5th Allpix Squared User Workshop

Wednesday, 22 May 2024 - Friday, 24 May 2024

University of Oxford

Book of Abstracts

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Simulating a cosmic ray detector for physics outreach projects

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Encouraging young students to study STEM subjects is an important responsibility of the scientific community. Small-scale detectors in particle physics outreach serve as an excellent gateway for discussing physics concepts. To determine the feasibility of the ITk-pix sensor for use in an outreach cosmic ray detector, a simulation has been developed with Allpix-Squared. Using the Deposition-Cosmics module to accurately simulate the cosmic muon environment at sea level, eight RD53A sensors were tested with up to 5,000,000 events. Simulation showed that this number of sensors will have a high enough area to produce a detection rate of 36.37 muons per minute, providing enough data for an engaging display. This indicates that the detector will be successful in facilitating the introduction of particle physics to high school students.

Will the talk be given in person or remotely?:

In person

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Performance of ATLAS ITk strip detectors in test beams and simulations

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The current Inner Detector of the ATLAS experiment is to be replaced with the all-silicon Inner Tracker (ITk) to satisfy more demanding performance requirements during the High-Luminosity LHC runs. The performance of ATLAS ITk strip module prototypes has been extensively evaluated using high-energy particle beams and, complementary to the measurements, full simulations of the experimental setup have been carried out using the Allpix-Squared framework.

This contribution focuses on comparison of key performance metrics of strip detectors obtained using Allpix-Squared simulations and test beam measurements at the DESY II test beam facility. The effect of the particle beam impacting the tested module at non-perpendicular angles is also explored and discussed.

Will the talk be given in person or remotely?:

In person

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A lightweight algorithm to model Radiation Damage Effects in Monte Carlo Events for High-Luminosity LHC experiments

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Radiation damage significantly impacts the performance of silicon tracking detectors in Large Hadron Collider (LHC) experiments such as ATLAS and CMS, with signal reduction being the most critical effect. While adjusting sensor bias voltage and detection thresholds can help mitigate these effects, generating simulated data that accurately mirrors the performance evolution with the accumulation of luminosity, hence fluence, is crucial.

The ATLAS and CMS collaborations have developed and implemented algorithms to correct simulated Monte Carlo (MC) events for radiation damage effects, achieving impressive agreement between collision data and simulated events.
In preparation for the high-luminosity phase (HL-LHC), the demand for a faster ATLAS MC production algorithm becomes imperative due to escalating collision rates, events, tracks, and hits, imposing strict constraints on available computing resources. This talk outlines the philosophy behind the new algorithm, its implementation strategy, and the essential components involved. The presentation also includes results from closure tests and first evaluation of algorithm performance.

Will the talk be given in person or remotely?:

Remotely

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Simulation and measurement of charge transport in the periphery of planar silicon sensors to understand humidity-induced breakdown

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The top oxide/nitride passivation layer of silicon sensors is known to be sensitive to ambient humidity and the sheet resistance of the interface with the air decreases in humid environments. Planar silicon sensors are usually operated at high bias voltages which, if operated in a humid environment, can lead to charging up of the passivation surface which in turn can lead to undesirable effects such as early electrical breakdown.

To explore the exact mechanisms behind this phenomenon, Synopsys TCAD was used to simulate the electrical behavior of the surface of a test structure for different relative humidity. The influence of humidity is characterized by the humidity-dependent mobility of impurity ions on the outer passivation surface. To verify the results of the TCAD simulation, Transient Current Technique (laser) measurements and accompanying Allpix Squared simulations have been performed in the edge region of the test structure, where humidity-related breakdown was observed.

For these simulations in the edge region, charge transport at the Si-SiO_2 interface had to be implemented in Allpix Squared. This implementation models the dynamics as charges propagate within the inversion layer. Comparing the simulations to the TCT measurements helps to validate the

TCAD simulation and to gain a better understanding of surface TCT measurements in the edge region of sensors, enabling further exploration of the humidity dependence of surface breakdown.

Will the talk be given in person or remotely?:

In person

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Spectroscopic X-ray Imaging with improved sub-pixel resolution and spectral fidelity thanks to probability distribution maps for initial position and energy for Timepix3 detectors using Allpix squared

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Using the simulation tool Allpix squared,
the center of mass (c.m) deposition maps were simulated for a wide range of monochromatic X-ray beams irradiating Silicon and Cadmium Telluride sensors of Timepix3.

