

# **VCI2016 - The 14th Vienna Conference on Instrumentation**

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## **Book of Abstracts**



# Contents

Welcome . . . . .	1
Opening . . . . .	1
Information from the Organizers . . . . .	1
New Opportunities for the Time Projection Chamber in its Fourth Decade . . . . .	1
Dark Matter Detectors . . . . .	1
Recent Developments in Silicon Detectors . . . . .	1
The ultralight DEPFET Pixel Detector of the Belle II Experiment . . . . .	2
The upgraded Pixel Detector of the ATLAS experiment for Run-2 at the Large Hadron collider. . . . .	2
How can Moore’s Law help making better detectors? . . . . .	3
Development of Ultra Fast Silicon Detector for 4D tracking . . . . .	3
Level-1 track trigger for CMS in HL-LHC . . . . .	4
Art and History of Vienna . . . . .	4
Recent Progress in Photodetectors . . . . .	4
SciFi - A large Scintillating Fibre Tracker for LHCb . . . . .	5
SoLid: An innovative antineutrino detector for searching oscillations at the SCK•CEN BR2 reactor . . . . .	5
From gated to continuous readout: an upgrade of the ALICE TPC . . . . .	5
Strategies for reducing the environmental impact of gaseous detector operation at the CERN LHC experiments . . . . .	6
Liquid xenon calorimeter for MEG II experiment with VUV-sensitive MPPCs . . . . .	7
Radiation Hard Silicon Particle Detectors for HL-LHC – RD50 Status Report . . . . .	7
The kaon identification system in the NA62 experiment at CERN SPS . . . . .	7
30-ps Time Resolution with Segmented Scintillation Counter for MEG II . . . . .	8

New Fast Interaction Trigger for ALICE . . . . .	9
Test-beam and laboratory characterisation of the TORCH prototype detector . . . . .	9
Radiation hardness study of Silicon Detectors for the CMS High Granularity Calorimeter (HGCal) . . . . .	10
Surface effects in segmented silicon sensors . . . . .	10
Graphical processors for HEP trigger systems . . . . .	11
Photon counting with a FDIRC Cherenkov prototype readout by SiPM arrays . . . . .	11
Novel real-time alignment and calibration of the LHCb detector and its performance . . . . .	12
LHCb VELO: Radiation Damage Effects and Operations in LHC Run 2 . . . . .	12
CLASSIC: Cherenkov Light detection with SiC . . . . .	13
The LHCb VELO Upgrade . . . . .	14
A novel Silicon Photomultiplier with bulk integrated quench resistors - utilization in optical detection and tracking applications for particle physics . . . . .	14
A detector for in-beam measurement of the ground state hyperfine splitting of antihydrogen . . . . .	15
The MoEDAL detector - a totally different LHC detector . . . . .	15
Performance of the latest prototypes of NUV-HD Silicon Photomultipliers . . . . .	16
A new timing detector for the CT-PPS detector of CMS . . . . .	16
Improving the Time Resolution in Cherenkov TOF PET with SiPMs . . . . .	17
Imaging the LHC beams with silicon and scintillating fibre vertex detectors . . . . .	17
The Belle II SVD assembly and mechanics . . . . .	18
Study of the breakdown voltage of SiPMs . . . . .	18
The Silicon Tracking System of the CBM experiment at FAIR . . . . .	18
Stability monitoring of historical buildings with a cosmic ray tracking system . . . . .	19
Summary of Medipix Technology's 3-Years in Space and Plans for Future Developments . . . . .	19
FoCal - a high-granularity electromagnetic calorimeter for forward direct photon measurements at LHC . . . . .	20
Ion space-charge effects in multi-GEM detectors: challenges and possible solutions for future applications . . . . .	21
The KLOE-2 Inner Tracker: detector commissioning and operation . . . . .	21
Large area CNT-Si heterojunction for photodetection . . . . .	22
The upgrade of the BelleII forward calorimeter . . . . .	22

A Novel Technique for the Measurement of the Avalanche Fluctuation of Gaseous Detectors . . . . .	23
Shower characteristics of particles with momenta up to 150 GeV in the CALICE scintillator-tungsten HCAL . . . . .	23
Characterization of a large CdZnTe coplanar quad-grid semiconductor detector . . . . .	24
Performance in electron beams of a tungsten-CeF <sub>3</sub> prototype for radiation-resistant high-energy physics calorimetry . . . . .	24
First prototypes of two-tier avalanche pixel sensors for particle detection . . . . .	25
Two-phase Cryogenic Avalanche Detector with electroluminescence gap and THGEM/GAPD-matrix multiplier . . . . .	26
Tremendously Increased Lifetime of Microchannel-Plate PMTs . . . . .	26
The ATLAS ITK strip detector - status of R&D . . . . .	27
Construction and Test of New Precision Drift-Tube Chambers for ATLAS Muon Spectrometer Upgrades . . . . .	27
Development of an extremely thin-wall straw tracker operational in vacuum - The COMET Straw Tracker System - . . . . .	28
Upgrades of the CMS outer tracker detector for the HL-LHC . . . . .	29
Behaviour of hybrid avalanche photo-detector for the Belle II Aerogel RICH in magnetic field . . . . .	29
Development of solar blind UV extended APD for the readout of Barium Fluoride crystals	30
AXEL - high pressure xenon gas TPC for neutrinoless double beta decay search . . . . .	30
Exploring the quality of latest sensor prototypes for the CMS Outer Tracker Upgrade . . . . .	31
GridPix detector - Development and Application . . . . .	31
The Phase-1 Upgrade of the CMS Pixel Detector . . . . .	31
Detection of High Energy Cosmic Rays with the Auger Engineering Radio Array . . . . .	32
Pixel Sensors with slim edges and small pitches for the CMS upgrades for HL-LHC . . . . .	32
Performance studies of resistive Micromegas detectors for the upgrade of the ATLAS Muon Spectrometer . . . . .	33
Operation and performance of the EEE network array for the detection of cosmic rays . . . . .	33
Thin hybrid pixel assembly fabrication development with backside compensation layer . . . . .	34
The Mini-EUSO telescope on the ISS . . . . .	34
Anode charge-up in resistive Micromegas and its quenching effect on spark development	35
The NA62 GigaTracker . . . . .	35

