20th Anniversary ”Trento” Workshop on Advanced Silicon Radiation Detectors

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Book of Abstracts

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The SiPM photodetector of the ePIC dual-radiator RICH at the EIC: overview and beam test results

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The dual-radiator RICH (dRICH) detector of the ePIC experiment at the future Electron-Ion Collider (EIC) will make use of silicon photomultiplier (SiPM) sensors for the detection of the Cherenkov light emitted by particles crossing its radiators. The photodetector will cover ~ 3 m^2 with 3×3 mm^2 pixels, for a total of more than 300k readout channels. This will be the first application of SiPMs for single-photon detection in a HEP experiment. SiPMs are chosen for their low cost and immunity to high magnetic fields (~ 1 T at the dRICH location). However, they are not radiation hard, demanding careful testing and attention to preserve single-photon counting capabilities and to maintain the dark count rates (DCR) under control over the years of running of the ePIC experiment. DCR control is achieved with operation at low temperature and recovery of the radiation damage via high-temperature annealing cycles. The exploitation of the SiPM precise timing with fast TDC electronics helps to reduce further the effect of DCR as background signal.

In this talk we present an overview of the ePIC-dRICH detector system, designed to provide continuous hadron identification in a broad momentum range from ~ 3 GeV/c to ~ 50 GeV/c in the forward region ($1.5 < \eta < 3.5$). The current status of the R&D performed for the operation of the SiPM optical readout subsystem will be reviewed. Focus will be given to recent beam test results of a large-area prototype SiPM readout plane consisting of a total of up to 2048 3×3 mm^2 sensors. The photodetector prototype is modular and based on a novel EIC-driven photodetection unit (PDU) developed by INFN, which integrates 256 SiPM pixel sensors, cooling and TDC electronics in a volume of $\sim 5\times5\times14$ cm^3. Several PDU modules have been built and successfully tested with particle beams at CERN-PS in October 2023 and in May 2024. The data have been collected with a complete chain of front-end and readout electronics based on the ALCOR chip, developed by INFN Torino.

Technology / 2

Recent Advances in Precision Silicon Detectors: Pushing Boundaries in Radiation Detection for Cutting-Edge Science at the Semiconductor Laboratory of the Max Planck Society

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This talk highlights recent breakthroughs in precision radiation detector technology developed at the Semiconductor Laboratory of the Max Planck Society. Pioneering advancements have enabled the production of ultra-high-quality, wafer-sized silicon detectors that meet the rigorous demands of various scientific fields, with a primary focus on creating unique, customized sensors unavailable on the commercial market.

Key developments include the latest advancements in silicon drift detectors (SDDs), pnCCDs, and DEPFET sensors, along with the innovative low-gain avalanche device, MARTHA, which offers enhanced performance in demanding applications. These technologies serve as the foundation for specialized detector systems designed for high-energy particle physics (e.g., BELLE II), astrophysics (e.g., ATHENA), material science (EDET and FSP TNG), and synchrotron beamline applications (LCLS, XFEL).

The presentation will provide an in-depth look at these recent innovations and discuss future directions that promise to further expand the capabilities of radiation detection technology across scientific disciplines.

Electronics and System issues / 3

Current status of the CMS Inner Tracker upgrade for HL-LHC

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During the High Luminosity programme of the LHC collider (called HL-LHC), planned to start in 2030, the instantaneous luminosity will be increased from $\sim 2 \times 10^{34} cm^{-2}s^{-1}$ to an unprecedented figure of about $\sim 7.5 \times 10^{34} cm^{-2}s^{-1}$. This will allow the Compact Muon Solenoid (CMS) to collect up to $\sim 4000 fb^{-1}$ of integrated luminosity over a decade.

However, in order to cope with the much higher pp-collisions rate, CMS will undergo an extensive improvement known as "Phase-2 upgrade": in particular, the silicon tracker system will be entirely replaced to comply with the extremely challenging experimental conditions.

This contribution will review the main upgrades of the CMS Inner Tracker and will present the most relevant design and technological choices. Moreover, the ongoing prototypes validation and the preparation for the large-scale production will be discussed.

Poster Session / 4

Radiation studies of CMOS sensor using high intensity X-ray irradiator

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Recent advancements in particle physics demand pixel detectors that can withstand increased energy and luminosity in the future collider experiments. In response, MALTA, a novel monolithic active pixel detector, has been developed with a cutting-edge readout architecture. This new class of monolithic pixel detectors is found to have exceptional radiation tolerance, superior hit rates, higher resolution and precise timing resolution, making them ideally suited for experiments at the LHC. To optimize the performance of these sensors before their deployment in actual detectors, comprehensive characterization has been conducted using irradiated sensor. For the further understanding of the effect of radiation, the sensors are being exposed to the high intensity X-ray source. These results will also be presented.

Wide bandgap semiconductor detectors / 5

Silicon Carbide Diodes at IMB-CNM: Advancing High-Precision Dosimetry for FLASH Radiotherapy

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The main challenge in radiotherapy (RT) is to deliver a sufficiently high curative dose to the tumour while maintaining tolerable doses to nearby organs at risk, and new treatment modalities are rapidly emerging. FLASH radiotherapy delivers a therapeutic dose several orders of magnitude faster (≥ 40 Gy/s) than conventional RT (0.05 Gy/s) and has been shown to reduce the likelihood of complications in normal tissues while providing a similar or better tumour control rate than conventional dose rates, reducing treatment time and organ motion-related issues. However, there are significant challenges to the clinical implementation of FLASH RT, as its requirements make most existing dosimetry equipment obsolete.

The physical properties of silicon carbide (SiC) make it an interesting material for radiation dosimetry. The wide bandgap of SiC reduces the rate of thermally generated charge carriers, thereby reducing leakage current and noise compared to silicon. Of particular interest is the signal yield per deposited mGy in SiC (425 pC/(mGy·mm3) for 4H-SiC) which is lower than for silicon. This makes SiC a good option for dosimetry in ultra-high dose pulsed radiation fields or direct beam monitoring, where the instantaneous dose deposition in the semiconductor is large and could saturate conventional silicon diodes. In addition, SiC has a higher displacement energy threshold and therefore higher radiation hardness than silicon. Today, SiC technology is mature and high quality substrates are available up to 200mm, allowing widespread use.

In this talk we will present the novel silicon carbide PiN diodes that have been designed and fabricated at IMB-CNM with the aim to respond to the technological challenges of FLASH RT. In a first characterization with 20 MeV FLASH electron beams at PTB (Germany), these diodes showed their suitability for relative dosimetry up to a dose of 11 Gy per pulse (4 MGy/s) and a dosimetric performance comparable to commercial diamond dosimeters [doi:10.1088/1361-6560/ad37eb]. The performance of the SiC diodes with FLASH proton beams was tested with 7 MeV protons at CMAM (Spain) where they showed good signal linearity with dose rate and reproducible response up to a dose per pulse of at least 20 Gy. Finally, the radiation resistance of the diodes was studied at CNA (Spain) using high LET, intense pulsed proton beams. The sensitivity of the diodes showed a progressive decrease at an initial rate of -1.34%/kGy of 1 MeV protons, and stabilised only for doses close to 750 kGy. However, the linear response with dose per pulse was maintained over a wide range of dose rates even for cumulative doses of several MGy. All of these measurements were made without the need for an external applied voltage. In conclusion, silicon carbide diodes fabricated at IMB-CNM are a real alternative to silicon and diamond dosimeters in a wide range of applications where accurate real-time relative dosimetry, fast response and long-term stability are required.

Poster Session / 6

First results of Back-side Illuminated SiPM for VUV/NUV light detection fabricated at Fondazione Bruno Kessler

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Advancements in 3D interconnecting technologies have significantly contributed to the emergence of a new generation of Silicon Photomultipliers (SiPM), which we can refer to as hybrid devices. These devices integrate the functionalities of digital SiPMs with the exceptional performance characteristics of specialized custom technologies. In recent years, the Fondazione Bruno Kessler (FBK) has been working on the technological development of Backside Illuminated (BSI) SiPMs for Vacuum Ultraviolet (VUV) and Near Ultraviolet (NUV) light detection, particularly in applications in particle physics experiments, such as detection of scintillation from liquefied noble gases.

For this wavelength range, a BSI detection technology faces critical challenges due to silicon's low photon interaction depth (less than 100 nm for λ = 400 nm). This necessitates the complete removal of the substrate, a process that has already been successfully demonstrated at FBK and the creation of a thin active "entrance window". Additionally, for VUV-sensitive devices, the glass carrier wafer must be removed from the entrance window, as it typically absorbs light for wavelengths shorter than 350 nm. We will present recent technological advancements in this area, including validation of the feasibility of full substrate removal and preliminary electrical performance data of the devices.

CMOS MAPS / 7

Upgrade of the Belle II Vertex Detector with depleted monolithic CMOS active pixel sensors

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The Belle II experiment currently records data at the SuperKEKB e+e- collider, which holds the world luminosity record of 4.7x10^34 cm-2 s-1 and plans to push up to 6x10^35 cm-2 s-1. In such luminosity range for e+e- collisions, the inner detection layers should both cope with a hit rate dominated by beam-induced parasitic particles and provide minute tracking precision. A research and development program has been established to develop a new pixelated vertex detector (VTX), based on the most recent CMOS pixel detection technologies. The VTX strategy entails higher space-time granularity, lighter overall structure and services compared to the current operating vertex detector based on two different technologies. The expected gains include more robustness against the machine background as well as higher vertexing and tracking performance.
The VTX design matches the current vertex detector radial acceptance, from 14 mm up to 140 mm. It includes 5 to 6 layers equipped with the same depleted monolithic active pixel sensors, OBELIX. Specifications target to sustain a maximal average hit rate of 120 MHz/cm2 with triggered read-out within an overall material budget lower than 3 % of X0. The two innermost layers are made of 4-sensor long modules cut out from processed wafers and submitted to post-processing operations in order to connect them at one end. Air cooling is currently under study for those two layers. The three to four outer layers use a light mechanical structure supporting a liquid-cooled plate in contact with the sensors connected to a flex printed cable.
The OBELIX sensor is designed in the Tower 180 nm technology, which pixel matrix is derived from the TJ-Monopix2 sensor originally developed for the ATLAS experiment. Featuring a 33 μm pitch and a time over threshold digitization over 7 bits, OBELIX time-stamps hits with a 50 ns binning. The digital trigger logic matches the required 30 kHz average Belle II trigger rate with 10 μs trigger

delay.
Two switchable additional features are intended for the outer layers coping with hit rates below 10 MHz/cm2. One corresponds to time stamping hits outside the matrix with 3 ns precision. The other provides continuous hit-information with 30 ns binning but with degraded position-precision for track-triggering. Recent simulations, showing that the degraded spatial granularity can still lead to useful track reconstruction efficiency at the first trigger level, will be discussed. The radiation environment requires a tolerance to 5x10ˆ14 1 MeV n_eq/cm2 and 1 MGy. In addition, the minimal material budget limits the cooling power and hence necessarily means warm operation of the sensor. This is a considerable challenge taking into account its estimated power dissipation around 200 mW/cm2 at the maximal average hit rate of the inner layer.
We will review all project aspects: the latest characterization of the TJ-Monopix2 forerunner sensor in beam after irradiation, design of OBELIX sensor, optimization of the geometry and cooling.

CMOS MAPS / 8

Performance tests of the MIMOSIS-2.1 CMOS Monolithic Active Pixel Sensor

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MIMOSIS is a CMOS Monolithic Active Pixel Sensor designed for the Micro Vertex Detector of the CBM experiment, currently under development at the FAIR facility in Darmstadt, Germany. The reticle size sensor is developed by a joint R&D program of IPHC Strasbourg, GSI and the Goethe University Frankfurt. It hosts a matrix of 1024 x 504 pixels with a 27 x 30 μm^2 pitch and has to combine a time resolution of ˜5 µs with a spatial resolution of ˜5 µm. Moreover, it has to handle a peak hit rate of 80 MHz/cm^2 with a continuous readout mode, and to withstand radiation doses of up to ˜5 MRad and ˜10^{14} n_{eq}/cm^2 per CBM year of operation.

The most recent, full feature prototype MIMOSIS-2.1 comes with multiple pixel design options. The more traditional DC pixels are complemented by fully depleted, top biased AC-pixels, which were both combined with an either 25 µm or 50 µm thick epitaxial layer. These different pixel options were tested in laboratory and with beam tests at DESY and CERN.

The sensor design and technology will be introduced, and the performance of the different pixel options will be compared.

