14th "Trento" Workshop on Advanced Silicon Radiation Detectors

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Book of Abstracts

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Session 7: LGAD (1) / 72

A High-Granularity Timing Detector for the Phase-II upgrade of the ATLAS Calorimeter system: sensor performance.

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The expected increase of the particle flux at the high luminosity phase of the LHC (HL-LHC) with instantaneous luminosities up to L ? 7.5 × 1034 cm-2 s-1 will have a severe impact on the ATLAS detector performance. The pile-up is expected to increase on average to 200 interactions per bunch crossing. The reconstruction and trigger performance for electrons, photons as well as jets and transverse missing energy will be severely degraded in the end-cap and forward region, where the liquid Argon based electromagnetic calorimeter has coarser granularity and the inner tracker has poorer momentum resolution compared to the central region. A High Granularity Timing Detector (HGTD) is proposed in front of the liquid Argon end-cap calorimeters for pile-up mitigation and for bunch per bunch luminosity measurements.

This device should cover the pseudo-rapidity range of 2.4 to about 4.0. Two Silicon sensors double sided layers are foreseen to provide a precision timing information for minimum ionizing particle with a time resolution better than 50 pico-seconds per hit (i.e 30 pico-seconds per track) in order to assign the particle to the correct vertex. Each readout cell has a transverse size of 1.3mm × 1.3 mm leading to a highly granular detector with about 3 millions of readout electronics channels. Low Gain Avalanche Detectors (LGAD) technology has been chosen as it provides an internal gain good enough to reach large signal over noise ratio needed for excellent time resolution.

Through a 4 period test-beam campaign at the CERN SPS H6A & B beamlines, proton and neutron irradiated LGAD prototypes for the HGTD upgrade were tested from several different technologies and manufactures. Gallium, boron and carbon implanted 1.3x1.3 mm2 diodes and 2 x 2 arrays are compared for achieved timing performance, post-irradiation efficiency and uniformity at fluences up to 6e15neq/cm2. Laboratory characterisation of large sensors arrays recently delivered (5x5 and 15x15 pads) will be also discussed. In addition the beam test measurement of a first HGTD module prototype made of 2x2 array sensor bump bonded to an ASIC called ALTIROC0, will be presented.

Session 2: Planar Sensors (1) / 73

Signal formation in heavily irradiated silicon particle sensors under charge multiplication

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Over the past years, an in-depth study of irradiated and annealed p-type silicon strip sensors as they will be used for HL-LHC Upgrades was performed. Measurements of the collected charge, noise and cluster size were regularly performed as a function of increasing annealing time and bias voltage. A large number of sensors under study showed a signal larger than the one originally deposited. This effect, known as charge multiplication (CM), can be attributed to an increase of the positive effective doping concentration, which in turn increases the electric field, in particular close to the n+ implants. This study reveals a number of interesting features which can enlighten the understanding of CM and have significant consequences for using these sensors at the HL-LHC after heavy irradiation. Beta source measurements with ALIBAVA readout and laser measurements in a TCT system were performed. In the TCT system, the transient current was recorded to correlate charge collection performance with signal formation. Emphasis is placed on two interesting results: when charge multiplication is significant, the signal pulses become significantly prolonged. The cluster size, which usually decreases in multiplication, gets broader.
This slow signal has not been reported before and constitutes a potential threat to HL-LHC applications which are based on fixed short signal shaping times due to the time structure of bunches in the LHC, where a large fraction if signal might be too late for the front-end ASICs. The delayed signal can be attributed to the large amount of holes generated by CM, that travel as a cloud to the backside of the sensor, generating a self-screening effect, or the so called "plasma"effect.

Session 3: Radiation effects in HEP experiments / 74

Measurement of Radiation Damage through Leakage Current Monitoring of the ATLAS Pixel Detector

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Radiation damage incurred by the silicon modules in the ATLAS Pixel Detector B-Layer, Layer-1, Layer-2, and disks from the beginning of 2011 through November 2018 has been monitored through measurement of the leakage current. The measurement makes use of the fact that leakage current changes by an amount proportional to the received hadronic fluence. The data are compared to predictions made with the Hamburg Model which is scaled to match their average magnitude. Comparisons of fluence predictions by PYTHIA8+FLUKA to the fluence determined from leakage current data combined with the Hamburg Model are also made for each barrel layer and disk. Projections of the lifetime of the Pixel Detector are made using several scenarios for expected future temperatures and fluence rates and extrapolating from the present leakage current data and Hamburg Model predictions, through year 2023 and 500 fb^{-1} of total collected luminosity.

Session 11: Technologies and Applications (2) / 75

Nuclear fragment energy measurements up to 400 MeV/A with BGO crystals coupled to SiPM arrays

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The measurement of proton and light nuclei fragmentation cross sections with energies up to $400\ MeV/A$, which is relevant for improving treatment-planning systems in hadron therapy, is the primary goal of the FOOT (*FragmentatiOn Of Target*) experiment. FOOT will use an inverse-kinematic approach profiting from the Lorentz boost to detect nuclear fragments that would otherwise stop in the target. The momentum, time of flight and energy will be measured by a spectrometer, a thin scintillator and a BGO calorimeter respectively, and will make mass identification possible. In this work we present the design of the BGO calorimeter and performance of its prototype.
The use of SiPM arrays coupled to the crystals allows a compact design for the calorimeter. We tested 2 different FBK SiPM arrays with 15 and $20\ \mu m$ microcell size, respectively, coupled to $24\ cm$

long BGO crystals in two different configurations (reflective for 15 and absorbent for 20). At the CNAO facility in Pavia, Italy, we have measured the detector response to low intensity ($\sim 10\ KHz$) proton and carbon beams with energies up to 220 MeV and 400 MeV/A, respectively. The reflective configuration on the 15 μm provides the best results: energy resolution is below 1% for carbon ions and smaller than 2% for protons down to 120 MeV; it increases to 3% for 70 MeV protons. Moreover, no saturation effect up to 4.8 GeV deposited energy is found. Non-linear response to ionizing particles is observed, which can be caused by scintillation quenching effects. The SiPM signals are sampled at 1 GHz rate to extract temporal properties of the light pulses. Observed differences in shapes of the pulses provide an additional possibility for particle identification and improved energy correction. Therefore, the 15 μm SiPMs are a good candidate for a photosensor in the BGO calorimeter of the FOOT experiment.

Session 9: LGAD (2) / 76

Position sensitive LGADs with single photon counting readout for X-ray detection

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In the past decade, hybrid silicon detectors with single photon counting readout have been a breakthough for several hard X-ray experimental techniques.
However, they still cannot be used for X-ray energies below 2 keV, since the electronic noise becomes comparable to the charge generated by single X-rays.
The amplification provided by LGAD sensors improves the signal-to-noise ratio and the signal of a photon can be discriminated from the electronic noise even for low energies. This can extend the single photon counting capability to the soft X-ray energy range.
The gain, electronic noise, signal-to-noise ratio as well as the fill factor of 150 um pitch microstrip sensors fabricated at FBK have been characterized using X-rays.
Although improvements in the segmentation and in the quantum efficiency for soft X-rays are required, these preliminary measurements show that LGADs are a promising technology for accessing the soft X-ray energy range using single photon counting readout.

Session 5: Planar Sensors (2) / 78

Charge collection efficiency study of neutron irradiated silicon pad detectors for the CMS High Granularity Calorimeter

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The replacement to the existing endcap electromagnetic and hadronic calorimeters in CMS for the high-luminosity running at the LHC (HL-LHC), will be a High Granularity Calorimeter (HGCAL) that will provide unprecedented information on electromagnetic and hadronic showers in the intense pileup of the HL-LHC. The electromagnetic section and the high-radiation region of the hadronic section will use hexagonal silicon sensors of thicknesses from 100 to 300 μm as active material. The radiation hardness of these sensors is the focus of this study.

Charge collection efficiency (CCE) is the single most revealing parameter to determine the level of radiation hardness of a silicon detector. To reduce increasing bulk leakage current with fluence the silicon sensors at HGCAL will be operated at -30° C. Thus, the CCE investigation of 30 irradiated samples was carried out at the target temperature of HGCAL.

