14th Geant4 Space Users Workshop

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Book of Abstracts

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The impact of low-energy electrons on EP-WXT based on Geant4 simulations

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The Einstein Probe (EP) mission is dedicated to time-domain astrophysics in 0.5–4 keV energy band to discover high-energy transients and to monitor variable objects. To realize these objectives, EP is equipped with a Wide-filed X-ray Telescope (WXT) which applies the micro-pore lobster-eye optics. Seward et.al 1973 first pointed out that low-energy electrons could cause serious background problem for soft X-ray instrument. We will present the impact of such low-energy electrons on the background of WXT based on Geant4 simulations. We will also introduce the magnetic diverter developed based on this investigation.

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Geant4 usage at JPL

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Space radiation is a key design consideration for any spacecraft. At JPL, radiation transport tools like Geant4 are used for understanding and estimating cumulative radiation effects such as total ionizing dose (TID) as well as the transient effects such as on instruments during operation. However, a variety of tools are available and used across various institutions participating in JPL missions. In my presentation, I will discuss TID validation analyses performed at JPL to compare commonly used radiation transport tools as well as overview some Geant4 analyses performed for JPL missions.

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Geant4 Electromagnetic Physics: status and perspectives

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Geant4 electromagnetic (EM) physics sub-libraries are responsible for simulation of different radiation effects for space applications. The current status of Geant4 EM physics available with the recent Geant4 release 10.6beta will be discussed. Special attention will be made for new features and EM parameters allowing to configure a space related simulation application. The preview of EM physics in the new release 10.6 will be also made, validation results versus experimental data will be shown.

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The EXACRAD Project

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Within the framework of the ESA financed activity AREMBES, there have been considerable efforts to set up a Space Physics lists. The realization that for some of the processes under consideration experiemental data is scarce or inconclusive has lead to the launch of another ESA financed project known as EXACRAD. At the heart of EXACRAD are 3 exprimental activities aimed at charcterizing: 1) soft proton scattering of ATHENA mirros;
2) secondary production from high energy protons and 3) electron back-scattering. In this presentation I will report on the status of these activities, highlighting their relevance to the ATHENA background characterization.

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GUIMesh: a tool to import STEP geometries into Geant4 via GDML

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Importing mechanical models constructed in CAD to Geant4 has always been a challenge requiring a great effort on behalf of the physicist. Since no open-source and generic solution existed to bypass this problem, a new tool, GUIMesh, was developed with Python to convert STEP geometries into GDML as tessellated solids using FreeCAD libraries.
The tool allows to determine the precision of the tessellation and to assign materials to each volume in a matter of minutes. Validation of the imported geometries and materials and the impact of geometry precision on the computing speed as well as future prospects will be discussed.

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Recent developments for Geant4 low-energy hadronic physics

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The developments for low energy hadron/ion cross sections, pre-compound model, and de-excitation module will be described. For neutrons, protons and light ions a new data set has been released for Geant4 10.5 and updated for coming release 10.5. Classes, responsible for the Glauber-Gribov hadron/ion nuclear cross section were reviewed and updated. The new Fermi-Break-up model for light ion fragmentation is now the default. A new general evaporation model for simulation of light ion emission is under development. New validation results will be reported.

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AREMBES: Geant4 validation for X-ray space missions and G4 simulator development

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AREMBES (Athena Radiation Environment Models and x-ray Background Effects Simulator) is an ESA project 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 and the validation of relevant physical processes against available experimental results. The project, wthat has contribution from 10 scientific institutes/SME in 7 different countries, is divided in 3 phases:

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 framework for a user-friendly radiation background simulator, construction of a representative ATHENA geometry model, and validation of the simulator performance

3) maintenance and upgrades.

We are at present in Phase 3.
We will review the results obtained so far in phase 1 and phase 2.