CaloCube: a new-concept calorimeter for the detection of high-energy cosmic rays in space . . . . .	36
LHM: a new noble-liquid detector concept based on bubble-assisted electroluminescence	36
Testbeam results of the first real time embedded tracking system with artificial retina . . .	37
Test beam results of 3D detectors constructed with single-crystal and poly-crystalline diamond . . . . .	37
Upgrade of the ATLAS Muon Spectrometer for Operation at the HL-LHC . . . . .	38
Progress and questions about sCVD Diamond Detectors for Particle Tracking . . . . .	38
Advances in micro-Resistive WELL ( $\mu$ -RWELL) detectors . . . . .	39
Electronics Development for the ATLAS Liquid Argon Calorimeter Trigger and Readout for Future LHC Running . . . . .	39
R&D on a new type of micropattern gaseous detector: the Fast Timing Micropattern detector . . . . .	40
The ALPIDE Pixel Sensor Chip for the Upgrade of the ALICE Inner Tracking System . . .	40
State of the art time resolution in TOF-PET detectors for various crystal sizes and types .	41
The COSINUS project: development of new NaI-based cryogenic detectors for direct dark matter search . . . . .	42
From Vertex detectors to Inner Trackers with CMOS pixel sensors . . . . .	42
SABRE: WIMP Modulation Detection in the Northern and Southern Hemisphere . . . . .	43
Current development status of High Voltage and High Resistivity CMOS technology for high energy physics applications . . . . .	43
Development of High-Resolution Detector Module with Depth of Interaction Identification for Positron Emission Tomography . . . . .	44
Recent results with HV-CMOS and planar sensors for the CLIC vertex detector . . . . .	44
WIMP tracking with cryogenic nuclear emulsion . . . . .	45
The SAFIR project: Status and perspectives . . . . .	45
Intraoperative probe for radioguided surgery with beta- decays in brain tumor resection	46
The MuPix HV-MAPS system-on-chip for the Mu3e experiment . . . . .	46
PROSPECTS FOR DETECTION OF WIMP DARK MATTER AND COHERENT NEUTRINO SCATTERING WITH THE LUX-ZEPLIN DETECTOR . . . . .	47
A low mass vertically integrated pixel system for the HL-LHC . . . . .	47
Operating performance of GCT: an end-to end Schwarzschild-Couder telescope prototype for the Cherenkov Telescope Array . . . . .	48
proton Computed Tomography images with algebraic reconstruction . . . . .	48

Design of a tracking device for on-line dose monitoring in hadron therapy . . . . .	49
New application of superconductors: high sensitivity cryogenic light detectors . . . . .	50
Improved Process Technologies in the SOI Pixel Detectors . . . . .	50
The iMPACT project tracker and calorimeter . . . . .	51
Performance of M <sup>o</sup> NCH, a 25- $\mu$ m pixel pitch detector for photon science . . . . .	52
Performance study of glass RPC detectors for INO-ICAL experiment. . . . .	52
The FLARES project: an innovative detector technology for rare events searches . . . . .	53
The DEPFET Detector-Amplifier Structure for Spectroscopic Imaging in Astronomy and for Experiments at Free Electron Lasers . . . . .	53
Development of a compact scintillator-based high-resolution Compton camera for molec- ular imaging . . . . .	54
Detector requirements for a 100-TeV collider . . . . .	54
Prospective overview of the CEPC detector . . . . .	55
Status and future perspectives of the ILC project . . . . .	55
Studies on Gas Electron Multiplier (GEM) modules of a Large Prototype TPC for the ILC	55
The Jiangmen Underground Neutrino Observatory . . . . .	56
Detector evolution for Gravitational Waves observations . . . . .	56
A new cryogenic detector for low mass dark matter search with CRESST-III . . . . .	57
Development of a composite large-size SiPM (assembled matrix) based modular detector cluster for MAGIC . . . . .	57
Construction and tests of an in-beam PET-like detector for hadrontherapy beam ballistic control. . . . .	58
Award Ceremony . . . . .	58
Summary Talk . . . . .	58
Closing . . . . .	59
Information from the Organisers . . . . .	59
Test of microchananel plates in magnetic field up to 4.5 Tesla. . . . .	59
Exploring the limits of time resolution in Cherenkov detection of electron-positron annihi- lation events . . . . .	59
Development of hole-type MPGD with funnel-capillary plate . . . . .	60
Vacuum-Compatible, Ultra-Low Material Budget Micro Vertex Detector of the Compressed Baryonic Matter Experiment at FAIR. . . . .	60

Design and properties of electronmagnetic particle detectors of LHAASO-KM2A . . . . .	61
A Custom Real-Time Ultrasonic Instrument for Simultaneous Mixture and Flow Analysis of Binary Gases in the CERN ATLAS Experiment . . . . .	61
Novel applications and future perspectives of a fast diamond gamma-detector . . . . .	62
Ultra-cold neutron detector for the spectrometer of the neutron lifetime measurement . . . . .	63
CVD Diamond Metallization and Characterization . . . . .	63
Low Energy Proton Detector Using APDs for the PENeLOPE Experiment . . . . .	64
Upgade of the ATLAS hadronic calorimeter for high-luminosity LHC run . . . . .	64
MONDO: a neutron tracker for particle therapy secondary emission fluxes measurements . . . . .	65
Measurement of 1.7 to 74 MeV polarised gamma rays with the HARPO TPC . . . . .	65
Development of an Event-driven SOI Pixel Detector for X-ray Astronomy - Improvement of an Intra-chip Readout Circuit for Low Noise Performance - . . . . .	66
easyPET: an innovative concept for an affordable tomographic system . . . . .	67
Development of High Temperature, Radiation Hard Detectors Based on Diamond. . . . .	67
Controlling kilometer-scale interferometric detectors for gravitational wave astronomy . . . . .	68
High temperature dependence of charge carrier properties in CVD diamond . . . . .	68
Fabrication and Characterization of Rectangular Strontium Iodide Scintillator Coupled to TSV-MPPC array . . . . .	69
Timepix3 as X-ray detector for time resolved synchrotron experiments . . . . .	69
CMS Alignment and Calibration . . . . .	70
Experience from design, prototyping and production of a DC-DC conversion powering scheme for the CMS Phase-1 Pixel Upgrade . . . . .	70
The wide-aperture gamma-ray telescope TAIGA-HiSCORE in the Tunka Valley: design, composition and commissioning. . . . .	70
Characterization of Neutral Trapped Antihydrogen in the ALPHA Experiment . . . . .	71
GaAs detectors with an ultra-thin Schottky contact for spectrometry of charged particles . . . . .	71
A survey on GEM-based readouts and gas mixtures for optical TPCs . . . . .	72
A setup to measure ion mobility in Argon and Neon based gas mixtures . . . . .	73
Linearity performance of small-cell SiPMs for prompt gamma imaging application . . . . .	73
A 16-ch module for thermal neutron detection using ZnS:6LiF scintillators with embedded WLS fibers coupled to SiPMs and its dedicated readout electronics . . . . .	74
The Calorimeter System of the new muon g-2 experiment at Fermilab . . . . .	74