We present CCE results of silicon sensors irradiated with neutrons at Rhode Island Nuclear Science Center (RINSC) and UC Davis McClellan Nuclear Research Center (MNRC) reactors up to 1e16 neq/cm2 fluences, as expected for HGCAL. Charge injections were generated by an infrared laser that models a minimum ionizing particle by penetrating the whole thickness of the investigated sensors, that include both polarities for the three thicknesses planned for HGCAL. The study involved samples from 8-inch wafers, which will be the HGCAL sensor size, as well as reference samples from 6-inch wafers. Conclusions between polarities and thicknesses to be applied for different fluence regions will be made, as well as comparisons with CCE reproduced by a simulation.

Session 2: Planar Sensors (1) / 80

Performance of LPNHE/FBK/INFN thin n-on-p planar pixels sensors for the ATLAS ITk

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In view of the LHC upgrade phases towards the High Luminosity LHC (HL-LHC), the ATLAS experiment plans to upgrade the Inner Detector with an all-silicon system.
The n-on-p silicon technology is a promising candidate to achieve a large area instrumented with pixel sensors, since it is radiation hard and cost effective.
The paper reports on the performance of thin n-on-p planar pixel sensors produced by FBK-CMM; the sensors were bum-bonded to the new
RD53A prototype chip.
After discussing the sensor technology an overview of 2018 testbeam results of the produced devices will be given, before and after irradiation, including cluster
properties, hit and charge collection efficiency and space resolution.

Session 10: CMOS Sensors (2) / 81

The PERCIVAL soft X-ray Detector

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The PERCIVAL collaboration to develop a soft X-ray imager able to address the challenges of high brilliance light sources such as new-generation synchrotrons and Free Electron Lasers, has reached one of its major milestones: a full 2-MegaPixel (P2M) system (uninterrupted 4 x 4 cm2 active area) has already seen its first light.

Smaller prototypes of the device, a monolithic active pixel sensor based on CMOS technology, have already been fully characterised, and have demonstrated high frame rate, large dynamic range, and relatively high quantum efficiency.

The PERCIVAL modular layout allows for clover-leaf like arrangement of up to four P2M systems. Moreover, it will be post-processed in order to achieve a high quantum efficiency in its primary energy range (250 eV to 1 keV).

We will present the P2M system, its status and newest results, bring these in context with achieved prototype performance, and outline future steps.

Session 1: Tracking detectors for HEP experiments / 82

Sensors and Electronics for 4D tracking: the TIMESPOT project

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High Luminosities planned at colliders of the next decades pose very severe requirements on vertex detector systems in terms of space resolution (tens of µm), radiation hardness (5 to 10 x 10ˆ16 1 MeV neutron equivalent cmˆ-2 and some Grad) and data throughput (nxTbit/s). Expected event pile-up (more than 100) introduces the need to add high resolution time measurements (better than 100 ps) already at the single pixel level, for both real-time and off-line track reconstruction.
This demand pushes towards a new concept of vertex detector system, where all these features must operate at the same time.
The TIMESPOT project (TIME and SPace real-time Operating Tracker) is a R&D project, financed by INFN, whose strategy consists in facing this experimental challenge at system level. It consists

of a research team gathering together state-of-the-art knowledges from different expertises and disciplines, in such a way to finalize existing technologies in the direction of an innovative tracking apparatus.
Many intersting results are already available as an outcome of the TIMESPOT activity. In sensor development, a 3D trench-based geometry has been chosen to be the best one concerning high time resolution applications and has been already submitted for fabrication. Activity on the design of dedicated front-end in 28-nm CMOS has led to the submission of a complete pixel read-out circuit, also integrating a TDC with 15 ps r.m.s. resolution. A special care is being dedicated to the development of real-time reconstruction algorithms for tracking. Pre-processing is based on the concept of so-called stubs or tracklets, which cam be pre-constructed and combined already at the front-end level.
In this paper, after a short overview of the project, we will illustrate some of TIMESPOT results obtained so far, with special emphasis on 3D trench sensors and front-end pixel electronics for high resolution timing.

Session 7: LGAD (1) / 84

CHARACTERISATION OF 50 µm THICK LGAD MANUFACTURED BY FBK AND HPK

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In this contribution, we will present the latest results from laboratory measurements on 50 µm thick LGAD fabricated by FBK and HPK. We will concentrate on the overall quality of the production, on the gain uniformity, and in a detailed study of the gain termination implant and its effect on the breakdown point.

Session 4: Technologies and Applications (1) / 85

Development of gamma insensitive semiconductor based diagnostics to qualify intense thermal neutron fields at the e_LiBANS facility.

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Compact silicon and silicon-carbide detectors were developed to qualify and monitor the intense thermal neutron field produced at the e_LIBANS facility in Torino, where typical fluence rates are of the order of 2 x 106 cm-2s-1 . The devices are sensitized to neutrons by means of a 6LiF deposit process optimized to maximize the neutron capture probability and the subsequent detection of the alphas and tritons reaction products. This communication describes the study of the performances of these detectors, based on dedicated measurement campaigns, in terms of linearity, gamma insensitivity and radiation hardness. Applications in spatial field mapping and in moderator based spectrometry are shown.

Session 11: Technologies and Applications (2) / 86

Advantages and needs in time resolving tracker for astro-particle experiments in space

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Since the 90's almost every astro-particle experiment operating in space included a tracker.
The requirements in terms of spatial resolution depend on the type of tracker: 10 μm or less for a spectrometric detector and 30-40 μm or even more for a gamma-ray tracker-converter or for a calorimetric experiment. With a total available powers of few hundreds of Watts and tens of m^2 of areas to be covered, another important requirement is the power consumption: each channel must require at the level of 1 mW or even more.
Current development in silicon detectors, such as LGAD, permit to include also temporal capability with resolution of tens of ps. At the same time the current technology in the front-end electronics would allow to read-out this kind of detectors with few mW per channel
In this contribution the advantages of a time resolving tracker in a typical astro-particle detector will be reviewed and a preliminary evaluation, based on a custom MC simulation, of the needed time resolution will be presented.

Session 11: Technologies and Applications (2) / 87

Development and operations of INFN optical modules for the SCT Telescope camera proposed for the CTA Observatory

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The Schwarzschild-Couder Telescope (SCT) is a proposal for the Medium Size Telescopes of the Cherenkov Telescope Array that is based on a two-mirror optical system designed to improve the telescope field of view and image resolution with respect to the single mirror Davies-Cotton solution. The SCT camera is planned to be instrumented with 177 photodetection modules, each composed of 64 Silicon Photomultiplier (SiPM) pixels. The third generation of 6x6mmˆ2 high density NUV SiPMs (NUV-HD3) produced by Fondazione Bruno Kessler in collaboration with INFN has been used to equip optical units to be integrated on the upgrade of the camera of the Schwarzschild-Couder Telescope prototype (pSCT) operating at the Fred Lawrence Whipple Observatory. Each optical unit is composed of an array of 16 NUV-HD3 SiPMs coupled with the front-end electronics designed for full-waveform nanosecond readout and digitization using the TARGET-7 ASIC. The units have been assembled and tested in the laboratories of INFN and are now integrated on the camera of the pSCT telescope. In this contribution we report on the development, assembly and calibration of the optical units that are currently taking data on the pSCT camera.

Session 2: Planar Sensors (1) / 88

Measurements of NitroStrip detectors irradiated with protons and neutrons

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Silicon detectors for applications in future high energy particle physics experiments face the challenge to withstand increasing radiation doses, while stringent requirements are set on resolution and material budget. The RD50 collaboration strives to understand the effects of radiation defects in silicon detectors and investigates novel ideas for radiation-hard detector concepts. One promising approach for more radiation tolerant silicon detectors is the introduction of foreign atoms into the silicon bulk material. The NitroStrip project is a common RD50 effort that aims to understand the effect of nitrogen enrichment on the radiation tolerance of high resistivity float zone silicon.

Silicon wafers equipped with strip sensors and diodes were manufactured using high resistivity float zone silicon, diffusion oxygenated float zone silicon, nitrogen enriched float zone silicon or magnetic Czochralski silicon.