Electronics and System issues / 9

Up-to-date test beam results of ATLAS ITk Pixel sensors and modules

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The ATLAS inner detector will be completely replaced with a new all-silicon tracking detector (ITk) in 2026-28 to cope with the challenging conditions of the High Luminosity LHC.
The pixel detector will be located in the innermost part of the ITk detector. It will be instrumented with 3D sensor technology it the innermost layer (L0), where a fluence up to 2 x 1016 neq/cm2 is expected, and with n-in-p planar hybrid modules 150 µm and 100 µm thick in the three outer layers (L2-L4) and in the first layer (L1), respectively.
The study of sensors and modules with beam is an important test bench to assess their performance and operation, both before and after irradiation to the expected fluence. In the last few years diVerent types of sensors produced by diVerent vendors became gradually available to be studied with beam. In the latest 2024 test beam season new sensor types, or produced with improved techniques, and modules equipped with the latest version of the readout chip also became available. First thick planar sensors produced by Micron are being tested both before and after irradiation during several test beam campaigns carried out in 2024. Eventually, the final version of the readout chip (ITkPixV2) was submitted in March 2023 and first modules assembled with the ITkPixV2 chip became available to be tested with beam this summer. Hence, this year test beam data includes several novelties to progress with the complete picture of the qualification of ITk pixel sensors. Some of the new 2024 test beam data are being analyzed and some are going to be collected soon. This talk will provide an overview of the ITk pixel sensors and modules qualification with test beams up to date with the latest 2024 results.

LGAD 1 / 10

Development and characterization of large area LGADs for space applications

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Low Gain Avalanche Diodes (LGADs) are silicon detectors that use the impact ionization process to achieve gain values of about O(10) and timing resolution of 30 ps for Minimum Ionizing Particles. In High Energy Physics, the state of the art LGADs used for timing layers have an active thickness of 50 µm and a channel size in the order of O(1 mm2). Space based experiments could benefit from a Time of Flight system composed by these sensors to distinguish between primary and secondary particles interacting in the tracker. Scaling up the technology to match the typical channel area of the microstrip sensors used in space-borne experiments deteriorates the timing capabilities of the LGADs due, in first approximation, to the increased capacitance. The devices used in this study consist of pad sensors with thickness 50 µm, 100 µm or 150 µm and presents different gain layer profiles to cope with the capacitance variation. Also various layouts are compared to see their effect on the time resolution. The performances of these devices are evaluated Current and Capacitance against Bias Voltage characterization along with Transient Current Technique, to simulate the passage of a Minimum Ionizing Particle , and radioactive sources. By evaluating gain, noise, and jitter, this work demonstrates it is possible to obtain 1 cm2 LGADs with a jitter as low as 40 ps. At the same time, the signal propagation and uniformity are studied since it was observed the channel size makes these features relevant for the timing capabilities.

Applications 2 / 11

DarkSide-20k large area light detection with FBK NUV-HD-Cryo triple dose SiPMs

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The DarkSide-20k experiment, currently under construction at the Gran Sasso Laboratory (LNGS), represents a significant advancement in the field of direct Dark Matter (DM) detection. Utilizing a liquid argon dual-phase time projection chamber (LArTPC) with a 20-tonne fiducial mass, DarkSide-20k is designed to extend the sensitivity limits in the search for Weakly Interacting Massive Particles (WIMPs), a leading dark matter candidate. The experiment represents the first large-scale deployment of SiPMs for light detection in this field in preference to PMTs, with the experiment containing ˜25 square metres of FBK NUV-HD-Cryo triple dose SiPMs for the detector and veto. We will discuss high level experimental design, the light detection design implementation, perspectives on production operations using SiPMs, and the current status of DarkSide-20k.

LGAD 1 / 12

Si-microstrip LGAD detectors for cosmic-ray space-borne instruments

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Silicon microstrip (Si-μstrip) sensors are employed in most of current space detector tracking systems for charged cosmic-rays, such as the DAMPE satellite detector or the AMS-02 detector onboard the ISS. As they allow for large-area coverage with contained electronic channels and power consumptions, they are ideal sensors for high-energy physics applications in space-borne instrumentation, and are planned to be instrumented in envisioned follow-up cosmic-ray space-borne missions such as the AMS-100 or the ALADInO next-generation magnetic spectrometers.

The efficiency of such systems is however already currently impacted by "backsplash" particles generated from downstream calorimeters, which can degrade tracking efficiency by tens of percent, especially at energies approaching 1 TeV.

One potential solution to overcome this limitation and enable new measurement approaches in next-generation instruments is the development of 5D tracking systems, which provide charge, time, and three-dimensional coordinate measurements for each layer of the tracker. This approach integrates the 3D-spatial coordinate and charge |Z| measurements with layer-resolved timing information, to: i) enable improved track finding; ii) provide a redundant and independent time-of-flight system to standard scintillator based detectors; iii) remove spurious tracker hits; iv) contribute independent particle ID information to transition radiation detectors (TRDs) or calorimeters. A key benchmark for timing resolution in next-generation space detectors is a timing accuracy below 100 ps, while a finer resolution of less than 50 ps could allow to achieve additional break-through objectives such as precise isotope separation that could allow groundbreaking sensitivities in understanding cosmic-ray physics and searches for heavy nuclear antimatter in cosmic-rays.

Such performances are already well within the capabilities of pixel LGAD systems developed for accelerator physics application. However, this level of performance in space applications requires significant reduction in readout noise and further advances in front-end electronics and consumption to comply with the stringent requirements of space operations.

LGAD-based tracking systems are primarily being developed for high-energy and high-intensity collider detectors, where timing resolution below 30 ps and spatial resolution on the order of 10 micrometers are required. These developments position LGAD as an optimal candidate for 5D tracking devices in large-scale detectors. In space, radiation hardness requirements are largely less demanding than those for high-intensity collider experiments. However, the integration of LGAD microstrips, currently available in O(cm
) area, to O(m
) area detectors necessitates careful consideration on capacitance noise and power consumption.

To address these challenges, in the context of the Pentadimensional Tracking Space Detector project (PTSD) we are investigating and developing an innovative concept of LGAD Si-microstrip instrument based on a detector capacitance mitigation design. The integration of LGAD and standard Si-μstrip sensors in a serial readout architecture will allow for a combination of two-dimensional coordinates and timing measurements, while minimizing the detector capacitance. A breadboard laboratory model will validate the requirements and space qualification of LGAD Si-microstrips. In this contribution, the status of R&D activities which are currently progressing will be presented.

In addition, a conceptual flight-demonstrator is being designed to be housed in a 3U CubeSat platform. This demonstrator will serve as a proof-of-concept for 5D tracking in space and will open new diagnostic opportunities for cosmic-ray and gamma-ray detection. The successful development of LGAD Si-microstrip based 5D tracking will enable sensitivities to perform ambitious objectives otherwise hardly achievable in the next generation of space-borne cosmic-ray instruments, paving the way for future discoveries in particle astrophysics.

LGAD 3 / 13

Synchrotron light source focused X-ray detection with LGADs, AC-LGADs, TI-LGADs and integrated chip readout

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The response of Low Gain Avalanche Diodes (LGADs), a type of thin silicon detector with internal gain, to X-rays of energies between 6-16 keV was characterized at the SLAC light source (SSRL). The utilized beamline at SSRL was 7-2, with a nominal beam size of 30 μm, repetition rate of 500 MHz, and with an energy dispersion ΔE/E of 10−4. Multi-channel LGADs, AC-LGADs, and TI-LGADs of different thicknesses and gain layer configurations from Hamamatsu Photonics (HPK) and Fondazione Bruno Kessler (FBK) were tested. The sensors were read out with a discrete component board or the FAST readout chip and digitized with a fast oscilloscope, CAEN fast digitizer, or the HD-SOC digitizer chip. Standard PiN devices were characterized as well. The devices'energy response, energy resolution and time resolution as a function of X-ray energy and position were measured. The charge collection and multiplication mechanism were simulated using TCAD Sentaurus, and the results were compared with the collected data.

Poster Session / 14

Comprehensive studies on calibration parameters of the LHCb Upstream Tracker

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The Upstream Tracker is a novel silicon microstrip detector installed during LHCb Upgrade 1. Since its successful commissioning, it has played a significant role in the experiment's new fully-software trigger system. The efficient performance of the UT detector requires constant monitoring and evaluation of the calibration parameters of over half a million sensors. Here, recent results regarding those parameters will be presented, and a few persisting issues will be addressed.

The analysed datasets come from different calibration measurements taken in the second half of 2024. They served as input for extensive studies regarding time evolution and spatial distributions of individual noise components, followed by a comparative analysis for different types of silicon sensors. Additional studies concerned the stability of readout chip configuration registers in terms of single-event upsets.

The results that will be discussed show that the Upstream Tracker demonstrates overall stable performance in all analysed calibration parameters. However, several local deviations have been identified, and there is an ongoing effort to minimise their influence on the detector's performance. The strategies for tackling the single-event upset issue will also be mentioned, as well as the prospects for further analysis developments with possible application of unsupervised Machine Learning methods.

Poster Session / 16

Qualification of Bump Bonding in CMS Inner Tracker Pixel Modules for the Phase-2 Upgrade

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To fully exploit the increased luminosity of the HL-LHC, the CMS Inner Tracker is undergoing a major upgrade to withstand extreme radiation levels of 1.2 Grad and hit rates of 3.2 GHz/ cm^2 while maintaining a reduced material budget and improved granularity. The detector modules feature thin 3D and planar silicon pixel sensors with a pixel size of 25x100 μm, bump bonded to a new

ASIC, called CROC (CMS Readout chip), designed in 65 nm CMOS technology and powered by a novel serial scheme. Modules are tested for functionality, noise, and bump bonding quality to meet stringent performance specifications. The bump bonding tests are essential for evaluating the integrity of the bump bonds, which connect the pixel sensors to the readout electronics. Accurate assessment of these connections ensures that the modules can withstand operational stresses and maintain high efficiency. Different methods have been developed to determine the bump bonding yield with electrical measurements. This work describes the various bump bonding test methods and presents results from the prototype modules, highlighting their performance and reliability under operational conditions.

LGAD 3 / 17

Impact of high deposited energy on Single Event Burnout in LGADs

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Low Gain Avalanche Diodes(LGADs) are prime candidates for high resolution timing applications in High Energy Physics, Nuclear science, and other fields. Over the course of their lifetime, these sensors are required to withstand enormous amounts of radiation (> 10^{15} neq/cm^2) while maintaining acceptable performances at hadron colliders. Particles interacting with highly biased sensors can produce irreversible damages known as Single Event Burnouts (SEBs).

Recent studies conducted using high energy protons or pions, i.e. minimum ionizing particles (MIPs), found that LGAD sensors operated below a certain threshold voltage greatly minimized the risk of permanent damage. Thus, the current expectation is that SEB events might be more likely when a particle deposits a high amount of energy in the interaction with silicon. Protons and ions in the O(10 - 100) MeV energy range deposit a high amount of energy in silicon in their interaction, increasing the probability of SEBs with respect to a MIP produced at higher energy accelerators under the same experimental conditions.

We exposed a variety of LGADs and AC-LGADs, pre-irradiated at the Rhode Island Nuclear Science Center up to 1.5 x 10^{15} neq/cm^2, to a high intensity beam of both 28 MeV protons and 330 MeV Gold ions produced at the BNL Tandem Van de Graaff accelerator. Results from this study allow us to strengthen our understanding of SEB and permanent radiation damages and parametrize the SEB mortality threshold in interactions with high deposited energy.

Poster Session / 19

Beam test and digitization of TaichuPix-3 silicon pixel detector for the CEPC vertex detector

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The TaichuPix series chips, as sensors designed for the CEPC vertex detector, do not have a complete digital model, resulting in lower accuracy in simulations, especially in the long barrel's forward region. Allpix-Square, as an open-source software, is able to simulate the physical process of silicon pixel detectors and digitization of the front-end electronics. With the beam test results with different incident angles at BRSF we conducted, and the AllPix-Squared simulation, we will be able to achieve high-precision digitization for the TaichuPix-3 chip. This report will show the comparison between simulation and beam test results in cluster size and efficieny variation with the incident angle and threshold.

Poster Session / **20**

Design and test of COFFEE2, the first HVCMOS prototype in 55nm process

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Silicon tracking detectors in future high energy physics experiments usually requires excellent spatial resolution, nanosecond level timing resolution, good radiation hardness and large area coverage. High-Voltage CMOS sensors, exploiting commercial CMOS technologies, are intrinsically radiation hard and cost-effective for use in large quantities. With successful development in 180nm and 150nm processes, HVCMOS has become promising technical candidates for experiments like CEPC and LHCb upgrade. To achieve better spatial resolution, more functionality and lower power consumption, deveopment of HVCMOS in sub-100nm process is being explored. This talk will present the design and preliminary test of COFFEE2 chip, the first HVCMOS prototype in 55nm process. The IV and CV curves are tested using a small array of passive sensor diodes, and a breakdown voltage of -70V is reached for a regular low-resistivity wafer. Pixels with a variety of in-pixel circuits are designed, with amplifiers and comparators. Signal responses are observed for laser and radioactive sources. Plans of future R&D will also be briefly discussed.