Validation of a highly integrated PET readout system scalable to several 10'000 channels	74
Development of a pixel sensor with fine space-time resolution based on SOI technology for the ILC vertex detector	75
Breakdown voltage and triggering probability of SiPM from IV curves	76
Precision Muon Tracking Detectors for High-Energy Hadron Colliders	76
Scintillating bolometric technique for the neutrino-less double beta decay search: the LUCIFER experiment	77
Radiation hard ceramic based Resistive Plate Chambers for forward TOF and T0 systems	77
Status of production for KamLAND-Zen 800 kg phase	77
Photon counting detector for the personal radiography inspection system "SIBSCAN"	78
Study of spatial resolution of low-material GEM tracking detectors	78
High Performance Embedded System for Real-Time Pattern Matching	79
Simulation of 3D Diamond Detectors	79
A solution for the inner area of CBM-TOF with pad-MRPC	80
The investigation of the internal structure of SiPM from KETEK, ZECOTEK, HAMAMATSU and SENSL companies after the neutron irradiation.	80
Scintillating Fiber Detectors for Precise Time and Position Measurements Read Out with Si-PMs	81
SiPM and front-end electronics performance for Cherenkov Telescope Array camera development	81
Laser processing in 3D Diamond Detectors	82
Development of the microstrip silicon detector for imaging of explosions at a synchrotron radiation beam.	82
The Belle II SVD Data Readout System	83
The CBM RICH project	83
Measurement of gamma-ray production from neutron capture on Gadolinium for neutrino experiments	84
Development of a Position-Sensitive Gamma-ray Camera Using Novel Scintillator and an MPPC	84
A new method for the neutron lifetime measurement	85
Beam test results on the detection of single particles and electromagnetic showers with microchannel plates	85
Novel PMTs of worldwide best parameters for the CTA project	86
Neutron detection in the frame of spatial magnetic spin resonance	86

Characterization and commissioning of the SST-1M camera for the Cherenkov Telescope Array . . . . .	87
Application of a Transient-Current-Technique based on a Two-Photon-Absorption process to the characterization HV-CMOS, LGAD and irradiated PIN sensors . . . . .	88
High sensitivity particle tracker based on optically readout GEM . . . . .	88
Development of CANDLES detector to search for neutrinoless double beta decay of $^{48}\text{Ca}$ . . . . .	89
Optimization of thin n-in-p planar pixel modules for the ATLAS upgrade at HL-LHC . . . . .	89
The CMS Level-1 Trigger Upgrade . . . . .	90
The TAIGA observatory - a hybrid detector array for gamma-ray astronomy and cosmic ray physics in the Tunka valley . . . . .	90
Longitudinally segmented shashlik calorimeter with SiPM readout . . . . .	91
Prototype sensors for intelligent module with integrated on-chip logic using strip and pixel sensors for CMS tracker phase-II upgrade . . . . .	91
A micropixel avalanche phototransistor for time of flight measurements . . . . .	92
Test beam results of the CMS 2S pT-module prototypes using the CBC2 read-out chip . . . . .	92
New Developments in the design and production of Low Gain Avalanche Detectors . . . . .	92
Study of the performance of a compact sandwich calorimeter for the instrumentation of the very forward region of a future linear collider detector . . . . .	93
Study of the light production mechanism of epoxy resins in an electric field . . . . .	94
The performance for the TeV photon measurement of the LHCf upgraded detector using $\text{Gd}_2\text{SiO}_5$ (GSO) scintillators. . . . .	94
High rate, fast timing Glass RPC for the high eta CMS muon detectors . . . . .	95
Cathode Drift Chambers for the GlueX experiment at Jefferson Lab . . . . .	95
A new imaging atmospheric Cherenkov camera for the H.E.S.S. telescopes . . . . .	96
Strip defect recognition in electrical tests of silicon microstrip sensors . . . . .	97
Electro-optical characterization of the first RGB-UHD SiPMs for improved radiation hardness . . . . .	97
A 65 nm CMOS analog processor with zero dead time for future pixel detectors . . . . .	98
Development of a PET Insert for Human Brain Imaging: Detection System . . . . .	98
Low material budget floating strip Micromegas for ion transmission radiography . . . . .	99
PANDA Barrel DIRC design performance studies . . . . .	100
Level Zero Trigger Processor for the ultra rare Kaon decay experiment - NA62 . . . . .	100
Feasibility study of a Single Probe Compton Camera for Laparoscopic Surgery . . . . .	101

A Real Time, High Resolution, particle radiography system based on scintillating optical fibers. . . . .	101
Instrumentation for beam radiation and luminosity measurement in the CMS experiment using novel detector technologies . . . . .	102
Performance studies under high irradiation and ageing properties of resistive bulk-micromegas chambers at the CERN Gamma Irradiation Facility . . . . .	102
Cryogenic characterization of new Silicon Photomultipliers produced at FBK and their use in DarkSide-20k experiment . . . . .	103
Radiation length imaging with high resolution telescopes . . . . .	103
The Muon Portal Project: design and construction of a scanning portal based on muon tomography . . . . .	104
Development of TOF-PET using Compton scattering by plastic scintillators . . . . .	105
Si-PIN radiation detectors with low leakage current, thin incident window and large active area for Nuclear Physics applications. . . . .	105
ATLAS Transition Radiation Tracker (TRT): Straw Tubes for Tracking and Particle Identification at the Large Hadron Collider . . . . .	106
Measurement of the two track separation capability of hybrid pixel sensors . . . . .	106
SuperNEMO - a new generation of underground experiments for double beta-decay investigations . . . . .	106
Upgrade of the CMS muon trigger system in the barrel region . . . . .	107
Overview of the Micro Vertex Detector for the PANDA experiment . . . . .	108
The diamond time of flight detector of the TOTEM experiment . . . . .	108
Development of a cryogenic x-ray detector for a kaon mass measurement. . . . .	108
The RPWELL - a robust gaseous radiation detector . . . . .	109
Overview of large-area gas electron multiplier detectors for the forward muon system of the CMS experiment at the high-luminosity LHC . . . . .	109
Signal formation in irradiated silicon detectors . . . . .	110
A Multi-Purpose Active-Target Particle Telescope for Radiation Monitoring . . . . .	111



434

## Welcome

435

## Opening

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436

## Information from the Organizers

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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  $^{136}\text{Xe}$ . 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.

Plenary 1 / 444

## Dark Matter Detectors

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Plenary 2 / 445

## 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.

Plenary 2 / 96

## 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 KEBK.

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  $\mu\text{m}$  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.

Plenary 2 / 247

## 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 read-out 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.

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.

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 obtain 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  $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , 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 read-out 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 m<sup>2</sup> 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.

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.

## Plenary 3 / 189

**From gated to continuous readout: an upgrade of the ALICE TPC****Authors:** Nikolai Smirnov<sup>1</sup>; Piotr Gasik<sup>2</sup>**Co-author:** Richard Majka<sup>1</sup><sup>1</sup> *Yale University*<sup>2</sup> *Technische Universitaet Muenchen (DE)***Corresponding Author:** p.gasik@cern.ch

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,  $dE/dx$  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.

