12th Geant4 Space Users Workshop

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Book of Abstracts

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A Bethe-Heitler 5D polarized photon-to-e+e-pair conversion event generator

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Past and current pair gamma-ray space telescopes use tungsten converters interleaved with tracker layers, for which the contribution of multiple scattering of the pair electrons in the tungsten dominates the single-photon angular resolution (example the Fermi LAT) and polarimetry with pairs has never been performed by a space polarimeter.

All-silicon telescopes could provide an angular resolution improvement of a factor of 3 at 100 MeV. With a gaseous active target a factor of 10 is within reach [NIM A 701 (2013) 225] and the single-track angular resolution is so good that polarimetry with pairs becomes possible [NIM A 729 (2013) 765] and has actually been demonstrated experimentally on beam [SPIE (2016) 99052R]. For these excellent telescopes, the recoil momentum dominates the single-photon angular resolution over most of the usable photon energy range and therefore an event generator that describes accurately the kinematic configuration of the particles in the final state must be used in simulations.

Current pair-conversion event generators (e.g. geant4 and EGS5 physics models) don't sample the five-dimensional differential cross section (5D DCS), but instead a product of 1D DCSs. In addition, most of them use high-energy and/or small angle approximations. Also the electron and positron polar angles are often generated independently so that energy-momentum is not conserved.
Few of them generators can simulate the conversion of linearly polarized photons, and only at high energy and none of them accurately [Astropart. Phys. 88 (2017) 60].

I have written an event generator that is sampling exactly the 5D Bethe-Heitler DCS, including for photons with a non-zero linear polarization fraction [NIM A 729 (2013) 765].
This event generator is using the BASES/SPRING instantiation of the VEGAS method : at a given energy, for a given target nucleus (nuclear conversion) or atom (triplet conversion), after a 5D grid has been optimized for DCS integration precision that is for event generator efficiency, the DCS is tabulated and stored, something that needs several seconds of computation.
Then zillions of gamma conversions can be generated quickly at that energy and for that target.
The polarization asymmetry properties of the Bethe-Heitler DCS were examined with that tool in Astropart. Phys. 88 (2017) 30, especially at low energy where most of the statistics is for cosmic sources.

I am now developing a VEGAS-free version of that code, that will allow the fast generation of the conversion of a photon of a given energy on a given target, with the same other properties as for the VEGAS-based generator, i.e., 5D, exact, polarized and strictly energy-momentum conserving.

Summary:

My goal is to make this generator available to the community as a Geant4 physics model.

Physics models and validations / 1

Recent updates on Geant4 physics validation for ESA AREMES project

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During the passed year a detailed Geant4 physics validation review and new verification studies were performed within the ESA AREMBES project. Several electromagnetic and hadronic models were addressed, focusing in particular on the space related physics. The low energy proton and electron scattering was considered, comparing the condensed history algorithms with respect to the single scattering approach results for several materials and incidence angles. Simulations of soft proton energy loss in matter were performed with different electromagnetic standard physics lists and compared with respect to theoretical expectations. Moreover standard Geant4 hadronic physics list were compared looking at space applications. In the present contribution an overview of the whole study described above will be given, focusing on the new results important for the space community on soft protons and electron backscattering. Finally the conclusions on the Geant4 physics coming from those results will be summarized.

Radiation environments and shielding (1) / 2

A "space dedicated" physics list from the AREMBES project

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AREMBES (ATHENA Radiation Environment Models and X-Ray Background Effects Simulators) is the new ESA software simulator designed for the ATHENA mission. It is created within the CIRSOS simulation framework to fully address the radiation background issues encountered by Athena and to be adaptable to other future X-ray missions.
Within this framework the correct and precise simulation of all relevant physical processes contributing to the background estimation is a key ingredient, entirely based on Geant4. A wide effort has been dedicated by the AREMBES team to identify the best possible physics models for space applications implemented into Geant4 and prepare a physics list "space dedicated" to be used in the AREMBES simulator. In the present contribution the relevant components of this physics list will be presented, focusing on the motivation of each choice, together with the physics list definition.

Radiation effects and single event effects / 3

GEANT4 implementation at Roscosmos SEE test facilities based on ion sources and at material's shielding properties determination

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The special degraders are used to achieve required heavy ion's characteristics at the only in Russia SEE test facilities based on high-energy ion sources. Heavy ion's characteristics (an energy, a linear energy transfer, a range) at electronic components' sensitive volume are calculated using different software, including GEANT4. Examples of GEANT4 and analogue software calculations results are presented in the paper. Besides that, GEANT4 is used for analytical determination of material's and

cover's radiation-shielding properties, the comparison of calculations and experimental results is presented in the paper.