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Geant4 tools in SPENVIS: A user perspective

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ESA's Space Environment Information System (SPENVIS, https://www.spenvis.oma.be) is providing interfaces to various Geant4-based tools that can be used for supporting scientific studies related to the characterisation of the space environment and its effects. More specifically, the users can employ these tools to verify instrument and detector responses, optimise space radiation shielding, investigate radiation-induced effects on spacecraft components and assess astronaut radiation hazards. Furthermore, SPENVIS and its Geant4 tools are integral part of ESA's Space Situational Awareness (SSA) Space Weather Service Network (http://swe.ssa.esa.int/) and supported by the Space Radiation Expert Service Centre (R-ESC).

The SPENVIS system contains several Geant4 tools 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 general, SPENVIS offers a user-friendly interface to these tools so that anyone with no previous knowledge of Geant4 can use them. Nevertheless, working with these tools and understanding their outputs can be cumbersome for an inexperienced user.

The purpose of this talk is to present the SPENVIS Geant4 capabilities to the Geant4 space user community and discuss some challenges that a user might experience when dealing with these tools. The latter could be important feedback for the Geant4 model developers.

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Microdosimetry with Geant4 for Quality Factor estimates

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Microdosimetry is the study of the stochastics of energy deposition in microscopic volumes by ionizing radiations and forms the physical basis of the quality factor, Q. The official connection was made more than 30 years ago by ICRU which defined Q as a function of the microdosimetric quantity lineal energy (y) instead of LET. Subsequently, ICRP re-defined Q(LET) to match the Q(y) of ICRU. Theoretical calculations of y-spectra are commonly based on Monte Carlo (MC) radiation transport simulations using either condensed-history (CH) or track-structure (TS) models. CH models are the most popular because of their moderate computing times but they suffer from a limited spatial resolution (um-mm). On the opposite side, TS models offer superior spatial resolution (nm-um) to the expense of high computing times. In human space missions, intermediate-energy electrons (keV-MeV) are of concern either as primary particles (e.g., in the Van Allen radiation belts) or as secondary delta rays in high-energy proton and heavy ion tracks. However, intermediate-energy electrons are only partially absorbed in micrometer-size targets, so accurate simulation of their transport is crucial to the calculation of reliable y-spectra for space radiation. The MC simulation of keV-MeV electrons is tricky due to the shortcomings of the available MC models, that is, CH models become less accurate < 1 MeV while TS models become impractical > 1 keV. Geant4 offers both CH (Standard EM, Livermore, Penelope) and TS (DNA package) physics models for electron transport. In this work we examine the influence of some user-defined CH parameters (step-size limit, SL, and tracking and production threshold energies, CUTS) to the calculation of the dose-averaged lineal energy (yD) in 1-3 um diameter spherical targets for intermediate-energy electrons. Calculations using the TS models of Geant4-DNA are also carried out and used as baseline for comparison. It is found that the influence of SL and CUT is of similar magnitude and sizeable (up to 60%). Choosing SL > diameter may lead to large errors unless very small CUTS are used. For low values of CUTS (<100 eV) and SL (<d/10), Standard EM Opt4 compares well against DNA Opt2 (differences < 20%) with a huge gain in computing time.

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IXPE related Geant4 simulation

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The next NASA Small Explorer (SMEX) mission, IXPE (Imaging X-ray Polarimetry Explorer) , will be launched in 2021, with three identical X-ray mirror module assemblies and Gas Pixel Detectors (GPD). IXPE introduces the capability for X-ray polarimetric imaging, uniquely enabling the measurement of X-ray polarisation with scientifically meaningful spatial, spectral, and temporal resolution, helping answer the fundamental questions.
A series of simulation activities together with the calibration for flight units are in progress. As an important tool to understand the background of the space instruments, Geant4 background simulation will be reported. This work foresee the study of background rejection to be implemented in on-ground analysis software, which is especially importance for faint extended sources, like molecular clouds and supernova remnants.

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Measurements and Geant4 simulations of the back-scattered electrons off ATHENA X-ray mirrors

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As part of the ATHENA mission development activity, dedicated experiments have been carried out to measure the electron back-scattering yield and their spectrum off the ATHENA X-ray mirror materials. The experiments have been simulated in Geant4 in details and excellent agreements achieved. This validated Geant4 as a tool for the simulation of electrons through the ATHENA X-ray optics.