LGAD 1 / **21**

Beam Test Preliminary Results of the ADA_5D LGADs Detectors and Front-end Electronics.

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Charge identification is a challenging task in space-based cosmic-ray (CR) experiments. This is due to the wide dynamic range required to identify CR elements, including heavy nuclei. Additionally, back-scattered radiation from the calorimeter degrades the charge resolution when it hits the same detector element traversed by the cosmic ray, hindering a correct identification of the cosmic nucleus.
This issue will be particularly relevant for future experiments aimed at exploring the highest energy part of the CR spectrum, as the amount of back-scattering increases with particle energy.
To address these challenges, the ADA_5D project, funded by the Italian National Institute for Nuclear Physics (INFN), is developing an innovative detector, based on arrays of Low Gain Avalanche Diode (LGAD) pixels. It is designed to be capable of simultaneously measuring position, charge (with a very wide dynamic range, up to Z˜40), and timing, with sub-nanosecond resolution. It uses a scalable technology suitable for covering wide areas (˜m²) with low power consumption, making it ideal for space experiments.
This presentation shows the first beam test results of the LGADs and front-end electronics being developed for the ADA-5D project. The test was carried out at the CERN-SPS North Area facility, during the 2024 winter campaign with Pb ions.
The beam test setup included a controlled environment where the prototypes were exposed to high-energy Pb fragment beams. The performances of the detector and of the front-end electronics were evaluated in terms of signal response and timing resolution. Preliminary results show promising performance, with the ADA_5D chip demonstrating stable operation under high-rate conditions.

Poster Session / 22

Performance degradation of SiPM sensors under various irradiation fields and recovery via high-temperature annealing

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Silicon Photomultipliers (SiPMs) are widespread photon detectors in high-energy physics. Their performance degrades significantly when exposed to radiation, particularly high-energy hadrons (neutrons or protons) that induce defects in the silicon lattice. A moderate level of radiation causes damage in SiPMs, leading to an increase in dark current and dark count rate (DCR) and potentially affecting the single-photon detection capability due to pile-up and limitations in the readout electronics. At very high doses, radiation damage can also modify operational parameters (breakdown voltage, gain) and decrease photon detection efficiency (PDE). Nevertheless, several studies show that high-temperature annealing can significantly accelerate the recovery of radiation-induced defects, thereby lowering dark current and DCR.

In this talk, we report on the studies performed in the context of the R&D for the dual-radiator RICH (dRICH) detector at the future Electron-Ion Collider (EIC), where a large number of SiPMs were tested for usability in single-photon applications in a moderate radiation environment. Proton irradiation was performed at the Trento Proton Therapy Centre, delivering integrated fluences up to 10^{11} 1-MeV n_{eq} /cm^2 to the SiPMs and studying different proton energies from 18 to 138 MeV. Neutron irradiation was conducted at the CN accelerator of the INFN Legnaro National Laboratories at integrated fluences up to 10^{10} 1-MeV n_{eq} /cm^2. Gamma irradiation was performed at the CERN GIF++ facility up to 1 krad. All sensors were characterised before and after irradiation, with special focus on their low-temperature performance at -30℃. Irradiated SiPMs underwent various annealing procedures to test their recovery capability from radiation damage. Particular attention was given to an annealing procedure exploiting the Joule effect, where high temperatures were achieved via self-heating of the sensor. Repeated irradiation and annealing cycles were performed to simulate a realistic experimental scenario and to assess the robustness of the sensors against such procedures.

A summary of the studies and the main results will be presented in this talk.

Applications 2 / 23

High-Resolution, High-Dynamic-Range Charge Detector for Ion Beam Monitoring

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We present an innovative charge detector with high resolution and wide dynamic range designed to fulfill the requirements of a monitoring system for a high energy ion beam. The detector prototype, constructed using Si planar diodes and a custom readout electronics, underwent extensive testing during HERD and AMS beam tests at CERN SPS facilities. Initial testing showcased the detector's exceptional performance, emphasizing both high resolution and a dynamic range capable of measuring nuclei with atomic numbers ranging from 1 to 80. The prototype's compatibility with fast, quasi real-time data analysis qualifies it as an ideal candidate for online applications. This work presents the results from the testing phase of the prototype, highlighting its capabilities and performance. Ongoing detector development, potential applications, and future developments aimed at enhancing the detector's functionality and versatility are also discussed.

LGAD 3 / 24

Test beam characterisation of the first DC-coupled Resistive Silicon Detector FBK production

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This contribution presents the test beam characterization of the first DC-RSD production at FBK.
DC-RSDs are an evolution of the AC-coupled RSD sensors, commonly called AC-LGAD. The DC-RSD design is characterized by the direct contact of the metal electrode with the n+ resistive layer and by the presence of trenches to avoid uncontrolled signal sharing among pixels.
Sensors with three different designs, squared pixels with 500 and 1300 microns pitch and triangular pixel of 500 microns side, have been exposed to a 5 GeV/c electron beam at the DESY laboratory, and their position and temporal resolutions measured.
This contribution will first introduce the experimental set-up, present the analysis method, and then show the results obtained for the different geoemtries.

Poster Session / 25

First Comparative Study on TI-LGAD samples without/with the grounded Guard Ring: A new insight into mechanism behind the self-induced signals

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The self-induced signals in trench isolated LGADSs can be driven by the complex interplay of trench-induced defects, electric field distortions, and temperature-dependent carrier dynamics. This self-induced signal phenomenon could be also related to the interplay between the guard ring (GR), trenches, and the n+ bias ring (implanted between two trenches). Such complex relation of many inter-linked phenomena may also lead to the enhanced duration of the avalanche multiplication supported by the positive feedback of the electron impact ionization at the periphery of the gain layer and the hole impact ionization at the corner of the SiO2 trenches. To our best knowledge the tests to directly assess the effect of grounded GR on ghost signals have not been performed yet. In this contribution we present the first comparative study on Ti-LGAD samples with/without grounding the guard ring. The two distinctive experimental techniques are applied: I-V measurements using a probe station at the Institute of Physics at the Czech Academy of Science and the TCT technique at the ELI ERIC, ELI Beamlines.

Poster Session / 26

Characterization of iLGAD with soft X-ray

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Hybrid detectors are highly attractive due to their high frame rate, large area coverage, and good radiation tolerance. However, for experiments with soft X-rays (200 eV - 2 keV) they are limited by the poor quantum efficiency of standard silicon sensors and by the low signal-to-noise ratio due to the small signal created by the soft X-ray photons. To overcome these limitations, inverse Low-Gain Avalanche Diode (iLGAD) sensors with a thin entrance window are being developed at Paul Scherrer Institute, in collaboration with Fondazione Bruno Kessler. iLGAD sensors bump-bonded to the 25 um pitch charge-integrating Mönch readout ASIC have been characterized using soft X-rays at 4th generation synchrotron radiation source MAX IV in Sweden. In this contribution, we will present the beam tests result, focusing on the spectral response of the iLGAD at different photon energies and temperatures. From the measurements, we have observed a reduction of signal amplitude above the silicon K-edge at 1825 eV, very likely caused by the gain suppression when photons are absorbed within/close to the gain layer. In order to verify the observation, the iLGAD module was titled with an angle of 55 degrees and measured with X-ray photons below the silicon K-edge. The spectral responses of both flat and tilted measurement configurations will be discussed, along with plans for further testing and improvements on iLGADs.

Poster Session / 27

Performance of irradiated TI-LGADs at 160 GeV SPS pion beams

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Trench-isolated (TI) LGADs, developed at FBK, are pixelated LGAD implementations where pads are separated by physical trenches etched within the silicon substrate and filled with a dielectric. Developed as an alternative approach to implant-based inter-pad separation (JTEs), this technology promises a dramatic reduction to dead regions, mitigating fill factor issues inherent to small-pitch pixelated LGAD matrices. Through a dedicated 160 GeV SPS pion test beam campaign, the time resolution, efficiency and inter-pad distance of Carbon Infused irradiated TI-LGADs is presented in MIP conditions. Fluences up to 2.5×10^{15} n_{eq}/cm^2 are evaluated, for single trench implementations with varied trench width. The combined timing and tracking readout used in this study, integrating ROI triggering, sub-μm multi-object alignment, multi-channel waveform digitization and achieving a 5-7 μm spatial resolution through a MIMOSA26 telescope, is also reviewed. Preliminary results are discussed for temperatures of -25 ^{o}C.

CMOS MAPS / 28

Timing response characterization of MALTA monolithic pixel detectors.

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The MALTA monolithic active pixel detector has been developed to meet the stringent demands of future high-energy physics experiments. To assess its capabilities, we performed fast-timing studies to define a figure of merit for this family of detectors. Conventional laser techniques are hindered by reflections from the sensor's metal layers, which restrict material penetration. We developed a triggered micro-X-ray system designed for precise timing measurements, that employs a micro-X-ray source that generates X-rays from a Cu-Cr target, synchronized with an external trigger signal. After validating the system with an LGAD, we used it to evaluate the timing performance of MALTA and MALTA2 pixel detector prototypes, providing insights into their operational characteristics.

LGAD 3 / 29

First experimental time-of-flight-based proton and helium radiography using low gain avalanche diodes

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Low Gain Avalanche Diodes (LGADs) are ultra-fast silicon detectors that allow the simultaneous measurement of an ion's position and time-of-arrival with a precision better than 100µm and 100ps, respectively. This excellent 4D-tracking capability enables the reconstruction of single-particle tracks even in high-luminosity environments, such as those encountered in high-energy physics experiments or ion beam therapy (IBT).
One particularly promising application for LGADs is ion computed tomography (iCT), an imaging modality designed to enhance treatment planning for IBT by directly determining the relative stopping power (RSP) map within a patient. Employing LGADs for iCT offers the dual advantage of maintaining clinically acceptable image acquisition times (typically under a few minutes) and integrating time-of-flight (TOF) measurements directly into the imaging process, a technique referred to as TOF-iCT.
In this work, we will present our progress in developing a TOF-iCT demonstrator system. This system incorporates single-sided LGAD strip detectors from FBK and a custom FPGA-based readout system developed at GSI. We will report on our initial ion imaging experiments at MedAustron, including the first Sandwich TOF-proton radiography of a small aluminium stair phantom and the first TOF-helium radiography of a mouse phantom. Finally, we will outline our plans for the development of a clinically viable TOF-iCT system based on LGADs.

Poster Session / 30

Development of in-house plating and hybridisation technologies for pixel detectors

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Within the CERN EP R&D programme and the AIDAinnova and DRD3 collaborations, innovative and scalable hybridisation and module-integration concepts are pursued for pixel-detector applications in future colliders. Most interconnect processes require specific surface properties and topologies of the bonding pads. An in-house Electroless Nickel Gold (ENIG) plating process is therefore under development, which is performed on single-die level and can be adapted to a large range of pad geometries and bonding techniques. The hybridisation processes under study include bonding with anisotropic conductive adhesives (ACA), as well as gold-stud bonding with epoxy underfill. The ACA interconnect technology involves conductive micro-particles embedded in an adhesive layer applied as either film or paste. The electro-mechanical connection between the sensor and ASIC is achieved via thermo-compression of the ACA using a flip-chip device bonder. This contribution

introduces the developed plating and interconnect processes, and presents recent results for dedicated daisy-chain test structures designed and produced by FBK as well as functional ASICs and sensors.

Applications 2 / 31

Performance of the CMS pixel detector during the LHC Run 3

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This talk will present the performance of the CMS experiment pixel detector during the LHC Run 3. Hit detection efficiency, collected charge and hit resolution will be presented as determined at the end of 2024 and as a function of the integrated luminosity delivered by the accelerator. Other important results, such as the Lorentz Angle determination, will be presented together with the high voltage bias scans that are performed regularly to monitor the detector health.

LGAD 2 / 32

AC-LGAD based ToF & out tracker detector for CEPC

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The AC-LGAD technology is chosen to be used as the time of flight detector and out track for the Circular electron-positron collider (CEPC). As suggested by the CEPC board, the time of flight is urgent for the flavor physics in CEPC, especially for the k/p and k/pi separation in the low-energy part. The AC-LGAD based ToF & out tracker would be located between the TPC and ECAL which would cover 90 m2 area. The expected performance is the 50 ps time resolution and 10 um spatial resolution. This talk would present the general design of the ToF & out tracker detector for CEPC.

Applications 1 / 33

LGAD Technology for Precise Reaction Time Measurement in Heavy-Ion Experiments, Medical Applications and Detector Diagnostics.

