 1.6 \text{ mm}^2$ size). As shown in Fig.1, the height of a SiPM channel (1.6 mm) extends over all 6 layers of the fibre mat. The pitch (0.25 mm) allows resolving the clusters of hit fibres of typically 2 or 3 channels width. The signals are therefore read out with fully customised 3-threshold electronics which shall push the spatial resolution beyond the digital resolution $D_{\text{fibre}}/\sqrt{12} = 72 \mu\text{m}$. Reading and processing the signals from 600'000 SiPM channels at a rate of 40 MHz is a major challenge requiring a dedicated FE chip as well as massive use of FPGAs and state-of-the-art optical links.

While the chosen technology - staggered fibre mats with SiPM array readout - has been previously demonstrated in the PerdAIX balloon experiment [2], the LHCb requirements and the environment push it to the limits in several respects. The scintillation light has to travel up to 2.4 m, the reflected light even up to 4.8 m, before it can be detected by the SiPM. This requires 250μm fibres of particularly long attenuation length (>3m) which is a challenge for the fibre producers. With a propagation delay of 6 ns/m there may be spill-over effects into the next bunch crossing.

The ionising dose in the inner region close to the LHCb beampipe is expected to reach 35 kGy, fortunately falling off to values of about 50 Gy close to the SiPMs. This means however that radiation damage affects mainly the light from the inner part which has anyway already the longest path the SiPM. The SiPMs, located more than 2.4 m above and below the beampipe, are exposed only to small ionizing doses, however they suffer from a 1 MeV equivalent neutron fluence of up to $1.2 \cdot 10^{12} \text{cm}^{-2}$ (without dedicated shielding). Proportional to the neutron fluence, the leakage current (or, equivalently, the dark noise rate) of the SiPMs rises to values which de facto makes them unusable. Normal operation can be restored by cooling the SiPMs, which suppresses the noise rate by a factor of about $2\Delta T/10$. The SiPMs in the LHCb SciFi Tracker are therefore foreseen to operate at -40°C. Full-size fibre module have been prototyped and were tested in particle beams. Close-to-final versions of the SiPM arrays and the readout electronics are available. The project is now at the transition to series production and on track for installation during the LHC shutdown LS2.

References:


Plenary 3 / 82

SoLid: An innovative antineutrino detector for searching oscillations at the SCK•CEN BR2 reactor

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The SoLid experiment intends to search for active-to-sterile anti-neutrino oscillation at the very short baseline of the SCK-CEN BR2 research reactor (Mol, Belgium). A novel detector approach to measure reactor anti-neutrinos was developed based on an innovative sandwich of composite Polyvinyl-Toluene and 6LiF:ZnS scintillators. The system is highly segmented and read out by a network of wavelength shifting fibers and MPPCs. High experimental sensitivity can be achieved compared to other standard technologies thanks to the combination of high granularity, high neutron-gamma discrimination using 6LiF:ZnS(Ag) scintillator and precise localisation of the Inverse Beta Decay products. This technology can be considered as a second generation antineutrino detector. This compact system requires limited passive shielding and relies on spatial topology to determine the different classes of backgrounds. We will describe the principle of detection and the detector design. Particular focus on the neutron discrimination will be made, as well as on the capability to use cosmic muons for channel equalization and energy calibration. The performance of the first full scale SoLid module 1 (SM1), based on the data taken at BR2 in February 2015, will be presented. We will conclude with the next phase, that will start in 2016, and the perspectives of the experiment.
From gated to continuous readout: an upgrade of the ALICE TPC

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A large Time Projection Chamber is the main device for tracking and charged particle identification in the ALICE experiment at the CERN LHC. After the second long shutdown in 2019/20, the LHC will deliver Pb beams colliding at an interaction rate of about 50 kHz, which is about a factor of 100 above the present read-out rate of the TPC. This will result in a significant improvement on the sensitivity of rare probes that are considered key observables to characterise the QCD matter created in such collisions. In order to make full use of this luminosity, a major upgrade of the TPC is required. The presently employed gating of the TPC wire chambers must be abandoned and continuously operated readout detectors using GEMs will be implemented.

To fulfill the challenging requirements of the upcoming upgrade, a novel configuration of GEM detectors has been developed. It allows to maintain excellent particle identification and efficient ion trapping by stacking four GEM foils operated under specific field configuration. Results of an extensive R&D program concerning ion backflow suppression, d\(E\)/d\(x\) resolution and stability against discharges will be presented. The status of the upgrade of the online calibration and data reduction system, as well as the development of a new readout electronics will be reported. We will also discuss the detector production phase, which is just starting.

\textbf{primary experiment:} ALICE

\textbf{Summary:}

Ungated operation of the ALICE TPC in the high-multiplicity environment of Pb-Pb collisions at 50\,kHz after LS2 will lead to a considerable accumulation of positive ions in the drift volume that emerge from the amplification region. The resulting space-charge distortions must be kept within limits that allow efficient online track reconstruction and distortion corrections.

The use of Gas Electron Multiplier foils offers an intrinsic ion backflow (IBF) suppression. IBF is defined as a ratio of the (ion) current measured at the cathode divided by the (electron) current measured at the readout anode. A final value of \(< 1\%\) should be achieved for the purposes of the ALICE TPC in order to avoid major distortions of the drift field. Extensive tests were carried out with different kinds of small prototypes to measure the IBF as a function of different voltage settings and gas mixtures. It was found that the best results can be obtained employing a four-GEM stack using foils with different optical transparencies, i.e. varying the pitch between GEM holes. The IBF in such a system can be reduced to the level of 0.6\% (in standard ALICE TPC Ne-CO\textsubscript{2}-N\textsubscript{2} (90-10-5) gas mixture) keeping the energy resolution at the acceptable level of 12\% as measured with an \(^{55}\text{Fe}\) source (see Fig. 1).

\textbf{Figure 1. Energy resolution at 5.9 keV and ion backflow for different GEM voltages.}

In addition, an extensive discharge probability studies have been performed to assure the stability of a chosen solution. Upper limits for the discharge probability upon irradiation with alpha particles (at a
gas gain of 2000) are found to be of the order of $10^{-10}$. This number is compatible with that for standard triple GEM systems that are operated routinely in high-rate experiments.

In order to check the feasibility of the upgrade solution, full-scale prototypes of Inner (IROC) and Outer (OROC) Readout Chambers have been built. Energy resolution of the four-GEM IROC was evaluated at the test-beam at CERN/PS with a beam of 1 GeV/c electrons and pions. The relative energy resolution was measured to be $<10\%$, comparable with the currently operated MWPC-based chambers. In a test-beam at the CERN/SPS, the detector was exposed to an intense hadron flux from a secondary production target. The measured discharge probability of $(6 \pm 4) \times 10^{-12}$ is compatible with an efficient and safe operation of the TPC in RUN 3 and beyond.

The four-GEM OROC prototype was assembled and successfully operated in 2015, being the largest detector of this type up to date. We therefore provide evidence that with the quadruple GEMs a solution exists which provides the performance and robustness needed for the ALICE TPC upgrade.

The start of the mass production of the readout chamber for the upgraded ALICE TPC is planned at the beginning of 2016. All the readout chambers are planned to be assembled until Q1.2019, when the LS2 is supposed to start and the TPC will be moved to the surface. Installation and commissioning of the chambers will last until the end of 2020.

**Plenary 3 / 296**

**Strategies for reducing the environmental impact of gaseous detector operation at the CERN LHC experiments**

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A wide range of gas mixtures is used for the operation of different gaseous detectors at LHC. Nowadays some of these gases, as C2H2F4, CF4 and SF6, are indicated as greenhouse gases (GHG) and dominate the overall GHG emission at LHC. The release of GHG is an important subject for the design of future particle detectors as well as for the operation of the current experiments. The different strategies adopted at CERN for reducing the GHG emissions from gaseous detectors at LHC are presented.

The standard approach is the recirculation of the gas mixture by the use of complex gas systems made of several functional modules. Besides their complexity, the stability of the system as well as the accumulation of impurities, need to be attentively evaluated for the good operation and safety of the detectors.

A second approach is based on the recuperation of the used gas mixture and the separation of its gas components for re-use. As state-of-the-art example, the CF4 recuperation plant based on warm separation developed for the CMS Cathode Strip Chamber system will be reviewed.

As a long-term perspective, the use of less invasive gases is also being investigated. An overview of environmental friendly gas possibilities will be discussed.

**primary experiment:**

All LHC experiments  **Summary:**

A wide range of gas mixtures is used for the operation of different gaseous detectors, depending on their technologies and physics purpose. Nowadays some of these gases, as C2H2F4, CF4 and SF6, are marked as greenhouse gases (GHG) with Global Warming Potential of 1430, 6500 and 23900, respectively. These three gases are widely employed in the four LHC experiments mainly for the Resistive Plate Chambers (RPC), Cathode Strip Chambers (CSC) and Gas Electron Multiplier (GEM) detectors, producing a considerable GHG emission value (Figure 1). The release of GHG is an important subject for the design of future particle detectors as well as for the operation of the current experiments: the European Union “F-gas regulation” restricts or bans the use of fluorinated gases to limit their environmental impact. Furthermore, even if these gases will always be available for research purposes, their cost will probably increase due to a decrease in the industrial production.
Several strategies have been adopted at CERN for reducing the GHG emissions by gaseous detectors. A common and efficient approach is the recirculation of the gas mixture by using complex gas systems. Besides their complexity, the stability of the system and the accumulation of impurities need to be attentively evaluated for good and safe detector operation. It has been demonstrated that impurities and fluorine species can be created by radiation if F-based gases are used and, by accumulation in the recirculated gas, they can affect the detector operation (Figure 2). Extensive studies have been conducted in the past for RPCs and are nowadays on-going for GEM-based detectors. The latter are often operated with a very high fraction of CF4 (up to 40%) to reach a high time resolution. A new compact and flexible LHC-like gas recirculation system has been developed both for R&D and laboratory activities, which contribute significantly to reduce the emission of GHGs at CERN and in worldwide laboratories. A triple GEM detector has been tested for the first time in gas recirculation by monitoring current, gas gain and the creation of impurities. Several experimental conditions have been studied demonstrating that fluoride species are created and accumulate, as well as O2 and H20, resulting in an increased recirculation fraction (Figure 3). Gas purification modules are therefore necessary and specific cleaning agents have been characterized for the LHC gas systems to absorb a wide spectrum of impurities. These studies have been applied for the design of the new gas recirculation for the LHCb GEM that will pave the way for a better understanding of GEM behaviour at high rate with gas recirculation for future applications.

A second approach to minimize the gas consumption is based on the recuperation of the small exhausted flow from recirculation systems and subsequent separation of the gas components for re-use. An example is the CF4 recuperation plant based on warm separation developed for the CMS CSC system. The recuperation process is based on CO2 bulk separation through membrane, CO2 residual absorption in 4 Å molecular sieve and final CF4 adsorption in 13X molecular sieve (Figure 4). The recuperation plant allows reducing the CF4 emission by more than a factor two. During the first LHC Long Shutdown the recuperated CF4 gas has been re-injected into the CSC system. Gas mixture composition and detector performances were monitored all along the test with gas chromatograph, infrared analyzer and a dedicated detector monitoring system based on single wire proportional counters.

As a long-term perspective, the use of less invasive gases has also being investigated. The hydrofluorocarbons are being substituted in industries by the hydrofluoroolefins (HFOs), which have a very low Global Warming Potential (about of 4-5). Refrigerant properties of HFOs are well known while ionisation processes in particle detectors have not been fully studied yet. Several tests are on-going to understand the RPCs performance with new environmental friendly gases as well as to study their interaction and effects with detector and gas system components.

Figures are in the attached file.

Plenary 3 / 375

Liquid xenon calorimeter for MEG II experiment with VUV-sensitive MPPCs

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The MEG II experiment is the upgrade of the MEG experiment to search for the charged lepton flavor violating decay of muon, $\mu^+ \rightarrow e^+ \gamma$. The MEG II experiment is expected to reach a branching ratio sensitivity of $4 \times 10^{-14}$, which is one order of magnitude better than the sensitivity of the current MEG experiment. The performance of the liquid xenon (LXe) gamma-ray detector will be greatly improved with a highly granular scintillation readout realized by replacing 216 photomultiplier tubes (PMT) on the gamma-ray entrance face with 4092 Multi-Pixel Photon Counters (MPPC). For this purpose, we have developed a new type of MPPC which is sensitive to the LXe scintillation light in VUV range, in collaboration with Hamamatsu Photonics K.K. We have measured the detailed properties of MPPC in LXe, and an excellent performance has been confirmed including high photon detection efficiency (>15%) for LXe scintillation light. The production of 4200 MPPCs was completed and a mass test was carried out at room temperature to measure the performance of all the MPPCs. Excellent performance of the LXe detector has been confirmed by Monte Carlo simulations based
on the measured properties of the MPPC. For example, energy resolution for 53MeV gamma-ray from the signal event is expected to reach 1%. The details of the performance of the VUV-sensitive MPPC will be reported, as well as the expected performance of the LXe detector by Monte Carlo simulations.

primary experiment:
MEG II experiment

Semiconductor Detectors / 315

Radiation Hard Silicon Particle Detectors for HL-LHC – RD50 Status Report

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It is foreseen to significantly increase the luminosity of the LHC by upgrading towards the HL-LHC (High Luminosity LHC). The Phase-II-Upgrade scheduled for 2023 will mean unprecedented radiation levels, way beyond the limits of the silicon trackers currently employed. All-silicon central trackers are being studied in ATLAS, CMS and LHCb, with extremely radiation hard silicon sensors to be employed on the innermost layers. Within the RD50 Collaboration, a massive R&D program is underway across experimental boundaries to develop silicon sensors with sufficient radiation tolerance.

We will present results of several detector technologies and silicon materials at radiation levels corresponding to HL-LHC fluences. Based on these results, we will give recommendations for the silicon detectors to be used at the different radii of tracking systems in the LHC detector upgrades. In order to complement the measurements, we also perform detailed simulation studies of the sensors, e.g. device structure optimization or predictions of the electric field distributions and trapping in the silicon sensors.

primary experiment:
RD50 Summary:

We will summarize the most recent results from the RD50 Collaboration and present the current state-of-the-art in radiation-hard silicon particle detector R&D for the Phase-2 LHC Upgrade.

Cherenkov / 59

The kaon identification system in the NA62 experiment at CERN SPS

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The Cherenkov detector identifying kaons in the beam line of the NA62 experiment will be presented. The main goal of the NA62 experiment at the CERN SPS accelerator is to measure the branching ratio of the ultra-rare \( K^+ \rightarrow \pi^+ \nu \bar{\nu} \) decay with 10% accuracy. NA62 uses a 750MHz high-energy un-separated charged hadron beam, with kaons corresponding to \( \sim 6\% \) of the beam, and a kaon decay-in-flight technique. An upgraded version of a gas-filled differential Cherenkov detector (CEDAR-KTAG) is used to perform the fast identification of kaons, before their decays. New photon detectors, readout, mechanics, cooling and safety systems have been realised to stand the kaon rate (50MHz average) and to meet the performances required for NA62. The CEDAR-KTAG must provide a kaon identification with an efficiency of at least 95% and precise time information with a resolution below 100ps. The fully equipped CEDAR-KTAG detector, its readout and front-end chain have been successfully commissioned during a pilot run at CERN in 2014. With the data taking started from June 2015, while the NA62 experiment is finalising the detector and read-out commissioning, the CEDAR-KTAG time resolution and efficiency have been measured to be within the required detector performances. The capability to distinguish between kaons and pions has been validated and the development of software trigger algorithms for online kaon identification has been completed.

**Summary:**

The main goal of the NA62 experiment at the CERN SPS accelerator is to measure the branching ratio of the ultra-rare \( K^+ \rightarrow \pi^+ \nu \bar{\nu} \) decay with 10% accuracy. This will be achieved by detecting about 100 \( K^+ \rightarrow \pi^+ \nu \bar{\nu} \) decays with a ratio signal/background \( \sim 10 \) in 2-3 years of data taking starting in 2015. NA62 uses a 750MHz high-energy un-separated charged hadron beam, with kaons corresponding to \( \sim 6\% \) of the beam, and a kaon decay-in-flight technique. Since pions and protons cannot be separated efficiently from kaons at the beam level, the identification of kaons within the high-intensity NA62 beam is mandatory. The time information is also essential to reconstruct the \( K^+ \rightarrow \pi^+ \nu \bar{\nu} \) decay and to guarantee the rejection of background induced by accidental overlap of events in the detector. A differential Cherenkov detector (CEDAR) filled with Nitrogen gas, and placed in the incoming beam, is used to perform the fast identification of kaons, before their decays. The CEDAR is insensitive to pions and protons and must provide an efficiency of at least 95% and precise time information with a resolution of at least 100ps. To stand the kaon rate (50MHz average) and to meet the performances required, an upgraded version (CEDAR-KTAG) with new photon detectors, readout, mechanics, cooling and safety systems has been realised for NA62. The fully equipped CEDAR-KTAG detector, its readout and front-end chain have been successfully commissioned during a pilot run at CERN in 2014. The kaon rate results in a \( \sim 10\text{MHz} \) rate in the sub-detectors after the 65m long decay region. Hardware lowest-level (L0) triggers are used to reduce the rate from \( \sim 10\text{MHz} \) to \( \sim 1\text{MHz} \), still preserving most of the decays of interest. Following a L0 trigger, most sub-detectors, KTAG included, transfer data to dedicated PCs, where two trigger levels (L1 and L2) are applied via software, to reach a final rate of \( \sim 10\text{kHz} \). With the data taking started from June 2015, while the NA62 experiment is finalising the detector and read-out commissioning, the CEDAR-KTAG time resolution and efficiency have been measured to be within the required detector performances. The capability to distinguish between kaons and pions has been validated and the development of L1 trigger algorithms for online kaon identification has been completed.

**30-ps Time Resolution with Segmented Scintillation Counter for MEG II**

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We have developed a timing detector with a ~30 ps time resolution for the measurement of ~50 MeV/c positron in the MEG II experiment using fast scintillator and SiPM. The adoption of SiPM allows flexible layout of the detector with high segmentation as well as a high precision time measurement due to the intrinsic properties. The detector is composed of 512 fast-plastic-scintillator counters. Six SiPMs from AdvanSiD, connected in series, are attached to each end of the scintillator to gain the photo-sensor coverage. The target resolution is achieved by measuring each particle’s time with multiple (on average 9) counters. A systematic R&D for maximizing the single counter time resolution and a series of beam tests to demonstrate the time-resolution improvement with multi-counter measurements were performed, and 30 ps resolution was achieved with 8-counter measurement. Now the detector R&D was completed and the construction is under-way. We have built 1/4 of the full detector so far, and a pilot run is foreseen this December using \(10^8\)/s muon beam, whose results will also be reported.

**primary experiment:**

MEG II

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**New Fast Interaction Trigger for ALICE**

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The LHC heavy-ions luminosity and collision rate from ~2020 onwards will considerably exceed the design parameters of the present ALICE forward trigger detectors and the introduction of a new Muon Forward Tracker will significantly reduce the space available for the upgraded detectors. To comply with these conditions a new Fast Interaction Trigger (FIT) will be build. FIT will be the main forward trigger, luminometer, and T0 detector. It will also determine multiplicity, centrality, and reaction plane of heavy ion collisions. FIT will consist of two arrays of Cherenkov radiators with MCP-PMT sensors and of a scintillator ring increasing the acceptance, improving the performance, adding sensitivity to detect beam-gas events and providing some degree of redundancy. The arrays will be placed on the opposite sides of the interaction point (IP). Because of the presence of the hadron absorber, the placement of the FIT arrays will be asymmetric: ~800 mm from IP on the absorber side and ~3200 mm from IP on the opposite side. Scheduled for installation ~2019, FIT is in the midst of an intense R&D and prototyping period. The timing, amplitude and efficiency characteristics are determined with relativistic particles and with fast lasers. The ongoing Monte Carlo studies verify the physics performance and refine the geometry of the FIT arrays. The presentation will give a short description of FIT, summary of the performance, and the outcome of the simulations.
primary experiment:
ALICE

Cherenkov / 245

Test-beam and laboratory characterisation of the TORCH prototype detector

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The TORCH time-of-flight (TOF) detector is being developed to provide particle identification between 2-10 GeV/c momentum for a flight distance of 10 m. It has been proposed for the upgrade of the LHcB experiment to complement the particle identification capabilities of the RICH detectors. TORCH is designed for large-area coverage, up to 30m², and has a DIRC-like construction with 10 mm thick synthetic amorphous fused-silica plates as a radiator. Cherenkov photons propagate by total internal reflection to the plate periphery and are focused onto an array of position-sensitive micro-channel plate detectors, customised in industry. The goal is to achieve a 15 ps time-of-flight resolution per incident particle by combining arrival times from multiple photons. The photon detectors will provide a spatial resolution of 0.4 mm by 6.6 mm in the vertical and horizontal directions, respectively, by incorporating a novel charge-sharing technique to improve the spatial resolution to be better than the pitch of the readout anodes. Prototype photon detectors and readout electronics have been tested and calibrated in the laboratory. These tests, together with the construction of a prototype TORCH detector and its first test beam measurements, will be presented.

primary experiment:
TORCH Summary:

The Time Of internally Reflected CHerenkov light (TORCH) detector [1, 2] is a novel time of flight detector technology for particle identification over a momentum range of 2-10 GeV/c for a flight distance of 10m. The detector uses a large area (up to 30m²) 10 mm thick synthetic amorphous fused-silica plates as a radiator. A fraction of the Cherenkov light generated when charged particles traverse the plate is internally reflected and propagated down the quartz length where it is focused onto an array of photodetectors. The Cherenkov angle of each photon is then reconstructed from its position on the detector array, thereby the path length of the photon is determined. Figure 1 shows a photograph of a TORCH prototype module that consists of a synthetic amorphous fused-silica bar of (120×350×10 mm³) coupled to a focusing block with a mirrored cylindrical surface. This prototype will provide verification of the TORCH concept at the CERN (PS beam facility - 1-12GeV/c) in November 2015, together with a detailed characterisation of the Micro-Channel-Plate Photo Multiplier Tube (MCP-PMT) prototype detectors, custom-developed in industry, together with associated fast readout electronics.
To reach 3σ pion-kaon separation over the 2-10 GeV/c momentum range, a time of flight resolution of 15 ps per incident charged particle is required. This is achieved by combining arrival times of multiple photons, leading to a required time resolution of 70 ps for single photons. This imposes stringent requirements on the timing performance of the photo detectors and the readout electronics. In order to correct for dispersion in the quartz, the time-of-flight resolution is also dependent on the spatial accuracy of the photo detectors, which also determines the Cherenkov angle resolution. To achieve the required performance, the TORCH collaboration is developing an MCP-PMT in collaboration with Photek Ltd, UK. The current prototype detector has 40mm diameter housing and 26.5×26.5mm active area with 4×32 pixels. The final tube design will allow close packing on two opposing sides with a fill factor of 88% in the horizontal direction. The final aim is to produce square, long-lifetime MCP-PMT detectors, with the ability to accumulate at least 5 C/cm² of integrated anode charge, and with a single photon time resolution of 40 ps. A novel method of coupling the output pads to a PCB through an Anisotropic Conductive Film (ACF) is adopted, which then connects to the customised external readout electronics.

The readout chain for the TORCH prototype is based on the NINO front-end amplifier/discriminator ASIC that was originally developed for the Time of Fight system of the ALICE experiment, along with the HPTDC chip for digitization [3, 4, 5]. The TORCH custom electronics boards have been developed using a 32-channel version of the NINO chip. The characterisation of the combination of the MCP-PMT and the full readout chain is performed with a Picosecond Precise Diode Laser that is operated in single photon mode. Preliminary results of offset-corrected charge sharing measurements for MCP-PMT are shown in Figure 2. The plot shows the detected charge for the MCP-PMT as the laser is stepped over the sensitive area (4 pixels), demonstrating that the proposed charge sharing method works as intended [6]. Laboratory measurements of the timing resolution have also been performed with single photons using the full readout chain, shown in Figure 3. This shows both time-walk corrected data (red line) and raw data (blue). The data were corrected using time over threshold calibration data (TOT) taken from laboratory measurements together with integrated non-linearity (INL) corrections for the HPTDC digitiser [7][8], where we have obtained ~ 85 ps timing resolution for a single channel.

These preliminary results show the feasibility of achieving good spatial and timing resolutions in the laboratory. We will extend these measurements with the TORCH prototype detector, at the CERN PS facility. The results obtained from the test-beam programme will be presented together with the laboratory calibrations. Prospects for future improvements of the TORCH technique will be described.


Semiconductor Detectors / 44

Radiation hardness study of Silicon Detectors for the CMS High Granularity Calorimeter (HGCAL)
The CMS collaboration is planning to upgrade the forward calorimeters as these will not be sufficiently performant with the expected HL-LHC (High Luminosity LHC) conditions. The High Granularity Calorimeter (HGC) is the technology choice of the CMS collaboration for this upgrade. It is realized as a sampling calorimeter with layers of silicon detectors that feature very high longitudinal and lateral granularities, and a coarser segmentation backing hadronic calorimeter based on scintillators as active material. The sensors are realized as pad detectors of size in the order of 1 cm² with an active thickness between 100µm and 300µm depending on the position respectively the expected radiation levels. For an integrated luminosity of 3000 fb⁻¹ and in the region η ~ 3, the electromagnetic calorimetry near shower max will sustain integrated doses of 1.5 MGy (150 Mrads) and neutron fluences of 10¹⁶ n/cm². Integrated doses at the location of the front layers of the existing HE are expected to reach 300 kGy (30 Mrads). After the first results on neutron irradiation of 300µm, 200µm and 100µm n-on-p and p-on-n devices that have been irradiated to fluences up to 1.5E16 n/cm² at JSI Triga reactor in Ljubljana, Slovenia. We present the latest results in terms of radiation hardness of these pad detectors as obtained with CV, IV, TCT and beta-CCE measurements.

### Surface effects in segmented silicon sensors

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The voltage stability, the charge-collection properties and the dark current of segmented silicon sensors are influenced by the charge and potential distributions on the sensor surface, the charge distribution in the oxide and passivation layers, and by Si-SiO₂ interface states. To better understand these complex phenomena, measurements on test structures and sensors, as well as TCAD simulations including surface and interface effects are being performed at the Hamburg Detector Lab. The main results of these studies are presented and some tentative conclusions, which are relevant for the sensor design, are drawn.

**Summary:**

Using TCT (Transient Current Technique) measurements with charge carriers produced by sub-nanosecond laser light of different wavelengths injected in-between the strips of a p+n silicon strip sensor, it has been observed that the charge distribution on the sensor surface changes with time. The time constants, which can be as long as days and even weeks, show a strong dependence on environmental parameters like humidity and temperature. Using GCDs (Gate-Controlled-Diodes) and MOS-FETs, the surface resistance $R_{\text{sq}}$ (SiO₂) has been determined at room temperature for different relative humidities. The variation of $R_{\text{sq}}$ with humidity can explain the observed variation of the time constants. A method of implementing different charge distributions on the sensor surface and of simulating the time dependence of surface charges in SYNONYS TCAD has been developed, and the time dependence of the electric field in the sensors calculated. The relevance of the surface charge distribution for the breakdown behaviour of segmented p⁺n and n⁺p sensors is discussed.

Oxide charges, in particular close to the Si-SiO₂ interface, and interface traps, also influence the breakdown and charge-collection properties of Si sensors. Using MOS-Cs (MOS Capacitors) and GCDs built on <100> and <111> n-type Si from four vendors, the $N_{\text{ox}}^{Effe}$ (effective oxide-charge density) and $I_{\text{surf}}$...
(surface current) have been determined before irradiation and for X-ray doses of 1 kGy(SiO$_2$) to 1 GGy(SiO$_2$). Assuming a uniform $N_{eff}^{ox}$, the electric field and the break-down behaviour of p$^+\text{n}$ and n$^+\text{p}$ strip sensors have been simulated with SYNOPSYS TCAD. With these simulations the layout of the AGIPD p$^+\text{n}$ Si pixel sensor has been optimized, and it has been demonstrated that break-down voltages above 900 V for X-ray doses between 0 Gy to 1 GGy can be achieved with technological and layout parameters, which differ from the standard ones.

MOS-FETs built on p- and n-type Si, have been used to determine $N_{eff}^{ox}$ during and after X-ray irradiations for doses between 10 Gy (SiO$_2$) and 15 kGy (SiO$_2$) for both directions of a $\approx$500 kV/cm electric field normal to the Si-SiO$_2$ interface. A strong dependence of $N_{eff}^{ox}$ on the electric field direction, and changes of $N_{eff}^{ox}$ with a time constant of $\approx$1 h after reversing the direction of the electric field direction, are observed. The latter effect is attributed to the charging and discharging of border traps. In addition, from these measurements the X-ray dose and electric field dependence of the electron and hole mobilities at the Si-SiO$_2$ interface have been extracted. The results of the measurements will be implemented in the TCAD simulations in order to understand the validity of the assumption of a uniform and field-independent $N_{eff}^{ox}$, made presently in TCAD simulations.

**Miscellaneous 1 / 120**

**Graphical processors for HEP trigger systems**

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General-purpose computing on GPUs is emerging as a new paradigm in several fields of science, although so far applications have been tailored as accelerator in offline computation. With the steady reduction of GPU latencies, and the increase in link and memory throughputs, the use for real-time applications in high-energy physics data acquisition and trigger systems is becoming ripe. We will discuss the use of online parallel computing on GPU for synchronous low level trigger, focusing on tests performed on CERN NA62 experiment trigger system. All the components of the latency have to be analyzed. The networking results the most critical one. Our envisioned solution to this issue is NaNet, an FPGA-based PCIe Network Interface Card (NIC) to enable GPUTdirect connection. The use of GPU in higher trigger system is also considered. In particular we discuss how specific trigger algorithms can be parallelized and thus benefit from the implementation on the GPU architecture, in terms of the increased execution speed. Such improvements are particularly relevant for the foreseen LHC luminosity upgrade where highly selective algorithms will be crucial to maintain a sustainable trigger rates with very high pileup. We will give details on how these devices can be integrated in a typical LHC trigger system. As a study case, we will consider the Atlas experimental environment and propose a GPU implementation for a typical muon selection in a high-level trigger system.

**primary experiment:**  
NA62

**Cherenkov / 62**

**Photon counting with a FDIRC Cherenkov prototype readout by SiPM arrays**
A prototype of a Focused Internal Reflection Cherenkov, equipped with 16 arrays of NUV-SiPM, was tested at CERN SPS in March 2015 with beams of relativistic ions at 13 and 30 GeV/n obtained from fragmentation of an Ar primary beam. The detector, designed to identify cosmic nuclei, features a Fused Silica radiator bar optically connected to a cylindrical mirror, of the same material, and an imaging focal plane of dimensions ~4 cm x 3 cm, covered with a total of 1024 SIPM photosensors. Thanks to the outstanding performance of the SiPM arrays, the detector could be operated in photon counting mode as a fully digital device. The Cherenkov pattern was recorded together with the total number of detected photoelectrons increasing as $Z^2$ as a function of the atomic number $Z$ of the beam particle. In this paper, we report on the characterization and test of the SiPM arrays and the performance of the Cherenkov prototype in the charge identification of the beam particles.

Summary:

The paper covers the construction and beam test of a prototype of an Internal Reflection Cherenkov (FDIRC), equipped with arrays of near-ultraviolet (NUV) Silicon PhotoMultipliers (SiPM). The detector is designed to identify cosmic nuclei and, in conjunction with a magnetic spectrometer, could provide mass separation for isotopes of astrophysical interest (most notably 9Be, 10Be). (see figure in the attached PDF file)

Fig. 1 Beam test layout: internal view of the FDIRC inside its light-tight box. Beam particles impinge at normal incidence on a single radiator bar.

In the paper, the characterization of the SiPM arrays, both in the lab and beam test, is described together with the details of the development of the dedicated front-end and readout electronics. The SiPM arrays outstanding performance, with negligible background in between adjacent photo-peaks, allowed to apply the technique of photon counting to the Cherenkov light collected on the focal plane. (see figure in the attached PDF file)

Fig. 2 (left) Integral Cherenkov signal from FDIRC vs. the squared value of the charge measured by the Beam Tracker; (right) Integral Cherenkov signal from FDIRC vs. $Z^2$ with one radiator bar.

Results are presented both for the integral and differential operation modes. In the former, the $Z^2$ dependence of the integrated Cherenkov signal provides a measurement of the electric charge of the fully stripped ion of atomic number $Z$, leading to its identification. In the latter, the geometrical Cherenkov pattern on the focal plane is fitted and the information on the Cherenkov angle is extracted. Factors affecting the angular resolution are discussed together with the strategy adopted to minimize these effects. Full MonteCarlo simulations of the generation and transport of the Cherenkov light along the radiator and the optics are described and compared with real data. primary experiment: CALET (CERN-RE25)
Novel real-time alignment and calibration of the LHCb detector and its performance

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The LHCb detector is a forward spectrometer at the LHC, designed to perform high precision studies of B and D hadrons. In Run II of the LHC, a new scheme for the software trigger at LHCb allows splitting the triggering of events in two stages, giving room to perform the alignment and calibration in real time. In the novel detector alignment and calibration strategy for Run II, data collected at the start of the fill are processed in a few minutes and used to update the alignment, while the calibration constants are evaluated for each run. This allows identical constants to be used in the online and offline reconstruction, thus improving the correlation between triggered and offline selected events. The required computing time constraints are met thanks to a new dedicated framework using the multi-core farm infrastructure for the trigger. The larger timing budget, available in the trigger, allows to perform the same track reconstruction online and offline. This enables LHCb to achieve the best reconstruction performance already in the trigger, and allows physics analyses to be performed directly on the data produced by the trigger reconstruction. The novel real-time processing strategy at LHCb is discussed from both the technical and operational point of view. The overall performance of the LHCb detector on the data of Run II is presented as well.

LHCb VELO: Radiation Damage Effects and Operations in LHC Run 2

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The LHCb detector is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing $b$ or $c$ quarks. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector (VELO) surrounding the $pp$ interaction region, a large-area silicon-strip detector located upstream of a dipole magnet and three stations of silicon-strip detectors and straw drift tubes placed downstream of the magnet. Calorimeters, RICH and Muon detectors for particle identification complement the detector.

The VELO comprises 42 modules made of two n$^+$-on-n 300 $\mu$m thick half-disc silicon sensors with R-measuring and Phi-measuring micro-strips, featuring a double metal layer for signal routing. One upstream module is manufactured with n$^+$-on-p technology, allowing a direct comparison of the two technologies. The VELO is installed as two movable halves containing 21 modules each to ensure its safety during beam injection.

The extreme proximity (~8 mm) of the VELO sensors to the LHC beam renders the VELO an ideal laboratory to study the effects of radiation damage on silicon detectors. Therefore, and to ensure efficient operation until the end of LHC Run 2, the radiation damage is studied closely with several methods complementing one another: IV scans, IT scans and CCE scans. The latest results as well as operational challenges for the VELO in LHC Run 2 will be presented.
We present the CLASSIC R&D for the development of a Silicon Carbide (SiC) based avalanche photodiode for the detection of Cherenkov light.

SiC is a wide-bandgap semiconductor material, which, thanks to the 3.3 eV bandgap, is insensitive to visible light. A SiC based light detection device has a peak sensitivity in the deep UV, around 280 nm, making it ideal for Cherenkov light. Moreover, the visible blindness allows the use of such a device for the disentanglement of Cherenkov and scintillation light in all those materials that scintillate above 400 nm.

Within CLASSIC, we aim at developing a device with single photon sensitivity, having in mind two main applications. One is the use of the SiC APD in a new generation ToF PET scanners concept, using the Cherenkov light emitted by the electrons following 511 keV gamma ray absorption as a timestamp. Cherenkov is intrinsically faster than scintillation and could provide an unprecedentedly precise timestamp. The second application concerns the use of SiC APD in dual readout crystal based hadronic calorimeter, where the Cherenkov component is used to measure the electromagnetic fraction on an event by event basis.

We will report on our progress towards the realization of the SiC APD devices, the strategies that are being pursued toward the realization of these devices and the preliminary results on prototypes in terms of spectral response, quantum efficiency, noise figures and multiplication.
system reading out the full detector at 40 MHz event rate.
All data reduction algorithms will be executed in a high-level software farm.

The Vertex Locator (VELO) is the silicon vertex detector surrounding the interaction region.
The current detector will be replaced with a hybrid pixel system equipped with electronics
capable of reading out at 40 MHz. The upgraded VELO will provide fast pattern recognition and
track reconstruction to the software trigger. The silicon pixel sensors have
with $55 \times 55 \mu m^2$ pitch, and are read out by the VeloPix ASIC, from the Timepix/Medipix family.
The hottest region will have pixel hit rates of 900 MHz/s yielding a total data rate
more than 3 Tbit/s for the upgraded VELO. The detector modules are located in a separate vacuum, separated from the beam vacuum by a thin custom made foil. The foil will be manufactured through milling and possibly thinned further by chemical etching.

The material budget will be minimised by the use of evaporative CO$_2$ coolant circulating
in microchannels within 400 um thick silicon substrates.
The current status of the VELO upgrade will be described and latest results
from operation of irradiated sensor assemblies will be presented.

**primary experiment:**
LHCb

**Summary:**
A4 summary in attached file

**SiPM / 294**

**A novel Silicon Photomultiplier with bulk integrated quench re- sistors - utilization in optical detection and tracking applications for particle physics**

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Silicon Photomultipliers (SiPMs) are a promising candidate for replacing conventional photomultiplier tubes in many applications, thanks to ongoing developments and advances in their technology. A drawback of conventional SiPMs is their limited fill factor caused by the need for a high ohmic polysilicon quench resistor and its metal lines on the surface of the devices, which in turn limits the maximum photon detection efficiency. At the Semiconductor Laboratory of the Max-Planck Society (HLL) a novel detector concept was developed integrating the quench resistor directly into the silicon bulk of the device resulting in a free entrance window. The feasibility of the concept was already confirmed by simulations and extensive studies of first prototype productions.

Recently SiPMs were also considered as an attractive alternative for tracking applications in vertex detectors. The requirements for a fast response, simple design and high fill factor can all be met by SiPMs. In addition the increased trigger probability for an avalanche by MIPs allows device operations at lower overbias voltages, resulting in decreased noise. The concept can be evolved further.
towards an imaging photo-detector.

A new design for an application of these SiPM devices as vertex detectors with active quenching developed by HLL and DESY as well as first simulation results will be presented. Also, first measurements of the trigger efficiency as a function of the applied overbias voltage will be shown.

primary experiment:

ILC Summary:

In recent years, Silicon Photomultipliers (SiPMs) profited from ongoing developments and improvements in technology, leading to devices having the potential to replace conventional photomultiplier tubes in many applications. The Geiger-mode operation of a passively quenched SiPM requires a high-ohmic quench resistor, which is usually realized in conventional devices by a structured polysilicon layer on the surface, leading to a decrease of the fill factor and therefore of the maximum photon detection efficiency (PDE). In order to improve on this drawback, the Semiconductor laboratory of the Max-Planck-Society has developed a novel front-side illuminated detector concept, called SiMPl (Silicon MultiPixel light-detector), with the quench resistors integrated into a high-ohmic silicon bulk. This is realized by a non-depleted bulk area beneath the active pixel area, which will act as this pixel’s quench resistor. As a consequence, the bulk material has to be adapted in order to fit the requirements for the quench resistor.

In this concept obstacles for light like metal lines or contacts can be omitted and therefore the fill factor can be increased (currently up to 85%). Moreover, within the array the entire surface area remains non-structured and can be easily coated with an anti-reflective layer or coupled to readout electronics.

The quenching mechanism has been demonstrated in a proof of principle production performed in-house and first prototypes (SOI material, 70 $\mu$m thickness, pixel size between 90 $\mu$m and 160 $\mu$m) allowed testing of the device performance.

The proposed detector has the potential of a low parasitic stray capacitance, high PDE especially in the blue and UV range and a simple processing, resulting in a high production yield and low costs. A peak PDE of roughly 35% was measured for a 405 nm wavelength which is comparable to commercially available devices. Since there was no specific entrance window engineering in the prototype production, an improved PDE up to roughly 65% can be expected after its implementation. Other characterisation measurements showed a lower optical cross talk probability at higher fill factors compared to commercial devices from Hamamatsu (MPPCs)(see attachment). Further, a dark count rate of approximately 100 $kHz/mm^2$ and afterpulsing probabilities of 15% - 20% were measured at a temperature of 253 K. The next SiMPl production line will feature an improved process technology in order to reduce the dark count rate and afterpulsing probability even further.

Future concepts for light detection applications with SiMPl will include devices with small pixel size for a high dynamic range as well as the utilisation of optical trenches, resulting in a higher cross talk suppression and higher PDE. Also single cell readout devices with active quenching and readout electronics bump bonded on the back of the detector are being devised.

In addition, SiPMs are considered to be a promising candidate for particle tracking applications due to their inherently high trigger efficiency and fast time stamping in the sub nanosecond range. In the case of the SiMPl concept, the topologically flat surface provides another advantage for this approach.

Since SiPMs are usually designed to detect single photons, an inherently high trigger efficiency for minimum ionising particles (MIPs) can be expected which is also supported by Monte-Carlo simulations. Hence, the operation of the SiPM devices at lower overbias voltages ($≈ 0.5 V$ in the case of SiMPl) will be sufficient for a trigger efficiency close to 100%. This, in turn, will drastically reduce the dark count rate and optical cross talk probability. For verification, a dedicated test setup was devised in which the trigger efficiency of SiMPl devices for high energy electrons for different overbias voltages can be determined as a function of the overbias voltage.

Currently, active quenching and readout electronics are being developed (see attachment) in collaboration with the DESY (Hamburg, Germany). This ASIC will allow the individual readout and masking of every pixel, increasing the resolution of the device and will ease the requirements for the bulk resistor, making very thin (down to 10 $\mu$m) devices possible. The fill factor of this concept will only be limited by the size of the bump bonds. In addition, the active quenching will improve the timing of the detector.
A detector for in-beam measurement of the ground state hyperfine splitting of antihydrogen

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The matter - anti matter asymmetry observed in the universe today still lacks a quantitative explanation. One possibility that could contribute to the observed state could be a violation of the combined Charge-, Parity- and Timesymmetries (CPT). A possible contribution to this asymmetry could come from a violation of the CPT symmetry. A test of CPT symmetry using anti-atoms is being carried out by the ASACUSA-CUSP collaboration at the CERN Antiproton Decelerator using a low temperature beam of antihydrogen - the most simple atomic system built only of anti particles.

While hydrogen is the most abundant element in the universe, antihydrogen is produced in very small quantities in a laboratory framework. A detector for in-beam measurements of the ground state hyperfine structure of antihydrogen has to be able to detect very low signal rates within high background. To fulfil this challenging task a two layer barrel hodoscope detector was developed. It is built of plastic scintillators with double sided readout via Silicon Photo Multipliers (SiPMs). The SiPM readout is done using novel, compact and cost efficient electronics that incorporate power supply, amplifier and discriminator on a single board.

This contribution will evaluate the performance of the new detector during the ASACUSA beamtime 2014 and 2015. We will also put a spotlight on the new, self developed, readout electronics and discuss possible further applications.

primary experiment:

ASACUSA CUSP Summary:

\begin{figure}[htp]
\centering
\includegraphics[angle=0,width=0.226\textwidth]{./ASACUSADetOnBeamline.jpg}
\includegraphics[angle=0,width=0.4\textwidth]{./asacusaDetector2014_2.jpg}
\captionbelow{left: Detector mounted to ASACUSA spectroscopy apparatus, right: Detector with one outer panel removed, readout electronics are mounted onto the detector}
\end{figure}

The detector is an octagonal shape hodoscope. Each of the sides is a removable panel supporting four individual bars.

The most inner part of the hodoscope is a pipe of 1 mm thick aluminium to stabilise the structure. From Geant 4 simulations it was determined that the scattering probability of pions from antihydrogen annihilations can be neglected within this frame.

The surrounding hodoscope is composed of two layers, each layer consists of 32 scintillating bars. As scintillating material Eljen Technologys EJ-200 was chosen for its long attenuation length, high light output and cost effectiveness (equivalent to St. Gobain BC-408).

The total length of the outer hodoscope is 606-mm and the whole structure is mounted on a movable waggon to enable quick access to a secondary detector in the central annihilation region.

The inner hodoscope layer has an overall scintillator length of 300-mm with a cross section of 20\times5-mm. The bars of the outer hodoscope have a length of 450-mm and a cross section surface of 35\times5-mm. Each bar is individually wrapped in aluminium foil with and air gap to provide reflectivity and suppression of crosstalk. The light guides reduce the cross section surface of the scintillators to match two KETEK PM3350TS SiPMs and are painted with reflective paint of type BC-680.
The readout of the SiPMs is done using self developed modules called Intelligent Frontend Electronics for Silicon photodetectors (IFES). This low-cost compact modules provide the bias voltage for the a pair of SiPMs in serial connection, an onboard amplifier and a discriminator operated with a stabilised reference voltage source.

The angular track resolution in the detector is defined by its geometry. The hit position along the scintillator bars is determined by combining the timing of upstream and downstream SiPM and their measured amplitudes. Particle identification is done by combining event quantities like angular distribution and multiplicity and training a naive Bayes classifier on measured background and antiproton annihilation data.

**Miscellaneous 2 / 180**

**The MoEDAL detector - a totally different LHC detector**

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MoEDAL- the newest LHC experiment – that began operating in June 2015 – is designed to search for highly ionizing avatars of new physics and extend the discovery horizon of the LHC in a complementary way. In this talk I will describe MoEDAL’s innovative and unconventional detector methodologies tuned to the prospect of discovery physics. The largely passive MoEDAL detector, deployed at Point 8 on the LHC ring, has a dual nature. First, it acts like a giant camera, comprised of very large array of nuclear track detectors - analyzed offline by novel ultra fast scanning microscopes - sensitive only to new physics. Second, a one tonne trapping detectors is uniquely able to directly detect magnetic charge and to capture the particle messengers of physics beyond the Standard Model for further study. MoEDAL’s radiation environment is monitored by a state-of-the-art real-time TimePix pixel detector array. Finally I will describe a proposed new MoEDAL sub-detector designed to extend MoEDAL’s reach from highly charge to millicharged particles (MMIPs).

**primary experiment:**
MoEDAL-LHC

**SiPM / 331**

**Performance of the latest prototypes of NUV-HD Silicon Photomultipliers**

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In this work, we will present the latest Silicon photomultiplier technology (SiPM), developed in Fondazione Bruno Kessler, designed to detect UV and blue light and named NUV-HD. With respect to the original NUV technology, shown at last VCI, the High-Density (HD) one has the same electrical field profile but a novel layout with a lower dead border area and the introduction of
trenches between cells. This new layout allows having a lower cell pitch, ranging from 15 to 40 µm, reducing the gain of the cell and the correlated noise probabilities, increasing the dynamic range and the fill factor, from 55% to 80% in bigger cells.

Considering the PDE, the new technology shows a peak centered in 400-420 nm as its predecessor, but reaches an impressive value of about 60% for the 40 µm cell. This technology reaches the highest PDE value compared to state-of-the-art commercial SiPMs.