This presentation summarises the comparative results obtained from measurements on these processed diodes and strip detectors. The devices were electrically tested and irradiated to fluences between 1e13 and 1e15 n_eq/cm². Irradiation was done with 23MeV protons at the facilities in Karlsruhe (KIT), with 24GeV Protons at Cern (IRRAD) and 1MeV neutrons at Ljubljana. The measurements on the irradiated sensors include charge collection measurements using a beta source, measurements of the electric field distribution using a transient current technique laser setup, electrical measurements and defect characterization using the thermally stimulated current technique. Furthermore, the measurements were repeated after multiple annealing steps. Observations and possible next steps will be discussed.

Session 9: LGAD (2) / 89

Studies of the acceptor removal mechanism in UFSD irradiated with neutrons and protons

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The radiation hardness of the gain layer is a main topic in the development of UFSD. The second UFSD production (UFSD2) by Fondazione Bruno Kessler (FBK) in Trento, in collaboration with University of Trento and National Institute of Nuclear Physics (INFN) in Torino, demonstrated a radiation hardness improvement in gain layer with co-implantation of Carbon.
In the third UFSD production (UFSD3) by FBK the Carbon implanted into the gain layer has been split in four doses with the aim to optimize the radiation hardness.
In this contribution I will report the measurement of acceptor removal performed on UFSD3 sensors irradiated with Neutron at fluences 4E14, 8E14 and 1,5E15 neq/cm2.
We will also report on the acceptor removal rate in UFSD induced by protons: UFSD sensors by FBK and Hamamatsu Photonics (HPK) have been irradiated with protons at four energies –24 MeV (KIT), 70 MeV (CYRIC), 800MeV (Los Alamos), 24 GeV (IRRAD) –and the results will be compared with the standard NIEL factor.

Session 2: Planar Sensors (1) / 90

Investigation of the interstrip isolation of p-type strip sensors

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Nowadays silicon strip sensors in high luminosity experiments usually consist of a p-doped bulk with n-type strip implants. General consensus is that such a design requires an additional interstrip isolation structure like a p-stop implant. If no additional implant is implemented between the strips, it is expected that the interstrip resistance will be insufficient before and especially after irradiation. Before irradiation, impurities in the material lead to positive oxide charge inside the silicon dioxide surface which attracts electrons from the bulk. Those electrons accumulate just beneath the silicon dioxide surface and between the strip implants which decreases the interstrip resistance significantly. If the interstrip resistance decreases too much, the spatial resolution of the detector will eventually be lost. Ionising radiation introduces fixed charge inside the silicon dioxide which again decreases the interstrip resistance and the spatial resolution is lost. Contrary to that expectation, a high interstrip resistance was observed after heavy proton irradiation with a fluence of $1x10^{15} n_{eq}/cm^2$.

This talk presents the investigation of the interstrip isolation of n^+p strip sensors and how it is affected by radiation. Therefore, sensors without a specific interstrip isolation implant are used and irradiated with x-rays, neutrons and protons. A major focus is set on the dependence of the interstrip resistance. Moreover, the seed and cluster signal as well as the cluster size is investigated and compared to samples with a p-stop implant to visualise possible differences and the performance of the samples in a real use case.

Session 1: Tracking detectors for HEP experiments / 91

Tracking particles at fluences near 1E17 $n_{eq}/cm\hat{}2\$$

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In this talk I will review the possibility of using very thin Low Gain Avalanche Diodes (LGAD) (~ 25µm thick) as tracking detector at future hadron colliders, where particle fluence will about 1E17 n_{eq}/cm^2 In the present design, silicon sensors at the High-Luminosity LHC will be 100- 200µm thick, generating, before irradiation, signals of 1-2 fC. In our talk, we will show how very thin LGAD can provide signals of the same magnitude via the interplay of gain in the gain layer and gain in the bulk up to fluences of about 1E17 n_{eq}/cm^2.

Session 8: 3D Sensors / 92

Fabrication of active-edge detectors without support wafer using a unique "perforated edge" approach

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Minimisation of insensitive volume in silicon sensors is highly demanded in many applications for high energy physics, structural biology, synchrotron experiments and nuclear medicine. A large contribution to this insensitive volume is the guard rings and current terminating structures required in conventional planar silicon sensor that surround the chip periphery. The maximum size of silicon sensors that is optimal is limited by the diameter or dimensions of the substrate and the overall yield of the fabrication process (the smaller the sensors the higher the overall manufacture yield). For these reasons, many imaging applications require the tiling of multiple sensors modules together to cover large areas. For standard silicon detectors, the insensitive guard-ring regions will result in a loss of information and result in imperfect images. Stanford Nanofabrication Facility (SNF), was the first to introduce the 'active edge', a new edge terminating structure, that replaces the insensitive guard ring area. The concept is based on the original '3D technology' proposed by S. Parker et al in 1995. The technique requires through silicon substrate electrodes, formed first by etching high aspect ratio holes using modern micromachining known as Deep Reactive Ion Etching (DRIE), originally developed for MEMS technologies. Several laboratories worldwide have investigated this approach using a support wafer that is required to provide mechanical integrity once the through substrate trench surrounding the entire periphery of the sensor is etched. The trench electrodes are subsequently doped using gas phase doping technique. Once the sensors are completed, the support wafer must be removed. This further complicates an already difficult technology. SINTEF have recently investigated a new edgeless design concept, known as the 'perforated edge'. The design allows possible future manufacture without the use of the support wafer. The integrity of the device wafer is retained since only small segments are removed during DRIE. We present here the design concept, fabrication, and the first characterization of this newly developed edgeless detector that can potentially be fabricated by a cost-effective manufacture process with high yield, suitable for state-of-the-art pixel sensor module assembly.

Session 4: Technologies and Applications (1) / 93

New beam test results of 3D pixel detectors constructed with poly-crystalline CVD diamond

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Detectors based on Chemical Vapor Deposition (CVD) diamond have been used extensively and successfully in beam conditions/beam loss monitors as the innermost detectors in the highest radiation areas of Large Hadron Collider (LHC) experiments. Over the last two years the RD42 collaboration has constructed a series of 3D pixel detectors using CVD diamond as the active material with laser fabricated columns in the bulk and characterized them in test beams. The electrical properties and latest beam test results from 2017 and 2018 of the efficiency and spatial resolution of the most recent 3D pixel detectors constructed with poly-crystalline CVD diamond will be presented. The devices were constructed with 50 μm $\times$ 50 μm cells with columns 2.6 μm in diameter. In one of the devices the cells were ganged using a surface metalization layer in a 5 $\times$ 1 cell pattern to match the geometry of the ATLAS FE-I4 pixel readout electronics and in the other the cells were ganged using a surface metalization layer in a 3 $\times$ 2 cell pattern to match the geometry of the CMS PSI46digV2.1-respin pixel readout electronics. In beam tests, using tracks reconstructed with a high precision tracking telescope, both devices achieved tracking efficiencies greater than 97\%. In the same beam tests, the first pulse height distributions from poly-crystalline CVD diamond 3D pixel devices were measured. Finally, the latest test beam results of irradiated poly-crystalline CVD diamond pad and pixel detectors will be presented.

Session 10: CMOS Sensors (2) / 94

Measurement of effective space charge concentration vs. neutron fluence in p-type substrates from LFoundry

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RD50 submitted a pixel detector prototype ASIC in 150 nm CMOS technology at LFoundry. The chip contains passive pixel arrays near the edge of the chip suitable for E-TCT measurements. The chips were manufactured on p-type silicon with two different initial resistivities. Chips were irradiated with neutrons in the Triga reactor in Ljubljana to several fluences up to maximal fluence of 2e15 n/cm2. Evolution of effective space charge concentration with neutron fluence was measured with E-TCT for the two different initial resistivities. Acceptor removal parameters were estimated and compared with other measurements.

Session 3: Radiation effects in HEP experiments / 95

Development of the BCM' abort and luminosity system at the HL-LHC based on poly-crystalline CVD diamond pixel-pad detectors

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For protecting the inner detectors of experiments and for monitoring the delivered luminosity at HL-LHC a radiation hard beam monitor is being developed. The BCM' proposal consists of a set of detectors based on poly-crystalline Chemical Vapor Deposition (pCVD) diamonds and dedicated Application Specific Integrated Circuit. Due to the large range of particle flux through the detector, flexibility is very important. To satisfy the constraints imposed by the HL-LHC we propose a solution based on segmenting each single diamond sensor into multiple devices of varying size and reading them out with a new multichannel readout chip bump-bonded to the detectors.

