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Book of Abstracts
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**Muon Forward Tracker in ALICE at the LHC**

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ALICE is an experiment designed to study heavy-ion collisions at the LHC at CERN. The Muon Forward Tracker (MFT) is one of the major ALICE upgrades installed during the Long Shutdown 2 to cope with the maximum interaction rate of 50 kHz for Pb-Pb collisions in Runs 3 and 4.

The MFT is a high-resolution tracking detector consisting of 10 layers of ALPIDE silicon pixel sensors with CMOS technology. The detector was designed to extend the physics program of ALICE by adding vertexing capabilities at forward rapidities and providing track information in front of the absorber of the Muon Spectrometer.

This contribution will review the design of the MFT and provide an overview of the technical aspects of the commissioning phase, outlining hardware and software implementations. It will also include insights into the detector structure, integration into the ALICE experimental setup, and a report on detector performance in 2022 and 2023 data taking.

**Submission declaration:**

Original and unpublished

4

**Suppression effect of Fe on irradiation of Silicon-based diodes using current-voltage measurements.**

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In this study, the suppression effects of Fe on irradiation of silicon (Si) diodes were investigated. Diodes fabricated on unimplanted and Fe-implanted p-Si diodes were irradiated with 4 MeV protons to a fluence of 1x10¹⁶ p/cm² and then characterized prior to and after irradiation using current-voltage (I-V) techniques. A decrease in current due to irradiation is more apparent in unimplanted p-Si diode than the Fe-implanted p-Si diode, indicating that the effect of irradiation has been suppressed on the Fe-implanted p-Si diode due to Fe-doping. The diode conduction mechanism for unimplanted p-Si diode changed, while that of Fe-implanted p-Si diode remained constant after proton-irradiation. The diode parameters were also evaluated on the fabricated diodes prior to and after irradiation. The obtained results suggest that Fe-induced defects in Si have improved the radiation-hardness of Si material. Hence, Fe, just like Au and Pt, is a suitable candidate in a bid to improve the radiation-hardness of Si material.

**Submission declaration:**

Original and unpublished
INSPIRE: challenge of 50-kg class satellite to open up MeV gamma-ray astronomy

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Recently, more than 300 satellites are launched globally every year, significantly lowering the hurdle to space exploration. Particularly, small satellites weighing less than several tens of kilograms are widely used in industry and telecommunications, but they are also crucial as a pathfinder for cutting-edge space science. Tokyo Tech successfully launched the 50 kg university satellite HIBARI in 2021, and plans to launch a second satellite, PETREL, in the second half of FY 2023. Both satellites attempt to control the attitude by variable geometry in orbit, and to observe ultraviolet radiation in the very early phase of the gravitational wave objects like kilonova (neutron star–neutron star merger). In this talk, I will first review these university satellite projects and then report on the world’s first MeV gamma ray small observation satellite (tentative name: INSPIRE), which is scheduled to be launched in FY2026. The satellite carries a Compton-camera box (CC-BOX), which can visualize 30–3000 keV X-/gamma-rays, along with high-sensitivity UV camera. CC-BOX consists of large area Si-PM (MPPC) array optically coupled with 3D position-sensitive Ce:GAGG scintillator to achieve an angular resolution of 7° (FWHM) by simultaneous imaging of 30–200 keV in pinhole mode and 200–3000 keV in Compton mode. The field of view is ˜1 str in every pointing. The prototype model of CC-BOX has already been installed and tested for diagnostic imaging in nuclear medicine and observation of atmospheric phenomena, such as in the world’s first successful gamma ray imaging of thunderclouds (Kuriyama et al. 2022, GRL). In this talk, I will describe in detail the imaging experiments using the prototype model to date, along with various environmental tests for the launch in FY2026. I will also discuss expected performance and observation plans in orbit to achieve various scientific goals.

Submission declaration:
Original and unpublished
In June 2022 the data-taking of the Belle II experiment was stopped for the Long Shutdown 1, primarily required to install the new two-layer DEPFET detector (PXD) and upgrade components of the accelerator. In May 2023 the whole silicon tracker (VXD) was extracted from Belle II and the new VXD commissioning phase began to be ready to take data by the end of 2023. We describe the challenges and status of this upgrade. We report on the performance of the SVD in terms of the high efficiency and the large signal-to-noise ratio. A novel procedure to group SVD hits event-by-event, based on their time, during reconstruction allows to significantly reduce the fake rate while preserving the tracking efficiency. In the layer closest to the I.P., the SVD average occupancy has been less 0.5%, well below the estimated limit for acceptable tracking performance. Higher machine backgrounds are expected at increased luminosity and the excellent SVD hit-time information can be exploited for background rejection. We have developed a method that uses the SVD hit-time to estimate the collision time (event-T0) with similar precision to the estimate based on the drift chamber with an execution time three orders of magnitude faster. Furthermore, the front-end chip (APV25) is operated in ‘multi-peak’ mode, reading six samples. To reduce background occupancy, trigger dead-time and data size, a 3/6-mixed acquisition mode, based on the timing precision of the trigger, has been successfully tested in physics runs. Concerning the radiation damage, the SVD dose is estimated by the correlation of the SVD occupancy with the dose measured by the diamonds of the beam-abort system. Although the moderate increase shown by sensor current and the strip noise due to radiation, we expect that the detector performance will not be seriously degraded during the lifespan of the detector.

Submission declaration:
Original and unpublished

Day 2 - Session 2 / 9

Synchrotron light source X-ray detection with Low-Gain Avalanche Diodes

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Low Gain Avalanche Diodes (LGADs) represent the state-of-the-art in timing measurements and will instrument the future Timing Detectors of ATLAS and CMS for the High-Luminosity LHC. While initially conceived as a sensor for charged particles, the intrinsic gain of LGADs makes it possible to detect low-energy X-rays with good energy resolution and excellent timing (tens of picoseconds). Using the Stanford Synchrotron Radiation Lightsource (SSRL) at SLAC, several LGADs designs were characterized with energies from 5 to 70 keV. The SSRL provides 10 ps pulsed X-ray bunches separated by 2 ns intervals with an energy dispersion (ΔE/E) of 10−4. LGADs from Hamamatsu Photonics (HPK) and Brookhaven National Laboratory (BNL) with different thicknesses ranging from 20 μm to 50 μm and different gain layer designs were read out using fast amplification boards and digitized with a high bandwidth and high sampling rate oscilloscope. PiN devices from HPK and AC-LGADs from BNL were characterized as well. The feasibility of reliable Compton scattering detection with LGADs was probed. The end goal is to utilize LGADs as a pass-through beam monitoring device for high-energy X-ray beams using Compton interaction. The charge collection and multiplication mechanism were simulated using Geant4 and TCAD Sentaurus, providing an important handle for interpreting the data. In this contribution, the results of the data analysis and simulation will be shown.
Comparative time resolution and field uniformity study of single cell 3D pixel structures after neutron and proton irradiation up to 1e17 neq/cm² at 120 GeV SPS beams

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The proven radiation hardness of silicon 3D devices up to fluences of $1 \times 10^{17} \text{n}_{\text{eq}}/\text{cm}^2$ makes them an excellent choice for next generation trackers, providing < 10 $\mu$m position resolution at a high multiplicity environment. The anticipated pile-up increase at HL-LHC conditions and beyond, requires the addition of < 50 ps per hit timing information to successfully resolve displaced and primary vertices. In this study, the timing performance, uniformity, and efficiency of neutron and proton irradiated single pixel 3D devices is investigated. Three different geometrical implementations are evaluated for fluences up to $1 \times 10^{17} \text{n}_{\text{eq}}/\text{cm}^2$ at 120 GeV SPS pion beams. The question of electronic bandwidth is also addressed, with respect to achievable time resolution, efficiency and collected charge. In such a tri-dimensional phase-space, an appropriate operating point is selected depending on the application requirements. A MIMOSA26 type telescope is used to provide detailed tracking information with a $\sim 5 \mu$m position resolution. Productions with single- and double-sided processes, yielding active thickness of 130 and 230 $\mu$m respectively, are studied, with pixel sizes that vary from $55 \times 55 \mu$m² to $25 \times 100 \mu$m². A comparison of field uniformity with respect to electrode geometry is presented, as well as a time resolution study for incidence angles up to 12°.

Submission declaration:
Original and unpublished

Module development for the ATLAS ITk Pixel Detector

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During operation the High Luminosity Large Hadron Collider (HL-LHC) will achieve unparalleled instantaneous luminosity, leading to approximately 200 proton-proton interactions during a bunch crossing. The existing ATLAS Inner Detector will be superseded by an entirely silicon-based system known as the Inner Tracker (ITk). The ITk’s innermost section will incorporate a cutting-edge pixel detector with diverse silicon sensor technologies being used across the five barrel and end-cap layers.

As initial modules have been assembled with the prototype ITkPix readout chip, a variety of aspects are under investigation. These range from production-related ones such as bump bonding, to as-
semblly methods of dedicated wire-bond mechanical protection, layout-related aspects such as the
distribution of data links amongst several chips and modules.

The talk will present results of several such studies, directly affecting the module production for the
ATLAS ITk Pixel detector.

Submission declaration:
Original and unpublished

Day 2 - Session 4 / 13

Measurements and TCAD simulations of innovative DC-RSD LGAD
devices for future 4D tracking

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Future HEP experiments will consider measuring concurrently the position and the time of a particle
hit with very good accuracy, i.e., 4D-trackers will be the basic option for future detection systems.
Within this framework DC-coupled Resistive Silicon Detectors (DC-RSD) low-gain avalanche diodes
(LGAD), an evolution of the AC-coupled design, are considered a very promising option. They com-
bine two different design innovations, LGAD and resistive readout (RSD), to achieve a spatial reso-
lution of a few micrometres using large pixels (150-200 micrometres), providing an excellent time
resolution (20-30 ps). The concept of DC-RSD has been finalized using an innovative mixed-mode ap-
proach to simulation: SPICE-based fast modelling to demonstrate the operating principle, followed
by full 3D TCAD simulations to optimize the sensor design parameters. TCAD simulations are an
excellent tool for designing this innovative class of detectors, enabling the evaluation of different
technology options (e.g., the resistivity of the n+ layer, contact materials) and geometrical layouts
(shape and distance of the read-out pads). In particular, a full 3D simulation domain guarantees a
very accurate evaluation of the electrical behavior while providing very precise timing information,
gaining access to the response of the detector device in terms of conduction and displacement cur-
rents.
This contribution reports the latest outcome of simulations, which have been instrumental in defining the design technical implementation. This contribution also describes the characteristics of the first DC-RSD production at FBK, to be submitted this summer, to explore multiple technological options and electrode layouts. Interesting information on the expected DC-RSD performance will be presented, extracted from recent experimental results obtained on AC-coupled resistive read-out sensors and on DC-RSD test structures.

Submission declaration:
Original and unpublished

Day 3 - Session 1 / 14

Development of the BCM’ system for beam abort and luminosity monitoring in ATLAS based on a segmented polycrystalline CVD diamond system and dedicated front-end ASIC

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The High Luminosity upgrade of Large Hadron Collider (HL-LHC) will increase the LHC Luminosity and with it the density of particles on the detector by an order of magnitude. For protecting the inner silicon detectors of the ATLAS experiment and for monitoring the delivered luminosity, a radiation hard beam monitor has been developed. We developed a set of detectors based on polycrystalline Chemical Vapor Deposition (pCVD) diamonds and a new dedicated rad-hard front-end ASIC. Due to the large range of particle flux through the detector, flexibility is very important. To satisfy the requirements imposed by the HL-LHC, our solution is based on segmenting diamond sensors into devices of varying size and reading them out with new multichannel readout ASICs divided into two independent parts - each of them serving one of the tasks of the system. In this talk we describe the system design including detectors, electronics, mechanics and services and present preliminary results from the most recent detectors fabricated using our prototype ASIC with data from beam tests at CERN.

Submission declaration:
Original and unpublished
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Radiation study of the LHCb UT front-end readout ASIC

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The LHCb Upstream Tracker (UT) is a new silicon strip detector of the phase-I upgrade. The detector signals are processed by custom-designed front-end ASICs, called SALT (Silicon ASIC for LHCb Tracking). The ASICs work at the sensor proximity. The radiation hardness in a radiation environment and radiation resilience of the ASICs are critical to the detector performance.

We studied the radiation effects of the SALT ASICs in a 100 MeV proton beam at CIAE (China Institute of Atomic Energy), and a 80 MeV proton beam at CSNS (China Spallation Neutron Source). In the former test, SEU (single event upset) effects in the registers have been studied to validate the chip design. In the latter study, we measured the SEU rates of event data and compared the possibilities that the SEUs happened in the memory buffer or during transmission.

In this presentation, the test facilities and setups, as well as the study methods will be described. Results of the two studies will be presented.

Submission declaration:
Original and unpublished

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A 2.56 Gbps or 10.24 Gbps 1:16 Deserializer in 55 nm for High-Energy Physics Experiments

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Deserializer is used to convert the high-speed serial data into a low-speed parallel data in the downlink direction of data transmission system in high-energy physics experiments. This paper presents the design and test results of a 2.56 Gbps or 10.24 Gbps 1:16 deserializer fabricated in a 55 nm CMOS process.

In order to meet the demand of current data volume and adapt to upgrade of the equipment in the future, the deserializer compatible with 2.56 Gbps and 10.24 Gbps data rates is proposed. The 2.56 Gbps or 10.24 Gbps 1:16 deserializer ASIC mainly consists of an equalizer, 1:4 DEMUX module, 4:16 DEMUX module, clock divider by 4, LVDS drivers and an automatic frequency comparator. The 1:4 DEMUX module and 4:16 DEMUX module are implemented by one and four 1:4 DEMUX units, respectively. According to the different data dates, there are two different 1:4 DEMUX units and clock divider by 4 have been designed. In order to improve the bandwidth, the high-speed 1:4 DEMUX unit and the high-frequency clock divider by 4 adopt the latches with an optimized compressed CML structure. And the low-speed 1:4 DEMUX unit and the low-frequency clock divider by 4 adopt CMOS latches to save power consumption.

The 2.56 Gbps or 10.24 Gbps 1:16 deserializer ASIC has been designed in 55 nm CMOS process with core area of 1120 μm × 600 μm. The simulation results show that the logic of output data at 2.56
Gbps and 10.24 Gbps are correct in different process corners. And the clean and open output eye diagrams can be obtained at the input data rate of 2.56 Gbps and 10.24 Gbps, respectively. The chip has been taped out and is being tested, the test results including logic and eye diagram test will be displayed in the poster.

Submission declaration:
Original and unpublished

Day 3 - Session 2 / 18

**ANALYSIS OF THE QUALITY ASSURANCE RESULTS FROM THE INITIAL PART OF PRODUCTION OF THE ATLAS18 ITK STRIP SENSORS**

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The production of strip sensors for the ATLAS Inner Tracker (ITk) started in 2021. During this time, a Quality Assurance (QA) program is being carried out continuously, by using specific test structures, in parallel to the Quality Control (QC) inspection of the sensors. The QA program consists of monitoring sensor-specific characteristics and the technological wafer process variability, as produced and after the irradiation with gammas, neutrons, and protons. After two years, half of the full production volume has been delivered and we present statistical and time-evolution information of the parameters measured as part of the QA performance.

The main devices used for QA purposes are miniature strip sensors, monitor diodes and the ATLAS test chip, which contains several test structures (e.g., bias resistors, interdigitated structures or field oxide capacitors). Such devices are tested by several sites across the collaboration depending on the type of samples (non-irradiated components or irradiated with protons, neutrons, or gammas).

All the parameters extracted from the tests are uploaded to a database, from which they are selected in the analysis process by the use of newly developed python scripts which interrogate the database, filter the data, and perform analysis, statistics and representation. These parameters are summarized in the form of histograms, time-evolution plots and correlation plots to get parameter distributions, trends, and meaningful parameter-to-parameter correlations. The purpose is to identify possible deviations in the fabrication, the sensor quality, or alternatively, changes in the behaviour of the test equipment or possible variability in the irradiation processes.

The results from these two years of production of the strip sensors of the ITk are presented. They have allowed the optimization of the measurements, setting soft limits, and analysis, and a better understanding of the device properties and fabrication trends. Those abnormal results are fed back to the vendor promptly.

Submission declaration:
Original and unpublished

Day 2 - Session 4 / 19

**Fast Timing with 3D silicon sensors**

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Novel collider experiments demand an increased performance of the silicon detectors used, such as withstanding $1 \times 10^{17} \text{n}_{\text{eq}}/\text{cm}^2$ in unprecedented pile-up conditions, and providing time resolution around 10ps. Currently, Low Gain Avalanche Diodes (LGADs) are the standard, achieving resolutions below 30ps. However, their limited radiation hardness is an area of ongoing research. As an alternative to LGADs, 3D sensors are interesting due to their proven radiation hardness. In 3D sensors, where the columns are etched into the sensor from the top (junction columns) and the back (ohmic columns), the drift distances can be very short, the depletion voltage is low and the electric field can be high, resulting in fast and short signals.

In this study, the time resolution of different 3D pixel and strip sensors was investigated with signals generated by electrons or an IR laser. Results show that 3D pixel sensors can achieve time resolutions of less than 30ps. TCT Timing measurements allow studying the position dependence of the time resolution, which is interesting for 3D sensors due to their complex electric field structure. We will show examples of position-timing maps, proving the direct correlation between time resolution and electric field. We also will demonstrate the time resolution of 3D sensors before and after irradiation, and show that 3D sensors can reach the time resolution of standard LGADs. In addition, our results demonstrate that the radiation-induced performance degradation in 3Ds can be less severe than in LGADs.

At last, we will present initial results from a production run of dedicated fast 3D sensors which have recently been produced at CNM as a common RD50 project. We will also discuss the general options for using fast 3D sensors as timing detectors in future collider experiments.

Submission declaration:
Original and unpublished
materials’ radiation tolerance. In this talk, we present test beam results of the latest planar and 3D diamond pixel detectors measured in the MALTA telescope at CERN using our prototype diamond detector ASIC. The 3D cells in these detectors have a size of 50µm x 50µm with columns 2.6µm in diameter and 100µm x 150µm with columns 4.0µm in diameter. A description of the production techniques used to produce these devices and beam test results for detectors will be presented and compared.

Submission declaration:
Original and unpublished

New concept of Si semiconductor Compton Camera

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Compton camera is a sensitive imaging detector for soft gamma-rays. So far, solid, liquid, and gas detector parts are used and developed. Reconstruction can not only give imaging but also remove background events to archive good sensitivity. However, the angular resolution is in principle limited to several degrees by Doppler broadening of atomic electrons. Here we propose a new concept of Compton camera using Si CMOS sensors to archive less than 1 degree angular resolution. We performed a Monte-Carlo simulation and confirmed the detector concept.