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The rapid advancement of Low Gain Avalanche Diode (LGAD) technology for charged particle detection has reached an impressive level demonstrating exceptional performance in applications such as reaction time measurement, beam monitoring, and ion computed tomography (ion CT). Recent measurements conducted at MedAustron with helium (He) and carbon (C) ions have delivered promising results, showcasing significant potential for heavy ion applications. This is particularly relevant for future FAIR experiments, where LGADs could serve as a superior alternative to the traditionally used CVD diamond-based detectors.
The ability of LGADs to achieve precise particle position and time-of-arrival measurements operated at room temperatures with accuracies better than 100 µm and 100 ps, respectively, further enhances their usage for detector diagnostic purposes, such as in beam telescope systems.
This presentation will highlight the results obtained with LGAD detectors for time-of-flight measurements of protons, He, and C ions at MedAustron. It will also detail the integration of these sensors with a custom-developed amplifier board and an FPGA-based readout system developed at GSI. Additionally, an example application of LGAD sensors for diagnosing radiation-induced damage in a polycrystalline CVD diamond sensor, and plans related to readout development for large-area detection systems, will be discussed.

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Status of the SINTEF 3D sensor production for the ATLAS ITk

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SINTEF MiNaLab is currently producing part of the 3D pixel sensors for the ATLAS ITk upgrade. Given the number of sensors requested and the complexity of the technology, the production has been split into two 24-wafer batches (Run-7 and Run-8). The two batches have been carefully scheduled to avoid conflicts in the clean room. Both batches use the common sensor layout for RD53B sensors in 50x50 (1E) configuration with slim-edge termination. Sensors are fabricated on 6-inch, Si-Si bonded wafers, with a device layer thickness of 150µm, using a single-sided processing approach. To mitigate concerns about curvature at sensor level after back-end processing, a new passivation layer has been implanted to balance the mechanical stress after support wafer removal and ease the bump-bonding process. Run-7 will be the first batch to reach the temporary metal step and the electrical characterization will start in early January 2025. In this presentation, we will focus on the

measurement results from standard planar test structures, 3D diodes and 3D pixel detectors obtained from Run-7 wafers. The status of Run-8 and expected delivery schedule of the full production will also be discussed.

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Extending SiPM Dynamic Range with Non-Linear Response Correction: The Single-Step Method Approach

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Silicon Photomultipliers (SiPMs) offer exceptional photon detection sensitivity, but face challenges in maintaining linearity across their operational range. At low light levels, the primary effect is the non-linearity of gain resulting from the voltage dependence of pixel capacitance. At high light intensities, the finite pixel count leads to non-linear response, limiting the dynamic range.

A key challenge in correcting non-linearity is the traditional requirement for a reference linear light source to determine the non-linear response correction. To overcome this limitation, the so called “single-step method”, originally developed for PMT calibration, can be applied. This technique is based on the difference in responses to two light sources, eliminating the need for an absolute reference. This approach effectively corrects SiPM non-linearity, significantly extending the usable dynamic range.

The talk will present and discuss the systematic studies conducted in the laboratory, where the response of various SiPMs with different pixel dimensions, operated at different temperatures, and overvoltages were measured and corrected using this method. Results highlight that the response function remains stable across an overvoltage range of 2-4 V and shows only mild temperature dependence over a 40 K range. Furthermore, linearity within 1% can be achieved by applying a single correction function within ± 5 K and ± 2 V of the original measurement conditions.

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Study of electrical characteristics of Low Gain Avalanche Detectors irradiated with 24 GeV protons

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Low Gain Avalanche Detectors (LGADs) are promising devices for high-precision timing and tracking applications in high-energy physics experiments. This study investigates the effects of radiation damage on LGAD performance following exposure to 24 GeV energy protons. The samples made

by Hamamatsu Photonics K.K. were subjected to varying proton fluences (Φ = 1E12-1E16 p/cmˆ2), and their gain and charge collection efficiency (CCE) were measured, revealing a degradation with increasing fluence. To further understand these effects, free carrier lifetime was characterized using the microwave-probed photoconductivity (MW-PC) method, which demonstrated a significant decrease in carrier lifetimes as proton fluence increased. Additionally, photoionization spectroscopy was employed to analyze defect energy levels within the band-gap associated with radiation-induced damage. Results indicate a correlation between proton fluence and the number of radiation-induced defect species, providing valuable insights into the mechanisms behind LGAD performance degradation. These findings contribute to the optimization of LGAD design for improved radiation hardness in future applications.

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Assembly and quality control tests of the 3D sensor modules for the innermost layer of the ATLAS ITk pixel detector

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The High Luminosity upgrade of the Large Hadron Collider (HL-LHC) will demand the ATLAS detector to face an increased instantaneous luminosity up to $7.5 \times 10^{34} cm^{-2} s^{-1}$ and an average of 200 proton-proton collisions per bunch-crossing. To cope with this challenge, the present ATLAS Inner Detector will be completely replaced with a new silicon-based Inner Tracker (ITk), made of a Pixel detector at a small radius and a large area Strip detector surrounding it. Specifically, the new Pixel tracker is based on hybrid detectors, in which the pixelated sensors are interconnected via bump-bonding to their dedicated readout ASICs. Whereas the same readout chip (ITkPix) –produced on a 65 nm CMOS technology –is used all along the pixel detector, two different technologies have been chosen for the pixel sensors: planar, for the outer layers, and 3D, for the innermost layer (L0). 3D sensors have been selected by their inherent radiation hardness, since the innermost layer will reach a fluence up to 2×10^{16} n_{eq} cm^{-2} (with a 1.5 safety factor), which is not suitable for planar sensor operation.
The basic unit of the pixel detector is the pixel Module. For the L0 layer, the pixel Module is known as "triplet", as it consists of an ensemble of three 3D pixel sensors individually hybridized to their respective readout chips (the so-called "bare modules") and mounted on a single flexible PCB, which allows for biasing and communication. To reduce the material budget, the modules are powered in serial power chains. There are three different designs for the triplet modules, according to their geometry: linear (with 3 bare modules in a row), which will populate the barrel section of L0; and two ring geometries (R0 and R0.5), in which the bare modules are disposed in a circle sector arrange, and will populate the coupled-ring and the intermediate-ring sections of the L0 end-cap, respectively. Seven European research institutes take care of the assembly and full quality control test of the triplets, with every institution specialized on a different geometry or specific stages of the production chain. The modules are then shipped to SLAC (US) to be loaded on the inner system local supports and interconnected in the serial power chains.
This talk aims at presenting an overview of the status of the ITk triplet modules, which are now entering in their production phase. Details of the assembly and testing procedures of the first triplet prototypes will be included, with a special focus on the specific tests carried out to assess the quality of the bump connectivity, the integrity of crucial sub-systems of the readout chip, and the stability of the sensor performance along the process. Some update of the serial power interconnection and loading on their final supports will be also included.

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Performance evaluation of pre-production modules of ATLAS ITk after full characterization process

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The ATLAS inner detector will be completely replaced with a new all-silicon tracking detector (ITk) in 2026-28 to cope with the challenging conditions of the High Luminosity LHC.
The pixel detector will be located in the innermost part of the ITk detector. It will be instrumented with 3D sensor technology in the innermost layer (L0), where a fluence up to 2 x 1016 neq/cm2 is expected, and with n-in-p planar hybrid modules 150 µm and 100 µm thick in the three outer layers (L2-L4) and in the first layer (L1), respectively.
Before starting production of final modules, following the ITk Pixel QC programme, pre-production quad modules were assembled with ITkPixv1.1 chips and 150 µm thick planar sensors at the University of Glasgow as a part of the United Kingdom contribution to the production. These modules went through a series of characterization processes to evaluate electrical performance before and after parylene coating at both +200 C and -150 C temperatures. Mechanical durability of the bump bondings is also tested by thermally cycling between high (+450 C) and low (-450 C and -550 C) temperatures, and stability of the module is tested by running the module for 48 hours. All the processes are run under constant monitoring of temperature, humidity, low voltage and high voltage; an interlock system also operates to ensure safety of the module. This study will focus on the performance of the modules at different stages of characterization.

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Overview of the design, assembly and quality control tests of the Quad modules for the ATLAS ITk pixel detector.

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The High Luminosity upgrade of the Large Hadron Collider (HL-LHC) will increase the integrated luminosity to 3000fb^{-1} and the instantaneous luminosity up to $7.5 \times 10^{34} cm^{-2} s^{-1}$ in the ATLAS experiment. This results in an average of 200 proton-proton collisions per bunch-crossing compared to 48 in the current Run-3. This increases radiation damage and device occupancy. To cope with this challenge, the present ATLAS Inner Detector (ID) will be completely replaced with a new silicon-based Inner Tracker (ITk), made of five layers instrumented with Pixel detector at a radius below 300 mm and 4 layers of Strip detector surrounding it up to a radius of 1000 mm. The Pixel tracker is based on hybrid detectors with most of the system consisting of quad modules, where a single planar silicon sensor is flip-chip bonded to an array of 2x2 readout chips to produce the bare module. For the inner most layer, where the radiation level is highest, the 3D sensor is used, and the module consists of 3 individual bare modules of sensor and front-end chip. The pixel system consists of 8016 quad modules and 452 triplet modules made from 1356 3D bare modules.
The ITk is targeting the same or better physics performance than the current ID which necessitates a lower mass approach than the present system. To deliver this serial powering has been chosen for the LV power delivery solution. The increased power density and radiation levels calls for a lower cooling temperature than the ID and an evaporative CO_2 systems has been developed.
The talk presents the design requirements of the quad module with validation data including: the validation of the bump performance; the robustness of the hybridisation to thermal cycles from -55C to +60C; the module coating used for HV performance; assembly tolerances, and the design of the module powering for a serial powering chain.
Over 300 quad modules have been assembled and tested during the per-production phase. The pre-production QC results will be summarised.

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Enhancing the Electro-Optical Properties of MOCVD GaN Structures for Radiation Sensor Applications by Chemical Surface Modification

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Gallium Nitride (GaN) and its alloys with In or Al are widely utilized in the production of light-emitting diodes, lasers, and sensors for chemical, gas, biological, and pressure detection. GaN is also critical for developing radiation-tolerant sensors used in the space industry, medical diagnostics, and high-energy physics applications. Direct-bandgap binary compounds like GaN are effective for creating dual-response devices that generate both electrical and optical signals.
GaN crystals can be grown using several methods, including metal-organic chemical vapor deposition (MOCVD) and ammonothermal (AT) techniques, which yield crystals with varying qualities. For example, AT GaN crystals exhibit a dislocation density as low as 100 cm^{-2}, while MOCVD GaN crystals typically reach higher dislocation densities. However, AT GaN often contains more homogeneously distributed vacancy-related defects throughout the crystal bulk. These dislocations create strain fields and space charge regions, affecting the electrical and optical properties of devices such as radiation detectors. Understanding the recombination dynamics of free carriers within the crystal bulk, surface, and dislocation networks is essential for optimizing device performance.
This study focuses on investigation of highly dislocated MOCVD GaN:Si wafers grown on sapphire substrates for radiation sensor fabrication. Variations in electro-optical properties between the center and edge of the wafer were analyzed. An increased yellow luminescence band in the photoluminescence spectrum was observed after etching of samples in potassium hydroxide (KOH) and orthophosphoric acid (H_3PO_4). Proton-induced luminescence was measured in situ on both pristine and etched MOCVD GaN:Si samples. Investigation revealed a stretched-exponential relaxation (SER) component within excess carrier decay transients, which highlighted differences in carrier lifetimes within the bulk of highly dislocated MOCVD and AT GaN crystals. These results indicate that dislocations attract point defects, forming regions of higher quality GaN within inter-dislocation volumes.
This research provides insights into enhancing the electro-optical characteristics of MOCVD GaN-based radiation sensors through chemical surface modifications.

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Characterisation of Crystalline Defects in 4H Silicon Carbide using DLTS and TSC

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It has become apparent that Silicon, though an excellent choice as a sensing material for current particle detectors, suffers greatly when exposed to heavy radiation, degrading properties like charge collection efficiency and increasing noise levels. Future collider experiments will require it to withstand stronger radiation fields. Therefore, either a frequent replacement of detectors, a leap in the radiation hardness of Silicon, or a shift to different materials is needed. Wide-bandgap materials are a natural choice, due to their significantly reduced leakage currents, even after irradiation. In recent years, substantial progress in the production of high-quality monocrystalline Silicon Carbide of the 4H polytype has led to a renewed interest in this material.

In this talk, a study focusing on crystal defects in n-type epitaxial 4H Silicon Carbide diodes will be presented. Microscopic defects in the crystal lattice, whether intrinsic or radiation-induced, introduce energy levels in the bandgap, leading to altered electrical characteristics of the material. The study primarily investigates the unirradiated material and its numerous defects. Results from Deep-Level Transient Spectroscopy (DLTS) and Thermally Stimulated Currents (TSC) are presented, complemented by current-voltage and capacitance-voltage measurements. TSC spectra simulations were utilised to correlate DLTS and TSC results, identifying some discrepancies between the spectra obtained with the two techniques. Results from unirradiated diodes are compared with those irradiated using 23 GeV protons at varying fluences up to $1{\cdot}10^{15}$ protons/cm^2.

