

## **Book of Abstracts**

## Geant4 2005 10<sup>th</sup> User Conference and Collaboration workshop

## November 3 – 10, 2005 Mercure Château Chartrons hotel, Bordeaux, France

- Geant4 international user conference with focus on simulations at the Physics – Medicine - Biology frontier
- Geant4 course for new comers
- Geant4 collaboration workshop

Plenary sessions 

Oral presentations

Poster sessions

Short course

Social events

#### Abstract Submission and Registration deadline : September 9, 2005

#### Local organizing Committee :

- S. Incerti (CENBG / IN2P3 / CNRS / Bordeaux 1 University)
- S. Kerhoas-Cavata (SPhN / DAPNIA / DSM / CEA
- Ph. Moretto (CENBG / IN2P3 / CNRS / Bordeaux 1 University)
- P. Chambon (CENBG / IN2P3 / CNRS / Bordeaux 1 University

## Hosted by

Centre d'Etudes Nucléaires de Bordeaux-Gradignan IN2P3 / CNRS – Bordeaux 1 University

Registration : http://geant4.in2p3.fr/2005

Contact : geant4-2005@cenbg.in2p3.fr



IN2P3 burner Kenorsa as Persones Necadama er de Phivaique des Particules

#### **CNRS / IN2P3 - Université Bordeaux 1**

Chemin du Solarium - Le Haut-Vigneau - B.P. 120 - 33175 GRADIGNAN Tél. 05 57 12 08 04 - Fax : 05 57 12 08 01 - http://www.cenbg.in2p3.fr



## Geant4 2005

Dear Colleague,

We are pleased to welcome you in Bordeaux – France – to attend the 10<sup>th</sup> international Geant4 conference. The 10<sup>th</sup> conference is the second of this series organized in France (the 5<sup>th</sup> conference was organized by the Laboratoire de l'Accélérateur Linéaire in Orsay – France in October 2000). This year, it is organized by the Centre d'Etudes Nucléaires de Bordeaux-Gradignan, a CNRS/IN2P3 – Bordeaux 1 University laboratory and will give an up-to-date report on the continuous developments and various applications of the CERN Monte Carlo simulation toolkit Geant4. Originally developed for the simulation of large scale particle physics experiments, the field of applications of Geant4 is growing fast worldwide especially at the physics-medicine-biology frontier. This year conference will give the opportunity to users to present their applications in this growing and demanding domain, and to learn the Geant4 toolkit through a dedicated short course.

The conference will be divided into three parts :

- a 2.5 day user session dedicated to Geant4 simulations with a strong interest at the physics-medicine-biology frontier.
- **a 8 hour new-user short course** presenting the last Geant4 version to new comers (providing the attendees with a CD-ROM).
- The classical 4-day Geant4 collaboration workshop accessible by invitation only. It will be mainly dedicated to Geant4 developers and will cover the Geant4 toolkit main topics.

We are expecting that all participants will find this conference stimulating and rewarding in many ways.

To conclude, we would like to thank our sponsors and all people who helped us in the organization of this event.

The Geant4 2005 local organizing committee, Sébastien Incerti, Sophie Kerhoas-Cavata and Philippe Moretto

> CENBG – IN2P3 – CNRS – Bordeaux 1 University CEA – DSM – DAPNIA



## **User Session and short course Agenda**

## November 3-5, 2005

Date	Time	
	08:00	Registration
Thursday	08:45	Opening session
November 3	09:00	User session 1 : Imaging
		<ul> <li>Chair : Joseph Perl (SLAC, USA)</li> <li>I. Piqueras : Study for the design of a multi modality imaging system dedicated to small animal</li> <li>A. Trindade : Simulation of the Clear-PEM scanner for breast cancer imaging with Geant4</li> <li>N. Lang : Simulated PET acquisition of a respiratory and cardiac moved NCAT-human torso phantom using the GATE toolkit</li> <li>P. Leroy : Geant4 simulations for Emission Tomography on low-activity radioactive waste drums with Compton detectors</li> </ul>
	10:20	Coffee break
	10:50	<ul> <li>User session 2 : Imaging and external beam therapy Chair : Sophie Kerhoas (CEA/DSM/DAPNIA/SPhN, France)</li> <li>Imaging         <ul> <li>I. Buvat : GATE : a simulation toolkit for emission tomography in nuclear medicine and molecular imaging</li> </ul> </li> <li>External beam therapy         <ul> <li>B. Faddegon : An accurate experimental benchmark of bremsstrahlung for radiotherapy</li> </ul> </li> </ul>

	<ul> <li>quality beams</li> <li>A. Raaijmakers : Simulations for the virtual prototyping of a radiotherapy MRI-linear accelerator system: Linear accelerator output, CT-data implementation, dose deposition in the presence of a 1.5 T magnetic field</li> <li>I. Cornelius : The Use of the Geant4 Toolkit at the CMRP: Application to Radiation Protection, Oncology and Medical Imaging</li> </ul>
12:10	Lunch
14:00	<ul> <li>Short course session 1 in main room (or focused discussions in parallel session)</li> <li>Introduction to Geant4, architecture, by John Apostolakis (30 min)</li> <li>Materials, geometry, by Gabriele Cosmo (45 min)</li> <li>Particles, generic ions, primary generator, gps, tracks, events, runs, by Makoto Asai (45 min)</li> </ul>
16:00	Coffee break
16:30	<ul> <li>User session 3 : Hadrontherapy Chair : Aatos Heikkinen (Helsinki Institute of Physics, Finland)</li> <li>I. Gudowska : Simulation of light ion transport in a water phantom using Geant4</li> <li>I. A. Pshenichnov : Fragmentation of light nuclei in water phantoms studied with Geant4</li> <li>H. Paganetti : Significance of time-dependent (four-dimensional) geometries for Monte Carlo simulations in radiation therapy</li> <li>H. Paganetti : Geant4 based proton dose calculation in a clinical environment: Technical aspects, strategies and challenges</li> <li>T. Sasaki : Status and plan for the hadron therapy simulation project in Japan</li> <li>T. Aso : A Geant4-based simulation of irradiation system for hadron therapy</li> </ul>
18:30	End
20:00	Welcome reception at Bordeaux City Hall (to be confirmed)

Friday November 4	08:00	Registration
	08:30	<ul> <li>User session 4 : Space and biology applications Chair : Philippe Moretto (CENBG, France)</li> <li>P. Gonçalves : Simulation of radiation monitors for future space missions</li> <li>G. Santin : Recent Developments in Geant4-Related Activities at ESA: Physics, Tools, User Interfaces</li> <li>S. Incerti : Geant4 simulations for microdosimetry at the cellular level and nanoprobe design</li> <li>Z. Francis : Geant4 DNA Physics processes</li> </ul>
	09:50	Coffee break
	10:20	<ul> <li>Short course session 2 in main room (or focused discussions in parallel session)</li> <li>Generalities on processes, by Marc Verderi (30 min)</li> <li>Electromagnetic processes, by Vladimir Ivantchenko (45 min)</li> <li>Hadronic processes, by J.P. Wellish (45 min)</li> </ul>
	12:20	Lunch
	14:00	<ul> <li>Short course session 3 in main room (or focused discussions in parallel session)</li> <li>Physics List, by Dennis Wright (20 min)</li> <li>Stacks, hits, digits, by Makoto Asai (30 min)</li> <li>Ul commands, by Makoto Asai (30 min)</li> <li>Visualisation, by Joseph Perl (30 min)</li> </ul>
	16:00	Coffee break and poster session
	17:30	User session 5 : High Energy Physics

	<ul> <li>Chair : John Apostolakis (CERN, Switerland)</li> <li>J. Yarba : Status of Use and Support of Geant4 at Fermilab</li> <li>J McCormick : Full Detector Simulation for the International Linear Collider</li> <li>B. Tomé : A Geant4 based simulation for Fresnel lenses</li> <li>Ph. Miné : H4SIM, a Geant4 simulation program for the CMS ECAL supermodule</li> <li>H. Yoshida : Geant4 education application</li> </ul>
19:10	End

	08:00	Short course session 4 in main room
Saturday November 5		<ul> <li>Optics, by Peter Gumplinger (30 min)</li> <li>Analysis tools, by Guy Barrand (30 min)</li> <li>Installation, by Gabriele Cosmo (15 min)</li> <li>Examples : hep, medicine, space ; documentation, by Dennis Wright (45 min)</li> </ul>
	10:00	Coffee break
	10:20	<ul> <li>User session 6 : Dosimetry and computing Chair : Pierre François Honoré (CEA/DSM/DAPNIA/SEDI, France)</li> <li>Dosimetry         <ul> <li>M. Schubert : Geant4 Simulations for Betadosimetry and Activity Measurements in Brachytherapy</li> <li>P. Guèye : Fundamental Physics and Basic Research in Brachytherapy with Geant4</li> <li>C. Thiam : Gate for brachytherapy applications and Gate simulations in a grid environment</li> </ul> </li> <li>Computing         <ul> <li>J De Beenhouwer : Importance sampling in Gate</li> <li>D. R.C. Hill : Possible issues to optimize stochastic simulation time with parallel sequences</li> </ul> </li> </ul>

	and unrolling
12:00	An update from Geant4 developers
13:00	Lunch
14:30	Social tour to Saint-Emilion vineyards and conference dinner
midnight	Return to hotels

	10:00	Social tour to Atlantic coast
Sunday		
November 6	20:00	Return to hotels

## **User Session 1**

# Imaging

## Study for the design of a multi modality imaging system dedicated to small animal

- Author(s) : I. Piqueras, D. Brasse and J.-L. Guyonnet
- Institution(s) : Institut de Recherches Subatomiques de Strasbourg (ULP-CNRS)
- Corresponding author e-mail : <u>Inmaculada.Piqueras@ires.in2p3.fr</u>

## • Summary

Small animal models are recognized as powerful tools in biomedical research. Improvement of non invasive imaging techniques is essential to gain full knowledge about these models. Furthermore, complementary information can be obtained combining two different imaging modalities [1]. At the Subatomic Research Institute (IReS, "Institut de Recherches Subatomiques de Strasbourg", France) we are developing a multi modality system combining X-Ray CT, SPECT and PET imaging devices dedicated to small animal [2]. Our design goal is to increase both spatial resolution and detection efficiency for the SPECT and PET systems. Simulation calculations with GEANT4 code were performed to optimize their performances. The SPECT system [3] consists of four cameras located around the animal based on pinhole aperture. Each camera is composed of 5 detector modules (Pixellated scintillator arrays of 64, 2.3 x 2.3 x 28 mm<sup>3</sup>, YAP:Ce crystals). Simulation calculations of the SPECT geometry design and its shielding will be presented. Moreover, simulation calculations have been employed to estimate the detection efficiency enhancement obtained by the used of events that undergo scatter interaction in two or more crystals of the array before full energy absorption. The PET system designed by our group is based on scintillator detectors arranged around the animal. Simulation calculations have been essential to determine the geometry of the system and the choice of the crystal. The X-Ray CT system and one of the four cameras of the SPECT system are already working. The PET system is under construction

#### References

[1] G.A. Kastis et al., "Compact CT/SPECT Small-Animal Imaging System", IEEE Trans. Nucl. Sci., vol 51, pp. 63-67, February 2004

[2] D. Brasse et al, "Design of a Small Animal PET System with High Detection Efficieency", Proceedings of the IEEE Nuclear Science Symposium and Medical Imaging Conference, Rome, Italia 16-22 october 2004

[3] D. Brasse et al, "Development of a High Resolution SPECT system dedicated to Small Animal Imaging", Proceedings of the IEEE Nuclear Science Symposium and Medical Imaging Conference, Rome, Italia 16-22 october 2004

[4] D. Brasse et al., "AMISSA: a multimodality imaging system for small animal", Proceedings of the Academy of Molecular Imaging, Orlando, 18-23 March, 2005.

## Simulation of the Clear-PEM scanner for breast cancer imaging with Geant4

- Author(s) : A. Trindade, On behalf of the Clear-PEM Project
- Institution(s) : LIP, Lab. Instrumentação Física Experimental Partículas, Lisboa
- Corresponding author e-mail : <u>andreia@lip.pt</u>
- Summary

#### 1. Introduction

The Clear-PEM detector is a positron emission mammography planar-system designed to image both the breast and the axillary lymph node areas [1]. It belongs to a new generation of positron emission scanners that aims to improve the detection of small breast lesions [2,3]. The proximity to the target volume under imaging and the lower background from the non-breast uptake provided by these dedicated devices when compared with the whole-body PET approach, leads to high detection sensitivities and better spatial resolutions. The development concept of the Clear-PEM detector takes advantages of compact photo-detectors, depth-of-interaction (Dol) measurement capability and efficient data acquisition systems. As in any other detector under development, Monte Carlo simulation provides a powerful technique of modelling the system response and an useful tool to optimize its performance. The Geant4 Monte Carlo code has been the basis of Clear-PEM detector simulation. mainly due to its versatility. This has allowed to develop a simulation tool able to reproduce in a realistic way the conditions of a typical breast exam with the Clear-PEM imaging system. It includes a patient model to simulate the radiation environment produced by FDG uptake in the different organs, a detailed description of the detector geometry and a particular module for front-end electronics, trigger and data filtering algorithms simulation.