## Plenary 3 / 296

**Strategies for reducing the environmental impact of gaseous detector operation at the CERN LHC experiments****Authors:** Beatrice Mandelli<sup>1</sup>; Mar Capeans Garrido<sup>1</sup>; Roberto Guida<sup>1</sup><sup>1</sup> *CERN***Corresponding Author:** beatrice.mandelli@cern.ch

A wide range of gas mixtures is used for the operation of different gaseous detectors at LHC. Nowadays some of these gases, as C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>, CF<sub>4</sub> and SF<sub>6</sub>, 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 CF<sub>4</sub> 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.

## Plenary 3 / 375

**Liquid xenon calorimeter for MEG II experiment with VUV-sensitive MPPCs**Author: Shinji Ogawa<sup>1</sup><sup>1</sup> University of Tokyo (JP)

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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.

## Semiconductor Detectors / 315

**Radiation Hard Silicon Particle Detectors for HL-LHC – RD50 Status Report**Author: Stefano Terzo<sup>1</sup><sup>1</sup> Max-Planck-Institut fuer Physik (Werner-Heisenberg-Institut) (D)

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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.

## 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.

Miscellaneous 1 / 199

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

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We have developed a timing detector with a  $\sim 30$  ps time resolution for the measurement of  $\sim 50$  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  $\sim 10^8/s$  muon beam, whose results will also be reported.

Miscellaneous 1 / 63

## New Fast Interaction Trigger for ALICE

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The LHC heavy-ions luminosity and collision rate from  $\sim 2020$  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:  $\sim 800$  mm from IP on the absorber side and  $\sim 3200$  mm from IP on the opposite side. Scheduled for installation  $\sim 2019$ , 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.

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 30m<sup>2</sup>, 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 there 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.

**Semiconductor Detectors / 44**

## Radiation hardness study of Silicon Detectors for the CMS High Granularity Calorimeter (HGCAL)

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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 cm<sup>2</sup> with an active thickness between 100µm and 300µm depending on the position respectively the expected radiation levels. For an integrated luminosity of 3000 fb<sup>-1</sup> and in the region  $\eta \sim 3$ , the electromagnetic calorimetry near shower max will sustain integrated doses of 1.5 MGy (150 Mrads) and neutron fluences of 10<sup>16</sup> n/cm<sup>2</sup>. 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/cm<sup>2</sup> 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.

**Semiconductor Detectors / 254**

## 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-SiO<sub>2</sub> 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.

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 GPUDirect 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.

Cherenkov / 62

## Photon counting with a FDIRC Cherenkov prototype readout by SiPM arrays

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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.

**Miscellaneous 1 / 101**

## **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.

**Semiconductor Detectors / 412**

## **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- $n$   $300 \mu\text{m}$  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 ( $\sim 8$  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.

**Cherenkov / 256**

## **CLASSIC: Cherenkov Light detection with SiC**

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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.

**Semiconductor Detectors / 382**

## The LHCb VELO Upgrade

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The upgrade of the LHCb experiment, scheduled for LHC Run-3, will transform the experiment to a triggerless

system reading out the full detector at 40 MHz event rate.

All data reduction algorithms will be executed in a high-level software farm.

enabling the detector to run at luminosities of  $2 \times 10^{33}/\text{cm}^2/\text{s}$ .

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  $55 \times 55 \mu\text{m}^2$  pitch, and are read out by the VeloPix ASIC, from the Timepix/Medipix family.

The hottest region will have pixel hit rates of 900 Mhits/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<sub>2</sub> 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.

**SiPM / 294**

## A novel Silicon Photomultiplier with bulk integrated quench resistors - 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.

Miscellaneous 2 / 373

## 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.

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).

**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  $\mu\text{m}$ , 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  $\mu\text{m}$  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.

**Semiconductor Detectors / 268**

## **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 Cherenkov 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 (Barcelona) 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.

SiPM / 326

## 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.

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.

**Semiconductor Detectors / 266**

## The Belle II SVD assembly and mechanics

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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.

**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  $15 \times 15$ ,  $25 \times 25$  and  $50 \times 50 \mu\text{m}^2$  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  $-20 \text{ }^\circ\text{C}$  and  $+20 \text{ }^\circ\text{C}$ . From the PA spectra the gain,  $G(V)$ , and from a linear fit to  $G(V)$ , the gain-breakdown voltage,  $V_{\text{bd}}^{\text{G}}$ , have been obtained. From fits to the I-V curves with and without LED illumination below and above breakdown, the current-breakdown voltage,  $V_{\text{bd}}^{\text{I}}$ , has been determined. It is found that there is a significant difference between  $V_{\text{bd}}^{\text{G}}$  and  $V_{\text{bd}}^{\text{I}}$ . The difference  $V_{\text{bd}}^{\text{I}} - V_{\text{bd}}^{\text{G}}$  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  $V_{\text{bd}}^{\text{I}} - V_{\text{bd}}^{\text{G}}$  difference is presented.

**Semiconductor Detectors / 227****The Silicon Tracking System of the CBM experiment at FAIR****Author:** Anton Lymanets<sup>1</sup><sup>1</sup> *GSI, Darmstadt***Corresponding Author:** anton.lymanets@cern.ch

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  $2\ \text{m}^3$  at below  $-5^\circ\text{C}$  so that its silicon sensors remain operational up to a particle fluence of  $10^{14}$  1-MeV  $n_{eq}/\text{cm}^2$ . The electronics inside, about 16 thousand ASICs with more than 2 million readout channels, will dissipate about 40 kW power. Bi-phase  $\text{CO}_2$  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.

**Miscellaneous 2 / 80****Stability monitoring of historical buildings with a cosmic ray tracking system****Authors:** Aldo Zenoni<sup>1</sup>; Antonietta Donzella<sup>1</sup>; Davide Pagano<sup>2</sup>; Francesco Fallavolita<sup>3</sup>; Germano Bonomi<sup>2</sup>; Paolo Vitulo<sup>4</sup><sup>1</sup> *University of Brescia*<sup>2</sup> *Universita di Brescia (IT)*<sup>3</sup> *University of Pavia*<sup>4</sup> *Università Pavia & INFN***Corresponding Author:** davide.pagano@unibs.it

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.

**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.

**Calorimeter / 66**

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

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The measurement of direct photon production at forward rapidity ( $y \sim 3-5$ ) 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.

**Gas Detectors / 6**

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

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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.

**Semiconductor Detectors / 426**

## Large area CNT-Si heterojunction for photodetection

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Multiwalled 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.

**Calorimeter / 5**

## The upgrade of the BelleII forward 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.

## 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.

## Calorimeter / 246

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

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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.

**Semiconductor Detectors / 76**

## 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 <sup>116</sup>Cd. For this purpose, it operates a demonstrator setup with 64 CdZnTe detectors, each with a volume of 1cm<sup>3</sup>, at the LNGS underground laboratory in Italy.

