ENSAR2 workshop: GEANT4 in nuclear physics

Wednesday 24 April 2019 - Friday 26 April 2019

Other Institutes

Book of Abstracts

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Characterization of CsI(Tl) and LYSO(Ce) detectors scintillators and validation with MCNPX and GEANT4 codes.

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ABSTRACT

The Monte Carlo method is used to calculate the photon detection efficiency of scintillator detectors exposed to gamma rays in the energy range of 59.5 KeV to 1274.54 KeV. This work aims at calculating the response functions for two scintillation detectors CsI(Tl) and LYSO(Ce) (Lu1.9Y0.1SiO5:Ce0.5%) of size 10x10x5 mm3, to gamma-ray sources up to 1274.54 keV. Both detectors were modeled with the software MCNPX and GEANT4 codes. The results were compared to experimental energy spectrum and photopeak efficiency measurements from 22Na, 137Cs, 60Co and 241Am radioactive sources. The results showed good agreement with the experimental data.

Keywords: gamma-ray spectrometry, inorganic scintillator, CsI(Tl), LYSO(Ce), Monte Carlo simulation, Energy Resolution, Efficiency.

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Nuclear reactions at low and intermediate energies / 4

Development of a simulation toolkit for lifetime studies based on Doppler-shift methods

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The Doppler-Shift Attenuation Method (DSAM) and the Recoil-Distance Method (RDM) are powerful tools to measure nuclear level lifetimes in the (sub) pico-second range which are used to determine model-independent transition strengths.
With respect to the common analysis of DSAM experiments, one can distinguish between analytical approaches and tools using Monte-Carlo methods. The latter subdivides into tools that only describe the slowing-down process (based on an initial velocity distribution and tabulated stopping powers) and the nuclear decay scheme on the one hand, and Geant4-based simulations which also incorporate the interaction of radiation with matter and allow to take into account different detector geometries on the other hand. Many dedicated Geant4 based simulations already exist. However, the vast majority is tailored to specific experimental conditions, e.g. with respect to the covered detector geometries and the nuclear reaction mechanism used to populate the states

of interest. This hampers the applicability and transfer to modifications of the experimental conditions.
While Monte-Carlo methods are commonly used in DSAM experiments, the majority of RDM experiments are analysed using analytical methods based on the fitting of the fast and slow components in the RDM γ-ray spectrum. The only clear exception are RDM experiments with fast radioactive beams for which Monte-Carlo methods in the analysis are well accepted.
In this talk we will present a Monte-Carlo simulation based on Geant 4.10 which enables generating DSAM as well as RDM γ-ray spectra. The code allows to simulate typical reaction mechanisms, e.g. fusion evaporation and multi-nucleon transfer reactions. In addition, various HPGe detector geometries are implemented, ranging from single crystals to highly-segmented crystals such as SeGA or AGATA. Special emphasis was put on a modular concept, which allows to implement further reaction mechanisms as well as detector geometries rather easily. We will apply the simulation tool to experimental data to demonstrate the flexibility of the code. We will show our approach to describe the nuclear de-excitation based on a mixture of Geant4-based modules and self-developed classes.

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Calculation of Delayed-Photoneutron Production in Heavy-Water Reactors using Geant4

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Understanding and predicting the dynamic behaviour of nuclear reactors is of paramount importance for reactor safety. This time-dependent behaviour is primarily driven by the emission of beta-delayed neutrons and photoneutrons following the decay of neutron-rich fission products. It is the production of these delayed neutrons which allows for a system-dependent "sluggishness"during power maneuvers, and are governed by the decay constants of the relevant precursors.

In this work we apply the Geant4 toolkit and recent fission yield data to calculate the photoneutron production from the thermal fission of ^{233,235}U and ^{239}Pu within a quasi-infinite bath of D_2O. The simulated photoneutron production rate was fit to a series of exponential terms enabling a direct comparison to historical "11 group" photoneutron data. Significant discrepancies were found comparing the simulation results to the recommended ^{235}U photoneutron yields within the shortest and longest half-life groups, including the 55.7 second half-life group; raising concerns on the validity of the yields derived from experimental data. A detailed discussion on the origin of the historical data will be presented along with explanations for the observed disagreement.

Poster session / 8

Modelling of Radiation Resiliant Ultrasonic Sensors

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Part of the ReDRESS Innovate UK project.

There is a need to test difficult to access, thick section steel components for weld defects and in-service corrosion that may lead to pressure vessel/component failure in the nuclear power generation industry that requires the application of high sensitivity ultrasonic testing (UT) techniques.

This project conducts research into the construction and testing of novel, radiation resilient, ultrasonic transducers manufactured from exotic materials and a variety of probe assembly techniques. The goal is to provide the nuclear industry with a reliable UT solution for prolonged in-service inspection and permanent monitoring. Two scenarios are envisaged: (a) elevated temperature, high radiation inspection close to the nuclear reactor (b) low radiation - inspection of nuclear waste containers stored at bespoke sites over very long periods. The objective is to develop a series of prototype ultrasonic probes designed to suit the specific in-service inspection needs.

Geant4 is used to support the development of the radiation resilient ultrasonic sensors through the examination of the effects of design on the radiation environment the sensitive components are subject to.

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Background simulation of the SABRE experiment

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The SABRE experiment (Sodium-iodide with Active Background REjection) will search for dark matter through the annual modulation in the rate of ultra-pure NaI(Tl) crystals. Dark matter signal is expected to modulate yearly because of the rotation of Earth around Sun, and thus the change of the relative velocity of the detector with respect to the dark matter halo.

The first phase of the experiment is the SABRE Proof-of-Principle (PoP), a single 5 kg crystal operated inside a liquid scintillator veto at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy.
The final experiment will consist of twin NaI(Tl) crystal arrays of about 50 kg, located in the north and south hemisphere: respectively at the LNGS in Italy, and at the Stawell Underground Physics Laboratories (SUPL) in Australia. The double location is a key feature in order to understand site related backgrounds, and to discriminate a modulation signal of seasonal origin, with opposite phase in the two sites, from a signal of galactic origin with the same phase.

The signal region for dark matter interactions is in the range 1-20 keV, and the background for this experiment is mainly due to the contamination of radioactive isotopes and cosmogenic activation in the detector material and surroundings.
A detailed GEANT4 simulation has been developed to estimate the background of the PoP, based on radio-purity measurements of the detector components.
This simulation will be compared with the PoP data and used as a tool to quantify the most important backgrounds.
Simulation of the full scale geometry is now under development, in parallel with the finalization of the design of the final experiment. In addition to the radioactivity, we have added the optical physics and the propagation of scintillation light in the crystals and in the liquid scintillator veto, in order to study and optimize the light collection efficiency.