#### 2. Simulation Components

#### The patient model

The NURBS CArdiac Torso (NCAT) phantom [4] provides a realistic model of the human anatomy suitable for nuclear medicine imaging applications. It was implemented in our simulation tool as a voxelized geometry to generate the FDG radiotracer distributions in the relevant organs or anatomical structures of a virtual patient. All voxels belonging to an organ were indexed to the same ICRU material chemical composition and density. The <sup>18</sup>F decays were homogeneous generated inside each voxel assuming the total number of events to be proportional to the activity concentration for a given organ. In order to correctly reproduce the radiation background present in the PEM exam the lungs, heart, kidneys, liver and stomach were considered as organs with radiotracer uptake as well as the adipose tissue filling the body contour. The relevant bone structures, spine and ribs, were also included in the geometry allowing an accurate modelling of scattering and attenuation within the body when photons are tracked through the medium before they reach the detector - Figure 1.

#### **Detector model**

Clear-PEM consists of two parallel detector heads each one holding 96 detector modules composed by a 4×8 LYSO:Ce crystal arrays. The 2×2×20 mm<sup>3</sup> crystals are optically isolated and each side of the crystal matrix optically coupled to a 32-pixel Hamamatsu S8550SPL APD array for Dol measurement. The detector covers a 16.2×14.1 cm<sup>2</sup> field-of-view (FoV) with a packaging fraction of the order of 50 %. A detailed description of the geometry and material properties of Clear-PEM was implemented in Geant4 including APDs, external housing, optical coupling, crystals wrapping and front-end electronic components (~ 35 k volume). Together with the detector model we included a 7.0 mm thickness lead shielding layer on which the patient model was positioned with the left breast pendant through a 20x20 cm<sup>2</sup> aperture - Figure 1.



Figure 1. A complete view of the implemented Geant4 geometry to reproduce a typical exam scenario with the Clear-PEM imaging system for the standard (a) and complementary (b) breast exams. It includes the torso phantom, scanner table and the geometry of the detector heads. The rotation movements of the detector are represented and can also be simulated with the developed tool.

## **DAQ-Trigger modelling**

We developed a high-level simulator for signal formation and data processing in the on-detector front-end and off-detector digital electronic systems. Main function blocks includes the translation of the Geant4 hits information (energy, position, and time) into a parameterized pulse shape, reproduction of the photo-detector and front-end electronics chain (crystals, APDs, amplifiers, multiplexing, and analogue-digital conversion), simulation of data filtering algorithms implemented in FPGAs and trigger logic for each valid dataframe as well as the simulation of the binary datastream output. Example applications of this module are bit-level comparisons against VHDL (hardware description language for designing digital electronics systems) FPGA testbenches, generation of test vectors to be stored in FPGA memories that will be used for system testing and evaluation of trigger performance (efficiency, ghosting, time and energy resolution) [5].

#### 3. Results

**Performance indicators** 

The described simulation components, have allowed to evaluate the performance of Clear-PEM in terms of detection sensitivity, spatial resolution, count-rates and data acquisition system performance. A peak detection sensitivity of 5 % and a 1.4 mm (FWHM) spatial resolution for a reconstructed point source at the center of the FoV and 10 cm distance between the detector heads, were found. We estimate the system count-rate for representative exam scenarios in realistic operational conditions. This means to account for the presence of detected background events (random coincidences and single events) coming from the torso geometry. For the evaluated breast volumes and detector separation distances, the contribution of each individual organ to the background was also assessed with and without the presence of the scanner table shielding - Figure 2a. The feasibility of the complementary exam to image the breast region close to the chest was also evaluated using the same methodology.



Figure 2. (a) System count-rate results for a selected standard exam scenario. Contributions of the more significant organs to the total singles-rate per detector head above 15 keV with and without scanner table shielding are also presented. True+scatter and random coincidence rates assumes an energy window 350-700 keV and 4 ns coincidence window. (b) 2D-OSEM reconstruction of the central plane of the breast with a 5 mm diameter lesion (non-corrected image). The simulated data corresponds to 5 minute acausistion time and a

#### Lesion detectability

We rely on simulated data to optimize the image reconstruction process with different algorithms under development for the Clear-PEM prototype [6]. The developed tool was recently used to reproduce a 5 minute exam with the Clear-PEM imaging system for lesion detectability evaluation. Computational requirements (70 CPU day on 32-bit Xeon 2.8 GHz) dictated the use of the CERN/LSF cluster facility and CASTOR mass storage system. Four standard background activities were considered (1.59, 2.04, 3.81 and 4.81 kBq/ml) and spherical lesions simulated, ranging from 1 to 10 mm diameter with central and peripherical locations within the breast. The exam scenario assumes two orthogonal projections covering a 10x10 cm<sup>2</sup> FoV. Preliminary image reconstructions performed with the 2D-OSEM algorithm, have shown a very good visibility of small lesion detection for conservative lesion/background ratios (13:1) and

small acquisition times (5 min.) - Figure 2b. Signal-to-noise ratio analysis, as a function of acquisition time, lesion size, location within the breast and backgorund activity are currently in progress and shall be presented.

#### • References

[1] M. C. Abreu *et al.,* "Design and evaluation of the Clear-PEM detector for positron emission mammography", *IEEE Trans. Nuc. Sci. (in press) 2005.* 

[2] C. J. Thompson, K. Murthy, Y. Picard, I. N. Weinberg, F. M. Mako, "Positron Emission Mammography (PEM): a promising technique to detect breast cancer", *IEEE Trans. Nucl. Sci.* vol. 42, 1012–1017, 1995.

[3] W. W. Moses, "Positron emission mammography imaging", *Nucl. Instrum.Meth.* vol. A 525, pp. 249-252, 2004.

[4] Segars W. P., "Development of a new dynamic NURBS-based cardiac-torso (NCAT) phantom" *PhD dissertation 2000, The University of North Carolina, USA*.

[5] C. Leong *et al,* "Design and test issues of a FPGA based data acquisition system for medical imaging using PEM", *Real Time Conference NPSS/IEEE 2005, Stockholm, Sweden.* 

[6] N. Matela *et al.*, "Comparison of different image reconstruction strategies in Clear-PEM", *CIMED2005* - Second International Conference on Computational Intelligence in Medicine and Healthcare, Lisboa, Portugal.

## Simulated PET acquisition of a respiratory and cardiac moved NCAT- human torso phantom using the GATE toolkit

- Author(s) : N. Lang, F. Büther, M. Dawood, O. Schober, K. Schäfers
- Institution(s) : University Hospital Münster Department of Nuclear Medicine
- Corresponding author e-mail : <u>langn@uni-muenster.de</u>
- Summary :

#### Introduction

Imaging accuracy in PET/CT studies is limited by organ movement during data acquisition. Cardiac and respiratory movement produces artifacts in reconstructed images. These artifacts may have severe consequences for diagnosis and correct treatment of patients. A GATE [1,2] simulation of the entire PET imaging process was done and allows the quantitative assessment of PET image quality of moving organs.

#### Materials and methods

The four dimensional (4D) cardiac-torso NCAT [3] phantom of the human thorax was used to produce a moving particle source. This data set represents the distribution of the radioactive <sup>18</sup>F-FDG PET tracer.

The phantom particle source was used within the Geant4 [4] based GATE-toolkit. This application mimics all major physical processes of a real PET scan. The decay of the positron emitter <sup>18</sup>F-FDG which is accumulated in the phantom heart and lung was simulated for different data sets. GEANT4 particle tracking and simulation of detector response is performed within the GATE package. Attenuation of the positron-decay photons in tissue is considered also by using voxel data of the NCAT phantom. The coincidence information in the PET scanner is saved in ROOT and ECAT7 data format for further analysis and image reconstruction. The PET coincidence data was reconstructed with standard iterative image reconstructed PET images with the original NCAT phantom data.

## Results

Simulation of a sample data set resulting in 1.7\*10<sup>A</sup> registered coincidence events took about 5 days on a 2.4 GHz Xeon processor. This statistics was sufficient for further iterative image reconstruction. Results are presented in Figure 1. The original activity distribution in the lungs is visible in the reconstructed images. The comparison of the source distribution with the images of the simulated PET scan will lead to a quantitative description of imaging quality.



Figure 1 : Transversal and sagittal slice of the thorax. In black/white the NCAT phantom is displayed, the simulated PET image is displayed in colour code where red corresponds to high source density, and blue to low activity. The clearly visible lung is bordered by the ribcage and the diaphragm. Basis for image reconstruction were 1.7 million detected coincidences, higher statistics will result in better image quality.

#### Conclusion/Outlook

The GEANT4 based Gate toolkit in combination with the NCAT thorax human phantom is an ideal platform to address imaging accuracy of dynamic PET studies. Further high statistics simulations have to be performed to achieve statistics comparable with a real patient scan (~500 MBq). Thus parallel computing has to be implemented. In a next step respiratory and cardiac motion will be simulated as a series of motion snapshots in order to mimic the motion and motion artifacts in PET/CT studies.

## • References :

[1] D Struhl et al. GATE: a PET(SPECT general purpose simulation platform. Nucl. Phys. B( Proc.Suppl.) 2003, **125C** 75-79

[2] GATE website: <u>http://www-lphe.epfl.ch/GATE/</u>

[3] W P Segars Development of a new dynamic NURBS-based cardiac-torso (NCAT) phantom. PhD dissertation, The University of North Carolina, May 2001

[4] S Agostinelli et al. GEANT4 – a simulation toolkit Nucl. Instr. Meth. *A506* 250-303 2003

## Geant4 simulations for Emission Tomography on low-activity radioactive waste drums with Compton detectors

- Author(s) : Patrice Leroy.
- Institution(s):

French Atomic Energy Commission Nuclear Measurements Laboratory CEA\_Cadarache, France

- Corresponding author e-mail : patrice.leroy@cea.fr
- Summary

The Emission Computed Tomography (ECT) coupled to Transmission Computed Tomography (TCT) for the attenuation correction is a non intrusive method for radioactive waste contrôle and elementary characterization. It is a non destructive method and hence cost effective. It could also provide the localization and the activity quantification of radionuclide and therefore minimize handling and secondary waste. Measured items are standard 220-litre oil barrels. Their apparent density is between 0.2 and 2 but could varies from different localisation in the waste package. This due to the wide variety of waste such as paper, PVC, concrete, steel... Their activity covers a large range from MBq to tens GBq. The radiological contents are mainly Co60 and Cs137 with many, various other radionuclides such as Sb125, Aq108, Co110, Eu152...However, 3D ECT acquisition time for low level waste drums is very long due to the collimator system which limits the flow of incident photons by more than two decades. Compton detectors allow the conception of electronically collimated ECT systems. Those highly physically or electronically segmented gamma detectors are able to track photons. The position and the deposited energy are measured for every photonic interactions. The relationship between the photon energy before and after a Compton interaction allows the calculation of the Compton diffusion angle. This reduces the possible localisation of the corresponding gamma source to a conic space and thus acts as a collimator. We study the feasibility of a such ECT system through Monte-Carlo simulation with Geant4 code coupled to the GATE toolkit and the G4LECS package for Doppler broadening ([1-2]). Monte-Carlo codes provide exact position of interactions and deposited energy. Those data are separately processed to fit to experimental results, tacking account of energetic and spatial resolution, time and spatial pile-up. The characteristics of the simulated detector are taken from recent example of Compton detectors([3-5]). Because of the size and the density of measured object, matrix effect must be corrected. A final Process rejects photons escaping from the detector and reduces the Compton background level([6-9]), while the attenuation correction is operated in ML-EM reconstructions([10]). Results show that improves quality of reconstructions mainly concerning very low radioactive waste drums. The effectiveness of the photon rejection process is evaluated through Monte-Carlo simulations.

#### References

[1] The GEANT low energy Compton scattering (GLECS) package for use

in simulated advanced Compton Telescope. R.M. Kippen. New Astronomy Reviews 48 (2004) 221-225.

[2] Doppler Broadening as lower Limit to the Angular Resolution of the Next Generation Compton Telescopes, A. Zoglauer, G. Kanbach, X-ray and Gamma-Ray Telescopes and Instruments for Astronomy, Proceedings of the SPIE, Volume 4851 (2003) 1302-1309.

[3] Overview of the nuclear Compton Telescope, S.E. Boggs, W. Coburn,

D.M. Smith, J.D. Bowen, P. Jean, J.M. Kregenow, R.P. Lin, P. von Ballmoos. New Astronomy Review 48(2004) 251-255.

[4] Tigress highly-segmented high-purity germanium clover detector, G.

Hackman et al. Nucl. Instr. And Meth A 543 (2005) 431-440.