Radiation environments and shielding (2) / workshop closing / 4

Plans for Using Geant4 in Space Elevator Research

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The space elevator is a means for moving large amounts of mass into space at relatively low cost. Modern concepts of this structure involve a gravitationally stabilized thin tether made of strong materials such as carbon nanotubes, extending to an altitude of 100,000 km. Along the full length of the tether many hazards, such as space debris, solar storms, radiation damage on tether materials and electromagnetic de-stabilzation of tether motion, must be studied. The planned use of Geant4 for each of these studies will be discussed after a brief introduction to the space elevator concept.

Summary:

Space elevator, Geant4 simulation of space elevator hazards

Physics models and validations / 5

Grazing Angle Soft Proton Scattering Measurements for X-ray Optics

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Orbital soft protons with energies from tens of keV to a few MeV can seriously degrade solid-state detectors in X-ray observatories. In order to improve and validate Geant4 simulations of soft proton grazing angle scattering in Wolter-type optics and to get a handle on the physical processes at work, measurements with eROSITA gold coated mirror samples have been performed at the accelerator facility in Tübingen in the past three years. Energy loss and scattering efficiencies have been investigated for incidence angles between 0.3 deg and 1.2 deg with proton energies around 250 keV, 500 keV, and 1 MeV.

A Geant4 physics process class has been implemented that reproduces the results of these measurements. This allows to assess the parameters of the scattered proton flux for a complete X-ray telescope and to estimate its contribution to the detector background and degradation. The code is currently under evaluation and will be refined once the new measurement data will be available.

The upcoming measurements will enhance the insights into the funneling behavior of astronomical X-ray optics by probing also the off-axis distribution of scattered protons and by extending the accessible angular range. Measurements of plane and curved mirror surfaces are planned, reusing the samples from eROSITA as well as testing new materials, e.g. silicon pore optics samples for ATHENA.

Physics models and validations / 7

Low energy proton scattering at glancing angles: new physics implementation and general validation

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Low energy protons (< 300 keV) can enter the field of view of X-ray space telescopes, scatter at small incident angles, and deposit energy on the detector. This phenomenon can cause intense background flares at the focal plane decreasing the mission observing time (e.g. the XMM-Newton mission) or in the most extreme cases, damaging the X-ray detector. Among the many physical processes that have been proposed to describe the scattering of soft protons by X-ray optics, only the Coulomb single and multiple scattering models are currently available in the official Geant4 toolkit.

Under the AREMBES (ATHENA Radiation Environment Models and X-Ray Background Effects Simulators) development activities, a new physics model ("the Remizovich scattering") is implemented, verified, and qualitatively validated on top of the Geant4 release 10.2. Both the new scattering physics and the Coulomb scattering already built in the official Geant4 distribution are used to reproduce the latest experimental results on grazing angle proton scattering.

Since the experimental data are not completely representative of the soft proton scattering experienced by current X-ray telescopes, we are not able to address any of the tested models as the one that can certainly reproduce the scattering behavior of low energy protons expected for the ATHENA mission. We can, however, discard multiple scattering as the model able to reproduce soft proton funnelling, and affirm that Coulomb single scattering can represent, until further measurements at lower energies, the best approximation of the proton scattered angular distribution at the exit of X-ray optics.

Summary:

Under the AREMBES (ATHENA Radiation Environment Models and X-Ray Background Effects Simulators) development activities, a new physics model ("the Remizovich scattering") is implemented on top of the Geant4 release 10.2 to describe low energy (<300 keV) proton scattering at glancing angles by the optics of X-ray space missions. Both the new scattering physics and the Coulomb scattering already built in the official Geant4 distribution are used to reproduce the latest experimental results on grazing angle proton scattering. We can discard multiple scattering as the model able to reproduce soft proton funnelling, and affirm that Coulomb single scattering can represent, until further measurements at lower energies, the best approximation of the proton scattered angular distribution at the exit of X-ray optics.

Space missions - instruments and detectors / 8

The BoGEMMS simulation of the AGILE mission and its benefits to future gamma-ray space telescopes.

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The accuracy of Monte Carlo simulations in reproducing the scientific performance of space telescopes (e.g. angular resolution) is mandatory for a correct design of the mission. This is particularly the case of gamma-ray Compton and pair production trackers, where the reconstruction of the primary photon energy and direction requires the full physical understanding of the particle tracks.

A brand-new Geant4 simulator of the ASI/AGILE space telescope, AGILESim, is built using the customizable BoGEMMS architecture to reproduce the in-flight observation of the Crab system (pulsar plus nebula) in the 100 MeV - 1 GeV energy range. The AGILESim mass model is composed by three instruments: a Tungsten-Silicon tracker (the AGILE/GRID), a CsI(Tl) Mini-Calorimeter (the AGILE MCAL) at the bottom of the tracker, and a Bicron BC-404 plastic scintillator anticoincidence (the AC) surrounding the tracking system. The BoGEMMS simulation output is digitized in post-processing according to the instrument electronic read-out logic, then converted in the AGILE operating data format, and finally analyzed by the standard mission scientific pipeline, including the Kalman filter, as a real observation in space.

