Workshop on Use of Monte Carlo Techniques for Design and Analysis of Radiation Detectors

ISRP10

15th-17th September, 2006
Coimbra, Portugal

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Departamento de Física da Universidade de Coimbra, Portugal
International Radiation Physics Society
Laboratório de Instrumentação e Física Experimental de Partículas – Coimbra

WELCOME

Dear Colleagues,

The International Radiation Physics Society (IRPS) soon will offer the Tenth in its series of International Symposia. These Symposia have been held at a variety of interesting locations on several continents. The Ninth Symposium, which was held in Cape Town, South Africa, was preceded by the *Workshop on Radiation Based Analytical Techniques*. The success of that Workshop caused the IRPS leadership to consider having workshops in advance of future symposia. Hence was born the idea to have the *Workshop on Use of Monte Carlo Techniques for Design and Analysis of Radiation Detectors* precede the Tenth Symposium.

The Workshop will be composed of a one-day session on detectors, a one-day session on Monte Carlo methods and codes, and a part-day hands-on session allowing attendees to work with the code of their choice. It is hoped that the lectures, the interactions among participants and presenters, the hands-on sessions, and the materials that will be made available will prove to make your decision to attend the Workshop a wise one.

We have assembled an impressive group of international scientists to speak on the topics embedded in the Workshop. We are very much indebted to these scientists and to the many other individuals who have worked diligently to prepare this event.

It is our great pleasure to welcome you to the Workshop.

William L. Dunn, Workshop Organizing Committee Chair
Jorge E. Fernández, Workshop Organizing Committee Co-Chair
M. Isabel Lopes, Workshop Organizing Committee Co-Chair

TECHNICAL PROGRAM

Friday, September 15

8:00 **Registration (Physics Department, room C7)**

9:30 **Welcome (Auditorium of Physics Department, ground floor)**

Oral Session: 9:45 – 12:30 (Auditorium of Physics Department, ground floor)

SESSION CHAIR: Armando J.P.L. Policarpo, *Lip-Coimbra, Portugal*

9:45 **Past, present and future of radiation detectors**
Glenn Knoll, *University of Michigan, USA*

10:30 **Recent developments in Micro-pattern Gaseous Detectors**
Fabio Sauli, *CERN, Switzerland*

11:15 **Coffee Break**

11:45 **Inorganic Scintillators research: principles and new materials**
Carel van Eijk, *Delft University, The Netherlands*

12:30 **Luncheon (Bar of the Medicine Faculty)**

Oral Session: 14:00 – 17:30 (Auditorium of Physics Department, ground floor)

SESSION CHAIR: Vitaly Chepel, *Universidade de Coimbra, Portugal*

14:00 **Semiconductor detectors**
Antonio Longoni, *Politecnico di Milano, Italy*

14:45 **Novel photo detectors**
Jaroslav Va´vra, *SLAC, USA*

15:30 **Coffee Break**

16:00 **Perforated semiconductor diodes for high efficiency solid-state neutron detectors**
Douglas McGregor, *Kansas State University, USA*

16:45 **Detectors in medicine**
Roberto Pani, *Univ. “La Sapienza”, Rome, Italy*

Saturday, September 16

Oral Session: 9:00 – 12:30 **(Auditorium of Physics Department, ground floor)**

SESSION CHAIR: J. Kenneth Shultis, *Kansas State University, USA*

9:00 **Monte Carlo methods for design and analysis of radiation detectors**
William Dunn, *Kansas State University, USA*

9:45 **Electron transport simulation**
Francesc Salvat, *University of Barcelona, Spain*

10:30 **Coffee Break**

11:00 **Photo transport simulation, including polarization**
Jorge Fernández, *University of Bologna, Italy*

11:45 **Neutron transport simulation**
Pedro Vaz, *Instituto Tecnológico e Nuclear, Portugal*

12:30 **Luncheon** **(Bar of the Medicine Faculty)**

Oral Parallel Sessions: 14:00 – 16:45

Session A (Physics Department, 1st floor, room AD1)

SESSION CHAIR: *Robin Gardner,* North Carolina State University, USA

14:00 **Past, current and future developments in MNCP, important to radiation detection and simulation**
Avneet Sood, *LANL. USA*