[5] Position sensitivity of the TIGRESS 32-fold segmented HPGE clover

detector, C.E. Svensson, et al. Nucl. Instr. And Meth A 540 (2005) 348-360.

[6] Ambiguity in gamma-ray tracking of "two-interaction" events, C.J.

Lister, et al. Nucl. Instr. And Meth A 547 (2005) 535-540.

[7] Three-Compton Telescope: Theory, Simulations, and Performance,

R.A Kroeger, W.N. Jhonson, J.D. Kurfess, B.F. Philips, E.A. Wulf. Gamma and Cosmic Ray Astrophysics Branch, Naval Research Laboratory Washington DC. [8] Germanium Strip Detector Compton Telescope Using Three

Dimensionnal Readout, E.A. Wulf, B.F. Philips, W.N. Johnson, R.A. Kroeger, J.D. Kurfess, E.I. Novikova. Geant4 space users

(http://geant4.esa.int/papers/Ge\_strip\_Compton.pdf).

[9] Gamma-ray tracking algorithms: a comparison, A. Lopez-Martens, et al. Nucl. Instr. And Meth A 533 (2007) 454-466.

[10] Edge-Preserving Regularization in Emission Tomography with

Transmission CT Boundary information Characterization of Waste Drums,

R. Thierry, J-L Pettier, D. Eck, IEEE Nuclear Science Symposium, Portland

## **User Session 2**

# Imaging and external beam therapy

## GATE : a simulation toolkit for emission tomography in nuclear medicine and molecular imaging

## Author(s) : Irène Buvat

Abstract not available at this time

## An accurate experimental benchmark of bremsstrahlung for radiotherapy quality beams

- Author(s) : Bruce Faddegon
- Institution(s) : University of California Comprehensive Cancer Center
- Corresponding author e-mail : <u>faddegon@radonc17.ucsf.edu</u>

#### • Summary

Preliminary work on comparing the results of Geant4 simulations to an accurate experimental benchmark of the angular and energy distribution of bremsstrahlung will be reported. The experimental benchmark is for 10-30 MeV electron beams incident on thick targets of Be, Al and Pb targets. Results are absolute, with accuracy of 5% or better in photon fluence in a given direction per incident electron, 3% or better in angular distribution of fluence. The higher-Z targets are in common use for therapy. Lower-Z targets are being developed for imaging purposes. The benchmark was measured on the research accelerator at the National Research Council of Canada (NRCC) (see Faddegon, Ross and Rogers, "Angular Distributions of Bremsstrahlung from 15 MeV Electrons Incident on Thick Targets of Be, Al and Pb," Medical Physics 18(4):727, 1991, and references therein). The measurements were compared to ITS and EGS4 in previous publications. The ITS simulations include the use of short steps in a thin layer of material at the target surface, and the EGS simulations include angular sampling of bremsstrahlung photons. These modifications result in significant improvement in the angular distribution of bremsstrahlung in the forward direction (Faddegon and Rogers, "Comparisons of Thick-target Bremsstrahlung Calculated with EGS and ITS," Nuclear Instruments and Methods, A327:556, 1993). Details of the experiment and results of recent calculations using Geant4 and EGSnrc, including timing comparisons, will be reported at the meeting. The presentation will serve to update Geant4 developers on this critical experimental benchmark for simulation of the treatment head of accelerators used in radiotherapy.

## Simulations for the virtual prototyping of a radiotherapy MRI-linear accelerator system: Linear accelerator output, CT-data implementation, dose deposition in the presence of a 1.5 T magnetic field

- Author(s) : A.J.E. Raaijmakers, B.W. Raaymakers, J.J.W. Lagendijk
- **Institution(s)** : UMC Utrecht, dept. of Radiotherapy
- Corresponding author e-mail : <u>a.raaijmakers@umcutrecht.nl</u>

#### • Summary

In the framework of the development of the integration of a MRI-scanner with a linear accelerator (in collaboration with Philips Medical Systems and Elekta) Monte Carlo simulations have to be performed to determine the influence of the magnetic field on the dose distribution. Therefore, we constructed a linear accelerator model, thoroughly validated our CT-data implementation and qualitatively investigated the changes in the dose distribution by a 1.5 T magnetic field.

An Elekta SL linear accelerator was simulated, using phase-space files at two levels: directly over and under the jaws. To increase the randomness in the phase-space files, the symmetry of the geometry was exploited by random rotation or mirror operations. To decrease calculation time, an OpenMosix cluster was established, allowing flexible membership by employee workstations. During nights and weekends up to 50 computers are available. The simulated dose distribution corresponds to measurements within 2% / 2 mm.

CT-data can be imported into GEANT4 using the parameterized volume implementation. A self-constructed nearest-neigbour navigation algorithm was compared to the GEANT4 SmartVoxelGrid optimisation. The latter showed superior performance with an optimisation factor of 0.1.

To check whether the dose deposition was simulated correctly, measurements of the dose deposition in a polystyrene phantom (with 4 cm air gap) were compared to simulations on CT-data of the same phantom, using the accelerator model described above. The polystyrene phantom was also modeled geometrically, for additional comparison. Agreement was found within 2% when using a maximum stepLength of 50 µm. Otherwise, a small deviation was shown directly after the gap (figure 1).

Additional validation was found in simulating a quasi-clinical treatment plan for a prostate region. The simulated dose distribution was compared to a calculation by the commercial treatment planning system 'PLATO'. (See figures 2, 3 and 4)

The dose distribution in the presence of a 1.5 T magnetic field shows, along with small differences, one striking effect: Electrons leaving the patient will be forced back into the phantom, causing dose increase at all tissue-air boundaries. This effect will be shown by simulations both on water phantoms and in patient anatomies.

All validation studies showed positive results. GEANT4 has already proved to be very useful for achieving the goals of this project. Next step will be to validate dose distributions in a magnetic field.



Figure 1: Effect of maximum steplength



*Figure 3: Dose distribution on prostate simulated by GEANT4* 



*Figure 2: Dose profiles over prostate. Plato compared to GEANT4* 



*Figure 4: Dose distribution on prostate calculated by PLATO* 

#### The Use of the GEANT4 Toolkit at the CMRP: Application to Radiation Protection, Oncology and Medical Imaging

- **Author(s)** : Iwan Cornelius<sup>1</sup>, Dale Prokopovich<sup>1,2</sup>, Andrew Wroe<sup>1</sup>, Ian Kwan<sup>1</sup>, Nirmal Painuly<sup>1</sup>, Lakshal Perera<sup>1</sup>, Erik Siegbahn<sup>3</sup>, Mark Reinhard<sup>2</sup>, Michael Lerch<sup>1</sup>,George Takacs<sup>1</sup>, Flavio Marchetto<sup>4</sup>, Roberto Cirio<sup>4</sup>, Anatoly Rosenfeld<sup>1</sup>.
- Institution(s):
- 1. Centre for Medical Radiation Physics, University of Wollongong, Australia
- 2. Australian Nuclear Science and Technology Organisation, Sydney, Australia
- 3. European Synchrotron Research Facility, Grenoble, France

4. Istituto Nazionale di Fisica Nucleare, Torino, Italia

• Corresponding author e-mail : <u>iwan@uow.edu.au</u>

#### • Summary :

The Centre for Medical Radiation Physics (CMRP) and it's collaborative partners are actively involved with the development of semiconductor detectors and dosimeters for radiation protection, radiation oncology, and nuclear medicine applications. The GEANT4 Monte Carlo toolkit is used extensively in our current research projects. This poster will give an overview of our experience with the toolkit, including: the use of GEANT4 to calculate the dose distribution of HDR brachytherapy sources for comparison with TLD, ionisation chamber, and MOSFET measurements; the simulation of silicon microdosimetry measurements of an isotopic neutron source; the simulation of MOSFET dosimetry of synchrotron microbeams to understand lateral dose enhancement effects (see figure below); estimating the effectiveness of various space shielding configurations using microdosimetry based calculations of biological dose; simulating small animal PET scanners using GATE; and the macroscopic verification of light ion fragmentation models via comparison with experimental data for energies and targets relevant to carbon ion therapy.



Figure: (left) Simulation of the response of an "edge-on" MOSFET to a synchrotron microbeam (right) Dose profile obtained using GEANT4 and PENELOPE the lateral dose enhancement from the silicon substrate of the MOSFET is illustrated by the skewness of the dose profile.

## • References

1. Edge on face-to-face (EOFF) MOSFET for synchrotron microbeam dosimetry: MC modelling,

A.B. Rosenfeld, E.A.Siegbahn, E. Brauer-Krish, A. Holmes-Siedle, M.L.F. Lerch, A. Bravin, I.M.Cornelius, G.J. Takacs, N. Painuly, H. Nettelback, T. Kron, IEEE Transactions on Nuclear Science, (To be published, December 2005 issue).

2. Microdosimetry simulations of solar protons within a spacecraft,

A. J. Wroe, I. M. Cornelius, A. B. Rosenfeld, V. L. Pisacane, J. F. Ziegler, M. E. Nelson, F.Cucinotta, M. Zaider, J. F. Dicello,

IEEE Transactions on Nuclear Science, (To be published, December 2005 issue).

# **User Session 3**

## Hadrontherapy

## Simulation of light ion transport in a water phantom using Geant4.

• Author(s) : I.Gudowska<sup>1</sup>, A.Bagulya<sup>2</sup>, V.Ivanchenko<sup>3</sup> and N.Starkov<sup>2</sup>

### • Institution(s) :

<sup>1</sup>Karolinska Institutet and Stockholm University, Stockholm, Sweden
 <sup>2</sup> Lebedev Physics Institute, Moscow, Russia,
 <sup>3</sup>Budker Institute for Nuclear Physics, Novosibirsk, Russia

## • Corresponding author e-mail : <u>Irena.Gudowska@radfys.ki.se</u>

#### • Summary

Radiation therapy is today in a state of very rapid development with new advanced intensity modulated treatment techniques combined with physical and biological optimization methods.

To be able to treat well also the severe radiation resistant tumors of complex local spread, intensity modulated ion beams combined with new computerized, biologically based therapy optimization methods are under development and belong to the most advanced treatment techniques. However, this treatment technique requires very accurate understanding of the complex processes of ion interaction with matter and the use of appropriate algorithms for particle transport in media. Monte Carlo technique with the accurate atomic and nuclear inelastic models for ion interactions with tissue equivalent materials provides very efficient tool for simulation of ion beam interactions with patient's body and helps in development of treatment planning system.

GEANT4 MC toolkit, version 7.1, has been used to study ion transport in the tissuelike media.

Spatial distributions of the energy deposition in the water phantom were calculated for <sup>1</sup>H, <sup>4</sup>He, <sup>12</sup>C and <sup>20</sup>Ne ion beams in the energy range from 100 up to 400 MeV/u.

The computer code IION based on Geant4 toolkit was developed. It allows different studies including the study on nuclear fragmentation of the beam and isotope production inside phantom media using the Geant4 Binary Cascade model.

The Geant4 results are compared with other Monte Carlo codes for transport of light ions in matter like SHIELD-HIT, PETRA, MCNPX, and with the experimental results from the light ion clinical facilities, HIMAC in Chiba, Japan and GSI in Darmstadt, Germany. The results obtained with the Geant4 version 7.1 show a good agreement with the experimental data.

#### Acknowledgements

This work was supported by VINNOVA (Swedish Agency for Innovation Systems) and by EU project INTAS-2001-0323.

## • References

1. Agostinelli S. et al. Geant4 – A simulation toolkit. Nucl. Instrum. Methods A 506, pp. 250-303, (2003).

2. A. Bagulya, I. Gudowska, V. Ivanchenko, N.Starkov and V. Grichine, GEANT4 study of light ion transport in a water phantom, Internal Report, MSF 2005-04, Karolinska Institutet (2005).

3. I. Gudowska, N.M. Sobolevsky, P. Andreo, D. Belkic, and A. Brahme "Ion beam transport in tissue-like media using the Monte Carlo code SHIELD-HIT" Phys. Med. Biol. 49 pp. 1933-1958 (2004)

4. T. Ersmark, P. Carlsson, E. Daly, C. Fuglesang, I. Gudowska, B. Lund-Jensen, R. Nartallo, P. Nieminen, M. Pearce, G. Santin, N. Sobolevsky "Status of the DESIRE Project: Geant4 Physics Validation Studies and First Results from Columbus/ISS Radiation Simulations", IEEE Transactions in Nuclear Science, Vol. 51, No 4, August, pp. 1378-1384 (2004)

#### Fragmentation of light nuclei in water phantoms studied with GEANT4

- Authors : I.A. Pshenichnov, I.N. Mishustin, W. Greiner
- Institution : Frankfurt Institute for Advanced Studies, J.-W. Goethe University
- Corresponding author e-mail : <u>pshenich@fias.uni-frankfurt.de</u>

#### • Summary

Energy deposition by beams of nuclei in tissue-like media is studied taking into consideration nuclear fragmentation reactions and production of secondary particles. The calculations are based on the GEANT4 toolkit (version 7.0). Experimental data on depth-dose distributions for 135A-400A MeV <sup>12</sup>C and <sup>18</sup>O ions in water are successfully described without any adjustment of the model parameters adopted in GEANT4. This gives confidence in successful use of the GEANT4 toolkit for Monte Carlo simulations of cancer therapy with beams of light nuclei. The approach makes possible to simulate all the major processes relevant to heavy-ion propagation in human tissues within a self-consistent approach.