More specifically, the coupling of the diffusion and repulsion of the charge carriers inside the sensor material, following the model of Benoit et al, were simulated as an Allpixˆ2 plugin.
Both the experimental measurements and the simulations generated the Time over Threshold (ToT) values, which were properly calibrated to energy values (keV). These energy values were used as weight for the calculation of the center of mass deposition maps of the different clusters sizes from 1 to 4 pixels. By matching the cluster energy and sub-pixel position calculated from the cluster shapes obtained by the Timepix3 simulation with the respective values derived from the GEANT4 charge deposition information it was possible to generate probability maps for each cluster position and energy.

To experimentally verify the simulated correction maps the initial position probability maps were applied to experimental data acquired with an Am-241 source. The c.m correction maps lead to a more uniformly irradiated final image. Furthermore, the initial energy probability maps were applied to experimental energy spectra acquired with an Am-241 source.

This research includes the calculation of the probability maps for Timepix3 with Cadmium Telluride semiconductor material, which is of interest for medical applications.

Will the talk be given in person or remotely?:

In person

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Extending Allpix Squared to Optimise a Minimum Ionising Particle Generator

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Access to a source of minimum ionising particles (MIPs) is essential when developing detectors for particle physics. Efforts by MPhys students at Oxford's OPMD group have led to a low-cost functioning MIP generator, built from a strontium-90 beta source and magnetic dipole filter.

Allpix Squared was an obvious choice to model optimising changes, for instance varying the magnetic field strength, or the filtering chamber's entrance and exit collimation. However, the framework's interface with other elements of our open-source simulation chain was mixed. Whilst geometry definitions from FreeCAD could already be imported in GDML format, the ability to load a spacially-varying magnetic field did not exist.

We extended the framework's MagneticFieldReader module to allow this functionality, along with making modifications to the DepositionGeant4 module to store a particle's energy as it arrives at (or is created within) a sensor. Modifications to bias the emission direction of a radioactive source were also used to reduce compute time.

Results of simulating the MIP generator match our broad expectations from a basic analytic evaluation, whilst preliminary experimental comparisons using a Timepix3 detector have shown some agreement, but need further investigation. Overall, this work has enabled modifications to the MIP generator that resulted in an improved output purity, and a greatly-increased throughput.

Will the talk be given in person or remotely?:

In person

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TCAD and Monte Carlo simulations of 3D pixel sensors

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Unlike traditional planar sensors in which different types of electrodes reside on the surfaces of the wafer, 3D sensors have both types of electrodes penetrating deep into the silicon bulk. This special configuration allows for the separation of the charge drift distance from the wafer's thickness, enabling 3D sensors to provide high temporal resolution and strong radiation hardness through adjustment of the inter electrode spacing.
Decades of R&D of 3D sensors have yielded excellent results, including the the 3D Double-side Double-column sensors (3D-DDTC) installed in the ATLAS Inner B-Layer (IBL). However, the double-sided technology necessitates thick wafers to alleviate wafer bowing issues, limiting the achievable minimum pixel size. Consequently, extensive studies have been conducted on 3D sensors based on single-sided technology, resulting in promising outcomes and paving the way for a new generation of 3D sensors known as small-pitch 3D pixel sensors, chosen for integration into the ATLAS Inner Tracker (ITk).
In addition to cylindrical electrodes, trench-shaped electrodes are also feasible. The unique shape of these electrodes ensures a uniform distribution of the electric field, thereby promises even better temporal resolution and radiation hardness. Preliminary test results have demonstrated a temporal resolution of approximately 10 ps, with no degradation observed after exposure to radiation damage levels up to $3.5*10^{16}$ n_{eq}/cm^2.

This presentation provides an overview of the development of 3D sensors with various designs. Furthermore, TCAD simulations and Monte Carlo simulations based on Allpix^2 to evaluate the intrinsic performance of 3D pixel silicon sensors will be discussed.

Will the talk be given in person or remotely?:

In person

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Experiments in DIY TCAD

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Over the last few years in the OPMD group we have been experimenting with developing our own "in house" semiconductor solver. Work is still in the early stages but we currently have a drift-diffusion solver capable of handling 2D devices, and with ability to implement various mobility and generation/recombination models. The simulator is all based on open source libraries, in particular the DUNE framework (https://dune-project.org/). It was developed originally to simulate charge packet shapes in CCD detectors but has applications also in particle physics detectors.