We will show a complete characterization focusing on the most relevant parameters of a SiPM (PDE, DCR, Correlated Noise probabilities, etc.) and comparing these values to the non-HD technology.

**Summary:**

In this work, we will present the latest high-density (HD) Silicon photomultiplier technology, developed at Fondazione Bruno Kessler (FBK, Trento), designed to detect near-UV and blue light, and named NUV-HD.

The HD SiPM technology features a smaller dead border region around each microcell (SPAD) of the SiPM by employing isolating trenches between cells. This allows having both a smaller cell pitch, ranging from 15 to 40 µm, and an increased fill factor, exceeding 80% for the bigger cell sizes. Furthermore, the trenches allow a reduction of the correlated noise with respect to the original NUV technology by reducing the transmission of the photons emitted by the hot carriers during the avalanche [1][2].

Fig. 1 outlines the most remarkable results, which are the very high peak photo-detection efficiency (PDE) of this technology and the low correlated noise. On the left, we can see that the NUV-HD technology has the peak PDE between 400 – 420 nm, but the efficiency remains very high down to 300 nm. This is very important for certain applications, such as the detection of Cherenkov light in Cherenkov Telescope Array (CTA). On the center, we can notice how the efficiency scales with the cell pitch, notably exceeding 60% with the 35 and 40 µm cells. In addition, because of the low gain of the smaller cells and the attenuation of the trenches, the NUV-HD technology provides low correlated noise, even at high PDE, as shown on the right of the same figure. This is important in a broad range of applications, starting from the aforementioned CTA to the detection of the scintillation light in high-resolution gamma-ray spectroscopy and medical imaging applications, such as ToF – PET.

Fig. 1: PDE spectrum of the 30 µm cell device at 12 Vov (left), PDE comparison of different cell sizes at 400 nm (center) and Excess Noise Factor (ENF) comparison expressed as a function of PDE of the cell (right).

The main electro-optical parameters are reported in the Table below. During the talk, we will show a detailed characterization of the new NUV-HD technology including noise behavior, signal shape and efficiency comparing the different cells. We will also report on the characterization of this new technology in the scintillation light readout, showing as an example the energy resolution of SiPM 4x4 mm2, 25 µm cell pitch, coupled to CeBr crystals of different dimensions.

**NUV-HD Characterization parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active area</td>
<td>1x1, 4x4 and 6x6 mm2</td>
<td></td>
</tr>
<tr>
<td>Cell size</td>
<td>From 15 to 40 µm</td>
<td></td>
</tr>
<tr>
<td>Fill Factor</td>
<td>From 55 to 83 %</td>
<td></td>
</tr>
<tr>
<td>Gain</td>
<td>4 · 106 VOV = 12 V</td>
<td></td>
</tr>
<tr>
<td>DCR</td>
<td>150 kHz/mm2 VOV = 12 V; T = 20 °C</td>
<td></td>
</tr>
<tr>
<td>Peak PDE</td>
<td>55 % VOV = 12 V; λ = 400 nm</td>
<td></td>
</tr>
<tr>
<td>Average PDE for UV and blue light</td>
<td>50 % 300 nm ≤ λ ≤ 450 nm</td>
<td></td>
</tr>
</tbody>
</table>

*reported values refers to 30 µm cell.

A new timing detector for the CT-PPS detector of CMS

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The CT-PPS detector will be installed in Roman pots positioned on both sides of CMS, ~ 200 meter downstream the interaction point. This detector will measure forward leading protons, allowing detailed studies of diffractive hadron physics and Central Exclusive Production. The main components of the CT-PPS detectors are a silicon tracking system and a timing system, QUARTIC, which measures the Cerenkov radiation emitted by the proton in quartz bars. In this contribution we present a possible alternative to the QUARTIC timing system, based on Ultra-Fast Silicon Detectors (UFSD). UFSD are a novel concept of silicon detectors based on the Low-Gain Avalanche Detector design, which are able to obtain time resolution of the order of ~ 20 ps. The use of UFSD has many attractive features as its material budget is small, the pixel geometries can be tailored to the precise physics distribution of protons, and timing and tracking planes can be house in the same Roman Pots. UFSD prototypes for the CT-PPS have been designed and manufactured by CNM (Barcellona) and FBK (Trento): we will show the first characterizations and new results of these productions and we will also presents first designs of the read-out electronics.

**primary experiment:**

CMS

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Improving the Time Resolution in Cherenkov TOF PET with SiPMs

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Silicon photomultipliers (SiPMs) were examined as photodetectors in Cherenkov time-of-flight positron emission tomography (TOF PET). The time-of-flight resolution and the detection efficiency of several devices by different manufacturers were measured in TOF PET setup. Effects which degrade the time resolution and the methods to correct them were studied in more detail with a picosecond laser setup.

**primary experiment:**

Bele II

**Summary:**

By measuring the time-of-flight (TOF) of the annihilation gammas in positron emission tomography (PET) the quality of activity distribution images of can be improved. The TOF resolution of available commercial PET scanners is mainly limited by the time evolution of scintillation light production. This limitation can be avoided by detecting prompt Cherenkov light, produced by electrons resulting from the annihilation gamma interactions in a suitable material. With this method, a TOF resolution of 87 ps FWHM has been achieved by using 15 mm thick PbF₂ crystals as Cherenkov radiators and microchannel plate photomultipliers (MCP PMTs) as photodetectors. For this measurements, a single side gamma detection efficiency ($\epsilon$) of only a 6% was measured, mainly due to the limited photon detection efficiency (PDE) of the MCP PMTs used. By using silicon photomultipliers (SiPMs) instead of MCP PMTs, an improved detection efficiency of $\epsilon = 14\%$ has been measured, while a value of 25% was implied by
simulations if the detector geometry was optimized. The measurements with SiPMs, however, were limited in TOF resolution: a value of about 422 ps FWHM has been demonstrated.

In this contribution, the latest measurements using different SiPMs produced by Hamamatsu, KETEK, AdvanSiD and SensL with $3 \times 3 \text{ mm}^2$ active area will be presented. The SiPMs were tested in a TOF PET setup, coupled to $5 \times 5 \times 15 \text{ mm}^3$ PbF$_2$ crystals. The TOF resolution and $\epsilon$ were measured at different SiPM operating voltages and at temperatures down to $-25 ^\circ C$. For coincidences between two detectors composed of AdvanSiD SiPMs and black painted PbF$_2$ crystals, a TOF resolution of 306 ps FWHM was obtained. The SiPM time response was significantly degraded by different processes that can occur in the device (i.e. optical crosstalk, afterpulsing...).

The timing properties of the SiPMs were also measured by exposing them to picosecond laser pulses. It was observed that the events corresponding to detection of 2 cell pulse heights (CPH) are composed of true double photon hits as well as delayed events, which deteriorate the TOF resolution. The measurements for different SiPMs and the methods to improve the timing resolution will be presented and discussed.

Miscellaneous 2 / 363

Imaging the LHC beams with silicon and scintillating fibre vertex detectors

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The LHCb Vertex Locator (VELO) is used to reconstruct beam-gas interaction vertices which allows one to obtain precise profiles of the LHC beams. In LHCb, this information is combined with the profile of the reconstructed beam-beam collisions and with the LHC beam currents to perform precise measurements of the luminosity.

This beam-gas imaging (BGI) method also allows one to study the transverse beam shapes, beam positions and angles in real time. Therefore, a demonstrator beam-gas vertex detector (BGV) based on scintillating fibre modules has been built and installed in LHC Ring 2 (at point 4). We present first results of the commissioning of this device and compare with recent results obtained in the LHCb experiment.

primary experiment:

LHCb VELO BGV Summary:

Luminosity $L$ is the quantity that relates the cross section $\sigma$ to the interaction rate $R$ of an accelerator based particle physics experiment. For a colliding bunch pair, one has:

$$ R = L \sigma \quad L = f_{\text{rev}} N_1 N_2 \Omega, $$

where $N_i$ is the bunch population of beam $i$, $f_{\text{rev}}$ is the revolution frequency, and the beam overlap integral

$$ \Omega = 2c \int \rho_1(x,y,z,t) \rho_2(x,y,z,t) dx \, dy \, dz \, dt $$

embodies the passage of the two bunches with spatial particle density distributions $\rho_1(x,y,z,t)$ and $\rho_2(x,y,z,t)$ across each other.

There are different methods to measure luminosity. In the LHCb experiment at CERN, the van der Meer method (VdM) and the beam-gas imaging method (BGI) are used.

The LHCb experiment at CERN is a forward detector that was designed to study particles containing $b$ or $c$ quarks.
It consists of several sub-systems, like the vertex locator (VELO), ring imaging Cherenkov detectors, a dipole magnet, further tracking detectors, a calorimeter system and a muon identification system. The LHCb VELO is an important instrument in the measurement of the luminosity with both VdM and BGI methods. It consists of two halves, each made up of 42 silicon strip sensors (21 r-measuring and 21 ϕ-measuring) installed inside the vacuum which can be moved to a distance of 8.2-mm from the LHC beams. The VELO is used to record interaction vertices, see Figure 1. Its resolution plays a crucial role in the BGI method.

The BGI method, which premiered at LHCb, takes advantage of beam-gas interactions inside the VELO in which gas is injected. The bunches of the two beams collide with the gas and each other, giving direct information about the $\rho_i$'s, crossing angle, offset, etc.

The LHCb BGI method provides precise measurements of the luminosity and beam profiles when the VELO is closed. However, its performance is degraded when the LHC is not in "STABLE BEAMS" and the VELO detectors are in retracted position. For this reason a dedicated device for the LHC, a demonstrator beam-gas vertexing detector, was designed, developed and recently installed in Point 4 on LHC Ring 2.

The BGV detector comprises 8 scintillating fibre modules (see Figure 2), each with two fibre mats, where one is rotated by $2^\circ$. The fibres are read out by silicon photo-multipliers (SiPMs) and the light yield is increased by using a mirror on the other end of the fibres. The scintillating fibre mats and SiPMs were developed in close collaboration with the Scintillating Fibre Tracker project of the LHCb upgrade. The SiPMs can be cooled down to $-40^\circ$-C and are read out with LHCb Beetle front-end chips and TELL1 readout boards.

The BGV demonstrator will be able to measure the transverse bunch profile at any LHC beam intensity and throughout all phases of the accelerator cycle, thus also giving insight into the emittance evolution of the beam. First results from this device will be shown, based on recent data taken during the 2015 LHC $p$-$p$ and Pb-Pb runs, and compared to BGI results obtained with VELO.


Semiconductor Detectors / 266

The Belle II SVD assembly and mechanics

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Co-author: - Belle II SVD Collaboration

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The Belle II experiment at the SuperKEKB collider in Japan will operate at an instantaneous luminosity approximately 50 times greater than its predecessor (Belle). The central feature of the experiment is a vertex detector comprising two layers of pixelated silicon detectors (PXD) and four layers of double-sided silicon microstrip detectors (SVD). One of the key measurements for Belle-II is CP violation asymmetry in the decays of beauty and charm hadrons, which hinges on a precise charged-track vertex determination and low-momentum track measurement.
Towards this goal, a proper assembly of the SVD components with precise alignment ought to be performed and the geometrical tolerances should be checked to fall within the design limits. We present an overview of the assembly procedure that is being followed, which includes the precision gluing of the SVD module components, wire-bonding of the various electrical components, and precision 3D coordinate measurements of the jigs used in assembly as well as of the final SVD modules.

**primary experiment:**
Belle II

**Summary:**
See attached files.

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**SiPM / 251**

**Study of the breakdown voltage of SiPMs**

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The breakdown behaviour of prototype SiPMs (Silicon Photomultiplier) with pixel sizes of 15×15, 25×25 and 50×50 μm^2 manufactured by KETEK has been investigated. The I-V (current-voltage) characteristics and the PA (pulse-area) spectra have been measured as a function of bias voltage in dark conditions, as well as with the SiPM illuminated with an LED with a wavelength of 470 nm. The measurements were made in the temperature range between –20 ℃ and +20 ℃. From the PA spectra the gain, G(V), and from a linear fit to G(V), the gain-breakdown voltage, V\textsubscript{bd}^G, have been obtained. From fits to the I-V curves with and without LED illumination below and above breakdown, the current-breakdown voltage, V\textsubscript{bd}^I, has been determined. It is found that there is a significant difference between V\textsubscript{bd}^G and V\textsubscript{bd}^I. The difference V\textsubscript{bd}^I-V\textsubscript{bd}^G is positive and increases with decreasing pixel size. We explain this difference by the difference between the turn-on and the turn-off voltage of the Geiger discharge. A possible model of the V\textsubscript{bd}^I-V\textsubscript{bd}^G difference is presented.

**Summary:**

The breakdown behaviour of prototype SiPMs (Silicon Photomultiplier) with pixel sizes of 15×15, 25×25 and 50×50 μm^2 manufactured by KETEK has been investigated. The I-V (current-voltage) characteristics and the PA (pulse-area) spectra have been measured as a function of bias voltage in dark conditions, as well as with the SiPM illuminated by an LED with a wavelength of 470 nm. The measurements were made in the temperature range between –20 ℃ and +20 ℃. A selection of preliminary results is given in this summary.

From the PA spectra the gain, G(V), and from a linear fit to G(V), the gain-breakdown voltage, V\textsubscript{bd}^G, have been obtained. Preliminary results of the measurements at 20℃ are shown in Fig. 1 and Table 1.

Fig. 2 left shows the I-V results at 20℃ for the dark current and for the LED illumination with the dark current subtracted. The shapes of the I-V curves in the region of the breakdown voltage are very different: The current increase for the dark current is significantly more abrupt than the one for the LED data. We interpret this difference as evidence for significant contributions to the dark current from regions outside of the depleted volume of the SiPM.

Fig. 2 right shows the corresponding inverse logarithmic derivatives, ILD=\((\text{dln}(I)/\text{dV}))^{-1}\), which has been obtained by a cubic spline interpolation from the I-V data. The ILD allows characterizing the breakdown behaviour:

E.g. for \(I(V)=A\cdot e^{\alpha V}\) \(\rightarrow\) \(\text{ILD}=1/\alpha\), and for \(I(V)=A\cdot(V-V_0)^n\) \(\rightarrow\) \(\text{ILD}=(V-V_0)/n\). For voltages below ~27.5 V the ILD has a linear behaviour with a negative slope. Thus the I-V curves are compatible...
with a power law with a negative index and a pole at $V_0$. Above $\approx 27.5 \text{ V}$ the voltage dependence of the ILD is quadratic with a positive slope. The reason for the differences between the dark-current and LED-current will be discussed at the conference. From fits to the ILD curves above $\approx 27.7 \text{ V}$, the current-breakdown voltages, $V_{bd}^\text{I}$, have been determined. The preliminary results are reported in Table 1.

We conclude that there is a significant difference between $V_{bd}^\text{G}$ and $V_{bd}^\text{I}$. The difference $V_{bd}^\text{I} - V_{bd}^\text{G}$ is positive and increases with decreasing pixel size. We explain this difference by the difference between the turn-on and the turn-off voltage of the Geiger discharge. A possible model of the $V_{bd}^\text{I} - V_{bd}^\text{G}$ difference will be presented.

Table 1. Values of the breakdown voltage from the gain measurement, $V_{bd}^\text{G}$, and from the current measurement with and without illumination by the LED measured at 20$^\circ\text{C}$. The results are preliminary.

**Semiconductor Detectors / 227**

**The Silicon Tracking System of the CBM experiment at FAIR**

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The central detector of the CBM experiment at FAIR is a Silicon Tracking System (STS) consisting of 8 tracking stations based on double-sided silicon microstrip sensors. It will deliver high-rate streamed data that is analyzed on a computing farm.

The functional building block is a detector module consisting of a sensor, microcables and a front-end electronics board. The double-sided microstrip sensors have a strip pitch of 58 $\mu\text{m}$, are AC-coupled and oriented under 7.5$^\circ$. Double metallization is employed to interconnect corner strips. Ultra-thin cables with up to 60 cm length and pitch matching that of the sensor strips transfer the analog signals to the readout electronics at the periphery of the stations. The readout ASIC is the STS-XYTER with self-triggering architecture that will deliver time and amplitude information.

The detector will be operating within a thermal enclosure of 2 m$^3$ at below $-5^\circ\text{C}$ so that its silicon sensors remain operational up to a particle fluence of $10^{14}$ 1-MeV n$_\text{eq}$/cm$^2$. The electronics inside, about 16 thousand ASICs with more than 2 million readout channels, will dissipate about 40 kW power. Bi-phase CO$_2$ evaporative cooling approach has been chosen.

In this contribution, the development status of components, system integration and the project time line for their production will be discussed.

**CBM Summary:**

The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) will study the phase diagram of strongly interacting matter at high net baryon densities and moderate temperatures. In this range of nuclear matter under extreme conditions a rich structure of changing phases is expected. The experiment will investigate proton-nucleus and nucleus-nucleus collisions at various beam energies in stationary target configuration. Detector systems for charged particle tracking, hadron and lepton identification and calorimetry will examine up to 1000 charged particle tracks per collision. The collision rates will be in the rage from 100 kHz to 10 MHz in order to access bulk observables as well as rare probes including open charm, low-mass vector mesons and charmonia. Due the event topology of some of the probes, CBM will be based on a streamed data readout by self-triggering electronics and online event selection by a high-performance computing farm.

The central detector system is the Silicon Tracking System (STS) installed in a 1 T magnetic dipole field. Its task is to provide track reconstruction and high-resolution momentum measurement. It will consist of 8 tracking stations with a total area of about 4 m$^2$ based on double-sided silicon microstrip sensors. The stations will be optimised for low material budget. Their radiation length will range between 0.3%
The functional building block of every station is a detector module consisting of a sensor, an analog microcable and a front-end board. The double-sided microstrip sensors with 58 $\mu$m pitch and in several sizes from $62 \times 22 \text{ mm}^2$ to $62 \times 124 \text{ mm}^2$, depending on the particle densities, feature 1024 AC-coupled strips per side oriented at 7.5$^\circ$ stereo angle and double metallization to interconnect short corner strips. Ultra-thin multi-layer cables with up to 60 cm length and the same line pitch (effectively for a stack) as the sensor strips are employed to transfer the analog signals to the readout electronics at the periphery of the stations. This is to keep the infrastructure of the fast electronics outside of the physics aperture. The microcables have a multilayer structure of signal and spacer layers minimizing capacitances and will be connected to sensors and readout electronics via TAB bonding. The readout ASIC is the STS-XYTER which delivers self-triggered time and amplitude information from the silicon sensors to the data acquisition system. About 900 modules will be placed on carbon fiber support ladders of different lengths.

The detector will be operating within a thermal enclosure of 2 m$^3$ at below –5$^\circ$C so that its silicon sensors remain operational up to a particle fluence of $10^{14}$ $1$-MeV $n_{eq}$/cm$^2$. The electronics inside, about 16 thousand ASICs with more than 2 million readout channels, will dissipate about 40 kW power. Therefore efficient cooling with a high volumetric heat transfer coefficient is required. Bi-phase CO$_2$ evaporative cooling approach has been chosen.

The STS detector concept was presented in the Technical Design Report approved in 2013. In this contribution, the development status of components, system integration and the project timeline for their production will be discussed.

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**Miscellaneous 2 / 80**

**Stability monitoring of historical buildings with a cosmic ray tracking system**

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Cosmic ray radiation, thanks to its high penetration capability and relative abundance, has been successfully used both in scientific studies and civil applications. We investigated, for the first time, the possibility of using cosmic ray radiation for the static monitoring of historical buildings, where severe conservation constraints apply and the time evolution of the deformation phenomena under study could be of the order of months or years. In this talk, we present the results of a feasibility study performed by means of Monte Carlo (MC) simulations, using the wooden vaulted roof of the “Palazzo della Loggia” in the town of Brescia (Italy) as a relevant case study. The results, based on a scintillating fiber detector, showed that horizontal displacements of the order of 1 mm could be detected with a week of measurement. Finally, as a proof of principle, we also developed a small-size detector prototype consisting of layers of scintillating fibers coupled to silicon photomultipliers. The first experimental results and their comparison to MC simulations are also presented.

**primary experiment:**

Monster & Co.

**Semiconductor Detectors / 3**
Summary of Medipix Technology’s 3-Years in Space and Plans for Future Developments

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NASA has evaluated 7 Timepix-based radiation imaging pixel detectors from the CERN-based Medipix2 collaboration on the International Space Station (ISS), collecting 3-years of data, as well on the recent EFT-1 mission testing the new Orion Multi-Purpose Crew Vehicle. These data along with data collected at ground-based accelerator facilities including the NASA Space Radiation Lab (NSRL) at Brookhaven in the US, as well as at the HIMAC facility at the National Institute for Radiological Sciences in Japan, have allowed the development of software analysis techniques sufficient to provide a stand-alone accurate assessment of the space radiation environment for dosimetric purposes. Recent comparisons of the performance of the Timepix with both n-on-p and p-on-n Si sensors will be presented.

The further evolution of the Timepix technology by the Medipix3 collaboration in the form of the Timepix3 chip, which employs a continuous data-driven readout scheme, is being evaluated for possible use in future space research applications. The Medipix2 Collaboration is also in the process of designing an updated version of the Timepix chip, called the Timepix2, which will continue the frame-based readout scheme of the current Timepix chip. Current plans are to replace the Timepix by the Timepix2 with minimal reconfiguration of the supporting electronics.

Longer-term plans include participation in the currently forming Medipix4 collaboration. A summary of the prospects will be included.

Medipix Summary:

NASA has evaluated the Timepix chips from the CERN-based Medipix2 Collaboration for use as space radiation monitors. 3 years of data from space and ground-based evaluations have demonstrated the efficacy of this technique. Future plans include consideration of the Timepix 2 from the Medipix2 Collaboration and the Timepix3 from the Medipix3 Collaboration, as well as the potential devices from the forming Medipix4 collaboration.

Calorimeter / 66

FoCal - a high-granularity electromagnetic calorimeter for forward direct photon measurements at LHC

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Co-authors: Gerardus Nooren; Hongkai Wang; Marco Van Leeuwen; Ton Van Den Brink

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The measurement of direct photon production at forward rapidity \((\gamma \sim 3-5)\) at the LHC provides access to the structure of protons and nuclei at very small values of fraction momentum \((x \sim 10^{-5})\). FoCal, an extremely-high-granularity Forward Calorimeter covering \(3.5 < \eta < 5.3\) is proposed as a detector upgrade to the ALICE experiment. To facilitate the design of the upgrade and to perform generic R&D necessary for such a novel calorimeter, a compact high-granularity electromagnetic calorimeter prototype has been built. The corresponding R&D studies will be the focus of this presentation. The prototype is a Si/W sampling calorimeter. It was instrumented with 24 layers of Monolithic Active Pixel Sensors, a total of 39M pixels. We will report on performance studies of the prototype with test beams at DESY and CERN in a broad energy range. The results of the measurements demonstrate a very small Molière radius (~11 mm) and good linearity of the response. Unique results on the detailed lateral shower shape, which are crucial for the two-shower separation capabilities, will be presented. We will compare the measurements to GEANT-based MC simulations, which additionally include a modeling of charge diffusion. The studies demonstrate the feasibility of this high-granularity technology for use in the proposed detector upgrade. They also show the extremely high potential of this technology for future calorimeter development.

**primary experiment:**
ALICE

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### Ion space-charge effects in multi-GEM detectors: challenges and possible solutions for future applications

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**Co-authors:** Abdulkareem Afandi \(^3\); Christina Strelí \(^2\); Diego Gonzalez Diaz \(^1\); Dorothea Pfieffer \(^1\); Eraldo Oliveri \(^1\); Hans Muller ; Joseph Alexander Smith \(^5\); Leszek Ropelewski \(^1\); Miranda Van Stennis \(^1\); Richard Hall-Wilton \(^6\); Richard Jackman \(^3\); Rob Veenhof \(^1\); Rui De Oliveira \(^1\); Silvia Franchino \(^1\); Thuong Thuong Nguyen \(^3\)

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Graphene is a single layer of carbon atoms arranged in a honeycomb lattice with remarkable mechanical, electrical and optical properties. It can be regarded as the thinnest and narrowest conductive mesh with a reported strong asymmetry in transmission of low energetic electrons and ions. Ideally this would make graphene a membrane transparent to electrons and opaque to ions, therefore solving the problem of ion back-flow in Micro Pattern Gaseous Detectors (MPGD). Graphene layers with an area of the order of a square centimetre were transferred onto metal support structures with holes of diameters from 30 to 70 micrometres and pitches of the order of twice the diameter of the holes, so that the graphene was freely suspended in the holes.

The graphene samples were installed into the conversion volume of a triple Gaseous Electron Multiplier (GEM), allowing a study of the transparency of the graphene to electrons and ions in gas as a function of the electric fields applied. We describe the transfer techniques of the graphene layers from the substrate to the experimental setup as well as the procedures to measure the charge transfer properties. Results will be presented with special attention to the challenges arising from defects in the graphene layers. We furthermore describe solutions to study the intrinsic transmission properties of this material and discuss applications where these techniques can be used to improve the state of the art of gaseous detectors.
**Gas Detectors / 148**

**The KLOE-2 Inner Tracker: detector commissioning and operation**

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The KLOE-2 experiment started its data taking campaign in November 2014 with an upgraded tracking system including an Inner Tracker built with the cylindrical GEM technology, to operate together with the Drift Chamber improving the apparatus tracking performance. The Inner Tracker is composed of four cylindrical triple-GEM, each provided with an X-V strips-pads stereo readout and equipped with the GASTONE ASIC developed inside the KLOE-2 collaboration. Although GEM detectors are already used in high energy physics experiment, this device is considered a frontier detector due to its cylindrical geometry: KLOE-2 is the first experiment to use this novel solution. The results of the detector commissioning, detection efficiency evaluation, calibration studies and alignment, both with dedicated cosmic-ray muon and Bhabha scattering events, will be reported as well as detector operation with collisions.

**primary experiment:**

KLOE-2

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**Semiconductor Detectors / 426**

**Large area CNT-Si heterojunction for photodetection**

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Multiwall carbon nanotubes (MWCNTs) consist of multiple layers of graphite sheets arranged in concentric cylinders, from two to many tens. These systems are closely related to graphite layers but in some features MWCNTs behave quite differently from graphite. In particular, their ability to generate a photocurrent in a wide wavelength range has been demonstrated either without or with the application of a draining voltage. In addition, the photocurrent signal has been reported to reproduce the optical absorbance of MWCNTs, showing a maximum in the near UV region. In this talk we will present main characteristics of a novel large area photodetector featuring low noise, high efficiency and great surface uniformity. This detector has been obtained by coupling the optoelectronic characteristics of MWCNTs with the well-known properties of silicon. MWCNTs are grown on n-doped silicon layer by Chemical Vapour Deposition creating a p-n heterojunction with high sensitivity to the radiation from UV to IR. An additional MIS junction is obtained with a metallic conductive layer deposited on the back of silicon substrate. The heterojunction is characterized by a 2.5 V threshold and a well-defined tunnel effect proportional to the radiation intensity. In this framework, we will report accurate measurements of the detector responsivity, linearity, quantum efficiency and photocathode uniformity. In addition we will discuss about the heterojunction threshold and the tunnel effect below it.

**primary experiment:**

CTA, Auger, PARIDE  **Summary:**
Large area CNT-Si heterojunction for photodetection

Carla Aramo for PARIDE experiment

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PARIDE (Pixel Array for Radiation Imaging Detector) is an INFN research program whose purpose is the development of radiation detectors made with carbon nanotubes as active media. Multiwall carbon nanotubes (MWCNTs) consist of multiple layers of graphite sheets arranged in concentric cylinders, from two to many tens. These systems are closely related to graphite layers and are generally considered to exhibit similar electronic properties. However, in some features MWCNTs behave quite differently from graphite. In particular, their ability to generate a photocurrent in a wide wavelength range from near ultraviolet (UV) to infrared (IR) has been demonstrated either without or with the application of a draining voltage. In addition, the photocurrent signal has been reported to reproduce the optical absorbance of MWCNTs, showing a maximum in the near UV region. This capability has been interpreted as due to the presence of van Hove singularities in the density of states of each single wall carbon nanotube constituting the MWCNT, together with the MWCNT low density of electrons at the Fermi level. Moreover, the application of high draining voltages (up to a few tens of Volts) has been shown to dramatically increase the photocurrent signal. The capability of MWCNTs to detect and follow the pulse shape of a 10 ns pulsed laser has been also demonstrated. These MWCNT properties made them an attractive material for UV photo detector and photosensor applications. In this talk we will present a novel large area detector featuring low noise, high efficiency and great surface uniformity. This detector has been obtained by coupling the optoelectronic characteristics of carbon nanotubes (CNTs) with the well-known optoelectronic properties of silicon. The proposed device mimics the behaviour of a p-n-p phototransistor where the CNT/silicon interface acts as base, while the emitter is Metal-Insulator-Semiconductor (MIS) junction between the back electrode and the silicon substrate and the collector is the CNT layer itself. The novelty of this detector resides on its peculiar sensitivity to the radiation, from UV to IR wavelength region. For this device the most surprising effect is the observation of a remarkable photoinduced significant resonant tunneling-like current completely absent in dark conditions and which is absent in the substrate without CNTs. Therefore, resonant tunnel-like current is generated only under light radiation and it is function of the wavelength as well as of the power intensity. In this framework, we will report accurate measurements of the detector responsivity, linearity, quantum efficiency and photocathode uniformity. In addition we will discuss about the heterojunction threshold and the tunnel effect below it. This photodetector is extremely promising in a future use in high energy physics experiments and medical applications. Highly pixelled surfaces can be obtained by micro- or nano- lithography so that they can be coupled to any kind of detector with light output such as scintillators and optical fibres. Pixelled large area photocathodes can be used for the medical imaging or to manufacture fluorescence light detectors or to detect Cerenkov light with high accuracy. Many high energy experiments need to detect radiation in UV wavelength range, where Cerenkov light (RICH detectors in ALICE, gamma ray astronomy, etc.), fluorescence light (UHE Cosmic ray physics) and most of scintillators operate. Solid detectors based on the use of silicon fail in the wavelength region 200-400 nm presenting very low quantum efficiency. CNTs instead are very sensitive to UV radiation. The cost of this detector is really very low. Large area photocathodes can be realized simply covering silicon layer with CNT, obtaining a photosensitive heterojunction. Coverage with ITO ensures the surface coating and makes the device employable.

**Calorimeter / 5**

**The upgrade of the BelleII froward calorimeter**

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The new facility SuperKEKB will be an upgrade of the existing KEKB electron-positron asymmetric collider, with a target luminosity of $8 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}$, about 40 times greater than that of KEKB. The accelerator upgrade is based on the novel low-emittance “nanobeams” scheme. The detector will also be upgraded to cope with the higher luminosity, pile-up and occupancy. We report here on the design and development of the new pure CsI calorimeter for the forward region. An intensive R&D has been carried on to study the performance of pure CsI crystals with APD’s (Avalanche Photodiodes) readout. Results about the signal to noise ratio of this detector for different
front end electronics configurations will be presented. A matrix of 16 crystals has been put on electron beam at the BTF facility in Frascati and at the MAMI facility in Mainz. Results in terms of energy and timing resolution of this prototype of the detector will also be discussed.

primary experiment:

BelleII

Gas Detectors / 261

A Novel Technique for the Measurement of the Avalanche Fluctuation of Gaseous Detectors

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Gas amplification of the electrons created by X-rays, UV photons, or charged particles plays an essential role in their detection with gaseous detectors. It acts as a “preamplifier” with a sufficient gain. However, its gain fluctuates because of avalanche statistics, thereby degrading the energy resolution for monochromatic X-rays. For large Time Projection Chambers (TPCs) the azimuthal spatial resolution at long drift distances is limited by the relative variance of the gas gain for single drift electrons. Conventionally, avalanche fluctuations are estimated from the gas-amplified charge spectrum for single electrons created by a UV lamp or a laser. We have developed a novel technique for the measurement of the relative variance of avalanche fluctuation ($f$) using laser-induced tracks, exploiting the fixed cluster size of one for each ionization act along the tracks. The primary electrons are multiplied by a gas amplification device, and then collected by several readout pad rows arranged along the laser beam. The signal charges on adjacent pad rows are compared for each laser shot. The value of $f$ is estimated from the width of the distribution of their differences using a straightforward relation. The technique is relatively simple and requires a short data-taking time of several tens of minutes. We present the experimental setup as well as the measurement principle, and the results obtained with a stack of Gas Electron Multipliers (GEMs) for several gas mixtures.

primary experiment:

ILC, Gaseous detectors

Summary:

Please find attached the PDF file for the summary.

Calorimeter / 246

Shower characteristics of particles with momenta up to 150 GeV in the CALICE scintillator-tungsten HCAL
In the R&D effort towards detectors at future high-energy colliders, CALICE is studying novel options for more compact hadron calorimeters. Using tungsten as dense absorber material appears to be an attractive alternative to iron. In this talk, a study of showers initiated by electrons, pions, kaons, and protons with beam momenta up to 150 GeV in the CALICE scintillator-tungsten HCAL is presented. Details of the data reconstruction and simulation as well as of the studies of systematic uncertainties are discussed. The resulting measurements of the calorimeter response to each particle type, as well as the energy resolution and detailed studies of the longitudinal and radial shower development, are presented. These results, of unprecedented detail, serve to validate and tune Geant4 simulation models for tungsten-based calorimetry. The data are therefore compared with several Geant4 simulation models.

**primary experiment:**

**CALICE Summary:**

"Shower characteristics of particles with momenta up to 150 GeV in the CALICE scintillator-tungsten HCAL"

by Eva Sicking (CERN) for the CALICE collaboration

We present a study of showers initiated by electrons, pions, kaons, and protons with beam momenta up to 150 GeV in the CALICE scintillator-tungsten hadronic calorimeter (W-AHCAL). The analysis results - including the W-AHCAL response, the energy resolution as well as longitudinal and radial shower shapes of unprecedented detail - serve to validate and tune Geant4 simulation models for tungsten-based calorimetry.

For $e^+$ showers, W-AHCAL data and simulation agree with each other well within the uncertainties for the detector response and the energy resolution, giving confidence in a correct implementation of the detector calibration and detector simulation. A fit to the energy resolution for $e^+$ data and simulations results in a stochastic term of approximately $29\%/\sqrt{\text{GeV}}$ and a constant term of approximately 1%.

For showers of $e^+\,\pi^+\,K^+$ and protons, the detector response is the same within systematic uncertainties for beam momenta up to 60 GeV, above which leakage effects in the hadron showers start to play an increasingly important role as shown in figure 1. The effect is reproduced by the Geant4 simulations.

For hadron showers, the Geant4 physics lists QGSP\_BERT\_HP and FTFP\_BERT\_HP reproduce the detector response, the energy resolution (figure 2) and average shower shapes such as the mean shower radius (figure 3) on the few-percent level while detailed longitudinal and lateral shower profiles are reproduced at the 15% level or better. In general, the FTFP\_BERT\_HP physics list gives a slightly better agreement with the W-AHCAL data for most observables, hadron types and particle energies than QGSP\_BERT\_HP. For the hadronic energy resolution of the W-AHCAL, a stochastic term of approximately $58\%/\sqrt{\text{GeV}}$ (61%/\sqrt{\text{GeV}}) is found for $\pi^+$ (proton) data and a constant term of approximately 5% is found for both $\pi^+$ and proton data. For both hadron types, the energy resolution has up to 5% lower values in FTFP\_BERT\_HP than observed in data, and up to 10% in QGSP\_BERT\_HP. The energy resolution for both electromagnetic and hadronic showers obtained for the W-AHCAL meets the expectations based on experience from the CALICE Fe-AHCAL equipped with steel absorbers instead of a tungsten absorbers.

Figure 1: Response of the W-AHCAL to $e^+, \pi^+, K^+$ and p for data.

Figure 2: The $\pi^+$ energy resolution for data and two Geant4 physics lists.

Figure 3: The $\pi^+$ mean shower radius for data and two Geant4 physics lists.
Characterization of a large CdZnTe coplanar quad-grid semiconductor detector

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The COBRA collaboration aims to search for the neutrinoless double beta-decay of $^{116}$Cd. For this purpose, it operates a demonstrator setup with 64 CdZnTe detectors, each with a volume of $1\text{cm}^3$, at the LNGS underground laboratory in Italy. Double beta-decays are associated with half-lifes of more than $10^{25}$ years. To be sensitive to those half-lifes, a high detection efficiency and especially an ultra low-background setup are, among other aspects, important requirements.

The usage of larger detectors is expected to be an improvement of the sensitivity. Detectors with a larger volume have a higher detection efficiency than the smaller ones. Due to the lower surface-to-volume ratio and the higher mass and thus, the usage of fewer detectors, the background can be reduced.

A large $(2\times 2\times 1.5)\text{cm}^3$ CdZnTe detector with a new coplanar-grid design is characterized for applications in $\gamma$-ray spectroscopy and low-background operation. The four coplanar-grids on the anode side offer the possibility of separating the detector in four single sectors. The electric properties as well as the spectrometric performance, like energy response and resolution, are investigated in several measurements. Furthermore, studies concerning the operational stability and the possibility to identify multiple-scattered photons, are conducted.

primary experiment:

COBRA

Performance in electron beams of a tungsten-CeF3 prototype for radiation-resistant high-energy physics calorimetry

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The High-Luminosity phase of the Large Hadron Collider at CERN (HL-LHC) poses stringent requirements on calorimeter performance in terms of resolution, pileup resilience and radiation hardness. A tungsten-$CeF_3$ sampling calorimeter is a possible option for the upgrade of current LHC detectors and for future HEP experiments.

A prototype of the calorimeter has been built and exposed to high energy electrons at the CERN SPS H4 beam line. The performance of the prototype, read out with different types of wavelength-shifting fibers, conventional clad plastic fibers and photo-luminescent radiation hard cerium-doped quartz fibers, will be shown in terms of energy resolution, uniformity and timing performance.

A detailed simulation has been also developed in order to compare with data and to extrapolate to different configurations. Additional studies on the calorimeter and the R&D projects ongoing on the various components of the experimental setup will be also discussed.

**primary experiment**

generic R&D Summary:

The High-Luminosity phase of the LHC collider, starting in 2025, will be characterized by high rates of ionising radiation, up to 60 Gy/h, and energetic particle fluences up to $5 \times 10^{14}$ cm$^{-2}$. The stringent requirements that this harsh experimental environment imposes are leading LHC experiments to consider the upgrade of detectors, especially in the forward part, which is more exposed to radiation.

One of the options considered for upgrades in forward electromagnetic calorimetry is a sampling calorimeter, with cerium fluoride active layers interleaved with tungsten absorber plates. This kind of calorimeter can be easily read out by wavelength-shifting (WLS) fibers. Such a design would allow to achieve an adequate resolution at an affordable costs.

Cerium fluoride crystals are good candidates for this detector, since they have proven to spontaneously recover, at room temperature, from damage caused by energetic hadrons [1]. Moreover it was shown that the $CeF_3$ production can be tuned such that the resulting crystals are extremely resistant to ionising radiation [2].

The calorimeter design foresees wavelength-shifting fibers running along depolished chamfers of each channel, to minimize the complexity of mechanical assembly, as described in [3]. Radiation hardness of the fibers is a key element for the development of a HL-LHC detector. For this reason, in addition to conventional clad WLS plastic fibers, different types of potentially radiation-hard fibers have been developed. Cerium-doped quartz is known to be quite radiation hard, and fibers made of this material, whose photo-luminescent excitation matches emission spectrum of $CeF_3$, have been tested for the channel readout.

This paper summarizes the results of beam tests on a single channel with high-energy electrons from the SPS accelerator at CERN. The active samples are 10 mm thick, while each absorber layer thickness is 3.1 mm. For lateral shower containment and alignment purposes, Bismuth Germanium Oxide (Bi$_4$Ge$_3$O$_{12}$ or BGO crystals were added to form a $5 \times 5$ matrix. The dimensions of the channel used (15 layers corresponding to $25 \times_0$) ensure a good longitudinal containment for electrons of the energies delivered by SPS, which range from 20 to 200 GeV.
The transverse cross section of the channel is $24 \times 24 \text{mm}^2$.  
A full simulation of the experimental setup has been developed using the GEANT4 package.  
The resolution of the calorimeter is of the order of 1% (9.5% for the stochastic term and 0.3% for the constant term of the resolution), for 200 GeV electrons, making it suitable for LHC experiments. A good agreement between data and simulations is found for a single channel setup.  
Uniformity of the response across the crystal face has been thoroughly studied in the tests. The H4 beam telescope allows to study the response of the $W - CeF_3$ channel as a function of the impact point across the front face. A good spatial uniformity is found, even if non-uniformities due to the light collection have been spotted, potentially limiting the position determination in this kind of calorimeter.  
Furthermore, cerium-doped quartz fibers coupled with Hamamatsu R1450 PMT show a fast direct Cherenkov component suitable for precise timing. A dedicated test to explore the timing capabilities of such signal has been performed, by surrounding a bundle of fibers in one corner of the prototype by black paper, in order to detect only the Cherenkov light generated in the fiber bundle.  
The timing performance, using Micro-Channel Plates detectors as reference, is presented.  
This work was performed with the support of the Swiss National Science Foundation, the Istituto Nazionale di Fisica Nucleare and the European Union’s Horizon2020 MSCA-RISE-2014 research project INTELUM under grant agreement N. 654168  

Semiconductor Detectors / 135

First prototypes of two-tier avalanche pixel sensors for particle detection

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In this paper, we present the proof-of-concept implementation and preliminary evaluation of a new type of silicon sensor based on Geiger-mode avalanche detectors. The proposed device, formed by two vertically-aligned pixelated detectors, exploits the coincidence between two simultaneous avalanche events to discriminate between particle-triggered detections and dark counts. This approach offers several advantages in applications requiring low material budget and fine detector segmentation as, for instance, for tracking and vertex reconstruction in particle physics experiments and charged particle imaging in medicine and biology. In addition, a timing resolution in the order of tens of picoseconds can potentially be achieved thanks to the fast onset of avalanche multiplication in Geiger-mode regime.  
A two-tier sensor assembly was designed and fabricated in a commercial 0.15μm CMOS process. The
sensor consists of a 48x16 pixel array, and includes avalanche diodes of different sizes to evaluate the
detection efficiency for different fill factors. Each pixel, having a 50μm x 75μm area, includes detect-
ers and electronics on both layers, with the top-layer signal transmitted to the bottom layer using
a vertical interconnection per pixel. The two layers were tested separately and proved to be fully
functional. Several sensor samples are currently being vertically-integrated through bump bonding.
The first test results on the vertically-integrated sensors will be discussed.

primary experiment:

APIX2 Summary:

The sensor presented in this contribution was developed in the framework of the INFN project APix2
[1].

The simplified block diagram of a 2-level pixel is shown in Figure 1a. Two different types of Geiger-mode
avalanche detectors were used in this design, having slightly different active-region thickness. The two
detectors were tested in a previous chip, demonstrating good characteristics, even though they were
fabricated in a standard CMOS process [2]. In the pixel, the detectors are passively quenched and their
output signals are digitized by means of a low-threshold comparator. The resulting pulses are shortened
by a programmable-length monostable circuit, providing a minimum pulse width of 750ps. The pixels
can be independently enabled or disabled with an arbitrary pattern, defined by a configuration register.
The output of the monostable in the top half-pixel feeds a coincidence detector located in the bottom
layer, and the coincidence output is stored in a 1-bit memory. Data can be transferred in parallel to an
output register for data readout. In this way, signal detection and data readout can be run in parallel,
thereby avoiding any dead time in the data acquisition process.

The monostable outputs were also sent to a row-wise OR gate, combining the outputs of all the active
pixels in a row to a single signal stream. This feature was included to improve the testability of the
chip and allows a wide range of tests if combined with proper setting of the configuration register, for
example mapping the dark count rate (DCR) and crosstalk probability between different pixels.

Bump bonding technique using 12-um solder bumps was chosen for the vertical integration, due to
the accessibility of the process and good yield obtainable even with small quantities of processed dies
(Figure 1b). The detectors were covered with a metal shield to avoid inter-layer optical cross-talk.

A few samples of top and bottom chips were wire-bonded for testing before proceeding to vertical
integration. Electrical tests showed the correct functionality of both avalanche detectors and electronics
in the two chips. Preliminary DCR statistics were acquired, demonstrating a median DCR lower than
10kHz for the largest detectors of both types, having 43μm x 45μm active area. Further characterization
of DCR statistics, uniformity and crosstalk are under way. Several samples are being processed for
vertical integration using bump bonding technique. The two-layer assemblies (Figure 1c) will be ready
for testing by the end of the year.

References:


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Two-phase Cryogenic Avalanche Detector with electroluminescence gap and THGEM/GAPD-matrix multiplier

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Two-phase Cryogenic Avalanche Detectors (CRADs) with THGEM multipliers have become an emerging potential technique for rare-event experiments. In this work the current status of the two-phase CRAD prototype in Ar, with electroluminescence (EL) gap and combined THGEM/GAPD-matrix multiplier, is described. The low threshold and high energy resolution of the detector is provided by the EL gap, optically read out in the VUV using compact cryogenic PMTs. The high spatial resolution of the detector is provided by the double-THGEM charge multiplier combined with a 5x5 matrix of Geiger-mode APDs (GAPDs), optically recording THGEM-hole avalanches in the Near Infrared (NIR). Proportional electroluminescence in EL gap in argon, with a minor (50 ppm) admixture of nitrogen to liquid Ar, has for the first time been systematically studied at cryogenic temperatures in the two-phase mode. The overall EL amplification parameter and the EL threshold measured in this work were in accordance with those predicted by the theory. The result on the EL threshold is particularly relevant to DarkSide and SCENE dark matter search-related experiments, where the operation electric field was thereby on the verge of appearance of the S2 signal. We also present the results on nuclear recoil detection in liquid Ar, using the two-phase CRAD and DD neutron generator, relevant in the field of energy calibration of rare-event detectors for dark matter search and coherent neutrino-nucleus scattering experiments.

**Primary Experiment:**

Cryogenic Avalanche Detectors

**Summary:**

Two-phase Cryogenic Avalanche Detectors (CRADs) with THGEM multipliers have become an emerging potential technique for rare-event experiments. In this work the current status of the two-phase CRAD prototype in Ar, with electroluminescence (EL) gap and combined THGEM/GAPD-matrix multiplier, is described. The low threshold and high energy resolution of the detector is provided by the EL gap, optically read out in the VUV using compact cryogenic PMTs. The high spatial resolution of the detector is provided by the double-THGEM charge multiplier combined with a 5x5 matrix of Geiger-mode APDs (GAPDs), optically recording THGEM-hole avalanches in the Near Infrared (NIR). Proportional electroluminescence in EL gap in argon, with a minor (50 ppm) admixture of nitrogen to liquid Ar, has for the first time been systematically studied at cryogenic temperatures in the two-phase mode. The overall EL amplification parameter and the EL threshold measured in this work were in accordance with those predicted by the theory. The result on the EL threshold is particularly relevant to DarkSide and SCENE dark matter search-related experiments, where the operation electric field was thereby on the verge of appearance of the S2 signal. We also present the results on nuclear recoil detection in liquid Ar, using the two-phase CRAD and DD neutron generator, relevant in the field of energy calibration of rare-event detectors for dark matter search and coherent neutrino-nucleus scattering experiments.