Energy deposition from nuclear reactions induced by secondary neutrons was calculated for carbon and neon beams. The elastic scattering and nuclear interactions of secondary neutrons, which result in the ionization processes induced by recoil protons, nuclei and nuclear fragments contribute 1-2 % of the total energy deposited in a (40-50 cm)<sup>3</sup> water phantom, depending on the beam energy, the charge and mass of beam ions. A similar neutron contribution to the total dose was calculated for proton beam irradiation characterized by less energetic secondary neutrons. Although the number of secondary neutrons produced per one beam particle is essentially larger for ion beams, the additional neutrons produced by heavy-ion beams do not appear to be a serious hazard to human body.



Figure 1. Average linear energy deposition by <sup>12</sup>C ions in water. GEANT4 calculations are shown by histograms, experimental data from GSI (Sihver et al., 1998) and RIKEN (Kanai et al., 1993) are shown by circles and triangles, respectively.

#### • References

1. I. Pshenichnov, I. Mishustin and W. Greiner, *Neutrons from fragmentation of light nuclei in tissue-like media: a study with GEANT4 toolkit,* **physics/0507091,** <u>http://lanl.arxiv.org/abs/physics/0507091</u>

2. L. Sihver, D. Schardt, and T. Kanai, *Depth-dose distributions of high-energy carbon, oxygen and neon beams in water,* Jpn. J. Med. Phys. **18** (1998) 1

3. T. Kanai, S. Minohara, T. Kohno, *et al.*, *Irradiation of 135 MeV/u carbon and neon beams for studies of radiation biology* NIRS-M-92 (HIMAC-004), 1993, NIRS, Chiba, Japan

#### Significance of time-dependent (four-dimensional) geometries for Monte Carlo simulations in radiation therapy.

- Author(s) : Harald Paganetti
- Institution(s) : Massachusetts General Hospital and Harvard Medical School
- Corresponding author e-mail : <u>hpaganetti@partners.org</u>
- Summary

Dynamic radiation therapy involves variable geometries. While intensity-modulated photon therapy (IMRT) is based on moving leafs in a multi-leaf collimator, intensity modulated proton therapy (IMPT) is based on changing magnetic fields. Conventional proton therapy using a scattering system is based on time-dependent range modulator settings. In addition to time-dependent beam properties, the patient geometry may be time dependent due to respiratory or cardiac motion.

To calculate dose delivery in dynamic radiation therapy, the results of 3D calculations are usually considered separately. This method becomes cumbersome if high time resolution is required or if the geometry is complex. It becomes even more challenging if interplay effects between different, independently moving systems are to be studied. The latter refers to a double-dynamic system, i.e. treatment head variations under organ motion.



Figure 1: GEANT4 model of a range modulator wheel at the Northeast Proton Therapy Center, which rotates during treatment.



Figure 2: GEANT4 model of a scanning magnet at the Northeast Proton Therapy Center (left) and proton tracks deflected in the beamline (right).



Figure 3: GEANT4 model of a linear accelerator for photon treatment (left), including the multi-leaf collimator for intensity modulated radiation therapy (right).

We developed GEANT4<sup>1</sup> based 4D Monte Carlo simulations to model electromechanical motion in the treatment head and to model respiratory organ motion. 4D Monte Carlo allows continuously changing geometrical setup during simulation. We successfully used this technique to model rotating range modulator systems and magnetic beam scanning systems for proton therapy<sup>2,3</sup> and to model multi-leaf collimators (with moving leafs) for IMRT. Graphical representations of these systems are shown in figure 1-3.

For organ motion studies, 4D dose calculation is applied using patient specific 4D CT information<sup>4</sup>. To accumulate dose deposition over different respiratory patient states, the position of each voxel as a function of time has to be known. Deposited dose can not simply be added geometrically but has to be accumulated per anatomical voxel. For motion analysis based on 4D CT, the tracking of voxel positions over time is non-trivial because internal patient anatomy deforms non-rigid. To correlate different respiratory states, volume (voxel) displacement maps (VDM) are required for the entire region of interest. A VDM is a transformation matrix, which describes positional voxel changes within a particular volume between different points in time.<sup>5</sup> To calculate a VDM a deformable image registration algorithm used. Then, local dose deposition per voxel is calculated for deforming geometries and total DVHs including motion effects are generated.<sup>6</sup> The local dose is calculated as a function of moving sub-volumes and not as a function of position relative to a coordinate system.

In 4D Monte Carlo the resolution of the simulation, i.e. the number of particles simulated for a particular state of the geometry, has usually only little influence on the speed of the calculation since motion is handled quickly by simply changing references (C++ pointer) within memory. Since each simulation step can be as small as considering only one particle history, this is in fact continuous. However, in the case of CT data the number of sub-volumes, one per voxel, is quite large. After each geometry change, GEANT4 goes through all volumes to check the material of each volume and performs a geometry optimization. Thus, for very high temporal resolution, the computational efficiency is somewhat reduced. For the present study we arbitrarily chose a temporal resolution of 0.4 seconds for patient modifications. Each temporal step corresponds to a specific number of proton histories.

The 4D Monte Carlo technique was applied to a lung cancer case planned for proton therapy. We show that the effect of motion on the dose distribution can be simulated effectively based on patient specific 4D CT information (figures 4-5)<sup>5</sup>.



Figure 4: Proton Monte Carlo dose distribution for the CT slice at iso-center as recalculated based on a treatment plan. The three phases correspond to the patient in exhale (left), in intermediate state (center) and in inhale (right)



Figure 5: Dose Volume Histograms for GTV and CTV obtained by 4D MC dose calculations for inhale position (solid lines) and based on the entire breathing phase with the exhale geometry transformed to the inhale geometry (dashed lines).

This work illustrates that, within GEANT4, organ motion and dynamic beam delivery (single-dynamic) as well as interplay between organ motion and dynamic beam delivery (double-dynamic) can be studied for any given time resolution (dose rate) and for realistic time sequences.

#### References :

<sup>1</sup> Agostinelli S *et al* 2003 GEANT4 - a simulation toolkit *Nucl. Instrum. Method. Phys. Res. A* **506** 250-303

<sup>2</sup> Paganetti H 2004 Four-dimensional Monte Carlo simulation of time dependent geometries *Phys. Med. Biol.* **49** N75-N81

<sup>3</sup> Paganetti H, Jiang H, Trofimov A 2005 4D Monte Carlo simulation of proton beam scanning: Modeling of variations in time and space to study the interplay between scanning pattern and time-dependent patient geometry Phys. Med. Biol. **50**, 983-990 <sup>4</sup> Pan T, Lee TY, Rietzel E, Chen GT 2004 4D-CT imaging of a volume influenced by respiratory motion on multi-slice CT

Med Phys. 31, 333-40

<sup>5</sup> Paganetti H, Jiang H, Adams JA, Chen GT, Rietzel E 2004 Monte Carlo simulations with time-dependent geometries to investigate organ motion with high temporal resolution *Int. J. Radiat. Oncol. Biol. Phys.* **60**, 942-950

<sup>6</sup> Rietzel E, Chen GT, Choi NC, Willet CG 2005 Four-dimensional image-based treatment planning: Target volume segmentation and dose calculation in the presence of respiratory motion *Int. J. Radiat. Oncol. Biol. Phys.* **61**, 1535-1550

## GEANT4 based proton dose calculation in a clinical environment: Technical aspects, strategies and challenges.

- Author(s) : Harald Paganetti, Hongyu Jiang
- Institution(s):
   Massachusetts General Hospital and Harvard Medical School
- Corresponding author e-mail : <u>hpaganetti@partners.org</u>
- Summary

<u>Purpose</u>: Goal of this study was the clinical implementation of a proton Monte Carlo dose calculation engine that could be used in parallel to our commercial treatment planning system. GEANT4.5.0.<sup>1</sup> was used as the Monte Carlo platform.

<u>Materials and Methods</u>: The beam entering the patient has to be modeled as accurate as possible. The treatment heads at the Northeast Proton Therapy Center were modeled including more than 1000 individual objects of the geometry.<sup>2</sup> This includes a time dependent simulation of the modulator wheel (for broad beam modulation) and the magnetic field settings (for beam scanning).<sup>3</sup> The code was benchmarked against measurements in phantoms. Because the treatment head incorporates extensive number of different settings (combinations of scatterers, variable jaws etc.) a software link was created to transfer this information from the treatment machine control system to the Monte Carlo input file. The prescribed range and modulation are not directly used as the input parameters, but translated into the corresponding settings of the treatment nozzle setup. Further, for broad beam modulation treatment, the Monte Carlo code must be able to simulate apertures and compensators based on the milling machine files.

The capability of using CT data information was implemented in GEANT4.<sup>4</sup> HUs were converted into materials with explicit element composition and density. Different Hounsfield unit to material conversion methods were tested. Based on this, we adopted a formalism in which the HU space is divided into 24 groups with each group sharing the same element composition and differing in the mass density.<sup>5</sup> We developed a method to dynamically assign the mass density to the materials during particle transport so that one HU group can share one material. Further, memory for CT voxels is assigned dynamically to allow calculations with at least up to 512 × 512 × 200 voxels. The GEANT4 standard tracking algorithm was modified to allow a time-efficient dose calculation.

A direct link of the Monte Carlo dose engine to the departmental patient database and the commercial planning system was established. Treatment information, like prescribed dose per field, size of the air gap, couch angle and gantry angle, is read from the patient database. This includes the capability of the Monte Carlo code to handle non-equidistant CT slicing.

Finally, based on the simulation of the ionization chamber reading, the dose delivered to the patient is predicted, using Monte Carlo for absolute dosimetry. A machine monitor unit corresponds to a fixed amount of charge collected in a

segmented transmission ionization chambers close to the snout of the treatment head.



**Figure 1.** Left: Schematic view of one of the proton treatment nozzles. Middle: Nozzle snout with aperture and compensator. Right: One of the rangemodulator wheels.



**Figure 2.** Graphical user interface to connect the treatment machine control system, the patient database, and the Monte Carlo input files.

<u>Results</u>: Monte Carlo dose calculation is used at the Northeast Proton Therapy Center. All clinically used treatment head configurations can be simulated (see Fig. 1). The setup is automated via a user interface, which uses information from the commercial planning system and the treatment machine control software to generate four Monte Carlo input files (see Fig. 2). The input files includes the settings for the treatment nozzle (gantry selection, first scatter lollipops, modulator wheel number and track, second scatter number, X and Y jaws, snout size and extension, and magnetic field), the incident protons at the nozzle entrance (mean energy, energy spread, angular spread, and beam spot size), the milling machine information for aperture and compensator, as well as the patient related information (gantry angle, couch angle, isocenter position in the FOCUS coordinate system, voxel numbers and slice dimensions in X and Y in the CT coordinate system, voxel offsets in X and Y, number of slices and their thickness, the positions of the CT slices in CT coordinate system).
Dose calculations are done on the CT grid resolution and have been performed for radiosurgery as well as for breast, paranasal sinus, spine, and lung malignancies (one example is shown in Fig. 3). The Monte Carlo code provides deposited energy per voxel, which has to be transferred to dose. Differences to the planning program could be identified.

The prescribed dose is converted into machine monitor units for patient treatment. The simulation predict an output factor, defined as dose to a calibration point (in cGy) divided by ionization chamber reading (in pC ; 300pC=1MU). The results on absolute dosimetry show excellent agreement with measurements (for 50 fields we found that the average absolute deviation from the experimental value was just 1.4%), (see Fig. 4).<sup>6</sup>



**Figure 3.** Isodose curves for one CT slice. Three fields for a paranasal sinus cancer (upper: pencil beam, lower: Monte Carlo). The isodose areas are for >90% prescription dose (red), >80% (orange), >60% <sup>2.2</sup> and >10% (dark blue).



**Figure 4.** Left: Simulated parallel-plate ionization chamber, which is being used to measure the output factor. Right: Simulated output factors (+) compared to measurements (o). The circles represent 3% deviation from the measured value. A

convenient way to plot output factors (in cGy per monitor unit (MU)) is to use the spread out Bragg peak range (SOBP<sub>r</sub>) and the modulation width (SOBP<sub>m</sub>).