14:45 **The PENELOPE Monte Carlo code**
José Fernández-Varea, *University of Barcelona, Spain*

15:30 **Coffee Break**

16:00 **Recent developments of the EGSnrc system**
Iwan Kawrakow, *National Research Council Canada*

Session B (Physics Department, 1st floor, room AD2)

SESSION CHAIR: William Dunn, *Kansas State University, USA*

14:00 **Applications of MCSHAPE and MCSHAPE3D to polarization and imaging experiments, and to detector response computations**
Jorge Fernández, *University of Bologna, Italy*

14:45 **Status and applications of the Geant4 toolkit**
Vladimir Ivantchenko, *CERN, Switzerland*

15:30 **Coffee Break**

16:00 **The FLUKA code**
Alfredo Ferrari, *CERN, Switzerland*

16:45 **Break**

17:30 BANQUET LECTURE **(Auditorium of Physics Department, ground floor)**

SESSION CHAIR: William Dunn, *Kansas State University, USA*

Status of the Monte Carlo – Library Least-Squares (MCLLS) approach for the non-linear radiation analyzer problem
Robin Gardner, *North Carolina State University, USA*

19:00 Banquet

Sunday, September 17

Hands-on Parallel Sessions: 9:00-12:00

Session A: **Working with MCNP**,	Avneet Sood
Session B: **Working with EGSnrc**,	Iwan Kawrakow
Session C: **Working with PENELOPE**,	José Fernández-Varea, David Bote, Lorenzo Brualla
Session D: **Working with GEANT4**,	Vladimir Ivantchenko, João Carvalho, Alexandre Lindote João Bastos
Session E: **Working with MCSHAPE**,	Vivianna Scot
Session F: **Working with FLUKA**,	Alfredo Ferrari, Stefan Roesler

12:00 **Luncheon** **(Bar of the Medicine Faculty)**

Abstracts

Past, present, and future of radiation detectors

Glenn F. Knoll

University of Michigan, USA

Sensors for the detection and spectroscopy of ionizing radiation have been under development for over a century. Some of the most important landmarks in this evolution will be briefly noted, with emphasis on active detectors and readout systems that are suitable for gamma ray spectroscopy. Current trends will be reviewed together with some promising developments that could lead to enhanced capabilities in the future.

Recent developments in Micro-Pattern Gaseous Detectors

Fabio Sauli

CERN, Switzerland

Several new models of advanced gaseous detectors have been introduced in the recent years, potentially capable of superior performances as compared to classic MWPC, in particular concerning their rate capability and multi-particle resolution. Two of them, the Micromegas and the Gas Electron Multiplier, have been successfully used in high-rate experiments, and are being considered as detectors for other projects in particle physics. Applications in other fields are also under development, exploiting their unique micropattern tracking performances. After a description of the new devices, I will discuss their major properties and operating performances, and outline the present and foreseeable progress in the field in view of future applications.

Inorganic scintillators research – principles and new materials

Carel W.E. van Eijk

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Inorganic scintillators have a special place in radiation detection in many sectors of fundamental and applied research, in most of the medical-diagnostic imaging modalities, and in many industrial measuring systems. The variety of applications and the ever-growing wish for better data imply a diversity of detector requirements that continue to change. In this lecture we will focus on counting of gamma-rays. In that case optimal-scintillator requirements are:

1) fast response time (10 - 100 ns) and fast signal rise time for good time resolution and handling of high counting rates,
2) high light yield (> 50,000 photons per MeV of absorbed gamma ray energy) for good energy, time and position resolution,
3) proportional response for good energy resolution, and
4) high density, ?, and high atomic number, Z, for high gamma ray sensitivity.

There are many other requirements, of which matching of the scintillation-wavelength spectrum with the sensitivity curve of the light sensor (silicon diode or photomultiplier tube), the possibility to grow large crystals (> 1 dm^3) and a modest price per cm^3 are very important.