Double beta-decays are associated with half-lives of more than 10<sup>25</sup> years. To be sensitive to those half-lives, 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 (2×2×1.5)cm<sup>3</sup> 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.

**Calorimeter / 240**

## 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.

**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 0.15 $\mu\text{m}$  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 50 $\mu\text{m}$  x 75 $\mu\text{m}$  area, includes detectors 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.

**Gas Detectors / 263**

## **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.

**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/cm<sup>2</sup>. This breakthrough in the lifetime of MCP-PMTs was accomplished by coating the MCP pores using an atomic layer deposition (ALD) technique.

## 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.

## Gas Detectors / 327

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

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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.

Gas Detectors / 129

## 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,  $\mu$ -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, *ie.* 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



$\mu\text{m}$  thickness Mylar foil and 70 nm aluminum deposition. Currently even thinner and smaller, 12  $\mu\text{m}$ -thick and 5 mm diameter, straw is under development by the ultrasonic welding technique.

## Semiconductor Detectors / 29

### 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  $5 \cdot 10^{34} \text{ cm}^2/\text{s}$  sometimes after 2024, to possibly reach an integrated luminosity of 3000/fb 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.

## Photon Detectors / 358

### 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 ( $\sim 5000 \times$  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.

#### 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 650ns 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.

#### 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 2.5MeV (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.

**Semiconductor Detectors / 33****Exploring the quality of latest sensor prototypes for the CMS Outer Tracker Upgrade****Author:** Axel Konig<sup>1</sup><sup>1</sup> *Austrian Academy of Sciences (AT)***Corresponding Author:** axel.konig@cern.ch

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 characterization 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.

**Gas Detectors / 303****GridPix detector - Development and Application****Author:** Jochen Kaminski<sup>1</sup>**Co-authors:** Christoph Krieger<sup>1</sup>; Klaus Desch<sup>1</sup>; Michael Lupberger<sup>2</sup>; Yevgen Bilevych<sup>2</sup><sup>1</sup> *Universitaet Bonn (DE)*<sup>2</sup> *University of Bonn***Corresponding Author:** jochen.kaminski@cern.ch

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.

**Semiconductor Detectors / 65****The Phase-1 Upgrade of the CMS Pixel Detector****Author:** Katja Klein<sup>1</sup><sup>1</sup> *RWTH Aachen***Corresponding Author:** katja.klein@physik.rwth-aachen.de

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  $1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . 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  $2.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ ; 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 CO<sub>2</sub>. 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.

**Astroparticle Detectors / 169****Detection of High Energy Cosmic Rays with the Auger Engineering Radio Array****Author:** Raphael Krause<sup>1</sup><sup>1</sup> *RWTH Aachen University***Corresponding Author:** krause@physik.rwth-aachen.de

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 17km<sup>2</sup> 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.

**Semiconductor Detectors / 26****Pixel Sensors with slim edges and small pitches for the CMS upgrades for HL-LHC****Author:** Caterina Vernieri<sup>1</sup>

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The CMS experiment will build a third generation Pixel detector for the HL-LHC. The foreseen integrated luminosity of 3000 1/fb 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.

**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 characterised 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  $100\mu\text{m}$  independent of the track incidence angle and the magnetic field ( $B < 0.3\text{T}$ ), with a rate capability up to  $\sim 10\text{kHz}/\text{cm}^2$ . 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 ( $10 \times 10\text{cm}^2$ ) and medium size ( $1 \times 0.5\text{m}^2$ ) resistive Micromegas chambers (bulk type and mechanical floating mesh type) using medium ( $10\text{GeV}/c$ ) and high ( $150\text{GeV}/c$ ) 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 ( $2\text{-}3\text{m}^2$ ) operational modules that will be realised during 2015, will be presented.

**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.

**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 m<sup>2</sup>. 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.

**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.

## Gas Detectors / 205

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

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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.

## 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  $1.3 \text{ MHz/mm}^2$  and provide single-hit timing with 200ps RMS resolution for a total material budget of less than  $1.5X_0$ . The tracker comprises three  $60.8\text{mm} \times 27\text{mm}$  stations installed in vacuum ( $\sim 10^{-6}$  mbar) and cooled with liquid  $\text{C}_6\text{F}_{14}$  circulating through micro-channels etched inside few hundred of microns thick silicon plates. Each station is composed of a  $200\mu\text{m}$  thick silicon sensor readout by  $2 \times 5$  custom  $100\mu\text{m}$  thick ASIC, called TDCPix. Each chip contains  $40 \times 45$  asynchronous pixels, each  $300\mu\text{m} \times 300\mu\text{m}$  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.

## Astroparticle Detectors / 302

### **CaloCube: a new-concept calorimeter for the detection of high-energy cosmic rays in space**

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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.

## 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 ~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.

Electronics / 212

## 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.

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.

**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~ $\mu$ s latency and 400~kHz at 30~ $\mu$ s 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%.

**Semiconductor Detectors / 372**

## Progress and questions about sCVD Diamond Detectors for Particle Tracking

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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.

**Gas Detectors / 121**

## Advances in micro-Resistive WELL ( $\mu$ -RWELL) detectors

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In this work we present the advances performed on the micro-Resistive WELL ( $\mu$ -RWELL) detector technology. The  $\mu$ -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,  $\sim 60\mu\text{m}$ , is a very compact device, robust against discharges and exhibiting a large gain ( $>10^4$ ), simple to construct and easy for engineering and then suitable for applications for large area tracking devices as well as huge digital calorimeters.

**Electronics / 108**

## 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.

**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.

**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  $5 \mu\text{m}$  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  $35 \text{ mW}/\text{cm}^2$  for the application in the Inner Layers and below

$20 \text{ mW}/\text{cm}^2$  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.

## Medical Applications / 310

### State of the art time resolution in TOF-PET detectors for various crystal sizes and types

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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 derivatives). 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  $2 \times 2 \times 5 \text{ mm}^3$ ,  $105 \text{ ps} \pm 4 \text{ ps}$  for  $3 \times 3 \times 5 \text{ mm}^3$ ,  $130 \text{ ps} \pm 5 \text{ ps}$  for  $2 \times 2 \times 20 \text{ mm}^3$  and  $140 \text{ ps} \pm 5 \text{ ps}$  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.

#### 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.

#### Semiconductor Detectors / 160

### 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 constraints 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.

**Astroparticle Detectors / 186**

## **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.

**Semiconductor Detectors / 345**

## **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  $10^{15} n_{eq}/cm^2$ .

### Medical Applications / 353

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

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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 mm<sup>3</sup> 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.

### Semiconductor Detectors / 226

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

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The physics aims at a 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% X0 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.