<u>Conclusion</u>: Proton Monte Carlo dose calculation for treatment planning support can be efficiently done using GEANT4 based software. Re-calculated plans can be used for decision making in the planning process. Further, simulation of ionization chamber reading allows the use of Monte Carlo for absolute dosimetry. Because of the successful calculation of absolute doses in a complex geometry, the present work also serves as a validation of the GEANT4 package for use in proton radiation therapy

### • References

- <sup>1</sup> Agostinelli S *et al* 2003 GEANT4 a simulation toolkit *Nucl. Instrum. Method. Phys. Res. A* **506** 250-303
- <sup>2</sup> Paganetti H, Jiang H, Lee S-Y, *et al* 2004 Accurate Monte Carlo for nozzle design, commissioning, and quality assurance in proton therapy *Med. Phys.* **31**, 2107-2118
- <sup>3</sup> Paganetti H 2004 Four-dimensional Monte Carlo simulation of time dependent geometries *Phys. Med. Biol.* **49** N75-N81
- geometries *Phys. Med. Biol.* 49 N75-N81
  <sup>4</sup> Jiang H, Paganetti H 2004 Adaptation of GEANT4 to Monte Carlo dose calculation based on CT data *Med. Phys.* 31, 2811-2818
- <sup>5</sup> Schneider W, Bortfeld T, Schlegel W 2000 Correlation between CT numbers and tissue parameters needed for Monte Carlo simulations of clinical dose distributions *Phys. Med. Biol.* **45** 459-478
- <sup>6</sup> Paganetti H 2005 Monte Carlo calculations for absolute dosimetry to determine output factors for proton therapy fields *Phys. Med. Biol.* **submitted**

# Status and plan for the hadron therapy simulation project in Japan

- Author(s) : Takashi Sasaki
- Corresponding author e-mail : <u>Takashi.Sasaki@kek.jp</u>
- Abstract

Japanese medical physicists and Geant4 developers started the collaboration to develop the software for simulating hadron therapy based on Geant4 in 2003. Within this collaboration, we are not only developing software, but also working seriously on validation of physics.

We have developed the prototype software and simulated the water phantom experiment at Hyogo Ion Beam Medical Center, Japan, and made the comparison to the measurement. Both agree well and performance of the software was proved.

We are working on the 2nd prototype and releasing beta version in the near future. It will include the simulation driver based on PYTHON, geometry model frame work, interface

to DICOM/DICOM-RT, visualization tools and also GRID environment. The detail of each components and results of physics validation will be presented in the talk.

### A GEANT4-based simulation of irradiation system for hadron therapy

- Author(s): T.Aso<sup>1,4</sup>, A.Kimura<sup>2,4</sup>, S.Kameoka<sup>3,4</sup>, K.Murakami<sup>3,4</sup>, T.Sasaki<sup>3,4</sup>
- Institution(s) :
  - 1 Toyama National College of Maritime Technology
  - 2 Ritumeikan University
  - 3 KEK
  - 4 JST CREST
- Corresponding author e-mail : <u>aso@slac.stanford.edu</u>

### • Summary

A Geant4-based simulation of irradiation systems for hadron therapy has been developed. At hadron therapy facilities, simulation tools are needed for the design of beam irradiation systems and for validating treatment planning systems. It is therefore required that the geometries and materials of the beam irradiation system may be modified with minimal effort. Our development is based on utilizing different beam line components, and maintaining extensibility for different facilities. The developed simulation provides the useful way to customize beam line components, and to obtain dose distribution in different beam line setups.

A toolkit for simulating hadron therapy facilities are developed by the Japanese collaboration. We provide the necessary software framework to model irradiation systems. We have implemented three different facilities in Japan, for a gantry treatment system at Hyogo Ion Beam Medical Center(HIBMC), a gantry treatment system at National Cancer Center(NCC), and an experimental system at National Institute of Radiological Science(NIRS). Any of those irradiation systems can be chosen for the simulation at run time. The components in the beam line are also modularized with common interfaces, such as translation and rotation as well as install or uninstall in the beam line.

In this presentation, we briefly talk about the developed simulation, its functionality and some results for physics validation.

# **User Session 4**

# Space and biology applications

### Simulation of radiation monitors for future space missions.

- Author(s) : P.Gonçalves, M.Pimenta and B.Tomé.
- Institution(s) : LIP.- Lisboa.
- Corresponding author e-mail : <u>patricia@lip.pt</u>
- Summary

Space radiation monitors are becoming an essential component in space missions, providing crucial radiation environment information for the in-flight protection of the spacecraft and instruments onboard. Several of the future space missions (e.g. LISA, Gaia, JWST, BepiColombo) are planned to carry radiation monitors. Given the limited resources on mass, power and accommodation on-board of a spacecraft, a new generation of compact and lightweight general purpose energetic particle detectors are being studied.

A GEANT4 based simulation of a compact lightweight radiation monitor to be included in the payload of future space missions is presented. The instrument must meet severe mass and power constrains, satisfy mission safety requirements and it is also required to perform as a scientific instrument. GEANT4 is a powerful tool for developing and optimising such detector concept thanks to its capabilities for describing the complex detector geometries and simulating the passage of particles through matter. Moreover, the presence of an optical physics process category in GEANT4 is of the utmost importance in the development of a scintillation based detector concept.

### • References

B.Tomé, "Simulations of Space Radiation Monitors", New Worlds in Astroparticle Physics, Faro, Portugal January 2005.

### Recent Developments in Geant4-Related Activities at ESA: Physics, Tools, User Interfaces

• Author(s) : G.Santin<sup>1</sup>, H.Evans<sup>1</sup>, R.Lindberg<sup>1</sup>, P.Nieminen<sup>1</sup>, A.Mohammadzadeh<sup>2</sup>, E.Daly<sup>1</sup>

• Institution(s) : <sup>1</sup>Space Environments and Effects Analysis Section, ESA/ESTEC, Noordwijk, The Netherlands; <sup>2</sup>Radiation Effects and Component Analysis Techniques Section, ESA/ESTEC, Noordwijk, The Netherlands

### Corresponding author e-mail : <u>Giovanni.Santin@esa.int</u>

### • Summary

The use of Geant4 for the assessment of the effects of radiation to space missions has significantly increased over the past years, as a result of developments of Geant4-based tools and applications. Recent past, ongoing and planned ESA projects are tackling long-standing requirements in the physics and the usability.

Extensions of the present physics models, both in the high and in the low-energy domains, are still required for a correct description of the impact of radiation to both manned and unmanned missions. Interfaces to models for the radio-biological risk assessment are also being developed. Developments for the estimate of degradation due to displacement damage in microelectronics will be described. Modelling of complex geometry set-ups is being addressed with an extensive use of GDML and the development of interfaces to external tools (including CAD).

In this presentation, various activities in ESA or in institutes collaborating with ESA are presented. Radiation effect studies for exploration programmes are being facilitated by interfaces to planetary atmosphere and magnetic field models, such as in the RESTEC and PLANETOCOSMICS projects, with Mars and Mercury as first application cases.

We will present recent enhancements in the functionalities of existing Geant4-based tools, such as the Sector Shielding Analysis Tool (SSAT) and the Multi-Layered Shielding Analysis Software (MULASSIS), and the development and application of the new Geant4 Radiation Analysis for Space (GRAS), a modular, extendable tool for space environment effect simulation, which includes analyses of cumulative ionising and NIEL doses, effects to humans, charging, fluence and transient effects in 3D geometry models. Results will be shown from the support to some selected missions, including JWST, HERSCHEL, and ConeXpress.

# Geant4 simulations for microdosimetry at the cellular level and nanoprobe design

- Author(s) : S. Incerti, C. Habchi, Ph. Moretto, T. Pouthier and H. Seznec
- Institution(s) : CENBG, IN2P3 CNRS Bordeaux 1 University
- Corresponding author e-mail : <u>incerti@in2p3.fr</u>

### • Summary

The Centre d'Etudes Nucléaires de Bordeaux-Gradignan (CENBG) is equipped with a new state of the art low energy electrostatic accelerator facility (Singletron type) since October 2005.

The Interface Physics-Biology group has developed a focused <u>microbeam</u> line able to deliver protons and alpha particles up to 3.5 MeV to individual living cells, with a beam resolution of a few microns, allowing a precise control of the dose delivered to cell nuclei. New biology protocols have been recently developed in order to observe precisely the cell geometry (nucleus and cytoplasm) from confocal microscopy. Thanks to Geant4 voxelisation capabilities, we are now able to calculate precisely the dose absorbed by the nucleus taking, into account second order effects, like scattering on residual air inside the beam pipe and scattering by collimator edges. The Geant4 toolkit is now being extended at very low energies (down to 7.5 eV) in the framework of the Geant4 DNA project. On a long term basis, we expect to contribute to the development of a full integrated model taking into account not only Physics processes but also secondary chemical reactions, in order to quantify DNA damages after a low dose irradiation. Applications will involve radiobiology, radiotherapy and dosimetry for aeronautics and astronautics.

In parallel, we are now developing a <u>nanobeam</u> line allowing to reach under vacuum a nanometric shooting accuracy. It will be mainly dedicated to analysis of biological or solid state samples. The Geant4 toolkit has been validated for ray-tracing at this scale and we are now presenting expected performances of the new CENBG nanobeam line using realistic quadrupole field maps.

### References :

A COMPARISON OF RAY-TRACING SOFTWARE FOR THE DESIGN OF QUADRUPOLE MICROBEAM SYSTEMS. S. Incerti *et al.* 2005. 10pp. Published in Nucl.Instrum.Meth.B231:76-85,2005

DEVELOPMENT OF A FOCUSED CHARGED PARTICLE MICROBEAM FOR THE IRRADIATION OF INDIVIDUAL CELLS. By Ph. Barberet *et al.*. Dec 2004. 6pp. Published in Rev.Sci.Instrum.76:015101,2005

SIMULATION OF CELLULAR IRRADIATION WITH THE CENBG MICROBEAM LINE USING GEANT4.

By S. Incerti *et al.* Oct 2003. 6pp. Published in IEEE Trans.Nucl.Sci.51:1395-1401,2004

SIMULATION OF ION PROPAGATION IN THE MICROBEAM LINE OF CENBG USING GEANT4. By S. Incerti *et al.* Sep 2003. Published in Nucl.Instrum.Meth.B210:92-97,2003

### Monte Carlo, track structure calculations of low energy particles in liquid water.

- Author(s) : Ziad FRANCIS, Gérard MONTAROU
- Institution(s) : Laboratoire de Physique Corpusculaire, Clermont-Ferrand
- Corresponding author e-mail : <a href="mailto:francis@clermont.in2p3.fr">francis@clermont.in2p3.fr</a>
- **Corresponding author full international address** : Laboratoire de Physique Corpusculaire 24, av des Landais, 63170 Aubière CEDEX FRANCE

### • Summary

Track structure calculations of charged particles are very useful for understanding the irradiation early stage damages in biological matter. Our calculations are mainly concentrated on protons, alphas and electrons interactions. For simplicity, liquid water is considered since it represents the major component of biological environment Protons, alphas and electrons can loose a part or the total of their energy in ionizations, excitations and charge transfer processes. In a first approach, we use the Born theory as described by Dingfelder et al. (2000), for the inelastic cross sections calculations. Elastic collisions are taken into account for electrons as described by Brenner & Zaider (1983) and by Emfietzoglou (2000), and are neglected in the case of protons and alphas. The Born theory, becomes no more valid at low incident projectile energies, semi-empirical models are used instead. Several different semi-empirical models are proposed; like the Rudd (1988) model for protons ionizations, the Miller & Green (1973) model for protons and alphas excitations as well as for total ionization cross section calculations. The charge transfer process is also taken into account for protons and for alphas, it is described by Dingfelder et al. (2000) and by Uehara et al. (2000). Processes are to be implemented in GEANT4 monte carlo simulation code, and be ready to use in several sub-microscopic simulations of dose measuring and stopping power estimation for particles in biological matter. These processes are able to track electrons till very low energies (~7eV), protons till ~100eV and alphas till ~1keV.

However these processes could be very time consuming and are unsuitable for macroscopic applications. They can only be used in liquid water volumes, extensions for other type of needed materials are to be studied in the future.

### • References :

*M. Dingfelder, M. Inokuti, H.G. Paretzke, 2000. Inelastic-collision cross section of liquid water for interactions of energetic protons. Rad Phys and Chem 59, (2000), 255-275.* 

M.E.Rudd, T.V.Goffe, R.D.DuBois, L.H.Toburen, 1985, Cross Sections for ionization of water vapour by 7-4000 keV protons, PHYS REV A **31** (1).

*Miller, J.H. and Green, A.E.S., 1973. Proton energy degradation in water vapor. Radiat. Res.* **54**, pp. 343–363

*M.* Eugene Rudd, 1988. User-Friendly model for the energy distribution of electrons from protons or electron collisions. Nucl. Tracks Radiat. Meas. Vol 16 No 2/3 pp 219-218

D.J.Brenner, M.Zaider. A Computationally convenient parametrisation of experimental angular distributions of low energy electrons elastically scattered off water vapour. Phys.Med.Bio. (1983) vol 29 Num 4 443-447.

Geont4 2005

# **Poster Session**

Posters are listed in alphabetical order of their first author.

Additional posters not listed here may be displayed during the conference.