Often the specifications of available inorganic scintillators do not meet the requirements. Therefore, research and development to introduce novel scintillator materials is imperative. Scintillator development as presented in this lecture is based on application of the Ce^{3+} ion as luminescence centre. The allowed 5d - 4f transition makes response times possible in the 10 - 100 ns range. The host material has to be selected for its high ?, Z, and it should have a relatively small forbidden gap between valence and conduction band (E_{gap}) for realising the above > 50,000 photons, the number of photons per MeV being proportional to 1/ E_{gap}. Obviously the host compound must be able to hold the Ce^{3+} dopant ions.

We will discuss research concerning new cerium doped rare-earth halide scintillators that have a large impact on inorganic scintillator application.

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Semiconductor detectors

Antonio Longoni

Politecnico di Milano, Italy

Recently developed semiconductor radiation detectors for imaging and spectroscopic applications in the field of X and Gamma rays will be briefly reviewed. New types of Silicon Drift Detectors (SDDs), in particular monolithic arrays of SDDs, and new active pixel detectors on high resistivity Silicon will be introduced. The advances in the development of radiation active pixel sensors based on CMOS technology will also be discussed. The attention will be focused on the basic working principles of the detectors introduced as well as on their performances.

Novel photon detectors

J. Va'vra

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, U.S.A.

The talk describes recent developments in the Photon Detectors. Since the author has spent the last 25 years working with the Cherenkov Ring Imaging detectors, the talk will be biased towards the single photon detection relevant to RICH technology. While discussing details of each photon detector, we will always mention the application they are used for. When possible, the author will try to mention his own experience with a particular technique.

Specifically, we will discuss the vacuum-based multi-anode detectors Hamamatsu H-8500 and H-9500 MaPMTs, and Burle and Hamamatsu MCP-PMTs from point of view of the timing resolution, the spatial response and the detection efficiency. In case of the MCP-PMTs we will discuss available techniques and the limits of the single photon timing resolution. We will mention two possible RICH applications for such performance: the Fast Focusing DIRC being developed at SLAC, and the TOP counter being developed by the Nagoya University in Japan. We will then turn to the silicone-based detectors such as the HPDs with PIN and APD diode readout, and the APD detectors working in a Geiger mode. We will compare their performance to the vacuum-based detectors. We will mention two possible applications: LHC-b RICH and Ferenz photon detectors. Finally, we switch the discussion to the GasPMT multi-pattern photon detectors and ask a question what is their chance to compete with the other methods. Specifically, we will discuss detectors with a multi-GEM design and a design combining the MCP and the Micromegas.

We give a chance to fragile, not yet entirely proven ideas.

Perforated semiconductor diodes for high efficiency solid-state neutron detectors

D.S. McGregor, S. Bellinger, D. Bruno, S. Cowley, W. Dunn, A. Egley, Q. Jahan, W.J. McNeil, E. Patterson, M. Elazegui, B.B. Rice, J.K. Shultis, C.J. Solomon, A. Streit, T. Unruh

SMART Laboratory, Mechanical and Nuclear Engineering Dept., Kansas State University, Manhattan, KS 66506 USA

Coated semiconductor diodes have been studied as potential neutron detectors for many decades. The basic configuration consists of a common Schottky barrier or *pn* junction diode, upon which a neutron reactive coating, such as ^{10}B or ^{6}LiF, has been applied. Such devices are compact, easily produced, and have low power requirements. However, they are restricted to low thermal neutron detection efficiencies, typically no greater than 5% intrinsic efficiency, due to energy self-absorption in the neutron sensitive coating,

A new configuration utilizing microscopic perforations backfilled with neutron reactive materials offers a solution to increase the efficiency. The devices are constructed from high-purity zone-refined Si, which are fabricated into *pin* diodes. Millions of microscopic perforations are etched into the diodes and backfilled with ^{6}LiF material. Efficiency is increased through increased semiconductor surface area in contact with the ^{6}LiF and also the increase in the probability of capturing a ^{6}Li(n,T)^{4}He reaction product. Monte-Carlo calculations indicate that intrinsic thermal neutron detection efficiencies exceeding 25% can be achieved for single devices no thicker than 500 microns. Sandwiched designs will allow for efficiencies exceeding 50%. Presented in the work will be the theory behind the designs, the process steps, characterization and results, and the future of these unique devices.