Submission declaration:
Original and unpublished

Characterization of a baseline vertex detector prototype for the CEPC

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The proposed Circular Electron Positron Collider (CEPC) presents new challenges for the vertex detector in terms of material budget, spatial resolution, readout speed, and power consumption. To address these challenges, a Monolithic Active Pixel Sensor (MAPS) prototype called TaichuPix has been implemented, which is based on a column drain readout architecture. The TaichuPix sensor chip has been characterized at the DESY test beam facility, and the results indicate a spatial resolution better than 5 µm and a detection efficiency better than 98% under the set threshold.

The baseline vertex detector is proposed with a three-ladder architecture, which will be double-sided with TaichuPix sensors. The double-sided structure is adopted to reduce the multiple scattering of particles and improve the impact parameter. This means that the silicon pixel sensors and cables are installed on both sides of the support structure. A ladder is made of common support together with two layers of silicon detectors. For this prototype, one side of a ladder is proposed to assemble two TaichuPix sensors on a flexible printed circuit board. Two flexible boards are installed on the front
and back sides of the lightweight carbon fiber support structure.
To verify the performance of the baseline vertex detector, six ladders were installed on the barrel, and the beam test was conducted at the DESY II TB21 facility. The beamline runs straight through the prototype, producing precise reconstruction points by multi-layer TaichuPix sensors. This presentation proposes to show the architecture and beam test results of the baseline vertex detector prototype.

Submission declaration:
Original and unpublished

Day 2 - Session 1 / 26

Development of Silicon Interposers with Embedded Microchannels and Metal Re-distribution Layer for the Integration of Hybrid Detector Systems

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One of the important challenges in the current radiation detector applications, as we advance in the further integration of the systems, is the cooling of the detectors. The larger heat densities, combined with the complexity of hybrid detector assemblies, complicate the full integration of the sensors, electronics, and services in the whole system. In order to overcome these difficulties micro-channel cooling has been proposed to increase the cooling efficiency, reducing the heat transfer path to the detector volume and therefore increasing the heat removal performance, while improving the integration of the cooling with the detector and front-end electronics hybrid system.

In this work, we present the development and fabrication of silicon interposers with buried micro-channels, which also incorporate a metal re-distribution layer (RDL) to contribute further in the integration of the system. These interposers are proposed for their application both in future high energy physics experiments and for advanced systems in photon science where the thermal, material, and integration requirements are very demanding, therefore they can benefit from these developments.

The microchannels and the metal tracks are created in several fabrication steps which will be described. Two methods have been followed to produce these interposers, called "pre-processing" and "post-processing", depending on whether the micro-channels are created before or after the metal lines. The advantages and disadvantages of the two approaches will be presented based on the multiple analysis techniques used to evaluate the different fabrication methods and to assess the final quality of the interposers. Additional considerations will be made on the potential of alternative technologies available to create interposers for further applications. With the advent of the Through Silicon Vias (TSV) technology, the proposed solution would provide further alternatives for the electrical interconnection of the detector/electronics hybrid with the external world, facilitating the signal and power input/output.

Submission declaration:
Original and unpublished
X-ray imaging camera using INTPIX4NA SOIPIX detector with SiTCP-XG 10GbE based high-speed readout system

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The SOIPIX (Silicon-On-Insulator PIXel) detector is a unique monolithic structure imaging device which is under development by the SOIPIX group led by High Energy Accelerator Research Organization (KEK).

We, the detector team in KEK Photon Factory (PF), are developing an X-ray camera using INTPIX4NA [1]. This detector has a 14.1 x 8.7 mm² sensitive area, 425,984 (832 column x 512 row matrix) pixels and the pixel size is 17 x 17 um². And this detector has high resolution and sensitivity for low intensity X-rays. The characteristics of this detector is suitable for imaging in optical systems with lower X-ray intensity, such as an X-ray zooming microscope using two Fresnel zone plates (FZP), which is also under development at PF [2].

To enable imaging under such conditions, we have developed a detector cooling system using a Peltier element to support longer exposure time (≈0.5 sec per frame). We have also developed new readout system using a newly developed DAQ boards, also developed by PF, equipped with SiTCP-XG (network controller implemented on FPGA) that supports 10 Gbps Ethernet to enable high frame rate imaging at several hundred hertz.

Our new X-ray camera was tested at the PF BL-14A, BL-14B and AR-NE1A experimental station, and the expected resolution and sensitivity characteristics were confirmed.

**Reference**


**Submission declaration:**

Original and unpublished

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Characteristics of the MTx optical transmitter in Total Ionizing Dose

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The dual channel multi-mode 850 nm optical Miniature Transmitter (MTx) is developed for data transmission of the ATLAS experiment at LHC. The MTx's are exposed to radiation field of proton-proton collisions. Tolerance in Total Ionizing Dose (TID) is required. The characteristics of MTx to the accumulated TID is investigated with X-ray and Co-60 gamma ray for the active components of the 850 nm multi-mode VCSELs (Vertical Cavity Surface Emitting Laser) and the customized LOCld laser driver developed in 0.25 um CMOS Silicon on Sapphire technology. The irradiation tests were conducted at increasing dose rates. The response to TID is observed with degradation on laser currents at the initial TID of less than 1 kGy, which anneals partially to a stable output to 90 % of the original. The optical eye-diagram after exposure is noisier, and remains well suitable for the required 5 Gbps in operation.

Submission declaration:
Original and unpublished

Day 2 - Session 1 / 30

Development of next-generation, no-gain Si photodiode array for HL-LHC

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Many of our sensors were installed in the previous LHC, and they contributed to the discovery of the Higgs boson. This HL-LHC upgrade required significant improvements from the previous product specification, such as one-digit-higher radiation hardness, suppression of increased dark current, and a substantial increase in the number of channels. To overcome these challenges, stealth dicing technology and a high-speed inspection system were introduced during the sensor production process. As a result, we succeeded in developing a new Si photodiode array (Si strip detector, Si pixel detector) for the HL-LHC. Production and delivery started in 2020.

In addition, the following two new technologies have been established. One is the introduction of the 8-inch process line, which succeeded in increasing the size of the sensor. It has already achieved the same characteristics as the proven 6-inch line, and production started in February 2023. The other is bidding on the flip chip bonding assembly market with our pixel sensor and customer-supplied ASIC. This talk will discuss in detail our efforts in developing a new sensor for the HL-LHC upgrade.

Submission declaration:
Original and unpublished
The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade

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Author: ATLAS-ITK Collaboration
(the speaker to be selected by the ITk Speakers Committee after the contribution acceptance)

ATLAS is currently preparing for the HL-LHC upgrade, with an all-silicon Inner Tracker (ITk) that will replace the current Inner Detector. The ITk will feature a pixel detector surrounded by a strip detector, with the strip system consisting of 4 barrel layers and 6 endcap disks. After completion of final design reviews in key areas, such as Sensors, Modules, Front-End electronics and ASICs, a large scale prototyping program has been completed in all areas successfully. We present an overview of the Strip System, and highlight the final design choices of sensors, module designs and ASICs. We will summarize results achieved during prototyping and the current status of production and pre-production on various detector components, with an emphasis on QA and QC procedures.

Submission declaration:
Original and unpublished

Day 1 - Session 4 / 32

The ATLAS ITk Pixel Detector: status and roadmap.

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In the HL-LHC era, the radiation is expected to reach unprecedented values, with non-ionizing fluence of 1e16 neq/cm² and ionizing dose of 5 MGy. To cope with the resulting increase in occupancy, bandwidth, and radiation damage, the current ATLAS Inner Detector is replaced by an all-silicon system. The Pixel Detector will consist of five-barrel layers and a number of rings, resulting in about 13 m² of instrumented area. The ITk pixel system has been very carefully designed including three different flavours of silicon hybrid detectors equipped with novel ASICS and data transmission chains. A new serial powering scheme has also been developed to minimize the amount of material in the detector. Along the lifetime of this project from design, prototyping and pre-production (current) stages many challenges have been encountered and unforeseen problems have to be solved. At the end of this contribution the audience will get a good understanding of the status of the ATLAS-ITk pixel project and what have been the biggest challenges faced up to the day of this presentation and what are the major ones that still has to overcome.

Submission declaration:
Original and unpublished

A 28Gbps PAM4 VCSEL Driving ASIC for the Front-end Readout Application in High-Energy Physics Experiments
Optical communication has been widely used in high energy physics experiments. 4-level pulse amplitude modulation (PAM4) technology is becoming the potential solution for higher rate optical data transmission with its advantages of more efficient fiber utilization and lower analog bandwidth requirement at the same data rate. This paper presents the design and test results of a 28Gbps PAM4 vertical cavity surface emitting laser (VCSEL) driving ASIC fabricated in 55nm CMOS process. A novel output driver stage is proposed with a 2:1 cross-combination PAM4 transform topology and a dual-feedforward capacitor structure to improve eye-diagram quality.

The 28Gbps PAM4 VCSEL driving ASIC consists of a Least Significant Bit (LSB) channel, a Most Significant Bit (MSB) channel, a novel PAM4 output driver circuit and the corresponding bias circuits. The LSB/MSB channel consists of an input equalization stage and a pre-amplification stage with shared-inductor peaking and active feedback technologies. The proposed novel output driver circuit adopts a simplified cross-combination topology to convert two independent non-return-to-zero (NRZ) voltage data directly into PAM4 current data and drive the VCSEL. On-chip AC coupling and stacked current mirror structures are used to match the threshold voltage of the VCSEL (about 1.8V), and a dual-feedforward capacitor structure, working together with the stacked current mirror, is proposed to effectively improve the bandwidth and the eye-diagram quality.

The core area of the 28 Gbps PAM4 VCSEL driving ASIC is 0.55mm×1.5mm. The simulation results show that the core power consumption of the ASIC is 133.8mW, the open and clear PAM4 eye-diagram can be obtained at the rate of 28Gbps, the ratio level mismatch (RLM) is better than 0.95, and the amplitude is 9mA. The chip has been taped out and will be tested in September, the test results, including electrical and optical tests, will be presented and discussed in the meeting.
undergoing comprehensive testing at both CERN and DESY test beam facilities. This year, single chip assemblies, along with the first full modules incorporating the final, full-size prototype readout chip (CROC) irradiated up to $\varphi_{eq} = 1 \times 10^{16} \text{cm}^{-2}$, have become available and were subjected to testing at DESY in July.

During this presentation, an overview of the preliminary test beam results obtained will be provided. The studies will cover hit efficiency, spatial resolution, and noise hit occupancy for both non-irradiated samples and irradiated assemblies. The preliminary findings are in line with previous results obtained with RD53A assemblies. The measurements described in this contribution paved the way for the submission of the final readout chip CROC_v2 and kickoff batches for planar production sensors for the Inner Tracker that have been launched recently.

Submission declaration:

Original and unpublished

Day 2 - Session 3 / 36

Characterisation of the first compensated LGADs from FBK before and after irradiation

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The next generation of high-energy and high-intensity hadron colliders for particle physics will require tracking detectors able to efficiently record charged particles in harsh radiation environments, where expected fluences exceed $10^{17}$ particles/cm$^2$.

Recently, thin Low-Gain Avalanche Diodes (LGADs), with an active thickness of $\sim 50 \mu$m, have proven their ability to combine precise timing with precise tracking measurements, making them suited candidates for 4D tracking in future experiments. At present, the gain mechanism of LGAD sensors under irradiation is maintained up to a fluence of $\sim 5 \times 10^{15}$ particles/cm$^2$. 
To enable the usage of LGADs in the extreme fluence regime, an innovative design of the LGAD gain layer, the $p^+$ implant responsible for the local and controlled signal multiplication, has been implemented to enhance their radiation tolerance by more than one order of magnitude: the compensated LGAD.

In the standard LGAD design, the gain layer is obtained by implanting $5 \times 10^{16}$ atoms/cm$^3$ of an acceptor dopant in the region below the $n^{++}$ electrode. In the compensated design, the gain layer results from the overlap of a $p^+$ and an $n^+$ implant: the difference between acceptor and donor doping will bring an effective concentration similar to standard LGADs. The new design will be more resilient to radiation, as both acceptor and donor atoms will undergo removal with irradiation, but if properly engineered, their difference will maintain constant. Therefore, the compensated LGADs will empower the 4D tracking ability to a fluence of $10^{17}$ particles/cm$^2$ and above.

The first production of compensated LGAD sensors has been released by the FBK foundry at the end of 2022. Electrical characterisation and signal analysis from compensated LGAD sensors before and after irradiation with neutrons will be presented and discussed. Future evolution of the design of compensated LGADs will be envisaged.

Submission declaration:
Original and unpublished

37

**Silicon photomultipliers for the nEXO light detection system**

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The nEXO experiment will search for neutrinoless double beta decay in 5 tonnes of liquid xenon enriched in the xenon-136 isotope. In order to achieve better than 1% energy resolution at the energy of interest, both charge signals and scintillation light will be detected. The scintillation light at 175 nm will be detected using ultraviolet-sensitive silicon photomultipliers (SiPM) covering an area of about 4.6 m$^2$. Recent results on SiPM device qualification from Hamamatsu and FBK, the development of photon-to-digital converters, and plans for large-scale SiPM integration in the nEXO detector will be presented.

Submission declaration:
Original and unpublished

Day 2 - Session 3 / 38

**Overview of the ATLAS High-Granularity Timing Detector: project status and results**

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The increase of the particle flux (pile-up) at the HL-LHC with instantaneous luminosities up to $L = 7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ will have a severe impact on the ATLAS detector reconstruction and trigger performance. The end-cap and forward region where the liquid Argon calorimeter has coarser granularity and the inner tracker has poorer momentum resolution will be particularly affected. A High Granularity Timing Detector (HGTD) will be installed in front of the LAr end-cap calorimeters for pile-up mitigation and luminosity measurement. The HGTD is a novel detector introduced to augment the new all-silicon Inner Tracker in the pseudo-rapidity range from 2.4 to 4.0, adding the capability to measure charged-particle trajectories in time as well as space. Two silicon-sensor double-sided layers will provide precision timing information for minimum-ionising particles with a resolution as good as 30 ps per track in order to assign each particle to the correct vertex. Readout cells have a size of 1.3 mm × 1.3 mm, leading to a highly granular detector with 3.7 million channels. Low Gain Avalanche Detectors (LGAD) technology has been chosen as it provides enough gain to reach the large signal over noise ratio needed. The requirements and overall specifications of the HGTD will be presented as well as the technical design and the project status. The R&D effort carried out to study the sensors, the readout ASIC, and the other components, supported by laboratory and test beam results, will also be presented.

Submission declaration:
Original and unpublished

Day 1 - Session 2 / 41

The LHCb VELO detector: design, operation and first results

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The LHCb experiment has been upgraded during the second long shutdown of the Large Hadron Collider at CERN, and the new detector is currently operating at the LHC. The Vertex Locator (VELO) surrounds the interaction region of the LHCb experiment, responsible of reconstructing the proton-proton collision (primary vertices) as well as the decay vertices of long-lived particles (secondary vertices). The VELO consists of 52 modules with hybrid pixel detector technology. Compared to the previous VELO detector, the upgrade VELO encompass an enhanced track reconstruction speed and precision, even at the expected higher occupancy conditions of the upgrade, due to its pixel geometry as well as a closest distance of approach to the LHC beams, with the first sensitive pixel being at just 5.1 mm from the beam line.

Cooling is provided by evaporative CO\textsubscript{2} circulating in 500 $\mu$m thick silicon microchannel substrates. The sensors consist of 200 $\mu$m thick n-on-p planar silicon sensors, read out via 3 front-end ASICs. The detector contains 41 million $55 \times 55 \mu m$ pixels, read out by a custom developed front-end ASIC (VeloPix). The VELO operates in an extreme environment, which poses significant challenges to its operation. During the lifetime of the detector, the sensors are foreseen to accumulate an integrated fluence of up to $8 \times 10^{15} \text{1MeV n}_{eq} \text{ cm}^{-2}$, roughly equivalent to a dose of 400 MRad. Moreover, due to the geometry of the detector, the sensors will face a highly non-uniform irradiation, with fluxes in the hottest regions expected to vary by a factor 400 within the same sensor. The highest occupancy ASICs foresee a maximum pixel hit rate of 900 Mhit/s and an output data rate exceeding 15 Gbit/s.

The design, operation and early results evaluating the radiation damage and detector performance throughout the first year of operation will be presented.

Submission declaration:
Original and unpublished
Hot spot visual evaluation of breakdown locations in ATLAS18 ITk strip sensors and test structures

Author: Andrew Fournier

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An important characteristic of silicon-based particle detectors, like those used for the forthcoming ATLAS ITk upgrade for the HL-LHC, is the leakage current. This characteristic is evaluated in the quality control stage of the new ITk strip sensors performing an IV measurement, where the sensors are biased up to -700V, typically showing low and stable leakage current. However, some sensors can exhibit a sudden leakage current increase during the IV measurement, so-called early breakdown, making the sensor unusable.

The analysis of these early breakdown conditions typically consists of visual inspection of the sensors using a microscope, as often this is caused by physical damage, be it a deep scratch, chipping on the edges of the sensor, or other damage. But up to this point, the association of the observed damage with the early breakdown is not definitive. Rather, this is an association by correlation, due to the limits of verification by observation with standard equipment.

A hot spot imaging setup has proven to be a valuable diagnostic tool to identify and understand these early breakdown conditions and elaborate on former understandings of these emissions. The regions responsible for the breakdown can be properly located by imaging the infra-red light emissions produced by them in breakdown conditions. These regions of interest can also be imaged at magnification to evaluate the more precise structure of the breakdown to better understand the damage. The regions discovered, which have improved our understanding of breakdown damage and its symptoms, include scratches, chipping, static charge buildup and manufacturer defects in the ATLAS18 strip sensors and test structures.

Submission declaration:
Original and unpublished

Analysis of MOS capacitor with p layer with TCAD simulation

Author: Yoshinobu Unno

Co-authors: Callan Jessiman; Celeste Fleta; Christoph Thomas Klein; Eric Bach Marquès; Ezekiel Staats; John Stakely Keller; Miguel Ullan; Thomas Koffas; Vitaliy Fadeyev; on behalf of ATLAS ITk Strip Sensor Collaboration
The ATLAS18 strip sensors of the ATLAS inner tracker upgrade (ITk) are under production since 2021. Along with the large-format n⁺-in-p strip sensor in the center of the wafer, test structures are laid out in the open space for monitoring the performance of the strip sensor and its fabrication process. One of the structures is a 1.2×1.0 mm² test chip that includes representative structures of the strips, and metal-on-silicon (MOS) capacitors. In addition to the standard MOS capacitor, a MOS capacitor is designed with a p implantation representative of the p-stop doping for isolating the n⁺ strips on the surface of silicon, the MOS-p capacitor. The C-V curve of the MOS capacitor shows characteristic behavior in the accumulation, depletion, and inversion regions as a function of bias voltage, from which one can deduce the amount of the interface charge. The MOS-p capacitor shows the C-V curve modulated by the properties of the p layer.