### BDSIM, an accelerator beamline simulation utility

- Author(s) : I. Agapov, G. Blair, J. Carter
- Institution(s) : Royal Holloway University London
- Corresponding author e-mail : <u>agapov@pp.rhul.ac.uk</u>

### • Summary

BDSIM is an utility for simulating various processes in accelerator beamlines based on Geant4 kernel. It has been initially developed as a tool for backgrounds studies in the beam delivery system of CLIC [1] and the International Linear Collider (ILC). The current application areas are mainly ILC detector backgrounds and collimation and simulations of beam diagnostics with the laser wire scanner.

BDSIM employs Geant4 kernel and run management. It consists of a set of classes representing standard accelerator components, the beamline building procedure and a set of physics processes introduced to speedup the calculations, which is critical due to a need to track particles for long distances, usual in accelerator studies. There is a predefined set of ROOT [3] histograms and output subroutines.

A preprocessor allows to construct geometry on the fly from a description file written in a language similar to MAD [2]. This allows to include standard accelerator components, geometrical objects described in a macrolanguage or geometrical objects stored in some external database.

Tracking of particles through standard accelerator components (dipoles, quadrupoles etc.) can be made considerably faster by using marix formalism. Runge-Kutta methods are used when tracking through a higher order multipole or through material.

Various physics processes have alternative implementation to allow faster calculations: bremsstrahlung, synchrotron radiation, muon transport.

There are several directions on ongoing development work: development of accelerator description format; fast EM shower calculations; neutron transport; dosimetry calculations. The current source code is available on the CVS repository at http://cvs.pp.rhul.ac.uk

### • References :

[1] G. Blair, Simulation of the CLIC Beam Delivery System Using BDSIM, CLIC note 509

[2] http://mad.home.cern.ch/mad/

[3] <u>http://root.cern.ch</u>

### Simulations of MWPC-based small animal PET scanners

- Author(s) : Holger GOTTSCHLAG, Norbert LANG, Klaus REYGERS, Klaus P. SCHÄFERS, Johannes P. WESSELS
- Institution(s) : Institut für Kernphysik, Westfälische Wilhelms Universität Münster; Department of Nuclear Medicine, University Hospital of Münster
- Corresponding author e-mail : <u>hgottsch@uni-muenster.de</u>

### • Summary

For small animal PET essentially two different types of Positron Emission Tomography (PET) cameras are currently available on the market [1]. These are crystal cameras and multi wire proportional chamber (MWPC) based cameras. While MWPC's are quite rare, crystal cameras are in common use. This is due to high spatial resolution (~1 mm) and good energy resolution. However, substending a large solid angle with crystals is very expensive. For this reason the chambers are often very small, so that scanning bigger animals like rats or rabbits is not feasible. MWPC based cameras basically consist of a gamma-to-electron converter and a wire chamber. MWPC's in principle can be produced in any size without exponential increase of the costs. Submillimeter resolutions are achievable as well, providing a homogenous resolution over a large field of view [2]. The resolution basically depends on the wire grid and readout pad dimensions. For a better quantitative understanding of an existing MWPC based PET camera (the quadHIDAC [3]) for imaging small animals, Geant4 simulations have been performed, and first results of these simulations will be presented. Based on these results a new design for an advanced gamma-to-electron converter with improved electron efficiency was developed. A higher efficiency would increase the image information so that the measuring time will decrease or tracers with lower activities can be used. Ideas of possible ways to provide energy discrimination will be discussed. With appropriate energy information, one can separate the background of Comptonscattered gammas from the directly produced gammas and increase the contrast of the image. Especially images of bigger animals (e.g. rats or rabbits), which means objects with more scatter material inside, would derive special benefit of that.

### References

[1] K.P. Schäfers, Imaging small animals with positron emission tomography, Schattauer GmbH Nuklearmedizin 3/2003; 42:86-89.

[2] K.P. Schäfers et al., Performance evaluation of the 32-module quadHIDAC small animal PET scanner. J Nucl Med. 2005 Jun; 46(6):996-1004.

[3] Jeavons AP, Chandler RA, Deuttmar CAR. A 3D HIDAC-PET Camera with submillimeter resolution for imaging small animals. IEEE Trans Nucl Sci 1999; 3:468-73.

### Bragg peak studies using Geant4 Bertini cascade

- Author(s) : Aatos Heikkinen 1, Andi Hektor 2, Pekka Kaitaniemi 3,
- **Institution(s)** : 1 Helsinki Institute of Physics, 2 National Institute of Chemical Physics and Biophysics, Tallinn, Estonia; 3 University of Helsinki
- Corresponding author e-mail : <u>aatos.heikkinen@cern.ch</u>
- Summary

We present validation of Geant4 Bertini cascade model [1] for Bragg peak generation. The suitability of this intra-nuclear cascade model for hadronic treatment is evaluated. The performance of Geant4 simulation in cluster [2, 3] and NorduGrid



environments are studied.

Fig.1 Bragg peak simulation using Geant4 Bertini cascade model and 200 MeV proton bullets.

### • References :

[1] A. Heikkinen, N. Stepanov, and J. P. Wellisch, Bertini intra-nuclear cascade implementation in Geant4, Proceedings of CHEP03, La Jolla, California 24.-28.3. 2003, http://arxiv.org/pdf/nucl-th/0306008.

[2] A. Heikkinen and T. Linden, Validation of the Geant4 Bertini Cascade model and data analysis using the Parallel ROOT Facility on a Linux cluster, Proceedings of CHEP04.

[3]A. Heikkinen et al., The Performance of a new Geant4 Bertini Intra-Nuclear Cascade Model in a High Throughput Computing (HTC) Cluster Architecture, Proceedings of SNA, Paris 22.-24.9., 2003.

### **Public Resource Computing and Geant4**

- Author(s) :Jukka Klem (HIP), Juan Lopez Perez (CERN), Ignacio Reguero (CERN), Christian Soettrup (CERN), Alberto Ribon (CERN), Philippe Defert (CERN)
- Institution(s) :CERN and Helsinki Institute of Physics (HIP)
- Corresponding author e-mail : <u>Jukka.Klem@cern.ch</u>
- Summary

Projects like SETI@home use computing resources donated by the general public for scientific purposes. Many of these projects are based on the BOINC (Berkeley Open Interface for Network Computing) software framework that makes it easier to set up new public resource computing projects. BOINC is used at CERN for the LHC@home project where about 10000 home users donate time of their CPUs to run the Sixtrack application. The LHC@home project has recently delivered the computing power of more than two Teraflops, which makes it interesting also for other applications that could accept the constraints imposed by the BOINC model that requires simple, relatively small, CPU bound programs that can run on a sandbox. Once these constraints are met, BOINC allows thousands of different instances of the programs to run in parallel. The use of Geant4 in a public resource computing project has been studied at CERN. After contacts with developers we found that BOINC could be useful to run the GEANT4 release testing process that we was found to be a good case study to explore what we could do for more complex HEP simulations. This is a simple test beam set-up to compare physics results produced by different program versions which allows validating new versions. The benefits and limitations of BOINC based projects for running Geant4 are presented.

# Monte Carlo calculation of dose rate conversion factors for in situ gamma spectrometry

• Author(s) : M. Lemercier, R. Gurriaran, P. Bouisset, X. Cagnat

### • Institution(s) :

IRSN (Institut de Radioprotection et Sûreté Nucléaire)

• Corresponding author e-mail : <u>Mickael.lemercier@irsn.fr</u>

### • Summary

The use of in situ gamma spectrometry is increasing nowadays thanks to its fast (immediate) results, good detection limits (comparable with laboratory results), and a good representativity of the average of the activity levels over the field under study. The measurement consists in bringing the Ge spectrometer to the field, then from the measured gamma spectra, the specific activity concentrations are derived. In a second step, the kerma rates per isotope are calculated using conversion factors existing in the literature.

Following the directive 96/29/EURATOM, the area monitoring requires the use of the quantity  $H^*(10)$ . However, the corresponding conversion factors necessary for in situ gamma spectrometry do not exist in the literature. In this work, Monte Carlo simulation has been used to infer the spectra of the photon fluence reaching the detector in the in situ gamma spectrometry technique. The conversion factors for  $H^*(10)$  have then been derived. Preliminary results will be presented.

# Possible issues to optimize stochastic simulation time with parallel sequences and unrolling

- Author(s) : David R.C. Hill and Romain REUILLON
- Institution(s) : Limos
- Corresponding author e-mail : drch@isima.fr and reuillon@isima.fr

### • Summary

Stochastic simulations always require a statistically sound Random Number Generator (RNG). In the case of Geant 4, the CLHEP library of classes provides a set of very interesting pseudo-random number generators (PRNGs). In addition to the quality of a PRNG, the speed of the algorithm and the ease of its implementation are common practical concerns. In this work we first discuss how to optimize the whole computing time of Geant4 simulation relying on parallel independent experiments which suppose a sound distribution of pseudo-random numbers. Second we present how to optimize the access speed to random numbers independently from the generation algorithm.

For parallel and distributed simulations, random numbers should be generated in parallel, i.e. each logical process (LP) should autonomously get its own subsequence of a global random sequence. If such an autonomy is not guaranteed, the parallelism is affected (Hellekaleck 1998), and each LP process must then refer repetitively to a central RNG which creates a bottleneck. Designers of parallel stochastic simulations always have to reply to this fundamental question: how can we make a safe RNG repartition in order to keep efficiency and a sound statistical quality of the simulation. Indeed the validation of such parallel simulation is a critical issue. Paul Coddington precisely states: "Random number generators, particularly for parallel computers, should not be trusted. It is strongly recommended that all simulations be done with two or more different generators, and the result compared to check whether the random number generator is introducing a bias (Coddington, 1996). The basic concept to parallelize an RNG is to take the elements of the sequence generated by the RNG and to distribute them among LPs in some way. Three major partitioning methods can be found in the literature [2-7]: the Leap Frog (LF) technique, the Sequence Splitting (SS) and the Independent Sequences (IS). We examine how they can be implemented and an example using GATE (Geant 4 derived software) will be given (Maigne et al. 2004). Hybridization of the previous technique is currently a research direction.

In addition to the possibility offered by parallel streams of random numbers, we recently showed that massive unrolling optimizations could now be efficiently applied to pseudo-random number generation on regular desktop computers (Hill 2003). This approach does not depend on the generation algorithm but it only stems from the classical unrolling optimization. A memory mapping approach is also introduced to overcome the limits we had with regular unrolling. Both approaches will be presented and are portable on Unix derived platforms. The implementation of such techniques on clusters and on a computing grid is discussed. Every research field using quasi-Monte Carlo simulation can be concerned by this kind of software optimization techniques.

### • References

Coddington P., Random number generators for parallel computers. NHSE Review, 1996 Volume, Second Issue.

Maigne L., Hill D., Breton V., Reuillon R., Calvat P., Lazaro D., Legre Y., Donnarieix D., "Parallelization Of Monte Carlo Simulations And Submission To A Grid Environment", Parallel processing letters, Volume 14, N°2, pp. 177-196.

Hellekalek, P. Don't trust parallel Monte Carlo !. Proceedings of the 12th workshop on Parallel and distributed simulation. Banff Canada. May 26 - 29, 1998, pp. 82-89.

Hill D., "URNG: A portable optimisation technique for every software application requiring pseudorandom numbers", Simulation Modelling Practice and Theory, Vol. 11, pp. 643-654.

# Grid collimator parameters optimization for "high energy" 3D computed tomography using Geant4

• Author(s) : A. Miceli, A. Flisch, R. Thierry, J. Hofmann, F. Casali

### • Institution(s) :

Empa – Materials Science & Technology, Department of Electronics/Metrology, Duebendorf, Switzerland

Università di Bologna, Department of Physics, Bologna, Italy

• Corresponding author e-mail: <u>alice.miceli@empa.ch</u>

### • Summary

The investigation of methods to reduce the scattering radiation produced in a 3D Computed Tomography (CT) system using a commercial 450 kV X-ray tube is an important task, because nowadays only 2D CT scanners are able to produce images with good contrast and Signal-to-Noise Ratio (SNR) in this energy range. In this work we studied the effect of the aperture pixel size and thickness of a 2D focused gold grid collimator on the reduction of scattering radiation. The apertures of the focused grid were aligned with the directions of the unscattered X-ray. The scatter reduction factor of this grid was compared with a parallel grid. Besides, the knowledge of the energy spectrum of the X-ray tube is of primary importance, when one wishes to study the full acquisition chain of a CT system by means of a MC code. Furthermore the knowledge of the X-ray spectrum requires particular instruments and measurements means which are rarely available from the X-ray tube manufacturers or in the literature. Thus the use of a simulated spectrum that fits the real produced spectrum is often a practical way to proceed with accuracy.

Up to now, Monte Carlo simulators (MCS) are the dedicated tools for such types when it comes to study complex photon-material interactions. MCS enable to calculate the outcome of several thousand photon histories, according to a given acquisition geometry and grid aperture. The MC code permits to rapidly and cheaply modify the collimator parameters, the geometry and the material. Moreover it enables to study separately the contribution of unscattered and any orders of scattered radiations. GEANT4 (G4) has been retained for our simulation because this MC code is nowadays widely shared and recognized by the scientific community, for the accuracy of the models implemented and for the range of validity, which goes from 250eV to 100GeV.