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The use of Geant4 simulations for training the artificial neural network used for the NeuLAND data analysis

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Precise experimental knowledge on a wide variety of observables is a key ingredient for improving our understanding of nuclear structure. As a result, each new generation of accelerator facilities produces larger amounts of data than the previous generation in order to improve the precision of the measurements. Hence, more advanced analysis tools are required to deal with these large amounts of data. Recently, the use of artificial neural networks is gaining popularity as such a tool for analysis. However, using an artificial neural network requires one to train the network beforehand using data with a known outcome. Access to data with a known outcome can be a bottleneck, because no experiment has a result that is known beforehand. As a workaround, neural networks can be trained using simulated data instead. However, for this training to be effective, the physical processes included in the simulation must provide an accurate description of reality. We shall discuss this problem in a case-study for fast-neutron detection using the NeuLAND neutron detector of the R3B experiment at the FAIR facility in Darmstadt, Germany. The detector responses (multi-neutron detection in particular) of NeuLAND have been studied extensively through Geant4 Monte Carlo simulations, which we hope to use for training an artificial neural network that can
analyze the NeuLAND data. However, before these simulations can be used for training a neural network, we need to make sure that the interactions used in Geant4 are well under control and have been benchmarked properly. In this presentation, some results will be shown indicating how inaccuracies in the Geant4 interactions can propagate through the neural network data processing.

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The Liège Intranuclear Cascade (INCL) model. Its evolutions and capabilities.

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INCL (Liège Intranuclear Cascade) is an intranuclear cascade model, a first step for modeling spallation reactions. It is usually combined with the de-excitation code Abla to simulate the entire reaction. We will quickly present how this model developed during the last three decades. We will also show how its present high reliability has been achieved, how it has been extended toward the low (< ˜100 MeV) and high (> 2-3 GeV) energy regimes, what are its capabilities inside Geant4 and the future developments.

Poster session / 13

V&V Analyses of the GEANT4 Monte Carlo Code Toolkit with Computational and Experimental Fusion Neutronics Benchmarks

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In the plasma of fusion reactors, tritium and deuterium react to create helium and a 14.1MeV neutron, which escapes the magnetic containment. For defining and verifying requirements and boundary conditions for fusion reactor systems, the neutron transport through reactor components and the interactions of neutrons with the encountered materials has to be assessed. To this end, 3D Monte Carlo particle transport codes are employed.

The current reference code for fusion neutronics calculations is the Monte Carlo N-Particle (MCNP) code developed by Los Alamos National Laboratory. Due to restrictions on the distribution of MCNP, there is a European effort to find alternative open-source codes. One potential alternative is the high-energy particle physics Monte Carlo code toolkit GEANT4. It has been expanded for fusion energy-range neutron transport simulations based on evaluated nuclear cross-section libraries and offers the potential to represent complex geometries and volumetric neutron sources. The aim of this work is to investigate the suitability of GEANT4 for fusion neutronics requirements and to expand the code where necessary. On this poster, the steps undertaken so far will be presented.

First, the basic neutron transport behaviour of GEANT4.10.3 was evaluated on the basis of two simple geometries filled with the most fusion-relevant isotopes in comparison with MCNP5-1.6. For this, nuclear data from the ENDF/B-VII.0 and the JEFF-3.1 library was used. The differential computational benchmark assumes a neutron beam with isolethargic energy distribution along the axis of a cylinder with length 2m and radius 1µm. After a single material interaction, the scattered or secondary neutrons passing through the cylinder side surface are recorded. The average relative deviation between GEANT4 and MCNP throughout the energy spectrum is <1% for all isotopes and libraries. The integral computational benchmark is a 30cm radius sphere with an isotropic 14.1MeV neutron source in the centre. The neutron flux averaged over the sphere volume is recorded. The total flux deviation between GEANT4 and MCNP is <1% for all isotopes and libraries with some larger deviations in individual energy groups for some isotopes.

Second, the consistency of GEANT4 calculations with experimental results was tested with geometry and source descriptions of the benchmark experiment "IPPE (Institute of Physics and Power Engineering) neutron transmission through iron shells"processed from the Shielding Integral Benchmark Archive and Database (SINBAD). Geometry and source description were converted for GEANT4 from MCNP input files. It consists of spherical iron shells of five different thicknesses between 2.5—28cm, the experimental setup for the creation of the 14.1MeV neutron source in the centre of the shells and the detector at a distance of 679cm. The Calculation/Experiment is acceptable for most of the energy spectrum with larger deviations in the range of 4—10.5MeV.

Third, another experimental benchmark from SINBAD was chosen: the "FNG (Frascati Neutron Generator) HCPB (Helium Cooled Pebble Bed) Tritium Breeder Mock-up". Here, the more complex geometry description made it necessary to convert the MCNP input via CAD to GDML for GEANT4. At the time of abstract submission, this work was still ongoing.

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The interface of BLOB with GEANT4

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Despite of its large use, the models implemented in Geant4 have shown severe limitations in reproducing the measured secondary yields in ions interaction below 100 MeV/n, in term of production rates, angular and energy distributions.
For this reason, we coupled BLOB (Boltzmann-Langevin One Body), a models dedicated to simulate such interactions, with Geant4 and its de-excitation phase.
BLOB is a semi-classical one-body approaches to solve the Boltzmann-Langevin equation. It includes a treatment of the mean-field propagation, on the basis of an effective interaction. BLOB introduces fluctuations in full phase space through a collision term where nucleon-nucleon correlations are explicitly involved. BLOB has been developed to simulate heavy ion interactions in the Fermi-energy regime.
We will present the preliminary results obtained in calculating double-differential cross sections and angular distributions of the secondary fragments produced in the 12C fragmentation at 62 MeV/n on thin carbon target obtained with this model coupled with Geant4 and its de-excitation phase.

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Geant4 Electromagnetic Physics

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The status of the Geant4 electromagnetic physics sub-libraries is presented. Current developments of electromagnetic physics is focused on implementation of next to leading terms of various electromagnetic processes including multiple and single scattering, gamma conversion, positron annihilation. Atomic de-excitation module is use in several electromagnetic models and in radioactive decay. Problems and perspectives of accurate implementation of atomic effects are discussed. The new validation results are presented.

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Geant4 pre-compound model and nuclear de-excitation module

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High and intermediate energy hadronic models should have a sub-model for simulation of nuclear de-excitation processes. In Geant4 there is a general pre-compound model and a general de-excitation module, which are used by many hadronic models. These models were recently modified and improved. Different aspects of these models are discussed and new validation results are presented.

Other applications / 19

Simulation of environmental radioactivity

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The study of environmental radiation is a challenging task. It is well known that natural gamma radiation may vary depending on the altitude, type of soil, building materials and even human presence. All these variables and uncertainties make it difficult to foresee the background radiation present at a specific region beforehand. In order to better understand the contributions of each individual background source, the EnsarRoot framework has been adapted for this goal.
EnsarRoot has been further developed to include a series of gamma-rays generators characteristic of the main natural radioactive sources. Considering these improvements, the framework reproduces gamma yields originated from decays of the three radioactive chains: Uranium (from which ^{222}Rn comes), Actinium and Thorium. Gammas emitted in the decay of ^{40}K have been also included. The data considered for all generators has been taken from the National Nuclear Data Center.
This report summarizes the simulation process to obtain a typical gamma background spectra, as well as, the benchmark between the simulated spectra and background measurements were done using an HPGe (High Purity Germanium) detector, which has been included as well in the EnsarRoot framework. The excellent resolution of the HPGe detector allows a very detailed analysis of the photon emitted by a wide range of nuclei. Experimental measurements and simulated data could be analyzed on equal footing using the same framework.