This study concludes that state-of-the-art 4H Silicon Carbide contains a multitude of defects already present prior to irradiation. These defects are therefore likely intrinsic, such as vacancies, or related to impurities and doping imperfections.

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Study of deep carbonated LGAD at IHEP

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Low Gain Avalanche Detectors (LGADs) are crucial for high-energy physics applications, especially in the harsh radiation environments of future colliders. This abstract introduces LGADs enhanced with deep carbon implantation, emphasizing their superior radiation tolerance.

LGADs achieve high temporal resolution and precise spatial measurements through an internal gain mechanism and fine structure. The deep implantation of a carbon layer significantly enhances performance by protecting the boron gain layer from deactivation caused by irradiation. This protection is critical for maintaining detector efficiency and longevity.

Our proton irradiation campaign demonstrates that deep carbon implanted sensors exhibit outstanding performance, with better charge collection efficiency and smaller gain deterioration after 80 MeV proton radiation exposure up to $2.5 \times 10^{16} n_{eq}/cm^2$ compared with shallow carbon implanted devices. These improvements ensure consistent and reliable operation in high-radiation environments, making LGADs with deep carbon implantation a pivotal advancement.

This presentation will delve into LGAD operation principles, merits and drawbacks of deep carbon implantation, and experimental results showcasing enhanced performance in radiation tolerance.

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Validation of TCAD simulations of the edge of planar silicon sensors to understand breakdown

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Silicon sensors are widely used in high-energy physics due to their low material budget and radiation hardness. However, they are susceptible to surface breakdown, particularly under humid conditions. This study aims to improve the understanding of the underlying mechanisms by developing new methods to probe the electric field at the sensor's edge. For planar sensors, avalanche breakdown primarily occurs at the Si-SiO_2-interface, where localized electric field peaks can form between the guard ring and the edge. The local electric field is influenced by defects at the oxide surface and interface as well as the geometry of the sensor. Therefore, accurate simulations are challenging and it is essential to validate simulation parameters by comparing the simulation results to measurements.

In this work, the edge region of planar silicon diodes was simulated using Synopsis TCAD. Current, capacitance, and Transient Current Technique (TCT) simulations were performed and compared to measurements. Additionally, Allpix Squared simulations were used to determine whether the surface electric field at the edge can be extracted from top TCT measurements with 660 nm laser pulses using the prompt current method, similar to edge TCT.

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Back-side-illuminated Silicon photomultipliers for improved radiation hardness

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Silicon Photomultipliers (SiPMs) are single-photon sensitive detectors that continue to attract increasing interest in several industrial and scientific applications that require fast detection speed, high sensitivity, compactness, insensitivity to magnetic fields and low bias voltages. In particular, the SiPMs are used in high-energy physics (HEP) experiments, and for the readout of scintillators in gamma-ray detectors for space experiments. In such applications they receive a significant dose of radiation (e.g. protons, electrons, neutrons, ···) which degrades their performance.
During the last years, at FBK (Trento, Italy) we have been developing many different technologies for SiPMs and SPADs, optimized for different applications. We also studied extensively the effect of ionizing energy loss effects and non-ionizing energy loss effects (i.e. bulk displacement damage) on many different SPAD and SiPM technologies, highlighting the most interesting effects on noise and detection efficiency.
Based on such results, we started specific technological improvements aimed to improve the radiation hardness of novel SiPMs technologies. We are currently working on several directions. Among the most promising: i) we are exploiting the reduction of the high-field active area, with a novel SiPM structure based on charge-focusing mechanisms and back-side illumination, to mitigate the noise increment due to back damage, and ii) we are working on active control and draining of radiation-induced charge in the dielectrics, to mitigate the electric field modification effects of ionizing-energy loss. We performed TCAD simulations of the microcell (i.e. SPAD) structure, and we estimated the noise generation (including field-enhancement effects), to verify and quantify the beneficial effects of charge-focusing on the mitigation of the irradiation-induced bulk-damage effects, showing a reduction of the primary dark count rate (also after irradiation) and a reduction of the activation-energy lowering after irradiation.

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Development and Wafer-level Characterization of the First Production of DC-RSD Sensors at FBK

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DC-RSDs are silicon sensors that aim to provide a time resolution for minimum ionizing particles in the order of 30 ps and a spatial resolution of a few percent of the channel pitch. These performances are enabled by internal charge multiplication and resistive charge division between the channels. The time resolution is expected to be the same as Low Gain Avalanche Diodes (LGADs). The performance of the resistive charge division mechanism was demonstrated in AC-LGADs or Resistive Silicon Detectors (RSD) where a capacitive coupling between readout electrodes and resistive layer was employed. DC-RSDs use a direct coupling between the electrodes and the resistive layer avoiding the bipolar signal of the AC-coupled designs and providing a better bias distribution to the resistive layer. The channel segmentation does not rely on interrupting the gain layer, aiming to maintain a fill factor close to 100%. The first DC-RSD sensor batch was fabricated at FBK with the aim to demonstrate the soundness of the sensor concept. This batch contains design variations of the sensors, trench isolation between channels to provide signal confinement on the resistive layer, and an improvement in the contact resistance between readout electrodes and resistive layer. This talk summarizes the characterization of the sensors performed at wafer level. Results on contact resistance, gain, breakdown voltage, and sheet resistance of the resistive layer will be shown.

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Silicon Carbide Detector Development for HEP and Medical Applications

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Silicon Carbide (SiC) detectors are gaining renewed research interest alongside the material's growing adoption in power electronics. The physical properties relevant to power electronics are also advantageous for detector applications, and SiC timing detectors could replace silicon detectors in the future. One limitation of SiC, however, is the currently limited epitaxial thickness that can be grown and depleted, which creates significant challenges for detecting and timing MIPs. This can be overcome by introducing charge multiplication, i.e., low-gain avalanche diodes (LGADs). SiC-LGADs are currently a topic of very high interest, as the performance of SiC-LGADs could surpass that of Si-LGADs.

We present the current status of SiC detector development at HEPHY and characterization of samples produced by CNM. The material properties of unirradiated 4H-SiC have been studied in an extensive literature review and by measurements using 50 and 100 µm thick detectors, for example, to determine the electron-hole pair ionization energy. In order to investigate the radiation hardness of 4H-SiC, two irradiation campaigns were conducted, reaching 1 MeV neutron equivalent fluences of $1 \cdot 10^{16}/\text{cm}^2$ and, recently, $1 \cdot 10^{18}/\text{cm}^2$. Above a fluence of $1 \cdot 10^{14}/\text{cm}^2$, the SiC epi-layer becomes intrinsic and can be operated in forward and reverse bias with negligible leakage currents. The charge collection efficiency has been investigated by alpha particles, protons, and UV-TCT and a TCAD radiation model has been built. In forward bias operation, charge enhancement (surpassing 100% charge collection efficiency) has been observed and is shown to correlate with the density of injected charge.

Furthermore, medical applications of SiC detectors at the MedAustron ion therapy facility are presented. SiC detectors have been used for ultra-high dose rate studies, providing crucial insights into the beam extraction profiles. Additionally, SiC microdosimeters and a SiC-based beam monitoring system are under development.

Finally, we present the design of our first SiC-LGAD run, which is currently being produced by CNM on 6-inch wafers. The expected performance of the SiC-LGADs, as well as the design challenges and tradeoffs, are discussed.

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A Wide Dynamic Range Beam Monitor for Ion Therapy Machines

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Many technologies initially developed for particle physics are now employed in medical particle beam therapy. One area where technology transfer is more challenging is particle sensing, as requirements differ substantially. While particle physics requires detecting and characterizing every particle hitting the detector, only the beam's statistical properties are important in ion beam therapy. However, the particle rates are substantially larger, reaching $10^{11}\ \text{cm}^{-2}\text{s}^{-1}$. We are working on a primary beam monitor to bridge the gap between these requirements. We have developed a detector system capable of detecting single particles at fluxes of up to around $10^{5}\ \text{cm}^{-2}\text{s}^{-1}$ while also being capable of characterizing the beam at clinical particle rates.

We will present the concepts employed in the particle detector and measurement results from prototype testing. The particle detector employs an array of low-noise integrators with variable gain,

initially intended for use in X-ray TFT panels. In the highest gain mode, the integrators showed a noise of 600 to 1000 e, enabling the discrimination of single particles when paired with suitable particle sensors. In the lower gain modes of the integrators, beams at clinical rates can be characterized. When needed, configurable attenuators can further extend the dynamic range. Tests were carried out using both silicon and silicon carbide (SiC) particle sensors. SiC sensors proved ideal for our detector due to their negligible dark current, enabling lifetimes up to $5 \cdot 10^{15}\ \mathrm{n_{eq}/(cm^2 s)}$. SiC Strip sensors were optimized for high-voltage operation using TCAD simulations to extend the lifetime of radiation damage sensors further. A tiled sensor layout was adopted for sufficient production yield.

Poster Session / 48

Investigation of the time resolution of TI-LGAD sensors for 4th generation synchrotron radiation sources

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The Swiss Light Source 2.0, a 4th generation synchrotron radiation source based on a Diffraction-Limited Storage Ring (DLSR), offers high brilliance and coherence with a fundamental pulse repetition rate of 500 MHz. In the soft X-ray branch, Time-Resolved Scanning Transmission X-ray Microscopy (TR-STXM) technique previously utilized Avalanche Photodiodes (APDs) to study dynamic phenomena with a time resolution of few hundred picoseconds using pump-probe techniques and leveraging on the bunch structure of the machine. However, the increased photon flux following the upgrade leads to a significant pile-up of X-ray pulses in APDs, limiting their performance and requiring a segmented detector to distribute the photons over several readout channels.
In collaboration with the Fondazione Bruno Kessler, we designed circular Trench-Isolated Low-Gain Avalanche Diodes (TI-LGADs) segmented into eight sectors with independent readout pads to address this challenge. This allows separating signals of individual pulses, supporting eight times the flux compared to the existing single-channel APD. In this study, the time resolution of a readout sector was characterized using a 660 nm red laser and soft X-ray photons (500–1400 eV) at the SoftiMAX beamline of MAX IV in Sweden read out using an oscilloscope. The impact of sensor bias voltage, beam intensity, and photon energy on time resolution was systematically investigated. Furthermore, we found the time resolution was also influenced by the bandwidth and sampling rate of the oscilloscope and the quality (slew rate) of the reference signal synchronized to the synchrotron. A time resolution of <100 picoseconds has been demonstrated highlighting the potential of TI-LGADs for high-flux soft X-ray detection at the upgraded SLS-2.0.

The experimental results will be presented in this contribution and further improvements for soft X-ray detection will be discussed.

Poster Session / 49

Development of the Silicon Electron Multiplier (SiEM) Sensor and Fast-timing Readout Tools For Sensor Characterization

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In the new era of HL-LHC experiments, fast-timing detectors are emerging as a critical priority. Typical requirements include a temporal hit resolution of 50 ps with a fine pitch of 50 µm, maintaining high spatial resolution and radiation hardness. These specifications are essential for track separation in high pile-up environments. To address these challenges, the development of non-standard sensor designs and advanced fast-readout electronics is required, pushing the limits of current technology.
The Silicon Electron Multiplier (SiEM) sensor is a novel concept for minimum ionizing particle (MIP) detection, designed to deliver excellent time and spatial resolution with fine pitch and internal gain obtained through an integrated metal grid. This approach aims to mitigate the typical gain deactivation mechanism that may affect performance in other sensor technologies, with an expected fluence of up to 10^{16} neq/cm^2. Manufacturing techniques such as metal-assisted chemical etching and deep reactive ion etching are being explored to produce the first SiEM demonstrators.
The characterization of such demonstrators requires the development of a dedicated fast-timing readout tool. The OPTIMA multichannel board is designed for fast readout of test structures and can simultaneously process data from 16 channels. A key feature of the OPTIMA board is its compatibility with the Timepix4 telescope for track reconstruction.
This contribution will present results from SiEM simulation studies, demonstrator manufacturing, and laboratory and test beam characterization of the OPTIMA board, conducted within the EP R\&D WP1.1 group at CERN.

Poster Session / 50

Simulation and Test Beam Results of Passive CMOS Strip Sensors

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Nearly all future high-energy particle detectors will employ large areas of radiation hard silicon sensors as their main tracking detectors, facilitating the need for cost-efficient, reliable and large scale production. A promising avenue of research are sensors based on the CMOS imaging process.

Three variations of passive CMOS strip sensors have been designed by the University of Bonn and produced by LFoundry in a 150 nm process. In order to reach strip lengths typical for HEP sensors, up to five reticules were connected via stitching during the photolithography process. Sensor samples have been irradiated up to a fluence of $1 \cdot 10^{16} \mathrm{n_{eq}}/\mathrm{cm}^2$ with reactor neutrons and up to $1 \cdot 10^{15} \mathrm{n_{eq}}/\mathrm{cm}^2$ with 23 GeV protons.