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Comparison of Insight-HXMT simulated background with observations

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We analysis the background observations of Insight-HXMT, and compare with our previous simulated results. The comparison shows great consistency between simulation and observation, which demonstrates our previous simulations are reliable.

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Quantitative estimation of biological effects after irradiation by MPEXS-DNA

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Biological effects for instance DNA single-/double-strand breaks (SSB/DSB) in nanodosimetry has been estimated quantitatively in conventional Monte Carlo methods. i.e. the methods simulate track structure of charged particles and distribution of molecular species such as hydroxyl radicals inside a cell nucleus. From the overlaid distributions of energy loss and molecular species on such geometry, the positions where physical and chemical interactions occurred with DNA components can be scored. This approach allows evaluating DNA damages induced by radiation with higher accuracy, but at the costs of huge computation times.
We evaluate radiation damages induced on DNA molecules with a new clustering algorithm that uses a simple geometry. Any complex cell geometries such as DNA double-helix structures are not necessary to take into account in this algorithm. Yields of SSB/DSB are estimated by this method based on sampled positions where DNA damages occurred. We developed an application with MPEXS-DNA to estimate DNA damages using this clustering algorithm, where MPEXS-DNA is a nanodosimetry simulator based on Geant4-DNA running on GPU devices. Our application predicts yields of SSB/DSB induced by ionization of charged particles (direct yields) and chemical interactions of hydroxyl radicals (indirect yields). We compared our results with other Monte Carlo codes and measurements. In conclusion, MPEXS-DNA agreed reasonably well with them.

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Geant4Py for X-ray Detector Background Simulations

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Geant4Py is a Geant4 Python interface distributed with the Geant4 source code that allows to develop Geant4 applications in the Python programming language. In order to simulate the photon and particle background of X-ray detectors in space, bindings for needed features such as the General Particle Source (GPS) were added to the Geant4Py environment along with general improvements and support for the most current Python versions. A Geant4Py application simulating the background of the XMM-Newton EPIC-pn detector is presented, which is written purely in Python and introduces only a small runtime overhead of roughly 25% for the investigated use case, compared to a Geant4 application written in C++.

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TRADCARE: a multi-physics SEE prediction software using Geant4 toolkit

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The scaling trend of highly integrated circuits makes them more and more sensitive to single event effects (SEE). It has now become necessary for circuit designers to figure out the sensitivity of their circuit and new technology during the design phase. The purpose of TRADCARE is to assess their reliability before manufacturing and therefore, reduce the testing costs. TRADCARE can also be used on existing technologies as preliminary analysis, to assess the testing need.

SEE occurrences are ruled by a stochastic process. Many prediction tools have grown up around of the Monte-Carlo approach which is commonly chosen to describe the particle transportation through the matter. Geant4 offers many interesting features both in technical (extended physiclist, low energy physics…) and practical (full custom, cross-platform, c++) aspects, and is the core of several prediction tools. However, the use of very detailed physical processes of particle transportation coupled with simplified approaches (i.e. parallelepiped sensitive volumes, single energy threshold value or critical charge) may only provide a rough estimation of SEE occurrences.

The spreading parasitic effects of a single particle strike results in an observable and measurable failure or defect at the circuit and system scale. Therefore, every physical mechanism involved in SEE should be thoroughly considered.

A multi-physics SEE prediction chain, including Geant4, was developed and implemented in the TRADCARE software. It is an engineering tool developed by TRAD, a company renowned worldwide for its unique expertise on radiation effects. This work presents:
• TRADCARE features and the characteristics of the implemented modules;
• the simulation flow with an emphasize on the Geant4 part;
• an application case on simple and complex circuits with the experimental comparison.

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GEANT4 simulation Study of the MIDAS dosimeter/radiation monitor

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The MIDAS device is a detector with wristwatch dimensions and mass less than 50g. It consists of a plastic scintillator cube connected to a silicon photomultiplier on its one face, while all the other faces are covered by a titanium box and 2 consecutive layers of fully depleted silicon pixel sensors with in-pixel signal processing electronics. Its purpose is not only to act as a LET spectrometer, but to determine the radiation field parameters near to an astronaut and enable the application of fluence to dose conversion factors for the evaluation of dose and subsequently dose equivalent. We have undertaken a detailed GEANT4 simulation of the device which has played a decisive role in its design. Methods and results of the investigation of the device capabilities will be presented as far as it concerns particle identification and kinetic energy determination.