With over 50% of the full production complement delivered, we have observed consistent characteristics in the MOS-p capacitors. Rarely and currently only in two batches, we have observed abnormalities. To further study them, we have simulated the MOS-p capacitor with TCAD software, which successfully reproduces the normal behavior, including a feature caused by a geometrical offset of the area of the metal and the p implantation, with the p doping and the interface charge within the expected range. By contrast, the overall shape of the two abnormal cases is only reproduced when introducing 1/10 of the doping of the p implantation and charge traps in the p implanted area. A smaller but distinctive feature in the behavior is reproduced with a non-uniform distribution of the interface charge or other equivalent component. These simulations help to take final decisions for the batches in production.

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A 10-Gb/s Serial Link Transmitter With 4-Tap FFE Function in 55-nm CMOS

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The serial data rate has reached the 10 Gb/s level nowadays in the data acquisition system (DAQ) in high-energy physics experiments. Due to various wireline transmission scenarios in different detector front-end readout environments, the high-speed chip-to-chip or board-to-board serial data transmission is encountering severe and various signal quality degradations. A general-purpose, low-power, area-saving and high-speed transmitter (Tx) technique with tunable pre-emphasis function is crucial and in great demand. This paper presents the design and test results of a 10 Gb/s high-speed serial link transmitter (Tx) with the adjustable 4-tap feedforward (FFE) function fabricated in a 55 nm CMOS technology. The half-rate topology is adopted in this FFE transmitter design with full CMOS logic cells working at 5 Gbps data rate. The proposed FFE transmitter consists of a demultiplexer (DMUX), two latch-chains, four high-speed
MUXes and an output combiner. With this half-rate topology, the needed maximum clock rate is 5 GHz, and thus the full CMOS logic cells can be safely used in the whole design to save power consumption. Besides, a custom-designed high-speed TSPC latch is designed to gain better performance in 5 Gb/s data rate. A high-speed CML-based 2:1 MUX is proposed to achieve the highest data combination in the system. The clock distribution tree is also deliberately designed between each sub-module to ensure sufficient timing margins for latches, DMUX and MUXes over different PVT combinations.

The proposed 10 Gb/s 4-tap FFE transmitter features an area of 120 μm x 290 μm, and the power consumption is around 50 mW including the CML output driver when working at the date rate of 10 Gbps. The chip has been designed and taped out in the end of 2022, and will be tested in September 2023. The test results will be presented and discussed in the meeting.

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Design and evaluation of a MeV gamma-ray camera aboard a 50-kg class small satellite

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Waseda University and Tokyo Tech are developing a 50-kg class small satellite, tentatively named INSPIRE, scheduled for launch in FY2026. The satellite’s primary detector is a BOX-type Compton Camera (CC-BOX). This camera covers a dynamic range spanning two orders of magnitude: it observes low energy (30 keV − 200 keV) in Pinhole mode and high energy (200 keV − 3 MeV) in Compton mode. The CC-BOX comprises a pixelized Ce:GAGG scintillator array and an MPPC array operating at 40V to cover total geometrical area of 10×10 cm^2. The Ce:GAGG scatter layer is 5mm thick, and the absorber features a four-layer, 20mm thick depth-of-interaction (DOI) structure. Additionally, Ce:GAGG elements are positioned on the sides of the detector to enhance its sensitivity than traditional Compton Cameras. For the observation of low-energy gamma rays, the scatter has 5mm square holes in each 5×5 cm^2 module to facilitate pinhole imaging. Furthermore, BGO shields are positioned on the side and bottom of the detector for efficient event rejection.

In this presentation, we begin by detailing the design of the CC-BOX, its data processing flow—including the DAQ board, USB board, and Raspberry Pi—as well as weight and power specifications. We then assess the detector’s anticipated performance through both hands-on device testing and simulations, focusing on detection sensitivity to point sources, imaging resolution, energy resolution, the BGO shield’s background removal capability, anticipated spectra when observing the Crab Nebula, and polarization observations. Finally, we share the findings from a series of environmental tests in preparation for the FY2026 launch, which cover the activation characteristics of the Ce:GAGG scintillator, high-rate data acquisition using Raspberry Pi, radiation damage assessment of the DAQ board, and engagement tests, including communication trials.

Submission declaration:
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Long-Distance Signal Propagation in AC-LGAD

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We investigated the signal propagation in AC-LGAD (aka RSD), which are LGAD with a common N+ layer and AC-coupled readout contacts, by measuring the interstrip/interpad capacitances and resistances and by IR laser injection on a large selection of AC-LGAD with either strips or pads. The interest for this topic derives from the realization that while large charge sharing between strips/pads is essential for good position resolution, large sharing beyond the next two neighboring contacts generates background signals which in general are detrimental to the sensor goal of low occupancy. The observed signal is composed of the sum of the induced signal from the moving collected charge on neighboring contacts and the pick-up of the signal conducted on the N+ layer common to all contacts.

To characterize the signal propagation, we determined the interstrip/interpad capacitance and resistance using CV measurements between the contacts separated by distances of up to more than 10x the pitch values. In addition, scans of IR laser signals were added to confirm the results with charge collection.

The sensors from a variety of manufacturer had variations of the following parameters:
- Readout dimensions: strip/pad metal contact size (length, width), pitch,
- Sensor production details: N+ layer resistivity, dielectric specs (thickness, value of permittivity), bulk thickness, doping of the gain layer.

The initial data suggest that the length of the strip plays a dominant role in determining the distance the pick-up extends. On the other hand, the N+ layer resistivity influences the strength of the picked-up signal. Our study compares the effect of all parameters listed above, including comparison of different manufacturers.

Of special interest is the difference in long-distance pick-up between strip sensors and pad sensors.

Submission declaration:

Original and unpublished

Feasibility study of implementing CMOS sensor in 55nm process for tracking

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High-Voltage CMOS (HVCMOS) sensors, featuring a deep n well separating the transistors and the depletion region, is intrinsically radiation hard and a good candidate for tracking systems in future high energy experiments, such as LHCb upgrade II or future electron-positron colliders. In hope of reducing the power density and incorporating more functionality in the same area, we are looking for foundries where HVCMOS sensors can be implemented in smaller feature size. In the talk we report the feasibility study using 55nm processes. Sensor diodes are designed with deep n well serving as electrode in a low-resistivity substrate, and the test results are reported. New design for MPW in 55nm high voltage process on a high-resistivity substrate will also be described.

Submission declaration:
Original and unpublished

Image quality assessment of flexile scintillation screens for curved X-ray imaging detectors

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Nowadays, the large-area flat panel imagers with TFT (thin film transistor) and CMOS (complementary metal-oxide semiconductor) process have been widely used in various X-ray medical imaging and non-destructive test (NDT) and security applications. Conventional flat-panel x-ray detector are manufactured using thin film transistor (TFT) processing on extremely large rigid glass substrates. Recently, a light and flexible array panel is being produced using a low-temperature TFT process on a thin plastic substrate that does not break. Research and development of large-area X-ray imaging detectors of curved and bendable types using new process manufacturing technologies are currently in active progress. Generally, scintillation materials are widely used as converters for X-rays into visible light in indirect X-ray imaging detectors. In this work, different flexible scintillation screens such as needle structured CsI:Tl with 200-700um thickness and granular Gd2O2S:Tb(GOS) materials with different mass density(140-250um thickness) on thin plastic substrates were used to prepare for curved X-ray imaging detectors. The used different flexible scintillation screens have a excellent X-ray energy absorption and green light emission wavelength and high spatial resolution properties. The various X-ray imaging performance such as X-ray linearity, signal to noise ratio, dynamic range, spatial resolution were measured and investigated. And quantitative image evaluation with X-ray phantom was studied in medical X-ray conditions. The dominant scintillation intensities of scintillating screens were clearly observed around green light emission wavelength (540-560nm). The X-ray images of both flexible CsI and Gadox scintillation screen showed sharper image and better spatial resolution. This paper will demonstrated the significant potential of flexible scintillation screens with high-resolution and high-sensitive for curved X-ray imaging detector.

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Day 5 - Session 1 / 50

The DMAPS Upgrade of the Belle II Vertex Detector

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The Super-KEKB collider is set to undergo a major upgrade to achieve a target luminosity of \(6 \times 10^{35} \text{cm}^{-2} \text{s}^{-1}\). A long shutdown is foreseen around year 2027, which provides the opportunity to revisit parts of the Belle II experiment. A new pixelated vertex detector (VTX) is being developed to match the upgraded interaction region. This silicon tracker aims to be more robust against the expected higher machine background and improve precision and standalone track finding efficiency.

The proposed VTX design comprises of five layers in a barrel-shaped configuration with minimal material budget.

The innermost layers are based on an "all-silicon ladder" concept with air cooling, targeting a material budget below 0.2% X0/layer.

For the three outer layers, liquid cooling and carbon-fiber support structures based on on ALICE-ITS2 with a material budget ranging from 0.3% X0 for later 3 up to 0.8% X0 for layer 5 will be used.

All the ladders feature the OBELIX depleted-MAPS CMOS sensor, with an active area of approximately 2 cm × 3 cm, designed in the Tower 180 nm technology.

The pixel-matrix, derived from the TJ-Monopix2 sensor developed for the ATLAS experiment, has a 33 μm pitch and an integration time of less than 100 ns.

The power-dissipation is less than 200mW/cm² at an average hit-rate of 60 MHz/cm². A digital trigger logic is designed to meet Belle II requirements, targeting a 30 kHz average trigger-rate with a 10 μs trigger delay and a maximum hit-rate of 120 MHz/cm².

The initial version of the sensor is expected to be designed and submitted for foundry production by late 2023.

The presentation will encompass various aspects of the project, including tests of the TJ-Monopix2 to validate pixel-matrix performance, a detailed focus on the OBELIX features and design status as well as prototype fabrication and testing of the mechanical concepts.

Submission declaration:

Original and unpublished

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X-ray polarimetry and spectroscopy with the CMOS detector IU233N5-Z

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X-ray and gamma-ray polarimetry are essential tools for studying the radiation mechanism of high-energy astrophysics. However, there are few such observations. The CMOS is a detector with better spatial and time resolutions compared to CCD. Then, we focused on a small pixel-size CMOS detector IU233N5-Z. That CMOS detector is an optical sensor with 1 million pixels and a small size (1.12×1.12 μm²). To evaluate the X-ray spectral performance, we irradiated the X-ray sources (55Fe, 57Co and 241Am) to CMOS at room temperature and obtained values of FWHMs (e.g., FWHM@5.9keV = 180 eV). These are a similar resolution to that of a CCD detector. In addition, from the Fe result, we obtained the depletion layer of the IU233N5-Z as 6 μm. Also, to evaluate the X-ray polarimetry, we irradiated 90Sr and observed the electron tracks as long as 30 pixels ∼30 μm. Furthermore, we beamed the polarized X-ray (15, 30, 50, and 70 keV) at SPring-8. From these measurements, we also observed tracks of the photoelectrons and found the indication of the X-ray polarization from the event directions. In this presentation, we will discuss these results.

Submission declaration:

Original and unpublished

Day 2 - Session 2 / 52

From 3D to 4D tracking: The Impact of Avalanche-based Detectors in Particle Tracking

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In this contribution, I will describe the evolution of silicon sensors following the introduction of controlled avalanche.

Submission declaration:

Original and unpublished

Day 4 - Session 3 / 53

Simulations and Performance Studies of a MAPS in 65 nm CMOS Imaging Technology

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Monolithic active pixel sensors (MAPS) produced in a 65 nm CMOS imaging technology are being investigated for applications in particle physics. Their main characteristic is integrating a sensing volume and readout circuit in the same silicon wafer, reducing material budget with respect to most hybrid sensors. Compared to the previously investigated 180 nm CMOS imaging technology, the 65 nm technology significantly improves the logic density of the circuitry. The investigated sensor design has a small collection electrode characterized by a low input capacitance, granting a high signal-to-noise ratio and low power consumption. These features are the main motivation for the Tangerine project, which aims to develop the next generation of silicon pixel sensors with a temporal and spatial resolution compatible with the requirements for a vertex detector at future lepton colliders. The developments are pursued in collaboration with the CERN EP R&D program on technologies for future experiments and with the ALICE ITS3 upgrade.

The project comprises all aspects of sensor development, from electronics engineering and sensor design using simulations, to laboratory and test-beam investigations of prototypes developed within Tangerine and the collaborating projects. The use of simulations when developing a MAPS is of great relevance, given the complex electric field configuration and the simultaneous need for high statistics. TCAD device simulations using generic doping profiles and Monte Carlo simulations have been used to build an understanding of the technology and predict the performance parameters of the sensor. Prototypes of a 65 nm CMOS sensor with a small collection electrode have been characterized in laboratory and test-beam facilities by studying their charge collection, spatial resolution, and efficiency. This contribution compares simulation results to test-beam data. The experimental results validate the employed simulation approach and establish this technology as a promising candidate for a vertex detector at future lepton colliders.

Submission declaration:
Original and unpublished

Day 4 - Session 1 / 54

ALICE ITS3: a truly cylindrical vertex detector based on bent, wafer-scale stitched CMOS sensors

Author: Jian Liu

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The new Inner Tracking System (ITS2) of the ALICE experiment at the LHC, upgraded during the LHC Long Shutdown 2 (2019-2021) with CMOS monolithic active pixel sensors (ALPIDE), is currently taking data and demonstrating excellent performance in the LHC Run 3. A replacement of the three innermost layers of the ITS2, called ITS3, is foreseen during the LHC Long Shutdown 3 (2026-2028) in order to further improve tracking precision and efficiency, particularly at very low transverse momentum (\(p_T > 0.1 \text{ GeV/c}\)).

The ALICE ITS3 is a cylindrically bent silicon vertex detector based on stitched wafer-scale monolithic active pixel sensors with a 65 nm CMOS technology. The large stitched sensors are 28 cm in length and can be thinned down to below 50 µm, where the sensors are flexible to be bent to form truly cylindrical half-barrels. Air-cooling is feasible thanks to the reduced sensor power consumption of < 20 mW/cm². An extremely low material budget of 0.05% X/X0 can be achieved in combination with lightweight carbon foam spacers as support structures.

This new technology for ITS3 was qualified with a set of test structures from the first submission (called MLR1: Multi-Layer Reticle 1). A successor prototype with dimensions of 14 x 259 mm, called MOnolithic Stitched Sensor (MOSS), has been designed to demonstrate the feasibility of the stitching process. Comprehensive laboratory characterizations and beam tests are underway to study the performance of MOSS.

In this contribution, the ALICE ITS3 detector concept, sensor bending mechanics and technology qualification achieved through MLR1 prototypes will be concisely reviewed. The MOSS design and its test system will be introduced, and the first results of the MOSS characterization in terms of manufacturing yield, power distribution and efficiency, data rates, noise, charge threshold, detection efficiency and spatial resolution will be discussed in detail.

Submission declaration:
Original and unpublished

Day 2 - Session 1 / 55

Characterisation and Simulation of stitched CMOS strip sensors

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In high-energy physics, upgrades for particle detectors and studies on future particle detectors are largely based on silicon sensors as tracking devices. Consequently, there is a need to investigate silicon sensor concepts that offer large-area coverage and cost-efficiency. Sensors based on the CMOS imaging technology present such an alternative silicon sensor concept for tracking detectors. As this technology is a standardised industry process it can provide a lowered sensor cost, as well as access to fast and large-scale production from a variety of vendors.

The CMOS Strips project is investigating passive CMOS strip sensors fabricated by LFoundry in a 150 nm technology. By employing the technique of stitching two different strip formats of the sensor have been realised. Besides, the strip design varies in doping concentration and width of the strip implant to study various depletion concepts and electric field configurations. Unirradiated and irradiated samples have been characterised by probe station measurements and test beam campaigns for the different sensor designs. In addition, the detector response was simulated based on Monte Carlo methods and electric fields provided by TCAD Device simulations. This contribution provides an overview of sensor characterisation measurements and studies on the hit detection efficiency, spatial resolution and noise of the strip sensors. The simulated detector response is presented and compared to test beam data. Furthermore, an outlook on the next sensor submission of the CMOS Strips project is given.

Submission declaration:
Original and unpublished

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Micro-vertex detection system for the WASA-FRS HypHI Experiments at GSI-FAIR

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The determination of the baryon-baryon interaction is crucial to build models on nuclear systems. Nowadays, nuclear spectroscopy provides insights into the nucleon-nucleon force, enabling effective modeling of the majority of measured isotopes. Notwithstanding, the scarcity of nucleon-hyperon or hyperon-hyperon interaction studies leads to poor prediction power when modeling nuclear systems that include strangeness, such as neutron stars. The hypernucleus, a bound system containing nucleons and at least one hyperon, can be considered as a small laboratory where to study the nucleon-hyperon interaction features.

The WASA-FRS HypHI Collaboration aims to study light hypernuclei by means of heavy-ion induced reactions [1] at GSI-FAIR (Germany), which stand out among other production methods because of the high multiplicity of the primary products. This fact allows for the determination of the primary vertex, which could highly improve the resolution of the lifetime measurement of the hypernucleus. The micro-vertex detection system has been developed with the main purpose of obtaining the event-by-event interaction point of the primary beam (I \sim 10^{7} \text{ pps}) on the target.

The micro-vertex detection system consists of four stations of single-sided micro-strip silicon detectors. The strip size is 80 μm for the first two stations and 160 μm for the latest ones, which are combined by pairs in the same Front-End electronics channel. Preamplifying and shaping of the signal is performed by sixteen ASICs (VATAGP8 from IDEAS). These chips are connected and controlled by three motherboards, also developed by the global manufacturer Alibava Systems.

My contribution to this symposium would consist in the description of the micro-vertex detection system, the presentation of its performance results from the first experimental tests with a low-energy beam accelerator at CMAM (Spain), and the introduction to its experimental purposes in the upcoming WASA-FRS Collaboration Experiments.