Detectors in Medicine

Roberto Pani

INFN –Dept. Experimental Medicine and Pathology
University La Sapienza" Rome Italy

Medical Imaging using ionizing radiations is divided into two major areas: the use of X-rays for transmission imaging and the use of radioactive tracers in emission imaging (molecular imaging or gamma ray imaging). Position sensitive detectors used in radiographic mode, are characterised by having a high flux, short duration exposure to radiation and a detector system that affords high spatial resolution. It is usually operated in integrating mode. The detectors are mainly silicon based and their technological potential is related to the enormous advances in micro-electronics and microprocessing needed to fit for the very high spatial resolution requirements (50 -200 μm). The types of detectors available fall broadly into two main categories: semiconductor detectors and scintillation detectors. Often semiconductors are also used for light read out as in the case of CCDs that are currently the most frequently used direct digital sensor for small area applications. Another example of light sensor development are photodiode and ceramic scintillator coated arrays for multi-slice spiral CT. On the contrary only amorphous silicon flat panel arrays currently achieve the areas required as in the case of mammography. However high-rate photon counting systems are needed, and it is still the challenge to be overcome in achieving the clinical requirements. Gamma imaging systems are designed to study metabolic pathways and physiology and are rarely capable of demonstrating anatomy to any high precision. They operate in an event counting mode with an energy resolution of approximately 10% in a conventional gamma camera. This is the field in which the most sophisticated detectors are currently under development. SPET (Single Photon Emission Tomography) and PET (Positron Emission Tomography) are the two typical modalities for which the detectors are designed. Solid state cameras using compound semi-conductors are the preferred solution although cost may be prohibitive. However current research in CdZnTe/CZT gamma cameras looks very promising. There is much interest in the development of digital positron or single photon cameras using new scintillation crystals and avalanche photodiodes or position sensitive PMT. The advent of new scintillators coupled to semiconductors or Position Sensitive PMT photo-detectors have been leading to a substantial improvement in the imaging of this field. In contrast with X-Ray detectors they have to fit the requirements of high photo-fraction, high detection efficiency, short scintillation decay time and high scintillation light yield for high energy resolution values. In this review a particular emphasis is done on the recent availability of a new scintillation crystal , the LaBr3:Ce that is showing an impressive light output with and energy resolution in close competition with one obtained by semiconductor detectors working at room temperature like CZT or CdTe. In addition the very short scintillation decay time could contribute in building new PET based on time of flight due to coincidence resolution time as low as 250 ps .Finally as an example of the latest advances in SPE, the recent results of a novel gamma camera prototype based on continuous LaBr3:Ce crystal and PSPMT, with sub millimetre spatial resolution values are presented and discussed.

Monte Carlo methods for design and analysis of radiation detectors

William L. Dunn

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An overview of Monte Carlo as a practical method for designing and analyzing radiation detectors is provided. The emphasis is on detectors for radiation that is either directly or indirectly ionizing. The Monte Carlo method has a rich history in radiation transport simulation, having been given its name by two researchers (Metropolis and Ulam) involved in neutron transport analysis in the late 1940s. This overview paper reviews some of the fundamental aspects of Monte Carlo, briefly addresses simulation of radiation transport by the Monte Carlo method, discusses differences between direct and inverse detection problems, and touches on how various Monte Carlo methods can be put to effective use in design and analysis of radiation detectors. The Monte Carlo method is very general and extends well beyond the confines of radiation transport. However, this paper focuses on those aspects of Monte Carlo that are useful in designing radiation detectors, in characterizing detectors, or in inferring desired properties from the responses of radiation detectors. Important special topics such as Markov Chain Monte Carlo are thus only briefly addressed, as they have not been widely used in radiation detector design or analysis.

Electron transport simulation

<u>F. Salvat</u>[1], J.M. Fernández-Varea[1], J. Sempau[2]

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The simulation of electron transport is intrinsically more difficult than that of photon transport, because of the large number of interactions undergone by a high-energy electron in the course of its slowing down. In this talk we will review the different strategies adopted in modern Monte Carlo codes, and provide practical examples to illustrate their capabilities and limitations.