Studies of the devices include the simulation of unirradiated sensor samples with Sentaurus TCAD as well as test beam campaigns conducted at the DESY II facility, focusing on the hit detection efficiency and resolution of samples at different fluences.

This contribution will give a brief overview of the most important results of these studies, with the main focus being put on the results of the test beam analysis.

Poster Session / 51

Status of the FBK SiPM production for the Far Detector of DUNE

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The Far Detector (FD) of the Deep Underground Neutrino Experiment (DUNE) will feature a Liquid Argon Time Projection Chamber (LArTPC) in which the scintillation light will be detected by Silicon Photomultipliers suited for cryogenic applications. Driven by the requirements of the DarkSide experiment, FBK has developed a SiPM technology for cryogenic applications (NUV-HD-Cryo SiPM) featuring a very low dark noise in the order of few mHz/mm2 at cryogenic temperature, low afterpulsing probability and a limited variation of the quenching resistance with temperature. In the framework of the DUNE collaboration, the NUV-HD-Cryo technology was further developed to obtain a device with high gain but limited crosstalk by increasing the number of Deep Trench Isolation (DTI) with the goal to have better Signal to Noise ratio for the DUNE readout module.
Big physics experiments usually require devices with the highest performance possible, with low to medium production volumes in a short time to fulfill the tight schedule of the experiments. In FBK we developed a small supply chain, which comprises an external foundry for the SiPM fabrication with FBK technology and an external packaging company, capable of delivering up to moderate volumes of production of silicon detectors in a package.

In this work,the NUV-HD-Cryo technology performance and the status of the FBK SiPM production for the DUNE experiment will be reported in terms of uniformity of the breakdown voltage, dark current and forward resistance of the SiPMs and quality assessment of the SiPM board packaging.

CMOS MAPS / 52

Characterization of silicon Monolithic Stitched Sensors for the ALICE ITS3

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The ALICE Collaboration at the Large Hadron Collider (LHC) will replace the three innermost layers of the Inner Tracking System (ITS) during the Long Shutdown 3 in 2026-2029. The new inner tracker, called ITS3, will consist of truly-cylindrical silicon barrels to improve the pointing resolution by a factor of two over a large momentum range and the tracking efficiency at very low transverse momenta (p_{T} < 0.3 GeV/c).
The first three layers will be equipped with stitched 27 cm long wafer-scale monolithic active pixel sensors built using a 65 nm CMOS imaging process technology. The sensors will be thinned to 50 μm to become flexible allowing the formation of truly-cylindrical barrels with an extremely low material budget of 0.09 % X/X_0 per layer. Starting from mid-2023, chip prototypes, the so-called MOnolithic Stitched Sensors (MOSS), have been produced to demonstrate the feasibility of the stitching process. A single chip has a dimension of 14 mm $\times$ 259 mm and a total of 6.7 million pixels organized in 10 repeated sensor units with pixel pitches of 18 and 22.5 μm. A second design is implemented in the MOnolithic Stitched Sensor with Timing (MOST) to evaluate on-chip powering segmentation containing 0.9 million pixels with 18 μm pitch distributed on a smaller area of 2.5 mm $\times$ 259 mm.
The primary goal of MOSS and MOST is to learn about the stitching technique implementation, yield and performance of wafer-scale sensors in view of the production of the ITS3 final-size full-functionality prototype sensor chip foreseen for summer 2025. The characterization campaign of the stitched sensors includes the verification of power domain impedances, DAC performance, pixel front-end readout response, threshold scans and fake-hit rate scans. This presentation will focus on the results and learnings from the characterisation campaign of the stitched sensors in the laboratory and in the test-beam facilities with an overview of the final chip features.

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Performance and operational experience of ALICE ITS2 in LHC Run 3

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The ALICE experiment underwent significant upgrades during the LHC Long Shutdown 2 (2019–2021), including the installation of the new Inner Tracking System (ITS2). ITS2 comprises seven layers with 12.5 billion pixels spanning 10 m², based on the ALPIDE CMOS Monolithic Active Pixel Sensors (MAPS), which offer an intrinsic spatial resolution of approximately 5 μm. Designed to handle Pb-Pb collisions at interaction rates of up to 50 kHz, ITS2 delivers enhanced tracking performance, particularly in terms of impact-parameter resolution and efficiency at low transverse momentum. This improvement is achieved through its increased granularity, low material budget of

0.36% X₀ per layer in the innermost layers, and the placement of the first layer at a radial distance of 23 mm from the interaction point.

ITS2 became operational at the start of LHC Run 3 and has since demonstrated excellent performance in both proton-proton and heavy-ion collisions. This contribution will present an overview of ITS2's operational experience and recent results, with a particular focus on detector calibration and tracking performance. Additionally, operational insights gained from ITS2 will be shared, highlighting lessons learned, including beam background mitigation, from which the development of future detectors like ITS3 and ALICE 3 will profit.

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Pixel column issue in the ATLAS ITk Pixel Modules

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Pixel modules are currently being built for the ATLAS ITk Pixel detector upgrade.

Since the preproduction phase, recurring chip malfunctioning was observed during electrical testing, that was bypassed by disabling some pixel core columns in the ITkPix readout chip.
This issue is therefore called the "core column issue" which is a direct disqualifier for a pixel module.
A concerning number of cases has been observed in pixel modules with ITkPix v1.1 as well as v2 chips which would lead to unacceptable module yield.
However, the behaviour is erratic and there is no smoking gun hinting at the origin of this issue.

In this contribution we want to present our debugging process, highlight the electrical behaviour during testing, present findings in the data collected via our production database and through visual inspection, and point towards possible causes of the issue.

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Performance evaluation of a CMS Outer Tracker PS module before and after irradiation

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The LHC is about to enter the High Luminosity phase (HL-LHC) with a luminosity of 5-7.5×10ˆ(34) cmˆ(-2)sˆ(-1) and a center-of-mass energy of 14 TeV. This phase will significantly increase the available data and impose tougher conditions on the detectors. To meet these new challenges, the CMS outer tracker will be updated with the new 2S and PS modules. Each module consists of a pair of silicon sensors: two strip sensors for the 2S module and one pixel and one strip sensor for the PS module. These modules are designed to withstand radiation and provide transverse momentum information to the L1 trigger. A PS module was studied at Fermilab to evaluate its efficiency, noise, and transverse momentum selection before and after exposure to radiation levels comparable to those expected in CMS during the HL phase. The most significant results from recent test beams are presented here, highlighting the module's performance both pre- and post-irradiation.

Poster Session / 60

CMS Inner Tracker Module Production and Qualification for the HL-LHC Upgrade

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The High-Luminosity Large Hadron Collider (HL-LHC) operation will push the CMS experiment to its limits, with an instantaneous peak luminosity of $7.5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and an integrated luminosity of $300\,\mathrm{fb}^{-1}$ per year. This environment will expose the CMS Inner Tracker (IT) Pixel Detector at the center of CMS to unprecedented radiation, with a 1 MeV neutron equivalent fluence of 2.3×10^{16} neq/cm^2 and a total ionizing dose of 1.2 Grad. To endure these conditions and handle hit rates of 3.2 GHz/cm^2 while managing a pileup of 140-200 collisions per bunch crossing, the new IT system will employ a highly granular design with thin silicon sensors, small pixels ($25 \times 100\,\mu\mathrm{m}^2$), and fast, radiation-hard electronics based on a 65 nm CMOS ASIC developed by the RD53 collaboration. Currently, pre-series modules for the IT system are being constructed, and rigorous testing is ongoing to validate both the module components and the quality control procedures. In the coming months, full-scale production of the IT modules will commence. The status of module production at the assembly sites, results from module testing and qualification, and the roadmap toward installation in 2028 will be presented.

Poster Session / 61

Novel method to assess the electromagnetic radiation damage using HGCAL silicon sensors

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Studies of the silicon dioxide (SiO2) passivation layer in n-on-p silicon sensors, which will be used in the CMS High Granularity Calorimeter (HGCAL), are important for improving their performance not only in High-Luminosity LHC run, but also in future high-energy physics experiments. This work explores a novel method for estimating surface damage in HGCAL sensors. Test diodes with different SiO2 variants were irradiated with X-rays, and their characteristics were measured at controlled temperature of -20°C. The results are then compared with previous measurements with MOS and strip-like sensors

Technology / 62

Results from a 2nd production run of low temperature wafer-wafer bonded pad-diodes for particle detection

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We are investigating the use of low temperature wafer-wafer bonding in the fabrication of next-generation particle pixel detectors. This bonding technique could enable the integration of fully processed CMOS readout wafers with high-Z absorber materials, facilitating the creation of highly efficient X-ray imaging detectors. It might also facilitate the integration of structures embedded inside the wafer bulk, such as deep uniform gain layers.

The bonding process results in a thin (nm-scale) amorphous layer at the bonding interface. To study the impact of this interface on detector operation, we fabricated simple wafer-wafer bonded pad diodes using high resistivity float-zone silicon wafers. Results from a first fabrication run of such diodes revealed that the presence of the bonding interface alters the depletion behaviour, with the interface acting as a heavily doped N++ layer. However, metal contamination of the bonding surfaces during fabrication compromised these results, making them unrepresentative of an ideal bonding interface.

In this talk, we present the results from a subsequent fabrication run, which does not exhibit this sort of metal contamination. These results confirm that the bonding interface behaves as a heavily doped N++ layer, even without contamination. Finally, we will discuss the reverse leakage current of the bonded samples.

LGAD 2 / 63

Characterization of the FBK-LGAD devices manufactured at an external foundry for large-volume productions

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In recent years, the HEP detector community has shown an increasing interest in LGAD sensors due to their excellent temporal resolution, good radiation resistance, and low material budget. A great example of this is the upcoming CMS Endcap Timing Layer (ETL), a subdetector which will feature four disks (14 m2) covered with these devices.
In this context, Fondazione Bruno Kessler (FBK), one of the qualified producers of the ETL LGAD sensors, has recently initiated a technology transfer of the FBK-LGAD technology to an external CMOS foundry (LFOUNDRY), in order to enable a larger and cost-effective production.
The first prototype run from LFOUNDRY was produced in May 2024. In order to evaluate the success of the technology transfer, this batch has been assessed against the CMS-ETL detector specifications. The initial characterization focused on the LGADs electrical properties (Leakage current, Breakdown Voltage, Depletion Voltage, Gain, Pad Isolation and Interpad distance). Additionally, a test beam at the H6 CERN hadron beam line allowed us to assess their performance in terms of collected charge and time resolution, while laboratory measurements on neutron-irradiated samples their radiation resistance. The positive results obtained are very promising for the future of large-scale LGAD production.

3D / 64

3D scans of timing resolution in 3D columnar silicon technology

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We present the 3D scans of the latest 3D columnar silicon sensor technology, manufactured at the CNM-IBM (RD50 Common project). Double Sided Double Type Technology is studied. Hexagon structures (5x5 array of 3D Si cells) are compared to Quadratic structures (10x10 array of 3D Si cells). Timing study is performed using TCT set up at ELI (both SPA where we exploited two wavelengths and TPA -TCT where we exploited different depths inside the active volume of 3D silicon sensors).

Poster Session / 65

Performance of an X-γ ray detection system based on a thick silicon LGAD

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The performance of a 300 um thick silicon low-gain avalanche diode (LGAD) as X-γ ray detector has been experimentally acquired and studied in detail. The LGAD can operate with multiplication gains between $M_s = 10$ and $M_s = 20$, at which a wide energy range X-γ ray spectroscopy using a ^{241}Am radiation source has been done. It is shown that the main contribution to the FWHM of the spectral lines is the statistical noise of the charge multiplication inside the LGAD structure, while the other electronic noise components associated to the detector, interconnections and charge amplifier have been found to give minor contributions. The excess noise affecting the spectral line widths is found to be proportional to the multiplication gain M_s, while the series noise components (white and 1/f) reduce with increasing M_s. Consequently, the LGAD structure shows a significant shortening of the optimum peaking time, resulting in an improved X-ray spectroscopy performance with respect to an equivalent standard detector for fast signal processing.

LGAD 3 / 66

Single-Particle Counting with LGAD Detectors in Therapeutic Proton Beams

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Low Gain Avalanche Detectors (LGADs) can operate in single particle counting mode directly in proton beams. These detectors are radiation hard, allowing operation under therapeutic beam fluences for extended periods. With timing resolution below 50 ps, LGADs can provide precise timing measurements of individual particles. This study examines the use of LGADs as particle counters for beam fluence monitoring. The timing measurements from these detectors can potentially be used to derive additional beam properties, such as the kinetic energy spectrum. Experimental tests were performed using two LGAD detector systems at the AIC-144 cyclotron facility (58 MeV protons) at the Institute for Nuclear Physics in Krakow. Comparison with ionization chambers validated the detectors' performance as beam monitors. The study included a detailed analysis of cyclotron beam time structures across multiple time scales, ranging from milliseconds to sub-nanosecond resolution. These measurements revealed characteristic features of the beam microstructure at different time intervals. Additionally, several methods were developed and tested to address pile-up events in high-intensity beam conditions.