**Astroparticle Detectors / 183**

## WIMP tracking with cryogenic nuclear emulsion

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Directional dark matter search experiment enable us to reveal the presence of Weakly Interacting Massive 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 <sup>14</sup>C decay in the emulsion. Since the intrinsic electron events will be significant background, a electron rejection power of at least 10<sup>-8</sup> 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<sub>2</sub> 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.

**Medical Applications / 158**

## The SAFIR project: Status and perspectives

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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 cm<sup>3</sup> 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.

## Medical Applications / 79

### 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.

**Semiconductor Detectors / 113****The MuPix HV-MAPS system-on-chip for the Mu3e experiment**

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Mu3e is a novel experiment searching for charged lepton flavor violation in the rare decay  $\mu \rightarrow e e e$ . 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  $\mu\text{m}$  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.

**Astroparticle Detectors / 322****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  $^8\text{B}$  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.

**Semiconductor Detectors / 133****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 micro-channel layer designed to circulate evaporated CO<sub>2</sub>. 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.

**Astroparticle Detectors / 204**

## **Operating performance of GCT: an end-to end Schwarzschild-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 Schwarzschild-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.

**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.

## 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.

**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  $2 \times 2$  cm<sup>2</sup> 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.

**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.

### Semiconductor Detectors / 306

## Performance of MÖNCH, a 25- $\mu$ m pixel pitch detector for photon science

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MÖNCH is a hybrid silicon pixel detector based on charge integration and with analog readout, featuring a pixel size of 25x25  $\mu$ m<sup>2</sup>. 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 cm<sup>2</sup> modules will be discussed.

### 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.

### 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.

### 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.

**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  $\sim 8^\circ$  (FWHM) for a  $^{137}\text{Cs}$  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  $\text{Gd}_3\text{Al}_2\text{Ga}_3\text{O}_{12}$  (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  $\sim 8.9^\circ$  (FWHM) of the present handheld camera to  $5.4^\circ$  (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

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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.

Plenary 4 / 274

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

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The International Large Detector (ILD) 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.

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% photocatode 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  $\text{CaWO}_4$  crystals operated as cryogenic detectors. Compared to previous runs the intrinsic radiopurity of  $\text{CaWO}_4$  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  $2 \backslash \text{GeV}/c^2$ . 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.

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.

Plenary 5 / 13

## Construction and tests of an in-beam PET-like detector for hadron-therapy beam ballistic control.

**Authors:** Arnaud Rozes<sup>1</sup>; Christophe Insa<sup>1</sup>; Daniel Christophe Lambert<sup>1</sup>; Franck Martin<sup>2</sup>; Gerard Montarou<sup>3</sup>; Loïc Lestand<sup>4</sup>; Magali Magne<sup>1</sup>; Robert Chadelas<sup>1</sup>

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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 ( $\gamma$  prompt), or charged particles like protons, or 511 keV  $\gamma$ -ray photons from the annihilation of a positron issued from the  $\beta^+$  emitters induced in the patient tissues along the beam path. The LAPD detector focuses on these 511 keV  $\gamma$  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  $\gamma$  from positron annihilations for the ballistic control in hadrontherapy, such as the low  $\beta^+$  activity, the short lives isotopes, the isotope diffusion through the patient tissues, and the large  $\gamma$  prompt background. Specific electronics based on Switch Capacitor Array (DRS 4) for the digitization and on the  $\mu$ TCA 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.

438

## Award Ceremony

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439

## Summary Talk

454

## Closing

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437

## Information from the Organisers

Board: 77 / 88

### Test of microchanenel 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  $\mu\text{m}$ . 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.

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  $\mu\text{m}$  and an effective diameter of 20 mm. The diameter of each hole is 50  $\mu\text{m}$ . 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.

Board: 57 / 336

## 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  $\mu\text{m}$  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  $\mu\text{m}$  Jazz/Tower CMOS process also used for STAR/ALICE trackers. The future sensors feature a spatial resolution of  $<5 \mu\text{m}$ , a non-ionizing radiation tolerance of  $>10^{13} n_{\text{eq}}/\text{cm}^2$ , an ionizing radiation tolerance of 3 Mrad and a readout speed of few 10  $\mu\text{s}/\text{frame}$ . 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.

Board: 6 / 339

## 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 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 10000particles/m<sup>2</sup> is realized with the design of PMT divider.

Board: 17 / 142

## 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 N<sub>2</sub> envelopes of the SCT and pixel detectors. Resolutions better than  $\pm 5 \times 10^{-5}$  and  $\pm 10^{-4}$  are respectively seen for C<sub>3</sub>F<sub>8</sub> and CO<sub>2</sub> leak concentrations in N<sub>2</sub>. A fourth instrument detects sub-percent levels of air ingress into the C<sub>3</sub>F<sub>8</sub> 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 C<sub>3</sub>F<sub>8</sub> 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 C<sub>3</sub>F<sub>8</sub> and C<sub>2</sub>F<sub>6</sub> concentrations to better than  $\pm 3 \times 10^{-3}$ . 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.

Board: 45 / 64

## 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  $\gamma$ -ray beam.

Data was collected for  $\gamma$ -beam energies between 2 and 7 MeV, at the HI $\gamma$ S

facility of TUNL.

The nanosecond-fast resolution of diamond detectors is exploited to distinguish bunches of  $\gamma$ -rays 16.8 ns apart.

It allows a precise direct determination of the time-structure of the  $\gamma$ -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

$\gamma$ -sources, such as ELI-NP and HI- $\gamma$ S-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 ( $\varnothing$  290 mm) has been made of aluminum foil with a thickness of 100  $\mu$ m 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  $\varepsilon \geq 80\%$ . 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 <sup>3</sup>He + 20 mBar CO<sub>2</sub> + 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

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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  $^{12}\text{C}(n,\alpha)^9\text{C}$  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.

Board: 76 / 83

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

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PENeLOPE is a neutron lifetime measurement experiment at the Forschungsreaktor 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<sup>2</sup>. 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 determind latency for time critical messages, IPBus and JTAG interfaces. The network has a n:1 topology and thereby reducing number of optical links.

Board: 86 / 85

## 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.

Board: 66 / 115

## 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 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.

Board: 27 / 292

## Measurement of 1.7 to 74 MeV polarised gamma rays with the HARPO TPC

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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.

Board: 2 / 131

## 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  $\mu$ s), fast readout time (~10  $\mu$ s), 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.

Board: 37 / 357

## 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.

Board: 58 / 337

## 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  $^{12}\text{C}(n,\alpha)^9\text{Be}$  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

Board: 4 / 264

## 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'Accelérateur 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.

Board: 49 / 214

## 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.

Board: 62 / 236

## Fabrication and Characterization of Rectangular Strontium Iodide Scintillator Coupled to TSV-MPPC array

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Europium doped Strontium Iodide (SrI<sub>2</sub>(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 SrI<sub>2</sub> 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.