A lucid description of the essentials of Monte Carlo simulation of charged-particle transport was given by Berger [1]. With the computer power currently available, detailed simulation of individual interactions is feasible for electrons with energies up to ~ 100 keV. For electrons and positrons with higher energies, Berger described two different simulation strategies, to which he referred as class I and class II schemes. These are condensed simulation schemes where the collective effect of multiple interactions is described using approximate multiple-scattering theories, or pre-calculated distributions. In class I simulations, the particle is moved in steps of fixed length, and the adopted multiple-scattering distributions account for the effect of all the interactions undergone by the particle along the step (complete grouping). In class II (mixed) simulations, hard interactions (with energy loss W or angular deflection *?* larger than certain cutoff values, W_c and $?_c$) are simulated individually, while soft interactions (with $W < W_c$ or $? < ?_c$) are described collectively by means of a multiple-scattering approach. Although class II schemes are computationally more involved, they have the advantage of providing an “exact” description of hard events. One of the limitations of class I simulation is that the required multiple-scattering distributions are available only for a discrete set of path lengths; this causes difficulties to describe transport in the vicinity of interfaces. A similar, but weaker problem is found in class II simulations.

Most of the available Monte Carlo codes use a combination of class I and class II schemes. Angular deflections are usually simulated following a class I scheme, with angular distributions obtained from the theory of Lewis. Energy losses due to inelastic collisions can be described either by a class I scheme (e.g., using the multiple-scattering theory of Landau) or by a mixed strategy that combines the CSDA for soft collisions with detailed simulation of hard collisions. Bremsstrahlung emission is always simulated using a class II scheme. Penelope [2] is one of the few codes that consistently apply class II simulation for all kinds of interactions.

References

[1] M.J. Berger, Monte Carlo calculation of the penetration and diffusion of fast charged particles, in Methods in Computational Physics, vol.1, pp. 135-215. B. Alder, S. Fernbach and M. Rotenberg, Eds. (Academic Press, New York, 1963).

[2] F. Salvat, J.M. Fernández-Varea and J. Sempau. PENELOPE - A code system for Monte Carlo simulation of electron and photon transport (OCDE NEA, Issy-les-Moulineaux, 2003).

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Photon transport simulation, including polarization

Jorge E. Fernandez

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Studies on radiative transfer lead to a clean formulation of polarised photon transport in terms of the vector Boltzmann-Chandrasekhar equation whose solution gives the four Stokes components of the flux, from which the full polarisation state of the photons can be determined at any given position, wavelength (energy) and solid angle. One of the relevant results observed during the formulation of the vector transport equation is the partial coverage of the wave properties of the photons with this model. In fact, even if the Boltzmann-Chandrasekhar vector equation is an important step forward for the description of radiative transfer with respect to the scalar approach used to describe “particle”-like photons, it is still insufficient to provide a whole description of an important phase-related property like coherence. In this sense, the above vector equation seems to be appropriate for describing photon beams which add incoherently among them, but not yet for describing coherent interference. In this article, it will be given a summarised view of the evolution of the Boltzmann transport equation from scalar to vector first, making possible the description of the evolution of the polarisation state. Then, it will be illustrated the state-of-the-art of the transport codes developed at Bologna based on this model. Finally, the application of the codes will be shown with some examples.

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Neutron transport simulation

Pedro Vaz

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Neutron transport simulation is usually performed for criticality, activation, dosimetry and shielding applications, among others. Particle transport simulation is closely associated to the existence of cross-section data for the energy ranges, types of particles, interactions and materials considered. Uncertainties in particle transport simulation incorporate and propagate uncertainties in the cross-section data used.

In the past, four major categories of neutron interactions have deserved great attention, in the energy range below 20 MeV: neutron elastic and inelastic scattering, neutron capture and fission. However, during the last fifteen years, innovative technological applications were proposed (Accelerator Driven Systems, Energy Amplifiers, Spallation Neutron Sources, etc.), involving the utilization of intermediate energy (hundreds of MeV) and high intensity (tens of mA) proton accelerators impinging in targets of high-Z elements. Unprecedented neutron fluxes (in excess of 10^{15} neutrons/cm/s) are generated by the spallation nuclear reactions in these targets. The computation of the particle fluxes and the energy deposition in several components of these systems (target, surrounding structural materials and actinides for ADS systems) became of paramount importance to perform studies of the thermal-hydraulic characteristics of the systems and the radiation damage, among others. Additionally, the increasingly use of protons, neutrons and light ions for medical applications (hadrontherapy) impose requirements on neutron dosimetry-related quantities (such as kerma factors) for biologically relevant materials, in the energy range of several tens of MeV. Shielding and activation related problems associated to the operation of medium- and high-energy proton accelerators, emerging space-related applications and aircrew dosimetry-related topics are also fields of intense activity requiring as detailed and accurate as possible medium- and high- energy neutron (and other particles) transport simulation.