Poster Session / 67

Study of the charge carrier properties of a pixelated 4H-SiC with Timepix3

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Recent advantages in detector production have facilitated the manufacture of pixelated 4H-SiC detectors, which can be an alternative to silicon ones especially in the harsh radiation environment, or in the environment with high temperatures, where such sensors profit from their higher band gap. Moreover, thanks to an elastic scattering cross-section of carbon for fast neutrons the SiC sensors have higher neutrons detection efficiency than Si sensors.

In the present contribution, we characterize pixelated 4H-SiC sensors of ˜80 µm sensitive thickness flip-chip bonded to the Timepix3 ASIC. Comprehensive testing was performed including measurement of IV curves, depletion voltage scans, determination of the achievable energy resolution for gammas and MIPs, as well as a study of the response to monoenergetic fast neutrons, and mixed relativistic ions. By performing measurements at grazing angle, the latter measurement allows to study the dependence of the holes drift velocity on the electric field when irradiating at grazing angle utilizing the 1.5 ns time-stamp measurement precision of Timepix3 [1]. The holes mobility was measured to be µh = (93.4+-4.4) cm2/V/s consistent with the literature.

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3D / 68

The influence of pixel cell layout on the timing performance of 3D sensors

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We report on the characterization of 3D columnar-electrode sensors featuring 55 µm-pitch square and hexagonal pixel cells, evaluated with the Two-Photon Absorption Transient Current Technique (TPA-TCT) using the SSD laser facility at CERN. These sensors, manufactured at IMB-CNM, are double-sided n-in-p diodes with a thickness of 285 µm. The study provides detailed maps of the electric field distribution within the pixel cells and examines the time spread between the actual time of arrival and the discriminated time across the pixel cell. The results offer valuable insights for optimizing 3D pixel sensors in applications requiring high precision in both spatial and timing resolution.

Applications 2 / 69

Silicon tracker requirements at a multi-TeV Muon Collider

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A Muon Collider with the centre-of-mass energy of 10 TeV is actively studied as a successor of the LHC thanks to its unique combination of high energy reach, clean final state and low environmental footprint. Very low level of synchrotron radiation allows to accelerate muons to multi-TeV energies in a compact ring with minimal energy losses, allowing to reach the discovery potential of the FCC-hh at a fraction of the cost. Yet the decaying muons create extremely intense beam-induced background consisting primarily of soft electrons and photons. Impact of this background is highest in close vicinity to the interaction region, reaching 1000 hits/cmˆ2 in the innermost layers of the tracking detector.

In our detailed full-simulation studies we have identified key aspects of the tracking-detector design necessary to achieve the target physics performance, which include low material budget, high granularity and high timing resolution at the level of tens of picoseconds.

This contribution will introduce the main technical aspects of the Muon Collider, focusing on the implications of the beam-induced background for the design and performance of the tracking detector. The two flagship technologies considered in our detector design will be discussed: DC-RSD and DMAPS, including the key areas of further R&D necessary to make these technologies suitable for the Muon Collider environment.

Wide bandgap semiconductor detectors / 70

Observation of bias-dependent position flipping of the electric field maximumin in neutron irradiated SiC diodes

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Pristine and neutron-irradiated silicon carbide (SiC) detectors were systematically characterized using the Two-Photon Absorption Transient Current Technique (TPA-TCT) at the laser facility of the University of the Basque Country (UPV/EHU). The investigated SiC detectors are p-in-n diodes, fabricated at IMB-CNM, with an active thickness of 50 microns.

Our study reveals a radiation-induced signal multiplication effect, attributed to modifications in the diode's electric field caused by radiation. This results in enhanced charge carrier generation post-irradiation. A comparison of the electric field distributions in pristine and irradiated diodes highlights these changes. These findings shed light on the radiation hardness and performance of SiC detectors, confirming their potential for use in high-radiation environments.

Applications 1 / 71

Timing-optimized FBK Silicon Photomultipliers for a modular ToF-PET scanner: the PETVision

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Positron Emission Tomography (PET) is one of the leading methodologies in medical imaging for cancer diagnosis, but PET scanners present some limitations in terms of cost and performance. In recent years, Time-of-Flight PET (ToF-PET) significantly improved image reconstruction by adding to the energy used in standard PET machines, the time of arrival information of the two $511\,keV$ annihilation photons. The PETVision project aims to use breakthrough findings in the ToF-PET research field to develop a highly sensitive, fully modular and cost-accessible scanner to achieve $75ps$ FWHM Coincidence Time Resolution (CTR). This challenge requires a revolutionary technology change in terms of photodetectors, readout electronics and integration methodology to push the limit of the timing performance.
In controlled laboratory conditions, a CTR of $96\ ps$ FWHM has been achieved by using FBK NUV-HD-MT SiPMs $3 \times 3\,mm^2$, $40\ \mu m$ cell size with metal masking outside the active area (M0) coupled with a $2\ mm \times 2\ mm \times 20\ mm$ co-doped LYSO:Ce:Ca crystal. A $60\ ps$ FWHM CTR was achieved using the same device on a $2mm \times 2mm \times 3mm$ crystal. These measurements have been performed using high-frequency readout electronics with high power consumption; thus, they are not scalable to multi-channel systems and are impractical for realistically sized imaging systems.
Therefore, much effort is being made to develop a novel, custom front-end System-on-Chip (SoC) ASIC to be coupled with these next-generation timing-optimized SiPMs and ensure high-timing performance. Preliminary results using the FastIC+ ASIC, developed at ICCUB and CERN, are extremely promising, showing a CTR of $89\ ps$ FWHM with a $3\ mm$ co-doped LYSO:Ce:Ca crystal using a FBK NUV-HD-MT $3 \times 3\ mm^2$ $50\ \mu m$ M0.
Thanks to the collaboration of several universities, research centres and industries, PETVision is set to make significant advancements in detector design, photo-sensor and front-end electronics by developing an affordable, fast and precise ToF-PET scanner, enabling early cancer detection and therapy monitoring, opening the way for personalized medicine.

LGAD 2 / 73

Timing resolution of thin LGAD sensors for high radiation environments

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Precise time tagging of particles become a pivotal ingredient in designing high-energy physics experiments. Low-Gain Avalanche Diodes (LGADs) with an active thickness of $\sim$ 50 μm have proved the ability of silicon sensors to provide precise timing down to about 30 ps. Such timing performance is maintained almost unchanged up to a fluence of $2.5{\cdot}10^{15}$ 1 MeV equivalent n/cm^2. Thinner substrates can further improve the timing resolution of the LGAD sensors.

At the end of 2022, FBK released a batch of thin LGAD sensors with an active thickness between 15 and 45 μm to investigate the effect of the thickness in improving sensor performances.
The state-of-the-art design of the LGAD gain implant from FBK has been used on thin substrates, exploiting the concurrent implantation of boron and carbon atoms in the multiplication region typical of LGAD sensors, resulting in the most radiation-tolerant LGADs ever produced by FBK.

In December 2024, thin LGAD sensors were tested on an electron beam at the DESY facility (Hamburg, Germany). Their timing performances will be presented. In particular, the impact of the sensor thickness on the collected charge and the timing resolution will be explored and discussed.

CMOS MAPS / 74

Latest developments on the first monolithic CMOS LGAD implemented in 110nm

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Monolithic CMOS silicon sensors represent an important innovation for high-energy physics experiments due to their cheaper production and assembly cost compared to hybrid ones. Indeed, in hybrid devices, the electronics and the sensor are produced on different silicon substrates, which must be later connected using bonding techniques. However, as far as the time resolution is concerned, the most mature and high-performance technology today is represented by the Low Gain Avalanche Diode (LGAD), where a silicon sensor with an internal gain is connected to a custom electronics in

a hybrid way.
The last ARCADIA submission exploited the integration of the LGAD concept in CMOS Monolithic Active Pixel Sensors (MAPS) to obtain the benefits provided by both technologies. The multiplication of the signals in MAPS has a major impact on the signal-to-noise ratio; hence, the power consumption of the in-pixel front-end can be lowered to achieve the same performances. In addition, this feature increases the attractiveness of these devices for space applications where low power absorption is desired. Nevertheless, the union of the two technologies still lies in its early stages, and vigorous R&D is necessary.
This presentation will focus on the last development concerning the passive and active structures with internal gain fabricated in a standard 110 nm CMOS technology within the ARCADIA project. An overview of the first production with a simulated and measured gain around 3 will be provided. In laboratory measurements and test beam results will be presented. Special emphasis will be placed on the problems encountered during the characterization of the monolithic structures with integrated electronics. In addition, the results of the second production with increased gain will be presented. Finally, the future perspectives and an insight into the ongoing R&D will be given.

Poster Session / 75

Katherine Generation 2: Advanced Readout System for Timepix3 Detectors

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The Katherine readout for Timepix3 [6] is among the most widely used acquisition systems for Timepix3 detectors. This device, which utilizes a Gigabit Ethernet interface, has been employed in numerous experiments by various scientific teams. However, as user requirements have evolved, it has become clear that Katherine cannot meet these increasing demands without limitations or additional modifications. To address this challenge, the Katherine readout for Timepix3 Generation 2 has been developed.

The primary focus of the new design is on multi-layer/detector support, coupled with compatibility with a broader range of chipboards. The updated device supports one or two standard CERN chipboards, as well as compatible chipboards designed by UWB/CTU. Additionally, through a specialized fanout board, users can connect up to four chipboards. A significant advancement is the native support for the Timepix3 Quad (3x3 grid) chipboard. In all configurations, uniform timing across all detectors is maintained, enabling the system's application in diverse coincidence and time-of-flight measurement setups.

Connectivity options have also been upgraded. In addition to the existing Gigabit Ethernet interface, the device now incorporates a USB 3.0 interface. This feature allows the system to achieve the full data rate of Timepix3 —40 MHits/s —a substantial improvement over the 14 MHits/s limit of Gigabit Ethernet. Users can choose between the two interfaces, each offering distinct advantages: Ethernet for straightforward remote control and USB for high data rates.

Another significant enhancement concerns the bias voltage supply for the sensors. Thick silicon sensors, CdTe, CZT, or GaAs sensors require higher bias voltages. To accommodate these needs, the device includes two independent high-voltage power supplies, with a voltage range from −1kV to +1kV, along with leakage current measurement capabilities.

In this contribution, the authors will present the key parameters of the newly introduced device. They will also provide examples of its application and discuss its potential use in extremely harsh radiation environments.

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Technology / 76

Flexible packaging for silicon detectors

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This work presents a packaging concept enabling planar and curved chip integration with a minimized material budget. Building on foundational techniques introduced two decades ago for the ALICE ITS1 and the STAR tracker, this approach uses flexible cables made of aluminum and polyimide. Additionally, instead of conventional wire bonding, which poses limitations in handling and bending of detector assemblies, single-point Tape Automated Bonding (spTAB) is employed. By creating openings in the polyimide layer, free-standing aluminum traces of the cables are directly bonded to the sensor, eliminating the need for additional wire connections.
Extending this concept, the entire printed circuit board (PCB) is rendered flexible by stacking three layers of 20 µm thick aluminum traces and 25 µm thick polyimide. These layers include a ground plane, a signal layer (supporting both digital and analog signals), and a bonding layer (replacing wire bonding). SpTAB is utilized both for inter-layer connections and for sensor bonding. In a prototype implementation, an ALPIDE chip is successfully bonded using this method, demonstrating an ultralight packaging solution that could be readily adapted for future designs needing flexible chip or compact electronics integrations. All fabrication and assembly steps took place at Fondazione Bruno Kessler, and the workflow will be outlined to illustrate the feasibility of this approach for upcoming experimental applications. Production results and characterization of the assembled device will be presented. Additionally, the testing setup and the outcome of the initial readout tests will also be showcased. Finally, we will quantify the flexibility of the complete assembly (chip plus PCB) and discuss how the spTAB connections behave under bending radii of only a few centimeters.

Poster Session / 77

Timepix4 Chipboard and Readout Concept

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The release of the Timepix4 [1] readout chip has opened new possibilities for the utilization of pixel detectors in experimental applications. With its exceptional time resolution (binning approximately 200 ps), larger detection area (512x448 pixels), and extremely high maximum data rate (160 Gbps), it is evident that the scientific community has gained a powerful new tool.