**Photon Detectors / 94**

**Tremendously Increased Lifetime of Microchannel-Plate PMTs**

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Microchannel plate (MCP) PMTs are very attractive photon sensors for low light level applications in B-fields. However, until recently the main drawback of MCP-PMTs was their aging behaviour which manifests itself in a limited lifetime due to a rapidly decreasing quantum efficiency (QE) of the photo cathode (PC) as the integrated anode charge (IAC) increases. In the latest models of PHOTONIS, Hamamatsu, and BINP novel techniques are applied to avoid these aging effects which are mainly caused by ion backflow impinging on the PC and damaging it.

Since four years we are running an aging test for new lifetime-enhanced MCP-PMT models by simultaneously illuminating various PMT types with roughly the same photon rate. This allows a
fair comparison of the lifetime of all investigated MCP-PMTs and will give some insight in the best techniques for a lifetime enhancement.

In this presentation the results of comprehensive aging tests will be discussed. Gain, dark count rate and QE were investigated for their dependence on the IAC. The QE was measured spectrally resolved and as a function of the position across the photo cathode to identify regions where the PC damage develops first. For the best performing tubes the lifetime improvement in comparison to the older MCP-PMTs is a factor of ~50 based on an IAC of meanwhile >9 C/cm². This breakthrough in the lifetime of MCP-PMTs was accomplished by coating the MCP pores using an atomic layer deposition (ALD) technique.

primary experiment:
FAIR/PANDA

Semiconductor Detectors / 239

The ATLAS ITK strip detector - status of R&D

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While the LHC at CERN, where the ATLAS and CMS experiments have discovered the Higgs Boson in 2012, is ramping up luminosity, upgrades to the LHC and experiments are planned. The major upgrade is foreseen for 2024, with a roughly tenfold increase in luminosity, resulting in corresponding increases in particle rates and radiation doses. In ATLAS the entire Inner Detector will be replaced for Phase-2 running with an all-silicon system. This talk will concentrate on the strip part. Its layout foresees low-mass and modular yet highly integrated double-sided structures for the barrel and forward region. The design features conceptually simple modules made from electronic hybrids glued directly onto the silicon. Modules will then be assembled on both sides of large carbon-core structures with integrated cooling and electrical services. The modularity allows assembly and testing at multiple sites, while the high integration density facilitates macro-assembly and system tests.

We will present the outcomes of the massive R&D effort underway, and show on-going development and prototyping efforts. A large number of components are currently being developed, with for many parts, prototyping efforts towards full-size components in full swing. The recent developments and test results will be presented. Particular emphasis will be given to silicon sensors and readout. In addition, assembly and QA procedures will be shown. We will also give an outlook towards mass production.

primary experiment:
ATLAS

Summary:
The presentation will give an overview of the planned detector and the status of the extensive R&D programme for the barrel and end-cap structures and modules.

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Construction and Test of New Precision Drift-Tube Chambers for ATLAS Muon Spectrometer Upgrades

Authors: Felix Mueller¹; Hubert Kroha¹; Korbinian Ralf Schmidt-Sommerfeld¹; Markus Fras¹; Oliver Kortner²; Paul Philipp Gadow¹; Robert Richter¹; Sandra Kortner¹; Sebastian Nowak¹
The Monitored Drift Tube (MDT) chambers of the ATLAS muon spectrometer demonstrated that they provide very precise and robust tracking over large areas. Goals of ATLAS muon detector upgrades are to increase the acceptance for precision muon momentum measurement and triggering and to improve the rate capability of the muon chambers in the high-background regions when the LHC luminosity increases. Small-diameter Muon Drift Tube (sMDT) chambers have been developed for these purposes. With half the drift-tube diameter of the MDT chambers and otherwise unchanged operating parameters, sMDT chambers share the advantages with the MDTs, but have an order of magnitude higher rate capability and can be installed in detector regions where MDT chambers do not fit in. The chamber assembly methods have been optimized for mass production, reducing cost and construction time considerably and improving the sense wire positioning accuracy to better than ten microns. The construction of twelve chambers for the feet regions of the ATLAS detector is currently in progress with the plan to install them in the winter shutdown 2016/17 of the LHC. Design and construction of the new sMDT chambers for ATLAS will be discussed as well as measurements of their precision and performance.

primary experiment:
ATLAS

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Development of an extremely thin-wall straw tracker operational in vacuum - The COMET Straw Tracker System -

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The COMET experiment at J-PARC aims to search for a lepton-flavour violating process of muon to electron conversion in a muonic atom, μ-e conversion, with a branching-ratio sensitivity of better than $10^{-16}$, 4 orders of magnitude better than the present limit, in order to explore the parameter region predicted by most of well-motivated theoretical models beyond the Standard Model. The need for this sensitivity places several stringent requirements on the detector development. The experiment requires to detect the monochromatic electron of 105 MeV, the momentum resolution is primarily limited by the multiple scattering effect for this momentum region. In addition, high power proton driver is essential to accumulate an enough statistics, i.e., high rate capability is necessary. Thus we need the very light material detector which can handle the high intensity beam in order to achieve an excellent momentum resolution, better than 2%, for 100 MeV region and to accumulate an enough statistics, up to $5 \times 10^9 \mu^-/s$. In order to fulfill such requirements, we decided to develop the straw-base planar tracker which is operational in vacuum and made by an extremely light material. The COMET straw tracker consists of 10 mm diameter straw tube, longer than 1 m length, with 20 μm thickness Mylar foil and 70 nm aluminum deposition. Currently even thinner and smaller, 12 μm-thick and 5 mm diameter, straw is under development by the ultrasonic welding technique.
Upgrades of the CMS outer tracker detector for the HL-LHC

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The LHC machine is planning an upgrade program which will smoothly bring the luminosity up to or above $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$ sometime after 2024, to possibly reach an integrated luminosity of 3000 fb$^{-1}$ at the end of that decade. In this ultimate scenario, called Phase-2, when LHC will reach the High Luminosity (HL-LHC) phase, CMS will need a completely new Tracker detector, in order to fully exploit the high-demanding operating conditions and the delivered luminosity. The new Tracker should have also trigger capabilities. To achieve such goals, R&D activities are ongoing to explore options and develop solutions that would allow including tracking information at Level-1. The design choices for the CMS Outer Tracker upgrades are discussed along with some highlights of the R&D activities.

Behaviour of hybrid avalanche photo-detector for the Belle II Aerogel RICH in magnetic field

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For the Belle II spectrometer a proximity focusing RICH counter with an aerogel radiator (ARICH) will be employed as a PID system in the forward endcap region of the spectrometer. The main challenge during ARICH R&D was a reliable multichannel sensor for single photons that operates in the high magnetic field of the spectrometer (1.5 T) and withstands the radiation levels expected at the experiment. A 144-channel Hybrid Avalanche Photo-Detector (HAPD) was developed with Hamamatsu Photonics K.K. and recently the production of 450 HAPDs was completed. While our first tests of HAPD performance in the magnetic field (before mass production) showed no issues,
we lately observed a presence of very large signal pulses (~5000× single photon signal), generated internally within about 20% of HAPDs, while operating in the magnetic field. The rate of these pulses varies from sample to sample. These pulses impact the HAPD performance in two ways: they introduce periods of dead time and in some cases damage to the front-end electronics was observed. In the talk we will present conditions under which such large pulses are generated, their properties and impact on HAPD performance, and discuss possible mechanism of their origin.

**primary experiment:**
Belle II

**Photon Detectors / 145**

**Development of solar blind UV extended APD for the readout of Barium Fluoride crystals**

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In order to take advantage of the very fast scintillation component of barium fluoride (decay time 0.9 ns at 220 nm) it is necessary to have a fast photosensor with high efficiency in the UV that is also able to discriminate against the larger slow (decay time 650 ns at 300 nm) scintillation component. We have developed a large area avalanche photodiode photosensor that has high quantum efficiency at 220 nm, strong discrimination against the 300 nm component and good rise and decay times. This sensor makes it possible to build a radiation-hard calorimeter based on barium fluoride for the Mu2e experiment at Fermilab that has good energy and time resolution and high rate capability.

**primary experiment:**
mu2e

**Gas Detectors / 242**

**AXEL - high pressure xenon gas TPC for neutrinoless double beta decay search**

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Observation of neutrinoless double beta decay ($0\nu\beta\beta$) is of essential importance to reveal the nature of neutrino, such as mass hierarchy, absolute mass and especially its Majorana property. In order to search for $0\nu\beta\beta$, we, AXEL project, are developing a time projection chamber filled with high pressure Xenon gas. The detector can potentially achieve high energy resolution, large target mass and strong background rejection power by tracking. By using gaseous xenon, it is possible to realize a high energy resolution of 0.5% at 2.5 MeV (Q value), better than several % in case of liquid. The deposited energy is determined by measuring the proportional scintillation lights which are generated...
by accelerating ionization electrons. We are developing a new readout scheme where light-emitting region is divided to cells and emitted lights are detected by MPPCs cell by cell. In addition to the robust structure, this scheme would have uniform response in wide area because the light-emitting region and MPPC corresponds one-to-one, so this scheme enables to achieve both high energy resolution and large size. We have produced a prototype chamber filled with 10 bar and 10 L Xe gas and evaluated the performance and obtained 5% (FWHM) energy resolution at 122 keV. This is expected to be further improved by the time of conference with new VUV-sensitive MPPCs. We will report about the studies of this prototype chamber and present future plans and final goals of AXEL.

primary experiment:
AXEL

Semiconductor Detectors / 33

Exploring the quality of latest sensor prototypes for the CMS Outer Tracker Upgrade

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The LHC will reach its nominal luminosity soon which will be further increased by a factor of five to seven during the third Long Shutdown (LS3) around 2024. This significant increase in luminosity along with the increasing radiation damage requires a complete renewal of the CMS Outer Tracker, the Tracker Phase-2 Upgrade, during the LS3. Two types of modules named PS- and 2S-module, both featuring trigger capabilities, will be implemented during this upgrade.

Milestones in the sensor R&D for the 2S-modules as well as first characterisation results are presented. AC-coupled silicon strip sensors of two vendors, produced on 6-inch as well as on 8-inch wafers, are considered. Both of them feature the demanded n-in-p technology. The wafer layout is presented which features new test structures improving the quality assurance at the manufacturer and in the laboratory is described. Results from the electrical characterisation as well as first beam test results comprising full scale 2S-module prototypes are discussed. Concluding long-term behaviour studies under varying temperatures and humidities provide insights into the robustness under environmental stress.

primary experiment:
CMS

Gas Detectors / 303

GridPix detector - Development and Application

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The GridPix detectors are an interesting new technology which combine a highly granular readout structure implemented by the pixelized Timepix ASIC with a
Micromegas mesh. The mesh is produced by photolithographic processing techniques and each mesh hole is aligned with one readout pixel. This allows for detecting single primary electrons with high detection efficiency. Both energy and spatial resolution profit from resolving the structure of tracks or X-ray conversions.

We have developed a wafer-based production of GridPix detectors and a scalable readout system allowing the construction and simultaneous operation of a large number of GridPixes in a complete experimental setup. Several application will be presented: A test beam with a large volume TPC at DESY has demonstrated the smooth operation of 160 GridPix detectors recording tracks of up to 50 cm length. Another application which will be covered in this presentation is the good X-ray energy resolution of about 3.85 %, which is important for low-rate experiments such as solar axion searches. Finally also tests of a GridPix based transition radiation detector in a magnetic field will be presented.

**primary experiment:**
LCTPC, CAST

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**Semiconductor Detectors / 65**

**The Phase-1 Upgrade of the CMS Pixel Detector**

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The CMS experiment features a pixel detector with three barrel layers (BPIX) and two disks per side (FPIX). While the detector was delivering high-quality data during LHC Run 1, it was designed for the nominal instantaneous LHC luminosity of $1.0 \times 10^{34}$ cm$^{-2}$ s$^{-1}$. It is expected that the instantaneous luminosity will reach twice the design value before Long Shutdown 3. Under such conditions, the present readout chip would suffer from data loss due to buffer overflow. The CMS collaboration is constructing a new pixel detector, to replace the present device during the Winter shutdown 2016/2017.

The goals of the Phase-1 Pixel Upgrade is three-fold: to operate with full efficiency at $2.0 \times 10^{34}$ cm$^{-2}$ s$^{-1}$; to increase detector acceptance and redundancy; and to reduce the material budget. The upgraded device thus features a modified readout scheme and a new readout chip, additional detection layers, and a new support mechanics as well as improvements of the services, including an evaporative cooling system based on CO2. This contribution will motivate the detector design and technological choices of the new pixel detector. Focussing then on BPIX, the implementation as well as the performance of new technical solutions will be outlined. Results from BPIX beam and system tests will be presented. The status of the BPIX construction and pixel module production will be described, and challenges, difficulties encountered as well as lessons learned will be discussed.

**primary experiment:**
CMS

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**Astroparticle Detectors / 169**

**Detection of High Energy Cosmic Rays with the Auger Engineering Radio Array**

**Author:** Raphael Krause

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Ultra High Energy Cosmic Rays induce extensive air showers in the Earth’s atmosphere. Within the Pierre Auger Observatory in Argentina, the Auger Engineering Radio Array has been built to measure MHz radio emission of these showers in addition to established techniques based on fluorescence emission and particle detection on ground. An area of around 17km² has been instrumented by 153 autonomous radio stations which record radio signals with frequencies between 30 to 80 MHz, covering the full zenith angular range with a duty cycle close to 100%. Recent progress will be presented on thorough calibration efforts of the radio array, and on measurements of the primary cosmic ray energies.

primary experiment:
Pierre Auger Observatory

Semiconductor Detectors / 26

Pixel Sensors with slim edges and small pitches for the CMS upgrades for HL-LHC

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The CMS experiment will build a third generation Pixel detector for the HL-LHC. The foreseen integrated luminosity of 3000 fb⁻¹ together with the high particle rates demands sensors with higher granularity and a sensor design with limited dead area surrounding the active Pixel array. This contribution will cover the recent development of pixelated sensors with the regular 100 um pitch and with pitches reduced to 50 and 25 um. Moreover, results will also be shown from silicon sensors where the inactive area surrounding the pixel array has been reduced to 200 um. The devices were first characterized in terms of DC performance at the probe station, mounted on readout boards and exposed to 120Gev protons at the Fermilab Test Beam Facility. The contribution will include the bench characterization of the devices and the measurements of their tracking performances, in terms of efficiency and resolution, as measured in the beam. The prototypes were irradiated at the CERN PS irradiation facility and their performance post-irradiation will also be presented.

primary experiment:
CMS

Gas Detectors / 171

Performance studies of resistive Micromegas detectors for the upgrade of the ATLAS Muon Spectrometer

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Resistive Micromegas (Micro MEsh Gaseous Structure) detectors have proven along the years to be a reliable high rate capable detector technology
characterized by an excellent spatial resolution. The ATLAS collaboration has chosen the resistive Micromegas technology (mainly for tracking), along with the small-strip Thin Gap Chambers (sTGC, mainly for triggering), for the phase-1 upgrade of the inner muon station in the high-rapidity region, the so called New Small Wheel (NSW). The NSW requires fully efficient Micromegas chambers with spatial resolution better than 100\(\mu\)m independent of the track incidence angle and the magnetic field (B<0.3T), with a rate capability up to \(\sim\)10kHz/cm\(^2\). Along with the precise tracking the Micromegas chambers should be able to provide a trigger signal, complementary to the sTGC, thus a decent timing resolution is required. Several tests have been performed on small (10x10cm\(^2\)) and medium size (1x0.5m\(^2\)) resistive Micromegas chambers (bulk type and mechanical floating mesh type) using medium (10GeV/c) and high (150GeV/c) momentum hadron beams at CERN including measurements inside magnetic field. Results on the measured efficiency, position and timing resolution will be shown demonstrating the excellent characteristics of the detectors that fulfill the NSW requirements. In addition, early test results from the first full size (2-3m\(^2\)) operational modules that will be realised during 2015, will be presented.

primary experiment:
ATLAS

Summary:
see attachment

Astroparticle Detectors / 42

Operation and performance of the EEE network array for the detection of cosmic rays

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P La Rocca for the EEE Collaboration

The EEE (Extreme Energy Events) Project is an experiment for the detection of cosmic ray muons by means of a sparse array of telescopes, each made of three Multigap Resistive Plate Chambers, distributed over all the Italian territory. The main scientific goals of the Project are the investigation of the properties of the local muon flux, the detection of extensive air showers and the search for long distance correlation between far telescopes. The Project is also characterized by a strong educational and outreach aspect since the telescopes are managed by teams of students and teachers who previously also took care of their construction at CERN. The experiment took a first coordinated data taking ("Pilot-Run") in fall 2014 and another ("Run-1") from February to April 2015. About thirty telescopes collected several billions of cosmic ray events that have been stored, reconstructed and analyzed thanks to the computing facilities at CNAF – the biggest Italian storage and computing center managed by INFN. In this presentation an overall description of the experiment will be given, including the design, construction and performance of the single telescopes. The operation of the whole array is also presented by showing the most recent results obtained from the analysis of the collected data.

primary experiment:
EEE Experiment

Summary:

The EEE (Extreme Energy Events) Project has started since several years the construction and installation of a set of cosmic ray telescopes with involvement of high school teams over the Italian territory [1]. Each telescope is made by three Multigap Resistive Plate Chambers (MRPC) of about 1.5 x 0.8 m\(^2\).
The excellent time resolution of these detectors allows to reconstruct with good precision the orientation of cosmic ray secondary muons crossing the telescope. Presently about 50 telescopes have been successfully installed in high schools distributed over the Italian territory, and most of them are taking data since a few years. During 2014 a special effort has been done by the EEE Collaboration to organize a first pilot run with a set of telescopes running continuously during a period of approximately 15 days, in order to understand and solve the problems originating from the control, monitoring, data transfer and analysis of a large set of data collected by detectors disseminated in a large geographical area. From February to April 2015 about 30 telescopes have been acquiring data at the same time. Throughout these 45 days, identified as Run-1, the telescopes collected several billion of cosmic ray events, with an acquisition trigger rate from each telescope ranging from 10 to 40 Hz, depending on the location and amount of shielding around the detector. All the data were transferred in real time to a central server and a series of data quality controls were carried out daily, with a feedback to the local users in order to improve the correct operation of the telescope and the data collection. Several analyses have already started on this huge amount of events [2], to monitor the muon flux as a function of time, to correlate it with the variation of the local pressure and temperature and to search for unusual variation of the flux, as due for instance to solar catastrophic events, such as solar flares [3]. The study of correlated events from two or more telescopes is also an important part of the analysis, allowing to identify extensive air showers which involve telescopes located in the same metropolitan area, or to search for long distance correlation between far telescopes. A study of the upward going particles was also carried out, providing interesting results on the telescopes performance. The peculiar structure of the EEE network allows to search for small anisotropies of the muon flux at the sub-TeV sky, in an energy region strongly influenced by large scale as well as local magnetic field features [4].

This contribution will report the present status of the Project, together with the main results from the 2015 Run-1 and future perspectives.

[1] Centro Fermi web site: http://www.centrofermi.it/eee


[3] M.Abbrescia et al. (the EEE Collaboration) "Results from the observations of Forbush decreases by the Extreme Energy Events experiment", PoS (ICRC2015) 097


Semiconductor Detectors / 333

Thin hybrid pixel assembly fabrication development with backside compensation layer

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ATLAS will replace the entire tracking system for operation at the HL-LHC. This will include a significantly larger pixel detector of approximately 8 m2. It is critical to reduce the mass of the pixel modules and this requires thinning both the sensor and readout to about 150 micrometers each. The bump yield in thin module assembly using solder based bump bonding can be problematic due to wafer bowing during processing at high temperatures. A new bump-bonding process using backside compensation on the readout chip to address the issue of low yield will be presented. Results from characterization of assemblies produced from readout wafers thinner to 100 micrometers and the effect of applying backside compensation will be presented. Bond yields close to 100% have been measured using the FEI4 readout chip.

primary experiment: ATLAS

Summary:
The ATLAS FE-I4 readout IC, ROIC, is almost 20 mm x 20 mm in size with order 10 micrometers of metal and dielectrics above the CMOS implants. When the die is thinned to a few hundred micrometers it bows due to the stress in the dielectric/metal layers no longer being resisted by a thick silicon substrate. This bowing is increased further as elevated temperatures due to the different coefficient of thermal expansions of the dielectric/metal layers and silicon substrate. Solder based bump-bonding typically takes place at 260°C and will increase the bow of the die significantly to several hundred micrometers. The size of the solder bumps are only 25 micrometers in diameter. Therefore, bowing of the ROIC will cause issues with the yield of the solder connections as they will not make electrical connection with the sensor and ROIC. The work will show that the bow of the die can be affected with the use of a post-processed dielectric layer and metal layer deposited on the backside of the wafer. The bow of the FE-I4 dies as a function of die temperature for different backside dielectric deposition is shown. The details of the fabrication process and the characterization techniques are described, as well as the final result. The processing technologies have been chosen to be compatible with both the existing CMOS ROIC but also with the through-silicon-via, TSV, technology of the foundry. The near 100% bond yield of assemblies made from 100 micrometer thick ROICs and 150 micrometers sensors are shown. The assemblies have been shown to be robust to thermally cycling from 60°C to -40°C 100 times and to thermal shock (defined as a sudden change from room temperature to -40°C).

**Astroparticle Detectors / 81**

**The Mini-EUSO telescope on the ISS**

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The Mini-EUSO project aims to perform observations of the UV-light night emission from Earth. The UV background produced in atmosphere is a key measurement for any experiment aiming at the observation of Ultra High Energy Cosmic Rays (UHECR) from space, the most energetic component of the cosmic radiation.

The Mini-EUSO instrument will be placed within the International Space Station (ISS) in the Russian Module and measures through a UV transparent window. The installation is foreseen for 2017. The instrument comprises a compact telescope with a large field of view, based on an optical system employing two Fresnel lenses for increased light collection. The light is focused onto an array of photo-multipliers and the resulting signal is converted to digital, processed and stored via the electronics subsystems on-board.

The instrument is designed and built by the members of the JEM-EUSO collaboration. JEM-EUSO is a wide-angle refractive UV telescope being proposed for attachment to the ISS, which has been designed to address basic problems of fundamental physics and high-energy astrophysics investigating the nature of cosmic rays with energies above 1020 eV.

Mini-EUSO will be able to study beside UHECRs a wide range of scientific phenomena including atmospheric physics, strange quark matter and bioluminescence. The mission is approved by the Italian Space Agency and the Russian Space Agency. Scientific, technical and programmatic aspects of this project will be described.

**primary experiment:**

JEM-EUSO

**Gas Detectors / 205**

**Anode charge-up in resistive Micromegas and its quenching effect on spark development**

**Author:** Maximilien Chefdeville¹
Fast evacuation of avalanche ions in Micromegas makes these detectors capable of withstanding very high rates with no loss of gain. But this intrinsic high-rate capability is often compromised by sporadic sparking which introduces dead time and is potentially harmful for the readout. Resistive electrode designs, by limiting spark current and keeping voltage drop locally, provide an effective remedy. They are thus quite popular, but there is actually more to them than simply spark attenuation. We propose that the spark probability is also drastically reduced because of charge-up of the resistive electrode surface. The underlying mechanism is a progressive reduction of field (in the region where spark-initiating avalanches develop) by the charges successively incoming onto the surface. We predict that the time constant with which the surface potential is relaxed is crucial to the success of this quenching mechanism. Small prototypes with a time constant varying over 5 orders of magnitude were built to verify this model. During tests in a high intensity hadron beam, spark quenching was observed for time constants larger than roughly 1-10 ns, corresponding to the avalanche timescale in Micromegas. These findings shed light on the basic mechanism of spark quenching in resistive detectors. Of general interest to the gaseous detector community, they also open the way to an optimisation of the resistivity value for best rate capability and full spark suppression.

primary experiment:
Sparking Gaseous Detectors

Semiconductor Detectors / 340

The NA62 GigaTracker

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The GigaTracker is an hybrid silicon pixel detector built for the NA62 experiment aiming at measuring the branching fraction of the ultra-rare kaon decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$ at the CERN SPS. The detector has to track particles in a beam with a flux reaching 1.3 MHz/mm$^2$ and provide single-hit timing with 200ps RMS resolution for a total material budget of less than 1.5$X_0$. The tracker comprises three 60.8mm x 27mm stations installed in vacuum (~ 10^{-6}mbar) and cooled with liquid C$_6$F$_{14}$ circulating through micro-channels etched inside few hundred of microns thick silicon plates. Each station is composed of a 200µm thick silicon sensor readout by 2 x 5 custom 100µm thick ASIC, called TDCPix. Each chip contains 40 x 45 asynchronous pixels, each 300µm x 300µm and is instrumented with 720 time-to-digital converters with 100ps bin. In order to cope with the high rate, the TDCPix is equipped with four 3.2Gb/s serialisers sending out the data. We will describe the detector and the results from the 2015 NA62 run.

primary experiment:
NA62

Astroparticle Detectors / 302

CaloCube: a new-concept calorimeter for the detection of high-energy cosmic rays in space
The direct observation of high-energy cosmic rays, up to the PeV region, will increasingly rely on a highly performing calorimetry apparatus, and the physics performance will be primarily determined by the geometrical acceptance and the energy resolution of the deployed calorimeter. Thus, it is extremely important to optimize its geometrical design, granularity, and absorption depth, with respect to the total mass of the apparatus, which is the most important constraint for a space launch. Calocube is a homogeneous calorimeter whose basic geometry is cubic and isotropic, so as to detect particles arriving from every direction in space, thus maximizing the acceptance; granularity is obtained by filling the cubic volume with small cubic scintillating crystals. This design forms the basis of a three-year R&D activity which has been approved and financed by INFN. A comparative study of different scintillating materials have been performed. Optimal values for the size of the crystals and spacing among them have been studied. Different geometries, beyond the cubic one, and the possibility to implement dual readout techniques have been investigated. A prototype, instrumented with CsI(Tl) cubic crystals, has been constructed and tested with particle beams. An overview of the obtained results will be presented and the perspectives for future space experiments will be discussed.

**Summary:**

A key point for understanding the nature of galactic cosmic rays is the possibility to perform a precise spectral measurement of individual elements up to the “knee” region, around PeV energies. At present, the only feasible instrument to measure energies above 10 TeV is a calorimeter. At PeV energies the cosmic-ray rate reaches about one particle per square meter per year. Thus, an effective acceptance of several m²sr is required in order to cover the “knee” spectral structure of light primary elements, by assuming a typical few-year space mission. This task poses a challenge, since space instruments are severely limited in mass and dimensions, so that any possible space-compliant calorimeter is unavoidably far from total-containment performances. The concept design explored by our R&D project is an homogeneous active volume, tessellated by uniform detection units, so as to detect particles arriving from every direction in space with an isotropic detector response. The basic geometry is cubic and the 3D segmentation is obtained by filling the volume with small cubic scintillating crystals, from which the name CaloCube. As a basic support to the project development, an extensive simulation work has been performed, aiming to optimize the overall geometry and to select the best active material. The calorimetric performances of several scintillating materials, ranging from low- to high-density crystals, have been compared, assuming a cubic geometry. Cylindrical and spherical geometries have also been studied. Finally, the possible implementation of the dual-readout technique (dual detection of scintillation and Cherenkov light) have been investigated. An intense laboratory activity was carried out, in order to perform a comparative study of a sample set of different scintillating materials (CsI, YAG, BaF2, YAP, LuAG, BSO, BGO and LYSO), aiming to characterize the optical properties, the response to ionizing particles, the possible extraction of Cherenkov signal. Studies of crystal wrapping, coatings, filtering and wave-shifting, suitable for the compact 3D structure of the calorimeter, have also been performed. A full prototype, constructed with CsI(Tl) cubic crystals (36mm side) that are read-out with photodiodes coupled with large dynamic-range font-end electronics, has been tested with high-energy ions, electrons, muons and hadrons. The measured performances are consistent with what expected, thus demonstrating the feasibility of the proposed calorimeter design.

**Gas Detectors / 265**

**LHM: a new noble-liquid detector concept based on bubble-assisted electroluminescence**
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We present a new noble-liquid detection concept and experimental results in LXe, based on the bubble-assisted Liquid Hole Multiplier (LHM). In this "local dual-phase detection element", a gas bubble is supported underneath a micro-pattern electrode (THGEM, GEM etc.) immersed inside the liquid. Ionization electrons and scintillation-induced photoelectrons (PE) extracted from a CsI photocathode, drift through the electrode’s holes; they induce electroluminescence (EL) in the bubble, with tens of photons emitted per drifting electron. A cascaded-LHM detector, operated through photon-mediated process in noble-liquid, would provide high light yields – detectable with internal or external photo-sensors. We will present LHM-prototype results in LXe, demonstrating the stability of the bubble-assisted concept in GEM and THGEM. Examples are: energy resolution (7.5\% for \mathbf{\sim} 6,000 electrons), efficient PE extraction from a CsI-coated THGEM and GEM in LXe and their collection into holes; EL photo-yields, time resolution (10ns) with scintillation photons and results of the cascaded-LHM operation will be provided. The merits of the bubble-assisted LHM concept will be discussed in the context of future applications for rare-event and other searches.

primary experiment:
Generic R&D Summary:

Large-volume dual-phase noble liquid time projection chambers are a preferred detection tool in rare-event search experiments. As their mass approaches the multi-tons, detection of scintillation photons and ionization signals call for new innovative solutions. Liquid Hole Multipliers (LHM) were initially suggested as a solution for the detection of ionization electrons and UV scintillation photons in future large-volume noble-liquid detectors. The idea consisted of a cascade of electrodes (such as THGEMs or GEMs), with a CsI photocathode deposited on one side of each electrode – all immersed in the noble liquid (Fig. 1). Multiplication occurs by generating electroluminescence photons in the holes of one element, which extract further electrons form the following one \cite{1}. First attempts to generate electroluminescence in our laboratory showed copious amount of light from a THGEM hole-electrode immersed in liquid xenon \cite{2}. The onset of the electroluminescence at suspiciously low voltages and its response to abrupt pressure changes led us to conclude that the observed light signals were in a xenon-vapor bubble trapped near the electrode holes and not in the liquid \cite{3}. Series of observations with a CCD camera installed on a new cryostat, proved the correlation between the electroluminescence signal and the existence of a bubble underneath the electrode (Figs. 2-4) \cite{4}. Furthermore, we could annihilate and generate a bubble intentionally, that, once created, remained stable for a period of days. In that bubble, we reached energy resolution as high as 7.5\% for \mathbf{\sim} 6,000 ionization electrons (while the XENON100 experiment reported \mathbf{-12}\% for the same amount of charge \cite{5}, though in a much larger detector). In this talk, we will introduce our new noble-liquid detector concept; we will describe the technique of creating a stable bubble supported under an electrode, the generation of light signals in different electrode structures, the detection of UV photons with a CsI photocathode, time resolution (\mathbf{\sim}10ns) and the possibility of photon multiplication in cascaded-LHM structures. We will further discuss the potential application of this concept, in future multi-ton noble-liquid detectors of DM, neutrino physics and other fields.


Testbeam results of the first real time embedded tracking system with artificial retina

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The retina experiment aims at developing a fast track finding system prototype for the high-luminosity LHC, capable to operate at 40 MHz event rate with hundreds of track per event. According to simulations this is technologically achievable by using the artificial retina algorithm, a massive parallel fast tracking algorithm, implemented in last generation commercial FPGAs. The artificial retina algorithm is inspired by neurobiology and is capable of pattern recognition and track fit. Hits from the tracking detectors are sent to a switch module routing the data to appropriate cellular units, the engines, that determine how well a set of hits matches with a specific track hypothesis. Finally a track fitter module interpolates the analog response of the engines and determines the track parameters with a resolution comparable with offline results.

A tracking prototype system based on 8 silicon strip detectors has been built as practical demonstrator of this innovative tracking system. The sensors are readout using Beetle chips, accepting trigger rates up to 1.1 MHz, and a custom data acquisition board based on new generation Xilinx Kintex7 FPGA. The retina algorithm has been implemented in the FPGA using a fully pipelined architecture and the embedded tracking system has been tested in a real experimental environment using protons at the CERN SPS facility. Testbeam results are presented and compared with simulations. Perspectives for the future are also discussed.

primary experiment:

Retina Summary:

In this work we present the testbeam results of an embedded tracking system prototype with artificial retina capable of fast track finding with a latency <1 μs and track parameter resolutions that are comparable with the offline results. The maximal event rate that the telescope can accept is 1.1 MHz and it is determined by the Beetle readout chip. The test was carried on using a 180 GeV/c proton beam at the CERN SPS. The tracking prototype system consists of 8 planes of single-sided silicon sensors with 512 strips each and 183 μm pitch; the active area of the sensor is about 100 cm2 with 500 μm thickness. The silicon telescope assembly positioned on beam is shown in Fig. 1 (left).

Fig. 1 [in attachment] Telescope assembly positioned on beam at the CERN SPS (left). Custom designed board based on Xilinx Kintex7 FPGA for data acquisition and real time tracking (right).
The sensors are positioned at a distance of 4 cm from each other and two plastic scintillators, upstream and downstream of the telescope, provide trigger signals to the Beetle readout chip for proton tracks traversing the tracking volume. A custom data acquisition (DAQ) board based on new generation Xilinx Kintex 7 lx160 FPGA has been developed and it is shown in Fig. 1 (right). It manages the readout ASICs, the sampling of the analog channels, and the retina algorithm implementation. The readout is performed at 40 MHz on 4 channels for each ASIC that corresponds to a decoding of the telescope information at 1.1 MHz. The FPGA resources have been divided among the different modules of the retina architecture: approximately 10% for the switch module that routes the data to appropriate cellular units for the processing stage, 50% for the pool of engines that evaluate how well a set of hits matches with a specific track hypothesis and 10% for the track parameter determination, keeping the rest for backup. This configuration allows to realise more than 1000 retina cellular units working in parallel with a clock frequency of the system greater than 200 MHz.

Testbeam results will be presented and compared with simulations, in particular for the evaluation of the tracking performance. Perspective for the future will be also discussed.

Semiconductor Detectors / 293

Test beam results of 3D detectors constructed with single-crystal and poly-crystalline diamond

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Results from prototypes of a novel detector using chemical vapor deposited diamond and resistive electrodes in the bulk forming a 3D diamond device will be presented. The electrodes of the device were fabricated with laser assisted phase change of diamond into a combination of diamond-like-carbon, amorphous carbon and graphite. The connections to the electrodes of the 3D device were made using a photo-lithographic process. A detector system consisting of 3D devices, one based on single-crystal CVD diamond and one based on poly-crystalline CVD diamond was connected to a multi-channel readout and was successfully tested in a 120GeV proton beam at CERN proving for the first time the feasibility of the 3D diamond detector concept for particle tracking applications. The electrical properties and beam test results of the prototype devices will be presented.

primary experiment:
The RD42 Collaboration

Gas Detectors / 166

Upgrade of the ATLAS Muon Spectrometer for Operation at the HL-LHC

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The High-Luminosity Large Hadron Collider (HL-LHC) will increase the sensitivity of the ATLAS experiment to low-rate high-energy physics processes. In order to cope with the 10 times higher instantaneous luminosity compared to the LHC, the trigger system of ATLAS needs to be upgraded. The ATLAS experiment plans to increase the maximum rate capability of the first two trigger levels to 1-MHz at 6-μs latency and 400-kHz at 30-μs latency, respectively. This requires new trigger and read-out electronics for the RPC (resistive plate) and TGC (thin gap) trigger chambers, and the replacement of the read-out electronics of the MDT (monitored drift tube) precision chambers. The replacement of the MDT read-out electronics will make it possible to include their data in the first level trigger decision and thus to increase the selectivity of the first level muon trigger. The RPC trigger system in the barrel will have to be reinforced by the installation of additional thin-gap RPC with a substantially increased high-rate capability compared to the current RPCs. This addition of RPCs will also increase the acceptance of the barrel muon trigger from 75% to 95%.

primary experiment:
ATLAS

Summary:
see attachment

Semiconductor Detectors / 372

Progress and questions about sCVD Diamond Detectors for Particle Tracking

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(On behalf of the ANR 12-BS05-0014 "MONODIAM-HE)

Chemical Vapor Deposition (CVD) diamond has been used extensively in beam conditions monitors as the innermost detectors in the highest radiation areas of BaBar, Belle, CDF and now all LHC experiments. Diamonds are considered as an alternate sensor for use very close to the interaction region of the HL-LHC, where the most extreme radiation conditions will exist. We present comparative test results of single-crystal chemical vapor deposition diamonds from various sources (industrial manufacturers and research laboratory). The influence of various parameters have been evaluated: Nitrogen contents, surface finishing techniques, temperature, metallization techniques, choice of metal... Long term studies have been carried out.

We will conclude about the readiness of diamond detectors for particle detection and tracking for the future programs at the High-Luminosity LHC.

primary experiment:
ANR12-BS05-0014

Gas Detectors / 121
Advances in micro-Resistive WELL (μ-RWELL) detectors

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In this work we present the advances performed on the micro-Resistive WELL (μ-RWELL) detector technology. The μ-RWELL is a compact spark-protected single amplification stage Micro-Pattern Gas Detector (MPGD). The detector amplification stage, realized with a structure very similar to a GEM foil, is embedded through a resistive layer in the readout board. A cathode electrode, defining the gas conversion/drift gap, completes the detector mechanics. The proposed structure has some characteristics in common with previous MPGDs, such as C.A.T. and WELL, developed more than ten years ago.

The new architecture, showing a fine space resolution, ~60μm, is a very compact device, robust against discharges and exhibiting a large gain (>10⁴), simple to construct and easy for engineering and then suitable for applications for large area tracking devices as well as huge digital calorimeters.

primary experiment: MPGD_NEXT

Summary:

In this work we discuss the advances performed on the μ-RWELL technology. The μ-RWELL is a compact spark-protected single amplification stage MPGD. The detector is realized by merging a suitable etched GEM foil with the readout PCB plane coated with a resistive deposition. The copper on the bottom side of the foil has been patterned in order to create small metallic dots in correspondence of each WELL structure. The resistive coating is performed by screen printing technique (or equivalent resistive coating technique).

The WELL matrix geometry is realized on a 50μm thick polyimide foil, with conical channels 70μm (50μm) top (bottom) diameter and 140μm pitch (of course different geometries can be considered in order to optimize the detector performance, especially in terms of gain amplitude). A cathode electrode, defining the gas conversion/drift gap, completes the detector.

The micro-RWELL has features in common either with GEMs or MMs - from GEM it takes the peculiarity of a “well defined amplifying gap”, thus ensuring high gain uniformity.
- from MMs it takes the resistive readout scheme that allows a strong suppression of the amplitude of the discharges.

Even though the amplifying element of the μ-RWELL is practically the same of the GEM, its signal formation mechanism is completely different. The signal in a GEM detector is mainly due to the electron motion, while in a μ-RWELL besides the very fast collection of the whole electron charge produced into the amplification channel also the ionic component contributes to the formation of the signal. In this sense the signal of a μ-RWELL is more similar to the one of a MMs.

The assembly aspect of the μ-RWELL technology is a strong point in favor of this architecture. It does not require gluing or stretching of foils or meshes: a critical and time-consuming construction step of both GEM and MM technologies.

With respect to the GEM and MM the proposed technology is extremely compact, does not require very stiff (and large) support structures, allowing large area covering based on PCB splicing with a reduced dead space (< 0.5mm).

The detector gain, about 10⁴ has been measured with X-rays in current mode. The use of thicker kapton for the realization of the amplifying component of the detector should allow to achieve gas gain larger than those obtained with the 50 micron thick amplification gap.

The detector rate capability, from 100 kHz/cm² to 600 kHz/cm² (measured with X-rays, for a surface resistivity of about 100 MOhm/square) can be tuned with a suitable segmentation of the resistive layer. The typical discharge amplitude for the μ-RWELL is of the order of few tens of nA.

Results from a test at the H4-SPS beam line with a μ-RWELL prototype, equipped with a 400micron strip pitch, show a space resolution of less than 60μm with a detection efficiency of the order of 98% (with 4 mm gas gap). The performances of the detector operated in magnetic field with different particle incident angles will be discussed.
Electronics Development for the ATLAS Liquid Argon Calorimeter Trigger and Readout for Future LHC Running

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The upgrade of the LHC will provide 7 times greater instantaneous and total luminosities than assumed in the original design of the ATLAS Liquid Argon (LAr) Calorimeters. Radiation tolerance criteria and an improved trigger system with higher acceptance rate and longer latency require an upgrade of the LAr readout electronics. In the first upgrade phase in 2019-2020, a trigger readout with up to 10 times higher granularity will be implemented. This allows an improved reconstruction of electromagnetic and hadronic showers and will reduce the background for electron, photon and energy-flow signals at the first trigger level. The analog and digital signal processing components are currently in their final design stages and a fully functional demonstrator system is operated and tested on the LAr Calorimeters. In a second upgrade stage in 2024-2026, the readout of all 183,000 LAr Calorimeter cells will be performed without trigger selection at 40 MHz sampling rate and 16 bit dynamic range. Calibrated energies of all cells will be available at the second trigger level operating at 1 MHz, in order to further mitigate pile-up effects in energy reconstruction. Radiation tolerant, low-power front-end electronics optimized for high pile-up conditions is currently being developed, including pre-amplifier, ADC and serializer components in 65-180 nm technology. This talk will give an overview of the future LAr readout electronics and present research results from the two upgrade programs.

primary experiment:

ATLAS Summary:

The LHC luminosity upgrades in 2019-2020 and 2024-2026 require the associated detectors to operate at luminosities of up to $7 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$, with the goal of accumulating a total integrated luminosity of 3000 $\text{fb}^{-1}$. To be able to retain interesting physics events even at rather low transverse energy scales, $E_T \approx 20 \text{GeV}$, for single objects, increased trigger rates are foreseen for the ATLAS detector. At the Level-0 and Level-1 selection stage acceptance rates of 1 MHz and 400 kHz are planned, combined with longer latencies in order to read out the necessary data from all detector channels. Under these conditions, the current readout of the ATLAS Liquid Argon (LAr) Calorimeters does not provide sufficient buffering and bandwidth capabilities. Furthermore, the expected total on-detector radiation doses of $10^{13} \text{n}_{eq}/\text{cm}^2$ (NIEL) and 0.3 kGy (TID) are beyond the qualification range of the current front-end electronics. For these reasons, an upgrade of the ATLAS LAr Calorimeter readout electronics is foreseen in two stages.

In 2019-2020, a new trigger readout will be installed to process 35,000 so-called Super-Cells which improves the longitudinal and lateral granularity for shower reconstruction by a factor of up to 10 compared to the current calorimeter trigger towers. This will allow the usage of more detailed shower shape variables in the reconstruction of electron, photon and energy flow trigger signals, and thus a further suppression of the background rate. The new readout components consist of 124 LAr trigger driver boards equipped with custom developed, radiation tolerant 12-bit SAR ADCs which sample the Super-Cell pulses at 40 MHz. Digital data are transferred on custom optical links at 5.44 Gb/s to the back-end system. 32 LAr digital processing board equipped with 4 Altera Arria-10 FPGAs each receive the data and apply a refined energy calibration already at trigger level. Digital filtering techniques are explored to mitigate the expected pile-up effects from 80-200 proton-proton collisions per LHC bunch crossing. Prototype versions of the front-end and back-end boards have been tested successfully. A demonstrator set-up is installed on the LAr Calorimeter system, which covers about 10% of the detector area. First measurements of calibration and collision data are performed with this setup in order to gain experience with the developed hardware components and to optimize the final system design.

The second upgrade phase is planned for 2024-2026. The Super-Cell readout will remain and will feed the future Level-0 trigger of ATLAS. In parallel, the full LAr Calorimeter will be read out at 40 MHz in order to provide the best possible information to the Level-1 trigger running at 1 MHz input rate. For this reason and for radiation tolerance requirements, the current front-end and back-end readout
The system for the 183,000 calorimeter cells will be fully replaced. The corresponding readout components are mainly an evolution of the Super-Cell readout, however exceeding the performance requirements in several aspects: 10 times higher bandwidth, 2 times faster optical links, improved ADC precision, low noise and low power.

The new electronics must be able to capture the triangular detector pulses of about 400-600 ns length with signal currents per channel of up to 10 mA and a dynamic range of 16-17 bit. The noise should be kept below 100 nA and the ADC power per front-end channel should not exceed 50 mW. With the available ASIC technologies different concepts of the readout design will be possible.

In 180 nm SiGe technology (IBM 7WL) and choosing unipolar shaping, two gain stages can cover the desired dynamic range. An ADC which matches the pre-amplifier and shaper will need to provide 14 bit digitization range. Such a design is shown to meet the noise requirements and achieve an integral non-linearity below 0.1%. Moreover, in simulations of the complete readout chain using the unipolar shaping approach signal pile-up is introducing a controllable baseline shift, and an additional digital CR shaping stage does not introduce a degradation of the energy resolution.

A recent approach in 65 nm technology is targeting a combination of pre-amplifier, shaper, ADC and serializer in a single Front-End System-On-Chip (FESOC). In this context, the development of a pre-amplifier and shaper as well as SAR ADCs is performed in 65 nm CMOS technology. Due to the lower voltage range, 2-gain and 4-gain readout modes are studied. The analog part is designed with programmable peaking time to optimize the noise level in presence of signal pile-up. The 65 nm ADC is laid out in SAR architecture and is completed with an active SEE detection mechanism by feeding the signals into two ADCs in parallel and comparing their output. In this way, the signal-to-noise ratio can be further improved in presence of radiation. Results for a 80 MHz 12-bit prototype design show ENOB values above 10.8 bits after 10 kGy irradiation, and similar performance is reached for a 14-bit layout.

In this contribution, results from the development and design of the two upgrade stages of the LAr Calorimeter readout will be presented, including experience from prototype boards and the demonstrator system of the Super-Cell readout as well as design studies and first tests of prototype ASIC components for the second upgrade phase.