The intermediate or high energy applications previously mentioned, require the accurate determination of integral and differential cross-section data for proton- and neutron-induced reactions and for charged particle production. These data are not experimentally available for all materials and energy ranges of interest. The use of theoretical models not always validated or benchmarked against experimental data became mandatory in situations when no experimental data exists in the data libraries. However, such applications triggered and were the driving force for major international efforts to compile new data sets, to undertake new measurements and to perform benchmark exercises and new evaluations of nuclear data that were in the meantime made available through the major cross-section data libraries available.

Medium and high energy neutrons impose stringent and specific shielding requirements to the systems and applications. Deep penetration of neutrons and the calculations of fluxes and doses deep in materials used for shielding are the typical example of computations where computing power is in some cases not available and the use of variance reduction techniques is mandatory.

During this presentation, the state-of-the-art computational tools and techniques currently available to perform hadron transport simulation using Monte Carlo techniques will be shortly reviewed; the role of the deterministic methods to perform neutron transport simulation will be discussed; the emerging importance of hybrid methods will be presented; cross-section data issues will be pinpointed.

Past, current, and future developments in MCNP important to radiation detection and simulation

Avneet Sood

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The general purpose Monte Carlo transport code, MCNP[1], can be used for neutron, photon, electron, or coupled transport. Specific areas of applications include radiation protection and dosimetry, radiation shielding, radiation detector design and analysis. MCNP simulates radiation transport through arbitrary three-dimensional configurations of materials. Important standard features make MCNP very versatile for its many applications. These features include a very general radiation source description and tally structures, geometry and tally result plotting, numerous variance reduction techniques, and extensive collection of cross-section data. Neutron, photon, and electron transport algorithms in MCNP have been successfully used for radiation detection simulation for many years. Recent improvements in MCNP physics models and tallies can have an important impact for radiation detection and simulation. Recent improvements in neutron physics include sampling the number of fissions from a Gaussian distribution with a fixed, isotope-dependent width. The approach results in a more microscopically correct neutron emission distribution. Factorial moments useful in nuclear safeguards measurements are calculated and included in the output. The electron transport algorithms in MCNP have been recently improved to sample the Landau distribution based on the continuous range of electron energies and specific electron step. This new treatment results in a more accurate and detailed estimate of electron straggling at lower energies and smaller geometries. Standard MCNP tallies have been very useful for radiation detector simulation. The usual quantities of interest to radiation detector simulation include surface current and pulse height tallies. Tallies on a mesh and radiographic tallies have recently been added. MCNP is continually undergoing improvements. An updated version of MCNP, version 5.1.50, is expected to be ready for release to RSICC at the end of summer 2006. Several additional new features important to radiation detection will be previewed.

References

[1] X-5 MONTE CARLO TEAM, “MCNP — A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory,” LA-UR-03-1987, Los Alamos National Lab. (April 2003).

The PENELOPE Monte Carlo code

J.M. Fernández-Varea[1], F. Salvat[1], J. Sempau[2]

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PENELOPE is a general-purpose code system for Monte Carlo simulation of coupled electron-photon transport. This code evolved from a low-energy electron and positron transport code (the name is an acronym for PENetration and Energy LOss of Positrons and Electrons), in which particle histories were generated by using detailed simulation schemes. To extend the electron transport mechanics to higher energies, class II (mixed) schemes were adopted, which are more stable and accurate that conventional condensed (class I) schemes.