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Latest Updates of Grazing Angle Soft Proton Scattering on X-ray Optics

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The question of soft proton scattering efficiency under grazing angles raised in 1999 quickly after the *Chandra* X-ray observatory was launched. Since then, measurements could confirm a reduction of the large discrepancy between soft proton radiation effects seen in orbit and simulations. Nevertheless, a complete experimental coverage of the relevant parameter space is still pending.

Experimental and theoretical advancement in this field as well as validation and a possible extension of simulation codes are part of the currently running EXACRAD project, which is funded by ESA. Its major goal is to provide the foundations for the thorough assessment of the charged particle background of the upcoming ATHENA X-ray observatory. This contribution will summarize the soft proton measurement results so far, highlight the short-term plans for extending the experimental coverage, and draw comparisons between experimental and simulation results.

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A comparative study of multiple scattering calculations implemented in general-purpose Monte Carlo codes

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The multiple scattering calculations, inherently implemented in all widely used, general–purpose Monte Carlo codes, play a critical role in the determination of any expected dose yield and are directly related to volume damage effects. Small changes in multiple scattering (lateral mainly), and therefore in the corresponding particle trajectories, can lead to significant changes in the affected target or detector irradiated areas. This effect may be critical in the ion beam modification of materials, as well as, in hadron therapy applications and – to the authors' best knowledge – it has never been thoroughly investigated in the past.

Thus, the aim of the present work is to examine the differences in the multiple scattering calculations, concerning protons, between GEANT4, FLUKA, MCNP6, PHITS and the widely used SRIM2013 compilation and to compare and benchmark the obtained values against the experimental results presented in the past for a variety of targets.

More specifically, in all Monte Carlo codes, protons were generated as beam particles at 158.6 MeV and were subsequently transported, impinging on a variety of thin and semi-thick (ranging from ~0.08 to 8 cm), pure, single–element targets, such as aluminum, beryllium, copper and carbon, which are typically used as shielding materials or components in complex devices. An attempt was also made to additionally examine a number of commonly implemented compounds. The obtained results, corrected for the effective distance between the target and the sampling surface (which critically depends on each target thickness), show small deviations for specific target element and thickness combinations. The final comparisons are presented in graphical form and the observed similarities and discrepancies are discussed and analyzed. Since multiple scattering calculations, however, have

not yet been fully benchmarked against experimental data over a broad energy range, the final assessment of the obtained results relies on the user.

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Welcome and overview of Greek Geant4-based activities

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ESA status report

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Geant4 usage at JAXA

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Geant4 kernel updates and prospect

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Improving LRO/CRaTER Measurements of Cosmic-Ray LET Spectra and Lunar Albedo Protons

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The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) sensor has been orbiting the Moon aboard the Lunar Reconnaissance Orbiter (LRO) since 2009. As is implied by its name, it was designed primarily to measure the effects of energetic particles in the near-lunar environment rather than to act as a spectrometer to measure the distribution of those particles. As such, it has now recorded the time-varying spectra of Linear Energy Transfer (LET), or more properly lineal energy, from those particles over nearly a complete 11-year cycle of solar activity. However, we have also been able to use it as a particle spectrometer, in particular to obtain measurements of secondary "albedo" protons ejected from the lunar surface by nuclear interactions of GCR particles with that surface.
Measurements of both albedo protons and GCR LET spectra are subject to backgrounds caused by the abundant flux of GCRs striking the telescope from outside its nominal fields of view. We have devised a variety of empirical corrections for the backgrounds in both sets of measurements to obtain the results published to date, both in journals and, for LET spectra, as a continuously-updated data product available on the World Wide Web. Recently, we have used updated simulations of the response of CRaTER to particles both inside and outside of its nominal fields of view, using the Geant4 Monte Carlo radiation-transport toolkit, to devise improved background corrections based on the detailed physics of the particle interactions with the active and inert components of the sensor. We will describe the details of these corrections, and will present mission-long sets of observations both of the time-varying GCR LET spectrum and of the temporally- and spatially-varying flux of albedo protons coming up from the lunar surface.