References:


Gas Detectors / 52

R&D on a new type of micropattern gaseous detector: the Fast Timing Micropattern detector

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Micropattern gaseous detectors (MPGD) underwent significant upgrades in recent years, introducing resistive materials to build compact spark-protected devices. Exploiting this technology further, various features such as space and time resolution, rate capability, sensitive area, operational stability and radiation hardness can be improved. This contribution introduces a new type of MPGD, namely the Fast Timing Micropattern (FTM) detector, utilizing a fully resistive WELL structure. It consists of a stack of several coupled layers where drift and WELL multiplication stages alternate in the structure, yielding a significant improvement in timing properties due to competing ionization processes in the different drift regions. Two FTM prototypes have been developed so far. The first one is uWELL-like, where multiplication takes place in the holes of a kapton foil covered on both
sides with resistive material. The second one has a resistive Micromegas-like structure, with multiplication developing in a region delimited by a resistive mesh. The structure of these prototypes will be described in detail and the results of the characterization study performed with an X-Ray generator with two different gas mixtures will be presented. First results on rate capability and time resolution based on data collected with cosmic rays and muon/pion test beams will also be presented.

primary experiment:

CMS

Electronics / 278

The ALPIDE Pixel Sensor Chip for the Upgrade of the ALICE Inner Tracking System

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The ALPIDE chip is a CMOS Monolithic Active Pixel Sensor being developed for the Upgrade of the Inner Tracking System (ITS) of the ALICE experiment at CERN Large Hadron Collider. ALICE is the first experiment at LHC implementing a large detector with MAPS technology. The ALPIDE chip is implemented with a 180-nm CMOS Imaging Process and fabricated on substrates with a high-resistivity epitaxial layer. It measures 15-mm by 30-mm and contains a matrix of $512 \times 1024$ pixels with in-pixel amplification, shaping, discrimination and multi-event buffering. The readout of the sensitive matrix is hit driven. There is no signaling activity over the matrix if there are no hits to read out and power is consumed proportionally to the occupancy. The requirements on detection efficiency above 99%, fake-hit probability below $10^{-5}$, spatial resolution of $5 \mu m$ are met. The capability to read out Pb-Pb interactions at 100-kHz is provided. The power density of the ALPIDE chip is projected to be less than 35 mW/cm² for the application in the Inner Layers and below 20 mW/cm² for the Outer Barrel Layers, where the occupancy is lower. This contribution will describe the architecture, design and main features of the final ALPIDE chip, planned for submission at the beginning of 2016. Early results from the experimental qualification of the pALPIDE-3 full scale prototype predecessor will also be reported.

primary experiment:

ALICE Summary:

The ALPIDE chip is a Monolithic Active Pixel Sensor (MAPS) that is being developed for a major upgrade of the Inner Tracking System (ITS) of the ALICE experiment at CERN Large Hadron Collider.¹[9954-3899-41-8-087002]. The existing ALICE ITS will be replaced during the second Long Shutdown of LHC (2019-2020) with a new detector entirely based on CMOS MAPS.¹[Snoeys2014167]. ALICE is the first experiment at LHC implementing a large detector with this technology and four major goals are pursued with the ITS upgrade.
The impact parameter resolution is expected to improve by a factor 3 combining a reduction of the radial distance of the innermost layer from the interaction point (from 39-mm down to 22-mm), an improvement of single point resolution due to a smaller pixel size and a reduction of the material budget of the innermost layers (from 1.14% \( X_0 \) to 0.3% \( X_0 \)).

The finer granularity together with the addition of one detection layer (from 6 to 7 layers) will improve tracking efficiency and resolution on transverse momentum in the low \( p_t \) range.

The new ITS shall also be capable of reading out Pb-Pb interactions at 100-kHz, a factor 100 improvement over the present readout capability.

Fast insertion and removal of the full detector for yearly maintenance and eventual replacement of modules is also a major requirement for the new system.

The new ITS detector will consist of seven cylindrical sensing layers with radial coverage from 22 mm to 400 mm and z-lengths ranging from 27 cm to \( \sim 1.5 \) m.

The total sensitive area is above 10 m\(^2\) and will be equipped with \( \sim 24000 \) pixel sensor chips for more than 12.5-billion pixels in total.

The requirements on the new ITS pixel chip are summarized in Table 1.

The ALPIDE chip is implemented in a 180-nm CMOS Imaging Process provided by TowerJazz\cite{Senyukov2013115}.

The availability of a deep p-well in this process allows to use full CMOS circuits in the pixels.

The circuits can be fabricated on substrates with a high-resistivity epitaxially grown layer.

The reverse bias on the charge sensing diodes can be increased by applying negative voltage to the substrate.

It was demonstrated that the technology exceeds the requirements of radiation tolerance of the ALICE experiment.

The ALPIDE chip measures 15-mm by 30-mm and contains a matrix of 512×1024 sensitive pixels measuring 29.24 μm \( \times \) 26.88 μm (z \( \times \) r\( \Phi \)).

Analog biasing, control, readout and interfacing functionalities are implemented in a peripheral region of 1.2 \( \times \) 30 mm\(^2\).

Each pixel features a low power (40 nW) analog front-end with shaping and discriminated output.

The pixel sensor and front-end are continuously active and discriminated hits are latched in storage memories in the digital section of the pixels.

There are three in-pixel memory elements constituting a three stages Multi Event Buffer.

The storage of an event frame in one of the three set of memories is gated by globally distributed strobe signals.

The architecture provides a minimum event time resolution under 2us.

Two major readout modes are supported, one in which the strobing and readout are triggered externally and a second one in which frames are continuously integrated and read out, with programmable duration of the hit integration time.

The readout of the sensitive matrix is hit-driven.

A Priority Encoder circuit provides the address of the first pixel with a hit in a double pixel column and subsequently resets its storage element.

This cycle is repeated until all hits initially presented at the inputs of a Priority Encoder after the assertion of a strobe pulse have been transferred to the periphery.
There is no signaling activity if there are no hits to read out and power is consumed proportionally to the occupancy. The 512 Double Columns and the corresponding Priority Encoders are grouped in 32 readout regions (sub-matrices). The 16 Double Columns inside each region are read out sequentially, while the regions are read out in parallel.

The 16 Double Columns inside each region are read out sequentially, while the regions are read out in parallel.

The readout circuits in the periphery include de-randomizing memories and perform data reduction and formatting. Hit data can be transmitted on two different data interfaces according to alternative operating modes envisaged for the upgraded ITS. A 1.2-Gb/s serial port with differential signaling is intended to be the largest capacity data readout interface for the chips of the three Inner Barrel layers, where the occupancy is highest. A bidirectional parallel data port is also present, with a capacity of 320 Mb/s.

It enables the grouping of data of neighbour chips in the four Outer Barrel layers where the occupancy is lower. A set of six chips send their data on a parallel bus to one chip acting as data collector. The collector transmits the assembled data packets off-detector on its serial port, but using a lower bit-rate for the transmission (400-Mb/s).

A reduction of power consumption and of the number of serial links to transmit data off-detector is achieved with this scheme.

The digital circuits of the periphery are implemented with protection techniques to mitigate the consequences of Single Event Upsets. The design of the periphery also emphasize minimization of power consumption and clock-gating techniques are extensively employed for this purpose.

The power density of the ALPIDE chip is expected to be less than 35 mW/cm$^2$ for the application in the Inner Barrel layers and below 20 mW/cm$^2$ in the Outer Barrel layers.

Two full scale prototypes of the ALPIDE chip (pALPIDE-1 and pALPIDE-2) have already been implemented and experimentally characterized. The characterization of single chips with beams (Fig. 1) has demonstrated that a detection efficiency above 99% is maintained over a large range of threshold settings. At the same time, the fake-hit probability remains order of magnitudes smaller than the requirement ($\lambda_{\text{fake}} << 10^{-5}$).

The spatial resolution is better than 5 $\mu$m and the average cluster size is about 2 pixels.

This contribution will describe the architecture, design and main features of the final ALPIDE chip, planned for submission at the beginning of 2016. A campaign of characterization and testing of the pALPIDE-3 chip, the third full-scale prototype on the development road map, is starting in October 2015. Early results from the experimental qualification of the pALPIDE-3 chip will also be reported.

Medical Applications / 310

State of the art time resolution in TOF-PET detectors for various crystal sizes and types
Time of flight (TOF) in positron emission tomography (PET) has experienced a revival of interest after its first introduction in the eighties. This is due to a significant progress in solid state photodetectors (SiPMs) and newly developed scintillators (LSO and its derivates). Latest developments at Fondazione Bruno Kessler (FBK) lead to the NUV-HD SiPM with a very high photon detection efficiency of around 50%. Despite the large area of $4 \times 4 \text{mm}^2$ it achieves a good single photon time resolution of $205 \pm 5 \text{ps FWHM}$. Coincidence time resolution (CTR) measurements using LSO:Ce codoped 0.4%Ca scintillators yield values of $73 \pm 2 \text{ps FWHM}$ for $2 \times 2 \times 3 \text{mm}^3$, $83 \pm 4 \text{ps}$ for $2 \times 2 \times 5 \text{mm}^3$, $100 \pm 4 \text{ps}$ for $2 \times 2 \times 10 \text{mm}^3$ and $122 \pm 6 \text{ps}$ for $2 \times 2 \times 20 \text{mm}^3$ crystal sizes. Results with standard LYSO:Ce are $95 \pm 5 \text{ps}$ for $2 \times 2 \times 5 \text{mm}^3$, $105 \pm 4 \text{ps}$ for $3 \times 3 \times 5 \text{mm}^3$, $130 \pm 5 \text{ps}$ for $2 \times 2 \times 20 \text{mm}^3$ and $140 \pm 5 \text{ps}$ for $3 \times 3 \times 20 \text{mm}^3$. A measured increase in cross-talk probability given by the crystal acting as a reflector could be a reason for the deteriorated CTR observed with the higher crystal cross-sections. Further measurements with various scintillator cross-sections ($1 \times 1 \text{mm}^2$ - $4 \times 4 \text{mm}^2$) will be a basis for discussing this influence to timing in TOF-PET. Additionally, CTR measurements with LuAG and GGAG type samples are presented and the results are interpreted in terms of their scintillation properties, e.g. rise time, decay time, light yield and emission spectra.

** primary experiment: 
Crystal Clear Collaboration

**Astroparticle Detectors / 431**

**The COSINUS project: development of new NaI-based cryogenic detectors for direct dark matter search**

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Many astrophysical observations can be explained by the existence of cold dark matter. Although nowadays its contribution to the energy density of the universe is known precisely, its particle nature remains still unknown. Clarifying the nature and origin of dark matter is one of the big challenges for modern particle physics.

Direct dark matter searches aim at the observation of dark matter particles interacting with the material of their earthbound detectors. Since many years there is a tension between the DAMA/LIBRA experiment observing an annual modulation signal, as expected for dark matter particles, and several other experiments with null results.

COSINUS, an R&D project recently initiated by INFN and located at Laboratori Nazionali del Gran Sasso (LNGS), offers the unique possibility to investigate and clarify the above discrepancy. In particular, COSINUS is designed to combine the DAMA/LIBRA detector material NaI with the well established phonon/light technique for particle identification and background rejection. We will present first results using CsI (undoped), which has similar crystal properties as NaI, as a cryogenic scintillating calorimeter. Furthermore, we will describe our current plans to develop and operate such cryogenic calorimeter based on NaI (undoped). The dedicated detector design for the first NaI-based proof-of-principle detector, including a cryogenic light detector as well as the objectives for the COSINUS project are reported.
From Vertex detectors to Inner Trackers with CMOS pixel sensors

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The use of CMOS Pixel Sensors (CPS) for high resolution, low material, vertex detectors has been validated with the 2014 and 2015 physics runs of the STAR-PXL detector at RHIC/BNL. This opens the door to the use of CPS for inner tracking devices, with 10-100 times larger sensitive area, which require therefore a sensor design privileging power saving, response uniformity and robustness. Exploiting the relaxed constrained on the spatial resolution of trackers and the added value of a 180 nm CMOS process, a specific small CPS prototype was fabricated in 2014, with 5 times larger pixels than those used in STAR. Its detection performances were assessed with particle beams, investigating in particular the impact of the reduced sensing node density on the detection efficiency. The studies were complemented by those of a full scale prototype (160k pixels) featuring small pixels for a vertex detector, in which large pixels could be implemented as a next step. The most prominent outcomes of this R&D, which validates for the first time the concept addressed, will be presented.

ILC Summary:

CMOS Pixel Sensors (CPS) have been successfully used during the two last data taking campaigns of the STAR-PXL detector, the first vertex detector based on the CPS technology, running at RHIC/BNL. It has proven to be reliable and to deliver the expected added value for the STAR physics programme. Based on a rolling shutter read-out architecture, the 400 sensors (called ULTIMATE) composing the PXL have allowed accumulating a sizable amount of experience with these devices. The latter was next used in a new generation of CPS exploiting a more advanced CMOS process based on a 180 nm feature size, which offers intrinsically the possibility to improve the sensor’s radiation tolerance and read-out speed as compared to the 350 nm process used for STAR.

Based on the validated read-out of the STAR-PXL and the added value of this 180 nm process, the proposed contribution to the conference addresses the application of CPS to tracking devices requiring 10 to 100 times larger sensitive area than typical vertex detectors and calling therefore for special attention devoted to power consumption, response uniformity and robustness.

A large fraction of the power consumption is due to the in-pixel circuitry. Power savings can then be achieved by minimizing the number of pixels per sensor, i.e. by increasing their dimensions. This approach is worth considering as the spatial resolution requirement for trackers is significantly less demanding than for the inner layers of a vertex detector. The increase of the pixel
surface has however drawbacks in terms of charge collection. The mean distance the signal charges cross until being collected increases as the collection diode density is reduced, increasing the probability for charge trapping by defects of the silicon crystalline structure. This probability is further enhanced after non-ionizing irradiation.

CPS exploring large pixel detection properties were manufactured in 2014 in a 180 nm CMOS process featuring 6 metalization layers and deep P-wells allowing to integrate both NMOS and PMOS transistors inside the pixels. Two different pixel dimensions of $36 \times 62.5 \, \mu m^2$ and $39 \times 50.8 \, \mu m^2$ were implemented. Each pixel incorporates a sensing node connected to a pre-amplifier featuring a feedback loop ended with a forward biased diode compensating the leakage current delivered by the sensing node and fixing its depletion voltage. The preamplifier is followed by a clamping circuit subtracting the pixel pedestal and connected to a discriminator located at the column end acting as single-bit ADC. The sensing nodes are staggered in order to maximize the collection diode density and to alleviate the spatial resolution asymmetry consequent to the pixels rectangular shape, which follows from read-out speed considerations. The matrix, made of 64 columns of 64 pixels (4096 pixels), is read out in rolling shutter mode addressing simultaneously all pixels belonging to a pair of neighboring rows. 8 columns feature (discriminator free) analog output for pixel circuitry assessment purposes. The read-out time of the sensor is $\sim 5 \, \mu s$.

The relatively large pixel size allows to integrate in-pixel circuitry for noisy pixel masking. Furthermore, the dimensions enable to concentrate the in-pixel circuitry within 3 metalization layers only. This allows integrating connection pads over the pixel array, using the 2 top metal layers. This connection strategy is followed for the ALICE Inner Tracker System (ITS) upgrade at the CERN-LHC, where laser soldering is foreseen to connect the sensors to their read-out flex cable. In the ULTIMATE sensor, a MIM (Metal-Inter-Metal) clamping capacitor was implemented using the 2 top metalization layer. The connection pads over the pixel array forced to explore new alternatives of the clamping capacitor implementation.

The prototyping of the large pixel concept addressed in particular the detection efficiency, the spatial resolution, the radiation tolerance and the in-pixel circuitry with a new clamping design. For this purpose, several pixel variants were designed and implemented in 8 different pixel arrays, including a reference pixel array based on 6 metalization layers.

The sensors were first studied in the laboratory, where their temporal and fixed pattern noise performance were assessed over a wide range of positive temperatures and where their response to an $^{55}$Fe source were studied and used to calibrate the charge-to-voltage conversion gain; these measurements were performed before and after irradiation with an X-Ray source (up to 150 kRad) and with 1 MeV neutrons (up to $1.5 \times 10^{12} \, n/cm^2$). The sensors were next tested on an electron beam of 450 MeV at the Frascati beam test facility. A telescope composed of analog output sensors (Mimosa-18) featuring a $1 - 2 \, \mu m$ spatial resolution were used to predict the beam particle impact position at the DUT location. The telescope was simulated in detail, accounting for multiple scattering. The predicted resolution amounts to $5 - 6 \, \mu m$. A nearly 100% detection efficiency was observed and a spatial resolution of $\sim 10 \, \mu m$ in both directions was found for all pixel variants tested, thus complying with all ambitioned performances.

This contribution will describe the large pixel design and the successful assessment of their performances with laboratory and beam tests. This is an important step towards the realization of CPS optimized for...
tracking detection layers. Indeed our results validate the possibility to fabricate a sensor featuring typically 160k pixels over 4 cm$^2$ of sensitive area, a 20 $\mu$s integration time and dissipating less than 100 mW/cm$^2$. Such a device, integrating the full signal processing circuitry, was already fabricated earlier this year for vertexing purposes, i.e. composed of 160k small, $22 \times 33 \mu$m$^2$, pixels. Its detection performances were assessed via two test beams campaigns, fully validating the read-out chain. The most prominent assessment outcomes will be summarized in this talk.

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SABRE: WIMP Modulation Detection in the Northern and Southern Hemisphere

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SABRE (Sodium-iodide with Active Background REjection) is a NaI(Tl) experiment designed to search for Dark Matter through the annual modulation signature. A DM signal on an Earth-based detector is expected to modulate yearly due to the change of the Earth’s speed relative to the galactic halo reference frame. The long standing result from the DAMA/LIBRA experiment at the Gran Sasso National Laboratory (LNGS) is consistent with this scenario, while a confirmation of this result by an independent experiment is still missing. SABRE consists of highly pure NaI(Tl) crystals operated in an active liquid scintillator veto. The scintillator provides a veto against external backgrounds and allows to tag the background arising from detector components. The SABRE experiment follows a two-phase approach. In the first phase, high-purity NaI(Tl) crystals will be operated at LNGS in an active liquid scintillator veto with the goal of lowering the background in the region of interest for Dark Matter detection at a level that is significantly below the one observed by DAMA/LIBRA. An unprecedented radio-purity for both the NaI powder and the crystal growth is needed to achieve this goal. The second phase will consist of two NaI(Tl) detector arrays located at LNGS and in the Stawell Gold Mine in Australia. The operation of twin full-scale experiments in both the northern and the southern hemisphere will strengthen the reliability of the result against possible seasonal systematic effects.

primary experiment:

Dark Matter Detection

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Current development status of High Voltage and High Resistivity CMOS technology for high energy physics applications

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CMOS active pixel sensors are currently being investigated for a potential application in the high-energy physics experiments. The integration of the CMOS circuitry in the sensing substrate will offer substantial reduction in the material budget and manufacturing costs. Additionally, having
the pre-amplifier and discriminator built-in, could eliminate the need for bump-bonding for pixel sensors, while maintaining characteristics needed for particle tracking.

Figure 1: Unit cell of the sensor with integrated CMOS circuitry

The upcoming upgrades of the LHC demand new particle tracking systems, which would be able to sustain tenfold increase in luminosity. Therefore, one of the key development aspects is to understand radiation hardness of the samples manufactured in various commercially available processes. This work will report on two different commercially available technologies: High-Voltage CMOS (fig. 1) in the AMS HV-CMOS 350nm process, and High-Resistivity CMOS in the TowerJazz HR-CMOS 180nm process.

The main areas of investigation are in-pixel charge collection efficiency, radiation hardness, uniformity and speed of the response, gain variation and pixel noise. The summary will be given of the latest results from non-irradiated and irradiated test structures up to HL-LHC strip tracking layer fluences, which reach $10^{15}\text{ }n_{eq}/\text{cm}^2$.

primary experiment:

ATLAS Summary:

Current development status of High Voltage and High Resistivity CMOS technology for high energy physics applications

HV/HR-CMOS

The on-going developments in sensor technology, especially driven by the need to upgrade the inner tracker of the ATLAS experiment at the LHC, demonstrate the potential of CMOS active pixel sensors being suitable for high energy physics applications. Although currently used hybrid-pixel detectors, where sensor and electronics are fabricated separately and then mated by bump-bonding technique, offer their own advantages the new CMOS sensors could provide characteristics needed for particle tracking while reducing manufacturing costs. Special interest is given to the sensors that can be manufactured using commercially available High-Voltage (HV) and High-Resistivity (HR) CMOS technologies.

Presentation

The presentation will be focused on highlighting the most recent results, which demonstrate the performance of the HV and HR CMOS prototype sensors before and after irradiation. One of the prototype chips that was characterized is the HVStripV1 manufactured in AMS HV-CMOS 350nm process. The chip contains 44 strip-like pixel matrix, where pixels are divided into two groups due to different in-pixel amplifier design. The characterization took place in both laboratory and test beam environments. In addition, several test chips were irradiated with $27\text{MeV}$ protons up to $10^{15}\text{n}_{eq}/\text{cm}^2$ fluence levels, and their characteristics were compared to the ones obtained before irradiation. Figures 1 and 2 illustrate both MIP and X-Ray spectra of the prototype chip, where preliminary results indicate that the sensor is still functioning after irradiation to high fluence levels.

Figure 1: MIP spectra obtained using $\text{Sr}^{90}$ source before and after irradiation;
Figure 2: X-Ray spectra acquired after irradiation before annealing the test chip

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Development of High-Resolution Detector Module with Depth of Interaction Identification for Positron Emission Tomography

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Co-authors: Agostino Di Francesco ; Carlos Leong ; Etienne Auffray Hillemanns ; Gianluca Stringhini ; Joao Varela ; Jose Carlos Rasteiro Da Silva ; Luis Ferramacho ; Manuel Rolo ; Marco Paganoni ; Marco Pizzichemi ; Miguel Silveira ; Paul Rene Michel Lecoq ; Ricardo Bugalho ; Rui Silva ; Stefaan Tavernier
We have developed a Time-of-flight high resolution and commercially viable SiPM based detector modules for the application in the new positron emission mammography (new ClearPEM) and other small organ specific PET scanners. The detector module has a single side readout and 4-to-1 coupling between LYSO crystals and SiPM, as opposite to the 1-to-1 coupling and double-side readout (with APDs) currently implemented into the ClearPEM. The crystal array consists of 8x8 pixels each with 1.53x1.53x15 mm³ separated by reflective foils. The crystal array is optically coupled to 4x4 SiPM array and readout by a high performance front-end ASIC with TDC capability (50 ps time binning). Optical simulations of the detector module has been done in Geant4 to study the different crystal surface treatments, as well as several coupling configurations between scintillators and SiPM to optimize the performance of the module. In this paper we present the results for two detector modules being one made up of crystal pixels with all sides polished capable of identifying all 64 crystals and another one made up of crystal pixels with the longer sides unpolished to get both depth of interaction and crystal identification. The preliminary results show a timing resolution of 375 ps, an average DOI resolution of 3 mm sigma and an average energy resolution of 28% FWHM.

primary experiment:

ClearPEM Summary:

The detector module is composed of 8x8 scintillator matrix produced by Crystal photonics Inc. (Fig. 1a&b), being each pixel 1.53x1.53x15 mm³ coupled onto a Hamamatsu MPPC array (S12642-0404PB) with 4x4 pixels each with 3x3 mm active area and 3.2 mm pitch (Fig. 1c). All crystal pixels are optically polished. 70 micron reflectors are placed between the crystal pixels and also wrapped around the crystal matrix itself. The overall dimensions of the crystal array are 12.8x12.8x15 mm³, and the pitch between crystals is 1.6 mm. Therefore, 4 crystals of the scintillator array are coupled to each MPPC pixel. The crystal matrix and the associated MPPC plug directly in the FrontEnd Boards forming a compact detecting unit. The FrontEnd boards integrates two ASICs allowing the readout and digitization of 128 MPPC pixels. On-chip TDCs produce two time measurements allowing the determination of the event time and the time-over-threshold (ToT). A Concentrator board reads the data from the FrontEnd boards and transmits assembled data frames through a serial link to the PCIe based DAQ board in the data acquisition PC. The entire setup is contained in a light tight box, where temperature is kept constant at 19°C by the cooling system. Energy measurement is based on the ToT. The expected ToT curve is nonlinear so an internal calibration circuitry is used for energy calibration which generates test pulses to obtain the ToT curve as function of the deposited charge. After this, to scale the energy and correct for saturation in different channels, discrete radiation sources (22Na 133Br and 137Cs) are used.

Two different crystal surface treatments have been tested. One with all pixel sides polished (detector module 1) and another with longer sides unpolished (detector module 2). In detector module 1 a glass plate is placed between the crystal and MPPC array. Optical grease is used as coupling in both interfaces. The glass guide between matrix and MPPC allows the light exiting the front face of the crystals to be shared among the 16 SiPMs. Crystal identification is based on light sharing and using the weighted average energy (Eq. 1). The alignment between the crystal array and the MPPC array is done by a custom-made PVC holder. For crystal identification a 22Na source is placed on the side of the crystal opposite the MPPC and 1 cm away from the crystal surface as it is shown in Fig. 2. The flood and the profile along x and y directions obtained with the crystal module 1 is shown in Fig. 3. In detector module 2 with the aim of having both the crystal identification and DOI information, the optical coupling between the crystal and MPPC is grease and a glass plate is placed on the other side of the crystal matrix, optically coupled with grease but out covered by a reflector to prevent light from escaping from the crystal and redirecting to MPPC instead. The crystal identification is based on the weighted average energy. But, as can be seen in Fig. (4a) the crystal position on the flood map is depth dependent because the glass plate on top makes the light sharing dependent on the depth in the way that per gamma interaction in one pixel more light will be shared to the neighbor crystals when the
interaction is closer to this glass plate than when the interaction happens closer to the MPPC. The DOI variable \((R)\) is defined in equation 2.

The 3D flood is mapped by extracting the \((X,Y,R)\) coordinate of each gamma interaction (Fig. 4b). The crystal identification for the edge channels obtained by appropriate 3D rotations in \((X,Y,R)\) space (Fig. 4c). To get the distribution of the \(R\) values for different DOIs, electronic collimation is used as shown in Fig. 5.

In this set-up a single 3x3 mm LYSO crystal glued to an MPPC is in coincidence with the crystal module. The 22Na point source is placed between the module and the individual crystal pixel. The distance between the source and the individual pixel is three times the distance between the source and the module and so the coincidence events in the module are restricted in a circular spot of 1mm. Then by precisely moving the module up or downwards, the whole length of the crystal is scanned. In each depth, the 64 coordinates of all 64 pixels are found by 2D Gaussian fitting. The distribution of the \(R\) values for different depths are plotted for each crystal pixel (Fig. 6). The peak position of the \(R\) values distributions are linearly correlated to the depths (Fig. 7). The linear fitting functions between the DOI and the \(R\) ratio are extracted for all 64 crystals. Having the fitting functions, for each depth the extracted DOI minus the real DOI for each 64 crystal is calculated to obtain the DOI resolution. The Gaussian fitting of the distribution of the DOI resolutions gives an average of 3mm sigma (Fig. 8). We will report on the final performance of the module including the improved DOI resolution, the energy resolution and the timing resolution.

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#### Recent results with HV-CMOS and planar sensors for the CLIC vertex detector

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The physics aims at the future multi-TeV CLIC linear \(e^+e^-\) collider impose high precision requirements on the vertex detector. The detector also has to match the experimental conditions, such as the time structure of the collisions and the presence of beam-induced backgrounds. The principal challenges are: a point resolution of 3 micron, 10 ns time stamping capabilities, ultra-low mass (0.2% \(X_0\) per layer), very low power dissipation (compatible with air-flow cooling) and pulsed power operation.

The R&D for the pixel detector follows an integrated approach addressing simultaneously the physics requirements and the engineering constraints. Two types of hybrid pixel detectors with ultra-small pitch (25*25 micron) and analogue readout are explored. Both make use of a dedicated readout ASIC (CLICpix), developed in 65 nm technology. CLICpix is either bump bonded to ultra-thin planar silicon sensors (with and without active edges), or AC coupled through a thin layer of glue to active HV-CMOS sensors. Results of recent beam tests and laboratory calibrations of a variety of assemblies with different sensor thicknesses are presented. Detailed simulations based on Geant4 and TCAD validate the experimental results and serve to optimise the detector design. The R&D project also includes the development of through-silicon via (TSV) technology, as well as various engineering studies involving thin mechanical structures and full-scale air-cooling tests.

**primary experiment:**  
**CLICdp Summary:**

Recent results with HV-CMOS and planar sensors for the CLIC vertex detector

The physics aims at the future multi-TeV CLIC linear \(e^+e^-\) collider impose high precision requirements on the vertex detector. The detector also has to match the experimental conditions, such as the time structure of the collisions and the presence of beam-induced backgrounds. The principal challenges are: a point resolution of 3 micron, 10 ns time stamping capabilities, ultra-low mass (0.2% \(X_0\) per layer), very low power dissipation (compatible with air-flow cooling) and pulsed power operation. The R&D for the pixel detector follows an integrated approach addressing simultaneously the physics requirements and the engineering constraints. Two types of hybrid pixel detectors with ultra-small pitch (25*25 micron) and analogue readout are explored. Both make use of a dedicated readout ASIC, CLICpix, developed in
65 nm technology. CLICpix is either bump bonded to ultra-thin planar silicon sensors (with and without active edges), or AC coupled through a thin layer of glue to active CCPDv3 HV-CMOS sensors. Both options have been tested extensively with particle beams and show excellent performance. Pixel-by-pixel calibrations have been carried out with radioactive sources and with X-rays of different energies. Detailed simulations based on Geant4 and TCAD validate the experimental results and serve to optimise the detector design. The R&D project also includes the development of through-silicon via (TSV) technology, as well as various engineering studies involving thin mechanical structures and full-scale air-cooling tests. In the framework of the CLIC pixel R&D, a new high-precision Timepix3-based beam reference telescope was constructed and commissioned.

Figure: Measurement of the fraction of 1-hit, 2-hit, 3-hit and 4-hit clusters with a CLICpix planar sensor assembly (200 micron sensor thickness) at the CERN SPS (top-left); AC-coupled assembly of CLICpix with a CCPDv3 HV-CMOS sensor (top-right); Measured detection efficiency of the CLICpix-CCPDv3 assembly as a function of the sensor bias (bottom-right).

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WIMP tracking with cryogenic nuclear emulsion

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Directional dark matter search experiment enable us to reveal the presence of Weakly Interacting Massless Particles (WIMPs). A promising detector of directional measurement is a fine-grained nuclear emulsion consisting of fine silver bromide crystals with 20 nm or 40 nm size. A critical issue for the success of the emulsion dark matter search experiment is to discriminate the nuclear recoil tracks and electron background tracks which come from stopping beta rays of $^{14}\text{C}$ decay in the emulsion. Since the intrinsic electron events will be significant background, a electron rejection power of at least $10^{-8}$ is needed.

We present a novel cryogenic approach to reject the electron background that makes use of phonon effect in nuclear emulsion. Since nuclear recoil tracks increase temperature of silver bromide crystals in the emulsion by producing phonon in the crystal, this approach allows us to extract nuclear recoil tracks and to achieve no sensitivity to electron tracks by operating the emulsion at LN$_2$ temperature.

For proof of principle, we have been investigating the sensitivity of fine-grained nuclear emulsions as function of temperature by exposing to gamma rays and ion beams from an ion implant system in range of 77 – 300 K. Results of gamma ray exposure indicate a dramatically reduction of the electron sensitivity with decreasing temperature. The nuclear track data is being analyzed.

First results on the performance will be presented.

primary experiment:

NEWS

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The SAFIR project: Status and perspectives

Author: Chiara Casella
SAFIR (Small Animal Fast Insert for mRi) is a non conventional preclinical PET detector, currently under development, to be used inside the bore of a 7T MRI scanner. The goal is simultaneous PET/MR imaging of small animals, with time granularities of the order of a few seconds, for fast and dynamic quantitative analysis of different biological processes (e.g. oxygen brain perfusion) at temporal resolutions never achieved so far.

To compensate for the statistics loss due to the short acquisition duration, high activities – up to 500 MBq – have to be injected into the animals. Beside the MR-compatibility, a high sensitivity (~5%), a good spatial resolution (~ 2 mm FWHM), an excellent coincidence timing resolution (~ 300 ps FWHM) and a high data throughput DAQ system are required.

The SAFIR detector will rely on matrices of L(Y)SO-type crystals, one-to-one coupled to SiPM arrays, and arranged into several rings, stacked axially. Different readout options are being investigated for the SiPM readout: the TOFPET, the STiC and the PETA ASICs. High rate tests with 2 matrices of LYSO crystals coupled to SiPM arrays, readout by each one of the proposed solutions have been performed, with two modules exposed to 500 MBq of FDG tracer in ~0.5 cm³ volume and operated in coincidence.

The status and perspective of the SAFIR project will be presented, with special emphasis on the results of the high rate tests.

**Primary Experiment:**
SAFIR

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**Intraoperative probe for radioguided surgery with beta-decays in brain tumor resection**

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The radio-guided surgery (RGS) represents a very useful surgical adjunct to intraoperatively detect millimetric tumor residues, enabling a radical resection. The main innovation of the RGS exploiting beta- emitters is the lower target-to-background ratio compared to the established technique using gamma or beta+ radiation, that allows the extension of the RGS to further clinical cases. For feasibility studies on brain tumors we developed and tested prototypes of an intraoperative probe detecting beta- decays, the device core being a scintillator with high light yield, non-hygroscopic property and low density. Portable readout electronics with wireless data transfer to the PC has been customized to match the surgeon needs. Preclinical tests with dedicated phantoms and test on ex-vivo specimen showed very promising results for the RGS application on brain tumors. This presentation will discuss the innovative aspects of the method, the status of the intraoperative probe development, the preclinical tests and the first tests on ex-vivo specimen of patients affected by meningiomas.
The MuPix HV-MAPS system-on-chip for the Mu3e experiment

Author: Dirk Wiedner

Co-authors: Andre Schoning; Ann-Kathrin Perrevoort; Frank Meier; Heiko Christian Augustin; Ivan Peric; Lennart Huth; Moritz Kiehn; Niklaus Emanuel Berger; Sebastian Dittmeier

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Mu3e is a novel experiment searching for charged lepton flavor violation in the rare decay $\mu \rightarrow eee$. Decay vertex position, decay time and particle momenta have to be precisely measured in order to reject both combinatorial and physics background. A silicon pixel tracker based on 50 um thin high voltage monolithic active pixel sensors (HV-MAPS) in a 1T magnetic field will deliver precise vertex and momentum information. The MuPix HV-MAPS chip combines pixel sensor cells with integrated analog electronics and a complete digital readout. The MuPix7 is the first HV-MAPS prototype having all functionality of the full sensor including a fast readout state machine and high speed serialization with 1.25 Gbit/s data output. Measurements for the MuPix7 pixel sensor chip including >98% efficiency for the full system in a high rate beam test will be shown.
PROSPECTS FOR DETECTION OF WIMP DARK MATTER AND COHERENT NEUTRINO SCATTERING WITH THE LUX-ZEPLIN DETECTOR

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The LZ is a second generation dark matter experiment. It is a follow-on to the LUX detector, which is currently the most sensitive WIMP direct detection experiment. The central LZ detector will contain 7 tonnes of active, liquid xenon. Further, LZ is predicted to observe dozens of solar $^8$B neutrino interactions via coherent neutrino-nucleus scattering. Along with being extremely sensitive to WIMP dark matter detector LZ may be the first measurement of the coherent neutrino scattering process. Understanding the expected neutrino interaction rates is crucial for extracting the WIMP signal and neutrino properties. I will discuss the status of the LZ experiment along with its projected sensitivity.

primary experiment:
LUX-ZEPLIN

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A low mass vertically integrated pixel system for the HL-LHC

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We will present the first characterization of a low mass, vertically integrated modular system optimized for the demanding thermal environments expected in the innermost layers of LHC experiments after the PH2 upgraded luminosity. The system is composed by a stack of three silicon layers for a total thickness of less than 1mm. From the top a radiation hard, 230 micron thick 3D silicon sensor (fabricated at CNM-Barcelona) with the same design of the ones used for the ATLAS-Insertable-B-Layer, integrated to a 100 micron thick FE-I4 front-end electronics pixel chip and a silicon microchannel layer designed to circulate evaporated CO2. The paper will show the system electrical and thermal functionalities, discuss results on the use of 3D printed ceramic components which could further improve the detector system’s large area design and conclude with future plans.

primary experiment:
LHC Detector Upgrade

Summary:

Detector systems composed of silicon sensors and advanced CMOS front-end readout chips need cooling to work efficiently. These systems are used for tracking ionising particles in particle physics experiments at the Large Hadron Collider. A key requirement is that these systems must contain as little material as possible so that they detect the particles but do not disturb their trajectory unduly. To achieve this requirement and obtain the necessary cooling, we are using the latest developments in Micro-Electro-Mechanical-Systems (MEMS) technology to make highly sophisticated microfluidic devices. High pressure CO2 liquid is used with these devices to obtain unprecedented cooling capacity with the lowest possible amount of material.
For future ATLAS innermost pixels layers CO2 microchannels where designed and tested to be coupled with the IBL pixel front end electronics chip. Devices compatible with the 2x2 cm2 area of the FE-I4 where successfully fabricated at CMI EPFL Switzerland and are shown in figure 1. Tests were performed using a CO2 plant were showing their robustness under 60 bar pressure.

A module compatible with the ATLAS IBL pixels was completed in July 2015 and was tested with particles in realistic conditions. A sketch of the module containing a 3D sensor, 100 um thin readout electronics substrate and about 760 um thick silicon substrate hosting at the top 190 micron deep microchannels and a picture of such module mounted on the readout board are shown in figure 1 (see attached file). It should be stressed that no thinning effort was performed on this particular cooling device and that a large margin exists to reduce its thickness.

Results from these tests give important information on the cooling requirements of these kinds of electronics chips. The plan is to irradiate the module to the levels achievable by the electronics functionality, 5x10^15 ncm^-2 and to test the response of particles in test beams to verify the material budget impact of the microchannels’ presence.

The microchannel methodology can also be extended to use in alternative thermally compatible substrates, such as 3D printed ceramic to enable large area cooling with connectors to be fabricated in an extremely low mass way, extending the applicability of the technique to areas where power density is lower. Prototypes are available and tests will be presented in this paper.

References

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Operating performance of GCT: an end-to-end Schwarzchild-Couder telescope prototype for the Cherenkov Telescope Array

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The Cherenkov Telescope Array (CTA) project aims to build the next generation ground-based Very High Energy instrument. It will be devoted to the observation of gamma rays over a wide band of energy, from 20 GeV to 300 TeV. Two sites are foreseen, one in the northern and the other in the southern hemisphere, allowing the viewing of the whole sky. The southern hemisphere array will consist of three types of telescopes with different mirror areas covering the low, intermediate and high energy domains. The high energy telescopes operate from 5 TeV to 300 TeV and will consist of a large number of Small Size Telescopes (SSTs) with a field-of-view of around 10 degrees. The Gamma-ray Cherenkov Telescope (GCT), a telescope based on a Schwarzchild-Couder dual-mirror optical design is one of the proposed CTA telescope designs for which an end-to-end prototype is currently being built.

The assembly of the GCT started on the French site of the Observatoire de Paris in spring 2015. The camera has been mainly assembled in Leicester and has been integrated in the GCT in fall 2015. The telescope is now fully assembled and operational. Its characteristics as well as its performance in the context of CTA specifications are presented in this contribution.
primary experiment:  
Summary:

Gamma-ray instrumentation

The Cherenkov Telescope Array (CTA) consortium gathers 1200 members working in more than thirty countries. The ambition of this project is to build, after HESS, MAGIC and VERITAS, the next ground-based Very High Energy (VHE) gamma-ray telescope array. Three classes of telescopes; covering high, medium and low energies; are foreseen. Among them, the Small-Size Telescopes (SSTs) are devoted to the highest energies from 5 to 300 TeV. They will be located on the Southern CTA site, planned to be located at the ESO (Cerro Armazones) site in Chile. Precise characteristics of the SST sub-array (size of the telescopes, number and spacing) have been defined by Monte-Carlo simulations, this leads to 70 4-meter SSTs at separations of about 250 meters spread over more than a square kilometre. Amongst the SST science requirements, the source localisation shall be in a area smaller than 5 arcseconds, the systematic uncertainty of a photon candidate energy shall be smaller than 15% and the field-of-view (FoV) needs to be larger than 8°. GCT (Gamma-ray Cherenkov Telescope) is a French-UK-US-Dutch-German-Japanese-Australian sub-consortium of CTA aimed at proposing an end-to-end SST. The telescope is based on a Schwarzchild-Couder (SC) optical design. This SC optical design has never been implemented before in gamma-ray astronomy and is an innovative and interesting alternative to the one-mirror Davis-Cotton design commonly used in ground-based Cherenkov astronomy. This design is particularly advantageous for the SSTs and is compatible with the large FoV requirement: it allows a compact structure and a lightweight camera and it enables good angular resolution across the entire FoV while allowing a reduction of the focal length and hence of the physical pixel and overall camera size.

The telescope mechanical structure consists of three main subsystems: the Tower, the Alt-Azimuth System, allowing the telescope to move in azimuth in the range ±270° and in elevation from 0 to 90°, and the Optical Supporting Structure / Counterweight. Its design has been optimized to provide a lightweight, simple and compact structure compatible with CTA specifications in terms of stiffness, cost or lifetime; to decrease manufacturing costs by using commercial-off-the-shelf modules and similar systems in the telescope; and to ease the mounting and maintenance phases. The assembly of the mechanical structure from pre-assembled subsystems is easy since its required only four FTEs for two days. The optical structure consists of two metallic lightweight mirrors and a camera. Two cameras will be tested on the prototype structure. These two cameras have similar physical sizes, a curved focal plane and a diameter of roughly 45 cm instrumented with 2048 6 mm-pixels for a total FoV of about 9°. They differ by the photosensors used since the first camera prototype uses MultiAnode Photo Multipliers (MAPMT) tiles whereas the second one uses Silicon Photo Multipliers tiles. The cameras are designed to record the very fast flashes (about tens of nanosecond) of Cherenkov light produced in the atmosphere from gamma-initiated electromagnetic showers. The full waveform signal is recorded from all 2048 pixels arranged in 32 tiles of 64 pixels. Each of the 32 tiles is connected to a preamplifier and a TARGET front end module providing digitization and the first level of trigger based on the discrimination on the analog sum of group of 4 neighbouring pixels in a module. The data lines cross a backplane and are gathered on 2 Data Acquisition Boards acting a switch to serialise to a lab computer the data from 16 modules each and providing absolute timestamp and synchronization with a White Rabbit interface. This strategy has proved through simulation to exclude reading the camera on a very high expected night sky background rate (~MHz) down to the goal of reading out rate of few hundreds of Hz for very high energy gamma ray events. A peripherals board controls humidity and temperature sensors, regulates the speed of fans which redistribute the heat inside the sealed enclosure, while the heat generated by the electronics is extracted through a chilled plate where cold water is circulated by an external chiller unit. Two motors operate a watertight lid at the focal plane that provides shielding from weather elements and protects the photosensors when the telescope is in its parking position during the day. When the lid is closed, its reflective surface is imaged by a CCD camera at the centre of the secondary mirror for pointing accuracy. Four calibrated LED flashers, each at a corner of the focal plane plate, can be controlled during operation to calibrate the photosensors and the electronic chain trough the reflection on the secondary mirror of the telescope.

Since the commissioning of the MAPMT camera prototype on the mechanical structure in fall 2015, the telescope prototype is fully operational. Tests on the structure are currently in progress and will be presented in the paper. The final telescope design has a total mass of about 7.8 tons, of which 50 kg is the camera, which is lighter than other CTA SSTs. Real and complete cost leads to 245 k€ (158 k€ for the mass production) for the mechanical structure and to 150 k€ for the camera. Three pre-production telescopes and camera are planned to include the lessons learnt from the prototypes. This will result in a final review iteration before full scale production aiming to provide the CTA southern site with 35
GCT telescopes.

Medical Applications / 211

**proton Computed Tomography images with algebraic reconstruction**

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Proton Computed Tomography (pCT) is a new imaging method with a potential for increasing accuracy of treatment planning and patient positioning in hadron therapy.

A pCT system based on a silicon tracker and a YAG:Ce calorimeter has been developed within the PRIMA/RDH/IRPT INFN CSN5 collaboration.

The pCT prototype has been tested under 62MeV and 180MeV proton beams at respectively Laboratori Nazionali del Sud (Catania, Italy) and Svedberg Laboratory (Uppsala, Sweden).

Data analysis has been performed using algebraic iterative reconstruction algorithms.

In this talk, functional characteristics of the pCT system under test beam will be discussed; images of non homogeneous phantoms resulting from the pCT reconstruction will be shown and main results in term of spatial and density resolutions will be reviewed.

**primary experiment:**

IRPT MIUR INFN

Medical Applications / 98

**Design of a tracking device for on-line dose monitoring in hadron therapy**

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Hadron therapy is a technique for cancer treatment that exploits ion beams (mostly protons and carbons). A critical issue is the accuracy that is achievable when monitoring the dose released by the beam to the tumor and to the surrounding tissues. We present the design of a tracking device, developed in the framework of the INSIDE project, capable of monitoring, in real time, the longitudinal profile of the dose delivery in the patient. It is possible by detecting the secondary particles produced by the beam in the tissues. The position of the Bragg peak can be correlated to the charged particles emission point distribution measurement.

The device will be able to provide a fast response on the dose pattern by tracking the secondary charged fragments. The tracks are detected using 6 planes of scintillating fibers, providing the (x,y,z) coordinates of the track intersection with each plane. The fibers planes are followed by a plastic scintillator and by a small calorimeter built with a pixelated LFS crystal.

A complete detector simulation, followed by the event reconstruction, has been performed to determine the achievable monitoring spatial resolution.

**primary experiment:**

**INSIDE Summary:**

Protons and carbon ion beams are presently used to treat many different solid cancers. Compared to the standard X-rays treatments the main advantage of this technique is the better localization of the dose in the tumor region sparing healthy tissues and surrounding Organs At Risk (OAR). This is a consequence of the way in which heavy charged particles lose most of their energy when interacting with matter: near the end of their range, in the Bragg peak, while X rays exponentially decrease their energy along the path traveled in matter. New detectors have to be introduced in the clinical use for the real time monitoring of particle range in charged particle therapy treatments.

It has been shown that the position of the released dose peak can be correlated with the emission pattern of secondary particles created by the beam interaction\footnote{Piersanti L. \textit{et al.}, Measurement of charged particle yields from PMMA irradiated by a 220 MeV/u $^{12}$C beam, \textit{Med. Phys. Med. Biol.} 59 (2014) 1857–1872. The proposed detector, developed in the framework of the INSIDE project\footnote{M. Marafini \textit{et al.}, The INSIDE project: innovative solutions for In-Beam dosimetry in hadrontherapy, \textit{ACTA PHYSICA POLONICA A}, (2015) Vol 127,\textit{5},1465}, is designed to operate as an in-beam monitor by means of charged particle tracking.

The device will be able to provide a fast response on the dose pattern by tracking the secondary charged fragments. The tracks are detected using 6 planes of scintillating fibers, providing the (x,y,z) coordinates of the track intersection with each plane. The fibers planes are followed by a plastic scintillator and by a small calorimeter built with a pixelated LFS crystal.

The design requirements are compactness, reliability, large geometrical acceptance and high tracking efficiency.
Dose Profiler mechanical structure, the scintillating fibers planes and the LFS crystal are shown in Figure~\ref{fig:ProfScheme}.\ \ A detailed simulation of the detector has been developed in order to optimize the detector design. The Monte Carlo software used for the simulations is FLUKA, release 2011.2. The performance in term of spatial resolution on the emission point of the protons have been evaluated using a Monte Carlo simulation of the interactions of a carbon beam of 220 MeV/u with a PMMA phantom: the obtained results, discussed in the framework of a standard clinical application, will be presented.