We will present the developments of our simulator including lessons learned about how to implement semiconductor solvers for others who may be interested, some results on the usual device structures, and the possibility of integrating our simulator with allpixˆ2, ESA pyxel, and other frameworks to provide electric field structure information

Will the talk be given in person or remotely?:

In person

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Simulation of CMOS Strip Sensors

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In high-energy physics, there is a need to investigate silicon sensor concepts that offer large-area coverage and cost-efficiency.
Sensors based on the CMOS imaging technologies present an alternative silicon sensor concept for particle tracking detectors. As this technology is a standard- ised industry process, it can provide a lower sensor production cost and access to fast and large-scale production from various 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. The implant design varies in doping concentration and width of the strip implant, making it possible to study various depletion concepts and electric field configurations.
Initial simulations of the strip sensor response were conducted using the Allpix2 framework. This study provides a first glimpse into the electric field within the sensor and its effect on generated charge carriers, based on TCAD device simulations. A comparison of different implant designs is made regarding their cluster size, which is then compared to data acquired at the DESY II test beam facility.

Will the talk be given in person or remotely?:

In person

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TCT simulations of synthetic diamonds using Allpix squared

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We have been validating the implementation of the diamond as a sensor material in Allpix Squared using the TCT approach. The transient current technique (TCT) is a powerful technique for investigating the charge carrier properties of a sensor material. Low field mobility parameters were extracted from the RD42 test beam data. TCT signals were simulated both for single and polycrystalline synthetic diamonds. A trapping model for grain boundaries of pcCVD diamond was implemented. This model assumes pcCVD diamonds as pre-irradiated scCVD (RD42, 2018). Simulation results are in agreement with the experimental results. I will present the simulation results and their comparison with the experimental results for single and polycrystalline CVD diamonds.

RD42, L. B. (2018). Diamond Detectors for high energy physics experiments. JINST 13 C01029.

Will the talk be given in person or remotely?:

In person

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Simulation of Hexagonal Pixel Configurations in Monolithic Active Pixel Sensors

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One of the aspects of the DESY Tangerine Project involves developing monolithic active pixel sensors (MAPS), which have been produced using 65 nm CMOS imaging technology and small collection electrodes. As a result, accurate simulations have shown to be crucial in assessing and predicting sensor performance, resulting in enhanced performance designs.

A simulation strategy that uses Technology Computer-Aided Design (TCAD) can combine Monte Carlo simulation with electrostatic field simulations to achieve this kind of characterization. The conventional square/rectangular pixel arrangements offer convenient fabrication and readout electronics, along with well-established data processing and analysis methods. The presented study examines the possible advantages of using a hexagonal pixel grid configuration over square or rectangular pixel layouts.

Efficiency, cluster size, and spatial resolution are used to evaluate these different configurations, and the square and hexagonal pixel geometries are compared. Additionally, time-dependent detector behaviour in response to incident particles of hexagonal pixel is simulated by means of transient simulations in detectors. The investigations conducted in this work underscore the potential of the hexagonal pixel grid to enhance the performance of MAPS in high-energy physics experiments.

Will the talk be given in person or remotely?:

Remotely

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Transient and SPICE Simulations of silicon sensors in the 65nm CMOS imaging process

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The goal of the TANGERINE project is to develop the next generation of monolithic silicon pixel detectors using a 65 nm CMOS imaging process, which offers a higher logic density and overall lower power consumption compared to currently utilized feature sizes.

The Analogue Pixel Test Structure (APTS) are sensors designed and developed by ALICE with readout boards developed by CERN EP R&D using a 65 nm imaging process to study the capabilities of this technology.

A combination of Technology Computer-Aided Design (TCAD) and Monte Carlo (MC) simulations are used to understand how the detector design affects the signal development in these sensors. Allpix Squared utilizes the electric field and generic doping profiles obtained with TCAD simulations to simulate the contribution of the detector response. The output is then introduced into a SPICE (Simulation Program with Integrated Circuit Emphasis) software to reproduce the electronics response used as readout in the actual sensors, which can be later compared with data obtained during laboratory characterizations and test beams.

In this contribution, the setup, the output of the detector and electronics response, and preliminary timing results will be presented.

Will the talk be given in person or remotely?:

Remotely

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electronCT Simulations with Allpix Squared

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electronCT is a rising project aimed at investigating the exploitation of multiple coulomb scattering of electrons in matter for tomographic imaging. One potential use case lies in the context of radiation therapy with electrons of energies in the range of 100 to 250 MeV. In this environment, the electronCT technique could be used to image the tumour with high precision just before the treatment using the same accelerator.