The physics validation of the simulation set-up is performed by (i) analytically computing the conversion efficiency of the tracker layers, (ii) reproducing the on-ground measured distribution of the AGILE tracker energy deposits, and (iii) evaluating the Point Spread Function for a simulated observation of a Crab-like source. The AGILESim results are in very good agreement with the real AGILE on-ground and in-flight data. The successful cross-comparison validates the BoGEMMS framework for its application to future gamma-ray trackers (e.g. eASTROGAM).

Summary:

A brand-new Geant4 simulator of the ASI/AGILE space telescope, AGILESim, is built using the customizable BoGEMMS architecture to reproduce the in-flight observation of the Crab system (pulsar plus nebula) in the 100 MeV - 1 GeV energy range. The AGILESim mass model is composed by three instruments: a Tungsten-Silicon tracker (the AGILE/GRID), a CsI(Tl) Mini-Calorimeter (the AGILE MCAL) at the bottom of the tracker, and a Bicron BC-404 plastic scintillator anticoincidence (the AC) surrounding the tracking system. The AGILESim results are in very good agreement with the real AGILE on-ground and in-flight data. The successful cross-comparison of the simulation results validates the BoGEMMS framework for its application to future gamma-ray trackers (e.g. eASTROGAM).

Radiation environments and shielding (2) / workshop closing / 9

Internal charging simulation at a Galileo like orbit – effect of the anisotropic shielding and of the environment definition

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Despite the shielding of the spacecraft payloads, the internal charging events are resulting from the high energy electrons accumulation inside thick dielectrics. On long time scales, this can create IESD (internal electrostatic discharges). This internal charging phenomenon, potentially leading to part or system failure, is well known to spacecraft designers and requires efficient shielding to protect vulnerable components of the payload. In order to assist the designer during the shielding design, ESA has initiated the development of radiation analysis software in the frame of the ELSHIELD project (Energetic Electron Shielding, Charging and Radiation Effects and Margins). This software is based on the GEANT4 library for high energy electron transport in the spacecraft and on SPIS [1]–[3] for the deposited charge transport in the payload components. Among other radiation tools, Geant4 has the capabilities to compute local three-dimensional maps of total ionizing dose and deposited charge.

Whereas the common use of Geant4 is to evaluate consequences of radiation on electronics, these two specific capabilities allow addressing the issue of internal charging. This charging effect can be mitigated by material conductivity, which is enhanced by dose deposition (i.e. radiation induce conductivity). Since Geant4 can supply three-dimensional maps of charge deposit and dose, it offers a very good opportunity to use these data to perform three-dimensional computations of internal charging. A specific version of SPIS called SPIS-IC (IC for Internal Charging) uses the Geant4 results as input in order to compute the material conductivity and the charge deposit transport.

In this workshop, we propose to present some simulations of the effect of the radiation belt electrons at a Galileo like orbit on a thick dielectric component inside the payload. As a component, we select a high flow rate communication cable from a SpaceWire standard platform. A natural electron environment coming from the radiation belts has been defined at the Galileo orbit (from a CNES/Onera R&T study). The simulations have been performed for three different shielding (i.e. two isotropic and one anisotropic) and for two different worst environments spectrum (i.e. worst one hour and worst six hours). The results of the simulation are analyzed in term of charging level (as a function of the time and the location inside the component) and IESD risk. We also analyze the uncertainty and the numerical error created at each stage of the simulation (GDML geometry, scoring mesh geometry, transport and scoring calculation using Geant4/GRAS, conductivity calculation in SPIS, transport equation in SPIS, …). We finally conclude on the necessity to perform time dependent and 3D calculations to have an accurate assessment of internal charging.

[1] P. Sarrailh, T. Paulmier, B. Dirassen, D. Rodgers, G. Santin, and F. Cipriani, "3D time dependent model of internal charging, comparison with experiments," presented at the 2015 IEEE Nuclear & Space Radiation Effects Conference (NSREC 2015), Boston, MA, USA, 2015.

[2] P. Sarrailh et al., "Three-Dimensional Model of Internal Charging using SPIS," in Proceedings of 12th Spacecraft Charging Technology Conference, Kitakyushu, Japan, 2012.

[3] "Spis website: http://dev.spis.org/."

Summary:

Internal charging simulations results of the effect of the radiation belt electrons at a Galileo like orbit on a thick dielectric component inside the payload are presented. As a component, a high flow rate communication cable from a SpaceWire standard platform has been selected. A natural electron environment coming from the radiation belts has been defined at the Galileo orbit. The results conclude on the necessity to perform time dependent and 3D calculations to have an accurate assessment of internal charging.