Submission declaration:
Original and unpublished
A double arm beam telescope based on the recently developed Timepix4 ASIC was built in order to perform tests of synchronous multiple-detector readout and track reconstruction with fast timing capability. The Timepix4 is a hybrid pixel detector readout ASIC designed to record time-of-arrival (TOA) and time-over-threshold (TOT) simultaneously in each pixel. It has a 448x512 pixel matrix with square pixels at a 55μm pitch. The TOA is digitised with a 195 ps TDC bin size and the TOT is proportional to the charge collected by the silicon sensor. The telescope is composed of eight planes with n-on-p silicon sensors. Two of these planes are instrumented with 300 thick sensors tilted with respect to the beam, to provide high quality spatial measurements, while the remaining two have100 thick sensors to achieve a better time response. Each detector assembly (sensor + Timepix4 ASIC) is cooled by a 3D printed titanium block directly attached to the test PCB, through which a cooling fluid is circulated. Both the cooling block and PCB have a circular cut-out to minimise the amount of material traversed by incident particles. The assemblies are readout by SPIDR4 systems. In addition to the Timepix4-based detectors, scintillators and a Cherenkov-MCP were placed in the beam acceptance in order to give reference timing measurements. The reference timing signals are digitised using the PicoTDC chip, that provides a fine timestamp of 3ps in its fastest configuration. First tracks were reconstructed using information from all four planes, which allows the assessment of temporal resolution using high energy particles. In this presentation, the initial results of the timing and spatial resolution of this telescope and plans for future R&D tests involving state-of-the-art sensors will be discussed.

Submission declaration:
Original and unpublished

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Long-term humidity exposure of ATLAS18 ITk strip sensors

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The ATLAS collaboration is upgrading its detector for High-Luminosity LHC operations scheduled to start in 2029. This involves making a new all-silicon tracker, called Inner Tracker (ITk), with instrumented strip area of 165 m².

The strip sensor type is n-on-p, chosen because of its radiation hardness and a relative fabrication simplicity. So far it has not been used in large-scale experiments. Many years of R&D investigations and pre-production experience showed that it works well, with the specification of the maximum operational voltage of 500 V. The sensors, however, show sensitivity to ambient humidity, e.g. reduced breakdown voltage at relative humidity (RH) values of about 40% and above. This is an issue for testability, but not real operations, where RH is very low. Therefore, the collaboration adopted the strategy of dry storage, testing, and shipment for sensors and related assembled components:
modules, staves, and petals. A few days long exposure to ambient air during assembly was shown to be tolerable.

The dry handling strategy becomes much more difficult to implement during the tracker integration, when barrels and disks are put together in large-size cleanrooms with RH range between 50 and 70%. The duration of each of numerous integration steps is several weeks, followed by testing. The effect of such long humidity exposures on the sensor properties was unknown. Therefore, we commenced a study of repeat sensor exposures to 75% RH. We chose 32 sensors for the study from different deliveries, and with different pedigrees in terms of initial performance on reception and recovery procedures used. Progressively longer exposures ranged between 4 and 266 days in duration. The cumulative exposure time was up to 2 years. No performance deterioration was seen, as evaluated by the visual inspection, IV characteristics, and other checks. We report the details of the tests, results, and implications.

Submission declaration:
Original and unpublished

**Day 3 - Session 1 / 60**

**Defect level identification of ATLAS ITk Strip Sensors using DLTS**

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With the upgrade of the LHC to the High-Luminosity LHC (HL-LHC), the Inner Detector will be replaced with the new all-silicon ATLAS Inner Tracker (ITk) to maintain tracking performance in a high-occupancy environment and to cope with the increase in the integrated radiation dose.

Comprising an active area of 165m², the outer four layers in the barrel and six disks in the end-cap region will host strip modules, built with single-sided micro-strip sensors and glued-on hybrids carrying the front-end electronics necessary for readout. Before being shipped out for module building, the ATLAS18 main sensors were tested at different institutes in the collaboration for mechanical and electrical compliance with technical specifications, the quality control (QC), while fabrication parameters were verified on test structures from the same wafers, the quality assurance (QA).

As part of ongoing studies in parallel to ITk Sensor Production QC and QA, diodes fabricated as part of the test structures were measured using Deep-Level Transient Spectroscopy (DLTS). This was done to achieve precise sensor simulations motivated by findings of anomalous leakage current behaviour, as well as to compile a more complete model of radiation damage in ITk Strip Sensors. Utilising DLTS spectra with varying test parameters, trap energy levels and cross-sections associated with defects in the devices were obtained. Furthermore, employing related measurements techniques, such as Thermal Admittance Spectroscopy (TAS), results were supplemented and expanded, or additional points of interest, such as the deep level profile and the capture kinematics of the trap levels, were investigated with double-pulse DLTS (DDLTS).

In this talk, results of the defect characterisation will be given. Spectra for unirradiated and irradiated diode samples from both prototyping and production period will be presented, and their details collected from Arrhenius analyses will be shown.
Imaging reconstruction method on X-ray data of CMOS polarimeter combined with coded aperture

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Submission declaration: Original and unpublished

Mighty Tracker - Performance Studies of the MightyPix for LHCb

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Submission declaration: Original and unpublished
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A new downstream tracking system, known as the Mighty Tracker, is planned to be installed at LHCb during LS4. The reason for this is an increase in instantaneous luminosity from $2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$ to $1.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ and therefore an overall higher irradiation and up to six times higher occupancy.

To keep the material budget as low or even lower as for the current detector, the Mighty Tracker is planned as a hybrid system with silicon pixels in the inner and scintillating fibres in the outer region.

For the pixel detector part HV-CMOS MAPS with a pixel size of $55 \mu\text{m} \times 165 \mu\text{m}$ will be used. This technology has been chosen because of its low production costs, low material budget, high radiation tolerance and good timing resolution.

To fulfill the requirements, the development and characterization of the sensors focuses on radiation damage with fluences up to $2 \times 10^{15} \text{MeVn}_{\text{eq}}/\text{cm}^2$ and a timing resolution $\leq 3\text{ns}$.

The timing resolution is restricted due to the $40\text{MHz}$ triggerless DAQ by LHCb.

To characterize and further develop the MightyPix, a new readout system called MARS (Mighty Tracker Readout System) has been developed in Bonn.

MARS is a modular system, able to test different single chips in the laboratory as well as at testbeam facilities.

It has been used to perform first characterization studies of development-chips investigating radiation tolerance and timing resolution as well as the dependence of the sensor settings on the overall performance.

This presentation covers first results of ongoing characterization studies of HVCMOS-MAPS with the newly developed readout system and an introduction to this.

Submission declaration:
Original and unpublished

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The ATLAS ITk strip local support structures

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A new silicon tracker of the ATLAS detector is envisioned for the Phase-II upgrade of the Large Hadron Collider experiment (LHC), the so-called High Luminosity LHC (HL-LHC). The new inner tracker (ITk) will consist of a silicon pixel inner tracker and a silicon microstrips outer tracker. Both of these sub-detectors are initiating the production phase during the year 2023. This contribution focuses on the Strip ITk detector. In particular, the high precision, low-mass, high thermo-mechanical performance support structures equipped with the silicon microstrip sensors, the so-called "staves" for the barrel region and "petals" for the endcap regions.

This contribution aims to describe in detail the design of these peculiar structures, and how this design advanced over the years to accommodate the evolving requirements of the detector. Special emphasis will be dedicated to detail the flexible, poliymide-based circuits called "bus tapes", which are completely embedded in the structures, as they constitute an important structural and electrical component of the supports. The main aspects of the electrical behavior of the structure will be described in detail as well.

The prototyping efforts at the ATLAS institutes, both of the supports themselves but also for their sub-components, will be also explained in depth. A strong collaboration effort was also motivated by the transfer of knowledge and assembly of the petal cores in industry, which was consolidated with the signing of a full production contract. This process will also be described.

Finally, the results of the recently completed petal pre-production, where 20 support structures were
manufactured and characterized at multiple ATLAS institutes with an ambitious Quality Control (QC) program, covering the mechanical, electrical and thermal performance of the supports will be detailed. The progress of the pre-production of the stave structures will also be presented.

Submission declaration:
Original and unpublished

Analysis of the results from Quality Control tests performed on ATLAS18 Strip Sensors during on-going production

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The ATLAS experiment will replace its existing Inner Detector with the new all-silicon Inner Tracker (ITk) to cope with the operating conditions of the forthcoming high-luminosity phase of the LHC (HL-LHC). The outer regions of the ITk will be instrumented with 18000 ATLAS18 strip sensors
Development of the system tests for the ATLAS Inner Tracker Strip Detector

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The new ATLAS Inner Tracker (ITk) will replace the current tracking detector of the ATLAS detector to cope with the challenging conditions for the Phase-II upgrade of the Large Hadron Collider experiment (LHC), the so-called High Luminosity LHC (HL-LHC). The new tracking detector is an all-silicon detector consisting of a pixel inner tracker and a silicon microstrips outer tracker, differentiated again in a central barrel section around the interaction point and two end-cap sections covering the forward regions for the collisions.

This contribution focuses on the currently developed full system tests for the ITk strips detector, being the testbed for testing and evaluating the performance of several close-to-final detector components before production. These will also serve in the future for training and testing purposes of the detector during operation.

The barrel system test is conducted in SR1 at CERN and will consist of 8 staves - mechanical core structures loaded with rectangular short (~2.5 cm) and long (~5 cm) strip sensor modules. In a similar fashion, the system test for the end-caps is developed at DESY in Hamburg/Germany loaded with up to 12 petals - again a core structure loaded with trapezoidal shaped sensors of various lengths and strip pitches including the readout and power electronics. The staves and petals are mechanically held in place within a support structure and connected to the electrical, optical and cooling services as realistic as possible as in the latter detector integration. As such it is possible to validate the detector design, verify the detector DAQ and perform tests with the services, e.g. concerning the dual-phase CO\textsubscript{2} cooling.

This contribution gives an overview of the developed system tests for the ITk strip detector, summarizes the current status of the two sites, and shows a selection of performance measurements conducted in the last months.

Submission declaration:
Original and unpublished
Design, fabrication, and preliminary test results of a new inverse-LGAD for soft X-ray detection

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The Low Gain Avalanche Detector (LGAD) is becoming increasingly a promising and important technology for soft X-ray imaging at the next generation light sources as well as for particle tracking applications in the demanding future high energy physics experiments. Different versions of LGAD have been under investigation to address specific needs for different applications. Particularly, in order to exploit the unique scientific imaging opportunities at the new XFELs, finely segmented detectors that can detect soft X-rays with energies as low as 250 eV are needed. The sensors must be able to provide an internal gain of ~10 to amplify the generated small signal to be above the noise floor of the readout electronics and must have an extremely shallow entrance window to allow the absorption of soft X-rays in the active volume of the sensor. In addition, due to the fine segmentation, the charge multiplication structure must be accommodated not on the segmented side of the sensor but on the opposite side, which would otherwise lead to extremely low fill-factors. We demonstrate a new inverse LGAD structure implemented in a sensor with n-on-n configuration as a strong candidate to fulfil these requirements. We will present the design, simulation and fabrication of the sensors as well as the preliminary characterization, including I-V and gain measurements.

Submission declaration:
Original and unpublished

Day 3 - Session 2 / 67

Identification and Recovery of ATLAS18 Strip Sensors with High Surface Static Charge

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The new all-silicon Inner Tracker (ITk) is being constructed by the ATLAS collaboration to track charged particles produced at the High-Luminosity LHC. The outer portion of the ITk detector will include nearly 18,000 highly segmented and radiation hard silicon strip sensors (ATLAS18 design). Throughout the production of 22,000 sensors, anticipating expected losses, the strip sensors are subjected to a comprehensive suite of mechanical and electrical tests as part of the Quality Control (QC) program. In a large fraction of the batches delivered to date, high surface electrostatic charge of 80 to several 100s of volts was measured. High static charge was also measured on the plastic sheets which sheathe the sensors for shipping and handling rigidity. Aggregate data from across QC sites indicate a correlation between observed electrical failures and the sensor/plastic sheet charge build up. To mitigate these issues, the QC testing sites introduced recovery techniques involving irradiation of the sensor surface with UV light or application of intensive flows of ionizing gas to remove accumulated static charge. In addition, significant modifications to sensor handling procedures were made to prevent subsequent build up of static charge. This presentation details a precise description of the issue, trend analyses of sensors initially failing electrical tests (I-V, strip scan, etc.) and their performance over time after the recovery treatment. We also discuss results after mitigation attempts by the vendor, and interesting cases where little static charge was observed.

Submission declaration:
Original and unpublished

Development of the X-ray polarimeter using CMOS imager: polarization sensitivity of a 1.5 µm pixel CMOS sensor

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X-ray polarimetry is expected to be an effective tool for revealing the geometrical and magnetic structures of celestial objects. With the launch of the Imaging X-ray Polarimetry Explorer (IXPE; Weisskopf et al. 2022) in 2021, polarimetric observations with high sensitivity in the 2-8 keV energy band have begun. However, hard X-ray polarimetry in the 10-30 keV energy band, where non-thermal radiation dominates and the number of photons is relatively abundant, is still challenging.

We are developing an imaging polarimeter using a micro-pixel complementary metal–oxide–semiconductor (CMOS) image sensor and a coded mask to realize polarimetry in the hard X-ray band of 10-30 keV. The polarization of the incident X-ray can be measured by tracing photoelectrons with a fine-pixel sensor. We call the project cipher (Coded Imaging Polarimetry of High Energy Radiation;
Odaka et al. 2020) and measured the modulation factor of the CMOS image sensors with a pixel size of 2.5 µm.

In this study, we evaluate the polarization sensitivity of a CMOS image sensor with a pixel size of 1.5 µm manufactured by Canon. In order to measure the modulation factor of the sensor, we irradiated the sensor with nearly perfectly polarized monochromatic X-rays at BL20B2 in SPring-8, a synchrotron radiation facility in Japan. The obtained modulation factors of the sensor were 8.8% at 10 keV and 13.5% at 16 keV, which were higher than that of the sensor with a pixel size of 2.5 µm measured by Odaka et al. (2020). These results show that the modulation factor can be improved by using a finner-pixel sensor. We also estimate the detection efficiency of the sensor. We will discuss the polarization sensitivity of fine-pixel sensors by comparing the results of the experiments and simulations.

Submission declaration:
Original and unpublished

A High-Precision Proton Irradiation Site for Silicon Detectors Providing Online Fluence Monitoring, Spatial Damage Resolution and Flexible Irradiation Procedures

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A modern irradiation site is in operation at the Bonn Isochronous Cyclotron since 2021. The accelerator typically provides 14 MeV/nucleon protons (up to alphas) with 1 µA beam current to the site. Devices-under-test (DUTs) are situated inside an insulated box, actively-cooled by nitrogen gas, to prevent annealing, featuring feed-throughs for powering or reading out the DUT. To achieve uniform fluence distribution on the DUT, the box is mounted on a 2D-linear stage which is moved through the beam on a meander-like pattern. In front of the box, a custom-made, calibrated beam monitor with dedicated readout electronics, provides online diagnostic of the beam parameters at the DUT with typically 2% relative uncertainty. This enables a beam-based, online dosimetry approach with comparable uncertainty, facilitating spatial resolution of the fluence distribution and the application of corrections during and after the irradiation. This allows for maximizing fluence uniformity, specifically relevant for low-fluence irradiations.

In this contribution, the setup and capabilities of the irradiation site are showcased with emphasis on its flexibility regarding user-specific campaigns. The concept of dosimetry via online beam parameter monitoring is explained, compared with the conventional offline dosimetry approach via foil activation for multiple irradiations and its advantages are demonstrated. Furthermore, the proton hardness factor measurement, using 150 µm thin silicon sensors, is shown, resulting in irradiations of typical DUTs to levels of $10^{16}$ n$_{eq}$/cm$^2$ within one day.

Submission declaration:
Original and unpublished
Array of Saturated Gain Avalanche Diodes (ASGAD) concept for tracking

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The Single Photon Avalanche Diode (SPAD) technology relies on saturated gain, i.e. the complete discharge of the diode, for detecting single charge carriers, electrons or holes, usually produced by single photons. SPADs will detect the carriers produced by charged particles, however the signal may be buried in thermal noise, without the ability to identify one (thermal) carrier from multiple ionization carriers. We introduce the ASGAD concept that overcome this issue, and enable high purity detection of charge particles enabling to achieve the outstanding timing resolution of SPADs, that is expected to be 10ps or better for digital SPADs. In general we will discuss the pros and cons of using saturated gain avalanche diodes associated with integrated digital electronics for tracking. We will also look at how this technology can be used beyond single photon detection for dark matter search and keV scale electron detection.

Submission declaration:
Original and unpublished

An Analog-Digital Hybrid Fine Interpolation TDC with Uncontrolled Delay Lines and Calibration Approaches

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With the development of physics experiments, many detectors utilize the time-to-digital(TDC) to achieve a high-precision Time-of-Arrival(ToA) measurement. An analog-digital hybrid fine interpolation TDC is proposed to achieve high time precision in this paper. The TDC consists of an analog-digital hybrid fine interpolator and a digital module. The analog-digital hybrid fine interpolator is composed of an uncontrolled delay line, switches and source followers. The uncontrolled delay line has a simple structure, finer measurement precision and various methods to calibration. For every incoming hit, the START signal transmits through the delay line. Once the STOP signal arrives, the switch is off and the analog voltage at each delay unit is sampled by the parasitic capacitor. The analog voltage can provide finer time precision. The fine time information is captured by the analog fine interpolation and the digital fine interpolation. A digital module provides the results of encoding, meanwhile controlling the switch to transfer the analog voltage through a source follower to an off-chip flash ADC.

Since the propagation delay of each delay cell is not known and also varies at different temperatures and power supply voltages, some calibration approaches are proposed. By injecting two known time-interval signals, the rising and falling time of the inverter can be estimated, while a calibration lookup table is produced. Meanwhile, an extra inverter adds at the end of the delay line to characterize the transformation of the source follower.
The TDC ASIC features a size of $1300\mu m \times 1200\mu m$ with 29 pads fabricated in a TSMC 0.18$\mu m$ process. The TDC is driven by a 330MHz, that is the fine interpolation is within 3ns. The simulations show the conversion rate is up to 30MHz and the precision is 5ps. The test is undergoing and the results will be reported in the conference.