Astroparticle Detectors / 165

New application of superconductors: high sensitivity cryogenic light detectors

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When we apply an AC current to a superconductor, the Cooper pairs oscillate and acquire kinetic inductance, that can be measured by inserting the superconductor in a LC circuit with high merit factor. Interactions in the superconductor can break the Cooper pairs, causing sizable variations in the kinetic inductance and, thus, in the response of the LC circuit. The continuous monitoring of the amplitude and frequency modulation allows to reconstruct the incident energy with excellent sensitivity. This concept is at the basis of Kinetic Inductance Detectors (KIDs), that are characterized by natural aptitude to multiplexed read-out (several sensors can be tuned to different resonant frequencies and coupled to the same line), resolution of few eV, stable behavior over a wide temperature range, and ease in fabrication. We present the results obtained by the CALDER collaboration with 2×2 cm$^2$ substrates sampled by 1 or 4 Aluminum KIDs. We show that the performances of the first prototypes are already competitive with those of other commonly used light detectors, and we discuss the strategies for a further improvement.

primary experiment:
CALDER, CUORE, LUCIFER

Summary:
Attached as PDF file

Semiconductor Detectors / 301

Improved Process Technologies in the SOI Pixel Detectors

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A monolithic detector using Silicon-On-Insulator (SOI) technology is one of promising technologies for future pixel detectors in various kinds of applications. It fabricates both sensors and readout circuits in a semiconductor process. It is also known that the technology is immune to Single Event Effect (SEE).

Remaining issues in the SOI pixel technology are radiation tolerance for Total Ionization Dose (TID) and sensor crosstalk from circuit signals. We have solved these issues by introducing double SOI technology and modifying implantation dose of Lightly Doped Drain (LDD) region of transistors. In the double SOI technology, an additional Si layer is inserted under transistor layer, so it shields the crosstalk. We confirmed the middle Si layer could suppress the crosstalk very efficiently. In addition, by applying bias voltage to the middle layer, it can compensate electric field created by oxide-trapped hole generated by irradiation. Thus the threshold shift caused by radiation can be adjusted to original value even in the device which is irradiated more than 10 Mrad(Si).

However, we observed drain current reduction after heavy irradiation. We found this is caused by parasitic transistors exist in the LDD region of transistors. By increasing the doping level of the LDD region, we confirmed such reduction could be avoided. We also found this doping level change improves Id-Vd characteristics of transistor in ultra-low temperature region (< 3K).

Medical Applications / 362

The iMPACT project tracker and calorimeter

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In recent years the use of energetic protons and carbon ions (hadrons) for cancer radiation treatment has exponentially grown in importance. Its effectiveness is anyway still limited by the necessity to rely on X-rays CT data to plan the dose delivery, which leads to aiming errors. Many groups are therefore trying to realize a proton CT (pCT) to overcome this limitation.

The iMPACT project (innovative Medical Protons Achromatic Calorimeter & Tracker) aims building a pCT scanner which overcomes present state-of-the-art limitations, mostly the low tracking speed, which requires long times (many minutes) to acquire a target 3D image. The iMPACT goal tracking speed is in fact 1 GHz, which would reduce the acquisition time from minutes to seconds. The tracker will use CMOS monolithic active pixel sensors (MAPS) for tracking high rate particles over a large area. MAPS allow to practically cover large areas respect to hybrid-pixel or micro-strip sensors, but specific improvements are necessary to effectively use them in a pCT scanner at such speed. Present state-of-the-art also does not offer a calorimeter capable of 1 GHz particle tracking. An achromatic calorimeter will hence be employed, i.e. a calorimeter where the position of the proton maximum stopping power (dE/dx) is used to derive its entrance energy.

This contribution will illustrate which solutions have been devised for both the tracker and the calorimeter and how that will boost the actual tracking performances.
Performance of MÖNCH, a 25-μm pixel pitch detector for photon science

Authors: Anna Bergamaschi¹; Bernd Schmitt²; Davide Mezza²; Davit Mayilyan²; Dominic Greiffenberg²; Erik Fröjd³; Gemma Tinti³; Marco Ramilli²; Martin Brückner⁴; Roberto Dinapoli⁵; Sebastian Francis Cartier⁵; Xintian Shi⁶; aldo mozzanica¹

MÖNCH is a hybrid silicon pixel detector based on charge integration and with analog readout, featuring a pixel size of 25x25 μm². Several prototypes have been commissioned, aimed at experimenting different solutions to optimize the detector performances for high and low flux applications at synchrotrons and X-FELs.

With an ENC of the order of 35 electrons RMS, MÖNCH is competitive with monolithic detectors and with CCDs in the fields of high resolution imaging and soft X-ray detection below the keV level, and its kHz frame rate capability can substantially shorten the time needed for a single measurement. Due to its extremely small pixel pitch, MÖNCH intrinsically features an elevate position resolution which, in low flux condition, can even overcome the pixel size: charge sharing between neighboring pixel can be exploited in position interpolation algorithms which can achieve a sub-micron resolution.

In order to achieve the high dynamic range required by XFEL experiments, one of the MÖNCH prototypes features a dynamic gain switching pixel architecture, which allows to adapt the pixel gain setting to the impinging photon flux.

Characterization results of different MÖNCH prototypes in terms of bump-bonding yield, linearity, dynamic range and position resolution will be shown, together with preliminary measurements. Finally, the perspective for the realization of a future low energy detector using 4x3 cm2 modules will be discussed.

primary experiment: synchrotrons, XFELS

MÖNCH is a research project which aims to push the development of hybrid pixel detectors to its limits in terms of photon flux, position resolution, energy information and low energy detection. It features a charge integrating (CI) pixel architecture, compressed in a 25-μm pixel pitch. Its finer granularity grants higher intrinsic spatial resolution and its lower pixel capacitance allows for higher readout rates. However, the small pixel pitch implies an increased difficulty in bump bonding and an almost constant charge sharing between neighbouring pixels, which in case of MÖNCH happens in ~90% of the cases. Nonetheless, in case of relatively low fluxes, the total extracted charge can be reconstructed using clusterization algorithms that exploit the analog output, and therefore allowing color imaging. Furthermore, using the same analog information in energy weighting interpolation algorithms, it is possible for MÖNCH to achieve a spatial resolution at the micrometer level. Although MÖNCH is primarily a research project, several practical applications could benefit from such a detector, and the most promising are related to low energy X-ray detection: with its kHz-level readout rate, MÖNCH can drastically reduce the acquisition time with respect to CCDs, which are commonly used in this energy range. Possible applications can be further divided in two main subsets: one requires high spatial resolution but has low incoming photon flux; the second has less strict requirements for position resolution but much more stringent specifications about speed and dynamic range.
In order to test possible pixel architectures, each one optimized for a given regime, several M\textsuperscript{\textregistered}NCH-prototypes have been realized. M\textsuperscript{\textregistered}NCH 02 consists of an array of 160×160-pixels with a 25-\textmu m pitch, resulting in an active area of 4×4-mm\textsuperscript{2}. The chip is divided in five sub-blocks, each featuring a different pixel architecture. Three of them feature a static gain selection, for synchrotron or X-ray tubes applications. In low gain mode they provide single photon sensitivity as well as a reasonable dynamic range for such a small area (>120 photons). In high gain they target high resolution, low flux experiments where charge sharing can be exploited to reach position resolution below the pixel pitch level. The other two blocks are equipped with a dynamic gain switching (DGS) mechanism similar to the one implemented in JUNGFRAU or AGIPD.

M\textsuperscript{\textregistered}NCH 03 is a prototype that benefits from the experience acquired from M\textsuperscript{\textregistered}NCH 02, and features a pixel architecture with static gain selection and optimized for an imaging application on an area of 1-cm\textsuperscript{2}. It consists of an array of 400×400 25-\textmu m pitch pixels, divided in 32 supercoulmns of 25×200 pixels.

In the last two years the prototypes 02 and 03 had been commissioned and a systematic performance characterization of both has been conducted. The bump bonding is performed in-house and latest encouraging result give a yield better than 99.95\%.

Noise characterization of M\textsuperscript{\textregistered}NCH 02 prototype provided fairly low values, reaching the ~35-e\textsuperscript{-}~ENC for the high gain setting, therefore setting a lower bound for the detector sensitivity in energy at energies below the keV-level. The pixel charge sharing has been exploited to reconstruct the photon interaction point via a two-dimensional interpolation algorithm, based on a generalization of the \eta distribution used for strip detectors. As a result, when used in single-photon regime, M\textsuperscript{\textregistered}NCH can achieve a position resolution of the order of 1-\textmu m.

Further ongoing characterization include the estimate of the dynamic range and linearity at all the different gain settings. To test the compliance of M\textsuperscript{\textregistered}NCH–with a possible low energy XFEL experiment, readout speed and DGS architecture will be both tested.

Astroparticle Detectors / 123

Performance study of glass RPC detectors for INO-ICAL experiment.

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Resistive plate chamber (RPC) detectors are known for their excellent timing and good spatial resolution, which make them favourable candidates for the tracking and triggering in many high energy physics experiments. The Iron Calorimeter (ICAL) detector at India-based Neutrino Observatory (INO) is one such experiment, which will use RPCs as an active detector element. The ICAL experiment is designed to study atmospheric neutrinos and various issues related with neutrino physics. The INO-ICAL has geometry that utilizes about 29000 RPC’s of 2m x 2m in size, interleaved between thick iron plates, producing muons via the interaction of atmospheric neutrinos with iron. The tracking information of the muons will be extracted from the two dimensional readout of the RPC’s and its position in respective layer along with the upward and downward directionality determined from the timing information. As a result, a precise measurement of timing response of these RPC detectors is quite important. Further, to design readout system for the ICAL detector, induced signal study and charge information is needed as well. In this paper, we present the detailed timing and charge spectra study for various glass RPC candidates. We also report the effect of various gas compositions on the timing and charge spectra of these RPC detectors.

primary experiment:

India Neutrino Observatory

Astroparticle Detectors / 398
The FLARES project: an innovative detector technology for rare events searches

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FLARES is an innovative project in the field of rare events searches, such as the search for the neutrinoless double beta decay. It aims to demonstrate the high potentiality of a technique that combines ultra-pure scintillating crystals to arrays of high performance silicon drift detectors (SDD), used to read their light. By optically coupling the two devices and working at temperatures of about 120K, a strong enhancement of the light emission should be obtained. This would allow to reach a 1% level energy resolution in a scintillation particle detector. The proposed technique will therefore combine in a single device all the demanding features needed by an ideal experiment looking for rare events. It should in fact guarantee high energy resolution, background abatement (provided specific features of the scintillating crystals that allow a strong abatement of the background due to alpha particles), low cost mass scalability and high flexibility in choice of the crystal.

The performances of a first production of matrices of SDD as well as first measurements of the low temperature light yield of a selection of high purity scintillating crystals will be presented and discussed.

primary experiment:

FLARES Summary:

The discovery of the neutrino oscillations has strongly renewed the interest in this field of particle physics. In particular some important questions like the nature of the neutrino (Dirac or Majorana) and its absolute mass still remain without an answer. The search for neutrinoless double beta decay (DBD0n) has therefore gained in the last years a primary role in the astroparticle physics field, since this elusive decay, if revealed, would demonstrate the Majorana nature of the neutrino and at the same time would give important information about its absolute mass scale.

The DBD experiments actually on the way exploit a variety of techniques in order to reach a sensitivity on the neutrino majorana mass (the neutrino mass parameter to which such experiments are sensitive) in the inverted hierarchy region (IH) of the neutrino mass spectrum. The most of them are based on the use of homogeneous detectors, in which the detector itself contain the isotope candidate for the DBD0n. The extreme rarity of the searched decay imposes the need of high detector/source masses (of the order of one ton or larger) with an easy mass scalability and of an almost zero background in the region of interest. The first aspect is often limited by cost and technical reasons, while the second aspect forces to perform the experiments underground, with heavy shieldings and developing challenging techniques with active event identification capability and/or event position reconstruction.

The use of inorganic scintillating crystals allows to reduce the background by means of particle identification. At the same time such detectors offer the possibility to have large scale detectors with low cost mass scalability in a low background environment without apparent limitations, but suffer a seemingly irreducible restriction in the attainable energy resolution, when coupled to photo-multiplier tubes (PMT) for the light read-out. The broadening of the upper tail of the unavoidable 2 neutrinos double beta decay (DBD2n), would therefore impose a strong limitation to the sensitivity reachable with such devices. A FWHM resolution better than 2% would be necessary in order to minimize this background.
In this contest the technique exploited by the FLARES project is a novelty. The light read-out of ultra-pure scintillating crystals is in fact performed by Silicon Drift Detectors (SDD), optically coupled to them. Such devices have in fact Quantum Efficiencies (QE) larger than 80% (compared to the 40% of the best commercial photo-tubes) in a wide range of wavelength, thus avoiding the degradation of the energy resolution due to the loss of carriers. In addition, silicon is one of the cleanest materials from the radioactivity point of view.

By operating both the scintillating crystal and the SDD at temperatures of about 120K, the light emission will be enhanced, thus increasing the number of collected carriers and therefore improving the energy resolution.

For example, a CaMoO4 crystals (containing the 100Mo as DBD0n candidate, with Q-value of 3034 keV) coupled to 40 SDDs and operated at 120K, the predicted FWHM resolution at 3 MeV is of about 37 keV, enough to guarantee a negligible contribution from the DBD2n decay events. With this detector concept it would be possible to build large mass compact structures of high performance detectors for DBD0n searches.

The FLARES project, funded by INFN-CSN5 and involving the INFN sections of Milano-Bicocca, Bologna and Trieste, started at the beginning of 2015 to build a prototype detector. Two kind of crystals are actually under study, CaMoO4 and CdWO4, both with attractive features in terms of scintillating properties. The crystal characterization and optical coupling optimization is performed both at room and low temperatures (~100K) in a dedicated setup allowing to work in vacuum conditions. The first SDD tests have been performed with silicon devices produced for ReDSoX, while a production dedicated to FLARES is under way, implementing thin entrance window and anti-reflecting coating in order to have improved QE. Low temperature noise tests have also been performed in order to optimize the electronics read-out chain.

The first test results show that in the energy range of interest for FLARES (~3MeV) the 1% energy resolution goal should be achievable.

## Semiconductor Detectors / 389

### The DEPFET Detector-Amplifier Structure for Spectroscopic Imaging in Astronomy and for Experiments at Free Electron Lasers

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The DEPFET detector-amplifier structure possesses several unique properties which make it extremely useful as readout element in semiconductor detectors and in particular as building block of semiconductor pixel detectors. Variations of DEPFETs can be tuned to specific requirements as to be sensitive only in predetermined time intervals, to measure signal charge with sub-electron precision, dead-time less readout and DEPFETs with signal compression. These devices have been shown to work in simulations and in prototypes. Now the first two fully developed detector systems have been finished and installed in the MIXS instrument of the Bepi-Colombo Mercury Planetary Orbiter scheduled to be launched in 2016. A further DEPFET detector system under development is the DSSC that will be installed in one of the beam-lines of the XFEL. The requirements on the two projects are rather different. While the MIXS sensors are supposed to measure precisely the energy and position of single photons down to very low energies but at moderate rates, the DSSC has to measure the number of photons arriving in each pixel within a time interval of 220 ns. Here the challenge is the capability of detecting single X-ray photons in one pixel simultaneously with up to 10.000 photons in some other pixels. Device functioning has been verified with sensors produced in a research laboratory. Now process and design have been adapted to an industrial type production line, allowing additional improvements.
DSSC Summary:

The presentation will be structured into three parts:

1) Presentation of the basic DEPFET principle with its basic properties and their use as basic cell in pixel detectors including variations with special properties:

   a. DEPFET Macro-Pixel Detectors using as basic cell a combination of a DEPFET and a SDD (Silicon Drift Detector).

   b. Gatable DEPFETs allowing the selection of time intervals in which the device is sensitive. This is of use for the observation of periodically changing objects as for example rotating neutron stars.

   c. RNDR (Repeated Non-Destructive Readout) DEPFETs that make use of the fact that reading the signal charge does not destroy or alter the signal so that the same charge can be read repeatedly and thus the measurement precision improves with the square root of the number of readings. A measurement precision of 0.25 electrons has been achieved.

   d. IQSDEPFETs (DEPFETs with Intermediate Charge Storage) allowing charge collection of an event in parallel with the signal readout of a previous picture. Thus uninterrupted sensitivity of the device can be achieved.

   e. DSSC (Depfet Sensor with Signal Compression) with linear response for small signal charge and strong non-linear response for high charge, designed for photon counting in XFEL experiments.

2) The MIXS (Mercury Imaging X-ray Spectrometer) using as focal plane detectors two identical DEPFET Macro-Pixel Detectors. This Spectrometer is fully commissioned, assembled and on its way to the launch site to be launched in 2016. Results of the sensor calibration will be given.

3) The DSSC pixel detector at XFEL (X-ray Free Electron Laser). This device has been invented in order to fulfill the harsh requirements present in the XFEL environment. While the MIXS sensors are supposed to measure precisely the energy and position of single photons down to very low energies but at moderate rates, the DSSC has to measure the number of photons arriving in each pixel within a time interval of 220 ns. Hence the challenge is to provide single photon detection capability down to 500 eV energy simultaneously with a high dynamic range up to 10,000 photons per pixel. That this is possible has been verified with sensors produced in a research laboratory. Now this process and design is adapted to an industrial type production line, allowing for additional improvements due to smaller feature sizes as well as faster turn-around time and lower production cost. Production of prototypes in this new technology has started and first results are expected at the time of the conference.

The talk will put its emphasis on concept, design, layout, properties and performance of the silicon sensors. System aspects will only be covered as long as they were relevant for the sensor development.

Medical Applications / 122

Development of a compact scintillator-based high-resolution Compton camera for molecular imaging

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Recently, the Compton camera that can conduct measurements across a wide range of energy (from a few hundred kiloelectronvolts to a few megaelectronvolts) has been studied in the medical imaging field such as nuclear medicine and ion beam therapy. We have earlier developed a small, lightweight scintillator-based handheld Compton camera for environmental surveys. Although the handheld Compton camera showed very high efficiency, its angular resolution of ~8° (FWHM) for a 137Cs source was slightly poor for medical imaging. Hence, in this study, we developed a new Compton
camera to improve the angular resolution. Both the scatterer and the absorber consist of a Ce-doped Gd3Al2Ga3O12 (Ce:GAGG) scintillator array and multi-pixel photon counter (MPPC) arrays. In the absorber, we applied a 3D position-sensitive scintillator block using a dual-side readout technique. Based on the results of the fundamental imaging test, we confirmed that the new Compton camera showed a significantly improved angular resolution from ~8.9° (FWHM) of the present handheld camera to 5.4° (FWHM) for 662 keV gamma rays. In this study, we also present results of the basic detector performances and that of 3D image reconstruction toward “color” molecular imaging using the new Compton camera.

Plenary 4 / 447

Detector requirements for a 100-TeV collider

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A 100 TeV hadron collider is the core aspect of the Future Circular Collider (FCC) study, an integral conceptual design study for post-LHC particle accelerator options in a global context. The study is exploring the potential of hadron and lepton circular colliders, performing an in-depth analysis of infrastructure and operation concepts and considering the technology research and development programs that would be required to build a future circular collider. This talk will give an overview of the FCC accelerator studies and present the environment for experiments and detectors at the 100 TeV hadron collider. Detector concepts and requirements are discussed in some detail.

Plenary 4 / 361

Prospective overview of the CEPC detector

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The Circular Electron Positron Collider (CEPC) has been proposed by the Chinese High Energy Physics Community to operate as a Higgs Factory, which would allow precision measurements of the properties of the recently discovered Higgs boson. The CEPC detector, with similar performance requirements to the ILC detectors but without power-pulsing, needs to provide significantly improved precision compared to the LEP detectors to make possible the Higgs precision measurements. This would require many innovative detector technologies and advanced electronics to be deployed. In this presentation, I will give an overview of the requirements and challenges, and discuss the possible detector technologies for each sub-detector. I will also report briefly the progress on several detector R&D topics.

Plenary 4 / 360

Status and future perspectives of the ILC project

primary experiment:

compton camera

primary experiment:

CEPC
The International Linear Collider (ILC) has been designed to lead the new era ushered in by the discovery of the Higgs boson. It requires a world-wide collaboration in physics case studies, advanced R&Ds on the accelerator and detector technologies, as well as government-level international agreements. Instruments with advanced technologies are developed and the physics reach with Higgs, top quark and new particle searches/studies are studied. Following the world-wide developments and supports by the researchers, the Japanese government is now seriously evaluating the case for hosting the ILC and various activities towards its realization have begun involving communities outside academic fields. In this talk, we introduce the recent status of ILC project and discuss its perspectives.

Primary experiment:
ILC

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Studies on Gas Electron Multiplier (GEM) modules of a Large Prototype TPC for the ILC

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The International Linear Collider (ILC) is one of two detector concepts at the ILC. It relies on highly granular calorimetry and a high precision tracking system. The tracking system consists of a Silicon vertex detector, forward tracking disks and a large volume Time Projection Chamber (TPC), which will be read out with micro-pattern gas detectors (MPGD).

Within the framework of the LCTPC collaboration, a Large Prototype (LP) TPC has been built as a demonstrator. Its endplate is able to contain up to seven identical modules of Micro-Pattern Gas Detectors (MPGD). Recently, the LP has been equipped with MPGD modules and studied with electron beams (1-6 GeV) in a 1 Tesla magnetic field. The interest of this talk lies in the studies of Gas Electron Multiplier (GEM) modules. In particular, after introducing the LP, recent results (drift velocity, field distortions, spatial resolution, alignment measurements) as well as the current status and future plans of the LCTPC R&D will be presented.

Primary experiment:
ILD TPC

Plenary 4 / 329

The Jiangmen Underground Neutrino Observatory
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The Jiangmen Underground Neutrino Observatory (JUNO) is a multipurpose neutrino-oscillation experiment designed to determine the neutrino mass hierarchy as a primary physics goal, by detecting reactor antineutrinos from two power plants at 53-km distance. The detector is placed at 1800-m.w.e deep underground and consists on a 20 kiloton liquid scintillator volume contained in a 35m-diameter acrylic ball and instrumented by more than 17000 20-inch PMTs ensuring a 77% photocathode coverage. To reach an unprecedented 3% energy resolution (at 1 MeV), the PMTs need a maximum quantum efficiency of ~35% and the attenuation length of the liquid has to be better than 22m (at 430nm). This precision on the energy is a key point to determine at the 3-4 sigma significance level the neutrinos mass hierarchy with six years of running. The measurement of antineutrino spectrum will also lead to the precise determination of three out of the six oscillation parameters to an accuracy of better than 1%. The experiment will also be able to observe neutrinos from terrestrial and extra-terrestrial sources.

The international collaboration of JUNO was established in 2014, the civil construction has started in 2015 and the R&D of the detectors is ongoing. JUNO is planning to start data taking around 2020. An overall picture of the detector as well as details on the different parts (inner target, water Cherenkov pool and muon tracker) and associated recent developments will be presented in this talk.

Plenary 5 / 448

Detector evolution for Gravitational Waves observations

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In the last two decades there has been a growing interest around the possibility to detect on Earth Gravitational Waves emitted by astrophysical sources. One hundred years after Einstein’s presentation to the scientific community of the theory of General Relativity, predicting their existence as a perturbation of space-time traveling through the Universe at the speed of light, a network of second generation detectors is being put into operation. It is based on ground based suspended Michelson interferometers aiming at the first direct detection of Gravitational Waves together with the possibility to localize their sources in the sky. An overview of the technological improvements performed in the construction of these sophisticated detectors is presented here with particular emphasis on the Advanced VIRGO interferometer. This experimental apparatus together with two similar ones known as Advanced LIGO will have the opportunity to increase the observable volume of the Universe by a factor of 1000, thus opening the era of Gravitational Waves astronomy.

Plenary 5 / 347

A new cryogenic detector for low mass dark matter search with CRESST-III

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The CRESST-II (Cryogenic Rare Event Search with Superconducting Thermometers) experiment, which second phase has successfully finished in summer 2015, aims at the direct detection of dark
matter particles. CRESST uses CaWO$_4$ crystals operated as cryogenic detectors. Compared to previous runs the intrinsic radiopurity of CaWO$_4$ crystals, the capability to reject recoil events from alpha-surface contamination and the energy threshold were significantly improved. The acquired data provides competitive limits on the spin-independent WIMP-nucleon cross section and probes a new region of parameter space for WIMP masses below $2\times10^3$ GeV/c$^2$. This potential for low-mass WIMP search can be further exploited by a new detector design planned for CRESST-III. We describe the experimental strategy for the near future and give a detailed technical description of the new cryogenic detector technology.

primary experiment:
CRESST Dark Matter Summary:
See file attached.

Plenary 5 / 341

Development of a composite large-size SiPM (assembled matrix) based modular detector cluster for MAGIC

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The MAGIC collaboration operates two 17m diameter Imaging Atmospheric Cherenkov Telescopes (IACTs) on the Canary Island of La Palma. Each of the two telescopes is currently equipped with 1039 photomultiplier tubes (PMTs). Due to the advances in the development of Silicon Photomultipliers (SiPMs), they are becoming a widely used alternative to PMTs in many research fields including gamma-ray astronomy.

Within the Otto-Hahn group at the Max Planck Institute for Physics in Munich, we are developing a SiPM based detector module for a possible upgrade of the MAGIC cameras and also for future experiments as, e.g., the Large Size Telescopes (LST) of the Cherenkov Telescope Array (CTA). Because of the small detector size (6mmx6mm) with respect to the 1-inch diameter PMTs currently used in MAGIC, we use a self assembled matrix of SiPMs to cover the same detection area. We developed an analog transistor circuit to sum up and amplify the SiPM signals of one pixel to a composite output without the drawback of summing the sensors capacitances. Existing non-imaging hexagonal light concentrators (Winston cones) used in MAGIC have been modified for the angular acceptance of the SiPMs using C++ based ray tracing simulations. The first prototype of our SiPM based detector module consists of seven channels and was installed into the MAGIC camera in May 2015. We will present the results of the first prototype and its performance as well as the status of the project and discuss its challenges.

primary experiment:
The MAGIC telescopes Summary:
The MAGIC telescopes are two 17 m diameter Imaging Atmospheric Cherenkov Telescopes (IACTs). They are situated at the Observatorio del Roque de los Muchachos on the Canary Island of La Palma. The huge mirror surfaces and the PMT equipped cameras are used to measure Cherenkov light from extended air showers, induced by very high energy cosmic gamma rays at an energy range from 30 GeV to several 10 TeV. Both Cameras consist of 1039 PMTs each, partitioned in 169 modules. To further increase sensitivity the Cherenkov Telescope Array (CTA) will be built. In the centre, four Large Size Telescopes (LST), each equipped with 1855 PMTs will be placed.
We are developing a modular SiPM based detector module for a possible upgrade of the MAGIC and CTA telescopes. Our main goal for the first prototype was to reveal possible construction, controlling
and electronics problems in building a detector module suitable for the operation environment of the telescopes. In particular problems including a high level of background light, the operation at ambient temperatures and the need of a large active detection area have been addressed. To be able to differentiate signal events from background light a fast signal response (FWHM < 5 ns) is necessary. Because SiPMs show no ageing effect when exposed to high levels of light, observations during e.g. moonlight are feasible.

To be compatible to the MAGIC camera our module consists of seven pixels. Each SiPM pixel is build up as a self assembled matrix of seven 6x6 mm² (14400 x 50 x 50 μm² cells) active area sensors (see figure 1 of attached pdf). The sensors are divided in groups of 2, 3 and 2 SiPMs respectively. Like this only the sensors of one group need to have the same breakdown voltage. In order to compensate for the spread in breakdown voltages and to limit currents we use a positive offset voltage on the anode side of each SiPM group in addition to a common HV for all pixels at the cathode side.

In each pixel a common-base transistor circuit (CB) with a low input impedance is used to amplify the signals before summation to a composite output signal. In this way the capacitances of the sensors are not summed and the fast signal pulse can be preserved. Some characteristics of the SiPMs e.g. rise time and FWHM are slightly increased due to the summation but photon counting is nevertheless still possible and single photo electron peaks can be clearly seen in a charge histogram. The summed current is then converted to an analog optical signal for transmission to the readout system.

We studied the constraints and possible optimization strategies for angular acceptance of the SiPM based modules. An optimal acceptance for light for light being reflected at the mirror with a sharp cut of at the mirror edge was targeted. Using light concentrators the necessary photosensor active area is reduced dramatically. For our simulations we used a C++ based non-sequential ray tracing library.

In May 2015 the first prototype was installed into the camera of MAGIC 1. It is included into the regular readout electronics (see figure 2 of attached pdf) and operated together with the PMTs during data taking to provide data for a performance and long term study.

Plenary 5 / 13

Construction and tests of an in-beam PET-like detector for hadrontherapy beam ballistic control.

Authors: Arnaud Rozes¹; Christophe Insa¹; Daniel Christophe Lambert¹; Franck Martin²; Gerard Montarou³; Loïc Lestand⁴; Magali Magne¹; Robert Chadelas¹

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We present the electronics, the construction and the first results obtained with a detector, called LAPD for Large Area Pixelized Detector. The LAPD is dedicated to the beam ballistic control in the context of hadrontherapy, using in-beam and real time detection of secondary particles emitted during the irradiation of the patient. These particles could be high energy photons (γ prompt), or charged particles like protons, or 511 keV γ-ray photons from the annihilation of a positron issued from the β⁺ emitters induced in the patient tissues along the beam path. The LAPD detector focuses on these 511 keV γ and is similar to a conventional PET (Positron Emission Tomography) camera. Nevertheless, there are some specific constraints, compared to conventional PET, to take into account when trying to use 511 keV γ from positron annihilations for the ballistic control in hadrontherapy, such as the low β⁺ activity, the short lives isotopes, the isotope diffusion through the patient tissues, and the large γ prompt background. Specific electronics based on Switch Capacitor Array (DRS 4) for the digitization and on the μTCA standard for the data acquisition system have been developed in order to acquire data with a minimum dead time. This detector has been partially tested in beam at HIT, and has also been characterized using FDG sources at the cancer therapy center of Clermont-Ferrand, and some preliminary results will be shown.

primary experiment:

hadrontherapy, PET

Summary:
The detector is made of two half-rings of 120 channels each. Each channel consists of a 13x13x15 mm³ LYSO crystal glued to a PMT. The PMT signal is sent to an Analog Sampling Module (the ASM board). Steps of the construction, up to the final detector, are shown on the pictures below, as well as the ASM board.

![Image Description](https://example.com/image1.png)

This block houses 4 PMTs and a BGO crystal with Anger geometry from an old Siemens HR+ PET camera.

![Image Description](https://example.com/image2.png)

The block is dismounted, and the four PMTs are recuperated both for the LAPD and the absorber of the Compton camera. The BGO crystals are also recuperated, re-polished, to be used for the absorber, and in a second phase of the LAPD.

![Image Description](https://example.com/image3.png)

PMTs are then tested on different test benches. Here a CAD view of one of the test bench, where 7 blocks of 4 PMTs are simultaneously illuminated.

![Image Description](https://example.com/image4.png)

Accepted PMTs are then soldered to build new “quartets”.

![Image Description](https://example.com/image5.png)

...and these quartets are glued to their LYSO crystals.

![Image Description](https://example.com/image6.png)

After crystal wrapping, lines of 5 quartets (20 channels) are built...

![Image Description](https://example.com/image7.png)

And the full LAPD detector is made of 12 lines (two half ring of 6 lines), or 240 channels...

![Image Description](https://example.com/image8.png)

Each line being readout by an ASM board.

![Image Description](https://example.com/image9.png)

A two line system has been tested at the CPO facility (proton beam).

![Image Description](https://example.com/image10.png)

CAD view of the 4 lines system which has been tested at the GANIL facility (carbon ion beam), and at the HIT facility (carbon ion and proton beam).

**Figure 1:** enter image description here

This VME 6U board is based on the DRS4 chip technology (Switch Capacitor Array) from the Paul Sherrer Institute and was specially designed for the LAPD detector. This board receives up to 24 differential analog input signals, with maximum amplitude of 600 mV, digitized by 12 bits - 33 MHz ADC. The sampling rate varies between 1 and 5 GHz, for a maximum buffer size of 1024 samples. The first part of the talk will be devoted to the description of the detector and its electronics. The second part of the talk
describes the various trigger strategy, and the going-on upgrade of the acquisition system to a µTCA based technology, allowing data transfer through an optical link in place of the present VME + Ethernet solution. Then the selection of the coincident 511 keV γ which give the lines of response is discussed, and the reconstruction using an iterative MLEM algorithm is presented. An alternative solution for the reconstruction is also presented. In the last part of the talk, few results from an experiment with one third of the detector (last picture above) and using proton and carbon ion beams at the Heidelberg Ion-Beam Therapy Center in 2014 are also shown. The detector Coincidence Resolution Time and energy resolution, are given. Reconstruction results obtained with a high intensity FDG source at the cancer research center of Clermont-Ferrand in 2015 are also shown.

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Award Ceremony

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Summary Talk

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Closing

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Information from the Organisers

Board: 77 / 88

Test of microchannel plates in magnetic field up to 4.5 Tesla.

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MCP based devices are promising candidates for fast timing measurements in high energy physics experiments with high magnetic fields. Experimental setup based on superconductive solenoid with 120mm bore was created in BINP. Influence of the strong magnetic fields up to 4.5T on the MCP photomultiplier parameters was studied. Several types of photodetectors produced in Novosibirsk
were tested. Tested samples had MCP channel diameter from 3.5 to 10 μm. Dependences of time resolution and amplification on magnetic fields are presented.

Board: 36 / 334

Exploring the limits of time resolution in Cherenkov detection of electron-positron annihilation events

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High time resolution is becoming increasingly important for many applications in nuclear medicine (e.g., Time-of-Flight Positron Emission Tomography, TOF-PET) and high energy and nuclear physics applications (e.g., Positron Annihilation Spectroscopy, PALS). Present commercial TOF-PET systems based on inorganic scintillators provide coincidence resolving times (CRT) in the order of 325 ps – 400 ps. Time resolutions at the level of 100 ps would drastically increase the signal-to-noise ratio of the reconstructed images. Ultimate time resolutions of 10 ps would allow direct image reconstruction.

We have performed experimental studies on employing the Cherenkov effect for bypassing the relatively slow scintillation processes and thus improving the CRT. The measurements show competitive results with state-of-the-art TOF-PET-scintillators approaching CRTs towards 100 ps, with the potential to be improved even further. Reduced energy information is inherent to this method. Possible solutions to this problem will be discussed as well.

The experiments were done using the Philips Digital Photon Counter (DPC), which provides excellent timing properties and single photon counting capability. For understanding the overall CRT, the intrinsic time resolution of the DPC and its individual single photon avalanche diodes were investigated using a femtosecond laser. The measurement results and their interpretation using Monte Carlo simulation will also be presented.

**primary experiment:**

TOF-PET, PALS

Board: 21 / 191

Development of hole-type MPGD with funnel-capillary plate

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A new glass capillary plate (CP) has been developed for a hole-type micropattern gas detector (MPGD). The developed CP has a funnel structure (funnel-CP) fabricated by utilizing a special manufacturing process for a standard CP. The open to surface area ratio is 83% for the funnel-CP. The higher ratio is expected to improve the collection efficiency of primary electrons created by the radiation because most of the electrons can enter the multiplication region without terminating on the upper CP electrode. Moreover, the higher optical transparency is reliable for digital X-ray radiography and cold neutron imaging. The funnel-CP developed for the first prototype MPGD has a thickness of 300 μm and an effective diameter of 20 mm. The diameter of each hole is 50 μm. The metal electrodes are fabricated onto the two flat surfaces of a plate. Basic performance tests of the hole-type MPGD were carried out with X-ray beams for several gas mixtures based on Ne and Ar at 1 atm. A gain of up to $1 \times 10^4$ and an energy resolution of 16% were obtained for 6 keV X-rays. An excellent imaging capability was demonstrated by the X-ray image. We report on the characteristics of the novel hole-type MPGD with the funnel-CP.

**Summary:**

Please look at attached file (VCI2016-Ishizawa-V1-myu-corr.pdf)

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**Vacuum-Compatible, Ultra-Low Material Budget Micro Vertex Detector of the Compressed Baryonic Matter Experiment at FAIR.**

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The Compressed Baryonic Matter Experiment (CBM) is one of the core experiments of the future FAIR facility at Darmstadt/Germany. The fixed-target experiment will explore the phase diagram of strongly interacting matter in the regime of high net baryon densities with numerous probes, among them open charm. The Micro Vertex Detector (MVD) will contribute to the secondary vertex determination on a 10 μm scale, background rejection in dielectron spectroscopy and reconstruction of weak decays. The detector comprises four stations placed at 5, 10, 15 and 20 cm downstream the target and inside vacuum. The stations are populated with highly-granular Monolithic Active Pixel Sensors implemented in the 0.18 μm Jazz/Tower CMOS process also used for STAR/ALICE trackers. The future sensors feature a spatial resolution of $<5 \text{ μm}$, a non-ionizing radiation tolerance of $>10^{14} \text{ n}_{eq}/\text{cm}^2$, an ionizing radiation tolerance of 3 Mrad and a readout speed of few 10 μs/frame. This paper focuses on the next and the last step before a final detector assembly, that is the precursor of the third CBM-MVD station. It is currently under construction, hosting 15 CMOS sensors. After integrating the device, our research will focus on a full characterization regarding vacuum compatibility and thermal management as well as aspects regarding metrology. Hence, we will report on the first results of the MVD precursor characterization and the lessons learned for the production phase.
Design and properties of electromagnetic particle detectors of LHAASO-KM2A

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Large High Altitude Air Shower Observation (LHAASO) is a proposed cosmic ray experiment which will be built in Daocheng, Sichuan Province of China, 4400m in altitude. One square kilometer detector array (KM2A) is focused on the exploring for origin of cosmic ray and studying on the knee physics, etc, which consists of 5242 electromagnetic particle detectors (EDs) and 1146 muon detectors (MDs). ED array is designed to measure the densities and arrival times of their secondary particles in the extensive air showers (EASs). ED is plastic scintillation detector, in which a layer of 5mm-thick lead is installed to increase the detection efficiency of secondary gammas. The performances of ED have been studied, such as detection efficiency, time resolution. Especially, a wide dynamic particle density range from 1 to 10000 particles/m² is realized with the design of PMT divider.

Primary experiment:

Scintillating detector Summary:

ED is designed to measure the density and arrival times of particles in EAS. To reach the requirement for KM2A, properties should reach the limits showed in table 1.

And ED should be working in the plateau with altitude of 4300m, with low air pressure, high ultraviolet and wide annual variation of temperature for 20 years.

Fig.1 Shows the picture for ED. It is mainly consist of plastic scintillators, wavelength shifting fibers, power supply, electron system and PMT.

All the compositions are measured before deployment to guarantee the good performance of ED. And properties of ED are measured with the Cosmic Ray Reference System. Proper scintillators and WLS fibers are chosen to get enough photoelectrons with high quantum efficiency PMT, as shown in Fig.2. Gain and threshold of electron system are optimized to get a good time resolution, as shown in Fig.3. Contributions for time resolution from different compositions of ED are studied. Especially, Dual read-out of anode and dynode for PMT is applied to reach the wide dynamic range of ED, as shown in Fig.4.

A prototype of KM2A had been built up at YBJ in the summer of 2004, and the stability of ED is proved by the operation in the last year, as shown in Fig.5.

With the design, ED reach the requirement. And properties are studied comprehensively.

A Custom Real-Time Ultrasonic Instrument for Simultaneous Mixture and Flow Analysis of Binary Gases in the CERN ATLAS Experiment

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Custom ultrasonic instruments have been developed for simultaneous monitoring of binary gas mixture and flow in the ATLAS Inner Detector. Sound transit times are measured in opposite directions in flowing gas. Flow rate and sound velocity are respectively calculated from their difference and average. Gas composition is evaluated in real-time by comparison with a sound velocity/composition database, based on the direct dependence of sound velocity on component concentrations in a mixture at known temperature and pressure.

Five devices are integrated into the ATLAS Detector Control System. Three instruments monitor coolant leaks into N2 envelopes of the SCT and pixel detectors. Resolutions better than $5 \times 10^{-5}$ and $10^{-4}$ are respectively seen for C3F8 and CO2 leak concentrations in N2. A fourth instrument detects sub-percent levels of air ingress into the C3F8 condenser of the new thermosiphon coolant recirculator. Following extensive studies a fifth instrument was built as an angled sound path flowmeter to measure the high returning C3F8 vapour flux (~1.2 kg/s). A precision of < 2% F.S. for flows up to 15 m/s was demonstrated. This device can also monitor C3F8 and C2F6 concentrations to better than $3 \times 10^{-3}$. These blends allow for lower temperature silicon tracker operation.

The instrument has many potential applications where continuous binary gas composition measurement is required, including hydrocarbon and anaesthetic gas mixtures.

**Summary:**

Precision ultrasonic measurements can simultaneously determine gas flow and mixture composition, exploiting the phenomenon that sound velocity in a binary gas mixture at known temperature and pressure depends uniquely on the concentrations of the components. We have developed ultrasonic analyzers using custom electronics, based on Analog Devices ADuC and Microchip dsPIC33F microcontrollers. The instruments employ the Senscomp model 600 capacitative 50 kHz ultrasonic transducer, used in many robotics and sensing applications. Transducer HV bias (350V) is provided via inexpensive custom DC-DC converters. Synchronous with the emission of ultrasound "chirps", the electronics starts a multi-channel 40MHz transit time clock, which is stopped by the detection of above-threshold sound pulses. Time-stamped bidirectional transit times, vapour temperature and pressure are pipelined at up to 100Hz from FIFO memories over Ethernet using MODBUS over TCP/IP for rolling-average flow and mixture analysis in the supervisory computer.

The present C3F8 evaporative cooling system of the ATLAS silicon tracker will be replaced with a thermosiphon exploiting the hydrostatics of the 92m shaft to the experimental cavern. In addition to three instruments monitoring the silicon tracker volumes for coolant leaks, two further devices will form part of the control system of the thermosiphon recirculator, monitoring return flow from the silicon tracker and air ingress into the surface level condenser. **primary experiment:**

ATLAS

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**Novel applications and future perspectives of a fast diamond gamma-detector**
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For the first time, a diamond sensor was operated for the characterisation of a high average-intensity γ-ray beam. Data was collected for γ-beam energies between 2 and 7 MeV, at the HIγS facility of TUNL. The nanosecond-fast resolution of diamond detectors is exploited to distinguish bunches of γ-rays 16.8 ns apart. It allows a precise direct determination of the time-structure of the γ-beam. The strong potential of such a detector for precise absolute flux, position and polarisation measurements are exposed. It is thus shown that diamond detectors are a decisive and unique tool for the detailed characterisation of upcoming γ-sources, such as ELI-NP and HIγS-2, which will revolutionise the future of nuclear physics.

Board: 94 / 192

Ultra-cold neutron detector for the spectrometer of the neutron lifetime measurement

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The gas-filled detector of ultra cold neutrons (UCN) has been constructed for the spectrometer of the neutron lifetime measurements (PF2/MAM, ILL, France). It is intended for UCN flux monitoring in measurement cycles. The detector consists of six proportional counters which are grouped into two independent counting channels and placed in the single gas volume. The entrance window (Ø 290 mm) has been made of aluminum foil with a thickness of 100 μm to ensure minimum UCN losses. The force acting on the foil at working conditions is about 660 kg. Therefore, the special stainless steel grid has been placed in front of the foil to support it from the neutron guide side (vacuum). The gas mixture is selected to minimize the “wall effect” and to achieve UCN efficiency ε ≥ 80%. The final composition of the gas mixture has been optimized during detector tests under the real experiment conditions (background and UCN spectrum) at ILL reactor. The selected working gas mixture is 13 mBar 3He + 20 mBar CO2 + 1060 mBar Ar. The detector has been successfully tested and it is currently being used at the UCN spectrometer at ILL.

Board: 59 / 354

CVD Diamond Metallization and Characterization

Authors: Anastasiia Adelberg ; Arie Ruzin ; Dmitry Fraimovitch ; Sergey Marunko
The diamond crystals have several attractive properties for detector applications. The very wide bandgap enables high temperature operation with low leakage currents; the high carrier mobilities should enable fast and efficient charge collection; the material can be used for a combined conversion-detection of fast neutron (through $^{12}$C(n,$\alpha_0$)$^9$ reaction creating a recoil atom and alpha particle); and the atomic number of diamond is similar to that of human body providing simple dose monitoring in medical applications.

The main challenges for spectroscopy grade diamond are charge collection efficiency, polarization and long term stability. The choice of contact material, pre-treatment, and sputtering process details have shown to alter significantly the detector performance.

We compared three diamond substrate grades: polycrystalline, optical grade single crystal, and electronic grade single crystal. We investigated the impact of plasma treatment on the surface properties. Characterization of diamond substrate permittivity and losses indicate grade and crystallinity related, characteristic differences for frequencies in 1 KHz-1 MHz range. Substantial grade related variations were also observed in surface electrostatic characterization performed by contact potential difference (CPD) mode of an atomic force microscope. Study of conductivity variations with temperature reveal that bulk trap energy levels are also dependent on the crystal grade.

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**Low Energy Proton Detector Using APDs for the PENeLOPE Experiment**

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PENeLOPE is a neutron lifetime measurement experiment at the Forschungsrektor Muenchen II aiming to achieve a precision of 0.1 seconds. The detector for PENeLOPE consists of about 1250 Avalanche Photodiodes (APDs) with an total active area of 1225 cm$^2$. The detector and electronics will be operated at the high electrostatic potential of -30 kV, the magnetic field of 0.6 T. This includes shaper, preamplifier, ADC and FPGA stage. In addition the APDs will be operated at 77 Kelvin. The 1250 APDs are divided into 14 groups of 96 channels each including some spare. Each group is processed by one FPGA card which reads out the 12-bit ADC with 1MSps. Also a complete new firmware was developed for the detector including a self-triggering readout with continuous pedestal calculation and configurable signal detection. The data transmission and configuration is done via the Switched Enabling Protocol (SEP). It is a time-division multiplexing low layer protocol which provides determinate latency for time critical messages, IPBus and JTAG interfaces. The network has a n:1 topology and thereby reducing number of optical links.

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**Upgrade of the ATLAS hadronic calorimeter for high-luminosity LHC run**

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The Tile Calorimeter is the hadronic calorimeter covering the central region of the ATLAS detector at the Large Hadron Collider. It is a sampling calorimeter consisting of alternating thin steel plates and scintillating tiles. Wavelength shifting fibers coupled to the tiles collect the produced light and are read out by photomultiplier tubes. An analog sum of the processed signal of several photomultipliers serves as input to the first level of trigger. Photomultiplier signals are then digitized and stored on detector and are only transferred off detector once the first trigger acceptance has been confirmed. TileCal will undergo a major replacement of its on- and off-detector electronics for the high luminosity program of the LHC in 2024. All signals are digitized and then transferred directly to the off-detector electronics, where the signals are reconstructed, stored, and sent to the first level of trigger at a rate of 40 MHz. This will provide better precision of the calorimeter signals used by the trigger system and will allow the development of more complex trigger algorithms. Changes to the electronics will also contribute to the reliability and redundancy of the system. Three different front-end options are presently being investigated for the upgrade and will be chosen after extensive test beam studies. A hybrid demonstrator module has been developed. The demonstrator is undergoing extensive testing and is planned for insertion in ATLAS.