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Geant4-based tools in SPENVIS

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For some time now, various Geant4 applications have been employed for the planning of space and planetary exploration missions and the significance of such tools has been also reflected in the evolution of the web-based ESA Space Environment Information System (SPENVIS, www.spenvis.oma.be). SPENVIS has been providing interfaces to various Geant4-based tools that can be used for a number of applications including instrument and detector response verification, space radiation shielding optimisation, component effects, support of scientific studies to the analysis of biological effects and astronaut radiation hazards.

The follow on system, known as SPENVIS Next Generation, has been under development under the ESA/GSTP-5 programme. The key objective is to upgrade SPENVIS into a new web-based service-oriented distributed framework, supporting plug-in of models related to the hazardous space environment, and including both a user-friendly interface for rapid analysis and a machine-to-machine interface for interoperability with other software tools.

As with its predecessor the new system will provide access to Geant4 tool such as GRAS (3D radiation analysis), MULASSIS (1D radiation analysis), GEMAT (micro-dosimetry), SSAT (shielding distribution), MC-SCREAM (NIEL effects in solar cells), MAGNETOCOSMICS (cosmic ray rigidity) and PLANETOCOSMICS (cosmic ray showers). In addition, the new system provides new ways for exploring these tools. Finally, the latest versions of the tools (compiled with Geant4.10) will be interfaced as they become available.

The purpose of this talk is to present the recent progress in SPENVIS related to the Geant4 tools but also to introduce SPENVIS-NG and its capabilities to the Geant4 space user community with particular emphasis for the model developers.

Radiation effects and single event effects / 11

Applications of MRED for Predicting Single Event Effects

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MRED (Monte Carlo Radiative Energy Deposition) is Vanderbilt University's Geant4 application for simulating radiation events in semiconductors. Geant4 is comprised of the best available computational physics models for the transport of radiation through matter. Geant4 is a library of c++ routines for describing radiation interaction with matter assembled by a large and diverse international collaboration. MRED includes a model developed by researchers at Vanderbilt University for screened Coulomb scattering of ions (currently available in the latest Geant4 release), tetrahedral geometric objects, a cross section biasing and track weighting technique for variance reduction, and a number of additional features relevant to semiconductor device applications. The Geant4 libraries contain alternative models for many physical processes, which differ in levels of detail and accuracy. Generally, MRED is structured so that all physics relevant for radiation effects applications are available and selectable at run time.

The underlying physical mechanisms for Single Event Effect (SEE) response are: 1) ionizing radiation-induced energy deposition within the device, 2) initial electron-hole pair generation 3) the transport of the charge carriers through the semiconductor device and 4) the response of the device and circuit to the electron-hole pair distribution and subsequent transport. Each of these occur on a different time scale and they are often assumed to be sequential, i.e., energy deposition determines the initial electron-hole pair generation, which in-turn impacts device and circuit response. We will provide a review of MRED applications that address issues as they relate to the mechanisms listed above.

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Single Scattering classes and NIEL computation within a screened relativistic treatment

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Single scattering classes G4eSingleCoulombScatteringModel and G4IonCoulombScatteringModel, included in Geant4, implement the screened-relativistic treatment for protons, ions and electrons incident on nuclei. This treatment accounts for effects due to the screened Coulomb fields, finite sizes and rest masses of nuclei. For electrons scattering on nuclei a complete treatment of Mott differential cross section is implemented. Nuclear form factors are implemented as well.
These classes allow obtaining both the nuclear stopping power and the non-ionizing energy loss (NIEL) for protons, ions and electrons in any target material. Details of the classes will be presented along with comparisons of Geant4 results respect to analytic ones.

Space missions - instruments and detectors / 13

Simulations for the Wide-field X-ray Telescope aboard Einstein Probe mission with Geant4

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Einstein Probe (EP) is a proposed small scientific satellite dedicated to time-domain astrophysics working in the soft X-ray band. It will discover transients and monitor variable objects in 0.5-4 keV, for which it will employ a very large instantaneous field-of-view (60o × 60o). Gravitational Waves will be its one of the important objectives. EP has two kinds of payloads including a Wide-field X-ray Telescope (WXT) and a Follow-up X-ray Telescope (FXT). Its wide-field imaging capability will be achieved by using micro-pore lobster-eye optics on WXT. We built a Monte Carlo model of EP satellite based on Geant4 and investigated its scientific performance. Here, we will introduce the EP mission and present some simulations of WXT about X-ray tracing and the instrumental background.

Radiation environments and shielding (1) / 14

An example of integrated pre-processing chain for Monte-Carlo based radiations and internal charging analysis

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The increasing complexity of future commercial missions and space environments of new scientific missions impact more aggressively and deeply the design of next generation space systems, payloads as well as the platforms. The use of COTS components and the mass optimization require a finer modeling of the impact of space environment on spacecraft, especially regarding radiation and internal charging effects. We are reaching now the limits of models like the sector shielding (ray-tracing) analysis and 3D realistic descriptions are needed for good results. New ESA missions will across complex space environments where the limit between canonical physical domains is not strict anymore and a multi-physics approach is required.