In this talk we describe the proposed system and present results from the first prototypes of multi-channel pCVD diamond sensors wire-bonded to the FE electronics produced in 65 nm TSMC technology. The prototype system characterized in test beams with 120 GeV hadrons at the CERN SPS and 260 MeV pions at PSI will be presented. Preliminary results for the amplitude distribution across the device will be presented at different negative and positive voltages. In addition, the noise distribution and efficiency will be presented. Based on the preliminary results further development of the system will be discussed.

Session 4: Technologies and Applications (1) / 96

SiCILIA - Silicon Carbide detectors for nuclear physics and Applications

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Silicon carbide (SiC) is a semiconductor material with highly suitable properties for high-power, high-frequency, and high-temperature applications. Silicon carbide (SiC) is a semiconductor with a wide, indirect band gap. Among all the wide band gap semiconductors, silicon carbide is presently the most intensively studied one and the one with the highest potential to reach market maturity in a wide field of device applications. It is a wide bandgap semiconductor with high breakdown electric field strength, high saturated drift velocity of electrons, and a high thermal conductivity. For these physical and electrical properties in many fields SiC overcomes silicon (Si), that is the dominating material of electronic industry.
The chemical and physical material properties are promising for high temperature and high radiation operation conditions [1]. The potential application of SiC as radiation hard material for detectors implementation and the possible use in several new INFN projects (NUMEN,NuReLP, ELIMED, FAZIA etc.) have led to the birth of a cooperation between INFN and IMM-CNR for a common R&D activity on Silicon Carbide technology named SiCILIA (Silicon Carbide detectors for Intense Luminosity Investigations and Applications) which has been totally funded by INFN. SiC diodes are predicted to be radiation harder than Si due to the high displacement threshold and potentially used as detectors in high radiation conditions. The remarkable progresses in the material growth process [2] and device technology of the last years, allowed to realize high performances SiC devices based on p-n junction [4]. They have been used to detect neutrons, X-rays, protons, alpha particles and heavier ions [5]. For nuclear community is very important the realization of detection system that can operate with high fluxes (10ˆ7 pps/mˆ2) and fluences (10ˆ14 cmˆ-2) of heavy-ions in order to determine the cross

sections of very rare phenomena (i.e. such as double charge exchange reactions). Silicon carbide technology offers today an ideal response to such challenges, since it gives the opportunity to cope the excellent properties of silicon detectors (resolution, efficiency, linearity, compactness) with a much larger radiation hardness (up to five orders of magnitude for heavy ions [6]), thermal stability and insensitivity to visible light. In the framework of SiCILIA [6] activities, several measurements have been performed on SiC prototypes, by using radioactive source and ions beams. In the contribution we discuss the project and the main results comparing also the SiC performance with that of others standard detectors.

References
[1] F. Nava, G. Bertuccio, A. Cavallini, E. Vittone Meas. Science Tech. 19, 102010 (2008)
[2] F. La Via, M. Camarda, A. La Magna, Appl. Phys. Rev., 1, 031301 (2014)
[3] M. Cutroneo et J. Material Res. 28, 87 (2012)
[4] F. Moscatelli, A. Scorzoni, et al. Nucl. Instr. Meth A 546, 218 (2005)
[5]]M. De Napoli et al. Nucl. Instr. Meth in Physics Research A 608, (2009)
[6] S.Tudisco et al. , Sensors 2018 Jul 15;18(7). pii: E2289. doi: 10.3390/s18072289.

Session 1: Tracking detectors for HEP experiments / 97

The CMS Pixel Detector Upgrade and R&D developments for the High Luminosity LHC

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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 $5-7.5\text{x}10^{34}cm^{-2}s^{-1}$ with an average number of pileup events of 140-200. This will allow the ATLAS and CMS experiments to collect integrated luminosities up to 3000-4500 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 on developments of new pixel devices.

Session 3: Radiation effects in HEP experiments / 99

Radiation effects in the CMS phase 1 pixel detector

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The Compact Muon Solenoid (CMS) pixel detector has been replaced in 2017 to meet the challenges of the high-pileup and high-luminosity environment from proton-proton collisions at the Large Hadron Collider (LHC). The current phase 1 CMS pixel detector has 4 barrel layers and 3 endcap disks to maintain tracking performance at instantaneous luminosities of 2x10e34/cm2/s, and now has withstood fluences up to 1e15 neq/cm2. The detector uses modules with n+ in n sensors of 100x150um2 with an active layer of 285um. The sensors are connected to PSI46dig readout chips, except for the innermost barrel layer where sensors are connected to PROC600 chips that have been designed especially to handle the high rates of the innermost layer.

In this presentation we discuss radiation-induced changes in pixel sensor and chip properties including depletion voltage and leakage current, as well as operational experience and lessons learned in dealing with these changes. We also present variations of radiation-induced changes with temperature, fluence, and time and results on performance and tracking observables. A model of these radiation-damaged induced pixel sensor properties is compared to data and is used to predict the sensor properties over the course of the LHC run 3.

Session 2: Planar Sensors (1) / 100

Planar pixel sensor development for the CMS Phase II upgrade

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The LHC is planning an upgrade program which will bring the luminosity up to about $7.5{\cdot}10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in 2027, with the goal of an integrated luminosity of 3000 fb^{-1} by the end of 2037. This High Luminosity scenario, HL-LHC, will present new challenges of higher data rates and increased radiation tolerance for the pixel detector ($2{\cdot}10^{16}\mathrm{n_{eq}}/\mathrm{cm}^2$, or equivalently 1 Grad, is expected on the inner pixel layer for 3000 fb^{-1} integrated luminosity). To build a pixel detector with good performance under these conditions, planar pixel sensors are the baseline technology for layers 2-4, while for layer 1 of barrel and forward pixel sensors, 3D sensors are considered as an option. A variety of n-in-p planar pixel sensors with pixel sizes of 50 × 50 $\mu\mathrm{m}^2$ and 100 × 25 $\mu\mathrm{m}^2$ and active thicknesses between 100 µm and 150 µm have been designed and produced at Hamamatsu Photonics and at FBK on 6 inch wafers. They were bump bonded at Fraunhofer IZM to ROC4Sens and RD53A read-out chips. Apart from the pixel size, the design variants differ with respect to the implantation and metalization geometry as well as the pixel isolation and biasing scheme. To select the most promising design ROC4Sens modules have been irradiated at CERN IRRAD with protons up to $4\cdot 10^{15}\mathrm{n_{eq}}/\mathrm{cm}^2$, at JSI Triga with neutrons up to $8\cdot 10^{15}\mathrm{n_{eq}}/\mathrm{cm}^2$, and RD53A modules with protons up to $1\cdot 10^{16}\mathrm{n_{eq}}/\mathrm{cm}^2$. In this talk results of irradiated as well as unirradiated planar sensor modules tested in the DESY and CERN test beam facility will be presented.

Session 6: CMOS Sensors (1) / 101

Design of fast depleted CMOS pixels for particle detection within the CERN-RD50 collaboration

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The industrial standard High Voltage CMOS (HV-CMOS) technology is a promising candidate for future particle physics experiments. The CERN-RD50 collaboration develops depleted CMOS sensors to improve their features so that they meet the requirements of future particle physics experiments. In this work we propose the design of a new prototype chip based on LFoundry 0.15um technology, which focuses on minimising the leakage current, increasing the break down voltage and improving the pixel speed. The chip consists of several test structures and an 8 x 8 matrix of 60 um x 60 um pixels with analog readout. The aim of this matrix is to improve the processing speed of depleted CMOS sensors while keeping the noise low. Two flavours of pixels have been designed: the continuous pixel and switched pixel. With carefully designing the amplifier and minimising the parasitic capacitance, the continuous pixel can deal with a maximum particle rate of 20M events/sec and the switched pixel is able to deal with as high as 50M events/sec, when the equivalent noise charge (ENC) is kept less than 100 e-.