Poster session / 21

EDGE, ExtendeD GDML Editor: A new GMDL CAD tool for GEANT4 based analysis and interoperability bridge for high-energy particle modelling tools.

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Nuclear structure / 22

Radioactive Decay in Geant4: Status and Plans

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The Geant4 radioactive decay process, models and databases have undergone many
upgrades during the past several years. These include refactoring the analog and biased decay to allow more efficient sampling, the modularization of the models which implement the various decay modes, physics improvements of the final state particle spectra for many of the decay modes, and the addition of new decay modes. Both the radioactive decay database and the photon de-excitation database have been extended and updated. Each of these topics will be discussed along with plans for future improvements. These improvements include further extensions of radioactive decay to include more decay modes, improved atomic de-excitation and an extensive set of validation plots.

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Fission Models in Geant4: Status and Plans

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Fission in Geant4 is currently simulated as both a separate process and as a de-excitation model in other inelastic processes. Several different models exist, each with different interfaces and functionalities. This has led to confusion about which models are used and what they do, and to the possibility of users double counting fission by incorrect assignment in physics lists. The inventory of Geant4 fission models will be discussed, highlighting the areas where physics is lacking or not yet addressed, and improvements which need to be made. Potential projects for the future will be presented, including re-organization and redesign of the fission interfaces, expansion of fission databases, physics improvement, validation and documentation.

Medical applications / 24

Assessment of specific absorbed fractions for HDRK-man phantom using Geant 4 code

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The main purpose of this paper is to present an overall study of the specific absorbed fractions (SAFs) of photon and electron sources to assess the internal doses after incorporation of radionuclides into the human body. SAF values for self and cross-absorption were calculated for a uniform distribution of mono energetic photon and electron emitters with energies ranging from 15 keV to 3 MeV. The voxelized human phantom "High Definition Reference Korean Man" (HDRK-man), which was implemented using GEANT4, has been used for many combinations of target-source organ. The results were compared to those of the International Commission on Radiological Protection Reference (ICRP133) and Zubal phantoms. It has been found that SAF values of the three models have a similar trend. Although, the SAF values for the HDRK-man phantom were higher than those of the other two models with a relatively good agreement with those for the ICRP133 phantom (differences of 13.9 ± 2.8 and 12.1 ± 3.2 for photon and electron particles, respectively). In order to analyze the

differences in SAF values, we calculated the chord length distributions (CLDs) for selected source-target combinations. The parameters of organ mass (or volume) and CLDs, other than the adopted computational procedures, mainly causes such discrepancies
The new arrangement of SAF values can be considered as an added-value for multidisciplinary research and the clinical community

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Geant4 simulation of the ELIMED/ELIMAIA beamline, an open Users beamline for irradiation with laser-driven ion beams

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The main direction proposed by the community of experts in the field of laser-driven ion acceleration is to improve particle beam features (maximum energy, charge, emittance, divergence, monochromaticity, shot-to-shot stability) in order to demonstrate reliable and compact approaches to be used for multidisciplinary applications, thus, in principle, reducing the overall cost of a laser-based facility compared to a conventional accelerator one and, at the same time, demonstrating innovative and more effective sample irradiation geometries.
The mission of the laser-driven ion target area at ELI-Beamlines (Extreme Light Infrastructure) in Dolní Břežany, Czech Republic, called ELI Multidisciplinary Applications of laser-Ion Acceleration (ELIMAIA), is to provide stable, fully characterized and tuneable beams of particles accelerated by Petawatt-class lasers and to offer them to the user community for multidisciplinary applications. The ELIMAIA beamline has been designed and developed at the Institute of Physics of the Academy of Science of the Czech Republic (IoP-ASCR) in Prague and at the National Laboratories of Southern Italy of the National Institute for Nuclear Physics (LNS-INFN) in Catania (Italy). In particular, the final section of the beamline, that includes the beam focusing, the energy selection, the dosimetric and sample irradiation parts, constitutes the so-called ELIMED (ELI MEDical and multidisciplinary applications) portion.
At ELIMED, controlled proton and ion beams, with energy ranging from 5 to 250 MeV, will be transported up to the in-air section where absolute dosimetry will be carried out with dose-rate independent devices. A transmission, dual-gap air ionisation chamber will provide the on-line measure of the dose at the irradiation point contemporary permitting the correction for the ion recombination effects. The maximum expected error in the final dose released to the sample is expected to be within 5%. ELIMED first irradiation is scheduled for 2020 when the first radiobiological campaign for in-vitro cells irradiation is expected.
In order to plan the first experiments a dedicated Geant4 application, fully simulating the entire beamline, has been realised. The application reproduces all the beamline transport elements, including detectors and the dosimetric device.
In this work, the status of the ELIMED/ELIMAIA beamline will be reported along with a complete description of the Geant4 application realised. The expected final beam characteristics, in terms of dose per pulse, dose-rate, beam spot size, directly derived by Monte Carlo simulations, will be discussed, as well. Perspective in the use of the Geant4-DNA package to apply Geant4 in the special case of high-dose-rate beams will be also discussed.

Other applications / 26

Simulation of ion backscattering from rough thin films

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Depth profiling and morphological characterization of thin film is of critical importance to a wide variety of modern technologies. Back scattering spectroscopy using MeV ion beams is considered as a powerful method for depth profiling elements in the near surface layer of solids. Generally, this technique is a one-dimensional method and the roughness and inhomogeneity of the target often is not considered. In the present work, influence of the surface roughness on back scattering spectra was studied. The back-scattering spectra from the different rough thin films, were studied with Monte-Carlo simulation and analytical solution.
The back-scattering spectra were simulated using the GEANT4 Simulation code by simulating the details of the particles trajectory as well as multiple and plural scattering of in-going primary ions and out-coming backscattered ones. All simulations were performed at the different incident and back-scattering angels.
The results of the simulations and analytical approximation of the back-scattering spectra show substantial changes in shape and amplitude as a function of surface roughness at the different incident and detection angels. Also effects due to the detector solid angle, beam spot size, multiple and plural scattering of incoming and outgoing beam were studied.