MONDO: a neutron tracker for particle therapy secondary emission fluxes measurements

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During Particle Therapy treatments the patient irradiation produce, among different types of secondary radiation, an abundant flux of neutrons that can release a significant dose far away from the tumor region. A precise measurement of their flux, energy and angle distributions is eagerly needed in order to improve the Treatment Planning Systems software and to properly take into account the risk of late complications in the whole body. The technical challenges posed by a neutron detector aiming for high detection efficiency and good backtracking precision will be addressed within the MONDO project, whose main goal is to develop a tracking detector targeting fast and ultrafast secondary neutrons. The neutron tracking principle is based on the reconstruction of two consequent elastic scattering interactions of a neutron with a target material. Reconstructing the recoiling protons it is hence possible to measure the energy and incoming direction of the neutron. Plastic scintillators will be used as scattering and detection media: the tracker is being developed as a matrix of squared scintillating fibers of $0.250 \text{ mm side}$. The light produced and collected in the fibers will be amplified using a triple GEM based image intensifier and acquired using CMOS Single Photon Avalanche Diode arrays. The principal detector goal will be the measurement of the neutron production yields, as a function of production angle and energy, using therapeutical beams.
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Current gamma-ray telescopes based on photon conversion to electron-positron pair, such as Fermi, use tungsten converters. They suffer of limited angular resolution at low energies, and their sensitivity drops below 1 GeV. The low multiple scattering in a gaseous detector gives access to higher angular resolution in the MeV-GeV range, and to the linear polarisation of the photons through the azimuthal angle of the electron-positron pair.

HARPO is an R&D program to characterize the operation of a TPC (Time Projection Chamber) as a high angular-resolution and sensitivity telescope and polarimeter for gamma-rays from cosmic sources. It represents a first step towards a future space instrument.

A 30cm cubic TPC demonstrator was built, and filled with 2bar argon based gas. It was put in a polarised gamma-ray beam at the NewSUBARU accelerator in Japan in November 2014. Data were taken at different photon energies from 1.7 MeV to 74 MeV, and with different polarisation configurations. The full experimental setup of the TPC and the photon beam will be described. First results from reconstructed conversion events will be shown.

The challenges and plans towards a balloon borne prototype will also be discussed. The TPC should be able to work autonomously with a very light environment. A lightweight system for gas circulation and purification was designed and tested for long term use. A topological trigger using the TPC signal with self-trigger electronics is under development.

primary experiment:
HARPO Summary:

We will show the first analysis result from measurements of polarised photons from 1.7 to 74 MeV at the NewSUBARU facility in Hyōgō, Japan, using the HARPO TPC.

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Development of an Event-driven SOI Pixel Detector for X-ray Astronomy - Improvement of an Intra-chip Readout Circuit for Low Noise Performance -

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We have been developing monolithic active pixel detectors, named “XRPIX” based on the silicon-on-insulator (SOI) pixel technology, for future X-ray astronomy satellite missions. Our objective is to replace X-ray Charge Coupled Devices (CCD), which are now standard detectors in the field. The XRPIX series offers good time resolution (~1 µs), fast readout time (~10 µs), and a wide energy range (0.5–40 keV) in addition to having imaging and spectroscopic capability comparable to CCDs. XRPIX contains a comparator circuit in each pixel for hit trigger (timing) and two-dimensional hit-pattern (position) outputs. Therefore, signals are read out only from selected pixels.

In our previous studies, we successfully demonstrated X-ray detection by the event-driven readout. We recently improved the X-ray spectral performance by introducing in-pixel charge-sensitive amplifier circuits and achieved an energy resolution of 320 eV (FWHM) for 5.9 keV X-rays with which Mn-K\(^{\alpha}\) and -K\(^{\beta}\) lines are resolved for the first time in the XRPIX series. We found that most of the readout noise can be attributed not to the sense-node but to the readout circuit. Thus, we designed a new prototype in which we modified the intra-chip readout circuits. In this presentation, we report on the recent development and evaluation results of the new device.

**primary experiment:**
X-ray Astronomy

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**easyPET: an innovative concept for an affordable tomographic system**

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Functional imaging is the state of the art in cancer diagnostics, monitoring of therapy effects and cancer drug development. Position Emission Tomography (PET), notably when combined with Computed Tomography (CT), has a recognized superiority over conventional imaging modalities. Cost and complexity are issues worth being considered as limiting factors in the adoption of PET technology.

The easyPET proposed here is an innovative concept, patented by Aveiro University, expected to reduce preclinical PET systems complexity and cost. It is based on pairs of scintillating crystals coupled to Silicon Photomultipliers (SiPMs) placed on a rotating mechanism with two degrees of freedom to cover the field-of-view of a conventional preclinical PET system. A prototype has been realized with a single detector pair as a demonstrator in 2D.

The paper reports the prototype qualification and optimization in terms of image contrast, sensitivity and spatial resolution. The encouraging results compared to the performances of commercially available systems motivate a feasibility study to produce a preclinical system with 3D imaging provided by multi-pair detectors.
**primary experiment:**

**Summary:**

Positron Emission Tomography (PET) is a powerful medical diagnostic tool capable of providing detailed functional information of physiological processes. PET technology plays a key role in detecting disease, studying its progression, evaluating the therapeutic response and accelerating the new drug development. The increasing demand for preclinical imaging studies leads to the production of dedicated small dimension PET systems.

The high spatial resolution required by these kind of systems (ideally under 1 mm FWHM, with respect to 4-6 mm FWHM of human PET) is achieved by employing smaller cross section crystals. A consequent drawback is the higher probability of having oblique photons penetrating neighbouring crystals and causing higher uncertainty in the determination of the interaction point. This effect, known as parallax error, results in a non-uniform position resolution. Several methods have been proposed to determine the depth of interaction (DOI) in crystals, improving spatial resolution despite of increasing system complexity and cost.

The easyPET concept (protected under a patent filed by Aveiro University) can be illustrated referring to a 2D model, shown in Figure 1. It consists of a pair of detector modules aligned on a mechanical system which executes two type of independent movements around the target volume. The pair of detectors rotates around the system center by moving along a circumference in steps of amplitude $\theta$, and at each instant centre of rotation performs a scan of range $\alpha$. A prototype with a 60 mm field-of-view was designed, engineered and commissioned (Figure 2). Silicon Photomultipliers represent a robust and compact choice to convert the light from scintillating crystals into electrical signals. Then a fast electronic readout allows to select coincident signals from the same decay event and to reconstruct in real-time the radioactive source spatial distribution in a plane.

The innovative system acquisition method leads to the following main advantages:

- reduced system complexity and cost thanks to the small number of detecting units,
- intrinsic immunity to scattered radiation and acollinear photon emission,
- intrinsic elimination of the parallax error without applying DOI measurements.

As a result, easyPET is capable to provide a uniform spatial resolution of $1.45\pm0.4$ mm FWHM, comparable with commercially available preclinical systems. The absence of effects degradating the image allows to decrease the detection threshold. In fact, existing apparatus have to discard Compton scattering events by selecting photons above 250 KeV, while with the easyPET a cut at 50 KeV is enough to obtain a high contrast image (Figure 3). A significant task is the evaluation of the system performances in terms of image quality with respect to exposure time. It is to be determined if the higher energy range adopted is able to compensate the reduced geometrical acceptance.

The presentation will deal about the project overview, the prototype qualification resuts, the performances comparison with state-of-the-art systems and the outlook regarding a feasibility study to employ multi-pair detectors and achieve 3D imaging functionality.

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**Development of High Temperature, Radiation Hard Detectors Based on Diamond.**

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Single crystal CVD diamond has many desirable properties compared to current, well developed, detector materials; exceptional radiation hardness and physical hardness, chemical inertness, Low Z (close to human tissue, good for dosimetry), wide bandgap (High temperature operation with lower noise, solar blind), intrinsic pathway to fast neutron detection through $^{12}$C($n,α)^{9}$Be reaction. However effective exploitation of these properties requires development of a suitable metallisation scheme to give stable contacts for high temperature applications. To utilise the available processing techniques to optimise sensor response through geometry and conversion media configurations, and to interpret experimental data, a reliable model is also required. Monte Carlo simulations of a diamond based detector have been developed using MCNP6 and FLUKA2011. These assess the performance in terms of spectral response and overall efficiency as a function of the detector and converter geometry. Sensors have been fabricated with varying metallisation schemes at Brunel University London and Micron Semiconductor Limited and subject to radiation tests including fast neutrons at SLB. Present results indicate that viable metallisation schemes for high temperature contacts have been developed and present modelling results, supported by preliminary data from partners indicate simulations provide a reasonable representation of detector response.

Controlling kilometer-scale interferometric detectors for gravitational wave astronomy

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The most promising gravitational waves (GW) detectors to date are kilometric Michelson interferometers with additional recycling Fabry-Perot cavities to enhance their sensitivity, and all the mirrors suspended. The second generation aims for the first direct detection of GW, and in order to do so, a sensitivity improvement of one order of magnitude is foreseen ($\sim 10^{-19}$ m rms). Several upgrades are underway, and among them the addition of a new optical cavity, which introduces new couplings, increasing the complexity to control the instrument.

A new technique, based on the use of auxiliary lasers, has been developed in order to bring the interferometer to its working point (all the cavities on their resonance) in an adiabatic way. Not only simulations are required, but also experimental tests that can be made in facilities like CALVA, located at Laboratoire de l’Accelerateur Lineaire in Orsay, and which consists of two coupled suspended cavities of 50 and 5m respectively, similar to the ones in Advanced Virgo (AdV).

We will review all the details of the implementation of this technique in AdV, being the propagation of a stable laser through a 3-km optical fiber one of the most problematic. A new technique of active phase noise cancellation based on the use of Electro Optical Modulators has been developed, and a first prototype has been successfully tested.

primary experiment: VIRGO

Summary:

The Virgo and LIGO gravitational wave detectors are kilometer-scale Michelson interferometer. The effect of a gravitational wave (GW) on free-falling masses (suspended mirrors) is a change on the distance ($\delta L$) that is proportional to the amplitude of the GW ($h$), $\delta L \propto h \cdot L$. With the interferometer set on dark fringe, an extra $\delta L$ will let some light pass to the detection point or Asymmetric port (ASY), that can be detected. However, the $\delta L$ foreseen to be measured are of the order of $\sim 10^{-19}$ m rms for a bandwidth of 100Hz. In terms of astrophysical sources, such a sensitivity will allow the detection of black hole binary inspirals of $30 M\odot$ up to 985 Mpc.

This performance can not be achieved by a simple interferometer, and in order to improve the sensitivity, some resonant optical cavities were added: two Fabry-Perot cavities, one in each arm, increasing the light pathlength, and an extra mirror (Power Recycling) between the laser source and the beam-splitter increasing the circulating power. This configuration was used by Virgo and LIGO on their first runs,
but to reach the performances that we just mentioned, a new mirror (Signal Recycling) has been added in the Advanced version of the detectors. It will be placed at the ASY and it will recirculate the signal produced by a GW.

Problems arise when one wants to acquire and control the interferometer, that is, to lock all the cavities on their resonance point and the interferometer on the dark fringe for as long as possible. The addition of the two recycling cavities causes the degrees of freedom to couple, making the global control of the interferometer an enormous challenge. The technique used to lock the cavities is called Pound-Drever-Hall (PDH) and it consists in adding Radio Frequency sidebands to the laser and demodulating the detected power. The resulting signal is linear around the resonance, and therefore can be used as an error signal, although outside this region it does not give any reliable information. The width of the linear region is related to the finesse of the optical cavity: the higher is the finesse, the steeper is the signal, allowing a more precise control of the correct position of the mirrors, although the linear range is smaller. This means that for the precision required by Advanced Virgo (AdV), the finesse needed is so high that, starting from free-swinging mirrors, the linear region is crossed too fast to allow the servo loops to control the cavities.

Therefore, a new locking technique has been developed, using auxiliary lasers (green) with a different wavelength from the main laser (infrared), and for which the mirror reflectivity requirements are relaxed, leading to a lower finesse at that wavelength. This allows a straight lock that cools down the mirrors around the resonance point before enabling the more precise control provided by the main laser. The strategy is to lock first the arm cavities using the auxiliary laser and then move them off-resonance in a controlled way in order to avoid interferences with the error signals in the other cavities composing the Central Interferometer (CITF). Then, the CITF can be locked with a technique already well-tested (third harmonic or “3f”) and once this is done, the arms can be brought to resonance.

The details of the implementation in AdV of this new technique are under study, in a test facility called CALVA, located at the Laboratoire de l’Accélérateur Linéaire. It consists of two coupled optical suspended cavities of 50 and 5m respectively, with the same dynamic and finesse as the AdV cavities. One of the main challenges is the transport of the main laser, already stabilized in frequency, through an optical fiber of 3km, in order to use it as a frequency reference for the auxiliary laser, which will be placed at the end of the arms. In order to avoid the laser to be spoiled by the addition of phase noise during its propagation, a new technique of active noise cancellation based on the use of Electro Optical Modulators has been developed and a first prototype has been successfully tested at CALVA.

High temperature dependence of charge carrier properties in CVD diamond

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Synthetic diamond is well suited in particle detector applications for its high radiation tolerance and fast carrier mobility. It is possible to operate a diamond detector at high temperature expected in extremely harsh radiation environments like future high luminosity beams and reactors. Therefore it is necessary to characterize and understand its electronic properties at high temperature. Several competing effects are expected to modify the charge collection efficiency and carrier mobilities in diamond. Deep levels in the band gap can act as trapping centers when the carrier density is high (important when intense radiation energy is deposited), and as generation centers when thermal excitations are enhanced at high temperature. Shallow levels in the band gap can affect carrier mobility and signal rise time through frequent trapping and de-trapping of carriers. We present signal time profile measurements using the TCT technique and charge collection efficiency from MIP energy deposition in high purity single crystal CVD diamond at high temperature. These can be used to resolve the role of traps in the bandgap of diamond and understand its electronic properties at high temperature.
Fabrication and Characterization of Rectangular Strontium Iodide Scintillator Coupled to TSV-MPPC array

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Europium doped Strontium Iodide (SrI₂(Eu)) is a promising scintillation detector for use in radiation detection because of its high light output (80000 - 110000 photons per MeV), excellent energy resolution around 3 % and low background radiation. These good characteristics make it promising for the gamma-ray imaging in the environmental applications as an alternative of Sodium Iodide (NaI(Tl)). For fabricating a compact radiation detectors, the coupling to solid-state photosensors, such as SiPM, is necessary, which has typically a square shape. The rectangular SrI₂ scintillators (25.4 x 25.4 x 10 mm) are fabricated with "Liquinert" process for removal of water, and evaluated with Photomultiplier and TSV-type MPPC. The initial results shows the excellent energy resolution around 3.6 % at 662 keV with PMT. The detail results coupled to TSV-MPPC with different temperature and shaping time will be shown in the conference.

Timepix3 as X-ray detector for time resolved synchrotron experiments

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Time resolved experiments are becoming more and more important in research carried out at synchrotrons. Timepix3 is a "data driven" ASIC that place a time stamp for every event. The resolution of the time stamp is 1.5625 ns. It enables accessing the nanosecond regime potentially revolutionizing time resolved experiments at synchrotron facilities. The Timepix3 ASIC flip chip bonded to a 300 µm thick Si detector.

We will report the results of the characterization of Timepix3 with synchrotron X-ray beam with particular reference to the timing characteristics.

In the DLS hybrid mode of operation, the electron beam circulating in the storage ring is made out of 686 contiguous bunches spaced 2 ns apart then a gap of 500 ns. In the middle of the gap it was placed an isolated bunch. Since the FWHM of the bunch is of the order of 50 ps when the data acquisition was triggered by the machine clock, the isolated bunch becomes an ideal tool to determine the actual time resolution of the detector. Histograms of the time of arrival of the photons were built leading to an estimation of the time resolution of the isolated bunch. When the beam was stopped down to 20 µm x 20 µm and impinging in the centre of the pixel it was obtained a time resolution of 10.21 ns for 20 keV photons, 20% signal threshold and 110 V bias voltage. A time resolution of 8.07 ns for 12 keV photons and 30% signal threshold is achieved when increasing the bias voltage to 350 V.
CMS Alignment and Calibration

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Determination of alignment and calibration constants plays one of the central role in the operation of the CMS experiment. Prompt and accurate alignment and calibration of the CMS components are crucial to achieve optimal performance of the detector and to allow the CMS physics program to reach its goals. Sophisticated algorithms and workflows are developed and routinely employed to align and calibrate various systems of the CMS detector. Also dedicated express streams of promptly reconstructed data events with reduced content have been deployed to achieve fast access to data samples after collection and their efficient processing in alignment and calibration workflows. We discuss details of the alignment and calibration procedures for all CMS components, recent results of the CMS operation at 13 TeV and achieved performance of the CMS detector for physics analyses. We also present plans for upgrade and future development.

Experience from design, prototyping and production of a DC-DC conversion powering scheme for the CMS Phase-1 Pixel Upgrade

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The CMS pixel detector will be exchanged during the technical stop 2016/2017. To allow the new pixel detector to be powered with the legacy cable plant and power supplies, a novel powering scheme based on DC-DC conversion is employed. After the successful conclusion of an extensive development and prototyping phase, mass production of 1800 DC-DC converters as well as motherboards and other power PCBs has started and will be finalized by the end of 2015. This contribution will summarize the lessons learned from the development of the power system for the Phase-1 pixel detector, and summarize the experience from the production phase.

The wide-aperture gamma-ray telescope TAIGA-HiSCORE in the Tunka Valley: design, composition and commissioning.

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The new TAIGA-HiSCORE non-imaging Cherenkov array aims to detect air showers induced by gamma rays above 30 TeV and to study cosmic ray above 100 TeV. TAIGA-HiSCORE represents an array of wide field of view (0.6 sr) integrating air Cherenkov detector stations, placed of 100 m from each other. They cover an area of initially ~ 0.25 km2 (array prototype) to ~ 5 km2 at the final phase of the experiment. Each station includes 4 neighbored PMTs with 20 or 25 cm diameter, equipped with light guides shaped as Winstone cone. We describe the design, specifications of the read-out, DAQ and control and monitoring systems of the array. The present
28 detector stations of the TAIGA-HiSCORE engineering setup are in operation since September 2015. Preliminary results of data taking are presented.

**primary experiment:**

**TAIGA-HiSCORE array**

Summary:

The gamma-ray detection beyond 10 TeV is extremely important for the search for the most energetic Galactic accelerators. The energy spectra of most known gamma-ray sources only reach up to a few tens of TeV and to 80 TeV from the Crab Nebula. Uncovering spectral shape of the gamma-ray sources up to few 100 TeV could answer the question whether some of these objects are cosmic ray pevatrons, i.e. Galactic PeV accelerators. Sensitive observations (an integral flux detection sensitivity for point sources of about $10^{-12}$ erg cm$^{-2}$ s$^{-1}$) in this (and beyond) energy range require very large effective detector areas.

The TAIGA-HiSCORE array is part of the gamma-ray observatory TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy). The TAIGA is currently under construction in the Tunka valley, about 50 km from Lake Baikal in Siberia, Russia. The key advantage of the TAIGA will be the hybrid detection of EAS Cherenkov radiation by the wide-angle detector stations of the TAIGA-HiSCORE array and by the Imaging Air Cherenkov Telescopes of the TAIGA-IACT array.

The TAIGA-HiSCORE installation is an array of the detector stations with spacing 100 m, equipped with four photomultipliers with a light-collecting Winston cone of 30 degree half-opening angle. Four photomultipliers are used for to increase the effective area of registration of Cherenkov light from air showers and reducing fluctuations of the background night sky. The principle of the TAIGA-HiSCORE array operation is based on the sampling of the Cherenkov light front of air showers. The detector stations measure Cerenkov pulse form and, in particular, the light amplitudes and its arrival time differences over a distance of few hundred meters from the shower core.

The TAIGA-HiSCORE array is intended to study gamma-quanta fluxes from the known local sources (first objective - Crab nebula) and unknown new sources at the energies exceeding 30 TeV. The present 28 detector stations of the TAIGA-HiSCORE setup are in operation since September 2015. This array covers 0.25 km$^2$. Stations are tilt at 250 to the south (see photo).

The control and monitoring of each detector is performed using the controller designed on the basis of microcontroller PIC24FJ Microchip. The main functions of the controller: the opening and closing of the lid and control of its position, heating of input plexiglas, monitoring of supply voltage, monitoring of high-voltage power supply and PMT anode current, flash-light overload protection. The control and monitoring system uses the modules Xbee-PRO S2B working by protocol ZigBee for wireless communication to manage controllers. The heating controller maintains a stable temperature for the DAQ in the electronics station.

Optical stations are linked to the central DAQ by the optical communication lines. The readout system consists of the following elements: digitization and communication system for the detection station, central DAQ, time synchronization system and software. The main DAQ-board is designed on the basis of DRS-4 chip and FPGA Xilinx Spartan-6. The time synchronization accuracy of the events is 0.2 ns. The time step of PMT signals digitization is 0.5 ns.

The reconstruction of the air shower events by TAIGA-HiSCORE data has an accuracy of: arrival direction ~ 0.1°, shower core ~ 6 m, primary energy ~ 15% and shower maximum height ~ 25 g/cm$^2$.

**Characterization of Neutral Trapped Antihydrogen in the ALPHA Experiment**

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The Antihydrogen Laser Physics Apparatus (ALPHA) experiment at CERN is designed to carry out detailed studies of the properties of neutral antihydrogen atoms. A comparison of the properties of hydrogen and antihydrogen allows a sensitive probe of fundamental symmetries in Nature. Recent achievements have paved the way for precision measurements. Experiments are performed through the adaption of well documented methods in atomic physics to the challenging environment of neutral antimatter handling.

ALPHA has recently reached several important milestones en route to precision measurements. These include trapping of cold antihydrogens, long confinement, and the first spectroscopic measurement. Methods to study gravitational effects have been demonstrated and the charge neutrality of trapped antihydrogen has also been tested to high precision.

A unique Silicon Vertex Detector (SVD) surrounding the neutral atom trap is used for the identification of antihydrogen annihilation. The SVD provides diagnostics of the antiproton plasma time evolution and, most importantly, individual antihydrogen annihilation event vertex locations. Characteristics of the SVD and analytical methods applied to the data produced by the SVD in different experimental setups, will be presented. In addition, an overview of the ALPHA physics goals and current progress will be reviewed.

GaAs detectors with an ultra-thin Schottky contact for spectrometry of charged particles

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Radiation damage-resistant semiconductor detectors are needed in experiments on measurements of cross-sections of nuclear reactions in the interactions of heavy ions with energies close to the Coulomb barrier for astrophysical applications. The low yield of such nuclear reactions is accompanied by enormous Rutherford scattering cross-sections that can quickly lead to failure of the conventional Si detectors. This work reports results of the development and characterization of detectors based on HP GaAs epilayers with an ultra-thin Schottky contact for such applications.

42 μm-thick GaAs epilayers with the carrier concentration of $3 \cdot 10^{11} \text{cm}^{-3}$ grown by chloride vapor phase epitaxy were used for fabrication of the detectors. An ultra-thin Pt Schottky contact (12 nm) to the GaAs epilayers was formed by the ion-plasma sputtering method.

Spectrometric characteristics of the detectors were measured using α-particle sources. The measured energy resolution (FWHM) of 13.2 keV (on the 5.499 MeV line of $^{238}$Pu) was at the level of the best Si detectors. Operating characteristics of the fabricated devices were examined. On the basis of the carried out measurements and simulation it is shown that the FWHM of the detector is close to its limit for VPE GaAs detectors and is mainly determined by the fluctuation in the number of collected electron-hole pairs.

A survey on GEM-based readouts and gas mixtures for optical TPCs

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We will survey the properties of optical gaseous TPCs, discussing the present sensitivity limits and prospects for calorimetry and tracking. Primary and secondary scintillation in both pure noble gases and mixtures will be discussed in detail, and a new set of systematic data for few relevant mixtures will be presented, taken with the help of a recently commissioned general-purpose optical TPC at the GDD group at CERN. Concerning the generation of secondary scintillation, particular emphasis will be placed on GEMs and micro-meshes, on the modelling of the scintillation process and on possible applications in fundamental and applied research.

primary experiment: RD51

Summary:

Gaseous time projection chambers with optical readout (OTPC) are flourishing. Developed in Charpak’s group at CERN in the late 80’s, they are finding niches of application in both fundamental and applied research. From the original work relying on UV scintillation (TEA, TMA, TMAE, N2) coupled to image intensifiers, going through IR-imaging with poorly-quenched Ar-CO2 mixtures, until the nowadays extended usage of N2 and CF4 scintillation in the visible and near-visible range, experimenters have exploited the avalanche scintillation of common additives to produce 3D-images, benefiting from the excellent cost/channel ratio and the performance of industry-grade light-imaging devices (e.g., CCD, CMOS cameras) coupled to fast photo-multipliers. Furthermore, the rapid rise of SiPMs and the consolidation of solid wavelength-shifters (e.g., TPB), has recently allowed to produce 3D images of MeV-electron tracks with sub-cm position resolution, by using the comparatively fainter electroluminescence signal of pure Xenon. At present, optical TPCs are proving instrumental in studies of exceedingly rare nuclear processes, chiefly pp and ββ decays. In applied research, their popularity is increasing either as electron-tracking γ-cameras, X-ray or thermal neutron detectors. Light imaging is indeed one of the best practical ways to perform quality assurance of micro-pattern gas detectors, and its potential to perform nanodosimetry as well as avalanche studies has been recently brought into focus.

Unfortunately, and despite the reasonably good understanding of the VUV-scintillation in pure noble gases, very little is known about the fundamental processes that determine the light production characteristics in admixtures commonly used in gaseous OTPCs: scintillation yield, wavelength-shifting and light-quenching probability, and recombination light. Potentially, the case of mixtures seems to be of much higher technological relevance than the relatively constrained case of pure noble gases (and it is found much more often in practice), however it remains as a comparatively green field in view of the associated complexity, with an extremely modest grand-total of ~5 scintillating molecules used in practical applications.

In this talk we will revisit the state-of-the-art of gaseous optical TPCs and will present new systematic measurements on light yields (primary and secondary) together with tracking performances and sensitivity for various gas mixtures, obtained in a recently commissioned optical TPC at the GDD lab at CERN (Fig.1). We will resort, exemplarily, to measurements performed both under uniform fields and with the GEM technology, the latter allowing to comfortably obtain very narrow depths of field and scintillation yields above 20000 ph per primary electron, without signs of instability or degradation. Simulations of the primary and secondary scintillation will be presented, incorporating molecular energy-transfer models when available, and focusing on the light emission in 3 characteristic bands:
i) Emission in the range 350-750nm due to avalanche scintillation in noble gas–based mixtures, with special attention to CF4 and N2 (covering the natural range of CCDs, SiPMs and APDs). This currently represents a fairly general-purpose emission that finds an easy and wide-spread use (Fig.2).

ii) The VUV-scintillation in noble gases (<200nm) in the presence of minute sub-% concentrations of additives yet capable of offering enough electron-cooling and low diffusion (CO2, CF4, CH4); i.e. the natural range of CsI-coated gaseous photo-multipliers (GPMs). TPCs operating in these conditions can approach the Fano factor in gas while offering very good tracking prospects. As an example, the (tolerable) impact of 0.5-1% CH4 on the energy resolution is shown in Fig.2, together with simulations. In those conditions, diffusion is reduced by a factor x10 relative to pure Xe.

iii) UV scintillation (200-350nm) with special attention to TMA (i.e., the natural range of conventional vacuum PMTs and MCPs), due to its relevance in rare event searches. The recently measured wavelength shifting efficiency of Xe-TMA is given in Fig. 3, overlying a simple model based on molecular transfer and making use of the previously measured TMA self-quenching rate.

A setup to measure ion mobility in Argon and Neon based gas mixtures

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To better understand the performance of different gas mixtures in gaseous detectors it is crucial to know the ion drift velocity $v_{Drift}$ in these gases. E.g. ions moving through the gas volume can create space charges and hence field distortions inside the detector. Knowing $v_{Drift}$ (or the ion mobility $\mu$) as function of the electrical field allows to simulate and correct for such distortions.

In order to measure $\mu$ a small gaseous detector utilising Gas Electron Multipliers (GEM foils) was constructed. A stack of three foils provides the gas amplification in this detector. At a distance $d_{Drift}$ above the GEM stack a wire grid is mounted, followed by the drift cathode. In addition, the drift volume is equipped with a field cage. The gap between grid and cathode is used to accelerate ions, which were produced in the GEM stack and drifted towards the drift cathode. Then the ion signal is read out either at the wire grid or at the cathode itself. In order to measure $v_{Drift}$ the time difference between the electron signal on the pad plane and the ion signal is measured. Together with $d_{Drift}$ the velocity of the ions - as well as the mobility - as function of the electrical field can be calculated.

During the construction of the detector different drift distances were examined as well as different ways of accelerating the ions. Several measurements were done with Ar and Ne based gas mixtures.

primary experiment: ALICE

Summary:

Introduction

The performance of gaseous detectors depends on the parameters of the gas mixture used. One of these parameters is the ion mobility $\mu$ which determines the drift velocity $v_{Drift}$ together with the drift field. A building up of space charge due to the slow ions (compared to the electrons) can impose a great challenge for e.g Time Projection Chambers running at high interaction rates and particle multiplicities, as will be the case of the upgraded ALICE TPC. Hence the knowledge of the exact ion drift velocity as function of the electric field (or $\mu$) allows to simulate such space charges. Then it is possible to correct for them or to apply measures hardware-wise in order to reduce the amount of ions drifting through the detector.

Idea of measurement
With the detector we constructed, the measurement proceeds according to following concept: 1) Some ionising radiation passes through the detector. 2) The primary ionisation is amplified by the gas amplification stage and hence a signal on the anode is observed. 3) This signal triggers the measurement on the drift cathode: At a given time \( T \) an ion signal will appear originating from the ions produced during the gas amplification. Based on the measurement of \( T \), \( \mu_{\text{drift}} \) can be calculated.

Detector setup

Since the expected amplitude of the ion signal is several orders of magnitude lower than the electron signal on the anode, a very low noise on the drift cathode is required. In addition, the signal is expected to have a width on the order of \( O(\text{ms}) \), so the preamplifier has to be chosen with special care.

Gas amplification stage

In the detector a stack of three \( 10 \times 10 \text{ cm}^2 \) Gas Electron Multipliers (GEMs) is utilised to amplify the primary charges. If stacks of GEM foils are used instead of single foils it is possible to operate each foil at a moderate \( U_{\text{GEM}} \) and achieve high gains as well as a good operational stability.

Field cage and drift cathode readout

After the gas amplification stage follows the drift volume, which is enclosed by a Field Cage (FC) with 8 field strips (strip distance: 3 mm, strip height: 9 mm) and with the drift cathode on the top (drift distance: 10.2 cm). In order to separate the strips from the walls they are suspended on 4 ceramic rods.

The last strip’s potential is matched to the highest potential of the gas amplification stage by an external resistor. To minimize the current through the resistor chain, high resistors of 200 M\( \Omega \) each were used. At some distance to the drift cathode a wire grid (or GEM) is mounted inside the drift volume. The gap between the grid and the cathode is used to accelerate ions to induce a higher signal amplitude. Hence a higher electric field as compared to the drift field has to be applied here. To reach the desired electric fields the corresponding HV elements have to be stable up to voltages as high as 10 kVm. To reach even higher drift fields a special structure can be mounted inside the FC on top of the GEM stack, which incorporates a mesh and a wire grid. This allows to reach a higher drift field by shortening the drift distance. In case this structure is used the grid takes over the role of the drift cathode. Furthermore, only the potentials on the field strips within the range of this structure are tuned to match the drift field. Since the cathode with the highest absolute voltage is used to read out the ion signal, the decoupling circuit has to be chosen carefully in order not to lose the signal partially.

Sets of measurements

With this setup \( \mu \) was measured for different drift length and drift field configurations. Several Neon and Argon based gas mixtures were examined as well as the effect of \( \text{O}_2 \) and \( \text{H}_2\text{O} \) contaminations.

Board: 97 / 351

**Linearity performance of small-cell SiPMs for prompt gamma imaging application**

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In this work, we present the linearity characterization of the ultra-high density SiPM technology (RGB UHD), recently developed at Fondazione Bruno Kessler (FBK). This technology features a very small cell pitch ranging from 7.5 to 12.5 \( \mu \text{m} \) giving a cell density from 20530 to 7400 cells/mm\(^2\). The high SPAD density is very important to improve the linearity of the SiPM in applications such as high-energy Gamma-ray spectroscopy and prompt gamma imaging (PGI) in proton therapy. Moreover,
the small cell size provides a ultra-fast recovery time, in the order of a few of ns for the smallest cells. A short recovery time reduces pile-up in high-rate application such as PGI. Using a 22Na source, we have measured a non-linearity (NL) of less than 0.5% at 1.274 MeV, for all the cell sizes. In this work, we will present the measurement of the NL of the UHD SiPMs for the PGI application, using a pulsed light source to simulate an energy range from 0.5 MeV to 20 MeV.

A 16-ch module for thermal neutron detection using ZnS:6LiF scintillators with embedded WLS fibers coupled to SiPMs and its dedicated readout electronics

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In this contribution, we will present the design of a 16-channel module for a 1D position-sensitive detection of thermal neutrons and measurements performed at the spallation neutron source at PSI. This module could constitute a building block for large detectors in neutron scattering experiments. Its sensitive volume consists of 16 individual ZnS:6LiF bars optically isolated from each other and placed side by side without gap. The bars are 2.5-mm wide, 2.8-mm thick, and 200-mm long. Each bar contains 12 homogeneously distributed embedded WLS fibers for collecting the scintillation light and the fiber bundle is coupled to a silicon photomultiplier (SiPM). This innovative structure with embedded WLS fibers provides both a high neutron absorption efficiency and a high scintillation light collection which is necessary to get a high trigger efficiency. The absence of optical crosstalk between the detection channels and their individual readout with SiPMs allow to reach the highest possible count rate capability. The count rate capability and the channel-to-channel uniformity of the 16-ch module that we measured at the spallation neutron source at PSI will be presented. A 16-channel FPGA-based readout board has been implemented with a dedicated digital signal processing algorithm. The algorithm, the readout board as well as the measurements of the trigger efficiency of the 16-channel detection module with this readout will be presented.

The Calorimeter System of the new muon g-2 experiment at Fermilab

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The electromagnetic calorimeter for the new muon g-2 experiment at Fermilab will consist of arrays of PbF2 Cherenkov crystals read out by large-area silicon photo-multiplier (SiPM) sensors. We report here the requirements for this system, the achieved solution and the results obtained from a test beam using 2.0–4.5 GeV electrons with a 28-element prototype array.

Validation of a highly integrated PET readout system scalable to several 10'000 channels
SiPMs allow a dramatically improvement of PET performance because SiPMs are intrinsically faster than PMTs and because SiPMs can easily be subdivided in a large number of small independent photodetector pixels. The good timing performance of SiPMs will result in better effective sensitivity. The small and independent photodetector pixels allow using one-to-one coupling between a SiPM pixel and a LYSO crystal. This will result in significant improvement of the spatial resolution compared to PMT base systems, where some form of crystal encoding must be used to identify the LYSO crystal where the interaction occurred.

A whole body PET scanner will typically have 30'000 LYSO crystals measuring 4x4x20mm. To take advantage of SiPMs in PET applications, it is mandatory to have highly integrated electronics readout. We have developed the 64 channel TOFPET1 ASIC for this purpose. It has 64 independent readout channels without multiplexing. The output is only digital, 80 bits per event. The rest of the electronics only has to transfer the data to the computer. The coincidence sorting is done in firmware. The readout electronics will scale to many tens of thousands of channels.

The electronics will be described, and we will present the performance of the readout in a test PET scanner setup with 2'048 channels.

We will report on rate performance, energy resolution, spatial resolution and time resolution of the system. Images with phantoms will also be presented.

**primary experiment:**

PETsys electronics, ClearPEM  
**Summary:**

The TOFPET1 ASIC used in PETsys front-end system has 64 channels and is optimized for timing with 25/50 ps least count. It uses a low threshold for timing and a high threshold for accepting the event. Both thresholds are separately configurable for each channel. Every time one of the 64 channels exceeds the high threshold a record is created giving the channel number, the time and the amplitude of the event, encoded in 80 bits. Activity in one channel does not cause any dead-time on one of the other channels. The dead time is negligible up to 100 kcps/channel.

The PETsys SiPM Readout System comprises three types of readout and data acquisition boards - FEB/A, FEB/D and DAQ boards - which together allow to assemble a complete scalable data acquisition system with tens of thousands SiPM channels for Time Of Flight PET applications.

The Front End Board type A (FEB/A 0808) is a low power, low noise SiPM readout board. The board is optimised for being used together with MPPC arrays and LYSO scintillating crystals. Each detector module measures 52.58 x 26.04 mm. The board integrates two TOF ASICs each reading one Hamamatsu S12642-0808PB-50 MPPC 8x8 pixel array. The board will also read analog SiPMs from most other vendors.

The Front End Board type D (FEB/D) is a carrier of the FEB/A readout boards. It collects the data from the ASICs and transfers them to the DAQ board. The FEB/D also provides power to the ASICs and MPPC arrays. The FEB/D board measures 105.7x105.7 mm. Up to eight FEB/A boards can be connected to the FEB/D, using either direct board-to-board connectors, or using flexible cables. Each FEB/D board collects data from 16 TOF ASICs (1024 channels) and transmits assembled data frames through a HDMI electrical serial link (4.8 Gb/s) or through a high-speed optical link (10 Gb/s). The data links of several FEB/D boards can be daisy-chained and interfaced to a single DAQ board input. The maximum output event rate per FEB/D is 73 M events/s if the HDMI link is used, and 152 M events/s if the optical link is used. The FEB/D board provides the required low voltages as well as 64 configurable SiPM bias voltage lines. The DAQ_V2 Board is a PCIe data acquisition board that collects data from the FEB/D boards. Up to twelve master FEB/D boards can be connected to the DAQ board, either using HDMI cables, or using optical fibres. The DAQ board provides the system clock (80-160 MHz) as well as synchronization signals.
that are distributed to all TOF ASICs in the front-end system. The maximum output event rate through
the PCIe bus is 250 M events/s. A coincidence trigger is implemented in the firmware of the DAQ board.
To validate the performance of the readout electronics a technical PET demonstrator scanner was built
having 2048 channels, covering two thirds of a ring with 24 cm diameter (Fig. 1). The LYSO crystals
measure 3x3x15 mm and are in one to one coupling with 3x3 mm MPPC pixels. The measured energy
resolution is 24% at the 511 keV peak (Fig 2). The time resolution with a point source in the middle is 375
ps FWHM (Fig 3). The flood diagram shows homogeneous sensitivity over the surface (Fig 4). Image
with a Na22 point source show a spatial resolution of 1mm in the centre.
Images with simple phantoms will also be shown.

Board: 48 / 184

Development of a pixel sensor with fine space-time resolution
based on SOI technology for the ILC vertex detector

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We are developing an SOI pixel sensor optimized for vertexing at the ILC (International Linear Col-
lider) experiment. The SOI (Silicon-On-Insulator) monolithic pixel detector is realized by standard
CMOS circuits fabricated on a fully depleted sensor layer. The circuit and sensor layers are insu-
lated by SiO$_2$ layer called buried oxide (BOX). The sensor layer is thinned to 50 $\mu$m for reduction
of multiple scattering. The new SOI sensor SOFIST is designed to store both position and timing
information of hits in each 20 $\times$ 20 $\mu$m pixel. The position resolution is further improved by the po-
sition weighted with the charges spread to multiple pixels. The target performance of the position
resolution is better than 3 $\mu$m. The pixel also records the hit timing of the charged particle by an em-
bedded timestamp circuit. The timestamp circuit has about 4$\mu$sec resolution. In order to store 2 hit
events during accumulation, there are 2 analog signal buffers and 2 timestamps in a pixel. The pixel
output signals can be readout by an 8-bit ADC implemented on each column. In this presentation,
we report the design principle, status of the design and development of the sensor.

Board: 100 / 342

Breakdown voltage and triggering probability of SiPM from IV curves

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This work presents a model describing the IV characteristics of SiPM detectors allowing to easily
determine important physics parameters like breakdown voltage $V_{BD}$ and triggering probability
$P_{Geiger}$. The proposed model provides a good description of experimental data taken with SiPM at
different temperatures ($-35^\circ$C to $+35^\circ$C) over a very wide range of currents, from $10^{-11}$A up to
$10^{-2}$A. The model allows determination of the SiPM characteristics, $V_{BD}$ and $P_{Geiger}$, which are
found to be in good agreement with those determined from AC measurements. If the SiPM $\mu$cell
capacitance is known (from CV or AC measurements) the model can be used to determine a detector thermal rate.

Board: 30 / 332

Precision Muon Tracking Detectors for High-Energy Hadron Colliders

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Small-diameter muon drift tube (sMDT) chambers are a cost-effective technology for high-precision muon tracking and trigger at the high background rates expected at future colliders. Chambers of this type are under construction for upgrades of the muon spectrometer of the ATLAS detector at high LHC luminosities. Several chambers have already been installed for LHC run II. The chamber design and construction procedures have been optimized for mass production while providing a precision of better than 10 micrometers in the sense wire positions and the mechanical stability required to cover large areas. The inherent mechanical precision allows for highly accurate monitoring of the absolute alignment of the chambers in the detector. The sMDT chamber design profits from the long experience with the MDT chambers in ATLAS and provides even higher reliability. The chambers are operated with a mixture of argon and CO2 gas at 3 bar and are not susceptible to aging. The rate capability of the sMDT chambers has been extensively tested at the Gamma Irradiation Facility at CERN. It fulfills the requirements for the highest background regions in the ATLAS muon spectrometer at HL-LHC as well as over most of the acceptance of muon detectors at future high-energy hadron colliders. The optimization of the readout electronics to further increase the rate capability of the detectors will also be discussed as well as the use of the chambers for a highly-selective first-level muon trigger.

primary experiment:

FCC

Board: 11 / 244

Scintillating bolometric technique for the neutrino-less double beta decay search: the LUCIFER experiment

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CUPID is a proposed future ton-scale bolometric neutrinoless double beta decay (0νDBD) experiment to probe the Majorana nature of neutrinos and discover Lepton Number Violation in the so-called inverted hierarchy region of the neutrino mass. In order to achieve this sensitivity improvement with respect to the current bolometric experiments, the source mass must be increased and the backgrounds in the region of interest dramatically reduced. The background suppression can be achieved detecting the different light yield emitted by α and β/γ events in a scintillating bolometer. The increase in the number of 0νDBD emitters demand for crystals grown with enriched material. LUCIFER, the first demonstrator of CUPID, aims at running the first array of enriched scintillating Zn^{82}Se bolometers (total mass of about 9 kg of ^{82}Se) with a background level as low as 10^{-3}
counts/(keV kg y) in the energy region of interest. We show the results of the first measurement performed on ZnSe enriched bolometers operated deep underground in the Hall C of Laboratori Nazionali del Gran Sasso.

primary experiment:

CUPID CALDER CUORE

Board: 20 / 174

Radiation hard ceramic based Resistive Plate Chambers for forward TOF and T0 systems

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Important scopes of many modern HEP and HI experiments are the start time and reaction plane determination. Despite of progress was done during last two decades in timing RPC development, mostly in frame of ALICE TOF R&D, present float glass based TOF systems with pads readout (like ALICE and STAR) have very limiting rate of operation and high percent of cross-talks. To use RPC systems for the start time and reaction plane determination in the forward region low resistive radiation hard material and chess-board like single cells system organization should be used.

Our work is concentrating on development of the CBM experiment Beam Fragmentation T0 Counter (BFTC). This detector will be located at the forward region around beam pipe and the particle fluxes are expected to be as high as 2.0x10^5 cm^-2 s^-1. Hit rate and occupancy limit cell size to be about 4 cm^2.

Single cell ceramic RPCs with low resistive floating electrodes were selected due to their high rate capabilities. One RPC base element consists of double-gap stacks, where the outer electrodes are high resistive Al2O3 ceramics with a Cu-Cr layer deposited on them and the floating electrodes are made of low resistive Si3N4/SiC ceramics. A complete cell is formed by three such base elements (20x20mm^2 or 48x48mm^2 active size six-gap RPC with 250 μm gap size).

A few such cells with different resistivity value of the floating electrodes were assembled and exposed with relativistic electrons at ELBE (HZDR) where the beam flux amounts to 1.5x10^5 cm^-2 s^-1 and with 6 GeV/c pions at the T10 beam-line (CERN). The binary gas mixtures 90% Freon / 10%SF6 or 95% Freon / 5% SF6 were used since iso-butane was found to be responsible for the whiskers formation. All cells have very low noise rate less than 0.5 Hz/cm^2. For both beam tests the efficiency stays over 90% and time resolution stays below 120 ps. even at rate > 1.0x10^5 cm^-2 s^-1.

primary experiment:

CBM Summary:

Important scopes of many modern HEP and HI experiments are the start time and reaction plane determination. Despite of progress was done during last two decades in timing RPC development, mostly in frame of ALICE TOF R&D, present float glass based TOF systems with pads readout (like ALICE and STAR) have very limiting rate of operation and high percent of cross-talks. To use RPC systems for the start time and reaction plane determination in the forward region low resistive radiation hard material and chess-board like single cells system organization should be used.

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low resistive Si3N4/SiC ceramics. A complete cell is formed by three such base elements (20x20 mm² or 48x48 mm² active size six-gap RPC with 250 μm gap size). The industrial production of grooved electrodes has been established. Both outer electrodes are grooved on the side facing the gas gap, while the floating electrode is grooved on both sides. Spacers are produced also from high resistive Al2O3 ceramics and do not distort field in active area for this design.

A few such cells with different resistivity value of the floating electrodes were assembled and exposed with relativistic electrons at ELBE (HZDR) where the beam flux amounts to 1.5x10^5 cm⁻² s⁻¹ and with 6 GeV/c pions at the T10 beam-line (CERN). The binary gas mixtures 90% Freon / 10%SF6 or 95% Freon / 5% SF6 were used since iso-butane was found to be responsible for the whiskers formation. All cells have very low noise rate less than 0.5 Hz/cm². For both beam tests the efficiency stays over 90% and time resolution stays below 120 ps. even at rate > 1.0x10^5 cm⁻² s⁻¹. More tests will be done soon with more advanced electronics PADI designed for CMB experiment which can improve significantly time resolution.

Also two probes of low resistive have been exposed to non-ionizing radiation doses in the order of 10^13 neq/cm² at the neutron beam of the MEDAPP facility of the FRM II. This dose is what has been calculated for one year of CBM operation for the STS exposure region and two orders of magnitude higher than the one expected for the TOF (10^11 neq/cm²/year). The bulk resistivity of both probes was measured before and after the irradiation. A factor 2 decrease of the bulk resistivity has been observed. This decrease is not a problem for efficiency and time resolution.