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Examples of applications cases of GEANT4 in space environment effects analysis with the SpaceSuite tools and feedbacks

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Since early 2000's GEANT4 knows an increasing use for the modelling of the space environment effects on space systems. New domains of applications recently appear of reached an operational level, like for instance in 3D internal charging analysis or in the prediction of the Single Events Effects (SEE/SEU) in electronic devices. These outline new usages, needs and challenges. It is proposed to illustrate this wtith three examples issued from application cases of SpaceSuite's tools.

With simulation kernels like ESA/GRAS, GEANT4 is more and more intensively used on realistic and complex geometries. In an industrial context, the temptation to directly import them from mechanical CAD models, through the STEP-AP format and convert it into GDML is high. But up to recently, this was remaining quite complicated. Generally, it may lead to a sever negative impact on the simulation performances. Due to the difference of geometrical approaches (Brep versus GDML) a direct conversion is generally done through a tesselation of surfaces deeply impacting GEANT4 simulations in terms of CPU time for large systems. In most of the cases, direct Monte-Carlo simulation are unreachable with realistic geometries.

SpaceSuite/EDGE CAD tool, with the recent evolutions of its STEP-AP importer, aims to address these issues with improved geometrical simplification capabilities and a new and innovative detessalation function. This last one allows, in most of the cases, to convert back to canonical CSG shapes from tesselated closed surfaces. It deeply optimises the geometry and reduces significantly the CPU time for the simulation. Moreover, tests have shown that an improper and direct tesselation may lead to significant errors or divergences in the final physical results. Examples, including CAD simplifications, and impacts on the simulations cost will be presented and discussed.

In the domain of the predictions of Single Event (SEE/SEU) on electronic devices, GEANT4 offers several key possibilities, directly exploited by the new SEE-U single event prediction tools recently developed by Artenum and ONERA in the frame of the SpaceSuite-O project. Through a fine 3D computation of the deposited energy of the incoming particles, with GEANT4, it is possible to numerically evaluate the SEU cross-sections of technologies depending on the size and the position of the transistors, independently on experimental measurements. Moreover, the set MoOra/GRAS/GEANT4 offers to compute the energy particle spectrum after shielding. EDGE's Sector Shielding analysis module, SAAM, allows to rebuild the detailed equivalent aluminium shielding in each point inside a spacecraft. Combining both it is then possible to evaluate in situ the final Software Event Rate for the selected device, opening by this strong optimisations possibilities. Examples and first results will be presented and discussed.

Last, Internal Charging is an increasing risk factor, especially for missions passing through the radiations belts. If the initial particles charges and doses rates inside your sensitive components can be computed with MoOra/GRAS/GEANT4, a simple static view of deposited charges is not enough for a proper evaluation of the electrostatic risk, the dynamics and migration of charges inside the dielectric to be consider for a proper evaluation of E-fields and currents. To handle this, MoOra and the SPIS-IC plasma code has been interfaced in order to model precisely in 3D and dynamically the internal charge evolutions and the charging risk. Concrete examples on scientific experiments will be presented and briefly discussed.

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Persistency of Geant4 Phase-Space Information for Radiation Effects and Instrument Background Analysis

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Detailed radiation analysis for scientific instruments may necessitate the retention of very detailed particle track information in order to post-process the track and ionisation data for different instrument conditions. For applications in commercial space industry, the retention of phase-space data can also be used as a method of quantifying the radiation local to a spacecraft subsystem without the need to release to the subsystem manufacturer the details of the overall spacecraft geometry. This paper examines particle phase-space data persistency for these two applications as implemented with ESA's GRAS application for the CIRSOS and AREMBES Projects, and discusses the strategies and pitfalls for this type of approach.

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Discussion and closing remarks

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Geant4 simulation for proton irradiation experiments of space-use imager

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For a real beam experiment, uniform irradiation to the device under the test is a key factor. I report Geant4-evaluation result for newly developed irradiation system.