Medical applications / 27

MIRTO: A microdosimetric study and RBE measurement with 62 MeV clinical proton beam

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CATANA (Centro di AdroTerapia ed Applicazioni Nucleari Avanzate) was the first Italian protontherapy facility dedicated to the treatment of ocular neoplastic pathologies. Since 2002, it is in operation at the LNS Laboratories of the Italian Institute for Nuclear Physics (INFN-LNS), to date 400 patients have been successfully treated. Nowadays, a slightly increased biological effectiveness (with respect to reference low-LET radiation) is considered in clinical proton treatment planning by assuming a fixed RBE of 1.1 for the whole radiation field. However, data emerging from various studies suggest and highlight how variations in RBE, which are currently neglected, might actually result in deposition of significant doses in healthy organs. Accurate knowledge of the RBE increase in eye protontherapy is of extreme importance as the distal part of the Spread-Out Bragg Peak (SOBP) often involves critical anatomical regions like optic nerve and the macula for which an excess of biological dose could lead to patient's vision loss. To our knowledge, while comprehensive literature exists on the clinical results of protontherapy treatment of uveal melanoma, no in-vitro data on the cellular radioresponse of uveal cancer cells along a clinical proton SOBP are available, with the exception of one study by Courdi et al (1994), who found an RBE of 1.27 at the distal end of a 65 MeV proton SOBP. In this study, however, melanoma derived from a metastatic axillary lymph node was used. Instead, we used a uveal melanoma cell line (MP38), deficient in BAP1 (BRCA1 associated protein-1), a known hallmark of aggressive disease. In addition, to evaluate damage incurred by a typical organ

at risk, normal epithelial cells from the retina was used.
A collaboration, between INFN-LNS, CMRP UoW, INFN-NA, IBFM-CNR, INFN-LNL, INFN-MI and INFN-TIFPA was established to perform an experimental measurement of major microdosimetric parameter the dose average lineal energy yd to derive RBE value along a typical SOBP for eye protontherapy. Microdosimetry measurements along the SOBP were carried out using silicon-based detector microdosimeter, a MicroPlus probe, mini-TEPC and a TEPC followed by application of MKM for RBE10 calculation.
In parallel, radiobiological measurements was performed irradiating the MP38 cells at the same positions along the SOBP. ARPE-19 cells from retinal pigmented epithelium will be also investigated in the distal end region. Radiation-induced cell death was evaluated by clonogenic assay and RBE values was calculated from constructed dose-response curves using the LQ model.
Monte Carlo (MC) simulations of the whole experimental set-up, including the physical characteristics of the proton beam, was implemented using the Geant4 toolkit. The spectra generated by these simulations was used as the physical input for the radiobiological simulations based on the MKM model, from which an estimation of the RBE along the SOBP was evaluated and compared with the experimental data.

Poster session / 28

Monte Carlo Dose Estimation from Linac Photon Beam using GATE/GEANT4

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During the last few years, Monte Carlo simulation is considered to be the gold standard method for radiation dose calculations. Thanks to the accuracy and the flexibility that it supplies, MC method is the most used for dose prediction in external radiation therapy. This work aims to set up a full geometrical model of an 18 MV Varian Clinac 2100C medical linear accelerator in photon mode, using Gate/Geant4 Monte Carlo simulation platform. The simulation contains the major components of the linear accelerator (LINAC) and a homogeneous water phantom. The Phase Space approach was used in order to reduce the CPU calculation time. To validate the 18 MV photon-beam linear accelerator model, measured and calculated relative depth-dose data for several radiation field sizes ranging from 6x6 cm2 to 40x40 cm2 along the central-axis and dose profile at different depths, were compared. A good tuning was found between the calculated and measured dose distributions in the water tank.

Detector simulation / 29

A simulation model for reproduction of the background radiation flash produced by high energetic H-like ions during their stopping in matter: I. The contribution of the electron capture processes - Radiative Electron Capture and Primary Bremsstrahlung.

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The background radiation flash produced by stopping of ions in matter is a main obstacle for detection of lower energy gamma-rays transitions emited by short-lived excited states in unstable nuclear systems obtained in experiments with relativistic ion beams. The large number of produced X-rays blinds the detectors and their pile-up in the detector's crystal volume may change the profile of the energy lines of interest in experimental data. In this sense, the ability to reproduce the background radiation would be extremely valuable in experimental data analysis, preparation of new experiments, and during development of new detectors and instruments.
Current work presents a first part of a more generic task to develop complete set of GEANT4 extension libraries to enable fast simulation of the bremsstrahlung background radiation produced as a result of stopping of highly energetic ions passing through matter and reproduce its influence on the detector system in terms of spacial and energy distributions and rates of the produced X-radiation.
This work is focused on the implementation of the electron capture processes - in the ion's bound states (Radiative Electron Capture in K, L, M shells) and in the continuum (the Primary Bremsstrahlung process) based on the known theoretical developments. Each process is represented by a separate GEANT4 physics class. The simulations using the developed physics process classes will be compred to the background radiation detected during 'fast'and 'stopped'beams RISING experimental campaigns at GSI. Results will be discussed.

Detector simulation / 30

Crystalline effects for electromagnetic processes in Geant4

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Crystals have an internally ordered structure resulting in anisotropy of electromagnetic interaction of charged particles with crystals. When particles move along crystal axes or planes, they can oscillate in their electric field.
For ultra-relativistic particles, i.e. ten or hundred GeV electrons and positrons the electric field of axes or planes is comparable to the Schwinger critical field of QED in the reference system of particles. In this case the electrons and positrons motion is characterized by synchrotron-like radiation with intense emission of hard photons. Therefore, the cross-section of photons emission as well as electron-positron pair production considerably increases.
Nowadays Geant4 treats any substance as the amorphous one and doesn't take into account the crystalline effects of radiation. Though this effects can be simulated well using a Monte-Carlo code based on a method direct integration of the Baier-Katkov (BK) formula [1], such kind of simulations require a considerable computational time problem.
We propose a method to modify standard electromagnetic physical processes in Geant4 to take into account the crystalline effects by fast simulations [2]. In particular, the cross-sections of bremsstrahlung for electrons and positrons and electron-positron pair production for gamma-quanta were multiplied by the correction coefficients. These coefficients were calculated by using full Monte-Carlo code based on BK quasi-classical method.
The electromagnetic (e.m.) shower for primary high energy electrons, positrons and gamma-quanta was simulated for oriented lead tungstate (PWO) (modified Geant4). In comparison with standard Geant4, the maximum of deposited energy shifts to the enter surface. Therefore, one can reduce the calorimeter thickness to contain the e.m. shower because the length of shower decreases significantly, starting from 10 GeV of primary particle energy. Moreover, this effect becomes more

pronounced at higher energies, which leads to the opportunity to develop a compact calorimeter for TeV scale.

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Nuclear structure / 32

Extending GEANT4 "Radioactive Decay"for the Analysis of Complex Total Absorption Analysis Cases

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We will present a new event generator created for the calculation of the response functions of total absorption spectrometers used in the study of complex beta decays. The development is based on an extension of the Radioactive Decay package. In the even generator, the level scheme of the decay of interest is divided in two regions: one region in which the original information from high resolution measurements is kept, and another region where the excitation energy is divided in energy bins that decay to lower lying levels using an statistical model. The statistical model is based on level density functions and gamma strength functions of E2, M1, and E1 character. Details of the use of this event generator in the analysis of the ISOLDE (CERN) experiment IS539 will be presented.