Session 8: 3D Sensors / 102

Performance of irradiated 3D pixel sensors interconnected to RD53A readout chip

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In this presentation results obtained in beam test experiments with 3D columnar pixel sensors interconnected with the RD53A readout chip will be reported. The 3D pixel sensors were produced at FBK foundry in an R&D agreement with Istituto Nazionale di Fisica Nucleare (INFN, Italy). A few modules, each consisting of a 3D pixel sensor bump-bonded to an RD53A chip, were irradiated at the CERN IRRAD facility to an equivalent fluence of about 1E16 neq/cm2 (1MeV equivalent neutrons). The modules were tested on high energy proton beams, both at CERN H6, using Bdaq53 hardware and software framework, and at the Fermilab Test Beam Facility (FTBF) using Yarr system. Results obtained from the two different systems will be shown, comparing module performance before and

after irradiation. Preliminary analysis of collected data shows hit detection efficiencies measured after irradiation which already at the level of the values required for the upgrade of the inner tracker of the CMS experiment.

Session 1: Tracking detectors for HEP experiments / 103

The CMS Outer Tracker Upgrade for the High Luminosity LHC

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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 $5 - 7.5x10^{34}cm^{-2}s^{-1}$ with an average number of pileup events of 140-200. This will allow the ATLAS and CMS experiments to collect integrated luminosities up to 3000-4500 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. CMS Tracker detector will have to be replaced in order to fully exploit the delivered luminosity and cope with the demanding operating conditions. The new detector will provide robust tracking as well as input for the first level trigger. This report is focusing on the replacement of the CMS Outer Tracker system, describing new layout and technological choices together with some highlights of research and development activities.

Session 2: Planar Sensors (1) / 104

Temperature and frequency dependent CV measurements of highly irradiated ATLAS strip detectors and diodes for impedance spectroscopy

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For medium and highly irradiated silicon devices such as strip detectors or diodes it has been observed that the commonly used CV method for deriving depletion voltage as well as doping level is not as easily applicable as for unirradiated devices. The reason for the arising difficulties is that defects created in silicon can capture and release charge carriers and therefore show a time dependency which affects the CV measurement. To be able to measure highly irradiated sensors a setup has been designed and assembled which enables a CV frequency variation down to 20Hz and temperature control to get down to -20 to -40℃ to investigate the influence of the defects superimposing the geometrical behaviour of the devices. With the measured data an impedance spectroscopy has been performed to differentiate between a capacitive (the ideal case) and a resistive behaviour which allows a determination of an effective time constant for the defects present. Lowering the temperature offers the possibility to increase

this time constant according to Boltzmann's law, and by this an effective energy depth of trap levels can be calculated.

Comparison with unirradiated devices indicates the effects introduced by radiation damage and comparison of diodes with strip detectors shows the role of the segmented front side.
As expected, strip detectors show at high frequencies a deviation from a pure capacitive behaviour which can be explained by the RC element caused by bias resistors. For unirradiated devices no temperature dependence is observed as it would be expected for a constant resistance whereas for irradiated sensors we observe a strong temperature dependece which can only be explained by either a temperature dependent resistance or some interaction with defects in the silicon.
Furthermore, it is shown which frequencies of the CV measurements are an optimal choice for different analysis goals like doping or effective energy depth determination.

Session 9: LGAD (2) / 105

Radiation tolerance of thin LGAD detectors and in-depth study of ILGAD timing performance

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A comprehensive radiation tolerance study of LGAD pad-like sensors manufactured at IMB-CNM and irradiated at CERN's PS-IRRAD proton facility up to a fluence of $3 \times 10^{15} n_{eq}/cm^2$ is presented here. Two different active thicknesses were studied: 35-microns and 50-microns; the effect of carbon co-implantation on the radiation tolerance was also investigated.
The building block LGAD sensor of proposed timing detector systems for the LH-LHC is designed as a pad diode matrix. The timing resolution of this LGAD sensor is severely degraded when the MIP particle hits the inter-pad region since there is no amplification in this region. This limitation is named as the LGAD \textit{fill-factor problem}. To overcome the fill factor problem, a p-in-p LGAD (Inverse LGAD) was introduced. Contrary to the conventional LGAD, the ILGAD has a non-segmented deep p-well (the multiplication layer). An in-depth study of the timing performance of an ILGAD prototype is presented. The realistic systematic effects that may degrade its timing performance are quatified. These studies were performed within the context of the RD50 collaboration and partially funded by the H2020 EU project AIDA-2020.

Session 3: Radiation effects in HEP experiments / 106

Radiation Damage studies with the LHCb VELO

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The VELO detector at the LHCb experiment is a silicon microstrip detector, and has operated for the first two periods of LHC running, with the most irradiated regions receiving fluences of over 4E14, 1MeV n_{eq} cm^{-2} by the end of this period. We review the impact of this radiation on the sensors, considering the impact on the leakage current, charge collection efficiency, cluster finding efficiency, and the depletion voltages, comparing this behaviour to predictions.

A loss of signal amplitude is observed with a dependency on the distance to the routing lines. Using the Perugia n-type bulk model and the Peltola surface damage model it is shown that up to 60% of the charge is collected by routing lines. This is caused by trapping of the otherwise mobile electron accumulation layer at the oxide-silicon interface, causing the shielding effect on the routing lines to be reduced. The observed drop in cluster finding efficiency can be explained by the angular dependence of charge loss to the second metal layer. The efficiency drop as function of track radius and angle is reproduced combining 2D and 3D TCAD simulations.

Session 7: LGAD (1) / 107

Ultra Fast Strip silicon detectors for beam monitoring in proton therapy

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Purpose
Due to their extra advantages, solid state silicon detectors were initially used in nuclear and particle physics experiments and rapidly gained widespread applications in many different fields (space,

medical, etc.). High detection precision, radiation resistance and very good time resolution are their main advantages that overcome many limitations of alternative gas detecting systems.
Low Gain Avalanche Detectors (LGAD) exploit the enhanced signal obtained through an extra doping layer in the conventional p/n junction of the silicon diode, to produce low thicknesses sensors (50μm) which have a faster charge collection (˜1 ns) and an improved time resolution of few 10's of ps under reversed bias voltage (Ultra Fast Silicon Detectors - UFSD) and are well suited for particle counting at high rates (100 MHz with efficiency > 99% in the current prototypes)

UFSDs are under study and development to be applied in particle therapy with two applications in mind: counting the particles delivered to a patient in a therapeutic beam and measuring the beam particle's energy through time-of-flight methods.
Methods
Two different designs of strip detectors have been developed at the Italian National Institute of Nuclear Physics (INFN) of Torino (Italy) in collaboration with the Bruno Kessler Foundation (FBK) of Trento, Italy, where the sensors were produced.
The first was optimized for high rate counting and was produced in two geometries: segmented in 20 short strips (length=15mm; pitch=200μm) or 30 longer strips (length=30mm; pitch=146 μm). The sensors will be read out with new version of TERA chip which was designed and developed at Turin university microelectronics lab to reach fast counting with rates up to 100MHz /channel.
Dedicated pile-up mitigation algorithms are under study and will be implemented in the FPGA where the logical pulses in output for the readout ASIC are collecting for real-time counting and analysis.
The second design was optimized, through a simulation with Geant4, in order to maximize the efficiency of coincidences for single protons passing two thinned sensors aligned to the beam, allowing to measure precisely the time of flight and hence the beam particle's energy. This led to a design with a square shape segmented in 8 strips (length=4mm; pitch=590μm).
Results
Strips sensors were characterized in the laboratory through laser test and I(V) curve studies and were also tested with therapeutic proton beams, with energy ranging from 62 to 227 MeV. Beam test results were obtained analyzing the waveforms collected using a digitizer.
The pileup inefficiency was measured by varying the beam flux and comparing the measured number of protons with the charge collected in a pinpoint dosimeter. The correction methods proposed were found operate up to an average count rate of 40 MHz, where the initial 30% counts loss was reduced to 8%.
The new UFSD sensors designed for energy measurement have not been tested on beam yet. However, Energy measurements using UFSD pads showed possibility to estimate beam energy using time of flight techniques with a statistical error as small as 0.4% at the highest beam energy and detectors at about 1m distance.
Conclusions
Based on the preliminary results, UFSDs are found to be promising for beam qualification and monitoring in Particle Therapy. The aim of this contribution is to report results of lab and beam tests using UFSD strip sensors with a therapeutic proton beam.