In this contribution, we discuss the challenges associated with designing instrumentation for Timepix4. We introduce the concept of the planned readout system for this detector and, more specifically, present the designed chipboards for Timepix4. These chipboards, compared to previous designs, are fundamental to achieving high-quality measurement results. The authors introduce two solutions for Timepix4: the first is a single-chip board carrier, and the second adopts a modular approach to detector chipboard design. The system is divided into two distinct components: the sensor module and the mainboard. This separation enhances flexibility, versatility, and ease of use while maintaining high performance and measurement accuracy.

The sensor module is built around the Timepix4 chip, which is bonded to the module and optimized for high-speed data transfer and signal integrity. Operating without active components aside from the chip itself, the module ensures simplicity and reliability. It features high-speed inter-board connectors (up to 40 Gbps), enabling data throughput of approximately 600 MHit/s. The modular design supports the integration of various sensor types and the construction of large-area detector systems.

The mainboard serves as the power and signal interface for the sensor module. It supplies the necessary voltage levels for the Timepix4 chip, employing a dual-stage power supply topology to ensure low noise and high stability. The mainboard also manages signal routing between the sensor module and the readout electronics, achieving a maximum data transfer rate of 5 Gbps per differential pair. The readout system is connected via four RJ45 connectors, offering flexible user setup configurations.

Initial tests conducted at the CERN SPS facility demonstrated (results will be presented) the detector's functionality and validated the design's technical feasibility. The modular architecture and scalable design of this system present promising applications for a wide range of high-performance particle detection setups.

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3D / 78

TCAD modeling of bulk and surface radiation damage effects in silicon devices

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Future frontier accelerators envisage the use of silicon sensors in environments with fluences exceeding 1×10^{17} 1-MeV n_{eq}/cm^2. Presently available silicon sensors can operate efficiently up to fluences of the order of some 10^{16} 1-MeV n_{eq}/cm^2. Therefore, novel sensors and readout electronics must be devised.
Within this framework, state-of-the-art Technology CAD (TCAD) tools can be proficiently used to account for both bulk and surface radiation-induced damage effects in semiconductor sensors, fostering design optimization and enabling a predictive insight into the electrical behaviour of novel solid-state detectors. In particular, the balance between extending already developed and available models and methodologies or devising different approaches should be carefully considered.
In this contribution, the different available TCAD numerical models addressing bulk and surface radiation damage effects will be illustrated. It will also be shown how these models have been used for the optimization of devices, particularly 3D sensors and Low Gain Avalanche Diodes. Moreover, the applicability of these models needs to be extended to extreme fluence scenarios, accounting for the modeling of acceptor and donor removals, impact ionization, carriers'mobility and lifetime, and traps dynamics.

CMOS MAPS / 79

Tangerine: Advancements in Sensor Development for Future Lepton Collider Vertex Detectors

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The Tangerine project focuses on the development of advanced sensor prototypes for silicon vertex detectors to be used in future lepton collider experiments. These detectors face stringent requirements, including excellent position resolution below 3um, minimal material budget with thicknesses below 50um, low power consumption of lower than 50mW/cm2, and time resolution on the nanosecond scale.

Over recent years, several prototypes have been designed and fabricated using a 65 nm CMOS imaging process with a small collection electrode. These range from chips equipped with analog front ends only, to the fully integrated hybrid-to-monolithic (H2M) chip. The latter employs a digital-on-top design flow and integrates a complete hybrid readout architecture within a monolithic chip. All prototypes have undergone extensive laboratory and beam testing, demonstrating full functionality.

In parallel, the project has developed a technology-independent simulation methodology that combines TCAD simulations with generic doping profiles and Monte Carlo simulations using the Allpix Squared framework. Despite limited process information, this approach has successfully produced results that align with experimental data across a range of observables.

This contribution presents an overview of the sensor prototypes and simulation workflow developed within the Tangerine project, along with an outlook on the ongoing efforts under the DRD3 collaboration.

Electronics and System issues / 80

The challenge of front-end electronics for future collider experiments: 28 nm CMOS and beyond

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The next generation of silicon pixel detectors at high energy physics experiments sets unprecedented and extreme requirements to the microelectronic systems that are used to read out the sensors. Front-end integrated circuits will have to provide advanced analog and digital signal processing functions in high-density pixel readout cells, while handling huge data rates, operating at low power and standing extreme radiation levels. The scientific reach of future experiments will rely on the performance of these front-end systems and on the capability of leveraging technological advances in microelectronics. This talk is focused on the current effort to qualify advanced CMOS technology nodes and develop chip designs addressing the needs and the technical challenges of future applications. Analog functions such as signal amplification and discrimination are still crucial in these new designs, and the talk will discuss how analog performance is affected by technology scaling and by the operation in extreme radiation environments.

Applications 2 / 81

Vertex detector requirements for Higgs, Electroweak and Top Factories

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To exploit the full potential of the physics at the Future Higgs, Top and Electroweak factories extremely lightweight and precise vertex detectors are needed, especially to precisely reconstruct the decay and interaction vertices in flavour physics processes and the measurement of Higgs and Z decays to bottom and charm quarks and tau-leptons.
I will discuss the requirements of those vertex detectors, covering the necessary impact parameter resolution, needed rate capability, and radiation tolerance, while keeping the material budget below 0.3% of a detection layer. I will discuss similarities and differences between vertex detectors at linear and circular colliders, including the requirements coming from the beam induced backgrounds.
These detector requirements translate into sensors used for the vertex detector, featuring about 3 μm spatial resolution and possibly provide timing information of the order of few tens of ns, while keeping power consumption minimal to allow for air-cooling thus minimising the detector material budget.
The detectors based on CMOS Monolithic Active Pixel Sensors (MAPS) technology which combine signal generation, amplification and readout into a single silicon die, are currently the best candidates for those vertex detectors. I will present an overview of existing and planned MAPS technologies and prototypes towards fulfilling the stringent future vertex detector requirements.
Lastly, a short outlook towards existing solutions for the main detector concepts will be given.

Poster Session / 82

Development and production of advanced 3D pixel sensors at FBK

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The increased luminosity at the HL-LHC has driven the need for higher radiation resistance in particle sensors, enhanced timing capabilities, and greater granularity in vertex detectors. FBK has advanced 3D detector technology, known for its strong radiation hardness (up to ˜2×10^{16} neq/cm²), by introducing innovations like stepper-based lithography to improve pitch reduction and process yield. Additionally, a 3D trench-based design has been developed, achieving superior timing resolution (˜10 ps) due to a uniform electric field. The poster will review these advancements and initial results from 3D-column and 3D-trench production batches under the AIDA Innova project.

LGAD 2 / 83

Overview of the Timing Detectors at ATLAS and CMS for the HL-LHC

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The CMS and ATLAS detectors at the CERN Large Hadron Collider (LHC) are undergoing significant upgrades to meet the challenges posed by the High-Luminosity LHC (HL-LHC). The CMS detector is implementing an upgrade program that includes a new MIP Timing Detector (MTD) with a time resolution of approximately 30-40 ps, aimed at mitigating the effects of high pileup levels expected at HL-LHC. The MTD features an Endcap Timing Layer (ETL), equipped with Low Gain Avalanche Detectors (LGAD) read out using the ETROC chip, that enhances CMS's physics capabilities.
Similarly, the ATLAS detector is addressing the increased particle flux through the development of a High-Granularity Timing Detector (HGTD), which also relies on the LGAD technology. HGTD will assist in pile-up mitigation and enable more accurate vertex assignment for tracks in the forward region where granularities are reduced, providing a timing resolution better than 50 ps per track for MIPs across the pseudo-rapidity range of 2.4 to 4.0.
Both projects encompass rigorous technical designs and specifications, and are now closing their prototyping phase and moving towards production. An overview of the status of both projects will be presented.

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Silicon carbide detectors: from material advantage to new applications

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In this talk an overview of the advantage of silicon carbide detectors will be presented in terms of leakage current, signal resolution and radiation hardness. To obtain high performance in the detectors for different applications, new growth process of the epitaxial layers have been developed and the characteristics of the epitaxial layers have been obtained by electrical measurements. Furthermore, these detectors with different structures have been used in different applications (neutrons, high energy particles, UV, X-Ray, ···) and the main results of these detectors will be reported in this overview. Finally, a specific study on the radiation hardness of these detectors for high energy particles and of the effect of high temperature in the detection of neutrons will be presented.

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The Trans-Iron Galactic Element Recorder for the International Space Station (TIGERISS)

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The Trans-Iron Galactic Element Recorder for the International Space Station (TIGERISS) is being fabricated to determine the source(s) of galactic cosmic rays by measuring the individual elemental abundances from 5B to 82Pb. In particular, TIGERISS will make definitive measurements of Ultra-Heavy Galactic Cosmic Rays (UHGCRs; Z >29). Thus, TIGERISS measurements will be sensitive to the s-process, r-process, and rp-processes of nucleosynthesis and will provide a critical aspect of multi-messenger studies to determine the relative contributions of supernovae (SN) and Neutron Star Mergers (NSMs) to the production of galactic matter. TIGERISS is planned to be launched in 2027 and attached at the SOX location on the Columbus module. The TIGERISS instrument has heritage from the TIGER and SuperTIGER long-duration balloon (LDB) experiments. TIGERISS has a geometry factor of 1.3 m^2 sr and is comprised of four layers of single-sided silicon strip detectors (SSDs) arranged with X-Y layers above and below two large-area Cherenkov detectors, one with an acrylic radiator (n = 1.49) and another with aerogel radiators (n =1.03). The combination of the Cherenkov velocity measurements with the precise measurements of the ionization and trajectory of the traversing cosmic rays leads to highly accurate charge measurements of < 0.25 c.u. over the entire elemental range of 5B to Pb82. The science goals of TIGERISS, mission status, instrument design and performance with a focus on the SSD design and performance will be discussed.

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Registration

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Welcome

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Conference photograph

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Conference closing

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Sensor Innovations in Dosimetry for Radiotherapy

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Radiotherapy, a cornerstone of cancer treatment, relies on the controlled delivery of ionizing radiation to selectively target and destroy tumor cells. Dosimetry, the measurement and calculation of absorbed radiation dose, plays a crucial role in maximizing therapeutic efficacy while minimizing damage to healthy tissues. This abstract focuses on the importance of research and development of innovative sensors for dosimetry in radiotherapy, exploring applications in advanced radiotherapy techniques, such as VMAT, Flash and Spatially Fractionated radiotherapy.

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Silicon sensors position and energy measuring systems for ionising radiation in space

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Solid state sensors have become the standard choice for radiation measurements in space since the early 2000s. Leveraging the development of tracking detectors for collider experiments, large area silicon strip systems have been designed and successfully operated in space in several astro-particle missions. With the multiplication of flight opportunities offered by the new space economy, the turnaround time for bringing in orbit new technologies have significantly shortened and can support developments of new technologies for the next generation of astroparticle missions as well as for small satellites for monitoring the Earth. The SpaceItUp! project, funded by the Italian Space Agency in Summer 2024, comes at the right time to support design optimization and qualification for space of some of the most performing devices for measuring position and energy of particles, like MAPS, LGAD and SiPMs. This talk reviews the goals and the status of this program.

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Experimental results on monitoring proton and carbon ion clinical beams using thin silicon sensors

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The excellent time resolution of LGAD and thin PIN silicon sensors allows for the measurement of the particle flux and profile of clinical beams with single particle sensitivity. The experimental results of a proton and carbon ion counter based on a 2.7 × 2.7 cm2 silicon sensor will be presented. The counter was also integrated with a Time-to-Digital Converter to measure particles'crossing time.

A 60 µm thick PiN diode and a 50 µm thick Low Gain Avalanche Diode were used for detecting carbon ions and protons at CNAO (Pavia), respectively. The sensitive area of both the sensors covers the cross section of a pencil beam and it is segmented in 146 strips with 180 µm pitch. The readout is based on the ESA-ABACUS frontend board, developed to house six 24-channel ASICs able to discriminate particle signal pulses in a wide range of charge (4-150 fC), with a maximum dead time of about 10 ns. The digital pulses produced by the discriminator for each particle are acquired by 3 Kintex7 FPGA boards implementing pulse counters for each channel. Alternatively, the digital pulses of 12 channels can be acquired by the CERN PicoTDC evaluation board providing the time measurements in time bins of 3 ps.

The measurements performed result in beam projections with a FWHM in agreement with beam profiles measured with gafchromic films. The proton counting efficiency shows a dependence on the beam energy because of geometric and pile-up effects, whereas an efficiency above 90 % with lower energy dependence is found for carbon ions. The time measurements with the TDC allowed for the study of the difference of crossing times of consecutive particles in one strip which shows a time structure compatible with the radio-frequency period of the synchrotron.

The results indicate that thin segmented silicon sensors, custom front-end readout with high rate capability and the use of picoTDC allow to perform 4D tracking in particle therapy.

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