Board: 80 / 287

## 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  $\mu$ m 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  $\mu\text{m} \times 20 \mu\text{m}$  and impinged in the centre of the pixel it was obtained a time resolution of 10.21 ns for 20 keV photos, 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.

Board: 92 / 54

## 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.

Board: 72 / 30

## 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.

Board: 5 / 328

## 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 km<sup>2</sup> (array prototype) to ~ 5 km<sup>2</sup> 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.

Board: 52 / 234

## 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.

Board: 53 / 430

## 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  $\mu\text{m}$ -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 [1]. 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  $\alpha$ -particle sources. The measured energy resolution (FWHM) of 13.2 keV (on the 5.499 MeV line of <sup>238</sup>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.

1. G.I. Koltsov et al., Semiconductors 46 (8) (2012) 1066–1071.

Board: 32 / 405

## 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.

Board: 16 / 92

## 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  $v_{\text{Drift}}$  in these gases. E.g. ions moving through the gas volume can create space charges and hence field distortions inside the detector. Knowing  $v_{\text{Drift}}$  (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  $d_{\text{Drift}}$  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  $v_{\text{Drift}}$  the time difference between the electron signal on the pad plane and the ion signal is measured. Together with  $d_{\text{Drift}}$  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.

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/ $\text{mm}^2$ . 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 n 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.

Board: 69 / 216

## **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.

Board: 89 / 272

## **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 PbF<sub>2</sub> 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.

Board: 34 / 284

## **Validation of a highly integrated PET readout system scalable to several 10'000 channels**

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SiPMs allow a dramatic 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 pixels and a LYSO crystals. 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 TOPPET1 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

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 Collider) 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 insulated by SiO<sub>2</sub> layer called buried oxide (BOX). The sensor layer is thinned to 50 μm for reduction of multiple scattering. The new SOI sensor SOFIST is designed to store both position and timing information of hits in each 20 × 20 μm pixel. The position resolution is further improved by the position weighted with the charges spread to multiple pixels. The target performance of the position resolution is better than 3 μm. The pixel also records the hit timing of the charged particle by an embedded timestamp circuit. The timestamp circuit has about 4 μsec 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  $10^{-4}A$ . 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 CO<sub>2</sub> 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.



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 ( $0\nu\text{DBD}$ ) 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  $\alpha$  and  $\beta/\gamma$  events in a scintillating bolometer. The increase in the number of  $0\nu\text{DBD}$  emitters demand for crystals grown with enriched material. LUCIFER, the first demonstrator of CUPID, aims at running the first array of enriched scintillating  $\text{Zn}^{82}\text{Se}$  bolometers (total mass of about 9 kg of  $^{82}\text{Se}$ ) 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  $\text{Zn}^{82}\text{Se}$  enriched bolometers operated deep underground in the Hall C of Laboratori Nazionali del Gran Sasso.

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. 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  $2.0 \times 10^5 \text{ cm}^{-2} \text{ s}^{-1}$ . Hit rate and occupancy limit cell size to be about  $4 \text{ cm}^2$ .

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  $\text{Al}_2\text{O}_3$  ceramics with a Cu-Cr layer deposited on them and the floating electrodes are made of low resistive  $\text{Si}_3\text{N}_4/\text{SiC}$  ceramics. A complete cell is formed by three such base elements ( $20 \times 20 \text{ mm}^2$  or  $48 \times 48 \text{ mm}^2$  active size six-gap RPC with  $250 \mu\text{m}$  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  $1.5 \times 10^5 \text{ cm}^{-2} \text{ s}^{-1}$  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  $0.5 \text{ Hz/cm}^2$ . For both beam tests the efficiency stays over 90% and time resolution stays below 120 ps. even at rate  $> 1.0 \times 10^5 \text{ cm}^{-2} \text{ s}^{-1}$ .

Board: 9 / 190

## 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 16.5m<sup>3</sup> xenon loaded scintillator in 25  $\mu$ m 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 31.4m<sup>3</sup> 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.

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.

Board: 19 / 168

## 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 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 at a strips pitch of 250  $\mu\text{m}$  to 300  $\mu\text{m}$  with the gas mixture of Ar-CO<sub>2</sub> (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  $2.4 \times 10^{-3} X_0$ . 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.

Board: 79 / 277

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

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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.

Board: 56 / 298

## Simulation of 3D Diamond Detectors

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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.

Board: 26 / 281

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

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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/cm<sup>2</sup>. 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/cm<sup>2</sup>. 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.

Board: 98 / 258

## 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, HAMAMATSU and SENSL SiPM properties after irradiation by the 0 - 35 MeV neutrons. The typical neutron fluence was about  $10^{12}$  n/cm<sup>2</sup>. 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.

Board: 63 / 393

## 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.

Board: 99 / 280

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

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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 ( $40\mu\text{m}$  and  $30\mu\text{m}$ ) 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  $40\mu\text{m}$  (NUV-SiPM) and  $30\mu\text{m}$  (NUV-HD SiPM) arranged in a layout of  $6\times 6\text{mm}^2$  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.

Board: 47 / 126

## Laser processing in 3D Diamond Detectors

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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  $O(\Omega\text{cm})$ . 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.

Board: 46 / 68

## 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  $0.05\times 0.5\text{mm}^2$  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  $\sim 10^3$ , spatial resolution of  $50 \mu\text{m}$  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 CO<sub>2</sub> 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  $\sim 10$  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 CO<sub>2</sub> gas radiator (pion threshold 4.65 GeV/c) in combination with a 13m<sup>2</sup> 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.

Board: 8 / 177

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

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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.

Board: 64 / 86

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

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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 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.

Board: 93 / 128

## A new method for the neutron lifetime measurement

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According to the PDG, the neutron lifetime is reported as  $880.3 \pm 1.1$  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.,  $8.4 \pm 2.2$  s, between two methods: counting surviving ultra-cold neutrons after storing ( $879.6 \pm 0.8$  s) and counting trapped protons from the neutron decay ( $888.0 \pm 2.1$  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.

Board: 31 / 344

## 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.

Board: 71 / 418

## Novel PMTs of worldwide best parameters for the CTA project

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Photo-multiplier Tubes (PMT) are the most wide spread 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  $\geq 400\text{nm}$ . A pulse width of  $\leq 3\text{ns}$  has been achieved at the selected operational gain of 40k. The after-pulsing for a threshold of  $\geq 4$  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.

Board: 90 / 355

## Neutron detection in the frame of spatial magnetic spin resonance

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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.

Board: 14 / 452

## **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<sup>2</sup> 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-amplifier 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.

Board: 22 / 193

## 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  $\text{CF}_4$  rich gas mixture ( $\text{He}/\text{CF}_4$  60/40) and a detailed optimization of the electric fields allowed to reach a high-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.