Submission declaration:
Original and unpublished

Day 3 - Session 3 / 72

The New and Complete Belle II DEPFET Pixel Detector: Commissioning and Previous Operational Experience

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The Belle II experiment at the SuperKEKB collider in Tsukuba, Japan, has collected $e^+e^-$ collision data between 2019 and 2022. After reaching a record-breaking instantaneous luminosity of $4.7 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and recording a dataset corresponding to $424 \text{ fb}^{-1}$, it is currently in its first planned long shutdown phase (LS1) until December 2023. Aside from upgrades of the collider and detector maintenance, the shutdown is used for the installation of the two-layer Pixel Vertex Detector (PXD) which forms the Belle II Vertex Detector (VXD) together with four layers of double-sided silicon strips (SVD). The VXD is essential for precisely reconstructing primary and decay vertices. As the innermost sub-detector, multiple scattering effects need to be reduced. PXD utilizes the depleted P-channel Field Effect Transistor (DEPFET) technology, allowing for a $75 \mu m$-thin sensitive detector area and a low material budget of 0.21% $X_0$ per layer. Each of the tracker’s 40 modules consists of an array of $256 \times 768$ pixels with a pitch ranging from $(50 \times 55) \mu m^2$ for the inner to $(85 \times 55) \mu m^2$ for the outer layer yielding high gain and high signal-to-noise ratio while retaining about 99% hit efficiency. This talk will discuss the experience of the 4-year operation of the previous single-layer PXD in harsh background conditions as well as commissioning and testing of the fully-populated PXD2 during LS1.

Submission declaration:
Original and unpublished

A High-Counting-Rate Readout ASIC for CZT Detectors

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Photon-counting detector computed tomography (PCD-CT) is a promising new technique for CT imaging. Compared to traditional energy-integrating detector CT (EID-CT), PCD-CT allows for more refined image reconstruction and lower radiation doses because it has higher energy resolution.
CdZnTe hybrid pixel detectors are usually used for PCD-CT. To avoid the stacking of signals, the application-specific integrated circuit (ASIC) used in CdZnTe hybrid pixel detectors is needed to feature a high counting rate.

An ASIC named Topmetal-PCD for CdZnTe hybrid pixel detectors have been designed in TSMC 180 BCD process, and consists of a three-side buttable matrix of 20 × 100 pixels with a pitch of 150 \( \mu \)m. Each pixel is composed of an exposed top-most metal, a charge sensitive preamplifier (CSA), a peak detecting and holding circuit, two source followers (SFs), three comparators and three 12-bit counters. The CSA is used to amplify the signal. A two-stage SF is connected after the charge-sensitive preamplifier to reduce the load, improve shaping time, and increase driving capability. The signal of the SF is split into the peak detecting and holding circuit and comparators. The threshold of each comparator can be adjusted by off chip. The output of each comparator is detected and counted by 12-bit counter. The pixel array is read out through a rolling shutter technique with a maximum frame rate of up to 10kfps. The analog front-end has a gain of \( \sim 11 \, \text{mV/ke}^- \) and the chip can deal with a maximum flux of \( \sim 200 \, \text{MHz mm}^-2 \text{s}^-1 \), while single pixel power consumption is as low as 80 \( \mu \)W. In addition, the ASIC has also an analog readout channel that can directly transmit the signal waveform off chip. The ASIC can be used the flip-chip bonding technique to directly connect to the detector for charge collection.

Submission declaration:
Original and unpublished

Day 5 - Session 1 / 74

A Digital Silicon Photomultiplier

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Silicon Photomultipliers (SiPMs) are state-of-the-art photon detectors used in particle physics, medical imaging, and beyond. They are sensitive to even single photons in the optical wavelength regime and achieve time resolutions in the order of 10 ps, which makes them candidates for timing detectors in tracking systems. The Geiger-discharge triggered in the sensitive elements of a SiPM, Single-Photon Avalanche Diodes (SPADs), yields signal amplitudes independent of the energy deposited by a photon or ionizing particle. This intrinsically digital nature of the signal motivates its digitization already on a SPAD level.

A digital SiPM (dSiPM) developed at Deutsches Elektronen Synchrotron (DESY), and produced in a LFoundries 150-nm CMOS technology is presented, introducing embedded CMOS circuitry for on-chip signal processing. Key features of the DESY dSiPM are hit position information on a pixel level, and hit time stamps per quadrant and 3 MHz readout frame. The pixels comprise four SPADs and have a pitch of 70 \( \mu \)m. The four time stamps are provided by 12 bit Time-to-Digital Converters (TDCs) with a resolution below 100 ps.

The chip is investigated in the laboratory to determine dark count rate, breakdown voltage, and TDC characteristics. Test-beam measurements demonstrate synchronous integration in a detector system, spatial hit resolution on a pixel level, and are used to study minimum-ionizing particle detection efficiency and time resolution.

Submission declaration:
Original and unpublished
Day 4 - Session 3 / 75

Performance evaluation of the high-voltage CMOS active pixel sensor AstroPix for gamma-ray space telescopes

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We have been developing the high-voltage CMOS active pixel sensor, AstroPix, mainly for the future gamma-ray space telescope, AMEGO-X. The gamma-ray detector of AMEGO-X consists of four identical stacked silicon tracker towers and requires ~6 × 10^4 cm^2 silicon area. The scientific purpose of the AMEGO-X mission dictates a number of requirements on the performances of the instrument, such as the energy range (25 keV - 1 GeV) and resolution, which affects the design of the detector. AstroPix has to be 500 µm thick and to be fully depleted by supplying bias voltage. Also the energy resolution must be < 10% (FWHM) at 60 keV and the pixel pitch should be 500 × 500 µm^2 in order to achieve the desired angular resolution of the gamma-ray detector. Furthermore, given the space-based nature of AMEGO-X, the power consumption of AstroPix needs to be limited (< 1 mW/cm^2). The first version of AstroPix was developed based on the experience of the developments of both ATLASPix and MuPix. Our development strategy is to incrementally upgrade the chip design towards fulfilling the requirements for AMEGO-X. While the development is under way, the latest version of AstroPix already reached the target pixel pitch. In this contribution, we report about the AstroPix developments and performance, such as I-V, noise, energy calibration/resolution/threshold, depletion depth, and their radiation tolerance.

Submission declaration:
Original and unpublished

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Scintillator’s effect and characterization for ultra-high resolution in digital X-ray flat-panel detectors

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Indirect flat-panel detectors typically use amorphous silicon thin film transistor (TFT) or silicon CMOS (complementary metal oxide semiconductor) matrix arrays combined with scintillation screen for a large X-ray imaging application. Conversion of incoming X-rays into electric signals in flat-panel detector is implemented through a scintillator that emits visible lights under X-ray exposure. Because the visible light is emitted in scintillator isotropically and photodiode array converts it in electric signal, the light spread and attenuation in scintillator grains play an important role for final high image quality.

In this work, different scintillation screens such as granular type Gd2O2S:Tb(GOS) materials with different 50-100um thickness on thin plastic substrates were used to prepare for ultra-high spatial resolution X-ray imaging detectors. The used high resolution CMOS flat panel detector is consisted of photodiode array surface with 1246(width) x 1650(height) pixels and 20μm pixel pitch (theoretical resolution limit: 25 lp/mm).

Their X-ray imaging performance of high resolution CMOS imager in conjunction with different high resolution scintillation screens was investigated in terms of the relative light-output to given X-ray exposure dose, modulation transfer function (MTF) and practical X-ray imaging with a phantom. The ultra-high resolution X-ray imaging could be implemented through the experimental results by using a CMOS imaging detector using different high resolution screens with thin GOS materials. We expect that this technology will open potential for excellent image quality improvement with ultra-high spatial resolution in practical imaging fields.

Submission declaration:
Original and unpublished

Day 4 - Session 2 / 78

Evaluation of the X-ray SOI pixel detector with on-chip ADC

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The monolithic X-ray SOI-CMOS detector “XRPIX” integrates a sensor layer and a CMOS layer by sandwiching an insulating layer made of SiO2 using SOI technology. This detector is planned to be installed in future X-ray satellites. SOI technology allows us to implement complex CMOS readout
circuits. The detection efficiency is high even for X-rays above 10 keV due to the thick depletion layer of several hundred μm. Therefore, by implementing the self-trigger function in pixel circuits, the time resolution of XRPIX is less than 10 μs, which is excellent for observing time-varying celestial objects. In order to achieve a large imaging area in the limited space of the satellite, it is essential that the ADC (analog-to-digital converter) be mounted on the detector (on-chip). We developed XRPIX9 with on-chip ADC and evaluated the performance of the ADC. The XRPIX9 is equipped with 16 units of 14-bit cyclic ADCs to read out 8 columns. And their convert speed is 5.96 μs. Cyclic ADC performs binary search by repeatedly using a common amplifier and comparator for the number of bits, thus enabling high-precision AD conversion in a small footprint. To evaluate the cyclic ADC, at first, external signals were input to the ADCs by connecting with the function generator. We evaluated the integral nonlinearity, differential nonlinearity, and input noise of the ADC, which were found to be 0.06%, 0.5 LSB, and 3 LSB respectively. We also irradiated XRPIX9 with 5.9 keV X-rays from 55Fe, then we successfully obtained X-ray signals via on-chip ADC. In this presentation, we will report these evaluations of the performance of on-chip ADC and their details.

Submission declaration:
Original and unpublished

Topmetal-L: A pixel sensor for charge tracking imaging of LPD

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The Low-Energy Polarization Detector (LPD) represents one of the effective payloads for the Polar-2 mission, characterized by wide field of view and large sensitive area capabilities. The primary objective of the LPD is effectively to measure low-energy X-ray polarization in the gamma-ray bursts. The LPD consists of 81 detector units, each containing a pixel sensor, a gas microchannel plate (GMCP), a detector cavity and an environmental monitoring sensor. The pixel sensor is responsible for collecting and processing charges amplified by GMCP for imaging. In the space, the X-ray radiation from gamma-ray bursts undergoes rapid fluctuations within a short period, while energy resources are limited and there is significant heat dissipation pressure. Hence, the pixel sensors are needed to possess the features of large arrays, high spatial resolution, high energy resolution, and fast readout capabilities at the low power consumption. A pixel sensor named Topmetal-L is an optimized large-area pixel sensor designed for space applications, with a chip size of 16.9mm × 24.0mm and consisting of 356 rows × 512 columns, with a pixel pitch of 45μm. The pixel circuit includes a low-power, low-noise folded cascode amplifier to achieve a high signal-to-noise ratio for energy information. It also features a feedback structure with a 1fF capacitor and an NMOS in parallel to provide amplification and adjustable decay time. Furthermore, a two-stage source follower readout structure is employed to minimize readout crosstalk. The gain of the pixel readout channel is 122mV/ke-, and the ENC is 20.0e-@1ke-. Total chip power consumption is 820mW. A checkpoint readout method for pixel array has been proposed to address polarization detection issues. This method improves readout speed while reducing power consumption, with
the speed enhancement and power savings depending on the scanning interval. The GDS file of Topmetal-L has been submitted for fabricating in July 2023.

Submission declaration:
Original and unpublished

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A 4.4-Gbps Serializer ASIC in 180 nm for NICA-MPD Detector

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The inner tracker of the Multi-Purpose Detector (MPD) at Nuclotron-based Ion Collider fAcility (NICA) is responsible for detecting charmed particles with average decay lengths (λ) of several hundred micrometers. Monolithic active pixel sensors are adopted in the inner tracker. A high speed serializer presented in this paper is used to convert the parallel data from the front-end of the pixel sensor chip into serial data and transmit off chip.

The serializer consists of a multiphase clock generator, ten Low-Voltage Differential Signaling (LVDS) data receivers (RXs), two multi-phase structure 5:1 multiplexers, a tree-structure 2:1 multiplexer, a high-speed clock receiver, a clock divider by 5, a duty cycle correction (DCC) circuit, a Current Mode Logic (CML) driver, and a PRBS self-test source. The 5:1 multiplexer adopts the multiphase structure to reduce the power consumption. To ensure the synchronization between the external data inputs and the internal clock, ten D flip-flops (DFFs) are used to latch the external input data. A multiphase clock generator is designed to provide high phase accuracy clocks for the 5:1 multiplexers. In 2:1 multiplexers, the tree structure is adopted to reduce the power consumption. Additionally, the DCC circuit is employed in the clock paths of the 2:1 multiplexers to ensure the correct duty cycle.

A test chip of the serializer has been manufactured and the chip has been fully tested. During the test, 10-channel parallel data with a data rate of 425Mbps is injected into the chip. The test results show that the output data rate is 4.25Gbps. The measured power consumption is 31 mA with 1.8 V power supply including the RX and CML driver. The measured total jitter is 49.37ps at a bit error rate BER of < 1 × 10−12, and the output amplitude is differential peak to peak of 600mV.

Submission declaration:
Original and unpublished

Day 2 - Session 3 / 82

Development of high-time-resolution ASICs in CMOS 28-nm technology dedicated to precision 4D-tracking
Following up and finalizing the developments of former RnD projects and studies (INFN-funded TimeSPOT, Falaphel, Scaltech28 projects), The IGNITE project plans to implement an integrated system module, comprising sensor, electronics, and fast readout, specifically aimed at 4D-tracking. System pixels are required to have pitch around 50 µm and time resolution below 30 ps. In this paper we present recent advancements on the development of a prototype ASIC, designed in CMOS 28-nm technology, which explores several circuital solutions on the front-end side. The Ignite_0 development is preparatory to the design of the first IGNITE full-ASIC, featuring a 64x64 pixel matrix, being completed in the future months.

The Ignite_0 has been submitted as a mini-ASIC containing new versions of a former 4D pixel design (the Timespot1 ASIC), consisting of an Analog Front End (AFE) and a high-resolution Time-to-Digital-Converter.

The TimeSPOT-type AFE is a Charge Sensitive Amplifier with Krummenacher feedback and discrete-time Offset Compensation. Some imperfections, present in the TimeSPOT 32x32 matrix version, are here corrected. New ideas on the AFE input stage and feedback circuit, aimed at obtaining a faster response and optimizing system performance in terms of time resolution and power, are here explored as well.

The TimeSPOT TDC, based on a Vernier-type architecture, has several improvements in terms of operational and SEU robustness. Furthermore, the front-end pixel size has been changed to make it compatible with the read-out of pixels from 55 µm (TimeSPOT) to 45 µm, by modifying only a redistribution layer (upper metal) according to the specific pitch adopted.

The Ignite_0 ASIC integrates additional important service circuits, and in particular DACs and PLLS, to test them on silicon before their integration on the 64x64 pixel matrix, which is presently ongoing. The explored solutions will be critically illustrated during the talk, highlighting their pro and cons.

Submission declaration:
Original and unpublished
Monolithic active pixel sensors featuring depleted substrates (DMAPS) present a promising alternative for pixel tracker detectors operating in high-radiation and high-rate environments. The utilization of highly resistive silicon substrates and high-voltage capabilities within commercial CMOS technologies holds the potential to significantly enhance radiation tolerance with respect to MAPS. TJ-Monopix2 and LF-Monopix2 chips are the most recent large-scale prototype chips in their respective development lines with a column-drain readout architecture.

Designed in 150 nm LFoudry technology, LF-Monopix2 uses a large charge collection electrode with pixel electronics embedded in it. Benefits of this design are short drift paths and a homogeneous electric field across the sensor that increase the radiation tolerance. Optimization of the pixel layout minimizes potential coupling from the digital circuitry into the sensor node while reducing the pixel size to 50 x 150 µm² compared to its predecessor.

TJ-Monopix2 is designed in 180 nm Tower Semiconductor technology. Featuring a small charge collection electrode design with separate readout electronics, the pixel pitch of this sensor could be reduced to 33 x 33 µm². A small detector capacitance allows for a large signal-to-noise ratio while an additional n-type layer across the pixel ensures full depletion of the sensitive volume.

In this talk, the latest test beam results of both DMAPS are presented. Timing studies and charge collection measurements of TJ-Monopix2 are highlighted. Performance of irradiated LF-Monopix2 chips after a fluence of up to 2e15 neq/cm² is shown.

Submission declaration:
Original and unpublished

Contrast Agent Estimation Result of 2-dimensional Photon Counting CT Detector which Combined MPPC and YGAY-scintillator Array

Author: fitri lucyana

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The great potential of photon-counting (PC) detectors in medical CT imaging is highly supported by their ability to count individual photons and measure their energy simultaneously, which makes it possible to obtain specific multi-energy imaging. It is appropriate with the use of contrast agents for medical CT imaging diagnostic, which has specific energy for each contrast agent. The development of PC CT which combined the multipixel photon counter (MPPC) and the yttrium-gadolinium-aluminum gallium garnet (YGAG) scintillator array was improved from 1-dimensional to 2-dimensional detector to shorten the imaging time, which will reduce the radiation exposure as an important factor for medical imaging. The 2D PCCT uses a 256-channel pixel array (with 1 × 1 mm for each pixel size) in the form of 16 × 16 channels, with four large-scale integrated circuit boards, each processing 64-channel signals. The initial CT imaging experimental setup is to estimate the contrast agent using 100 keV and 0.1 mA X-ray generator tube voltage and current respectively and using 11.6 mm and 32 mm of each diameter and high of the Gadolinium (Gd) contrast agent sample. We obtained CT image data with 6 different energy thresholds at 27-33 keV, 33-50 keV, 50-65 keV, 65-80 keV, 80-90 keV, and 90-100 keV. We applied the filtered back projection algorithm to reconstruct the CT images for every row (the horizontal 16-channel array). We successfully obtained the contrast agent estimation by 3D CT image of the 5mg/mL and 10 mg/mL Gd contrast agents. The initial qualitative concentration estimation was obtained by comparing the CT value data results with the ideal CT value of NIST data. The estimation result is 10.43 ± 1.55 mg/mL and 5.47 ± 1.62 mg/mL respectively for 10 mg/mL and 5 mg/mL Gd contrast agents. We will briefly report the result of the detailed quantitative evaluation.

Submission declaration:
Original and unpublished

Study of double-sided silicon pixel ladders with low material budget

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Double-sided silicon pixel ladders have been designed and developed as one of the vertex detector prototype concepts for the Circular Electron-Positron Collider (CEPC). With the primary goal to research the properties of Higgs particles, the vertex detector of the CEPC must be thin enough and have high position measurement accuracy to identify heavy flavor quarks and tau leptons efficiently. Two layers of pixel chips are precisely glued to both sides of the same supporting structure, thereby efficiently minimizing the material budget. Each double-sided ladder consists of two layers of MAPS chips thinned to 50 μm, two flex cables, and a 1.8 mm thick carbon fiber support. The material budget of the double-sided ladder is about 0.24% X₀/ sensitive layer, representing a reduction of approximately 35% compared to the previous single-sided ladder.
To validate the design and study the performance of the double-sided ladder in terms of spatial resolution and detection efficiency, a beam test system was set up and tested with electron beam at Institute of High Energy Physics. The test system comprises four single-sided ladders devised as a beam telescope to provide reference tracks, with a double-sided ladder positioned at the center of this telescope, serving as the device under test (DUT). The test results show that at an electron energy of approximately 1.3 GeV, the measurement residual of each layer of the double-sided ladder is about 6.9 μm. The detection efficiency is above 99.5%, and the fake-hit rate is less than 10⁻⁶. Two
hits from two layers of the double-sided ladder can be used to construct a mini-vector with a better resolution about 5.0\,\mu\text{m}. Considering the big beam energy spread and the effects of multiple Coulomb scattering due to low energy, the test results are reasonable and validate the technological process of the double-sided ladder.