For radiation and internal charging effects, thanks to a long-term R&D effort sustained at ESA/TEC-EPS and inside the community, a set of Monte-Carlo based simulation models are now available and fully operational. GRAS is a 3D Monte-Carlo based radiation effects analysis tool based on GEANT-4 that sees its scientific applications growing-up. But, up-to-now, the lack of a user-friendly interface, especially regarding the CAD modeling, has limited its use in an industrial context. Also initiated by ESA and maintained by the SPINE community, SPIS is an open-source software dedicated to the modeling of spacecraft-plasma interactions. Based on a 3D PIC model, widely used, SPIS became the de-facto European standard in charging analysis. Via several ESA projects (ElShield, CIRSOS, 3DMICS, …) and an internal R&D done at ONERA, SPIS has been recently extended to internal charging effects, down-stream to radiations analysis.

However, the driving of such multi-steps modeling chain as a whole remained complex and arid, especially by the lack of adapted and unified open source pre-processing tools. Moreover, the integration of such simulation tools with other engineering systems, like B-Rep based CAD applications used in the industry, was still very challenging.

A strong internal R&D effort has been performed at Artenum to address these issues by the development ab-initio of a self-consistent set of new and dedicated software and user interfaces to set-up and control GEANT-4 based models.

EDGE, for ExtendeD Gdml Editor, is a CAD tool able to create, edit and visualize geometries in GDML format, used as input of GRAS. Embedding a 3D view and offering a rich GUI, EDGE not only allows creating, editing and importing geometrical systems, but also offers the possibility to graphically create material properties and assign them to the geometry. Using the CAD capabilities of the Keridwen IME, EDGE also builds a link with industrial CAD tools with the possibility to import STEP-AP 203/214 files, convert GDML models into an equivalent geometric model for radiation analysis and export them to Gmsh (.geo) format used by SPIS and/or various mesh formats.

This is completed by a dedicated WYSIWYG user interface, or Radiation Manager, allowing to fully set-up a GEANT-4 simulation kernel, like GRAS, including the loading of the geometry, the material attribution, the setting of particles sources and the simulation settings through a standard .g4mac script and the various geometrical support for scoring and data exchanges.

Integrated as a new OSGi bundle in the SPIS-IC IME, the Radiation Manager directly transfers computed data (e.g. deposited dose and charge) to the SPIS kernel for internal charging analysis.

To evaluate the relevance of the proposed approach, first tests have been perform on a basic and non space-validated but still realistic, in terms of complexity, electronic system with an ARM based computer board (i.e. simple Raspberry Pi card). In this test, the card has been initially imported from a pre-existing STEP-AP geometry file, converted by a surface tessellation and simplified with EDGE in order to build-up a model compliant with GRAS. Various simulations have been performed with GRAS, using the Radiation Manager, and considering different shielding configurations.

These first results have fully confirmed the relevance of the global approach and the possibility to model realistic and quite complex devices, starting from an industrial input CAD file. They also confirm that the EDGE, Radiation Manager, GRAS and SPIS-IC chain is operational and might be used in an industrial context. However, these first tests have also outlined several constraints on the used tessellation method for the stability and the relevance of GEANT4 simulations. These different results will be presented and discussed.

Radiation environments and shielding (2) / workshop closing / 15

TRAD's GEANT4 Activity: Cryostat Study

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Proton beam irradiation on a cryostat can induce device activation that causes radio protection issues and cryostat transportation delay. The aim of this study, funded by CNES, was to predict the behaviour of a cryostat during and after irradiation using a chain of software tools:

- FASTRAD for cryostat modelling and import to GEANT4,
- GEANT4 for dose and transmitted spectra calculation in different cryostat volumes including DUT, Devices Under Test, located inside the cryostat,
- FISPACT for activation calculation in these volumes based on particle spectra,
- RAYXPERT for radio protection calculation based on these activation data.

Another important point was to assess the TID, Total Ionizing Dose, and TNID, Total Non-Ionizing Dose, deposited on DUT inside the cryostat. The dose results obtained with GEANT4 calculations were compared to real cryostat irradiation measurements performed with an equivalent beam configuration.