Board: 13 / 423

## Development of CANDLES detector to search for neutrinoless double beta decay of $^{48}\text{Ca}$

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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  $^{48}\text{Ca}$  double beta decay using  $\text{CaF}_2$  scintillator. The main advantage of  $^{48}\text{Ca}$  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  $\text{CaF}_2$  crystals in the Kamioka underground observatory, Japan. The detector consists of 96 pure  $\text{CaF}_2$  crystals immersed in liquid scintillator for an active shield. Sensitivity for 0nbb half-life obtained from 60 days data in 2013 was  $> 0.8 \times 10^{22}$  year. In 2014, a cooling system and a magnetic cancellation coil were installed with the aim to increase light emission of  $\text{CaF}_2$  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,  $\text{CaF}_2$  scintillating bolometer.

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  $\mu\text{m}$  thick sensors, interconnected to FE-I4 read-out chips and irradiated up to a fluence of  $1.4 \times 10^{16}$  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  $\mu\text{m}^2$ ) 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  $\mu\text{m}^2$  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.

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 initially 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 10x10 degrees offers a very cost effective way to construct a 10 km<sup>2</sup> array for gamma-ray astronomy.

Board: 87 / 119

## 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<sup>2</sup>, 3.3 mm thick tiles (20/20 lead/plastic scintillator), for a total of 11 X<sub>0</sub>; 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 X<sub>0</sub>. 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 μm<sup>2</sup> 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.

Board: 43 / 31

## 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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The high luminosity upgrade of the LHC is targeted to deliver 2500 fb<sup>-1</sup> at a luminosity of 5x10E34 cm<sup>-2</sup>s<sup>-1</sup>. 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  $1 \times 10^{15}$  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  $100 \mu\text{m} \times 1.5 \text{ mm}$  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.

Board: 75 / 78

## 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.

Board: 44 / 57

## 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  $\sim 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ . 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  $\sim 3000 \text{ fb}^{-1}$  of integrated luminosity and resolve  $\sim 200$  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.

Board: 74 / 60



## 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.

Board: 84 / 295

## 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.

Board: 10 / 213

## 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 ( $\approx 10$  ns) flash of light or, in other cases, as train ( $\approx 1$   $\mu$ s) 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  $\theta_{13}$  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.

Board: 65 / 93

## The performance for the TeV photon measurement of the LHCf upgraded detector using Gd<sub>2</sub>SiO<sub>5</sub> (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 measure  $\gamma$  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  $30 \text{ Gy/nb}^{-1}$  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  $200 \mu\text{m}$  were obtained using 50-250GeV 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.

Board: 33 / 23

## High rate, fast timing Glass RPC for the high eta CMS muon detectors

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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  $1010 \Omega\cdot\text{cm}$ ) could stand particle rates of few kHz/cm<sup>2</sup> in its single-gap version and few tens of kHz/cm<sup>2</sup> 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.

Board: 18 / 161

## 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.

Board: 7 / 410

## A new imaging atmospheric Cherenkov camera for the H.E.S.S. telescopes

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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 pneumatics 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.

Board: 55 / 267

## 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.

Board: 83 / 371

## 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  $\mu\text{m}$ , 10  $\mu\text{m}$  and 12.5  $\mu\text{m}$ , corresponding to a cell density of 20500, 11500 and 7400 cells/ $\text{mm}^2$ , respectively. Depending on different layout splits that we tested, the fill factor (FF) of the cells varies between 33% and 57%, for the 7.5  $\mu\text{m}$  cell, and between 47% and 68%, for the 10  $\mu\text{m}$  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  $\mu\text{m}$  and 10  $\mu\text{m}$  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/ $\text{mm}^2$ . The PDE at 515 nm was 22%, 26% and 29%, for the 7.5  $\mu\text{m}$ , 10  $\mu\text{m}$  and 12.5  $\mu\text{m}$  cells, respectively, which are very high values, considering the small cell sizes.

Board: 81 / 319

## 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  $5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$  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.

Board: 35 / 313

## 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 of 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.

Board: 29 / 314

## 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  $7\text{MHz}/\text{cm}^2$  with  $100\mu\text{m}$  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:CF<sub>4</sub> 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  $^{55}\text{Fe}$  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.

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  $22^\circ$  and  $140^\circ$ . Its primary purpose is the clean separation of pions and kaons ( $>3\sigma$ ), for momenta up to 3.5 GeV/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  $\sim 10\%$  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 ( $\sim 5$  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.

Board: 38 / 399

## 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  $\theta$ .

### Experiments

<sup>137</sup>Cs 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 calibrated image. To achieve higher spatial resolution, optimization of the detection system is necessary in future.

Board: 67 / 118

## 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  $9 \times 9$  sqcm and a range of 3 cm water equivalent. Each layer is read-out by two wavelength shifter (WLS) fibers and a  $8 \times 8$  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  $9 \times 9$  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<sup>2</sup>, strip pitch of 400 μm, amplification gap of 128 μm, 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<sup>2</sup>. 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.

Board: 96 / 384

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

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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<sup>2</sup> of WIMP-nucleon spin-independent cross section for particles with a mass of 1 TeV/c<sup>2</sup>. 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<sup>2</sup> 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.

Board: 54 / 248

## Radiation length imaging with high resolution telescopes

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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.

Board: 1 / 37

## 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 ( $6 \times 3 \times 7 \text{ m}^3$ ) 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.

Board: 39 / 185

## 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  $\gamma$ -rays is constrained by the differences in arrival time. Better time resolution could be 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  $3 \times 3 \times 3 \text{ mm}^3$  scintillators and  $3 \times 3 \text{ mm}^2$  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.

Board: 50 / 221

## Si-PIN radiation detectors with low leakage current, thin incident window and large active area for Nuclear Physics applications.

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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  $\mu\text{m}$  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/cm<sup>2</sup>·100 $\mu\text{m}$  at full depletion and at room temperature for devices with an active area with hexagonal shape and large about 9 cm<sup>2</sup>.

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/cm<sup>2</sup>·100 $\mu\text{m}$  for devices with active area of the order of 4 cm<sup>2</sup>.

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.

Board: 24 / 220

## **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  $|\eta| < 2$  and  $p_T > 0.5$  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.

Board: 42 / 19

## **Measurement of the two track separation capability of hybrid pixel sensors**

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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.

Board: 12 / 349

## 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 <sup>82</sup>Se source with the total exposure of 500kg·yr to probe the half-life sensitivity  $T_{0\nu} = 1 \times 10^{26}$  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.

Board: 70 / 394

## 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 reorganisation 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.

Board: 51 / 230

## 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.

Board: 41 / 9

## 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  $\sim 50$  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.



Board: 88 / 200

## 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)

Board: 23 / 208

## The RPWELL - a robust gaseous radiation detector

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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).

Board: 15 / 72

## 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.

Board: 40 / 2

## 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.

Board: 85 / 352

## **A Multi-Purpose Active-Target Particle Telescope for Radiation Monitoring**

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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 cm<sup>2</sup>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.