**Submission declaration:**

Original and unpublished

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**Radiation tolerance tests and performance verification of pnCCD at high temperature for future satellite mission HiZ-GUNDAM**

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Gamma-ray bursts (GRBs) are the most luminous explosion in the universe, where an equivalent energy of almost a solar mass is convert into X-rays and gamma rays in milliseconds to minutes. HiZ-GUNDAM is a satellite for observation of early universe via GRBs, currently under development. This satellite features wide-field X-ray monitors with Lobster-Eye Optics and X-ray pixel detectors. This monitor has high sensitivity to the X-ray with an energy range of 0.4–4 keV, thus it can detect very distant GRBs in the early universe. A pnCCD, which is a type of back-illuminated X-ray CCD, has an effective imaging area of 5.5 cm×5.5 cm, manufactured by PNSensor, will be positioned on the focal plane of the X-ray monitor. For the basic investigation of the characteristic and performance of the pnCCD, the sensor with 128×256 pixels, pixel size of 75 µm, and Si thickness of 450 µm was selected. High-energy cosmic rays degrade pnCCD’s performance, increasing dark current and CTI (Charge Transfer Inefficiency) due to ionizing and displacement damage. These factors might affect observations, causing lower-detectable energy thresholds to degrade and number of hot pixels to increase. Furthermore, the pnCCD in HiZ-GUNDAM will be operated at temperatures range of -20 to 20 ℃, which is higher than the typical use at -100 ℃ in other satellite missions such as XMM-Newton and eROSITA. Therefore, we conducted a radiation tolerance test at room temperature using proton beams, of which energy was tuned at 10 MeV such that the proximal end of the Bragg peak lies within the pnCCD with Si thickness of 450 µm. After irradiation protons equivalent to three years of nominal operation for HiZ-GUNDAM, the dark current increased from 0.03 to 9.3 pA/pixel. In our presentation, we will present the details regarding the dark current, CTI, and spectral performance.

**Submission declaration:**

Original and unpublished
Day 3 - Session 3 / 87

From particles to timed tracks - The next generation of hard and software for test beams

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Test Beam characterisation is the gold standard test to prove novel detector concepts based on precisely reconstructed and time-tagged particle trajectories. This is done by beam-telescopes that are expected to have high spatial and good temporal resolution. Telescopes data needs to be synchronised with various readout types: Triggered readout architectures, data-driven approaches and devices with fixed shutter intervals. This flexibility is realised with a trigger logic unit (TLU) providing a common clock, trigger and trigger IDs. Steering of the TLU and beam telescopes can be provided in the EUDAQ2 DAQ framework. Upgrades of the telescope are currently being developed based on the successful existing systems, to cope with increasing rate and precision requirements. An additional region of interest triggers with a time resolution of a few nanoseconds and LGADS as high precision timing layers with a resolution below 100ps are being commissioned.

To reconstruct the data recorded at test beams, the Corryvreckan framework has been developed and is provided to users. It is an open source project, allowing for flexible event building supporting all kinds of readout modes of new prototypes. It can natively read in data recorded with EUDAQ2 and hence telescope and TLU data from the DESY II test beams. Additionally Corryvreckan features modules for clustering in space and time, basic correlations, track reconstruction, detector alignment and device under test efficiency study.

The contributions aims to introduce the current status and upgrade projects of the DESY infrastructure to motivate the need for flexible reconstruction frameworks. Afterwards the Corryvreckan framework will be presented with an emphasis on the event building, track reconstruction and alignment capabilities. Finally selected characterisation results of timing layer upgrades for the telescopes are presented to showcase the capabilities of Corryvreckan and an outlook towards future improvements of the facilities and software framework will be given.

Submission declaration:
Original and unpublished

Day 3 - Session 1 / 88

Probing of radiation damage with light-emitting quantum defects in Silicon

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Irradiating a semiconductor with energetic particles gives rise to structural damage and defect formation via nonionizing energy loss processes. The build-up of stable radiation damage often proceeds via complex dynamic annealing processes, involving point-defect migration and interaction. This also occurs during the ion-implantation for electronic device fabrication and resulting defect structures depend on the density of collision cascades and the ion-beam flux. On the other hand, radiation-induced light-emitting defects, such as carbon-based defect complex of the G-center in silicon, have been regarded as promising quantum light sources for applications e.g. in quantum networking. However, the formation dynamics of these G-centers and the correlation between their optical linewidth broadening and atomic radiation disorder have rarely been studied. Here, we report on our study of the formation dynamics of G-centers in silicon for a series of proton beam flux conditions [1]. We compare the G-center optical properties characterized by time-resolved photoluminescence and observe a dose-rate effect on G center formation efficiency and optical line width. Furthermore, we perform ab initio electronic structure calculations, which provide insight into the atomic disorder induced inhomogeneous broadening by introducing vacancies, Si interstitials, and oriented strain fields in the vicinity of a G center. Our results can guide directions for the efficient formation of G centers for quantum applications. Moreover, our results indicate that the optical signal from G-centers enables atomic scale sensing and characterization of radiation damage resulting from ultradilute low-fluence irradiation, e.g., expanding capabilities for dark-matter searches.

References:

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Day 3 - Session 2 / 89

Curing early breakdown in silicon strip sensors with radiation

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In preparation for the forthcoming High-Luminosity phase of the Large Hadron Collider, the ATLAS experiment is working on major upgrades to its detector systems to effectively accommodate the increase in radiation levels and track density. The foremost among these upgrades entails the replacement of the current inner tracking detector with an advanced all-silicon Inner Tracker (ITk). In the outer region of the ITk apparatus is the Strip Detector.

Central to the new strip tracking system are the ITk Strip modules, comprising silicon sensors and hybrid Printed Circuit Boards housing the integral read-out Application-Specific Integrated Circuits (ASICs) as well as power distribution services. Thorough characterization of the electrical characteristics of the silicon strip modules at various stages of the assembly procedure holds paramount significance in evaluating module performance. This rigorous evaluation ensures timely identification of any anomalies, thereby enabling proactive remedial measures. Notably, during the course of these electrical assessments, certain modules manifested breakdown phenomena occurring below the prescribed threshold of 500 V, as mandated by the ITk Quality Control protocols.

Based on these observations, controlled exposure to low levels of radiation was suspected to elevate the breakdown voltage in susceptible sensors. This contribution presents results from two irradiation campaigns to investigate potentially beneficial effects of irradiation. One study investigates the effects of gamma irradiation on complete modules showing an early breakdown due to glue spreading over the sensor guard ring. For this study, modules were exposed to an ionizing dose of 11 krad (corresponding to the dose accumulated after several days of operation in the HL-LHC) utilizing a 60Co source. The second campaign focuses on silicon sensor test structures with low breakdown voltage due to intentionally caused mechanical defects and their development after exposure to reactor neutrons. In both cases, preliminary findings suggest a discernible improvement in the breakdown voltage.

Submission declaration:
Original and unpublished

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Single event effect in ATLAS ITk Strip readout chips

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The ATLAS experiment will build an all-silicon tracker in the Phase II upgrade for the High Luminosity LHC (HL-LHC) at CERN. For the silicon strip detector of the Inner Tracker (ITk), a new readout system has been designed to cope with the increased occupancies and harsher radiation environment. This readout system is comprised of the ABCStar (ATLAS Binary Chip), the analog front-end chip, and the HCCStar (Hybrid Controller Chip), the active interface chip between the ABCStars on the hybrid and the off-detector electronics. ABCStar ASIC is fabricated using 130 nm CMOS technology to read out signals from 256 sensor strips through binary readout channels. HCCStar ASIC is the digital interface for the ITk Strips hybrids, both in the endcap and in the barrel, they operate together to perform detector readout and control, up to 11 ABCStars are connected to a single HCCStar. The injection of high-energy particles into the chip will cause single event effects (SEEs) such as bit flips of electronic devices. Special considerations have been made in the design to reduce digital state changes and ensure reliable operation, we tested the effectiveness of the protection by running separate chips inside the proton beam, and layout is that all chips concurrently fit into a 20 mm beam spot. This report will introduce the study of the SEE effects of ABCStar V1 and HCCStar V1 with a single-chip test system at the proton beam platform of the China Spallation Neutron Source (CSNS). The study of SEE in registers and data transfer is carried out under different energies (80MeV, 60MeV, 40MeV, 20MeV). Relative to ABCStar V0 chip, bit flips in the ABCStar V1 significantly reduced as expected, the total ionizing dose effect is monitored as well during the experiment.
Day 4 - Session 2 / 91

Performance Evaluation of Event-Driven SOI Pixel Detector ”XR-PIX8.5” for Cosmic MeV Gamma-ray Observation

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Submission declaration:
Original and unpublished

Cosmic MeV gamma-ray observations are important for understanding physics in high-energy astronomical objects such as gamma-ray bursts and blazars. However, there has been no progress since COMPTEL on board the Compton Gamma Ray Observatory in the 1990s, thus a new satellite for MeV gamma-ray observations is needed. Compton scattering is the dominant interaction between MeV gamma-rays and matter. The minimal way to reconstruct the arrival direction of an incident gamma-ray is to utilize both the deposit energy and hit position measured in both the scatterer and absorber, giving an event circle. In order to improve the angular resolution, one can measure the track of the Compton-scattered electron with a pixel sensor and utilize the estimated initial momentum of the electron to reduce the circle to an arc. We have been evaluating an event-driven Silicon-on-Insulator (SOI) pixel detector XRPIX8.5 as a scatterer for future MeV gamma-ray telescopes. XRPIX is a detector that incorporates both a thick depletion layer and high-speed, low-noise CMOS pixel circuits simultaneously by utilizing SOI technology and issues trigger and coordinate information immediately after detecting signal. The pixel size of XRPIX8.5 is 36 um square and thus it is expected to measure electron tracks for gamma rays with the energy of several hundred keV since, for instance, an electron with the energy of 300 keV creates a track of ~500 um in silicon. In this contribution, we report on the evaluation of the depletion layer thickness of XRPIX8.5, which can be fully depleted at room temperature, the sensor response when irradiated with gamma-rays such as 662 keV of Cs-137 and 511 keV of Na-22, and a method for estimating the initial direction of electron track.

Submission declaration:
Original and unpublished

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Alpha-Particle Imaging SiPM Array Sensor with High-Resolution Technique

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For a more precise evaluation of the alpha-particle emitting radiopharmaceuticals, images with a high spatial resolution are required. In this study, we propose an alpha-particle imaging SiPM Array Sensor in conjunction with a high-resolution technique. A high-resolution image is recovered using the four images obtained by moving the device along the x- and y-directions. This method uses several low-resolution images acquired by slightly shifting the alpha imaging detector. A high-resolution image is then reconstructed using the MLEM algorithm in conjunction with the measured low-resolution images and the system matrix containing the mechanical shifts, sub-sampling, and measured point spread function of the imaging system. The results show that, using the device with a pre-defined pixel resolution, the proposed technique produces the images of alpha-particles with an improved resolution of approximately 14%. We conclude that the proposed technique has potential in the development of radiopharmaceuticals for targeted alpha therapy.

Submission declaration:
Original and unpublished

Day 1 - Session 2 / 98

Operational Experience and Performance with the ATLAS Pixel detector at the Large Hadron Collider at CERN

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The tracking performance of the ATLAS detector relies critically on its 4-layer Pixel Detector. As the closest detector component to the interaction point, this detector is subjected to a significant amount of radiation over its lifetime. At present (in 2023 LHC proton-proton collision RUN3) ATLAS Pixel Detector on innermost layers, consisting of planar and 3D pixel sensors, operate after integrating fluence of $O(10^{15})$ $1$ MeV n-eq cm$^{-2}$.

The ATLAS collaboration is continually evaluating the impact of radiation on the Pixel Detector. In this talk the key status and performance metrics of the ATLAS Pixel Detector are summarised, putting focus on performance and operating conditions with special emphasis to radiation damage: charge collection in data and modelling with radiation damage simulation; 3D sensors performance and comparison with planar sensors vs fluence; operational issues at high rate and mitigation techniques adopted for LHC Run3.

Submission declaration:
Original and unpublished

Day 5 - Session 2 / 99

MARTHA - Monolithic Array of Reach TThrough Avalanche photo diodes

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We propose a novel APD array showing near 100% fill factor. The APDs operate in proportional mode at low or moderate gain and exhibit very high detection efficiency also in inter pixel gap regions. By applying a fully depleted reach-through structure light entrance side and electronics side are kept separated. In contrast to common APD arrays the avalanche process is sustained in the inter pixel gap regions as well. A non structured boron doped multiplication region (MR) extends over the entire array. Parasitic early breakdown at the n+ pixel edges is caused by electric field peaks near to convex doping shapes. In our approach it is suppressed by a n-doped layer, called field drop region (FDR), located directly beneath the n+ pixels. The positive space charge of this fully depleted layer causes a reduction of the electric field to a non-critical level when it reachs the n+ edges. The FDR gets depleted by the negative MR space charge preventing pixel shortage. We started a first prototyping on 450µm thick p-type float zone. Measures for excess noise reduction are implemented to optimize the sensor for photon science applications. For MR a high energy implantation was chosen. The peak concentration is in a depth of about 6µm. Due to the wider MR a lower electric field is required to achieve the same gain. Lower electric field results in a smaller k value (hole/electron ionization rate) and lower excess noise. Since MR and FDR implantations are lithographically confined to the area of the APD array a classical multi guard rings can be used for edge termination. The prototype design contains small pixel and strip arrays for eta-plot measurements. We will present a detailed description of the operating principles and plan to compare first measurements with simulations.

**Submission declaration:**

Original and unpublished

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**102**

**Design of a Pixel Detector Readout Scheme with Controllable Delay Chain for Enhanced Positioning Accuracy**

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Pixel detectors play a crucial role in various fields such as optical imaging and particle physics experiments. However, traditional pixel detectors face limitations in their electronic readout systems, including resolution and response speed. To address these challenges, we propose a novel readout scheme incorporating a controllable delay chain within each individual pixel. This scheme allows for simultaneous transmission of the pulse generated by particle impact to both the top and bottom of the pixel array, by propagating the particle signal in multiple directions. The differences in transmission path length are then exploited to accurately determine the particle’s position. By controlling the delay time of the delay unit within each pixel, our design accommodates variations in delay magnitude. This flexibility enables the extraction of precise position information based on the differences in delay among multiple transmission directions. The circuitry within each pixel primarily comprises a low-noise charge-sensitive amplifier, comparator unit, and controllable delay unit for establishing energy reconstruction signals. Our proposed scheme incorporates two readout configurations. The first configuration employs two transmission delay chains, enabling signal transmission in both forward and backward directions after a particle hit. The second configuration utilizes four transmission delay chains, facilitating signal transmission in four directions: up, down, left, and right.
For evaluation, we designed a prototype chip using TSMC 180-nanometer technology, featuring a pixel array size of 10 rows by 20 columns, with a chip area of 2.83mm x 3.81cm. Test results demonstrate that the delay unit accuracy of a single pixel is 3.12ps, with a controllable delay range of 4.976ns to 29.76ns distributed among six levels. The achieved pixel timing resolution is 44.12ps. Moreover, we verified the robustness of the input delay chain circuit under various PVT (process, voltage, and temperature) conditions, highlighting the stable performance of our design.

Submission declaration:
Original and unpublished

Development of two-dimensional neutron imager with a sandwich configuration

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It is known that neutrons can be measured with a high spatial resolution of several microns by combining a charged particle conversion layer and a semiconductor pixel sensor [1]. Its spatial resolution is limited by an electrical noise and the flight range of secondary particles within the sensor volume from the conversion layer.

In order to reduce the effect of secondary particle flight distance, we have developed a device with a new configuration in which a conversion layer is sandwiched between active sensors and two emitted particles are simultaneously measured. We are considering using the new configuration for verification experiments of the equivalence principle in a microscopic scheme. In this presentation, we report the results of the first simultaneous measurement.


Submission declaration:
Original and unpublished

Improving MVCT Image Quality for Quantitative Analysis of Inter-fractional Organ Motion in Prostate Cancer Radiotherapy
Image-guided radiation therapy (IGRT) is important for minimizing daily uncertainties in patient setup when delivering radiation doses to the target volume and adjacent organs at risk (OAR). In intensity-modulated radiation therapy (IMRT), the analysis of megavoltage computed tomography (MVCT) allows for the evaluation of inter-fractional motion, which refers to the movement and changes of organs between radiation treatment sessions. However, poor MVCT image quality can make it difficult to delineate organs and cause inter-observer variability, resulting in inaccurate tracking of changes over time.

This study proposes a tracking and observation framework to quantitatively analyze inter-fractional organ movements in prostate cancer patients using a deep learning-based MVCT image quality improvement method. In this study, we collected datasets of planning kVCT and MVCT images from prostate cancer patients who underwent helical tomotherapy. The proposed technique aims to improve the quality of MVCT images by reducing noise and enhancing contrast using a generative adversarial network. Then, the contours of the major organs considered for prostate cancer treatment, including the bladder, prostate, and rectal balloon, are delineated on daily MVCT images. Using this framework, it is possible to quantitatively evaluate the changes in prostate position according to the changes in rectal balloon position and bladder volume, thereby increasing the accuracy of treatment planning and the efficiency of radiation dose delivery. Ultimately, this framework can enhance the tracking and observation of treatment effects and side effects.

**Submission declaration:**
Original and unpublished

**Day 2 - Session 4 / 105**

**PIONEER: conceptual design and testbeam studies of the next-generation rare pion decays experiment**

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PIioneer is a next-generation experiment proposed at the Paul Scherrer Institute to perform high precision measurements of rare pion decays. By improving the precision by an order of magnitude on the charged-pion branching ratio to electrons vs. muons and the pion beta decay, PIONEER will provide a pristine test of Lepton Flavour Universality and the Cabibbo angle anomaly. At the centre of the experiment, a high-granularity active target (ATAR) will stop the pion and characterise its decay. The ATAR is being designed to provide detailed 5D tracking information, allowing the separation of the energy deposits of the pion decay products in both position and time. The chosen technology is Low Gain Avalanche Detectors (LGAD). These are thin silicon detectors with moderate internal signal amplification. Several types of LGADs still under development are being evaluated to achieve a ~100% active region, such as AC-coupled LGADs (AC-LGADs) and Trench Insulated LGADs (TI-LGADs). Since a range of deposited charge from Minimum Ionizing Particle (MIP, few 10s of KeV) from positrons to several MeV from the stopping pions/muons is expected, the detection and separation of close-by hits in such a wide dynamic range will be the main challenge.
Using the CENPA Tandem accelerator at the University of Washington, we studied the LGADs response of MeV-range deposits from a proton beam. This contribution will introduce the PIONEER experiment conceptual design and its physics case. The results of the test-beam study will also be presented.