Having the proof of principle of this new imaging technique already established at beam tests at the ARES accelerator at DESY, Hamburg, it is vital to understand how the quality of imaging changes due to environmental factors. These factors include changes of beam parameters and the impact of the detector design and technology on the image quality. This task requires realistic and well controllable simulations of the beam setup. In this contribution, we present how Allpix Squared is used for these simulations and present preliminary results obtained from these simulation studies.

Will the talk be given in person or remotely?:

Remotely

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Simulating monolithic active pixel sensors: A technology-independent approach using generic doping profiles

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The optimisation of the charge collection behaviour in the sensitive region of CMOS sensors with nonlinear electric fields requires precise simulations, and this can be achieved by a combination of finite-element electrostatic field simulations and Monte Carlo methods.
This talk aims to demonstrate that by making basic assumptions and performing simulations based on the fundamental principles of silicon detectors and using generic doping profiles, performance parameters of MAPS can be inferred and compared for different sensor geometries. A procedure for this will be described in detail, along with example results. The described procedure utilises Sentaurus TCAD together with Allpix Squared, and serves as a toolbox for performing sensor response simulations without detailed knowledge of the sensor doping concentrations and manufacturing process.

Will the talk be given in person or remotely?:

In person

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Evaluation of Allpix Squared simulations for laser-TCT experiments: data/MC comparison

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The Transient Current Technique (TCT) is a flexible laboratory characterization method for silicon sensors. By precisely injecting charges with laser pulses and analysing waveforms, produced as the deposited charge drifts in the sensor bulk, one may experimentally study different charge collection features of the sensor under test. The Allpix Squared framework offers capabilities of simulation of such experiments, thanks to a dedicated DepositionLaser module, which models the interaction of laser light with silicon sensors.

The goal of this work is to validate performance of Allpix^2 for laser-TCT simulations. This talk features data/MC comparisons of transient current measurements, performed on a CMS Phase-2 strip sensor demonstrator. The experimental data were taken by the means of laser charge injections, using red and infrared lasers, and pulses of different durations (picosecond and nanosecond range). The Allpix^2 transient simulation was performed with DepositonLaser module. For precise modelling of the sensor features, such as electric field and weighting potential, TCAD was used.

Will the talk be given in person or remotely?:

Remotely

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Timing Resolution Studies for the MightyPix: A proposal

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Abstract for Allpix2

During long shutdown 4 of the LHC, there will be an upgrade to the LHCb tracking systems to allow the experiment to operate at higher luminosities ($1.5 \times 10^{34} cm^{-2} s^{-1}$). The downstream tracker, known as the Mighty Tracker, is made up of two different detection mediums: scintillating fibres and monolithic CMOS sensors called MightyPix. The MightyPix design is based on knowledge from the ATLASPix1 and the MuPix2. A key specification of the MightyPix is to have a timing resolution $\sim 3 - 4ns$. Allpix2 simulations are proposed to determine if this timing resolution is achievable or if additional timestamps are required. This talk will outline the plans for this study.

Will the talk be given in person or remotely?:

In person

Welcome and Allpix Squared overview / 19

Welcome from the workshop organisers

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Will the talk be given in person or remotely?:

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Recent Developments & New Features

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Will the talk be given in person or remotely?:

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Ongoing & Future Developments

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Will the talk be given in person or remotely?:

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Simulation of the H2M MAPS

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Monolithic CMOS sensors integrate the sensing volume and the processing electronics in the same silicon die, leading to complex structures with hundreds of small size features per pixel (sensor diode, transistors, metal wires…). In addition, the electric field in such sensors cannot be accurately expressed analytically as it is highly dependent on the shape and concentration of doping regions. TCAD simulations are thus required to compute the electric field prior to any further study. Most details of the structure such as the CMOS part are often not implemented in the TCAD simulation in order to reduce complexity and focus on the sensing part. While this approach is almost always justified by the independence of the two parts, the H2M, a 35um pitch monolithic sensor, exhibits a limit to this method: while the sensing volume is designed to be symmetric, measurements show a clear asymmetry of the detection efficiency.

This contribution explains how TCAD and Allpix² simulations helped to qualitatively reproduce the measurement and corelate the observed asymmetry with the layout of the electronics. Ongoing work to improve matching with the measurements will also be presented as well as lessons learned in the process, with a focus on the differences compared to a standard CMOS simulation flow.

Will the talk be given in person or remotely?:

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Discussion & Closeout