Session 11: Technologies and Applications (2) / 108

Relative Stopping Power measurement and metallic prosthesis artifacts reduction in proton Computed Tomography

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In hadron therapy a highly conformed irradiation field is delivered to the target by moving the beam and modulating its energy.
Treatment plans require precisely measured patients' Relative (to water) Stopping Power (RSP) maps, which are currently extracted from X-rays tomographies. This translation unavoidably introduces uncertainties in the determination of the RSP maps.
The employment of protons themselves for the tomographic imaging of the patients (proton Computed Tomography - pCT) could mitigate this source of errors.
Such an application basically needs a tracker, to trace the trajectory of each proton, and a calorimeter, to estimate its energy loss inside the patient.
The Prima-RDH-IRPT collaboration built a 5x20 cm2 field of view pCT apparatus, suitable for preclinical studies, composed of a microstrip silicon tracker and a YaG:Ce calorimeter. We have recently tested this apparatus using appropriate test objects (phantoms) at the Trento Proton Therapy center.
In this contribution, we present tomographies of an electron density calibration phantom and an anthropomorphous head phantom, together with an introduction of the experimental apparatus, the analysis method and the reconstruction algebraic algorithms.
A very good correlation between measured and expected RSP was obtained from the density phantom tomography, with discrepancies less than 1%.
Simultaneously, we produced tomographic sections of the anthropomorphous head, showing some of its anatomical structures.
Furthermore, in comparison with X-rays tomographies, we pointed out the drastic reduction of artifacts due to the presence of metallic prosthesis, which are visible in the anthropomorphous head tomographies.

Session 9: LGAD (2) / 109

Development of large-area UFSD sensors for the CMS MIP Timing Detector

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The CMS MIP Timing Detector, proposed for the HL-LHC upgrade, will be instrumented with O(10) square meters of ultra-fast Silicon detectors (UFSD) in the forward region. These UFSDs are aimed at measuring the time of passage of each track with a precision of about 30 ps. In this presentation, the progress towards the development of this large area detector is reviewed, pointing out the current status and the R&D path toward the final sensor design.

Session 6: CMOS Sensors (1) / 110

Large Area Monolithic Pixel Detectors implemented in 180 nm HVCMOS Process

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HVCMOS pixel detectors developed for applications in particle physics (experiments Mu3e, ATLAS, CLIC) will be presented. The detectors have been implemented in 180 nm commercial HVCMOS process. High resistivity substrates and quadruple well structure have need used. The sensors have

been realized as systems on a chip, they contain active pixel matrix, readout circuits and digital blocks. Design and measurement results will be presented.

Session 1: Tracking detectors for HEP experiments / 111

Results and perspectives from RD53 on the Next Generation Readout Chips for HL-LHC silicon pixel detector phase 2 upgrades

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The Phase 2 upgrades of silicon pixel detectors at HL-LHC experiments feature extreme requirements, such as: 50um x50um pixels, high rate (3 GHzx/cm2) unprecedented radiation levels (1 Grad), high readout speed, serial powering. As a consequence a new readout chip is required

The RD53 collaboration has designed RD53A, a large scale chip demonstrator designed in 65 nm CMOS technology, integrating a matrix of 400x192 pixels. It features design variations in the analog and digital pixel matrix for testing purposes.
The chip size is 20.0mm by 11.8 mm. RD53A is not intended to be a production IC for use in an experiment, and contains design variations for testing purposes, making the pixel matrix non-uniform. The 400x192 pixel matrix features in fact three flavors of analog front-ends and two digital readout architectures. The pixel matrix is built up of 8 by 8 pixel cores. In addition the 64 front-ends within a core are organized in 16 so-called analog islands with 4 fronts ends each, which are embedded in a flat digital synthesized sea.

RD53A has been submitted in August 2017, was received in December 2017 and the whole 2018 year has been dedicated to its comprehensive characterisation.

Test results on single chips including performance qualification for the three analog front-ends will be presented. In addition, the ongoing activities in view of the final chip implementation for the experiments will be outlined

Session 9: LGAD (2) / 112

Annealing and Characterization of Irradiated Low Gain Avalanche Detectors

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Low Gain Avalanche Detectors are a promising technology in the field of ultra fast timing detectors. Studies of the radiation hardness of LGADs have raised questions about the relation between the onset of multiplication and the depletion of the amplification layer.
To address these questions and to investigate the change of gain and the electric field after irradiation and annealing, LGADs were irradiated with 24 GeV/c-protons to a fluence of 1e14 neq/cm² and annealed at 60℃. TCT, edge-TCT, IV and CV measurements were carried out after consecutive annealing steps. After a reduction of gain after irradiation, no effect of annealing was observed. The onset voltage of charge multiplication measured with TCT changes with annealing and is believed to be related to a change in the electric field profile inside the bulk of the sensor.

Session 1: Tracking detectors for HEP experiments / 113

Prototyping and System Testing for the ATLAS ITK Pixel Detector Upgrade

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In 2026 the High-Luminosity Large Hadron Collider (HL-LHC) is scheduled to replace the successful LHC. The HL-LHC will deliver up to ten times the amount of data as the currently running machine, owing to a higher instantaneous luminosity. This increased luminosity will result not only in a much more demanding environment in terms of radiation damage, but also in up to 200 interactions happening simultaneously in one bunch crossing –conditions the current ATLAS tracking detectors can not cope with.
It is therefore foreseen to replace the whole inner tracking system of ATLAS with an all-silicon tracker comprising pixels in the inner layer and strips of varying length in the outer layer. The tracker will cover a pseudorapity region up to eta<4 considerably extending the range of the current tracking capabilities.
The Pixel detector will consist of five layers in the central region and multiple disk-like structures in the forward regions. The total silicon area will amount to about 13 m2 with a total of nearly 10000 individual silicon pixel modules. To provide sufficient radiation tolerance, different sensor types will be employed depending on the region of the detector. A radiation hard readout chip is developed in cooperation with the CMS collaboration within the RD53 Collaboration in 65 nm technology. To be able to accommodate the much more advanced detector within the envelopes of the existing experiment, novel powering, control and data transmission techniques are being employed.
To prototype the system and integration aspects of these new approaches, an extended system testing program is currently exercised. As first prototypes of the foreseen readout ASIC only become available now, a complete first testing campaign has been performed on modules based on the readout frontend of the ATLAS insertable b-layer, the Fei4 ASIC[1]. The Fei4 includes already many of the features of the future readout chip and allows to test a wide range of system aspects.
Modules are assembled in a distributed fashion over many participating institutes. Their testing, shipment and continuous quality control is exercised. In parallel, fully functional local supports are constructed and their mechanical, thermal and electrical performance is tested. Modules and local supports are combined into system tests which allows to exercise the integration and study system aspects of the planned detector layout. As the detector will for the first time employ a serial powering scheme [2-4], particular attention is put on all aspects related to the powering concept, its control and its influence on the operation and performance of the detector.
In this talk, experience and results from various system tests will be discussed and an outlook on the future plans for prototyping, system testing and integration will be given.

References:
[1] M. Garcia-Sciveres et al., NIM A636 (2010), 155
[2] T. Stockmanns et al., NIM A511 (2003), 174-179
[3] D. Bao Ta et al., NIM A557 (2006), 445-459
[4] L. Gonella et al., JINST 5 (2010), C12002

Session 5: Planar Sensors (2) / 114

Microelectronic Test Structures for the Development of a Strip Sensor Technology for High Energy Physics Experiments

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The planned upgrade of the Large Hadron Collider (HL-LHC) requires the development of new tracking silicon sensors for the future ATLAS detector. These new devices must fulfil the specifications established by the ATLAS collaboration, in order to guarantee the proper performance of the tracking system during the life time of the experiment. A prototype strip sensor layout have been designed at IMB-CNM using a new python-based layout tool, and fabricated in 6-inches substrates by the semiconductor manufacturing company Infineon Technologies AG.

This work presents a set of test structures, capable to evaluate key device elements as the implant and metal resistivity, the bias resistance, the coupling capacitance between strip implant and strip metal, the study of the surface leakage current, or the influence of the sensor edge design in the device breakdown voltage. A complete analysis of these parameters pre-irradiation and after a proton and gamma irradiations, up to doses similar to the ones expected in the future ATLAS Inner-Tracker (ITk), is presented. This study shows the relevance of microelectronic test structures to monitor and improve the technology of tracking silicon sensors for High Energy Physics Experiments.