GEANT4 tools / 33

ExpertRoot. A GEANT4 and FairRoot based framework for simulation and reconstruction of Nuclear Physics experiments at ACCULINNA2 and SuperFRS facilities.

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The ExpertRoot framework supports all the stages of the lifecycle of an experiment:
planning and feasibility studies, detailed simulations of the detector response and digitization, particle identification (PID)
and reconstruction, reconstruction of entire events.

The interaction with GEANT4 classes is implemented via VMC.
Thoroughly control over the production of secondaries, tuning of physics, stepping actions, etc. is demanded
by the low energy nuclear Physics experiments and realized in the ER framework.

The key features of the framework are:
- an interface library for reading, converting and calibrating the experimental data
- a generator for the realistic cocktail beam
- an extended set of interactions including decays on the flight, interfaces to the external physical models,
phase space dominated parameterizations etc.
- flexibly parameterized models and procedures (starting from geometry creation and ending with particle identification
and reconstruction) are built for all the detectors in use.
- a database with realistic parameters of the detection modules present in the lab and used in the experiments is supported
- The same geometry is used for simulation and reconstruction
- the same PID and reconstruction algorithms are used for the simulated and experimental data
- Such effects as energy loss in the target and dead layers of the detectors are taken into account in the simulation (stochastically) and the reconstruction (in average).

The architecture of the framework, principle algorithms and an experimental example will be discussed in the talk.

Detector simulation / 34

A Monte Carlo based method for fine calibration of Si Telescopes.

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In order to fully explore the particle identification and measurement capability of the telescopes built from two or more silicon strip detectors, one has to calculate all the dead layers of the detectors as well as the calibration coefficients for each channel. The most reliable way of solving this problem is to combine various measurements with calibration sources and detailed Monte Carlo simulations. Such a technique developed in the ACCULINNA-2 group in Flerov Lab in JINR will be presented. The technique allows for a pixelwise analysis of active and dead layers. The pixel can be defined as an arbitrary combination of two mutually perpendicular strips belonging to any detectors in the telescope. The results including achieved accuracy and stability will be reported. Data quality issues will be discussed as well.

Nuclear reactions at low and intermediate energies / 35

Cross-sections of Light Nuclei in the Glauber-Gribov representation

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The Glauber-Gribov approach (corrections for both elastic and inelastic nucleon screening) is considered for the description of light nucleus-nucleus cross-sections. It was found that electromagnetic

nucleus radii are result in better description of measurements. The calculations are compared with experimental data for the reaction cross-sections

GEANT4 tools / 36

GROOT: A novel Geant4 and ROOT Monte Carlo tool for nuclear physics

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A very brilliant gamma beam system with pencil-size beamspot will be installed at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP), which is one of the pillars of the ELI Project. Monte Carlo simulations are crucial for the proper implementation of the instruments that will be used for experiments and for external users who come to perform experiments at the facility. For this reasons, we developed GROOT, an efficient Monte Carlo software based on Geant4, integrating a n-body event generator of ROOT libraries and a Qt interface in order to provide a fast, reliable and user-friendly tool to be used in nuclear physics experiments, with a particular focus on the study of photo-nuclear reactions of astrophysical interest with silicon detectors. In this talk, a brief overview of ELI-NP facility and part of its research program is given, the advantages of GROOT are shown and the results of the simulations performed in order to evaluate the effects of the electromagnetic background, the energy and angular straggling of the emitted particles and the detector resolution on some selected physics cases are discussed.

Poster session / 38

Molecular Imaging at Cellular Level: Theoretical treatment using Geant4 code

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Abstract:

Introduction: Molecular imaging is a model of visualization the cellular function and follow-up the molecular process in living organisms. Positron Emission Tomography (PET) is one of these imaging modalities. The essential objective in molecular imaging modalities is to gain images with optimized quality and exhaustive data of object to provide a detailed report about the measurement of radioactive tracers distribution in vivo. Spatial resolution is one of the factors that limit the realization of this goal. Whenever, the overlapping measurement between two objects as accurately as possible an excellent image resolution will be obtained. This study will focus on how closely micro tracks can be resolved in an image formed by the nuclear emulsion film traversed with a positron; this will be presented in a theoretical treatment using Geant4 code. Simulation study: This

study provides a model for determining the resolution of positron-Nuclear Emulsion image. This model based on Monte Carlo Simulation- Geant4 code (1), Object –Oriented data analysis framework (2), Reconstruction algorithm (Iterative Correction) (3), FEDRA library (4) and Allen et al method (5). We propose an innovative technique rely on the nuclear emulsion film detector for positron radiography. Human cells are labeled with the positron emitting radiotracer to be loaded to the nuclear emulsion film detector. Positron tracks are detected and the positions of positrons passing through the patient's body are measured to produce more sophisticated image with high precision reconstruction. Three mandatory classes will be implemented: G4VUserDetectorConstruction to design the nuclear emulsion sheets, G4VUserPhysicsList to implement the positron source and all the expected physical processes from the interaction of the concerned particle with a matter and G4VUserPrimaryGenerationAction to design the positron particle travelling along the z axis with energy selected 1 MeV positioned at the center of two detectors in a Cartesian coordinate system with an isotropic momentum direction. Results and conclusion: This model provides a resolution limit ˜10 µm for the distance of closest approach squared. This result allows a quantitatively exploring the prospects for the use of positron imaging techniques at the cellular metabolic scale using Emulsions. This model develops a trace reconstruction and vertex search algorithm which allows controlling the randomness of the positron's path by accessing the annihilation vertex. This would provide a visual representation similar to that obtained with PET, but at the cellular level.

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Underground experiments / 39

Development of neutron detectors for key astrophysical nuclear reactions

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Many experiments operate detectors that are susceptible to fast neutron-induced backgrounds [1]. To decrease these backgrounds many collaborations, including the nuclear astrophysics community, operate their experiments in deep underground laboratories. But even in such low background environments it is critical to accurately know the environmental neutron flux.

One way to measure this is the capture-gated neutron spectrometry [2,3], which has in the last years been extended to setups based on hybrid 3He- Liquid/Plastic scintillator detection systems [4,5].

The very early stages of such developments rely on Monte Carlo simulations that can predict the number of interactions, deposited energies and time-correlations. These simulations require precise moderation models for the different materials. At very low neutron energies the data-driven Geant4 NeutronHP physics are required for the most reliable results, and optimally one should include the molecular corrections to the scattering cross sections in various materials. These corrections are currently only implemented for a few materials such as polyethylene and water.

In order to better investigate the possible effects on simulations with and without molecular corrections we have studied the neutron moderation process for a EJ309 detector using GEANT4 and compared it to the results of simulations, where the scintillator was replaced by polyethylene and water, with and without molecular corrections. We will present these comparisons and preliminary results of measurements using a hybrid liquid scintillator-He3 detector.