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Status of production for KamLAND-Zen 800 kg phase

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KamLAND-Zen is an experiment for neutrinoless double beta decay search with xenon 136 based on large liquid scintillator detector KamLAND. In order to reduce the cosmogenic isotopes and environmental radio-activities (Uranium, Thorium Potassium), KamLAND-Zen set 16.5m³ xenon loaded scintillator in 25 μm thickness and 3.16 m diameter nylon balloon.

First phase of the experiment (KamLAND-Zen 400, 400 kg xenon gas) released a lower limit for the neutrinoless double beta decay half-life. But sensitivity is restricted by the contamination of balloon (mini-balloon) which is introduced by construction. Then KamLAND-Zen collaboration planed to upgrade the detector especially for the new mini-balloon which can contain 800 kg xenon gas with 31.4m³ liquid scintillator in 3.84 m diameter (KamLAND-Zen 800).

We present the current status of KamLAND-Zen 800, new mini-balloon construction and methods to avoid the background contaminations.

primary experiment:
KamLAND-Zen

Board: 68 / 201

Photon counting detector for the personal radiography inspection system “SIBSCAN”

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The current situation with international terrorism and drug smuggling generated a need for mass screening of the peoples for a detection of the illegal items hidden in the clothes or inside of a human body. At present time, the single way to do it effectively is a radiographic inspection. Due to the need of examination of a lot of healthy people the system should operate at the lowest possible dose defined by physical limits and the local regulations. More than 10 years ago the digital scanning radiography system based on multistrip ionization chamber was suggested in the Budker Institute of Nuclear Physics.

The last modification of the system operates with the detector filled with pure Xe at 15 bar, having quantum efficiency 70% and a pitch of channels 1.5 mm. The detector demonstrates excellent radiation resistance and its parameters stability after 5 year operations at a load up to 1000 persons per day. Currently, the installations operate in several Russian airports and at subway stations in some cities.

At present time we design a new detector operating in direct photon counting mode having superior parameters than gas one, based on assemblies: scintillator - SiPM. The detector prototype has close to zero noise, higher quantum efficiency and count rate capability more than 5MHz per channel (20% decreases) that leads to better image quality and improved detection capability.

Study of spatial resolution of low-material GEM tracking detectors

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Spatial resolution of GEM based tracking detectors is simulated and measured. The simulation include GEANT4 based transport of high energy electrons with careful accounting of atomic relaxation processes including emission of fluorescent photons and Auger electrons and custom post-processing, including accounting of diffusion, gas amplification fluctuations, distribution of signals on readout electrodes, electronics noise and particular algorithm of final coordinate calculation (center of gravity). The simulation demonstrates that the minimum of spatial resolution of about 10 \( \mu \text{m} \) can be achieved with a strips pitch of 250 \( \mu \text{m} \) to 300 \( \mu \text{m} \) with the gas mixture of Ar-CO\(_2\) (75%-25%). At a larger pitch the resolution is quickly degrading reaching 80-100 \( \mu \text{m} \) at a pitch of 500 \( \mu \text{m} \). Spatial resolution of low-material triple-GEM detectors for the DEUTRON facility at VEPP-3 storage ring is measured at the extracted beam facility of VEPP-4M collider. These detectors are made of light components and the amount of material in the sensitive area is about 2.4x10\(^{-3}\) X0. The resolution of one DEUTRON detector was measured with 500 MeV electrons and the measured value is equal to 35 \( \mu \text{m} \) for orthogonal tracks. More results of simulations and measurements with different gas mixture and higher energy beam will be presented.

primary experiment:

KEDR Summary:

Charge particle tracking detectors based on triple-GEM cascades are used in several projects at the Budker Institute of Nuclear Physics. This study was inspired by the question of what is the physical limit of spatial resolution of this kind of detectors.

Spatial resolution of GEM based tracking detectors was simulated and measured. The simulation includes GEANT4 based transport of high energy electrons with careful accounting of atomic relaxation processes including emission of fluorescent photons and Auger electrons and custom post-processing, including accounting of diffusion, gas amplification fluctuations, distribution of signals on readout electrodes, electronics noise and particular algorithm of final coordinate calculation (center of gravity). The simulation demonstrates that the minimum of spatial resolution of about 10 \( \mu \text{m} \) can be achieved with
gas mixture of Ar – CO₂ (75%-25%) at a strip pitch of 250 μm to 300 μm. At a larger pitch the resolution is quickly degrading reaching 80-100 μm at a pitch of 500 μm.

Spatial resolution of low-material triple-GEM detectors for the DEUTRON facility at VEPP-3 storage ring was measured at the extracted beam facility of VEPP-4M collider with the same gas mixture as used in the simulations. The amount of material in these detectors is reduced by etching of copper at GEMs electrodes and using the readout structure on thin kapton foil rather than on glass fiber plate. The exact amount of material in one DEUTRON detector was measured by studying multiple scattering of 100 MeV electrons in it and the result of these measurements is $X/X_0 = 2.4 \times 10^{-3}$ that corresponds to the thickness of copper layer on GEMs of 3 μm. Spatial resolution of one DEUTRON detector is measured with 500 MeV electrons and the measured value is equal to 35 μm for orthogonal tracks.

More results of the simulations studies with different gases will be shown in the presentation as well as the results of the measurements with different gas mixtures and higher beam energies in order to reduce multiple scattering.

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**High Performance Embedded System for Real-Time Pattern Matching**

**Author:** Calliope-louisa Sotiropoulou

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In this paper we present an innovative and high performance embedded system for real-time pattern matching. This system is based on the evolution of hardware and algorithms developed for the field of High Energy Physics (HEP) and more specifically for the execution of extremely fast pattern matching for tracking of particles produced by proton-proton collisions in hadron collider experiments.

A miniaturized version of this complex system is being developed for pattern matching in generic image processing applications. The system works as a contour identifier able to extract the salient features of an image. It is based on the principles of cognitive image processing, which means that it executes fast pattern matching and data reduction mimicking the operation of the human brain.

The pattern matching is executed by a custom designed the Associative Memory (AM) chip. The reference patterns are chosen by a complex training algorithm implemented on an FPGA device. Post processing algorithms (e.g. pixel clustering) are also implemented on FPGAs.

The pattern matching can be executed on a 2D or 3D space, on black and white or grayscale images, depending on the application and thus increasing exponentially the processing requirements of the system. We present the firmware implementation of the training and pattern matching algorithm, performance and results on a latest generation Xilinx Kintex Ultrascale FPGA device.

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**Simulation of 3D Diamond Detectors**

**Authors:** Alexander Oh¹ ; Giulio Tiziano Forcolin² ; Natko Skukan³ ; Steven Alexander Murphy¹ ; Veljko Grilj³ ; Vladyslav Tyzhnevyi¹

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3D Diamond detectors present an interesting prospect for future Particle Physics experiments. They have been studied in detail at beam tests with 120 GeV protons and 4 MeV protons. To understand the observations that have been made, simulations have been carried out using Sentaurus TCAD in order
to understand the movement of charge carriers within the sample, as well as the effects of charge sharing. Reasonable agreement has been observed between simulation and experiment.

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A solution for the inner area of CBM-TOF with pad-MRPC

Authors: Ingo-Martin Deppner; Yi Wang

Co-authors: Bo Xie; Christian Simon; Jochen Frühauf; Mariana Petris; Mladen Kis; Norbert Herrmann; Pengfei Lyu; Pierre-Alain Loizeau; Yongjie Sun

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The Compressed Baryonic Matter (CBM) experiment, constructed at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, has decided to use the MRPC technology to build its Time-Of-Flight (TOF) wall. Tsinghua University is a group member of CBM-TOF and is doing research on low-resistivity glass and high rate MRPC. The volume resistivity of our glass is on the order of 1010 Ωcm. High rate MRPCs preserve an excellent 60ps intrinsic time resolution under a load of as much as 40 kHz/cm2. According to the particle flux rate distribution, the whole CBM-TOF wall is divided into four rate regions named Region D, C, B and A (from inner to outer). The particle flux at the inner region D can be excess 20kHz/cm². A pad-MRPC assembled with low resistive glass was designed to construct this area. This module consists of 10 0.22mm-gap and 16 readout pads (2cm x 2cm). The prototype has been tested in the 2014 October GSI beam time and 2015 February CERN beam time. The calibration is done with CBM ROOT. A couple of corrections has been considered in the calibration and analysis process (including time-walk correction, gain correction, strip alignment correction and velocity correction) to access actual counter performances such as efficiency and time resolution. An efficiency of 98.8% and time resolution of 60ps are obtained. All these results show that the prototype is fully capable of the requirement of the CBM-TOF.

primary experiment:

FAIR-CBM

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The investigation of the internal structure of SiPM from KETEK, ZECOTEK, HAMAMATSU and SENSL companies after the neutron irradiation.

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We will present recent results on the investigation of changes in the KETEK, ZECOTEK, HAMA-MATSU and SENSIL SiPM properties after irradiation by the 0 - 35 MeV neutrons. The typical neutron fluence was about $10^{12}$ n/cm$^2$. The changes of the internal structure of the irradiated SiPMs was studied by the measuring of the C-V and C-F characteristics. The spectral distribution of the noise before and after irradiation was investigated. We have observed the strong influence of the SiPM manufacturing technology on their radiation hardness. The application of the obtained results to the development of the readout electronics is discussed.

Scintillating Fiber Detectors for Precise Time and Position Measurements Read Out with Si-PMs

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We present the development and performance of compact scintillating fiber detectors read out with silicon photomultipliers for tracking and timing to be used with different particles (electrons, protons, heavy ions) at very high particle rates (in excess of a MHz per SciFi readout channel). The compact size, fast response, and insensitivity to magnetic fields make these detectors suitable for a variety of applications. Several fiber layers are staggered into ribbons. We are considering different readout scenarios in which a) each fiber is individually coupled to a single photo-sensor and b) fibers are arranged in columns and coupled to Si-PM arrays.

In particular, we will present the SciFi tracker / time of flight detector, that will be used by the Mu3e experiment at PSI to reduce combinatorial backgrounds in the search for the lepton flavor violating decay $\mu \rightarrow eee$ at very high rates. The design and performance of this detector will be discussed. We also present the SciFi beam position detectors that will be used by NA61 at CERN to track the incoming heavy ion beam particles. We will discuss the performance of this detector and saturation effects due to the very high light yield obtained with incident heavy ions.

SiPM and front-end electronics performance for Cherenkov Telescope Array camera development

Author: Daniela Simone$^1$

Co-authors: Elisabetta Bissaldi $^2$; Francesco Giordano $^3$; Giovanni Ambrosi $^4$; Maria Ionica $^4$; Riccardo Paoletti $^5$; Valerio Vagelli $^4$; Nicola Giglietto $^3$

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In the last years many efforts in developing new technology related to Silicon Photomultipliers (SiPMs) have been done. These photosensors consist of an array of identical Avalanche Photodiodes
operating in Geiger mode and connected in parallel to a single output. The Italian Institute of Nuclear Physics is involved in a R&D program in order to develop a SiPM-based camera that will be part of the Cherenkov Telescope Array (CTA). In this framework tests on innovative devices suitable to detect Cherenkov light in the blue and near-UV wavelength region, the so called Near Ultra-Violet Silicon Photomultipliers (NUV SiPMs), are ongoing. Tests on photosensors produced by Fondazione Bruno Kessler (FBK) are revealing a promising behaviour in term of performance: low operating voltage, capability to detect very low intensity light down to single photon, high Photo Detection Efficiency in the range 390-410 nm. A campaign of test on SiPMs with several micro-cell size (40\(\mu\)m and 30\(\mu\)m) arranged in different geometrical structures have been performed to choose the best device for CTA requirements. In particular a comparison between technology of sensors characterized by a micro-cell of 40\(\mu\)m (NUV-SiPM) and 30\(\mu\)m (NUV-HD SiPM) arranged in a layout of 6 x 6 mm\(^2\) pixel size in single configuration and in a matrix arrangement will be presented. In addition results on studies for the development of a front-end electronics optimized for the new NUV SiPM will be given.

**Laser processing in 3D Diamond Detectors**

**Author:** Steven Alexander Murphy

**Co-authors:** Alexander Oh ; Andrij Zadoroshnyj ; Bangshan Sun ; David Whitehead ; Giulio Tiziano Forcolin ; Iain Haughton ; Lin Li ; Martin Booth ; Patrick Salter

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A technique for electrode production within diamond using a femtosecond laser system is described. Diagnosis tests to quantify the stress, the diamond to graphite ratio, and the resistivity of these electrodes are discussed. A 3D electronic grade single crystal diamond detector produced using this technique is shown, and the electrodes have a resistivity of \(\Omega(\text{cm})\). An improvement to the technique through the use of an adaptive wavefront shows a reduction of the diamond to graphite ratio, and smaller, higher quality electrodes were manufactured.

**Development of the microstrip silicon detector for imaging of explosions at a synchrotron radiation beam.**

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In situ imaging of explosions allows to study material properties under very high pressures and temperatures. Synchrotron radiation (SR) is a powerful tool for such studies because of its unique time structure. New beam line at the VEPP-4M storage ring will allow to get X-Ray flux from each bunch close to \(10^6\) photons/channel where channel area is 0.05x0.5 mm\(^2\) and average beam energy is about 30 keV. Bunches in the machine can be grouped into trains with 20 ns time gap. In order to meet these requirements a new detector development was started based on Si microstrip technology. The detector with a new dedicated front-end chip will be able to record images with maximum signal equivalent to \(10^6\) photons/channel, with signal to noise ratio of \(-10^3\), spatial resolution of 50 \(\mu\)m and maximum frame rate of 50 MHz. The detector has to draw very high peak and average currents
without affecting the front-end chip, therefore a specific design of Si sensor should be developed. The front-end chip has to provide signal measurements with the dynamic range of about $10^4$ or more and recording of the signal to an analogue memory with the rate of 50 MHz. The concept of such detector will be discussed in the presentation. The results of the simulations of the main detector parameters and the results of the first measurements with the prototype sensors will be presented.

Board: 82 / 330

The Belle II SVD Data Readout System

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The Belle II Experiment at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, will explore the asymmetry between matter and antimatter and search for new physics beyond the standard model.

172 double-sided silicon microstrip sensors are arranged cylindrically in four layers around the Belle-II collision point to be part of a system, called the silicon vertex detector (SVD), which would measure the tracks of the collision products of electrons and positrons. A total of 1748 radiation-hard APV25 chips read out 128 silicon strips each and send the analog signals by time-division multiplexing out of the radiation zone to 48 Flash Analog Digital Converter Modules.

Each of them applies processings to the data; for example, it uses a digital finite impulse response filter to compensate line signal distortions, and extracts the peak timing and amplitude from a set of data points for each hit, using a neural network.

We present an overview of the SVD data readout system, along with aspects like sensor material budget, sensor mechanics, the CO2 cooling system, radiation hardness, front-end electronics, cabling, power supplies, data processing, and electromagnetic compatibility characteristics.

Board: 25 / 228

The CBM RICH project

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The Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion research (FAIR) in Darmstadt will investigate the QCD phase diagram in the region of highest net-baryon density in fixed target heavy ion collisions up to ~10 AGeV beam energy, starting in 2022. In its electron configuration the CBM detector concept includes a large Ring Imaging Cherenkov detector (RICH) which will provide access to rare di-electron probes.

This RICH is based on a CO2 gas radiator (pion threshold 4.65 GeV/c) in combination with a 13m² segmented spherical focussing mirror. Hamamatsu H12700 Multianode Photomultipliers were recently selected as sensor type for the Cherenkov photon detection, following an extensive sensor R&D program. This program also covered detailed radiation hardness tests using neutrons (nuclear reactor) and high energetic gammas (Co60) at different irradiation facilities.

A highly integrated FPGA-TDC based readout chain for the PMTs is currently under development.
The detector concept was approved by building a laterally scaled prototype detector, reflecting the final design in all major dimensions and characteristics. Several test beams at CERN PS helped to provide valuable information on the photon statistics, the ring resolution, and the general performance and operation of the full system.

We report on the design and status of the RICH development, show results of the prototype beam tests, and present results of the photon sensor R&D.

**primary experiment:**

**CBM**

**Summary:**

See 1-page summary including figures in the pdf attachment.

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**Measurement of gamma-ray production from neutron capture on Gadolinium for neutrino experiments**

**Author:** Takatomi Yano

**Co-authors:** Atsushi Kimura; Hideo Harada; Iwa Ou; Kaito Hagiwara; Makoto Sakuda; Nobuyuki Iwamoto; Pretam Das; Shoji Nakamura; Takaaki Mori; Yusuke Koshio

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Gadolinium-157 is the nucleus, which has the largest thermal neutron capture cross-section. Gadolinium-155 also has the large cross-section. These neutron capture reactions provide the gamma-ray cascade with the total energy of about 8 MeV. This reaction is recently applied for several neutrino experiments, e.g. reactor neutrino experiments and Gd doped large water Cherenkov detector experiments, to recognize inverse-beta-decay reaction.

A good Gd(n,g) simulation model is needed to evaluate the detection efficiency of the neutron capture reaction, i.e. the efficiency of IBD detection.

This kind of study is crucial especially for water Cherenkov detectors, because of their Cherenkov threshold. In this presentation, we will report the development and study status of a Gd(n,g) calculation model and comparison with our experimental data taken at ANNRI/MLF beam line, J-PARC.

**primary experiment:**

ANNRI J-PARC

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**Development of a Position-Sensitive Gamma-ray Camera Using Novel Scintillator and an MPPC**

**Author:** Shunsuke Kurosawa

**Co-authors:** Akihiro Yamaji; Akira Yoshikawa; Hiroyuki Chiba; Kei Kamada; Rikito Murakami; Takahiko Horiai; Yasuhiro Shoji; Yuji Ohashi; Yuui Yokota

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Recently, we have developed novel crystals such as Ce:GAGG and Ce:La-GPS, and up to now, we succeeded in growth of 2-inch-diameter bulk crystal. Here, Ce:La-GPS has a good light output of over 35,000 photons/MeV, good energy resolution of ~ 5% at 662 keV (FWHM) and no hygroscopic nature. As the next step, we have assembled a scintillation array camera with La-GPS pixel scintillators, and this array was coupled to a Multi-Pixel Photon Counter (MPPC) array. We succeeded in obtaining the 2-dimension image in flood-field irradiation of gamma rays from a Cs-137 source, and each pixel was well-separated. In this presentation, we show the results of its gamma-ray imaging.

A new method for the neutron lifetime measurement

Author: Hidetoshi Otono¹

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According to the PDG, the neutron lifetime is reported as $880.3 \pm 1.1 \text{ s}$ in 2015. Although the neutron lifetime is a crucial parameter for the unitarity in the CKM matrix, there is a 1% discrepancy, i.e., $8.4 \pm 2.2 \text{ s}$, between two methods: counting surviving ultra-cold neutrons after storing ($879.6 \pm 0.8 \text{ s}$) and counting trapped protons from the neutron decay ($888.0 \pm 2.1 \text{ s}$).

A experiment at J-PARC employs an electron-counting method, based on a experiment at ILL by R. Kossakowski et al; Pulsed neutron beams pass through a time projection chamber (TPC) which detects electrons from the neutron decay, and also measures the neutron flux with mixed $^3\text{He}$ via the $^3\text{He}$(n, p)$^3\text{H}$ reaction. The performance of the TPC was recently published – Nucl. Instr. and Meth. A 799, 187-196 (2015).

A new TPC housed in a solenoid coil is also considered. The TPC is divided into three regions by anode and cathode wires. The main systematic uncertainties on the experiment at ILL and J-PARC are related to the subtraction of background events against electrons from the neutron decay, and the separation between the neutron decay and the $^3\text{He}$(n, p)$^3\text{H}$ reaction. The newly introduced magnetic and electric fields for the TPC reduce these uncertainties, which would reach a 0.1% accuracy and offer a clue to help resolve the 1% discrepancy among the neutron lifetime measurements. In this talk, our current status and prospect will be presented.

Beam test results on the detection of single particles and electromagnetic showers with microchannel plates

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IMCP is an R&D project aimed at the exploitation of secondary emission of electrons from the surface of micro-channel plates (MCP) for fast timing of showers in high rate environments.

The usage of MCPs in “ionisation” mode has long been proposed and is used extensively in ion time-of-flight mass spectrometers. What has not been investigated in depth is their use to detect the ionizing component of showers. The fast time resolution of MCPs exceeds anything that has been previously used in calorimeters and, if exploited effectively, could aid in the event reconstruction at high luminosity colliders.

Results from tests with electrons with energies up to 150 GeV of MCP devices with different characteristics will be presented, in particular detection efficiency and time resolution.

**primary experiment:**

**MCP HL-LHC**

Summary:

At the Large Hadron Collider (LHC), there are typically 20-30 overlapping interactions per beam crossing, spread over a length of about 5 cm root mean square (RMS) along the beam axis. In such an environment, the event reconstruction profits from soft charged radiation removal, by exploiting the association of individual particles to the correct interaction point, while neutral contribution to pile-up is subtracted using average energy density. Such approach will be strained at the High-Luminosities of LHC (HL-LHC), where about 140-200 collisions per beam crossing are expected in a time spread of 200 ps with a density of one interaction vertex per mm, resulting in a high probability for tracks from nearby vertices to be merged into a fake, high-energy event vertex. Moreover, pileup from energy deposits associated to neutral particles, mainly photons, which cannot be associated to any vertex, degrades the calorimeter performance in terms of energy measurement and particle identification, as particles appear to be less isolated. A precise time measurement of the energy deposits inside the calorimeter (with resolution of about 20 ps), would mitigate such effects, allowing to resolve in time the energy deposits from different interaction vertices.

In this work, the response of microchannel plates (MCPs) to single relativistic particles and to the ionizing component of electromagnetic showers is characterized. MCP properties to detect ionizing particles, using the secondary emission of electrons at the MCP surface, began to be investigated in [4]. Results showed that a detection efficiency of 70% and time resolution of 70 ps could be achieved [5]. Recently, technological developments within the LAPPD collaboration [6], renewed the interest in this detection technique. A set of measurements has also been reported in [7], using photodetectors based on MCP multipliers. In these devices, the Cherenkov light produced by a minimum ionizing particle (MIP) passing through an optical window hits a photocathode, releasing secondary electrons which are then multiplied inside the MCP layers. Results quoted show a time resolution of 20-30 ps at shower maximum.

As a variation to these studies, the use of MCPs as secondary electron emitter has been investigated using PMT-MCP based detectors with inhibited photocathode, preventing the avalanche formation from the photoelectrons. Such setup, referred to as “ionization-MCP” (i-MCP), allows the elimination of the
photocathode, improving the radiation tolerance of the device and resulting in a more robust design. After an initial set of measurements with 500 MeV electrons reported in [8], a deeper characterization of the response to single particles and high energy electromagnetic showers has been performed using several prototypes with MPC wafers of different geometry and properties. Results obtained in [8], are confirmed using an electron beam of higher energy (20-50 GeV) extracted from the SPS accelerator at CERN. Among the results obtained, a maximum efficiency to single particles near 70% is achieved together with a time resolution of ~ 20 ps, furthermore a 100% is measured in response to showering electrons.

REFERENCES


Novel PMTs of worldwide best parameters for the CTA project

Authors: Dominik MuellerNone; Razmik MirzoyanNone

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Photo-multiplier Tubes (PMT) are the most widespread detectors for measuring fast and faint light signals. In cooperation with the companies Hamamatsu Photonics K.K. (Japan) and Electron Tubes Enterprises Ltd. about six years ago we started an improvement program for the PMT candidates for the Cherenkov Telescope Array (CTA) project (England). CTA is the next major Imaging Atmospheric Cherenkov Telescopes array for ground-based high energy gamma-ray astrophysics. A total of ~100 telescopes of sizes of 23m, 12m and 4m in diameter will be built in Northern and Southern hemispheres. For CTA we need PMTs with the highest quantum efficiency and photo electron collection efficiency, short pulse width of a few ns, very low after-pulsing and transit time spread. The manufacturers were able to produce 1.5' PMTs of enhanced peak quantum efficiency of ~ 40%. These collect up to 95-98% of photo electrons onto the first dynode for the wavelengths ≥ 400nm. A pulse width of ≤ 3ns has been achieved at the selected operational gain of 40k. The after-pulsing for a threshold of ≥ 4 photo electrons is dramatically reduced, down to the level of 0.02%.

We will report on the measurements of 1.5' PMTs from Hamamatsu and Electron Tubes Enterprises as candidate PMTs for the CTA project. The novel 1.5' PMTs have the worldwide best parameters.

Neutron detection in the frame of spatial magnetic spin resonance

Author: Erwin Jericha

Co-authors: Gerald Badurek; Joachim Bosina; Masahiro Hino; Peter Geltenbort; Tatsuro Oda; Wilfried Mach

This presentation is related to neutron detection in the context of the polarized neutron optics technique of spatial magnetic spin resonance. By this technique neutron beams may be tailored in their spectral distribution and temporal structure. We have performed experiments with very cold neutrons at the high-flux research reactor of the Institut Laue Langevin in Grenoble to demonstrate the potential of this method in combination with a travelling wave magnetic resonator field. A combination of spatially and temporally resolving neutron detection allowed us to characterise a prototype neutron resonator. By using a neutron detector with the properties mentioned we were able to record neutron time-of-flight spectra, assess and minimize neutron background and provide for normalization for the spectra owing to variations in reactor power and ambient conditions at the same time. All these features may be achieved by a single detector as will be illustrated by our presentation. We will present the characteristics of the detector and its acquisition system and exemplify the advantages of the detection technique by selected neutron spectra that demonstrate the potential of the spatial neutron magnetic resonance technique.

Characterization and commissioning of the SST-1M camera for the Cherenkov Telescope Array

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The Cherenkov Telescope Array (CTA), the next generation very high energy gamma rays observatory, will consist of three types of telescopes: large (LST), medium (MST) and small (SST) size telescopes. The SSTs are dedicated to the observation of gamma-rays with energy between a few TeV and few hundreds of TeV.

The SST array is foreseen to have 70 telescopes of different designs. The single-mirror small size telescope (SST-1M) is one of the proposed telescope designs under consideration for the SST array. It will be equipped with a 4 m diameter segmented mirror dish and with an innovative camera based on silicon photomultipliers (SiPM).

The challenge is not only to build a telescope with exceptional performance but to do it foreseeing its mass production. To address both these challenges, the camera adopts innovative solutions both for the optical system and the readout parts.

The photodetector plane (PDP) of the camera is composed by 1296 pixels, each made of a new hollow, hexagonal light guide coupled to a hexagonal SiPM designed by the University of Geneva and Hamamatsu. The SiPM area is 94 mm$^2$ read with 4 summed channels with total capacitance of 3.4 nF.

As no commercial ASIC would satisfy the CTA requirements when coupled to such a large sensor, dedicated per-channel amplifiers electronics have been designed and their performance will be presented.

The readout electronics also uses an innovative approach in gamma ray astronomy by going fully digital. All signals coming from the PDP are digitized in a 250 MHz Fast ADC and stored in ring buffers waiting for a trigger decision to send them to the pre-processing server where calibration and higher level triggers will decide for their storage.

The latest generation of FPGAs are used to achieve high data rates and also to exploit all the flexibility of the system as for instance each event can be flagged according to its trigger pattern. All these features have been demonstrated in laboratory measurements on realistic elements and the results of these measurements will be presented in this contribution.

Board: 60 / 404

Application of a Transient-Current-Technique based on a Two-Photon-Absorption process to the characterization HV-CMOS, LGAD and irradiated PIN sensors

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Transient Current Techniques (TCT) based on laser-induced photo-currents produced by Single Photon Absorption (SPA) processes have been extensively used during the last two decades as a powerful tool to study many of the properties relevant to operation of semiconductor detectors.

Very recently, an innovative Transient Current Technique was introduced where the free charge carriers are created in a Two-Photon-Absorption (TPA) process induced by a focused femto-second laser pulse with a wavelength of 1300nm. The fact that in a TPA process the absorption of the light
depends on the square of the intensity of the light beam used for the current generation allows a localized TPA-induced electron-hole pair creation in a micrometric scale voxel centered on the laser waist. As a consequence, this new technique opens the possibility to carry out a 3D mapping of the sensor’s space-charge properties with micrometric resolution.

Due to its intrinsic spatial resolution, the TPA-TCT technique should be a very appropriate choice for the characterization of the alterations of the sensor’s active (charge collecting) volume induced by radiation damage and especially for the case of partially depleted sensors as it is the case of the carrier collecting n-well implemented in HV-CMOS sensors. Likewise, the study of Low Gain Avalanche Detector (LGAD) is suited for the use of the TPA-TCT technique.

High sensitivity particle tracker based on optically readout GEM

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GEM-based detectors have had a noticeable development in last years and have successfully been employed in different fields from High Energy Physics to imaging applications.

Light production associated to the electron multiplication allows to perform an optical readout of these devices. The big progress achieved in CMOS-based photosensors make possible to develop a high sensitivity, high granularity and low noise readout.

In this work we present the results obtained by reading out the light produced by a triple-GEM structure by means of a 4 mega-pixel CMOS sensor with a noise level lesser than 2 photons per pixel. The choice of a CF4 rich gas mixture (He/CF4 60/40) and a detailed optimization of the electric fields allowed to reach a light-yield enough high to obtain, for the first time, very visible signals of cosmic ray muons.

About 600 photons/mm were collected in average along the muon tracks and about 40 pixels/mm gave a response three sigmas large than the pedestal. Tracks due to electrons produced in natural radioactivity were also acquired and a light yield 10 times larger than cosmics was measured.

A test beam is foreseen for November 2015. More quantitative evaluations of the detector performance (e. g. space resolution, tracking efficiency, light yield, energy released resolution) are expected. These results will also be presented at the conference.

**primary experiment:** MONDO

**Summary:**

An electron multiplication structure was obtained by stacking three standard GEM foils one above the other with a 3 mm wide drift gap and two 2 mm wide transfer gaps. An He/CF4 (60/40) gas mixture was used to supply the detector.
In order to maximise the light yield, a first set of measurements was performed by varying the electric fields in the detector. The light produced by the GEM stack, when crossed by cosmic ray muons, was acquired by a photo-multiplier.

The light yield shows a maximum value for drift field values between 1.5 kV/cm and 2.0 kV/cm. It increases very rapidly with the drift field and it is almost stable for values in the range 2.0 ÷ 3.0 kV/cm.

After the light production was optimised, the acquisition of images by means of a Hamamatsu CMOS-based camera was performed. This camera provides several qualities that make it an optimal choice for this kind of applications: noise level lesser than 2 photons per pixel, a quantum efficiency higher than 70% in the CF$_4$ emission spectral range and a granularity of 2048 × 2048 pixels. It was equipped with a lens with an aperture of f/0.95.

Thanks to the optical system it was possible to acquire images of cosmic muons crossing the chamber and ionizing the gas mixture within the drift gap.

It was measured that the linear light collection density is of about 600±60 photons per track millimeter. Since, according to a simulation, about 8 primary electrons are expected per millimeter, about 75 photons are detected per primary electron. From the analysis of all the recorded muon tracks, an amount of 40±5 pixels with a response three sigma over the pedestal per track millimeter was measured.

Tracks of electrons due to natural radioactivity were also acquired. The light collection in those cases is almost 10 times larger than for minimum ionizing muons.

**Development of CANDLES detector to search for neutrinoless double beta decay of 48Ca**

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The observation of neutrino-less double beta decay (0nbb) would be one of the most realistic way to prove the Majorana nature of the neutrino and lepton number violation. CANDLES studies 48Ca double beta decay using CaF$_2$ scintillator. The main advantage of 48Ca is that it has the highest Q-value (4.3 MeV) among all the isotope candidates for 0nbb. In principle, it enables us to measure signals in region with very low background condition.

The CANDLES III detector is currently operating with 300kg CaF$_2$ crystals in the Kamioka underground observatory, Japan. The detector consists of 96 pure CaF$_2$ crystals immersed in liquid scintillator for an active shield. Sensitivity for 0nb half-life obtained from 60 days data in 2013 was > 0.8 × 10$^{22}$ year. In 2014, a cooling system and a magnetic cancellation coil were installed with the
aim to increase light emission of CaF2 and collection efficiency of the photo-multipliers. After this upgrades, light yield was increased to 1000 p.e./MeV which is 1.7 times larger than before.

We report on detector performance and stability improvements by upgrades, obtained from analyzing commissioning run data. In addition, we present a plan for future detector upgrades in 2015. Upgrading by installing neutron and gamma-ray shields to reduce the remaining backgrounds is expected to increase our sensitivity to $>10^{23}$ year. We also report the future development of the next generation detector, CaF2 scintillating bolometer.

**primary experiment:**

double beta decay

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**Board:** 61 / 425

**Optimization of thin n-in-p planar pixel modules for the ATLAS upgrade at HL-LHC**

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The ATLAS experiment will undergo around the years 2023-2025 a major upgrade of the tracker system in view of the high luminosity phase of the LHC (HL-LHC). Thin planar pixel modules are promising candidates to instrument the new pixel system, thanks to the reduced contribution to the material budget and their high charge collection efficiency after irradiation. The performance of 100-200 μm thick sensors, interconnected to FE-I4 read-out chips and irradiated up to a fluence of $1.4\times10^{16}$ neq, will be compared in terms of charge collection and hit efficiency.

New designs of the pixel cells, with an optimized bias structure, have been implemented in n-in-p planar pixel productions, and the possible gain in the hit efficiency investigated as a function of the received irradiation fluence. The outlook for future planar pixel sensor productions will be discussed, with a focus on sensor design at the pixel pitches (50x50 and 25x100 μm2) foreseen for the new ATLAS read-out chip in 65 nm CMOS technology. Highly segmented sensors will represent a challenge for the tracking in the forward region of the pixel system at HL-LHC. In order to reproduce the performance of 50x50 μm² pixels at high eta, FE-I4 compatible planar pixel sensors have been studied before and after irradiation in beam tests at high incidence angle with respect to the short pixel direction. Results on cluster shapes, charge collection and hit efficiency will be shown.

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**Board:** 73 / 36

**The CMS Level-1 Trigger Upgrade**

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The LHC RUN2 which has just started marks the beginning of a new era. It is expected that the integrated luminosity delivered by LHC will increase markedly and this will open new opportunities for discoveries as well as for precision measurements. The increased luminosity presents a challenge for the CMS Level-1 trigger system which is being upgraded to cope with the new LHC environment which is characterized by large detector occupancies caused by a dramatic increase of the pile-up events. The new CMS Level-1 trigger presented here is based on uTCA technology, Xilinx Virtex-7 690 FPGAs and 10 Gbps optical links. The Level-1 trigger upgrade will provide initialy for electron/photon and tau triggers of increased efficiency and better background rejection as well as for
pile-up subtraction for all triggers. This system will be upgraded further in 2016 and will be able to process data at full detector granularity by employing the novel Time Multiplexed Trigger (TMT) architecture. The TMT architecture provides for dramatic increase of energy and position resolution of all Level-1 trigger objects. The design and performance of this system using the first data from RUN2 are presented here.

Board: 3 / 252

The TAIGA observatory - a hybrid detector array for gamma-ray astronomy and cosmic ray physics in the Tunka valley

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The TAIGA observatory addresses ground-based gamma-ray astronomy at energies from a few TeV to several PeV, as well as cosmic ray physics from 100 TeV to several EeV. TAIGA will be located in the Tunka valley, ~50 km West from Lake Baikal. The different detectors of the TAIGA will be grouped in 6 arrays to measure Cherenkov and radio emission as well as electron and muon components of atmospheric showers. The combination of the wide angle Cherenkov detectors of the TAIGA-HiSCORE array and the 4-m Imaging Atmospheric Cherenkov Telescopes of the TAIGA-IACT array with their FoV of 10×10 degrees offers a very cost effective way to construct a 10 km² array for gamma-ray astronomy.

primary experiment:

TAIGA Summary:

In recent years, ground-based gamma-ray astronomy at very high energies (VHE) became the most dynamically developing field in high-energy astroparticle physics. More than 150 sources of TeV gamma rays have been discovered and studied with Imaging Atmospheric Cherenkov Telescopes (IACTs) of the third generation (HESS, VERITAS, MAGIC). However, gamma rays with energies higher than 80 TeV have not been detected up to now. For an extension to higher energies one needs an array with several square kilometers area.

This talk presents the gamma-ray observatory TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy) which addresses crucial questions of gamma-astronomy and of cosmic ray physics. TAIGA is under construction in the Tunka valley, about 50 km from Lake Baikal in Siberia, Russia. The key advantage of TAIGA is the combined detection of air shower Cherenkov radiation by the wide-angle detector stations of the TAIGA-HiSCORE array and the IACTs of the TAIGA-IACT array. The HiSCORE data will allow reconstructing the shower arrival direction with an accuracy of about 0.1 degree, the shower axis within 5–6 m, the shower energy E₀ with about 10–15% and the shower maximum height Xmax with 20–25 g/cm². The main task for the IACT array is separating gamma-initiated air showers against the background of charged cosmic rays. Simultaneous measurement of air showers by several of the more densely spaced wide-angle Cherenkov detectors allows increasing the distance between the IACTs up to 1000 m. The HiSCORE and IACT arrays complement each other. This allows constructing a detector with an area of ~5 km² for a price which is about 10 times less than a mere IACT array (like CTA) and to search for super-high energy gamma rays.

TAIGA-HiSCORE is a net of detector stations with spacing 75–200 meters, each equipped with four PMTs with a light-collecting Winston cone of 30° half-opening angle. The principle of HiSCORE is the sampling of the Cherenkov light front of air showers. The detector stations measure the light amplitudes and the arrival time differences over a distance of a few hundred meters. The main DAQ-board is designed on the basis of the DRS-4 chip and the FPGA Xilinx Spartan-6. The accuracy of the time synchronization of detector stations is 0.2 ns and the time step of the PMT waveform digitization 0.5 ns. The energy threshold for gamma-ray detection is ~30 TeV. The TAIGA-HiSCORE engineering array with 28 detector stations is in operation since September 2015. The full array with 500 detector stations, distributed over an area of 5 km², is planned to be completed in 2020.

The TAIGA-IACT array will consist of 16 IACTs distributed over an area of 5 km². Its reflector area will be about 10 m², with a focal length of 4.75 m. The imaging cameras with 547 PMT-based pixels have a total Field of View of 9.72×9.72 degree. Each PMT is equipped with a Winston cone with an entrance size of 30 mm and an exit spot of 15 mm diameter. The entire array of pixels is divided into clusters of
For additional suppression of the background of charged cosmic rays, TAIGA will be equipped with a muon array. It consists of underground muon detectors with total area of 2000-3000 m². The first stage of this subarray uses the muon scintillation counters formerly operated as part of EAS-TOP and KASCADE-Grande. This so-called Tunka-Grande detector with 19 scintillation stations was put in operation in October 2015. Each station has a surface part with 12 scintillation counters (size of each is 80×80×4 cm³) and an underground part with 8 of the same counters. The DAQ of the Tunka-Grande array is rather similar that of the Tunka-133 wide angle Cherenkov array operated since 2009. Simulations show that gamma rays with energies >100 PeV can be rather effectively identified by the hybrid operation of the TAIGA-Muon array and Tunka-Rex (Tunka Radio extension) which presently consists of 44 antenna stations spaced by 200 m and spread over about 3 km². Also Tunka-Rex will be extended in the future.

Longitudinally segmented shashlik calorimeter with SiPM read-out

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Shashlik calorimeters are particular types of sampling calorimeters where the stack of alternating slices of absorber and scintillating material is crossed by wavelength shifting fibers (WLS) perpendicularly to the absorber and scintillator tiles. Characterized by low cost and good performances, shashlik calorimeters are usually not suited for longitudinal segmentation since the fibers are often grouped and coupled to photomultipliers at the back of the stack. This contribution presents the test of a compact shashlik calorimeter readout by Silicon PhotoMultipliers (SiPMs) where longitudinal segmentation has been achieved alternating WLS fibers of different lengths. The calorimeter is composed of 40 8x8 cm^2, 3.3 mm thick tiles (20/20 lead/plastic scintillator), for a total of 11 X0; 64 0.8 mm WLS fibers are used for the light readout: half of the fibers cross the whole calorimeter, while the other half cross only the last 5.5 X0. The SiPM readout has been implemented by means of a custom electronic board directly embedded on the last calorimeter tile: each WLS fiber is readout by a 1.2 mm diameter circular SiPM with 673, 40x40 μm² area cells. The embedded readout allows to stack more shashlik modules one after the other, minimizing the dead zones and also improving the longitudinal segmentation. The performances of the calorimeter in terms of energy resolution and e-/pion separation have been evaluated on the CERN PS-T9 beamline in the 1-5 GeV energy range.

Prototype sensors for intelligent module with integrated on-chip logic using strip and pixel sensors for CMS tracker phase-II upgrade

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he high luminosity upgrade of the LHC is targeted to deliver 2500 fb-1 at a luminosity of 5x10E34 cm-2s-1. Higher granularity, 140 collisions per bunch crossing and existing bandwidth limitations require a reduction of the amount of data at module level. New modules have binary readout, on-chip pT-discrimination and capabilities to provide track finding data at 40 MHz. The CMS collaboration has undertaken R&D effort to develop new planar sensors for the pixel-strip module, which has to withstand 1x10E15 1 MeV neutron equivalent flux in the innermost layer of the tracker. The module is composed of a strip sensor and a macro pixel sensor with 100 μm × 1.5 mm pixel size. Sensors were characterized in the laboratory and the effects of different process parameters on planar n-in-p sensor concepts were studied. Module prototypes were built, noise studies on a new type of module design for the PS module were performed and beam tests of the first prototype assemblies are done. Status and progress of this effort will be discussed.

A micropixel avalanche phototransistor for time of flight measurements

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This paper presents the results of a study of the new micropixel avalanche phototransistor (MAPT) on the basis of silicon. MAPT is a modification of well-known silicon photomultipliers (SiPMs) and differs from them in that each photosensitive pixel MAPT operating in Geiger mode further comprises an individual transistor operating in binary mode. This provides high amplitude of single photoelectron signal with significantly shorter duration. The obtained results are compared with the parameters known SiPMs.

Test beam results of the CMS 2S pT-module prototypes using the CBC2 read-out chip

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For the High Luminosity LHC (HL-LHC), a major upgrade is foreseen for the CMS experiment. In its Phase II, the accelerator will achieve luminosities up to ~5 x 10^34 cm^-2 s^-1. To cope with the increased rates and occupancies, CMS replaces the current tracker with an entirely new system which is able to withstand the increased radiation corresponding to ~3000 fb^-1 of integrated luminosity and resolve ~200 collisions per bunch crossing while being able to provide information to the first level trigger and maintain the excellent tracking performance. It is foreseen that the future outer tracker pT modules provide trigger information by means of an on-board pT discrimination logic. To achieve this, a new front-end readout chip, the so-called CBC, is under development in 130 nm
CMOS technology. The results of the first test beam of the double strip layer 2S pT-module prototype using the CBC chip and future outlook will be presented.

**New Developments in the design and production of Low Gain Avalanche Detectors**

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In this contribution we will present our new design and production of Low-Gain Avalanche Detectors fabricated at FBK, Trento, Italy. LGAD detectors are becoming increasingly popular as they combine the benefits of traditional silicon detectors with those of APDs, specifically low noise and large signals. LGAD are also particularly well suited for the design of Ultra-Fast Silicon detectors, which are silicon detectors able to measure the time of the particle hit with the precision of few tens of picoseconds.

In this new production we are proposing the traditional n-in-p LGAD design, where the multiplication happens at the segmented n electrode, together with the double-sided LGAD geometry, in which the segmentation is on the ohmic side. In addition we are also proposing a new mechanism of pixelization via AC coupling which offers very uniform electric fields together with segmented electrodes and we introduce in each pad a lateral collector ring, meant to prevent the charges produced by particles hitting the sensor periphery from generating a delayed signal. We will present first measurements and their comparison with simulation.

**Study of the performance of a compact sandwich calorimeter for the instrumentation of the very forward region of a future linear collider detector**

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The FCAL collaboration is preparing large scale prototypes of special calorimeters to be used in the very forward region at a future linear electron positron collider for a precise and fast luminosity
measurement and beam-tuning. These calorimeters are designed as sensor-tungsten calorimeters with very thin sensor planes to keep the Moliere radius small and dedicated FE electronics to match the timing and dynamic range requirements.

A partially instrumented prototype was investigated in the CERN PS T9 beam in 2014. It has been operated in a mixed particle beam (electrons, muons and pions) of 5 GeV/c. The results demonstrated a very good performance of full readout chain. The high statistics data were used to study the response to different particles, perform sensor alignment and measure the longitudinal shower development in the sandwich. In addition, Geant4 MC simulations were done, and compared to the data.

Study of the light production mechanism of epoxy resins in an electric field

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Evidences of a contamination of the physics data with an instrumental background arising from light signals produced inside the photomultipliers assembly have been reported by several experiments over the past years. In some cases the instrumental background has been described as a fast (≈ 10 ns) flash of light or, in other cases, as train (≈ 1 µs) of pulses similar to the glowing in gas. That has been also the case of the Double Chooz detector, a reactor neutrino experiment which recently measured the 013 mixing angle through the reactor antineutrino disappearance, where the unexpected background has been suppressed in the data analysis using the characteristic feature of the light emission. A specific study of the phenomena has been carried out in order to characterize the signals and to identify the processes underlying the effect. The mechanisms of light emission originating from the PMTs were identified and it has been found that the dominant one arises from the light produced by the combined effect of heat and high voltage across the epoxy resin covering the electric components. A correlation of the rate and the amplitude of the signal with the temperature has been observed. Additionally evidence of the impact of the seasonal variation of the detector temperature has found after three years of data taking. The results can be particularly relevant for other neutrino experiments that are known to use analogous optical units and similar materials.

primary experiment:
Double Chooz Summary:

Evidences of a contamination of the physics data with an instrumental background arising primarily from light signals produced inside the photomultipliers assembly have been reported by many experiments over the past years (1–5). It is possible that the spurious light emission is detected by some of the surrounding or opposite tubes in such a way that the event can satisfy the trigger logic and be recorded on disk. In some cases it is necessary to turn permanently off some PMTs to reduce the contamination of the physics sample with spurious events or to limit an undesirable dead time (6). A set of cuts, typically based on the event topology, have to be used to reject the instrumental background offline. The evaluation of the cut efficiency and acceptance, as well as the monitoring over time of the background stability in rate and amplitude, are then required over the entire data taking. Additionally the effect can be considered a potential concern for the future giant neutrino detectors equipped with several thousands of PMTs (7, 8).