Session 3: Radiation effects in HEP experiments / 115

New simulation of particle fluence for the LHCb VELO Upgrade

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The LHCb experiment is dedicated to studying CP violation in heavy flavour quark sector, rare decays of mesons containing beauty and charm quarks and searching for New Physics. This challenging physics programme requires excellent tracking system capable of providing high spatial resolution for single hit detection, best possible impact parameter and primary and secondary vertices reconstruction resolution and time resolution of tens of femto-seconds. The central part of the LHCb tracking system constitute Vertex Locator (VELO), built using silicon micro-strip technology. During Run I and Run II data taking periods (2010 –2012 and 2015 –2018 respectively) the detector was operating as close as 8 mm from the LHC beams and registered a particle fluence that ranged up to 10ˆ15 1MeV neq/cm2 with very non uniform radiation field. New VELO pixel sensors, planned for RUN III, will be situated at the distance of approximately 5 mm from the proton beams and will have to withstand almost ten times higher particle fluences. A new simulation of particle fluence with the FLUKA package for the LHCb VELO Upgrade is described in this presentation. Comparison of the Run II simulation with the measurements is discussed as well.

Session 6: CMOS Sensors (1) / 116

Results of the Malta CMOS pixel detector prototype for the ATLAS Pixel ITK

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The upgrade of the ATLAS experiment for the High-Luminosity LHC requires the installation of a new Inner Tracker detector to cope with the 5 fold increase in luminosity and a 10 fold increase in number of interactions per bunch crossing. A Monolithic Active Pixel Sensor prototype, MALTA, has been developed on 180 nm TowerJazz CMOS imaging technology, following the latest developments in CMOS sensor processing combining high-resistivity substrates with on-chip high-voltage biasing to achieve a large depleted active sensor volumes, to meet the radiation hardness requirements (1.5x10^15 1 MeV neq/cm2) of the outer barrel layers of the ITK Pixel detector. MALTA combines low noise (ENC<20 e-) and low power operation (1uW/pixel) with a fast signal response (25 ns bunch crossing) in small pixel size (36.4 x 36.4 um2), and a small collection electrode (3um), with a novel high-speed asynchronous readout architecture to cope with the high hit-rates expected at HL-LHC. This contribution will present the results from the extensive lab testing and characterisation in particle beam tests have been conducted on this design and present the improvements that are being implemented in the next versions of the chip.

Session 5: Planar Sensors (2) / 117

Development of Large Area Silicon Drift Detectors at FBK for Astrophysical Applications

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We report on the activity carried out at FBK in partnership with INFN and INAF, supported by ASI, aimed at the development of large area (about 95cm2) Silicon Drift Detectors for astrophysical applications. The presentation is focused on a brief description of the state of the art of the general technological aspects related to the production of these devices for LOFT (Large Observatory for X-ray Timing) mission of the European Space Agency (ESA) and the eXTP mission (enhanced X-ray Timing and Polarimetry) of the Chinese Academy of Science.

Session 11: Technologies and Applications (2) / 118

DEEP_3D Project: a monolithic 3D detector for neutron imaging

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Neutron imaging provides information on materials and structures otherwise opaque to X-rays. Neutron sensors with high spatial resolution and high efficiency find application on disparate number of fields.
The detection of neutrons by using semiconductor materials, that are are not sensitive to neutrons, act by using converter materials that can emit light, charged particles, gamma-rays or their combinations.
The most important converter materials are Boron-10 and Lithium-6, which emit mainly charged particles, whereas Gadolinium-157 and Cadmium-113 emit gamma rays and secondary electrons.
The aim of DEEP_3D (Detectors for neutron imaging with Embedded Electronics Produced in 3D technology) project, financed by INFN V commission, is the realization of a 3D monolithic detectors for neutrons coupled with boron, lithium or their combination.
The talk will cover aspects relevant to the electronics design, layout and validation of the key technological steps of these innovative 3D pixel sensors.

Session 8: 3D Sensors / 119

Radiation hard 3D silicon pixel sensors with thin active substrates

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A new generation of 3D pixel detectors with high granularity and thin active substrates is being developed for the upgrade of the ATLAS Inner Tracker (ITk) at HL-LHC. The new sensors will have to fulfil the requirements for the innermost pixel layers in terms of radiation hardness and rate capabilities.

Two productions of 3D sensors compatible with the new RD53A chip (the prototype of the future ITk chip) have been carried out at CNM, Barcelona. Both feature a single side process in which all columns are etched from the top-side. This allows the use of support wafers to keep the structure rigidity and achieve thin active substrates.

The first CNM production used Silicon-on-Insulator (SOI) wafers which needed to be etched in order to provide bias to the backside. The second production instead uses Silicon-on-Silicon (Si-Si) wafers

where the bias can be provided directly through the conductive silicon support avoiding further stress of the structure.

Both productions include 3D silicon pixel sensors with two pixel cell sizes, 50x50 μm^2 and 25x100 μm^2, and active thicknesses of 150 µm which are compatible with the baseline of the ITk innermost pixel layer.
Full modules with sensors from the SOI production have been assembled at IFAE and characterised at beam tests before and after proton irradiation at the KIT Cyclotron.
Results of these studies and very first measurements of the new Si-Si production will be presented.

Session 6: CMOS Sensors (1) / 120

Characterization of the 180nm HV-CMOS ATLASPix large-fill factor Monolithic prototype

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The ATLASPix is a monolithic pixel sensor designed in ams aH18 HV-CMOS technology to demonstrate the achievable performances and demonstrate the radiation hardness of the technology. The prototypes were produced in an engineering run on three substrate resistivities spanning from 20 to 200 $\Omega \cdot cm$. We present here the characterization in laboratory and test beam of the produced samples. Unirradiated, proton, and neutron irradiated samples were tested for efficiency, spatial and temporal resolution. The functionality of the different design blocks for tolerance to TID was also evaluated.

Session 8: 3D Sensors / 121

Test beam characterization of irradiated SINTEF 3D pixel sensors

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The upcoming High Luminosity LHC (HL-LHC) puts stringent requirements on the tracking detectors situated closest to the interaction point in the planned Inner Tracker (ITk) of the ATLAS experiment. 3D pixel detectors have been proposed as a candidate for the innermost layers of the ITk since these detectors decouple the sensor thickness and the inter-electrode spacing, effectively increasing the radiation hardness.

The SINTEF prototyping R&D run (run 4) for radiation hard 3D silicon pixel detectors features ultra thin device layouts down to 100 and 50um active thicknesses, with a variety of compatibility. The layouts discussed here are compatible with the ATLAS pixel readout ASIC RD53A, allowing nominal signal thresholds below 1ke-.
The flip-chip and UBM processing steps was done by Fraunhofer IZM in Berlin, and these hybrids were mounted on Single Chip Cards (SCC) and bonded at the University of Oslo.

Noise vs. thickness scans demonstrates that the capacitance is dominated by device thickness, inferring less intrinsic noise in thinner devices.

Pre-irradiation tests, performed at the SPS testbeam facility at CERN shows an efficiency loss that is consistent with the non-active column geometry of the 50x50 1E pixel matrix, giving an overall efficiency > 97%. While devices irradiated to a fluence of 5x1015 neqcm-2 have an efficiency within optimistic expectations for such thin devices.

Session 4: Technologies and Applications (1) / 122

The development of a 3D detector on a hydrogenated amorphous silicon substrate

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The vertex detectors of the future hadronic colliders will operate under proton fluencies above 10E16 p/cmsq. Crystalline Silicon detector technology, up to now, has kept the pace of the increasing fluencies in the LHC era and it is still the prevalent vertex detector technology for the present and for the immediate future. Looking ahead in time an alternative solution for such a detector has to be found because for the future there is no guarantee that Crystalline Silicon will hold this challenge. Hydrogenated amorphous silicon (a-Si:H) has outstanding radiation hardness performances although the development of planar detectors did not have very successful results. A possible way to overcome the difficulties of building an a-Si:H detector can be solved by using the 3D-technology. For these reasons the development of hydrogenated amorphous silicon vertex detectors based on 3D-technology have been proposed and the technological solutions in order to build these detectors are described in this talk.