In this talk we will briefly review the physics interaction models, and tracking algorithms, used to describe the transport of electrons/positrons and photons, particularly the mixed simulation scheme for electrons and positrons. The structure of the code system will also be described. PENELOPE is designed as a set of Fortran subroutine packages, which are operated from a steering main program, to be provided by the user. Besides the interaction and tracking routines, the code system includes the geometry package PENGEOM, a flexible tool that allows the simulation of particle transport though complex material systems consisting of homogeneous bodies limited by quadric surfaces. Variance reduction techniques (particle splitting, Russian roulette, interaction forcing) can also be applied routinely. To help occasional users, recent versions of the code include a generic main program, called PENMAIN, that is operated from an input file (i.e. does not require any programming work) and allows the simulation of a large variety of practical problems.

PENELOPE is able to simulate the transport of electrons/positrons and photons, with energies in the range from a few hundred eV up to about 1 GeV, in materials with arbitrary compositions (with molecular cross sections obtained from the additivity approximation). The code system has been thoroughly validated in many practical applications, as well as in benchmark comparisons of simulation results and experimental data. The capabilities of PENELOPE will be discussed on the basis of a few examples dealing with the simulation of radiation sources and detectors employed in medical physics and x-ray microanalysis.

References

[1] F. Salvat, J.M. Fernández-Varea and J. Sempau. PENELOPE - A code system for Monte Carlo simulation of electron and photon transport (OCDE NEA, Issy-les-Moulineaux, 2003).

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Recent developments of the EGSnrc system

Iwan Kawrakow

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EGSnrc is a package for the Monte Carlo simulation of coupled electron and photon transport in the energy range between 1 keV and several tens of GeV. Compared to its predecessor EGS4, EGSnrc offers a substantially improved condensed history implementation, which permits the artifact free simulation of charged particle transport at the 0.1% level, various improvements in the simulation of electron and positron interactions, and several cross section extensions mainly relevant for low energy photon transport applications. This talk presents several improvements recently implemented into EGSnrc: i) Use of exact differential cross sections for pair production in the nuclear field ii) Explicit simulation of pair production in the electron field (a.k.a. triplet production) from the Vortuba-Mork expression iii) Radiative corrections for Compton scattering iv) A new C++ class library that provides a general purpose geometry package, several particle sources, and various other utility classes which make development of EGSnrc based applications easier. Items i) and ii) are discussed in more detail in an accompanying presentation at the ISRP--10 conference. The influence of iii) on quantities such as mass energy absorption coefficients, mass energy transfer coefficients, and relative dose distribution in the external beam radiotherapy energy range are examined. The usefulness of the general purpose geometry package is demonstrated by comparing the calculated response of realistic ionization chambers to the response of chambers approximated with a cylindrical geometry.

Applications of MCSHAPE and MCSHAPE3D to polarization and imaging experiments, and to detector response computations

Jorge E. Fernandez[1,2], Viviana Scot[1]

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MCSHAPE is a Monte Carlo code which can simulate the diffusion of photons with arbitrary polarization state and has the unique feature of describing the evolution of the polarization state along the interactions with the atoms. The model is derived from the so called 'vector' transport equation [1]. The code accurately simulates the propagation of photons in heterogeneous media originating from either polarized (i.e., synchrotron) or unpolarized sources, such as X-ray tubes.

The 3D version of the code [2] is based on a sample modeling using a 3D regular grid of cubic voxels. At each voxel, the local composition is specified by giving the number of chemical elements, their weight fractions, the atomic characteristics of each element, the total mass attenuation coefficient and the density.

Photoelectric effect, Rayleigh and Compton scattering, the three most important interaction types for photons in the considered energy range (1-1000 keV), are included in the simulation with state-of-art extent of detail. A unique algorithm is used to describe the Compton profile which avoids the low energy bias present in other MC codes [3].

In this paper we discus some applications of the 1D and 3D versions of MCSHAPE. In first place, the code is used to analyze a polarization dependent experiment. Then, 1D, 2D and 3D imaging experiments are simulated. Finally, the influence of polarization and multiple scattering on the response function for solid state detectors is discussed.

1. J.E. Fernandez and V.G. Molinari, *Nuclear Instruments and Methods in Physics Research* **B73,** 341 (1993).
2. V. Scot, J.E. Fernandez, L. Vincze and K. Janssens. “3D extension of the Monte Carlo code MCSHAPE for photon-matter interactions in heterogeneous media”**.** Submitted to NIM-B (2005).
3. J.E. Fernandez and V. Scot. “Unbiased Monte Carlo Simulation of the Compton profile” Submitted to NIM-B (2005).