Submission declaration:
Original and unpublished

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Large-area X-ray polarization detector detection unit prototype

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The Low-energy X-ray Polarization Detector (LPD) is a large-area and wide-field X-ray polarimeter planned to be installed on the Chinese Space Station. The LPD is used to measure the polarization of the gamma burst itself and its very early X-ray afterglow, and to carry out studies of the celestial body and radiation mechanisms at the center of the gamma burst. The LPD consists of 15 detection units with the same structure and function. We designed a detection unit prototype with six pixel detectors compactly placed on the front-end electronics board with an effective detection area of $27.36 \text{ cm}^2$. A single pixel detector has 16 analog output channels, and the detector data is amplified, digitized, and transferred via the board-to-board connector to the back-end electronics board for processing. The prototype also has an internal high voltage circuit board dedicated to providing high voltages up to -4 kV. The test results show that the detection unit prototype can read out 96 channels of pixel detector data simultaneously, provide configurable data compression, storage and encoding, and meet all the functional requirements of the detection unit.

Submission declaration:
Original and unpublished

Day 3 - Session 3 / 107

ABCStar, the ATLAS ITk Strip Analog Front-End ASIC Production

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The ATLAS experiment at CERN will replace its tracker with an all-silicon tracker during the Phase II upgrade for the High Luminosity LHC. The tracker is comprised of a pixel-based detector at lower radius and a strip-based detector at higher radius. The application specific integrated circuits (ASICs) for the strip tracker are nearing the end of their production. The analog front-end ASIC for the strip detector is the ABCStar. The ABCStar consists of the analog front-end, the first level trigger latency buffer and event buffer and digital readout circuitry. The production process will be discussed as well as a significant issue that was discovered during production and the mitigations applied.

Submission declaration:
Original and unpublished

A high-speed low-noise front-end ASIC prototype for high-intensity ionization chamber

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A novel ionization chamber measures the position and arrival time of each ion for the high intensity beam detection. The biggest challenge of the ionization chamber is to design a high-speed low-noise charge readout chip in which the charge collection electrodes and the readout electronics are integrated into a same silicon chip in a standard CMOS process. A high-speed low-noise front-end readout ASIC prototype is presented in this paper. The ASIC prototype is composed of a charge collection electrode, a Charge Sensitive Amplifier (CSA), a discriminator and buffers. The charge collection electrode is an exposed top-most metal with a size of 996 $\mu$m $\times$ 85 $\mu$m, named Topmetal, and surrounded by the same metal layer, named Guardring. The Guardring is to form focusing electronic field to improve the charge collection efficiency in the normal operating mode and to inject the signal in test operating mode. The Topmetal is directly coupled to the CSA. The CSA can be set in different gain modes through three-bit switches to change the value of the feedback capacitor. The output of the CSA is split into two branches. One is connected to a two-stage source follower to transmit the analog signal off-chip. The other is AC coupled to the discriminator. The threshold of the discriminator can be adjusted off-chip and the output signal can be transmitted off-chip by a buffer. The ASIC prototype has been manufactured in a 180 nm process and come back to the lab. The test results show that the charge conversion gains of different modes are 324.8 mV/fC, 98.63 mV/fC and 40.58 mV/fC. The input equivalent charge noise is about 30 e-. The linear input charge range is about 9.6 fC with a linearity of less than 3.4%. The shaping time of the CSA can be less than 1 $\mu$s.

Submission declaration:
Original and unpublished

Performance of CMOS pixel detector IU233N5-Z damaged with 200 MeV proton beam

Author: Hiromitsu Takahashi\textsuperscript{None}
CMOS pixel detectors have a fine pixel size of 1-10 \( \mu m \) and are planned to use in X-ray astrophysical observations. \( \sim \)100 MeV protons inside South Atlantic anomaly dominate the radiation damages for the detectors onboard satellites. We irradiated 10 Gy of 200 MeV protons (\( \sim 1.6 \times 10^{10} \) /cm\(^{-2} \)) to the CMOS detector IU233N5-Z, which is an optical sensor but also has X-ray sensitivity. Although the number of hot pixels was increased, we still observed line features of \( ^{241} \text{Am} \) source. We will present the performance comparison before/after the proton irradiation.

**Submission declaration:**
Original and unpublished

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**Hi Beam-SEE: a silicon pixel sensor-based beam monitor for heavy-ion experimental terminals**

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Noninterceptive and high-accuracy beam monitors are critical for the experimental terminals at the high-intensity heavy-ion accelerator facility (HIAF) complex. The Hi Beam-SEE, a silicon pixel sensor-based beam monitor, has been designed to measure the track of every single particle. The Hi Beam-SEE consists of the detectors and the readout system. When the charged particle passes through the detector field, it will ionize the gas along its track. In the presence of the electric field, the ionized electrons drift to the position-sensitive anode (PSA), on which the silicon pixel sensor is placed. The projection of the track can then be reconstructed with the charge collected by the silicon pixel sensor.

The Topmetal-M silicon pixel sensors are used in the Hi Beam-SEE. The Topmetal-M is a large area pixel sensor (18 mm × 23 mm) prototype fabricated in a new 130 nm high-resistivity CMOS process, and it contains 400 rows × 512 columns square pixels with a pitch of 40\( \mu \)m. Part of each pixel’s top metal layer is exposed to sense the drifting charge; thus, it can directly collect the charge in the gas. The in-pixel circuit mainly consists of a low-noise charge-sensitive amplifier to establish the signal for the energy reconstruction and a discriminator with a Time-to-Amplitude Converter (TAC) for the Time of Arrival (TOA) measurement.

A beam test of the Hi Beam-SEE has been carried out with \(^{209} \text{Bi}^{36+}\) with the energy of \( \sim 10.32 \text{MeV/u} \), and an excellent spatial resolution of \( \sim 12.77 \mu \text{m} \) has been achieved.

**Submission declaration:**
Original and unpublished
Design and Preliminary Characterization of a High-Speed Front-End Readout ASIC for CdZnTe Detectors

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Nuclear radiation detection is an important technique for various fields such as medical imaging, homeland security, and space science. CdZnTe is a suitable semiconductor material for room-temperature nuclear radiation detection, which can directly convert X-ray or gamma-ray into charge signal, with high energy resolution and efficiency. However, it is limited by the hole tailing effect and charge trapping effect, which degrade its energy resolution and stability. To solve these problems, a high-speed front-end readout ASIC for CdZnTe detectors is proposed. The ASIC consists of a charge-sensitive amplifier (CSA), source-followers, a peak-hold circuit, and a comparator. The CdZnTe is AC coupling to the ASIC, avoiding the influence of semiconductor dark current on the circuit. The CSA converts the charge signal from the detector into a voltage signal, and uses a fast shaping technique to reduce the influence of hole tailing effect on the signal amplitude and shape. The output of the CSA is split into the source follower, the peak-hold circuit, and the comparator. The source-follower acts as an intermediate stage, reducing the load pressure of the CSA and ensuring high bandwidth. The peak-hold circuit directly obtains the energy information of the signal, and uses dynamic threshold technique to reduce the influence of charge trapping effect on the signal energy resolution and stability. The comparator compares the output signal of the CSA with a dynamic threshold and generates a digital pulse, which can be used for fast particle counting.

The front-end ASIC has been manufactured in a 180nm CMOS process. The chip size is 1.2mm×1.1mm. Test results show that the counting rate can be up to 5×10^6 counts/s with a power consumption of about 10mW and a noise of 762e-. A CdZnTe crystal has been coupled with the ASIC for detecting gamma-ray irradiation. The test is ongoing.

Submission declaration:
Original and unpublished
presents the design and test results of a 10Gbps high-speed optical receiver ASIC for applications in high-energy physics experiments. This ASIC uses a pseudo-differential inverter-based TIA structure for low noise consideration, adopts a double-threshold controlled automatic gain controllers (AGC) structure to achieve wide-range gain control. A shared-inductor peaking technique is proposed to achieve high bandwidth with efficient area consumption.

This optical receiver ASIC mainly consists of TIA sub-module, limiting amplifiers (LA) sub-module, AGC sub-module, DC offset cancellation circuits (DCOC), received signal strength indicator (RSSI), and output drive stage. The TIA adopts a pseudo-differential structure based on the inverter structure to convert the high-speed small photocurrent from the Photo-Diode into an amplified voltage signal. The limiting amplifier further amplifies the voltage signal with the shared-inductor peaking technology to improve the bandwidth. Dual-threshold AGC enables continuously adjustable gain with a wide adjustable range and low power consumption. The output drive stage circuit adopts continuous time linear equalizer (CTLE) peaking structure with 50 ohm output impedance matching.

The post-layout simulation results show that this optical receiver ASIC has a transimpedance gain of 77dB with a 12 GHz bandwidth, and an equivalent input noise current of 1.99uA. The whole power consumption is 84mW when working at 10 Gbps, and a sensitivity 40 uA of -16.32dBm @BER 1E-12. The ASIC has been taped out in the end of 2022 and will be tested in September 2023. The optical eye-diagram test, optical sensitive test and the full link BER test will be conducted, the test results will be presented in the meeting.

Submission declaration:
Original and unpublished

Day 1 - Session 1 / 113

Early performance of the tracking detector for the FASER experiment

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FASER is a new experiment designed to search for new light weakly-interacting long-lived particles (LLPs) and study high-energy neutrino interactions in the very forward region of the LHC collisions at CERN. The experimental apparatus is situated 480 m downstream of the ATLAS interaction-point aligned with the beam collision axis. The FASER detector includes four identical tracker stations constructed from silicon microstrip detectors. Three of the tracker stations form a tracking spectrometer, and enable FASER to detect the decay products of LLPs decaying inside the apparatus, whereas the fourth station is used for the neutrino analysis. All tracker stations have been installed in the LHC complex in 2021. After the commissioning, FASER has been taking physics data since the start of LHC Run 3 in July 2022. In the first year of run3, we have already collected data delivered from 40 fb^-1 (inverse femtobarns) of proton-proton collisions with a center-of-mass energy of 13.6 TeV, which allows us to achieve the first neutrino observation with a collider and constraints unexplored parameter space of dark photons. This talk describes the design, construction and performance with early data of the silicon tracker stations.

Submission declaration:
Original and unpublished

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Design and preliminary performance of scintillators-based unmanned aerial vehicle for multiple radiation detection

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ABSTRACT
Unmanned aerial vehicles (UAVs) provide an efficient method of remotely sensing environments that humans cannot approach with conventional aircraft due to serious hazard or access limit. The use of UAVs has been suggested as suitable solution in numerous disciplines, including wildfire thermal imaging, radiological survey and radiation activity monitoring since the Fukushima nuclear accident. Many researches have adopted different types of UAVs and radiation detection sensors and have proposed various radiation monitoring systems and data management systems in a site.

In this work, we propose a novel method of using a commercially available drone for aerial’s multiple radiation detection, which consists of a high-resolution image camera for environmental observation. We have designed and developed the remote multiple radiation monitoring system with different types of scintillating screens for radiation detection tasks. A latest compact drone (model: mavic 2 pro) with 322(L) x 242(W) x 84(H) mm dimension consists of CMOS image array for vision imaging acquisition. Different commercial scintillation screens such as CsI:Tl, GAGG(Ce) and FOS(Fiber Optic Scintillator) with Gd2O2S:Tb materials were applied to measure the X-ray exposure dose, gamma ray activity and neutron reaction. The various design parameters such as scintillator types and radiation types were selected and investigated for preliminary possibility under practical X-ray, gamma-ray condition and neutron conditions.

For evaluation and optimization of the various situations about multiple radiations, different configuration parameters are investigated. The characteristics of the CMOS image sensors with and without scintillator in a drone, such as dose response linearity, dose rate dependence, and minimum detectable activity were evaluated. This result has demonstrated that the unmanned aerial vehicle with a camera and scintillator can be used as a low sensitivity dose rate meter in a situation to detect various types of radiations.

Submission declaration
Original and unpublished

Day 5 - Session 1 / 115

Depletion depth studies with the MALTA2 sensor, a depleted monolithic active pixel sensor

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MALTA2 is a depleted monolithic active pixel sensor developed in the Tower Semiconductor 180 nm CMOS imaging process. Monolithic CMOS sensors offer advantages over current hybrid imaging sensors both in terms of increased tracking performance due to lower material budget but also in terms of ease of integration and construction costs due to the integration of read-out and active sensor into one ASIC. Current research and development efforts are aimed towards radiation hard
designs up to 100 Mrad in Total Ionizing Dose and $3 \times 10^{15}$ $1\,MeV\,n_{eq}/cm^2$ in Non-Ionizing Energy Loss. One important property of a sensor’s radiation hardness is the depletion depth at which efficient charge collection is made via drift movement. Grazing angle test beam data was taken during the 2023 SPS CERN Test Beam with the MALTA telescope and Edge Transient Current Technique studies were performed at DESY in order to develop a quantitative study of the depletion depth for both un-irradiated and irradiated MALTA2 samples. These measurements together with efficiency, cluster size and timing measurements before and after neutron irradiation show that MALTA2 is an interesting tracking sensor for HL-LHC and beyond collider experiments, providing both very good tracking capabilities and radiation hardness in harsh radiation environments.

Submission declaration:
Original and unpublished

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Test beam performance of pixel detectors for the Inner Tracker Upgrade of the ATLAS experiment

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During the high luminosity phase of the Large Hadron Collider (HL-LHC) up to 200 proton-proton interactions per bunch crossing will be produced. The inner detector of the ATLAS experiment will be completely replaced with a new Inner Tracker (ITk) to cope with the resulting harsher environment. The pixel detector, located in the innermost part of the ITk, will be subject to radiation fluences up to $2 \times 10^{16}$ $n_{eq}/cm^2$. The ITk pixel detector will be instrumented with different detector technologies depending on the distance and position from the interaction point, to withstand the expected fluences and deal with the expected extremely large particle multiplicity. n-in-p planar and 3D sensors with different thickness and pixel size will be used, whose production is carried out by different vendors and institutes. All combinations of sensor type and vendor are being characterized as soon as they are available with test beam campaigns to assess their performance, both before and after irradiation. An overview of the current test beam results will be given.

Submission declaration:
Original and unpublished

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Understanding the Humidity Sensitivity of Sensors with TCAD Simulations

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During the prototyping phase of the ATLAS Inner Tracker Upgrade for the High Luminosity project, several n-in-p large area silicon strip sensors showed signs of early breakdown when biased at a relative humidity (RH) higher than 20%. To understand the sensor’s humidity susceptibility, Synopsys TCAD simulation software was used to implement the geometry of n-in-p diodes, test structures placed on the same wafer as the main sensor. The electrical behavior of the diodes has been simulated for different effective RH values. The humidity effect was modeled using a thin resistive layer of polysilicon placed on top of the passivation. The sheet resistance of the polysilicon layer was adjusted according to literature values of the sheet resistance of the passivation surface as a function of RH. To crosscheck the simulation results, current-voltage measurements of the diodes have been performed until breakdown conditions were reached in a RH controlled environment. Hot-electron emission in the localized breakdown region was imaged using a near-infrared camera. Once the location of the avalanche breakdown is known, Top-Transient Current Technique (Top-TCT) scans are performed in the same positions. The distribution of the electric field estimated from TCT measurements is compared to the TCAD simulation results. By performing both simulations and measurements, we gain a better understanding of the evolution of the electric field and the accumulation of free charge carriers which lead to early breakdown in humid environments.

Submission declaration:
Original and unpublished

119

TCAD simulation of the electrical performance of the ATLAS strip sensor for the HL-LHC

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To cope with the increased occupancy and radiation dose expected at the High-Luminosity LHC, the ATLAS experiment will replace its current Inner Detector with the Inner Tracker (ITk), consisting of silicon-based pixel and strip sub-detectors. The strip detector will consist of many n+-in-p sensors fabricated by Hamamatsu Photonics, with 300 um signal-generation thickness and approximately 75 um strip pitch. To guide the operation of these sensors in the ITk, it is desirable to understand the basic mechanisms underlying their performance, including the effects of the radiation fluence (up to 10^15 1-MeV neq/cm^2) expected during operation.

To this end, we have used Sentaurus TCAD to develop a 2D simulation of the ITk large-format strip sensor, based on detailed optical and electrical measurements of the sensors and of test devices fabricated on the same wafers. Sensor IV and CV behaviour is reproduced in the simulation by implementing charge trapping due to defects in the silicon, either inherent or radiation-induced. Trapping parameters are informed by existing frameworks, such as the Perugia model of surface and bulk radiation damage, and by deep-level transient spectroscopy of the wafers. In addition, the regions of the sensor involved in early breakdown - located through measurements of optical emission - are investigated, as well as the humidity dependence of early breakdown. These simulation results help validate the performance of the ITk strip sensor throughout its operational lifetime.

Submission declaration:
Day 2 - Session 1 / 120

Investigating the impact of 4D tracking in ATLAS and beyond

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The Inner Detector of the ATLAS Experiment will be upgraded to a full-silicon Inner Tracker (ITk) to cope with the extreme conditions of the High-Luminosity phase of the Large Hadron Collider, currently foreseen to start with Run 4 towards 2029. In order to address the challenge of pileup in the forward region of ITk, a High Granularity Timing Detector (HGTD) will provide time track measurements with a precision of 30ps for tracks with pseudo-rapidity larger than 2.4. Due to the high radiation dose in proximity of the interaction point, the two innermost pixel layers of the ITk are designed to be replaced after 2000 fb⁻¹. This represents a unique opportunity to bring in technological innovation and fully exploit the potential of HL-LHC by including fast-timing through 4-dimensional (4D) tracking in the ATLAS barrel region, enabling full hermitic coverage when combined with the HGTD. In this contribution, we will demonstrate how the availability of a timestamp for the tracks in the central ATLAS region allows to significantly enhance the physics potential and discovery reach beyond what can be achieved with the HGTD alone. In order to study the impact of 4D tracking on future collider experiments, the studies are extended to a generic detector layout via the ACTS library.