### • References:

M R Ay, M Shahriari, S Sarkar, M Adib and H Zaidi 2004 *Monte Carlo simulation of x-ray spectra in diagnostic radiology and mammography using MCNP4C* Phys. Med. Biol. **49** 4897-4917.

J. Apostolakis, S. Giani, M. Maire, P.Nieminen, M.G. Pia, L. Urban *GEANT4 Low Energy electromagnetic models for electrons and photons* INFN/AE-99/18.

# **User Session 5**

# High Energy Physics

### Status of Use and Support of Geant4 at Fermilab

- Author(s) : Julia Yarba
- Institution(s) : Fermilab
- Corresponding author email : <u>varba\_j@fnal.gov</u>
- Summary

The presentation will cover the status of use of the Geant4 simulation toolkit in the Fermilab experimental program.Geant4 is currently being employed as a modelling engine in the Fermilab Neutrino experiments MiniBooNE and MINOS, in the CMS project where Fermilab is largelyrepresented, in the rapidly raising ILC efforts, and in the area of Medical Physics. This talk will also present the efforts that the Fermilab Computing Division is putting towards supporting the growing community of Geant4 users at and around Fermilab.

• References :

http://cepa.fnal.gov/psm/geant4/index\_frame.shtml

### Full Detector Simulation for the International Linear Collider

- Author(s) : Jeremy McCormick
- Institution(s) : SLAC
- Corresponding author e-mail : jeremym@slac.stanford.edu
- Summary

The research program for International Linear Collider (ILC) detectors requires a simulator that can accept a variety of geometries in a common format. The Simulator for the Linear Collider (SLIC) and its geometry package, Linear Collider Detector Description (LCDD), provide a flexible and powerful system for inputting various detector geometries, including prototypes of full detectors and test beams. The Geometry Description Markup Language (GDML), from the LHC Computing Group (LCG), forms the backbone of the LCDD system, providing constants, materials, solids and the volume hierarchy. On top of this, LCDD allows the specification of sensitive detector meta-information. This system allows the specification of geometry at runtime with no additional C++ coding required on the part of the end user. This presentation will describe the architecture of this Geant4-based package. It will also provide an overview of the input XML format. Additionally, some other, outstanding features of the SLIC simulator package and some physics results will be presented.

• References :

http://www.lcsim.org/software/slic

http://www.lcsim.org/software/lcdd

http://www.lcsim.org/software/gdml

### A Geant4 based simulation for Fresnel lenses.

- Author(s) : J. Costa, M. Pimenta, B. Tomé
- Institution(s) : LIP Laboratório de Instrumentação e Física Experimental de Partículas
- Corresponding author e-mail : <u>bernardo@lip.pt</u>

### • Summary

The use of a Geant4 based engineering tool for the optics design and simulation of Fresnel lens systems is presented.

The use of Fresnel lenses has been discussed in the last few years within the framework of cosmic rays experiments based on the detection of Cerenkov and fluorescence photons. In most Cerenkov telescopes the collection of light is made with large mirrors. However the field of view of mirrors is small as the imaging quality decreases drastically for off-axis angles and large detection areas placed at the focal plane significantly reduce the effective aperture of the telescope due to obscuration. To cover a large area of the sky a possible alternative solution is to use refractive optics. However there are a number of problems to cope with for normal lenses namely the significant amount of light absorption due to the lens thickness, the lens weight, and even the placement of the lens at the detector. Due to their small thickness, Fresnel lenses provide a confortable alternative for these apparatus, which, profitting from their lightness, turns the construction and use much easier.

The design and optimization of the optical system of such detectors is usualy performed with commercial programs to optimize the lens profile in order to minimize the optical aberrations. However, these tools are usually not included in the Monte Carlo simulation programs of the experiments, where simplified models or lookup tables are alternatively used. As will be shown, the Geant4 toolkit can be used to perform realistic simulations and optimizations of a Fresnel lens system. In the framework of Geant4 it is then possible to develop a realistic end-to-end simulation of a physics experiment using a Fresnel lens.

In the present Geant4 simulation the Fresnel lens geometry is described by using a parameterized replication of G4Cons volumes. Each lens groove is described as a frustum of a cone, with cross section represented by a straight line with the slope computed from the lens sagita equation. A Lens object is instantiated by defining the following parameters: minimum and maximum lens radius, starting azimuthal angle, azimuthal angle span, number of grooves, lens material, lens mother volume, lens position and lens thickness. It can thus represent either a monolithic lens or a lens petal.

As a working example a 1.7m plano-convex Fresnel lens was simulated. The implemented Fresnel lens is made up of a central monolythical lens with layers of lens petals.

### H4SIM, a GEANT4 simulation program for the CMS ECAL supermodule

- Author(s) : Philippe Miné, on behalf of the CMS collaboration
- Institution(s) : Laboratoire Leprince-Ringuet, IN2P3-CNRS, Ecole Polytechnique
- Corresponding author e-mail : <u>pmine@poly.in2p3.fr</u>

### • Summary

The electromagnetic calorimeter (ECAL) of the CMS experiment at the CERN LHC is made of 82728 lead tungstate (PbWO4) crystals. It consists of a barrel subdivided into 36 supermodules and two end-caps. Lead tungstate exhibits the highest density (8.28 g/cm3) and the shortest radiation length (0.89 cm) of all scintillators used in high-energy physics. It is thus adequate to build a compact detector which can measure electron and photon energies higher than one TeV. It is a fast scintillator, which is mandatory for the challenging requirement of the LHC high intensity operation, where 20 interactions are expected every 25 ns. It can survive the high radiation environment.

A supermodule was tested at CERN in the H4 area, with electrons, muons and pions ranging from 20 to 250 GeV. The H4SIM program is a stand-alone simulation based on GEANT4, especially designed to reproduce the conditions of this beam. In this program, the geometrical and physical characteristics of the ECAL supermodule are described by the engineering data used in the detector description database (DDD) of CMS, written in XML. The DDD is identical to the one used in the general CMS simulation program OSCAR, which includes all the other subdetectors, like the central charged particle tracker and the hadronic calorimeter.

An interactive version of H4SIM displays a first window from which standard GEANT4 commands can be sent, together with additional ones specific to the ECAL barrel. A second window displays views of the generated events. A batch version uses the same commands as data cards to generate an output file in ROOT format. An interface program takes into account the pedestal and the electronic noise of the scintillation light read by APS's. It converts the energy deposited in each crystal into ADC counts in the same format as the physical data recorded from the test beam.

We present the results for the energy resolution, the position determination and the effect of the cracks between modules, both for H4SIM and for beam data. The dependance on the choice of the GEANT4 cuts was investigated. We find a good agreement between physical data and simulation. We discuss the possibility to use cosmic rays for calibration and the relevant modification expected for H4SIM.

### References :

- [1] The Electromagnetic Calorimeter Project, Technical Design Report, CERN/LHCC 97-33
- [2] <u>http://cmsdoc.cern.ch/documents/04/in/in04\_001</u>
- [3] http://cmsdoc.cern.ch/~h4sim

### Geant4 for Education in HEP and Radiation Therapy - A Toolkit Approach -

• Author(s) :

M. Maire: LAPP Annecy K. Amako, G. Iwai\*, S. Kameoka\*, K. Murakami, T. Sasaki: KEK (\* JST) T. Hasegawa, K. Maruyama: Kitasato University D. Wright: SLAC Y. Kawanishi, **H. Yoshida**: Naruto University of Education

• Corresponding author e-mail : <u>yoshidah@naruto-u.ac.jp</u>

### • Summary

We report on the workshop "Geant4 for Education" which was held in September in Naruto under the sponsorship of KEK. It was a kick-off for a collaboration among the teachers and the Geant4 developers. The participants of the author list have different teaching or research backgrounds in High Energy Physics and radiation therapy. We focused on education in both fields. We defined three categories of "users"; students, teachers, and Geant4 programmers. We opted not to provide course materials for students but to provide toolkits for teachers to use Geant4 to create course materials. Our works concentrated on selecting and defining "generic" detector geometries in HEP and several concrete "standard" detectors in radiation therapy. Use of Python interface to improve the interactivity and easy construction of geometries was demonstrated and its improvement was discussed. A common physics lists for both fields were created with interactive capabilities of switching on/off each process. A prototype of Geant4 server over the network was introduced as an example of use cases in the classroom. We will report on the further development of the toolkits.

# **User Session 6**

# Dosimetry and Computing

### Geant4 Simulations for Betadosimetry and Activity Measurements in Brachytherapy

- Author(s) : Mario Schubert, Simon Ellgas, Walter Assmann
- Institution(s) : Maier-Leibnitz-Laboratorium der LMU und TU München
- Corresponding author e-mail : <u>mario.schubert@physik.uni-muenchen.de</u>
- Summary

### The RadBioMat project

The RadBioMat project aims at developing radioactive brachytherapy (short range radiotherapy) implants. These modulate the wound healing to inhibit undesired scarring after surgery. The radiation used is <sup>32</sup>P (T<sup>1</sup>/<sub>2</sub>=14.3 d, 696 keV mean Energy, no gamma).

Within the project a radioactive ion implanter was designed and built to produce the implants. Furthermore a dosimetry system has been set up, and biocompatible and even biodegradable materials have been tested for irradiation damage.

For animal tests two typical cases have been selected: Glaucoma filtering and paranasal sinus surgery.

The project partners are physicians for ophthalmology and otorhinolaryngology, the central institute for medical technology, the department for nuclear physics, and three industrial companies.

To provide accurate and geometrically correct doses in brachytherapy while minimizing the dose for the surrounding tissue, good knowledge of the dose distribution and the activity of the radioactive implant is essential.

### Beta dosimetry

Dose measurements in water phantoms using the OPTIDOS scintillation dosimeter have been compared with dose distributions calculated with Geant4 using the Low Energy extension.

Several validations between measurements and simulations have been performed. The real activity was determined by liquid scintillation counting or using NIST/PTB traceable sources (<sup>32</sup>P, <sup>90</sup>Sr). For the simulation of real treatments a DICOM CT data interface with full segmentation has been integrated in the Geant4 application.

### Production control / quality control – activity measurement

For the production and the quality control afterwards an activity measurement system has been established. This system is using a silicon detector in a fixed reproducible geometry for electron counting. Simple spectroscopy is used to provide repeatable results. The data processing is done by the ROOT toolkit.

So far a calibration has to be done for each geometry and material using liquid scintillation counting after dissolving the implant in acid or organic solvent. To avoid the time consuming procedure for each new material and geometry a Geant4 simulation was used to calculate the calibration factors. This enables to calibrate even non-soluble materials.

Geant4 has shown to be of great help in developing new therapeutic techniques. It can improve the accuracy of betadosimetry as well as fasten the quality control of radioactive implants.

### Fundamental Physics and Basic Research in Brachytherapy with Geant4

- Author(s) : Paul Guèye
- Institution(s) : Hampton University
- Corresponding author e-mail : <u>gueye@jlab.org</u>

### • Summary

For the past two years, the Brachytherapy Research Group of the Center for Advanced Medical Instrumentation at Hampton University (Virginia, USA) has made several breakthroughs for ex-vivo and in-vivo characterization and optimization of beta dose Brachytherapy. One research focuses on the development of scintillating based detectors to determine absolute 3D dose distribution measurements with accuracy better than ±100 [m [1]. These detectors have also the capability of extracting information on the uniformity or non-uniformity of Brachytherapy sources. Another research aims at measuring 2D and 3D in-vivo dose maps to provide real time feedback to physicians for (possible) adjustment of patient treatment planning [2]. We have also recently entered novel fundamental studies on the energy dependence of cancer cells to address, among others, mono-energetic Brachytherapy source treatment, reaction mechanisms associated with cancer cell destruction, and cancer genome identification [4, 5]. Each of the research conducted at CAMI is strongly coupled to dedicated Geant4 Monte Carlo simulations. The toolkit is primarily used to optimize the detector development. At the fundamental level, a combined Geant4 and molecular biology code is being developed to provide understanding of energy deposition and associated physics processes at the molecular level [6]. Recent publication works indicate possible problems in the tracking and/or physics within the electron algorithms of Geant4 [6]. A research program focusing on the measurements of absolute cross sections in the energy regime of interest is underway to obtain key information on the corresponding physical processes [7]. We will review results obtained from this research and address the impacts for the Geant4 community.