Radiation environments and shielding (1) / 16

The X-IFU instrument background

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ATHENA (Advanced Telescope for High Energy Astrophysics) is the second large mission in ESA Cosmic Vision 2015-2025, with a launch foreseen in 2028 towards the L2 orbit. The mission addresses the science theme "The Hot and Energetic Universe", by coupling a high-performance X-ray Telescope with two complementary focal-plane instruments. One of these, the X-ray Integral Field Unit (X-IFU) is a TES (Transition Edge Sensor) based kilo-pixel array, providing spatially resolved high-resolution spectroscopy (2.5 eV at 6 keV) over a 5 arcmin FoV.
Given the lack of data on the background of X-ray detectors in L2, the only viable solution to predict the background level is with the use of Geant4 simulations. The particles-induced background for this kind of detectors accounts for two components, namely the low energy particles (< ~100 keV) concentrated by the mirrors and reaching the detector from inside the field of view, and the high energy particles (> ~100 MeV) crossing the spacecraft and reaching the focal plane from every direction. In particular, these high energy particles lose energy in the materials they cross, creating secondaries along their path that can induce an additional background component.
We present here the latest results obtained by the X-IFU team in the estimate and reduction of these two background components thanks to Monte Carlo simulations.

Space missions - instruments and detectors / 17

AREMBES general overview

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AREMBES (Athena Radiation Environment Models and x-ray Background Effects Simulator) is an ESA contract that foresees the development of a software simulator based on Geant4, capable of addressing all the background issues that the ATHENA mission will experience during its lifetime, together with the development of improved environment models for the L2 halo orbit radiation. The project, that has contributions from 10 scientific institutes/SME from 7 different countries, is divided in 3 parts: 1) Analyses of data relative to radiation effects and experience from previous X-ray missions, improvement of L2 radiation environment models, and improvement of the Geant4 physics models, 2) Development of a user-friendly radiation background simulator framework, construction of a representative ATHENA geometry model, and validation of the simulator performance 3) maintenance and upgrades.
We will review the results obtained so far in part 1, focusing on the particle environment analysis (the improvement of Geant4 physics model will be explored more deeply in dedicated talks), and provide some hints about the final simulator expected features, along with a typical use case scenario.

Software tools / 18

From CAD geometries to Geant4 via CADMesh

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Space radiation detectors could be rather complex, due to their specific geometries and materials. In addition, the need of trustful physics analysis and/or accurate detector response simulation taking into account all sources of secondary particles resulting from the interaction of primary particles with the detector materials, drives the need of a detailed detector geometry implementation.
The Geant4 simulation toolkit has been successfully applied to the field of space physics, namely in the simulation of Space Radiation Environment and Effects. The common procedure to import mechanical drawings of space detectors provided by design engineering teams in CAD files, is to code versions of these drawings into Geant4 through the Geant4 Geometry classes or by commercial tools such as FASTRAD® [ref]. Recently, a very useful tool was developed - CADMesh [refs]- which allows 3D tessellated geometrical volumes to be converted to a GDML format that can then be imported into Geant4 applications. This enables to simulate detector geometries imported directly from CAD systems in the form of STEP files. However, a dedicated procedure has to be followed in order to correctly import geometries corresponding to the different materials into Geant4 applications. The complete conversion procedure applied to two space radiation monitors, MFS and RADEM, resulting in geometries navigable by Geant4, is presented.

Summary:

The CAD files of two instruments designed for space missions, MFS for Alphasat and RADEM for JUICE, were successfully converted into GDML and simulated with Geant4. Procedure and results will be presented.

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Characterizing Radiation-Induced Contact Degradation in Silicon Carbide Devices via Electrothermal Simulations

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Device reliability is critical to the integrity of electronics systems used in the aerospace industry (e.g. satellites, cubesats, spacecrafts, etc.). In particular, R&D in device reliability is indispensable for electronics operating in harsh environments, such as in Low Earth Orbit (LEO), where particle radiation is prevalent. In particular, radiation-induced degradation at metal-semiconductor (MS) interfaces has been shown to cause device failure. It is therefore crucial to gain insight on the time-dependent distributions of various parameters at irradiated MS interfaces. However, experimentally irradiating and testing electronics is costly and time consuming. Therefore, researchers often resort to simulation techniques to gain insight on how their systems are affected in these harsh environments. In this work, the electrical and thermal effects induced by particle radiation is studied by leveraging the power of GEANT4. Using a custom MATLAB framework, the simulations from GEANT4 are used to locally define generated electron/hole pairs to a high degree of accuracy, and a Finite Element Analysis solver (COMSOL Multiphysics) is used to model the time behavior of the device's electrical and thermal properties.

Developing device-level solutions that can mitigate contact degradation requires one to have insight on thermal effects at the MS interface, which include the time-dependent electrical field and temperature profiles of an irradiated device. For example, a SiC Schottky diode reverse biased to -100 V, when exposed to radiation, is highly vulnerable to local melting in the Schottky contact (Figure 2).1 Interface temperatures exceeding the melting points of the metal and/or semiconductor will, at best, degrade the interface and thus the material properties of the device, with the potential to cause a Single Event Breakdown.