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Nuclear reactions at low and intermediate energies / 40

Calculation of the neutron production induced by radiogenic alpha-decay with Geant4

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The calculation of the neutrons produced in (alpha,xn) reactions in a certain material require the calculation of the alpha-tracks, the cross sections of the neutron production reactions involved and the energy distributions of the secondary neutron energy distributions.

All these ingredients are present in Geant4, namely the slowing down of the alpha particles (EM physics), the neutron production cross sections and secondary particle energy distributions (G4ParticleHP) based on ENDF-6 formatted data libraries and the particle and process biasing techniques.

The ParticleHP module of Geant4 has been used to model neutron production induced by radiogenic alpha decay. Several results obtained with differen tinput cross section libraries and energy spectra have been compared with other codes.

Energy applications / 41

Geant4 simulation of ADS

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Acceletator driven system (ADS) is simulated by the Geant4 tools - the mass layered geometry and scoring. The ADS target was simulated with different geometries of cooling layers. The neutron output spectra as well as energy deposition profiles are shown. The ADS power (and other parameters) dependence on driver thickness are shown. The medical isotope production is simulated in the batch mode (2000 jobs with 5000 events each)

Nuclear reactions at low and intermediate energies / 42

Transport of low energy neutrons and charged particles in Geant4

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Geant4 allows to use the information available in ENDF-6 format data libraries for the transport of low energy neutrons and charged particles (up to 20 MeV). This is done by the so called G4ParticleHP model (previously G4NeutronHP). We will show the performance of the model, showing its capabilities and limitations. We will also talk about how to use it and about which simulations can be done with this model and which ones can not. Finally, we will propose future developments to improve the performance of the code.

Nuclear structure / 43

A new Photon Evaporation model for Geant4

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Geant4 uses the so called G4ParticleHP package to model the low energy neutron and charged particle interactions according to the information available in ENDF-6 format data libraries. In these libraries the photon production is presented in some cases in an uncorrelated way, for example for neutron capture reactions. Thus, this information can not be used to produce the secondary γ-rays for simulations requiring energy conservation event by event.
We have developed a code capable to generate de-excitation γ-rays in a correlated way using as much information as possible available in the RIPL-3 and ENSDF nuclear structure data libraries, among other useful information. The code follows the same philosophy of the DICEBOX or DECAYGEN codes. It generates the complete level scheme and branching ratios of the nucleus by using all the information experimentally known (known level scheme and known branching ratios) and completing the missing information with the most reliable statistical models. This code is able to generate automatically cascades for a large variety of nuclei (at least 100-200) without requiring a specific input for each particular isotope. The code has been implemented into GEANT4, which will allow performing more reliable GEANT4 simulations in a large variety of fields.

Poster session / 44

DEVELOPMENT OF AN ANALYTICAL MODEL FOR THE DEPTH DOSE PROFILE PRODUCED BY GAMMA RADIATION

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Monte Carlo codes are among the most used tools today for calculations and simulations related to medical physics [1] and particularly for studies of low dose medical applications.

In this work, we have undertaken on the development of an analytical model with the aim of calculating the deposit dose produced by ionizing radiation inside a medical phantom (filled with light water). The CNSTN cobalt 60 source irradiator was used as the experimental validation platform for this study. A Monte-Carlo modeling of the irradiator was thus performed by the Geant4 toolkit [2], with validations of some dose deposition results obtained by referring to previous experimental work. The model was then adapted to our case of study, by developing a more specific configuration, suitable for gamma radiation beam and variable energy beams.
The study of the theoretical behavior of the doses produced by these photons [3] in a phantom filled with water was also carried out. The numerical results obtained demonstrate different behaviors according to the different energies. Digital fitting was then made by the Matlab tool for these different behaviors. The compilation of all these results led to the development of an analytical model for the prediction of the behavior of the deposited doses in the case of the studied phantom.
Further studies of these same works, with 2D analytical modeling and the generalization of the study for the cases of other types of radiations, will be established later.

Poster session / 45

The cross section of the inelastic interaction of protons and helium nuclei with the tungsten obtained with the PAMELA space experiment

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We present the energy dependence of the cross section for the inelastic interaction of protons and helium nuclei with the tungsten in the energy range from a few hundred MeV to a hundred GeV using the data of the PAMELA space experiment. It was intended for the precision measurements of the cosmic ray fluxes of different nature and include a set of detectors for the reliable determination of the particle characteristics (their type and energy). Identification of particles was carried out with the tracker system in magnetic field, time-of-flight and anticoincidence systems. A coordinate-sensitive calorimeter with a tungsten absorber, in turn, allows us to study the topology of the interaction of particles inside it, and calculate the cross-section of their inelastic interaction. We present the comparison of the obtained results with the measurements at accelerators and with existing theoretical models. The results of the work can be demanded for the development of numerical models describing particle's interactions.

GEANT4 tools / 46

Biasing in Geant4

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There is a class of simulation problems for which the events of interest are rare. The shielding problem -with very few particles exiting the shield, where the dose estimates are to be made-, the very thin detector case -with very few particles interacting in it- or the dose estimate in an electronic chip inside a satellite -because of the tiny volume of the chip compared to the large satellite structure one- are some examples of such problems. In these, "standard" -also called "analog"- simulations are very inefficient, as spending only a marginal fraction of the CPU time inside the region of interest, often

leading to poor estimates. Biasing techniques are a set of methods to simulate rare events efficiently by focusing the CPU power on the region of interest, still exploiting the same accurate physics modeling of the analog simulation. Very used in packages like MCNP, they are being developed in Geant4 to -not only provide exiting techniques- but also to allow advanced users to invent and implement their own customized techniques. We will present how this scheme is realized in Geant4 and the status of these developments.

Medical applications / 47

Covering the upper clinical energy range of Geant4-DNA for proton transport in liquid water