Status and applications of the Geant4 toolkit

Vladimir Ivanchenko
(on behalf of Geant4 Collaboration)

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Geant4 is a toolkit for Monte Carlo simulation of the transportation and interaction of particles in matter [1, 2]. It is based on an object-oriented approach and c++. The development and the maintenance of the toolkit are provided by the Geant4 international collaboration. Since the beginning of the BaBar experiment at SLAC [3] Geant4 has been used for detector simulation. Now it has become an established tool, used in the Monte Carlo production for three LHC experiments since early 2004. It is applied in many other HEP experiments and in medical, space and other researches.
The overview of the toolkit is presented. Geant4 includes a significant set of components for geometry description, particle definition, navigation and tracking, physics models for electromagnetic, hadronic, optical, photo-nuclear and electro-nuclear interactions, event scoring, visualization and management of software components. There are data-driven and theory-driven physics models. The infrastructure for applying of fast parameterization of physics processes is also provided. Configurations of physics models tailored for large scale simulations and for other applications have been recently developed and are now part of the toolkit.
Improvements and extensions to Geant4 capabilities continue, while its physics models are refined and results are accumulated. The progress in physics performance is provided with validation efforts and physics comparisons against data in collaboration with different experiments and user groups. The status in the validation suites for Geant4 releases is briefly described.
A review of Geant4 applications for radiation detectors is presented. It includes a number of Geant4 studies for HEP, Geant4 space science applications developed under ESA supervision, and some Geant4 medical applications. Recent developments and plans for further Geant4 upgrades relevant for radiation detectors are also discussed.

References

[1] Geant4 Collaboration (S. Agostinelli et al.), Nucl. Instr. Meth. A506 (2003) 250.
[2] J. Allison et al., IEEE Trans. Nucl. Sci, 53 (2006) 270.
[3] BABAR Collaboration (B. Aubert et al.), Nucl. Instr. Meth. A479 (2002) 1.

The FLUKA code

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FLUKA is a general purpose MonteCarlo radiation transport code which can transport a variety of particles over a wide energy range in complex geometries.

The code is a joint project of INFN, the Italian National Institute for Nuclear and Particle Physics, and CERN, the European Laboratory for Particle Physics: part of its development is also supported by the University of Houston and NASA.

FLUKA is used throughout the world by a vast community in several fields,including but not only, particle physics, cosmic ray physics, detector simulations and design, accelerator design, neutronics, radiation protection, dosimetry, space radiation and hadron therapy.
The code is the standard tool used at CERN for dosimetry, radioprotection and beam-machine interaction studies.

The talk and the hands-on session will give a glimpse into the code physics models and their applications to real life problems, with particular relevance to the most recent developments.

The code physics will be discussed and demonstrated mostly through examples and benchmarks against relevant experimental data, both for simple experimental setups and for more complex configurations. Heavy ion interactions and their relevance for hadron therapy and space radiation will be also discussed.
Dosimetry of Cosmic Ray induced showers in the atmosphere, relevant for aircraft crew dosimetry, and for future manned missions to MARS will be also discussed.

Emphasis will be also given to examples for applications in radiation physics and detector simulations and design, ranging from simple neutron detectors to simulations for complex high energy physics detectors.

Status of the Monte Carlo - library least-squares (MCLLS) approach for the non-linear inverse radiation analyzer problem

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All the methods (and topics) necessary to implement the MCLLS approach are described and discussed including: (1) the correction of spectral pulse pile-up distortion by Monte Carlo calculation with the code CEARIPPU, (2) the Monte Carlo codes CEARXRF and CEARCPG for generating the necessary elemental library spectra for the LLS calculation for X-ray fluorescence and neutron capture prompt gamma-ray analyzers, (3) generation of detector response functions for detectors with linear and non-linear responses for Monte Carlo simulation of pulse-height spectra, and (4) the use of the differential operator technique to make the necessary iterations for non-linear responses practical.

Notes

Notes

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