Double Chooz is a reactor neutrino experiment aiming to measure the mixing angle 013 through the reactor antineutrino disappearance. The electron antineutrino produced by the two reactor cores of the Chooz nuclear power plant in France, are detected through inverse beta decay (IBD) in a hydrocarbon liquid scintillator that provide the free proton targets. Results obtained with the far detector, the first operational located 1050 m from the two reactors, show the reactor electron antineutrino disappearance consistent with neutrino oscillations. From a fit to the observed energy spectrum we found 013 to be \(\sin^2 2 \theta_{13} = 0.090^{+0.032}_{-0.029} \) (9). A near detector, placed at 400 m from the reactor cores and almost identical to the far one, is now in operation and it is expected to reduce reactor and detector systematic
uncertainties. During the preliminary tests of the Double Chooz far detector, an instrumental background not evidenced at the time of the characterization of the PMTs in laboratory has been observed. An unexpectedly high PMT coincidence rate was measured before the detector was filled with liquid scintillator. Light pulses, not caused by light leaks, were detected when the PMTs were switched on, with a rate correlated to their high voltage values.

Figure 2: Coincidence rate measured with 16 monitor PMTs versus total number of PMTs on (left) and trigger rate progression as the high voltages of all PMTs are ramped up (right). Rate is measured by the 4-fold coincidence

Fig.1: Coincidence rate measured with 16 monitor PMTs versus total number of PMTs on (left) and trigger rate progression as the high voltages of all PMTs are ramped up (right). Rate is measured by the 4-fold coincidence

None of the tubes was able to justify the measured trigger rate, but each PMT was an effective emitter with a rate of the order of $\approx 0.1-1 \text{ s}^{-1}$, with some units more active than the others. The effect remained substantially unchanged after the filling of the detector. Even though the largest charge signal was typically produced by the emitter itself, the light spread out among the other PMTs after several reflections triggering the DAQ and contaminating the data sample during the physics run.

Detailed investigations, also with laboratory tests on photomultipliers of the same type of the ones installed in Dobule Chooz, have been carried out in order to clarify the features of the light pulse and its production mechanism. It has been observed that the light emission was produced by corona discharge caused by the polarization of the epoxy used to insulate the PMT base circuit. It has been demonstrated that the polarization was induced by the combined effect of heat and high voltage.
Figure 3: Glowing of epoxy samples placed on a resistor recorded in dark conditions with the high sensitivity CCD

The performance for the TeV photon measurement of the LHCf upgraded detector using Gd2SiO5 (GSO) scintillators.

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The Large Hadron Collider forward (LHCf) experiment is motivated to understand the hadronic interaction relevant to the cosmic-ray air shower development. LHCf is the only experiment which measures $\gamma$ and $\pi^0$ spectra in the very forward region ($\eta > 8.4$), so called "zero-degree" region, at the LHC. The LHCf detectors were compact sampling and imaging calorimeter installed in the gaps of the pipes $\pm 140$ m away from the interaction point 1. Since the energy flux is large in this region, the irradiation dose-rate of the calorimeter reaches 30 Gy/nb$^{-1}$ at 13 TeV collisions. Before starting Run 2, we have upgraded the detectors with GSO scintillator which is known as one of the most radiation-hard scintillators. Also we developed the shower imaging hodoscope layers with 1mm pitch GSO bars for the calorimeters. So far the performance for the $\gamma$-ray measurement has been confirmed in SPS. The energy resolution of 3 % and the position resolution of less than 200 $\mu$m were obtained using 50-250 GeV of electron beams. On 10-13th June 2015, LHCf has completed the 13TeV operation successfully. We succeeded to measure the neutral particles, including TeV $\gamma$ and $\pi^0$, in the very forward region. The reconstructed $\pi^0$ mass resolution was 5%.

In this paper we will focus on the performance of photon measurement such as linearity of the energy scale, photon-hadron separation, stability during the operation and so on.
To improve the muon trigger efficiency of the high eta region of the CMS experiment and to cope with the expected luminosity increase in the second phase of the LHC, new RPC detectors using low-resistivity materials are proposed to equip part of the high-eta region. Several beam tests at DESY and CERN have shown that new detectors using low resistivity glass (of less than 1010 Ω.cm) could stand particle rates of few kHz/cm² in its single-gap version and few tens of KHz/cm² in its multi-gap version. Test of several months at GIF has confirmed the robustness of such detectors and new tests in the new GIF++ facility are planned to complete the study. In parallel the excellent timing the RPC and MRPC could provide will be exploited by developing a new low-noise ASIC equipped with precise TDC device.

Cathode Drift Chambers for the GlueX experiment at Jefferson Lab

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We report on detailed studies of the performance of a 12,500-channel drift chamber system with both cathode and wire readout operational in HallD in Jefferson Lab (Virginia, USA). The GlueX experiment uses tagged polarized photon beams from the recently upgraded 12GeV Continuous Electron Beam Accelerator Facility to search for hybrid mesons with exotic quantum numbers, as predicted by lattice QCD. The identification of such mesons requires full reconstruction of all charged particles and photons with high position and momentum resolution. Twenty-four planar drift chambers of 1m-diameter are located within the bore of a 2T-solenoid. The chambers have cathode strips on both sides of the wire planes, allowing to reconstruct tracks with high density close to the beam line. The cathodes/wires are readout by 125MHz-flashADCs/F1-TDCs. The use of only 2-micron thick copper strips and a light frame made mostly of Rohacell with g10 skin (to allow detection of low energy photons by outside e.m. calorimeters) posed technical challenges. The emphasis of the report is on the resolution studies. As the two cathode planes and the wire register the same avalanche, this allows uniquely to study the charge induction process and the strip resolution. In addition, we report on results with two modified chambers with a drift gap of 3cm studying the possibilities for cluster counting as PID and also to be used as a transition radiation detector for e/pi separation.

primary experiment:
GlueX at JLab

A new imaging atmospheric Cherenkov camera for the H.E.S.S. telescopes
The High Energy Stereoscopic System (H.E.S.S.) is an array of five imaging atmospheric Cherenkov telescopes (IACT) located in Namibia. Four of them started operations in 2003 and their cameras are currently undergoing an extensive upgrade, with the goals of reducing the system failure rate, reducing the dead time of the cameras and improving the overall performance of the array. The upgraded components include the readout and trigger electronics, the power, ventilation and pneumatic systems and the control and data acquisition software. New designs and technical solutions have been introduced: the upgraded readout electronics is based on the NECTAR analog memory chip, while the camera control subsystems are based on an FPGA coupled to an embedded ARM computer. The control and data acquisition software is based on C++ libraries such as Apache Thrift, ZMQ and Protocol buffers. These hardware and software solutions offer very good performance, robustness and flexibility. Upon completion, the upgrade will assure the continuous operation of H.E.S.S. at its full sensitivity until and possibly beyond the advent of CTA. The present contribution describes the design, the testing and the performance of the new components of the H.E.S.S. camera upgrade.

primary experiment:

HESS Summary:

Figure 4: View of the High Energy Stereoscopic System (H.E.S.S.) of imaging atmospheric Cherenkov telescopes

The H.E.S.S. array of imaging atmospheric Cherenkov telescopes consists of four 12-m telescopes (CT1-4), which started operations in 2003, and a fifth 28-m telescope (CT5), inaugurated in 2012. The system is sensitive to cosmic gamma rays of energies from ~30 GeV up to 100 TeV. The cameras of the first four...
Telescopes are composed of 960 photomultipliers each and have been operated without any upgrade for 13 years. The main reasons for the upgrade are 1) reduce the failure rate and the downtime caused by ageing of the electronic components in a harsh, dusty environment and 2) reduce the readout deadtime of 450 µs to about 5.5 µs, thereby improving the efficiency of stereoscopic observations including CT5. The newly developed hardware will lead to several improvements in the overall performance of the array, especially below 100 GeV and above 1 TeV.

Major upgraded electronics components include the 60 front-end readout modules, called “drawers”, the drawer interface box, hosting the trigger logic, and the power distribution box, distributing 24V DC power to all drawers. All these components are built around an Altera Cyclone IV FPGA coupled to an ARM-based system-on-chip module via a 16-bit memory bus interface. The flexibility of this new architecture allows for further improvements in the trigger and readout performance, which are currently in early testing phase.

The signals from the PMTs are sampled by the readout at 1 GHz. The sampling window is 16 ns per event. Each pixel has two readout channels with different gains, the dynamic range is greater than 2000. The noise in the high gain channel is about 0.5 mV (RMS) and the end-to-end readout bandwidth is ~330 MHz. The camera can sustain trigger rates above 10 kHz (previously it was 1kHz). The trigger signal is transmitted from the drawers to the trigger board inside the drawer interface box and back using two shielded wire pairs of CAT-6a ethernet cables. The data is sent via TCP/IP to a central camera computer. All the slow control communication is also done over network, using the Apache Thrift communication protocol, while the monitoring data is serialized using Protocol buffers over ZMQ sockets. The same software base is cross-compiled for both the x86 and the ARM using the CMake tool and the openembedded software framework. The ventilation and pneumatics systems of the camera have also been completely renewed. All the upgraded components underwent several quality tests before deployment; the first camera was upgraded in July 2015, and is now undergoing commissioning. The deployment of the other 3 cameras is expected to take place in Q4 2016. Monte Carlo simulations of the performance of the upgraded cameras are ongoing. Furthermore, a prototype readout module is being evaluated for use as main readout of an APD-based detector at the BESSY X-ray femtoslicing facility.

Strip defect recognition in electrical tests of silicon microstrip sensors

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This contribution describes the measurement procedures and data analysis of AC-coupled double-sided silicon microstrip sensors with polysilicon resistor biasing. The most thorough test of a strip sensor is an electrical measurement of all strips of the sensor; the measured observables include e.g. the strip’s current and the capacitance. These measurements are performed to find defective strips, e.g. broken capacitors (pinholes) or implant shorts between two adjacent strips.

When a strip has a defect, its observables will show a deviation from the “typical value”. To recognize and quantify certain defects, it is necessary to determine these typical values, i.e. the values the observables would have without the defect. Piecewise least-median-of-squares (LMS) linear fits are applied to determine these “would-be” values of the observables. An LMS fit is robust against outliers, i.e. it ignores the observable values of defective strips. Knowing the typical values allows to recognize, distinguish and quantify a whole range of strip defects.

This contribution explains how the various defects appear in the data, how to distinguish them from similar defect signatures, how to resolve correlations between signatures, and in which order the defects can be recognized.
The analysis has been used to find strip defects on 37 double-sided trapezoidal microstrip sensors for the Belle II Silicon Vertex Detector, which have been measured at the Institute of High Energy Physics Vienna.

Electro-optical characterization of the first RGB-UHD SiPMs for improved radiation hardness

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We characterized the RGB SiPMs with Ultra-High-Density cells (RGB-UHD) manufactured at Fondazione Bruno Kessler (FBK), Trento. The devices feature circular cells, with a pitch of 7.5 um, 10 um and 12.5 um, corresponding to a cell density of 20500, 11500 and 7400 cells/mm2, respectively. Depending on different layout splits that we tested, the fill factor (FF) of the cells varies between 33% and 57%, for the 7.5um cell, and between 47% and 68%, for the 10 um cell. These cells have a very small capacitance and gain, thus featuring very fast recovery time, lower correlated noise and less sensitivity to radiation damage, when compared to larger cells built with a similar technology. Such characteristics are of great interest in applications that require high dynamic range and/or good resistance to radiation damage, such as the CMS ECAL upgrade. We tested samples of the UHD-SiPM technology, featuring a circular active area with 1.5 mm diameter. The experimental characterization showed that all the cell sizes and layout splits were working and capable of single-photon resolution. The microcell recharge time constant was 3.5 ns and 4.5 ns, for the 7.5 um and 10 um cells, respectively. At an overvoltage of 6 V, we measured an Excess Noise Factor below 1.1 for all cells and a DCR in the order of 200 KHz/mm2. The PDE at 515 nm was 22%, 26% and 29%, for the 7.5 um, 10 um and 12.5 um cells, respectively, which are very high values, considering the small cell sizes.

A 65 nm CMOS analog processor with zero dead time for future pixel detectors

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Next generation pixel chips at the High-Luminosity (HL) LHC will be exposed to extremely high levels of radiation and particle rates. In the so-called Phase II upgrade, ATLAS and CMS will need a completely new tracker detector, complying with the very demanding operating conditions and the delivered luminosity (up to $5 \times 10^{34} \text{cm}^{-2}s^{-1}$ in the next decade).

This work is concerned with the design of a synchronous analog processor with zero dead time developed in a 65 nm CMOS technology, conceived for pixel detectors at the HL-LHC experiment upgrades. It includes a low noise, fast charge sensitive amplifier featuring a detector leakage compensation circuit, and a compact single ended comparator that guarantees very good performance in terms of channel-to-channel dispersion of threshold without needing any pixel-level trimming. A 3-bit Flash ADC is exploited for digital conversion immediately after the preamplifier. The conference paper will provide a thorough discussion on the design of the different blocks making up the analog front-end channel.

**Development of a PET Insert for Human Brain Imaging: Detection System**

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In recent years, the combination of techniques such as PET and MRI has shown a great potential to study the processes and progression of diseases (cancer, Alzheimer’s) as well as to control and observe novel treatments response. A brain-size PET detector ring insert for an MRI system is being developed that, if successful, can be inserted into any existing MRI system to enable simultaneous PET and MRI images of the brain to be acquired without mutual interference.

The PET insert consists of detector modules arranged in a ring of 30 cm diameter. Each detector block is composed of a scintillator crystal array coupled to the Philips Digital Photon Counting. We divided the study of the detection system in three stages. First, we characterized the coupling of the scintillator crystal with the SiPM. Next, we simulated the behaviour or the ring insert using Monte Carlo methods. Finally, we verified the simulation results with the collected data. Several crystals, including LYSO, BGO and GaGG were tested.

As a result of this methodology, we obtained the I-V curves and the energy and time resolution of our system. Results show that the coupling is appropriate and that the sensibility of our system is adequate to move to the next study phase: MRI compatibility.

**primary experiment:**

SiPM characterisation  **Summary:**

Medical imaging represents the set of techniques and processes used to create images of the body. One one hand, the principal techniques that offer anatomical information of the patient are computational imaging (CT) and nuclear magnetic resonance (MRI). On the other hand, there are nuclear medicine techniques like positron emission tomography (PET) and single photon emission computational tomography (SPECT), that provide us with morphological in vivo information of the living system.

In this manner, combining an anatomical and a morphological technique becomes a necessity to provide patients with an accurate understanding of their disease. In particular, brain imaging represents an extreme challenge due to the high precision tumor localisation and new and more powerful MRI devices are being created, reaching magnetic field as high as 9 Tesla. Thus, we believe that it is important to provide hospitals with a PET device that can be inserted into any existing MRI with a detection system capable of avoid the interference between this two instruments.
The acquisition system consists of two detectors (figure 1) separated a distance of 30 cm. Between the detectors, a radioactive source is placed. The source is a positron emitter and in this case in particular, we used Na-22.

Each one of the detectors is constituted by a scintillator crystal array optically coupled to a silicon photomultiplier (SiPM) of 32mm x 32mm. The crystal is a LYSO cube of square section equal to that of the SiPM and with a height of 20 mm. Five of the six faced are painted in white in order to increase the number of optical photons detected. The SiPM has 16 dies with 4 pixels each.

The data was collected using different configurations of the system. Moving the source along the detectors axis we obtained three positions: a) equidistant of both detectors, b) 10 cm to detector 1, c) 5 cm to detector 2. In addition, the source was put either on position 0 that is laying down or 1 that is standing. Moreover, for each position of the source, the two detectors system was rotated with a 30 degrees step, consequently in 6 steps we are able to obtain a complete tomographic information. All measurements were took for half an hour per position.

The simulation was carried out using GATE (Geant4 Application for Emission Tomography). Additionally to the system described above and after the verification of the simulation with the experimental data, we study a complete ring PET insert with a human head phantom (figure 2). Results show promising capabilities for the MRI compatibility.

**Low material budget floating strip Micromegas for ion transmission radiography**

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Floating strip Micromegas are high-accuracy and discharge insensitive gaseous detectors, able to track single particles at fluxes of 7MHz/cm² with 100μm resolution. We developed low-material-budget detectors with one-dimensional strip readout, suitable for tracking at highest particle rates as encountered in medical ion transmission radiography or inner tracker applications. Recently we additionally developed Kapton-based floating strip Micromegas with two-dimensional strip readout, featuring an overall water-equivalent-thickness of 0.3mm.

These detectors were tested in high-rate proton and carbon-ion beams at the tandem accelerator in Garching and the Heidelberg Ion Beam Therapy Center, operated with an optimized Neon:CF₄ gas mixture. By coupling the Micromegas detectors to a new scintillator based range detector, ion transmission radiographies of PMMA and tissue equivalent phantoms were acquired. The range
detector with 18 layers is read out via wavelength shifting fibers, coupled to a multi-anode photomultiplier.

We present the performance of the Micromegas detectors in particle beams and under irradiation with a $^{55}$Fe source, discuss the energy resolution of the scintillator range telescope and present the image reconstruction capabilities of the combined system. We acknowledge support for the measurements at HIT by the DFG project on Ion Based Computed Tomography.

**primary experiment:**

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Board: 95 / 202

**PANDA Barrel DIRC design performance studies**

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The experiment PANDA, Antiproton Annihilation at Darmstadt, is designed to measure reactions induced by high intensity antiproton beams up to 15 GeV/c, at the Facility of Antiproton and Ion Research (FAIR), under construction at GSI, Darmstadt. Being a fixed target experiment PANDA features a Target Spectrometer (TS) surrounding the interaction point and a Forward Spectrometer (FS) for the high momentum reaction products. Particle identification in the barrel region is of paramount importance and will be performed by means of detecting internally reflected Cherenkov light (DIRC), with a Barrel DIRC covering polar angles between 22° and 140°. Its primary purpose is the clean separation of pions and kaons (>3sigma), for momenta up to 3.5GeV/c. The Barrel DIRC design, inspired by the concept successfully employed in the BaBar experiment, features significant novelties. Notably, at PANDA the Cherenkov photons are focused by a lens system onto an array of microchannel plate photomultipliers which are coupled to a compact expansion volume. The radiators, made of synthetic fused silica, extend over the full length of the barrel region while the width is subject to optimization, since a wide plate offers significant fabrication cost reduction. We describe the design of the PANDA Barrel DIRC and present decisive measurements performed with test beams at GSI and CERN in 2015, using both narrow and wide plate radiator geometries.

Board: 78 / 111

**Level Zero Trigger Processor for the ultra rare Kaon decay experiment - NA62**

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The NA62 experiment is designed to measure the (ultra)rare decay $K^+ \rightarrow \pi \nu \bar{\nu}$ branching ratio with a precision of ~10% at the CERN Super Proton Synchrotron (SPS). The L0 Trigger Processor (L0TP) is the lowest level system of the trigger chain. It is hardware implemented using programmable logic. The architecture of the L0TP is completely new for an high energy physics experiment. It is fully digital, based on a standard gigabit ethernet communication between detectors and L0TP Board. The L0TP Board is a commercial development board, Terasic DE4, mounting an Altera Stratix IV FPGA. The primitives generated by sub detectors are sent asynchronously using the UDP protocol to the L0TP during the entire beam spill period (~5 seconds). The L0TP realigns in time the primitives coming from 7 different sources and manage the information of the time plus all the characteristics
of the event as energy, multiplicity, position of hits, to select good events with a comparison with preset masks. It should guarantee a maximum latency of 1 ms. The maximum input rate is 10 MHz for each sub-detector, while the design maximum output trigger rate is 1 MHz. A complete trigger less parasitic acquisition of the primitives it is possible using mirroring switches to monitor the L0 behaviour. A first version of the L0TP was commissioned during the 2014 NA62 pilot run and it is used in the current data taking. A review of the trigger performance will be presented.

Feasibility study of a Single Probe Compton Camera for Laparoscopic Surgery

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Purpose
This study shows the one solution to detect radioactive biomarker at laparoscopic surgery by using single Compton camera probe and position sensor.

Methods
We designed prototype imaging-probe including radiation detectors and optical markers. Position sensor (POLARIS) measure spatial coordinates of detector positions by tracking attached optical markers. And Compton scattering angle was calculated from detected energy values using GAGG scintillators and SiPMs. Gamma-ray incident direction is estimated by three-dimensional mapping of each position’s Compton cones, which is represented by Compton scattering angle θ.

Experiments
137Cs with the energy peak value of 662 keV was used as radiation source. After acquisition of coincidence events, Compton cones were calculated and reconstructed image using back projection method (BP). The staying time at each probe spatial positions were also recorded and calculate sensitivity distribution on projected image. And calibration value was calculated and multiplied to back projection image.

Results
Measurement results indicated the possibility of imaging radiation source, and we achieved spatial resolution 130 mm FWHM at BP image and 61 mm FWHM at sensitivity calibrationed image. To achieve higher spatial resolution, optimization of the detection system is necessary in future.

A Real Time, High Resolution, particle radiography system based on scintillating optical fibers.

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A particle radiography device, designed and developed with the aim of achieving real-time data acquisition and large detection areas, is presented. The prototype is composed by a residual range detector and a tracker. The residual range, consisting of a stack of sixty ribbons of 500 micron square BCF12 scintillating fibers (Sci-Fi), has a sensitive area of about 9 × 9 sqcm and a range of 3 cm water equivalent. Each layer is read-out by two wavelength shifter (WLS) fibers and a 8x8 pixels, 3 sqmm, matrix of Hamamatsu MPPC sensor. The Bragg peak shape is calculated real-time by the time over a suitable threshold for each channel. The tracker, based on 500 micron square BCF12 Sci-Fi has a sensitive area of about 9 × 9 sqcm and about 150 micron spatial resolution. For each particle the crossing position of the tracker and the range is acquired in time coincidence real-time. The results of the measurements taken using the prototypes and a 62 MeV proton beam and a comparison with the GEANT4 simulations of the detector are presented. In order to achieve the prefixed objectives and to determine the main choices, accurate GEANT4 simulations and a precise characterization of different types and sizes of scintillating optical fibers, available on the market, have been performed. Test results of the measurements performed with 62 MeV proton beam of CATANA facility at Laboratori Nazionali del Sud are presented.

Board: 91 / 368

Instrumentation for beam radiation and luminosity measurement in the CMS experiment using novel detector technologies

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The higher energy and luminosity of the LHC initiated the development of dedicated technologies for radiation monitoring and luminosity measurement. A pixelated luminosity detector counts coincidences in several three layer telescopes of silicon pixel detectors to measure the luminosity for each colliding LHC bunch pair. In addition, charged particle tracking allows to monitor the collision point. The upgraded fast beam conditions monitor measures the particle flux using 24 two pad single crystalline diamond sensors, equipped with a fast front-end ASIC produced in 130 nm CMOS technology. The excellent time resolution is used to separate collision products from machine induced background. A new beam-halo monitor at larger radius exploits Cerenkov light produced by relativistic charged particles in fused quartz crystals to provide direction sensitivity and time resolution to separate incoming and outgoing particles. The back-end electronics of the beam monitoring systems includes dedicated modules with high bandwidth digitizers developed in both VME and microTCA standards for per bunch beam measurements and gain monitoring. All new and upgraded sub-detectors have been taking data from the first day of LHC Run II operation in April 2015. Results on their performance and essential characteristics using data since the start-up of LHC will be presented.

Board: 28 / 307

Performance studies under high irradiation and ageing properties of resistive bulk-micromegas chambers at the CERN Gamma Irradiation Facility
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Resistive bulk-micromegas chambers produced at the CERN have been installed at the new CERN Gamma Irradiation Facility (GIF++) in order to study the ageing effects on the chambers performance and evaluate the detector behaviour under high irradiation.

The chambers have an active area of 10 x 10 cm\(^2\), strip pitch of 400 μm, amplification gap of 128μm, and the possibility to adjust the width of the drift gap as needed.

We will present the detector performance as function of the photon rate up to 130 MHz/cm\(^2\). The ageing properties will be showed as function of the integrated charge, as well as studies of the current intensity and its stability with time. Finally, the experimental results will be compared with GEANT simulations in particular for the determination of the detector sensitivity to photons from 137Cs.

primary experiment:

Detector R&D Summary:

We will give an overview of the performance of resistive bulk-micromegas chambers operated in a very high particle rate environment. The chambers have an active area of 10 x 10 cm\(^2\), with strip pitch of 400 μm, amplification gap of 128μm and the possibility to adjust the width of the drift gap as needed. During the test the drift gap was set to 5 mm. The gas mixture used for these chambers corresponds to Ar/CO\(_2\) 93% and 7%, respectively, with a gas flow of 5 l/h. The operational gain is about 5x10^3.

Ageing studies are carried out in a new CERN Gamma Irradiation (GIF++) in the North Area of the Super Proton Synchrotron (SPS) where a 14 TBq 137Cs source is combined with a high-energy particle beam. GIF++ allows to perform long-term ageing studies with a spectrum of primary (662 KeV) and scattered photons from cesium that matches the energy spectrum expected for background in LHC muon detectors.

The facility is being fully operational since spring 2015 and the chambers have been installed there in May 2015.

We will describe the experimental set-up and the ageing properties of the micromegas detectors as function of the integrated charge, including studies of the current intensity and its stability with time. A system of attenuation filters are used to control the 662 keV beam, i.e. the dose that the chambers are exposed to. We will also present the detector performance as function of the photon rate up to maximum, approximate 130 MHz/cm\(^2\).

The result of the efficiency measurements before, during and after the irradiation for a total integrated charge of about 0.1C/cm^2 will be shown as a function of the amplification voltage.

Finally, the experimental results will be compared with GEANT simulations in particular for the determination of the detector sensitivity to photons from 137Cs.

Cryogenic characterization of new Silicon Photomultipliers produced at FBK and their use in DarkSide-20k experiment

Authors: Alberto Gola\(^1\); Alessandro Ferri\(^1\); Alessandro Razeto\(^2\); Andrea Mandarano\(^3\); Claudio Piemonte\(^1\); Claudio Savarese\(^4\); Davide Sablone\(^5\); George Korga\(^5\)
DarkSide-20k is an innovative experiment whose scientific purpose is the direct detection of dark matter in the form of WIMPs. Its design allows to reach a sensitivity of $9 \times 10^{-48}$ cm$^2$ of WIMP-nucleon spin-independent cross section for particles with a mass of 1 TeV/$c^2$. The detector will be a two-phase (liquid-gas) Argon Time Projection Chamber. To detect Argon scintillation light DS-20k will rely on the new technology of Silicon Photomultipliers (SiPM), interesting for the extremely high gain and resolution. The top and the bottom of the TPC will be instrumented with about 15 m$^2$ of SiPMs arranged in 6000 tiles. The SiPMs will be required to work at cryogenic temperatures. This challenging environmental condition modifies in non-trivial ways parameters of the devices that have to be absolutely under control for any experimental purpose. In this poster we will show the characterization at cryogenic temperatures of three new prototypes produced by FBK: Standard Field NUV-HD, Low Field NUV-HD and Low Quenching Resistance RGB-HD. In particular we will focus on the measurement of: dark count rate (DCR), after-pulse (AP) probability, direct and delayed cross-talk (CT) probabilities, break-down voltage, gain and photo detection efficiency (PDE). Pictures and sketches of the experimental setup, with a brief description, will also be produced. Future R&D studies envisioned for SiPMs are described together with the experimental considerations to push on some particular features.

Radiation length imaging with high resolution telescopes

Author: Ulf Stolzenberg

Co-authors: Ariane Frey; Benjamin Schwenker; Carlos Marinas; Florian Jochen Lutticke; Philipp Wieduwilt

The construction of low mass vertex detectors is of high interest for next generation collider experiments like Belle II. Test beam experiments with multi GeV particle beams and high resolution tracking telescopes provide an opportunity to obtain precise 2D images of the radiation length $X/X_0$ of thin planar targets like detector modules. The method developed to measure the radiation length uses hits from the reference telescope and requires no readout of the detector module under study.

At the heart of a spatially resolved $X/X_0$ measurement is a precise reconstruction of the particle’s hit position and scattering angle at the target plane. The main challenges are the alignment of the reference telescope and the calibration of its angular resolution. Systematical uncertainties can be minimized by conducting a calibration measurement, where the module under study is replaced by an aluminium target with a well known thickness profile.

In order to demonstrate the capabilities of $X/X_0$ imaging, a test beam experiment with the AIDA telescope has been conducted at the DESY test beam facility. The device under test was a mechanical prototype of a DEPFET pixel module for the Belle II vertex detector. A data sample of 25 million tracks at 4 GeV has been collected with a rate of 700 Hz within three hours. The data is sufficient to resolve bump bonds below the readout ASICs and to measure the thickness profile of the all-silicon DEPFET module.
The Muon Portal Project: design and construction of a scanning portal based on muon tomography

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P.La Rocca for the Muon Portal Collaboration

Cosmic ray tomography is a technique which exploits the scattering of cosmic muons to perform non-destructive inspection of high-Z materials without the use of artificial radiation. A muon tomography detection system can be used as portal monitor at border crossing points for detecting illegal targeted objects.

The Muon Portal Project is a joint initiative between Italian research and industrial partners, aimed at the construction of a real size detector prototype (6 x 3 x 7 m³) for the inspection of cargo containers by the muon scattering technique. The detector consists of four XY tracking planes, two placed above and two below the container to be inspected. The planes are made of plastic scintillator strips with embedded WLS fibres, which transport the light to custom-designed silicon photomultipliers. A dedicated electronics combine signals from different strips to reduce the overall number of channels, without loss of information. Detailed GEANT4 simulations have been carried out under different scenarios to investigate the response of the apparatus.

After a research and development phase, which led to the choice and test of the individual components, the construction and installation of the detection modules is almost completed. This talk will describe the present status of the Project, focusing on the design and construction phase, as well as on the preliminary results obtained with the first detection planes.

primary experiment: Muon Portal

Summary: The Muon Portal is a recently started project which aims at the construction of a real size tracking detector (about 18 m² surface) for the detection of cosmic muons. This apparatus has been designed to inspect the travelling cargo containers using the muon tomography technique: by measuring the deflection suffered by muons when traversing high-Z materials, it is possible to reconstruct a 3D image of the volume to be inspected and detect the presence of fissile (U, Pu) samples inside containers, in a reasonable amount of time, compatible with the requirement of a fast inspection technique. This is of special concern, due to the new control rules which will be operational in the next years.

The detection setup is based on eight position-sensitive planes (giving X- and Y-coordinates), four placed below and four above the volume to be inspected, with good tracking capabilities for the charged particles (muons and electrons). The overall size of the inspection volume corresponds to that of a real 20'-Box container, namely 6 m x 3 m x 3 m. Compared with similar apparatus designed for the same application by other research groups, the detector of the Muon Portal Project shows some peculiarities inherited from several research fields, making it an innovative detection setup on the whole.

The detection planes are segmented into strips of extruded plastic scintillators with two wavelength-shifting (WLS) fibres in each, to transport the light produced in the scintillator material to the photo-sensors at one of the fibre ends, in order to optimize the amount of collected photons, still maintaining at a reasonable level the cost and the size of the detection setup.

The photo-sensors used are Silicon Photomultipliers (SiPMs) custom-made by STMicroelectronics in order to fit the size of the WLS fibres and match their emission spectrum.

To reduce the overall number of channels (in the order of 10000), the electronics was specifically designed to combine the signals from different fibres in order to reconstruct the muon hits on each plane: their combination is able to unambiguously identify the interested strip inside each module without loss of information for cosmic ray events.

Detailed GEANT4 simulations were carried out in order to investigate the overall response of the apparatus, including the effect of the mechanical supports, the basic structure of the container (roof and doors) and the albedo due to the soil. Secondary cosmic particles are modelled with realistic energy and angular distributions of muons and electrons as derived from CORSIKA simulations for proton-induced showers. The tomographic images are reconstructed developing tracking algorithms and suitable imaging
software tools. Simulations have demonstrated the possibility to reconstruct a 3D image of the volume to be inspected in a reasonable amount of time, compatible with the requirement of a fast inspection technique 2.

Due to the large acceptance of the detector for cosmic rays, coupled to the good angular reconstruction of the muon tracks, it is also planned to employ such detector for cosmic ray studies, complementing its detection capabilities with a set of trigger detectors located at some distance from it, in order to measure multiple muon events associated to extensive air showers.

The 48 detection modules have been completed and partially installed on the mechanical structure [3, 4, 5]. A first campaign of measurement is ongoing to evaluate the performance of the detection planes already installed.

For further details visit our Web site: http://muoni.oact.inaf.it


P. La Rocca et al., Journal of Instrumentation 9, C01056 (2014)

C.Pugliatti et al., Journal of Instrumentation 9, C05029 (2014)

G.V.Russo et al., Journal of Instrumentation 9, P11008 (2014)

**Development of TOF-PET using Compton scattering by plastic scintillators**

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Positron Emission Tomography (PET) is an effective method of cancer diagnostics. One of the major approaches to improve the spatial resolution is the time-of-flight technique (TOF), where the initial position of back-to-back γ-rays is constrained by the differences in arrival time. Better time resolution could achieved with faster scintillators due to less time jitter. Hence, we focused on a plastic scintillator having a time constant faster than that of typical inorganic scintillators used in PET scanners. We thus propose TOF-PET using Compton scattering with plastic scintillators. Compton-PET consists of inner scattering and outer absorbing layers, made of plastic and inorganic scintillators, respectively. When we obtain the position and energy deposit for both scattering and absorption point, we can estimate the incident direction in a conical shape.

As the first step, we made a pair of timing measurement systems, that used 3 × 3 × 3 mm$^3$ scintillators and 3 × 3 mm$^2$ MPPCs. We compared the time resolution of the plastic scintillator with that of LYSO(Ce) and GAGG(Ce) scintillators. The obtained time resolution of each scintillator (FWHM) is 249, 336, and 376 ps, for the plastic, LYSO(Ce) and GAGG(Ce) scintillators, respectively. Plastic scintillators could achieve a time resolution better than that of LYSO(Ce) and GAGG(Ce). Other basic experiments to verify the feasibility of our Compton-PET will be presented.

**Si-PIN radiation detectors with low leakage current, thin incident window and large active area for Nuclear Physics applications.**

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**Co-authors:** David Quirion 2; Giulio Pellegrini 3; Manuel Lozano Fantoba 2
Silicon PIN-type radiation detectors with high resistive substrate were simulated, designed and fabricated for nuclear physics applications. The main design considerations of the Si PIN-type radiation detector were a low leakage current and thin incident window of the p+ and n+ layers. Two technologies have been used to fabricate thin and thick substrates (from 200 µm to 1mm).

The first technology incorporates one extracting ring and a floating guard ring around the active area of the detector in order to obtain leakage current density values of the order of 2 nA/cm²·100µm at full depletion and at room temperature for devices with an active area with hexagonal shape and large about 9 cm².

In the second technology three floating guard electrodes and an edge protection structure were incorporated to increase the breakdown voltage (>1000V) and to minimize the leakage current density to values lower than 2 nA/cm²·100µm for devices with active area of the order of 4 cm². Shallow p+ and n+ layers and thin metal/passivation layers were also incorporated to minimize particles/ions energy loss. The doping profile of the p+ and n+ layers were measured by means of SIMS technique and the detectors have been electrically characterized. Experimental results will be presented and discussed.

**ATLAS Transition Radiation Tracker (TRT): Straw Tubes for Tracking and Particle Identification at the Large Hadron Collider**

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The ATLAS Transition Radiation Tracker (TRT) is the outermost of the three inner detector tracking subsystems and consists of ~300000 thin-walled drift tubes ("straw tubes") that are 4 mm in diameter. The TRT system provides ~30 space points with ~130 micron resolution for charged tracks with |η| < 2 and pT > 0.5 GeV/c. The TRT also provides electron identification capability by detecting transition radiation (TR) X-ray photons in a Xe-based working gas mixture. Performance of the TRT in the LHC Run 1 was studied and will be presented in this report. The LHC luminosity in Run 2 will be significantly increased and the TRT will operate at very challenging conditions of high particle fluxes. In these conditions TRT occupancy will be significantly higher than in Run 1. Significant effort to prepare TRT operation in Run 2 was done in many areas and the results of these efforts will be presented in the talk. Expected TRT particle identification and tracking performance will also be presented.

**Measurement of the two track separation capability of hybrid pixel sensors**

**Authors:** Francisca Muñoz Sánchez¹ ; Marco Battaglia²

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Large Hadron Collider experiments face new challenges in Run-2 conditions due to the increased beam energy, the interest for searches of new physics signals with higher jet $p_T$ and the consequent longer decay length of heavy hadrons. In this new scenario, the capability of the innermost pixel sensors to distinguish tracks in very dense environment becomes crucial for efficient tracking and flavour tagging performance. In this talk, we discuss the measurement of the two track separation capability of hybrid pixel sensors using the interaction particles out of the collision of high energy pions on a thin copper target. With this method we are able to evaluate the effect of merged hits in the sensors under test due to tracks closer than the sensor spatial granularity in terms of collected charge, multiplicity and reconstruction efficiency for different incidence angles and relative distances in between the DUT and the target. Two pixel detector technologies, 3D silicon and new planar from the qualification batch of the ATLAS-IBL detector, were studied.

SuperNEMO - a new generation of underground experiments for double beta-decay investigations

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The SuperNEMO experiment is dedicated to the search for neutrinoless double beta-decay which would imply, if observed, violation of the lepton number conservation, could give unique information on the neutrino mass hierarchy, and state if neutrinos are Majorana particles, confirming thus the existence of physics beyond the Standard Model. The SuperNEMO experiment builds upon the design and experience from the NEMO-3 experiment. It is based on the tracking and calorimetry techniques, which allow the reconstruction of the final state topology, including timing and kinematics of the double beta-decay transition events, offering a powerful tool for background rejection. Upgrades to the detector technologies, improved radiopurity of construction materials, and a significant increase in source mass will allow SuperNEMO to improve half-life sensitivities by two orders of magnitude. The experiment will use about 100 kg of enriched $^{82}\text{Se}$ source with the total exposure of 500kg·yr to probe the half-life sensitivity $T_{0\nu} = 1\times10^{26}$ years with the corresponding sensitivity on the effective neutrino mass of $40 - 100$ meV. An overview of the progress in the construction of the SuperNEMO demonstrator module and the improvements foreseen compared to the NEMO-3 experiment will be presented.

primary experiment:
double beta-decay

Upgrade of the CMS muon trigger system in the barrel region

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To continue triggering with the current performance in the LHC’s Run-2 the Level-1 Trigger of the Compact Muon Solenoid experiment will have to undergo a significant upgrade. One part of this upgrade is the reorganisation of the muon trigger path from a subsystem-centric view in which hits in the Drift Tubes (DT), the Cathode Strip Chambers (CSC), and the Resistive Plate Chambers (RPC) were treated separately in dedicated track-finding systems to one in which complementary detector systems for a given region (barrel, overlap, and endcap) are merged at the track-finding level. This in turn requires the development of a new system to sort as well as cancel-out the muon tracks found by each system.

An overview will be given of the new Track-finder system for the barrel region, the Barrel Muon Track Finder (BMTF) as well as the cancel-out and sorting layer, the upgraded Global Muon Trigger (uGMT). Both the BMTF and uGMT will be implemented in a Xilinx Virtex-7 card utilizing the uTCA architecture. While the BMTF will improve on the proven and well-tested algorithms used in the Drift Tube Track Finder during Run-1, the uGMT is an almost complete re-development due to the re-organisation of the underlying systems from complementary track finders to regional track finders. Additionally the uGMT will calculate a muon’s isolation using energy information received from the calorimeter trigger. This information is added to the muon objects forwarded to the Global Trigger.

Overview of the Micro Vertex Detector for the PANDA experiment

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The fixed target experiment PANDA will use cooled antiprotons that will be available at FAIR in Darmstadt. Its innermost tracker is the Micro Vertex Detector (MVD), specially designed to ensure the secondary vertex resolution for the discrimination of short-lived charmonium states. Hybrid epitaxial silicon pixels and double sided silicon microstrips will equip four barrels surrounding the interaction point and six forward disks.

The experiment features a triggerless architecture with a 160 MHz clock signal, therefore the MVD has to run with a continuous data transmission with hits which will have precise timestamps. In addition the energy loss of the particles in the sensor will be measured as well. The challenging request of a triggerless readout suggested to develop custom readout chips for both pixel (ToPix) and microstrip (PASTA) devices.

The powering and cooling of the readout are challenging since the routing and the MVD services are foreseen in the backward region only.

Since the simulations show that the main component affecting the material budget of the MVD is the cabling, aluminum interconnections are foreseen instead of copper in the active volume. The support structures are made of carbon fibers and highly thermal conductive carbon foam with embedded cooling pipes underneath the readout chips. Detector prototypes have been built and tested to validate the design of each component and the triggerless readout. An overview of the project will be reported.

The diamond time of flight detector of the TOTEM experiment

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This contribution describes the upgrade project of the TOTEM Collaboration to measure the time of flight (TOF) of leading protons in the vertical Roman Pots (RPs). The aim of the upgrade is to improve the ability of the experiment to tag and select Central Diffractive (CD) processes. The installation of a TOF detector inside the RP will allow to determine the position of the vertex where the CD protons are produced, thus allowing the protons’ association with one of the vertices reconstructed by the CMS detectors. In this contribution the TOF detectors developed for this purpose, based on scCVD diamond sensors, will be presented. The detectors will measure the protons’ TOF with 50 ps time resolution. To achieve this performance, a dedicated fast and low-noise electronics for the signal amplification has been designed. Indeed, while diamond sensors have lower noise and faster signals than silicon sensors, the amount of charge released in the medium is lower. The ADC of the diamond signal is performed with the SAMPIC chip, which performs a sampling of the waveform up to 10 Gsa/s. The clock distribution system, based on the Universal Picosecond Timing System developed at GSI, is optimized to reduce the uncertainty on the TOF measurement to a negligible level. An overview of the control system which interfaces the timing detectors to the experiment DAQ is finally given together with the measurements performed in several test beams where satisfactory results were obtained.

Development of a cryogenic x-ray detector for a kaon mass measurement.

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The ASPE!CT project (Adaptable Spectrometer Enabled by Cryogenic Technology) is developing a commercially viable, cryogenic platform addressed to a wide range of cryogenic sensors. The cryogen-free, adiabatic demagnetization refrigerator is specially designed for use with cryogenic detectors at sub-Kelvin temperatures. The project pushes the technology into the realm of reliable, compact, touch-button devices. The prototype detector stage is designed to operate with a specially developed cryogenic sensor (e.g. Magnetic Penetration Thermometer) which will be optimized to achieve a resolution of about 10 eV at the energies range typically created in kaonic atoms experiments (~10keV). The mid-term target is to lower the temperature range and to introduce continuous, high-power, low-temperature cooling, to bring a high-resolution cryogenic spectrometer system to the market. Later stages of the project should see an optimized experimental set-up performing high-resolution kaon-mass measurements in a beam to be provided by the J-PARC (Tokai, Japan) or DAΦNE (Frascati, Italy)

The RPWELL - a robust gaseous radiation detector

Author: Shikma Bressler¹
Co-authors: Amos Breskin ¹; Dan Shaked-Renous ¹; Jana Schaarschmidt ¹; Lior Arazi ¹; Luca Moleri ²
The RPWELL detector is a single-sided THGEM (copper clad on one side only) coupled to the readout electrode through a sheet of large bulk resistivity. In the last two years, laboratory and accelerator studies were performed in various single-element, RPWELL prototypes with a large variety of Ne- and Ar-based gas mixtures; these have demonstrated its large dynamic range (from single electrons to thousand-times MIPS), high gains (> 106), and high detection efficiency over a broad particle-flux range. The RPWELL operation under these conditions was stable, with MIP detection efficiency > 98%, with no observable discharges. This makes it an attractive, industrially mass-produced detector for large-area applications in particle, astroparticle and nuclear physics, as well as in homeland security.

We will further discuss the preliminary performance of RPWELL-based UV-photon detectors, with CsI-coated electrodes; among potential benefits for this application are the high sensitivity to single photoelectrons and large dynamic range (discharge-free operation under highly ionizing background).

**primary experiment:**
Not yet defined

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**Overview of large-area gas electron multiplier detectors for the forward muon system of the CMS experiment at the high-luminosity LHC**

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We report on the status of the project to install large-area triple-foil gas electron multiplier (GEM) detectors in the end-cap muon system of the Compact Muon Solenoid (CMS) experiment at the LHC operating at the high luminosity planned after the current period of data-taking (run 2). In the pseudo-rapidity region 1.6 < \eta < 2.4, the GEM detectors will suppress the rate of background triggers while maintaining high trigger efficiency for low transverse momentum muons, and enhancing the robustness of muon detection in the high-flux environment of the end-cap region. GEM detectors will also be used to extend the range of muon identification up to about \eta = 3.0.

We describe the design of the GEM chambers, readout electronics, and data acquisition system for the three stations in each endcap, located at increasing distances from the interaction point. For the intermediate station, the design is fixed and we describe plans to install several of the intermediate station detectors in the CMS detector during the current data-taking period, run 2.

We describe the design and requirements for GEM (and other micro-pattern gas detector) systems for the innermost and outermost stations. Compact, fast-timing designs are under consideration for the innermost station. Mechanical design for the outermost station, which requires the largest detector area of the three stations, is also described.

**primary experiment:**
CMS

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**Signal formation in irradiated silicon detectors**

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Radiation damage in silicon detectors results into three main changes of the detector performance: a variation of the effective doping concentration, an increase in the leakage current, and a decrease in the charge collection efficiency. These effects are the measurable consequences of the creation of defects in the silicon lattice, which act as either sources or sinks of charge carriers. Deep defects acting as generation centres are responsible for the leakage current, while the trapping phenomena lowering the charge collection efficiency can be caused by any kind of defect, the most effective being the ones with a high capture cross section and detrapping time. The change in the effective doping concentration is a result of two processes: dopant removal and introduction of ionized defects. All these effects contribute to distort the signal generated by impinging MIP particles, making the detailed studies of these changes very important in the design of future detectors and associated electronics.

We have implemented in the Weightfield2 simulation program the effect of charge trapping and the creation, for high doses, of the double junction effect. With this simulation program we have investigated the modifications of the signal from MIP particles for increasing doses. We have applied this study to the Low-Gain Avalanche silicon Detectors (LGAD), and we have demonstrated how internal gain might compensate for the reduced charge collection efficiency.

A Multi-Purpose Active-Target Particle Telescope for Radiation Monitoring

Continuous monitoring of the radiation background is a key requirement in many applications. Traditional detectors can either measure the total radiation dose omnidirectionally (dosimeters), or determine the incoming particles’ characteristics within a narrow field of view (spectrometers). Instantaneous measurements of anisotropic fluxes thus require several detectors, resulting in bulky setups. The multi-purpose active-target particle telescope (MAPT), based on a novel detection principle, can measure particle fluxes omnidirectionally. It consists of an active core of scintillating fibers whose light output is measured by silicon photomultipliers, and fits into a cube with an edge length of 10 cm. It identifies particles using extended Bragg curve spectroscopy, with an overall sensitivity range of 25 to approximately 1000 MeV per nucleon. MAPT’s unique layout results in a geometrical acceptance of about 800 cm²•sr and an angular resolution of 6°, which can be improved by track-fitting procedures. During a first beam test of a simplified prototype, the detector’s energy resolution was found to be less than 1 MeV for protons with energies between 30 and 70 MeV. Possible applications of MAPT include the monitoring of radiation environments in spacecraft, deep space habitats, and ground-based installations. Other use cases are the measurement of energy straggling in medical radiation therapy applications and the monitoring of beam profiles in accelerator facilities.