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Proton beams used in radiotherapy treatments can reach energies up to 250 MeV for deep-seated tumours. However, the existing cross section models included in Geant4-DNA [1,2] cover up to 100 MeV only. The goal of this work is to extend the current applicability range of Geant4-DNA for proton transport in liquid water up to, at least, 250 MeV.
Due to the energy range considered, the relativistic quantum mechanics theory is used following the work done by F. Salvat [3] in order to obtain an expression of the doubly-differential cross section (DDCS) with respect to the energy transferred, W, and recoil energy, Q. The latter is defined as the kinetic energy of a free electron with momentum equal to the momentum transfer. Considering the interaction in first order perturbation and modelling the projectile as a free particle (plane wave), the so-called Relativistic Plane Wave Born Approximation (RPWBA), the contributions of the projectile and the target to the DDCS appears separately. This approximation is only valid for incident energies of the projectile much larger than the typical ionization and excitation energies of the media. In the case of liquid water molecules, the largest value is around 500 eV. Under these conditions, the DDCS becomes proportional to the projectile charge and inversely proportional to its squared velocity. As for the target, its contribution is represented bythe generalized oscillator strength (GOS). The difficulty in its numeric calculation is due to the complexity of electronic wave-functions of liquid water molecules: spherical symmetry is not fulfilled because of the non-central potential and, additionally, they are perturbed by the effect of the interaction between molecules in the condensed phase. Modelling of GOS is, then, necessary. We split the GOS model into two Q ranges, low-Q (distant interactions) and large-Q (close interactions). For distant interactions, the GOS is modelled using semi-empirical optical dielectric functions of liquid water obtained in [4]. In the case of close interactions, the GOS is modelled as if the electrons of the liquid water were free and at rest. This way of GOS modelling allow us to obtain the contribution to the DDCS of each shell of the liquid water separately.
Once DDCS have been obtained, it is possible to calculate other magnitudes, such as cross sections or the stopping power. In the absence of cross section experimental data for the energy range of interest in this work, we have compared our calculation of the mass stopping power with the PSTAR tabulated values, founding a notable agreement from 1 MeV to 10 GeV.
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Other applications / 48

Geant4 simulations of the n_TOF lead spallation target: a benchmark study

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Monte Carlo (MC) simulations are a key tool to study the fundamental features of a neutron beam, such as the neutron flux or the γ-ray background, in the design and optimization of experimental facilities. Traditionally, the most widely used MC codes in this field had been MCNPX and FLUKA. However, the Geant4 toolkit has also become a competitive code for the transport of neutrons after the development of the Neutron High Precision Package (G4NeutronHP, later included in G4ParticleHP), that uses evaluated neutron libraries (ENDF-B, JEFF, and JENDL) to simulate the transport of neutrons below 20 MeV.
This work aimed at validating the intra-nuclear cascade models implemented in the Geant4 toolkit using, as benchmark, the flux and energy distribution of the neutron beam measured at the two experimental areas (EAR1 and EAR2) of the n_TOF facility at CERN. To simulate the neutron production and transport in the lead spallation target of the n_TOF facility, the geometry of the spallation source and the properties of the 20 GeV/c proton beam were accurately modelled following the technical details. The simulations were performed using different officially released Physics Lists, including the aforementioned G4NeutronHP package and considering thermal scattering of neutrons below 4 eV.
The results show a remarkable agreement with the experimental data and the MC calculations using FLUKA and MCNP, and reflect the impact of the choice of hadronic model in the integral neutron production.

Medical applications / **49**

G4_Med, a Geant4 benchmarking tool for medical physics applications

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Originating from high-energy and nuclear-physics domains, Geant4 is being adopted with increasing interest in the medical physics community, where it continues to gain significant momentum. Of particular interest to the medical physicists is its completeness, with a physics engine that covers the hadronic and nuclear interactions, of particular interest for novel ideas and techniques in the medical sector. Typical applications range from dosimetry to nanodosimetry, imaging to radiation protection and hadron therapy. Validation and performance monitoring focused on physics quantities relevant to this domain are of crucial need. In addition, it is important to identify the most appropriate physics models for a specific medical physics application. To respond to these needs, we developed G4-Med, an automated benchmarking tool and regression testing system of Geant4 for medical physics. The test suite currently includes tests cases covering from fundamental physical quantities (e.g. cross-section, point-dose-kernels), to semi-realistic set-ups typical of medical physics applications. Both electromagnetic and hadronic physics processes are tested and validated against experimental data. G4_Med is automated by means of the geant-val platform (https://geant-val.cern.ch/layouts) which is already used for regression testing of the Geant4 hadronic physics.
This talk will describe the general structure of G4_Med, its current status, and integration with validation efforts of the larger Geant4 community, with emphasis on the aspects relevant for nuclear physics. Outlook and future prospects will also be discussed.

Other applications / 50

Extensive atmospheric cosmic-ray-shower simulations in the South Atlantic Magnetic Anomaly for aeronautical applications

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In the last few decades, the development of aircraft with higher maximum cruising altitude and greater autonomy, as well as a significant increase of air traffic, has increased the problem of controlling the ionizing radiation dose level received by pilots, aircrew and aircraft electronics, and has begun to worry radioprotection and flight safety organizations. The study of the effects of atmospheric cosmic radiation on avionics, aircrew and embedded systems detectors requires a detailed description of the radiation field incident on the aircraft, especially neutrons, protons and alphas. Using simulations based on the Monte Carlo codes Geant4 and MCNPX, this work aimed to develop a virtual environment that allows the simulation of the transport of cosmic radiation incident on large and complex systems, such as clouds, aircraft, on ground monitoring stations, embedded detectors, electronic devices of the aircrafts etc., in the atmosphere from ground level up to 100 km, and considering the effects of Earth's magnetic field. In order to do so, the transport of the primary cosmic radiation (PCR) and secondary particles through the atmosphere subjected to the Earth's magnetic field were modeled. Methodologies were also developed to model the primary cosmic source incident in the atmosphere and to obtain the fluence rate and angular distribution of the cosmic-ray-induced particles as a function of altitude. The results obtained from simulations were compared to experimental data taken at ground level and flight altitude, for different geographic regions and dates, evaluating the (adequability) adecuacy of the physics models used to estimate the cosmic radiation transport in the atmosphere for energies above 20 MeV. Analyses were also performed of the influence of the Earth's magnetic field using the Geant4 code as well as simplified analytical calculations, and concluded that their influence starts to be significant for altitudes above 40 km. As a product of this work, a virtual environment was developed that corresponds to a fraction of the terrestrial atmosphere up to 100 km altitude in a region of 50 km in diameter, which describes the fluence, composition, energy spectrum and angular distribution of the cosmic-ray-induced particles in the atmosphere as a function of altitude and space weather variables. This platform models the primary cosmic radiation independently of external software, as the intensity of the PCR can be modulated using neutron counting from an on-ground neutron monitoring station, making the virtual platform standalone.

Underground experiments / 53

Underground Experiments

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Low-background experiments searching for dark matter, neutrinos and other rare processes heavily rely on GEANT4 in order to calibrate the detector responses, estimate the background rate and topology, predict the expected signals. Moreover, Monte Carlo simulations are extensively used

in order to optimize the design of new experiments. The physics involved includes low-energy hadronic processes for neutron transport, the simulation of high-energy cosmic rays interactions and the optics in scintillator based experiments. I will summarize the main features and the needs shared by these experiments.

I will be able to attend the workshop on FRIDAY 26th ONLY.