Furthermore, Single Event Transients can be explicitly studied under any device design and radiation type. Figure 2 depicts an example of this process, where a 1 GeV/n Ar ion penetrates 12 um of Silicon (Si), with two operating N-MOSFETs on the top-left corner, labeled M1 and M2. The GEANT4 data (Fig. 1a) was parsed, processed, and imported into COMSOL Multiphysics (Fig. 2b).

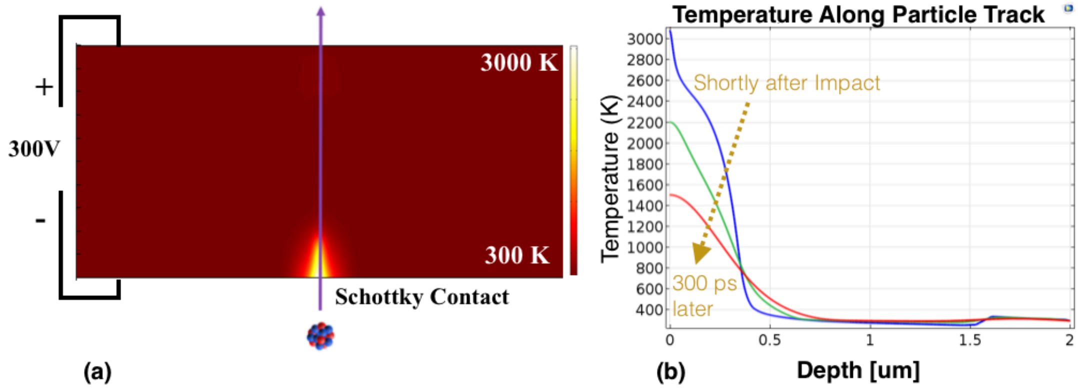

Figure 1: Figure 1. (a) Thermal surface plot of SiC Schottky diode struck by a heavy ion. (b) Temperature profile along the track of the penetrating ion.

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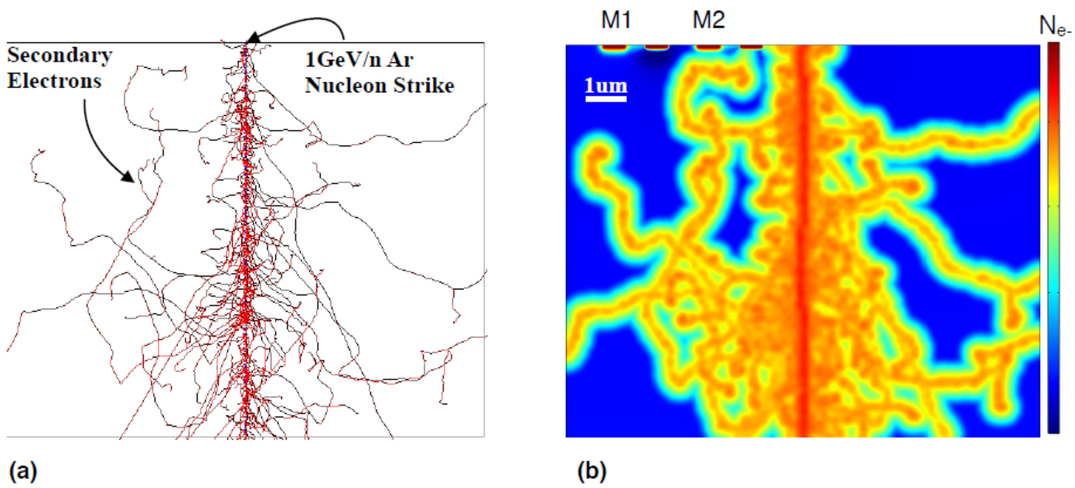

Figure 2: Figure 2. (a) Monte Carlo simulation (GEANT4) of 1 GeV/n Ar Ion penetrating Si substrate (b) Imported GEANT4 data into COMSOL Multiphysics simulation of dual-MOSFETs (M1 & M2). Snapshot ~2 ps after Ar ion impact.

Figure 2. (a) Monte Carlo simulation (GEANT4) of 1 GeV/n Ar Ion penetrating Si substrate (b) Imported GEANT4 data into COMSOL Multiphysics simulation of dual-MOSFETs (M1 & M2). Snapshot ~2 ps after Ar ion impact.

Summary:

Radiation-induced degradation at metal-semiconductor (MS) interfaces has been shown to cause device failure. It is therefore crucial to gain insight on the time-dependent distributions of various parameters, such as the electric field, power density, and temperature, at the MS contact. Developing device-level solutions that can mitigate contact degradation requires one to have insight on the steady-state and transient behavior of irradiated contacts. In this work, the electrical and thermal effects induced by particle radiation is studied by leveraging the power of GEANT4, and using COMSOL Multiphysics to simulate the time-dependent behavior.