Submission declaration:
Original and unpublished

The study of gamma-radiation induced displacement damage in n+-in-p silicon diodes

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The bulk damage of p-type silicon detectors caused by high doses of gamma irradiation has been studied. The study was carried out on different types of n+-in-p silicon diodes with various oxygen concentrations and silicon bulk resistivities. Secondary-ion mass spectrometry (SIMS) technique was used to determine the relative concentration of oxygen in individual samples. The diodes were irradiated by Cobalt-60 gamma source to total ionizing doses ranging from 0.50 up to 8.28 MGy, and annealed for 80 minutes at 60℃. The main goal of the study was to characterize the gamma-radiation induced displacement damage by measuring current-voltage characteristics (IV), and the evolution of the full depletion voltage (VFD) with total ionizing dose by measuring capacitance-voltage characteristics (CV). It has been observed that the bulk leakage current increases linearly with total ionizing dose, and the damage coefficient depends on the initial resistivity and oxygen concentration of the silicon diode. The effective doping concentration, and therefore also VFD, significantly decreases with increasing total ionizing dose, before starting to increase again at specific dose. We assume that the initial decrease of effective doping concentration is caused by the effect of acceptor removal. The Transient Current Technique (TCT) was used to verify the full depletion voltage and to extract the electric field distribution and the sign of the space charge of the silicon diodes irradiated to the lowest and the highest delivered total ionizing doses. Another noteworthy observation from this study is that the IV and CV measurements of the gamma irradiated diodes did not reveal any annealing effect.

Submission declaration:
Original and unpublished

Automated Assembly of Larger Detector Structures for the ATLAS New Inner Tracker

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The ATLAS experiment is currently preparing for the HL-LHC upgrade, with an all-silicon Inner Tracker (ITk) that will replace the current Inner Detector. The ITk will feature a pixel detector surrounded by a strip detector, with the strip system consisting of 4 barrel layers and 6 endcap disks. The strip tracker will consist of 11,000 silicon sensor modules in the central region and 7,000 modules in the end-cap region, which are mounted onto larger carbon-fibre support structures called 'petals' for the end-cap and 'staves' for the barrel. To facilitate the assembly of these larger detector structures, an automated system has been developed for mounting modules on petals. The automated procedure streamlines and simplifies the production process and ensures uniformity across the four international production clusters. The system utilizes advanced robotic technology to mount the modules on petal cores and reduce the potential for operational error while increasing throughput. This contribution summarizes the latest results from the assembly of the first ATLAS ITk pre-production petals earlier this year.

Submission declaration:
Original and unpublished
Timing and Gain Performance of Teledyne e2v’s LGADs before and after Irradiation

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Low Gain Avalanche Detectors (LGADs) are a novel silicon sensor technology being developed to design full 4D trackers able to measure precisely both spatial and temporal coordinates. The first deployment of this technology will be in the ATLAS and CMS timing layers at the High Luminosity LHC where, by adding fast timing information to each crossing track, they will allow to better separate overlapping events.

Further developments of this technology will be pursued in anticipation of their use at future collider experiments where 4D tracking detector systems will be needed to cope with an unprecedented number of pile-up and beam background events through the addition of precise timing information to each point along the track. In this context, the University of Birmingham, University of Oxford, Rutherford Appleton Laboratory and Open University are working with the UK foundry Teledyne e2v to establish their processing line for LGAD production. The addition of Te2v to the currently established LGAD manufacturers will significantly increase LGAD production volume capabilities.

This talk will present a detailed study of the performance of the first batch of LGADs produced at Te2V, before and after irradiation with 27 MeV protons. A sample of wafers with varying gain layer implant energy/dose have been tested for IV and CV characteristics, gain and timing measurements. The study is performed at different levels of fluence up to roughly 1e15 1 MeV neq/cm\(^{-2}\), with the goal of assessing the timing performance of these devices as a function of gain after irradiation.

Submission declaration:

Original and unpublished

Time resolution and radiation hardness of monolithic pixel sensors in BiCMOS technology

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The MONOLITH H2020 ERC Advanced project aims at producing a monolithic silicon pixel ASIC with 50µm pixel pitch and picosecond-level time stamping. The two main ingredients of the project are fast and low-noise SiGe BiCMOS electronics and a novel sensor concept, the Picosecond Avalanche Detector (PicoAD). The PicoAD uses a patented multi-PN junction to engineer the electric field and produce a continuous gain layer deep in the sensor volume. The result is an ultra-fast current signal with low intrinsic jitter in a full fill factor and highly granular monolithic detector.

Testbeam measurements of the proof-of-concept PicoAD prototype, based on a 2019 ASIC design, shows full efficiency and time resolutions of 13ps at the center of the pixel and 25ps at the pixel edge, for an average of 17ps over the pixel surface.

A new monolithic prototype with improved SiGe BiCMOS electronics was produced in 2022 on a 350Ωcm substrate. Although this ASIC does not have an internal gain layer, it provided 20ps time resolution in a testbeam with pions. This prototype was irradiated with 70MeV protons with the electronics on. Laboratory measurements with a 90Sr source for a detector irradiated with \( 10^{16} \) n\_eq/cm\^2 show a time resolution of 46ps at a sensor bias voltage of 200V, and 40 ps at 325 V.

These results give confidence that SiGe BiCMOS processes can be a candidate for the production of very high time resolution pixelated detectors for future colliders and other disciplines that involve very high radiation environments.

Submission declaration:
Original and unpublished

Study on magnetic field and pH response with angular correlation measurement of Yb-169 for double photon coincidence imaging

Author: Boyu Feng
Co-authors: Akihiro Nambu; Donghwan Kim; Hamdan Mohammad; Hideki Tomita; Hiromitsu Haba; Hiroyuki Takahashi; Kenji Shimazoe; Mizuki Uenomachi; Qinghong Zhu; Yudai Shigekawa

In the field of medicine, nuclear medicine imaging is a crucial technique for obtaining non-invasive information about the body’s interior. It involves detecting radiation emitted from within the body and visualizing its distribution externally. A novel approach in nuclear medicine imaging is being developed, which combines angle correlation measurements with the fusion of magnetic fields, pH values, and radioisotopes.

In this study, we utilized Yb-169, a multi-photon nuclear species with a relatively long-lived intermediate state, as a replacement for In-111, which is commonly used in clinical applications such as SPECT. The unique property of changes in the emission angles of gamma rays when influenced by external fields such as magnetic or electric fields during the intermediate state of cascade nuclear decay was leveraged. This allowed us to detect the precession motion of atomic nuclei induced by the application of a static magnetic field and changes in solution pH, which manifest as oscillations in gamma-ray angle correlations. Additionally, by comparing the observed information on gamma-ray angle correlations with calculated frequencies and pre-known values of magnetic field strength or pH, we were able to acquire information about the distribution of radioactive isotopes.
In this research, the measurement system employed 8x8 arrays of GAGG (Gd3(Al, Ga)5O12(Ce)) scintillators arranged in a ring as detectors. For the photodetectors, Hamamatsu Photonics’ MPPC (Multi Pixel Photon Counter) was utilized. The readout circuitry adopted a system using a dToT (dynamic Time over Threshold) board. This system allowed for the simultaneous and independent readout of detection timing and detection energy for all channels. In this experiment, the angle correlations of coincidence events associated with Yb were measured, and the changes in temporal response when applying a magnetic field and varying the pH value were quantified.

Submission declaration:
Original and unpublished

Day 1 - Session 2 / 128

Operation and performance of the CMS silicon detectors

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The CMS silicon tracking system consists of an inner part with hybrid pixel modules and an outer part with silicon micro-strips. The silicon trackers have been successfully taking data during LHC Run 1 and 2. During Long shutdown 2, the pixel detector underwent an extensive refurbishment program to address the problems encountered during Run 2. The DCDC converters which exhibited failures during power cycles have been replaced. A new innermost barrel layer with improved versions of the ASICs (PROC600 and TBM) has been installed. After the re-installation of the pixel detector in June 2021 a thorough period of commissioning followed for both detectors, including the acquisition of 3.5M cosmic muon track for alignment. This contribution will summarize the refurbishment of the pixel detector during LS2 and the performance of both silicon detectors during early Run 3. The change of detector performance with increasing irradiation will be discussed including an outlook towards the end of Run 3.

Submission declaration:
Original and unpublished

Day 1 - Session 4 / 130

Design and construction of the CMS Inner Tracker for the HL-LHC Upgrade

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The High Luminosity Large Hadron Collider (HL-LHC) at CERN is expected to collide protons at a centre-of-mass energy of 14 TeV and to reach the unprecedented peak instantaneous luminosity of \(5 \times 7.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}\) with an average number of pileup events of 140-200. This will allow the ATLAS and CMS experiments to collect integrated luminosities up to \(3000-4000 \text{fb}^{-1}\) during the project lifetime. To cope with this extreme scenario the CMS detector will be substantially upgraded before starting the HL-LHC, a plan known as CMS Phase-2 upgrade. The entire CMS silicon pixel detector will be replaced and the new detector will feature increased radiation hardness, higher granularity and capability to handle higher data rate and longer trigger latency. In this talk the Phase-2 upgrade of the CMS silicon pixel detector will be reviewed, focusing on the features of the detector layout and technological choices and summarising the R&D activities.

Submission declaration:
Original and unpublished

Day 1 - Session 4 / 131

Design and construction of the CMS Outer Tracker for the HL-LHC Upgrade

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The High Luminosity LHC (HL-LHC) is expected to deliver an integrated luminosity of \(3000 - 4000 \text{fb}^{-1}\) by the end of 2039 with peak instantaneous luminosity reaching to about \(5 - 7.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}\). During the Long Shutdown 3 period, several components of the CMS detector will undergo major changes, called Phase-2 upgrades, to be able to operate in the challenging environment of the HL-LHC. The current silicon outer tracker has to be replaced with a new one for operating in the HL-LHC period. The Phase-2 Outer Tracker (OT) will have high radiation tolerance, higher granularity and capability to handle higher data rates. Another key feature of the OT will be to provide tracking information to the Level-1 trigger, allowing trigger rates to be kept at a sustainable level without sacrificing physics potential. For this, the OT will be made out of modules which have two closely spaced sensors read-out by a common front-end ASIC, which can correlate hits in the two sensors creating short track segments called “stubs”. The stubs will be used for tracking in the L1 trigger stage. In this contribution, the design of the CMS Phase-2 OT, the technological choices and first results with pre-production devices will be reported.

Submission declaration:
Original and unpublished

Day 1 - Session 1 / 135

Welcome to Vancouver

Submission declaration:
Day 1 - Session 1 / 136

**Welcome from the LOC**

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Day 5 - Session 2 / 137

**Closing remarks**

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**Submission declaration:**

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Day 5 - Session 2 / 138

**Introduction to new venue**

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**Submission declaration:**

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Day 3 - Session 3 / 139

**Future directions and challenges of ASICs**

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**Submission declaration:**

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Day 4 - Session 1 / 140

**The future of bent MAPS, full-wafer (stitched) design: status and challenges**

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Monolithic Active Pixel sensors (MAPS) have been undergoing significant advances over the last decade in terms of integration densities, radiation hardness and speed. They became the technology of choice for precise vertex detectors at high energy physics experiments with moderate radiation loads, notably STAR at RHIC, ALICE at LHC, and are being considered for future FCC-ee detectors.

Being based on commercial CMOS imaging processes, MAPS naturally benefit from the fast progress in the field of commercial imaging. In particular, smaller feature sizes and larger wafers are becoming available now; 65 nm on 300 mm wafers are the state of the art today. Typical sensitive layer thickness are 30 μm or even less, depending on the technology, allowing overall thickness of only...
50 μm. At those thicknesses, the sensors become flexible enough to be bent into truly cylindrical shapes down to radii below 2cm. Together with a processing option called stitching, it is possible to produce sensors of wafer scale, making it possible to build real detector half-cylinders out of single sensors, which brings down the material budget to a minimum.

This contribution will showcase the state of the art of wafer-scale, bent MAPS, detail the design challenges, report on first results from prototype circuits, and outline the next steps to make technology available for the first applications. In particular, a number of recent results from a first prototype run with two different 26 cm long MAPS will be given.

Submission declaration:

Day 4 - Session 2 / 141

Skipper CCD technology and the newer MAS CCD

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Submission declaration:

Poster session upload slots / 142

A 2.56 Gbps or 10.24 Gbps 1:16 Deserializer in 55 nm for High-Energy Physics Experiments

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Poster session upload slots / 143

A 28Gbps PAM4 VCSEL Driving ASIC for the Front-end Readout Application in High-Energy Physics Experiments

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Poster session upload slots / 144

A 10-Gb/s Serial Link Transmitter With 4-Tap FFE Function in 55-nm CMOS

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Poster session upload slots / 145

A High-Counting-Rate Readout ASIC for CZT Detectors
Topmetal-L: A pixel sensor for charge tracking imaging of LPD

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A 4.4-Gbps Serializer ASIC in 180 nm for NICA-MPD Detector

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Single event effect in ATLAS ITk Strip readout chips

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Design of a Pixel Detector Readout Scheme with Controllable Delay Chain for Enhanced Positioning Accuracy

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A high-speed low-noise front-end ASIC prototype for high-intensity ionization chamber

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Design and Preliminary Characterization of a High-Speed Front-End Readout ASIC for CdZnTe Detectors
A 10Gbps Optical Receiver in 55nm CMOS for Front-end readout electronics in High-Energy Physics Experiments

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Design and evaluation of a MeV gamma-ray camera aboard a 50-kg class small satellite

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Imaging reconstruction method on X-ray data of CMOS polarimeter combined with coded aperture

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Development of the X-ray polarimeter using CMOS imager: polarization sensitivity of a 1.5 \( \mu \text{m} \) pixel CMOS sensor

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Large-area X-ray polarization detector detection unit prototype

Image quality assessment of flexible scintillation screens for curved X-ray imaging detectors

Corresponding Author: bkcha@keri.re.kr
Scintillator’s effect and characterization for ultra-high resolution in digital X-ray flat-panel detectors

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Contrast Agent Estimation Result of 2-dimensional Photon Counting CT Detector which Combined MPPC and YGAY-scintillator Array

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Alpha-Particle Imaging SiPM Array Sensor with High-Resolution Technique

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Improving MVCT Image Quality for Quantitative Analysis of Inter-fractional Organ Motion in Prostate Cancer Radiotherapy

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Silicon photomultipliers for the nEXO light detection system

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Micro-vertex detection system for the WASA-FRS HypHI Experiments at GSI-FAIR

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Mighty Tracker - Performance Studies of the MightyPix for LHCb

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The ATLAS ITk strip local support structures

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Study of double-sided silicon pixel ladders with low material budget

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Substrate-Less ultra-thin TiO2 ionizing radiation detector: Fabrication, structural characterization and Electrical Performance Analysis

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The Diamond XBPM Detector System for High Energy Photon Source

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Automated Assembly of Larger Detector Structures for the AT-LAS New Inner Tracker

Corresponding Authors: scott.lee.beaupre@cern.ch, sbeaupre@sfu.ca
Development of two-dimensional neutron imager with a sandwich configuration

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Hi'Beam-SEE: a silicon pixel sensor-based beam monitor for heavy-ion experimental terminals

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Study on magnetic field and pH response with angular correlation measurement of Yb-169 for double photon coincidence imaging

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Direct-conversion X-ray CMOS detector assembled with perovskite

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X-ray imaging camera using INTPIX4NA SOIPIX detector with SiTCP-XG 10GbE based high-speed readout system

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HEPS-BPIX40: the upgrade of the hybrid pixel detector for the High Energy Photon Source

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Muon Forward Tracker in ALICE at the LHC

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Module development for the ATLAS ITk Pixel Detector

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First Test Beam Results of Irradiated Single and Quad Modules Equipped with HPK Planar Pixel Sensors and CROC Readout Chips for the CMS Phase 2 Upgrade

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Feasibility study of implementing CMOS sensor in 55nm process for tracking

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X-ray polarimetry and spectroscopy with the CMOS detector IU233N5-Z

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Poster session upload slots / 184

Test beam performance of pixel detectors for the Inner Tracker Upgrade of the ATLAS experiment

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Poster session upload slots / 185

Suppression effect of Fe on irradiation of Silicon-based diodes using current-voltage measurements.

In this study, the suppression effects of Fe on irradiation of silicon (Si) diodes were investigated. Diodes fabricated on unimplanted and Fe-implanted p-Si diodes were irradiated with 4 MeV protons to a fluence of $1 \times 10^{16}$ p/cm$^2$ and then characterized prior to and after irradiation using current-voltage ($I$-$V$) techniques. A decrease in current due to irradiation is more apparent in unimplanted p-Si diode than the Fe-implanted p-Si diode, indicating that the effect of irradiation has been suppressed on the Fe-implanted p-Si diode due to Fe-doping. The diode conduction mechanism for unimplanted p-Si diode changed, while that of Fe-implanted p-Si diode remained constant after proton-irradiation. The diode parameters were also evaluated on the fabricated diodes prior to and after irradiation. The obtained results suggest that Fe-induced defects in Si have improved the radiation-hardness of Si material. Hence, Fe, just like Au and Pt, is a suitable candidate in a bid to improve the radiation-hardness of Si material.

Poster session upload slots / 186

Radiation study of the LHCb UT front-end readout ASIC

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Poster session upload slots / 187

Characteristics of the MTx optical transmitter ASIC in Total Ionizing Dose

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Poster session upload slots / 188

Evolution of the electrical characteristics of the ATLAS18 ITk strip sensors with HL-LHC radiation exposure range

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A High-Precision Proton Irradiation Site for Silicon Detectors Providing Online Fluence Monitoring, Spatial Damage Resolution and Flexible Irradiation Procedures

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Radiation tolerance tests and performance verification of pnCCD at high temperature for future satellite mission HiZ-GUNDAM

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Performance of CMOS pixel detector IU233N5-Z damaged with 200 MeV proton beam

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The study of gamma-radiation induced displacement damage in n+-in-p silicon diodes

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New concept of Si semiconductor Compton Camera

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Design and simulation of a radiation hardening pixel in the CIS detector used in high total ionizing dose damage environment
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Analysis of MOS capacitor with p layer with TCAD simulation

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Analysis of transient response in CMOS image sensor induced by photons with different energies by the Monte Carlo method

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Understanding the Humidity Sensitivity of Sensors with TCAD Simulations

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TCAD simulation of the electrical performance of the ATLAS18 strip sensor for the HL-LHC

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Hot spot visual evaluation of breakdown locations in ATLAS18 ITk strip sensors and test structures

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Long-term humidity exposure of ATLAS18 ITk strip sensors

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Analysis of the results from Quality Control tests performed on ATLAS18 Strip Sensors during on-going production

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Welcome from the IAC

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Day 1 - Session 3 / 203

Roundtable

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