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Class II simulation of electron and proton transport: PENELOPE and PENH

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Content
The interaction physics and the transport algorithm of the electron-photon Monte Carlo code system PENELOPE have been introduced as an option in the Geant4 toolkit. PENELOPE implements a strict class II (mixed) algorithm for the simulation of electrons and positrons in matter. The algorithm is defined by cutoff values of the energy loss for inelastic interactions and bremsstrahlung emission, and by a pair of energy-independent parameters that determine the cutoff scattering angle of elastic collisions as a function of the energy of the transported particle. Hard interactions, with energy transfer and/or angular deflection larger than the corresponding cutoff, are described from the corresponding restricted differential cross sections. The effect of soft interactions (with sub-cutoff energy loss and/or scattering angle) that occur along a trajectory step between hard interactions is simulated by means of the random-hinge method; the accumulated angular deflection is applied at the hinge and the total energy loss is described by means of a continuous slowing down process with constant stopping power.
Class II simulation algorithms present clear advantages in from of the more conventional class I (complete grouping) algorithms used in many high-energy Monte Carlo codes, at the expense of a certain complication of the simulation program. We shall comment on practical aspects of the coding of strict class II schemes for the simulation of the transport of charged particles, as implemented in PENELOPE for electrons and positrons, and in the recently developed code PENH for protons. The stability of simulation results under variations of user-defined parameters will be demonstrated.

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GEANT4 TOOLS FOR THE DESIGN AND ANALYSIS OF PHOTOFISSION EXPERIMENTS AT ELI-NP

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<p>A rich photo-fission program is proposed at the new Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility in Magurele-Bucharest, Romania. It is based on the highest brilliance gamma beam system (GBS) that will be available at ELI-NP with energies up to 20 MeV.</p>

<p>In one type of experiments, radioactive ion beams (RIBs), formed from the fission fragments produced by irradiation of uranium targets with high-energy photons, will be used to study exotic neutron-rich nuclei. The other major photo-fission experimental program will study open issues in our current understanding of fission, like transmission resonances in the fission isomeric shelf, ternary fission, and others.</p>

<p>The IGISOL beam line uses a cryogenic gas cell to stop and extract the photo-fission fragments used to form RIBs. A Geant4 module was developed to design this gas cell and maximize the RIB rates. To improve the ion energy-loss calculations, various parameterizations of the ionic charge state were implemented and compared to existing data. For this experimental program, we will present simulated ion production rates and efficiencies.</p>

<p>As a precursor to the experimental photo-fission studies at ELI-NP, a neutron-induced fission experiment on 233U has been performed at the research reactor in Budapest, Hungary, in order to test and develop data acquisition systems, data analysis methods and to have a reference point for the simulated results. The recorded gamma-ray spectrum has been unfolded from detector response using the matrix inversion method obtained after a full GEANT4 implementation and simulation of the experimental setup. Preliminary results for gamma-ray multiplicity and average total energy per fission event are presented, emphasizing the use of GEANT4 as an important tool for data analysis.</p>

GEANT4 future perspectives / 56

Geant4 current status and prospects

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2019 is the 20th year anniversary of Geant4 public releases. After 20 years with several architectural evolutions, Geant4 is still steadily evolving. It finds quite a wide variety of user domains including high energy physics, nuclear physics, space engineering, medical applications, material science, radiation protection and security. In this presentation, we will present the current status of Geant4 kernel including the recent and on-going developments, and prospects for the next decade.

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Geant4 scoring functionalities

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In this presentation, we will overview the scoring functionality of Geant4 simulation toolkit that allows users to score various physics quantities such as flux or dose distribution without writing much of C++ code. This functionality is of particular benefit for shielding or radiation protection studies where no particular detector has to be simulated. We will also briefly introduce Geant4's built-in analysis tool that enables the user to create plots and histograms without linking to external libraries.

Other applications / 58

Reflection of low-energy neutrons in nanodiamonds using Geant4

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A study has been carried out in order to see the feasibility of Nanodiamond Particles (NDP) application as a reflector for Cold Neutrons (CN), Very Cold Neutrons (VCN) and Ultra Cold Neutrons (UCN) in Geant4. NDP has a large scattering angle probability against VCN and UCN compared to the other materials due to their high optical potential. This unique feature makes this powder a prominent candidate to be used as a reflector for VCN and UCN. Moreover, they can also be implemented for a quasi-specular reflection of CN at a small incidence angle due to multiple small-angle scattering of neutrons from nano-sized inhomogeneities in the scattering potential. A new process has been prepared in order to add NDP cross sections to the predefined processes. The Three-Dimensional geometry of previous experiments carried out in order to observe the NDP reflection has been developed in Geant4, in order to validate the implementation. The results show that there is a good agreement between the new method implemented in Geant4 and the experimental data.

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General discussion

Energy applications / 60

Adaptation of GEANT-4 to Criticality Calculations for Nuclear Reactors

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GEANT-4 is well suited for criticality calculations in nuclear reactors, thanks to its ability to track particles, in this case neutrons, in time as well as in space. This sets it apart from traditional Monte Carlo codes such as MCNP, which treat neutrons on a generation-by-generation base. The latter gives inherently incorrect results, in particular for systems that are far from critical. This presentation will describe a GEANT-4 based code, G4-STORK, which was developed to model nuclear reactors. Features such as population control, Doppler broadening of absorption resonances and treatment of delayed neutrons will be discussed. Comparisons with MCNP will be shown.

Medical applications / 61

A hybrid method calculating linear energy transfer for intensity modulated proton therapy

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Intensity modulated proton therapy (IMPT) is an advanced form of radiation therapy in which the trajectory and energy of a focused beam of protons is precisely controlled so as to irradiate a tumor spot-by-spot and layer-by-layer with proton beamlets [1,2]. While the radiobiological effects of IMPT depend primarily on the physical dose distribution, studies have shown that linear energy transfer (LET) plays an important role as well [3]. LET can be used as indicator for radiobiological outcome at the microscopic level, which would justify the use of LET-based objectives in treatment plan optimization [4]. We developed a method using a hybrid approach to calculate proton LET for IMPT based on LET data pre-computed by Geant4 Monte Carlo (MC) simulations in a water phantom. The hybrid method was incorporated into our in-house treatment planning system (TPS) as an extension to calculate LET in voxelized patient geometries. First, we commissioned the Geant4 MC code to model three proton treatment nozzles in clinical use at our institution: one with no range shifter (VAC machine), a second with a range shifter 42.5 cm away from isocenter (RS machine), and a third with a range shifter 30 cm away from isocenter (ERS machine). The code was used to generate pencil beam LET kernels for all 97 proton energies used clinically. Second, the LET kernels were incorporated into the TPS using a ray-casting algorithm. Inhomogeneities were taken into account using water-equivalent thickness (WET). Since the LET kernels were pre-calculated, the time required to compute LET distributions in patient geometries was greatly reduced. It was found that the LET distributions calculated by our hybrid method agreed well with those found using a full MC calculation developed at Mayo Clinic in Rochester, Minnesota [5]. These LET distributions computed using our hybrid method were used to evaluate potential clinical benefits and toxicities for various tumor sites including lung, head and neck, esophagus, and brain. The LET calculation code has also been used in IMPT treatment planning, allowing for radiobiological optimization by including LET-weighted constraints in the inverse treatment planning process.

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Welcome to all the participants

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Pratical information