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Space Missions in IHEP and Geant4 Applications

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To estimate the influence of radiation environment, performance of critical detectors and radiation damage, event by event simulation methods are necessary for space-based telescope development. In this presentation an outline of space-based mission in IHEP is given, which emphasize on the Geant4 analysis performed in support of the performance estimate, detector responses, shielding optimize etc. Examples given in this report include the Hard X-Ray Modulation Telescope(HXMT), the Space Variable Objects Monitor（SVOM）, POLAR and Gravitational wave burst high energy Electromagnetic Counterpart All-sky Monitor(GECAM).

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Geant4 Simulations of Space Radiation Sensors and Environment at The Aerospace Corporation

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Geant4 is a vital tool for understanding and calibrating the response of space-borne radiation sensors at The Aerospace Corporation, and for understanding the space radiation environment that they measure. In the year and a half since the last Geant4 Space Users' Workshop, we have used the code to continue to refine our understanding of the response, both foreground and background, of sensors aboard the Van Allen Probes and the Lunar Reconnaissance Orbiter (LRO), and we will show some examples. As part of this, we have begin making use of the extensions to the basic Geant4 code that enable import of CAD geometries and that perform adjoint Monte Carlo simulations, and we will present some initial evaluations of performance relative to our standard use of Geant4 (geometry via CSG with Geant4 primitives, forward Monte Carlo simulations). With regard to the environments measured by our sensors, we have also used Geant4 to conduct an extensive parametric study of the effects of hydrogen in the upper layers of the lunar surface on "albedo" protons coming up to be measured by LRO after production in cosmic-ray interactions with the regolith, and we will present a summary of the results.

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Full X-ray mircropore optics modelling for the BepiColombo MIXS instrument

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The modelling of X-ray micropore optics have raised a considerable interest, in the framework of some recent and future missions like BepiColombo or the next X-ray observatory ATHENA, in order

to not only help during design phases but also provide a precise knowledge of the low-energy particle focusing on the focal plane detectors.

As a first step, we have fully simulated the BepiColombo MIXS instrument, by means of Geant4 and the XRTG4 tracer, including a realistic model of the actual MIXS micropore optics. Preliminary results show a good correlation between our model and the main figures of merit obtained during ground X-ray tests performed on the MIXS flight model, which open up promising prospects for future further investigations

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Collaborative Iterative Radiation Shielding Optimisation System – CIRSOS

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CIRSOS is an integrated modelling environment (IME) for radiation effects analysis in space mission developments. It provides a complete set of models and tools required for a mission radiation effects analysis at different phases of its developments from conception to operation. It was initially developed in support of the ESA Cosmic Version programme, the JUICE mission in particular. It will also be used as a baseline tool in the background modelling framework for the ATHENA mission. This talk will introduce the overall design of CIRSOS, its main components and features.

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Welcome

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Introduction to Surrey Space Center

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ESA status report

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NASA/JPL status report

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JAXA status report

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Geant4 in CAS

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20th anniversary of ESA's engagements with Geant4

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At the edge of space - overview of some recent publications with Geant4 content

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Invited presentation and status reports from Geant4 developers (1) / 32

General introduction and Geant4 kernel updates

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Status reports from Geant4 developers (2) / 33

Geant4 EM physics updates

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Status reports from Geant4 developers (2) / 34

Geant4 hadronic physics updates

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Status reports from Geant4 developers (2) / 35

Geant4 GUI/Vis updates

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Q/A

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Modeling of Irradition Effects in sub-N7 CMOS Logic Devices Using Layout-Based Design

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Modern electronic systems can be disrupted or damaged by high energy particles. Radiation effects have become a critical reliability issue in nanometer-scaled logic devices, particularly for aviation applications or space environments, and now increasingly for safety critical ground-level applications such as transportation and medicine. In the industrial development process of such devices the radiation tolerance is studied at particle accelerator facilities or gamma-ray sources. However, this method is time consuming and very expensive, and the availability of such facilities is limited. If the degradation of device performance due to irradiation can be simulated by software, the test time and cost of investment for device development will be greatly reduced. Furthermore, with the advancement of semiconductor technology, the characteristic dimension of devices such as modern SRAMs and logic cells have already reached the nanometer-scale. The potential radiation effects and

tolerances are inherently different for devices at the nanometer-scale and devices at the micrometer-scale.

We present a consistent TCAD modeling toolchain for upcoming semiconductor technology nodes that incorporates a high-energy particle simulator and a sophisticated device and mixed-mode circuit simulator. Layout-based design and technology rule files provide a quick setup of the sub-N7 devices under test. Our toolchain enables the calculation of radiation effects on SRAM and logic cells containing state-of-the-art FinFET and nanowire transistors.

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A Study of Reverse Monte Carlo and Space Charge Effect Simulation with Geant4