Session 10: CMOS Sensors (2) / 123

Design optimisation of depleted CMOS detectors using TCAD simulations within the CERN-RD50 collaboration

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In this work we report the main TCAD simulation results of a depleted CMOS detector designed in the 150 nm HV-CMOS process from LFoundry. These results have been used in the design of a test chip, the second prototype developed by the CERN-RD50 collaboration (RD50-MPW2), recently submitted for fabrication. The main aim of this study is to optimise the leakage problem seen in laboratory measurements of the first prototype developed by the collaboration (RD50-MPW1).

In order to minimize the leakage current in the second prototype, two design choices have been made. Firstly, particular attention has been paid to blocking the generation of certain filling layers added by the foundry during the post-processing stage. Secondly, a series of guard rings have been included around the device to prevent the sensor depletion region from coming into contact with the edge of the chip. These investigations will be presented. In addition, TCAD simulations have also been used to identify the best conditions for increasing the voltage applied to the sensor thus improving its radiation tolerance. The analysis takes into account the effect of the distance between the pixel bias ring and the sensing diode, and different shapes of the sensing diode.

Session 6: CMOS Sensors (1) / 124

Fully depleted monolithic sensors in 110 nm CMOS

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Fully depleted monolithic CMOS sensors allow the prompt collection by drift of large signals. They therefore can offer better signal-to-noise ratio, time resolution and radiation tolerance with respect to conventional solutions. In this presentation, a technology that, thanks to a patterned back-side, allows a full depletion of the substrate in the 100 um - 400 um range is presented. The technology is fully compatible with a standard CMOS process. The results obtained on first prototypes fabricated in a 110 nm PDK are presented and near term plans to consolidate the technology platform will be discussed.

Session 10: CMOS Sensors (2) / 125

Transient Current Technique characterization of HV-CMOS sensor prototypes after irradiation

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Silicon detectors built in high-voltage and high-resistivity CMOS technology are an interesting options for the outermost pixel layers of ITk (Inner Tracker), the new all-silicon tracking system foreseen for the ATLAS experiment upgrade for the high luminosity LHC program. They are less expensive and easier to produce with respect to standard hybrid silicon pixel detectors, which would represent an important advantage, given the large area silicon detector to be built. Furthermore they allow to reduce the material budget before the calorimeter.
This technology must be carefully tested and characterized: one of the techniques used for this purpose is the TCT (Transient Current Technique): electron-holes pairs are produced in a precise position of the detector using a IR laser beam, allowing to probe parameters like the depletion depth of the sensor.
TCT measurements have been performed on the H35DEMO chip, produced by ams, before and after proton and neutron irradiation. The proton irradiation have been performed at the Bern Inselspital cyclotron (18 MeV) and at the Proton Syncrotron at CERN (24 GeV) up to more that 10^{15} 1 MeV neq/cm^2. The neutron irradiation has been performed at the Jožef Stefan Institute reactor in Ljubljana up to $2 \cdot 10^{15}$ 1 MeV neq/cm^2. Measurement technique, data analysis, issues encountered and results will be presented.

Session 5: Planar Sensors (2) / 126

NUV-sensitive SiPMs developed at FBK and Applications

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Near Ultraviolet, High Density (NUV-HD) SiPM technology, developed at FBK (Trento, Italy), is based on a p-on-n junction and features peak photon-detection efficiency (PDE) in excess of 60% at 410 nm. Dark Count Rate (DCR) is in the order of 100 kHz/mm2, correlated noise is 10% at 55% PDE and microcell pitch ranges between 15 um and 40 um. Sensitivity remains high down to 320 nm, with a PDE of 48% (including package).
Single Photon Timing Resolution (SPTR) of NUV-HD SiPMs was below 30 ps FWHM, when measured on single SPAD with covered edges, and increased to 75 and 180 ps FWHM for SiPMs with active areas of 1x1 mm2 and 3x3 mm2, respectively, because of the electronic noise. NUV-HD SiPMs provide state-of-the art 85 ps FWHM coincidence resolving time (CRT) in PET applications, reading out the light of a Ca co-doped LYSO crystal.
Recent interest in the SiPM readout of liquid scintillators (mainly LAr and LXe) triggered the development of a cryogenic variant of the NUV-HD technology (NUV-HD-Cryo), which is optimized

for operation at cryogenic temperatures and features a DCR of a few mHz/mm2 at 77 K. At this temperature, few-photon counting capability was demonstrated, with S/N larger than 14, using a 24 cm2 SiPM array coupled to a single analog readout channel. Ongoing optimizations include the development of devices with extended deep-UV sensitivity: preliminary results show a PDE of 20 % at 178 nm.

Session 7: LGAD (1) / 127

Latest developments of Low Gain Avalanche Detectors at FBK

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Several efforts have been done in the last years at FBK to develop a new generation of Low Gain Silicon Detectors for tracking and timing applications in HEP experiments. The last UFSD3 production has been devoted to studying specific methods to improve the radiation hardness, as requested by the future Endcap Timing Layer of CMS at the High Luminosity LHC. Moreover, new microfabrication methodologies, like as stepper photolithography and photocomposition technique have been implemented in order to demonstrate the production feasibility of large-area and low-defectiveness sensors. Electrical and functional characterization, carried out by FBK and INFN Torino, will be reported and discussed. Plans for future LGAD productions at FBK will also be discussed. In particular, the ongoing activities are devoted to the development of a new LGAD design, based on the trench-isolation technique (TI-LGAD). This new scheme is very promising in reducing the inter-pad distance and then the minimum achievable pixel dimension of the sensor.

Session 4: Technologies and Applications (1) / 128

Timing performance of small cell 3D silicon detectors

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A silicon 3D detector with a single cell of 50x50 um2 was produced and evaluated for timing applications. The measurements of time resolution were performed for 90Sr electrons with dedicated electronics used also for determining time resolution of Low Gain Avalanche Detectors (LGADs). The measurements were compared to those with LGADs and also simulations. The studies showed that the dominant contribution to the timing resolution comes from the time walk originating from different induced current shapes for hits over the cell area. This contributiondecreases with higher bias voltages, lower temperatures and smaller cell sizes. It is around 30 ps for a 3D detector of 50x50 um2 cell at 150 V and -20C, which is comparable to the time walk due to Landau fluctuations in LGADs. It even improves for inclined tracks and larger pads composed of multiple cells. A good agreement between measurements and simulations was obtained, thus validating the simulation results.

Session 10: CMOS Sensors (2) / 130

Parametrisation of the response of ALPIDE Monolithic Active Pixel Sensors to low energy nuclei

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We report on the characterisation of the response of the ALPIDE MAP sensor to nuclei of energy 20-220 MeV/a.m.u.. ALPIDE has been designed for the upgrade of ALICE experiment at the LHC: the new tracker will be fully efficient, with improved sensitivity, for particles with transverse velocity larger than 0.7c and charge ±1. The operating regime considered in this work is really different: slower nuclei release much more energy in silicon, proportionally to Z2/β2, increasing signals by up to orders of magnitude in amplitude and spatial extension. Since the only available observable quantity is the cluster size understanding and parametrising the response of front-end electronics for different settings of current thresholds, bias potential and acquisition time, is far from trivial. We provide here results from measurements taken in Trento (protons 20-220 MeV) and in Catania (H, He, C, O nuclei 62 MeV/a.m.u.). The agreement with predictions from Geant4 Monte Carlo simulations and TCAD calculations proved sufficiently good to analytically parametrise the response of ALPIDE to low energy nuclei.

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Visit of Underground archeological site

(https://www.cultura.trentino.it/eng/Cultural-venues/All-cultural-venues/Museums-and-collections/Tridentum.-S.A.S.S.-Underground-Archaeological-Site-Sas)

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Welcome cocktail

On site

Session 1: Tracking detectors for HEP experiments / 133

The Lorentz Angle in the ATLAS Pixel Detector: Effects of Operating Parameters and Radiation Damage

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The ATLAS pixel sensors use a non-zero Lorentz angle to increase the spread of the charge and thus improve the achievable spatial resolution. The value of the Lorentz angle in the four pixel layers is constantly monitored during data taking. The presentation summarises the results of the study of its magnitude as a function of the operational parameters (temperature and depletion voltage) and of the bulk radiation damage experienced by the sensors. Results from cosmic ray and collision data are compared to detailed simulation predictions including radiation damage effects.