### • References :

- [1] P. Guèye et al., A scintillating fiber based detector for beta Brachytherapy treatments, submitted to NIM (2005)
- [2] P. Guèye et al., In-situ 3D dose distribution measurements for Brachytherapy treatments: a feasibility study, submitted to NIM (2005)
- [3] P. Guèye et al., Real time dose distribution measurement for breast Brachytherapy treatments, submitted to NIM (2005)
- [4] P. Guèye *et al.*, *Energy distribution mapping of beta Brachytherapy sources*, submitted to NIM (2005)
- [5] P. Guèye et al., Preliminary study of the energy dependence of breast cancer cell irradiation, submitted to NIM (2005)
- [6] E. Poone et al., Accuracy of the photon and electron physics in Geant4 for radiotherapy applications, Med. Phys. Jour. **32(6)**, 1696 (2005)
- [7] http://www.jlab.org/~gueye/CAMI/cami\_web and www.jlab.org/glab

### **GATE for brachytherapy applications**

### • Authors: Cheick THIAM <sup>(1)</sup> and Lydia MAIGNE <sup>(1)</sup> Vincent BRETON <sup>(1)</sup>, Denise DONNARIEIX <sup>(2)</sup>

### Institutions:

<sup>(1)</sup> Laboratoire de Physique Corpusculaire, 24 avenue des Landais, 63177 Aubière cedex

<sup>(2)</sup> Unité de Physique Médicale, Département de Radiothérapie - Curiethérapie, Centre Jean Perrin BP 392 63011 Clermont-Ferrand cedex

### • Corresponding author e-mail : <u>thiam@clermont.in2p3.fr</u>

### • Summary

GATE is a simulation toolkit for PET and SPECT applications based on the GEANT4 code. Specific modules are added on top of GEANT4, for PET and SPECT requirements and facilitate the usage of the code. Our study shows that Gate can also be applied to model brachytherapy-radiotherapy applications. In this approach GATE platform is used to calculate the relevant dosimetric quantities for treatment planning in brachytherapy-radiotherapy.

We are trying to validate the GATE code (low energy range for photons and ectrons) by simulating <sup>106</sup>Ru/<sup>106</sup>Rh source and all dosimetric quantities recommended by the AAPM Task Group 43 (TG-43) for three designs of <sup>125</sup>I seeds (Symmetra Model I25.S06, Best Model 2301 and model 6711).We study also the analysis methods for dose calculations adapted for the dosimetric applications.The analysis method will be implemented in GATE simulation platform. Thus to calculate air kerma strength, we used the track length estimator method. we modified GATE toolkit to recover information concerning the track energy.

All the sources characteristics have been simulated respecting welded ends, radioactive distribution in the source, materials and rays energy spectra. Autoabsorption of the sources as titanium characteristic X-ray production has been taken into account. Our Monte Carlo results were compared against consensus values reported in the AAPM TG-43 dosimetry protocol stemming from Monte Carlo simulations and measurements and other Monte Carlo codes.

Concerning <sup>106</sup>Ru/<sup>106</sup>Rh, we simulated CCB, CCA, CCX and CCZ applicators models manufactured by BEBIG. The results are compared with those calculated by the Hokkanen method empirical and obtained with MATHEMATICA software; they are also compared with those resulting from the Plaque Simulator (analytical toolkit) and with the experimental measurements obtained with scintillator plastic exit of the BEBIG certificate calibration. Results are satisfging.

The total Monte Carlo uncertainty affecting our results is composed of evaluated statistical and cross sections uncertainties.

We calculated in liquid water the dose rate function and anisotropy function for the three sources  $(^{125}I)$  previously quoted. The calculated dose-rate constants for the three sources were found to be quite different from the recommended values of the

TG-43 report, especially for the model 6711 and the Symmetra model. Radial dose functions and anisotropy functions are in very good agreement with recommended TG-43 values in particular for the Best Model 2301. An ocular brachytherapy treatment using thirteen <sup>125</sup>I model 6711 seeds has been simulated and compared to analytic treatment planning.

The use of GATE (Geant4) to model and calculate dosimetric quantities particularly for low-energy brachytherapy sources has been shown.

Key words: iodine-125, rhodium-106, brachytherapy, ophthalmic applicator, GATE

### • References

<sup>1</sup>"Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43" Med. Phys. 22 (2), February 1995, R. Nath, L.L. Anderson, G. Luxton, K.A. Weaver, J.F. Williamson, A.S. Meigooni.

<sup>2</sup>"GATE: a simulation toolkit for PET and SPECT" Phys. Med. Biol., 49 (2004) 4543-4561, Jan S., Santin G., Strul D., Staelens S. and al.

<sup>3</sup>OpenGATE collaboration: <u>http://www-iphe.unil.ch/~PET/research/gate/</u>

<sup>4</sup>PCSV team (Clermont Ferrand):<u>http://clrpcsv.in2p3.fr/</u>

### GATE simulations in a grid environment

### • Authors: Cheick THIAM <sup>(1)</sup> Vincent BRETON <sup>(1)</sup>, Denise DONNARIEIX <sup>(2)</sup>, Lydia MAIGNE <sup>(1)</sup>

### • Institutions:

<sup>(1)</sup> Laboratoire de Physique Corpusculaire, 24 avenue des Landais, 63177 Aubière cedex

<sup>(2)</sup> Unité de Physique Médicale, Département de Radiothérapie - Curiethérapie, Centre Jean Perrin BP 392 63011 Clermont-Ferrand cedex

### • Corresponding author e-mail : <u>thiam@clermont.in2p3.fr</u>

### • Summary

The Monte Carlo platform GATE (Geant4 Application for Tomographic Emission) is now used for dosimetry applications such like radiotherapy and brachytherapy. The aim of the developments actually performed is to enable an application of the GATE platform in clinical routine. However, this perpective is only possible if the coputation time of the simulations is highly reduced. The new grid architectures, developed within the framework of EGEE European project, is there to answer this feauture.

James pseudorandom number generator (RNG) is used in GATE simulations. Our work has consisted into parallelize the simulations on multiple processors part of the grid by partitioning a sequence of random numbers generated by the RNG into suitable independent subsequences. At this date, we produced a thousand of random status files of some KBs corresponding to each independent subsequences of the RNG.

In order to facilitate the access to the grid for novice users or praticians, we developed all the functionalities to create, split, launch and monitor GATE simulations on the EGEE infrastructure on the web portal (GENIUS). The transparent and secure access to the grid is provided by the portal accessible from the following URL <a href="https://clrglop208.in2p3.fr">https://clrglop208.in2p3.fr</a>. To launch simulations an authentification and an authorization are required. A demonstration concerning the usage of the portal will be shown.

To highlight the speed-up obtain by launching simulations on the grid, we present some computing time tests. The results obtained show a gain factor which can go up to 20 that make us envisage a future usage of GATE simulations for treatment planning in clinical routine.

Key words: GATE, computing grids, web portal.

### References

<sup>1</sup>GATE: "a simulation toolkit for PET and SPECT" Jan S., Santin G., Strul D., Staelens S. and al, *Phys. Med. Biol.*, 49 (2004) 4543-4561.

<sup>2</sup>OpenGATE collaboration : <u>http://www-iphe.unil.ch/~PET/research/gate/</u>

<sup>3</sup>Parallelization of Monte Carlo Simulations and Submission to a Grid Environment L.Maigne, D. Hill, P. Calvat, V. Breton, R. Reuillon, D.Lazaro, Y. Legré, D. Donnarieix,., Parallel Processing Letters journal, Vol. 14, No. 2 (June 2004), p 177-196.

<sup>4</sup>GENIUS: "a simple and easy way to access computational and data grids"

A. Adronico, R. Barbera, A. Falzone, P. Kunszt, G. Lo Re, A. Pulvirenti, A. Rodolico, Future Generation Computer Systems, volume 19, Issue 6, pages 805-813, 2003.

<sup>5</sup>GENIUS web portal:<u>https://genius.ct.infn.it</u>

<sup>6</sup>PCSV team (Clermont Ferrand) : <u>http://clrpcsv.in2p3.fr</u>

<sup>7</sup>EGEE Project: <u>http://public.eu-egee.org/</u>

### Importance Sampling in Gate

- Author(s) : J. De Beenhouwer, S. Staelens, Y. D'Asseler, I. Lemahieu
- Institution(s) : Ghent University
- Corresponding author e-mail : jan.debeenhouwer@ugent.be

### • Summary

Monte Carlo simulations are computationally very expensive and Gate simulations are no exception. Geometrical importance sampling is next to analytical approaches and more efficient tracking of particles through voxelized phantoms, a way to increase the efficiency of simulations. It is a variance reduction technique based on the crude criterion that only photons with a high detection chance should be tracked. Photons are increasingly split into exact copies with lowered weights as the distance to a detector decreases. Photon paths leading away from a detector are less likely to result in detection and therefore these photons are subjected to Russian roulette in order to increase the simulation efficiency. However, the technique introduces branches into the particle history. This results in a much more complicated pulse calculation when used for single photon emission computed tomography (SPECT) simulations. Its maximum efficiency is inversely related to the sensitivity of the detector and despite the detangling and increased tracking overhead, it can result in a 5 to 15-fold increase over analog simulations. Figure 1 shows the energy spectrum of a Ga67 point source in a water phantom both with and without importance sampling. Table 1 shows the simulation details.

$$QF = \left(\sum weight\right)^2 / (N * \sum weight^2)$$
 (1)

The quality factor (QF) in equation 1 indicates the variation in the weights of detections. The efficiency of each simulation is calculated as the QF times the number of detections per second. Division of the efficiencies gives an indication of the relative efficiency, being 5.1 in this case.

Aca time	30 s	30 s
Detections	5 165 891	325 920
	0.02	1
	0.92	1
Sim. time	5,600,000 S	1,954,000 s
Activity	100MBq	100MBq

### Table 1


Figure 2 shows excellent agreement in spatial resolution for low (Tc99m) and medium (Ga67) energy setups with point sources placed at 3.65 cm, 13.65 cm, 24.65 cm and 38.65 cm from the collimator, both with and with out importance sampling. Ongoing research will concentrate on the combination of importance sampling with forced detection in order to increase the efficiency further.



#### References :

Haynor D.R., Pollard K.R., Harrison R.L., Lewellen T.K., *Applications Of Importance Sampling To Simulations Of Emission Tomography*, IEEE Nuclear Science Symposium, 22-27 Oct. 1990 Pages:1579-1583

### Geant4 2005

# Possible issues to optimize stochastic simulation time with parallel sequences and unrolling

• Author(s) : David R.C. Hill, Romain REUILLON and LIMOS

#### • Institution(s) :

UMR CNRS 6158 Blaise Pascal University ISIMA, Campus des Cézeaux BP 10125 63177 Aubière Cedex FRANCE

#### • Corresponding author e-mail : <u>drch@isima.fr</u>

#### • Summary

Stochastic simulations always require a statistically sound Random Number Generator (RNG). In the case of Geant 4, the CLHEP library of classes provides a set of very interesting pseudo-random number generators (PRNGs). In addition to the quality of a PRNG, the speed of the algorithm and the ease of its implementation are common practical concerns. In this work we first discuss how to optimize the whole computing time of Geant4 simulation relying on parallel independent experiments which suppose a sound distribution of pseudo-randdom numbers. Second we present how to optimize the access speed to random numbers independently from the generation algorithm.

For parallell and distributed simulations, random numbers should be generated in parallel, i.e. each logical process (LP) should autonomously get its own subsequence of a global random sequence. If such an autonomy is not guaranteed, the parallelism is affected (Hellekaleck 1998), and each LP process must then refer repetitively to a central RNG which creates a bottleneck. Designers of parallel stochastic simulations always have to reply to this fundamental question: how can we make a safe RNG repartition in order to keep efficiency and a sound statistical quality of the simulation. Indeed the validation of such parallel simulation is a critical issue. Paul Coddington precisely states: "Random number generators, particularly for parallel computers, should not be trusted. It is strongly recommended that all simulations be done with two or more different generators, and the result compared to check whether the random number generator is introducing a bias" (Coddington, 1997). The basic concept to parallelize an RNG is to take the elements of the sequence generated by the RNG and to distribute them among LPs in some way. Three major partitioning methods can be found in the literature [2-7]: the Leap Frog (LF) technique, the Sequence Splitting (SS) and the Independent Sequences (IS). We examine how they can be implemented and an exemple using GATE (Geant 4 derived software) is given (Maigne et al. 2004). Hybridization of the techniques previously listed is currently a research direction.

In addition to the possibility offered by parallel streams of random numbers, we recently showed that massive unrolling optimizations could now be efficiently applied to pseudo-random number generation on regular desktop computers (Hill 2003). This approach does not depend on the generation algorithm but it only stems from the

## Geant4 2005

classical unrolling optimization. A memory mapping approach is also introduced to overcome the limits we had with regular unrolling. Both approaches will be presented and are portable on Unix derived platforms. The implementation of such techniques on clusters and on a computing grid is discussed. Every research field using quasi-Monte Carlo simulation can be concerned by this kind of software optimization techniques.

#### References

Coddington P., Random number generators for parallel computers, 28 April 1997. http://www.npac.syr.edu/users/paulc/papers/NHSEreview1.1/PRNGreview.ps .

Maigne L., Hill D., Breton V., Reuillon R., Calvat P., Lazaro D., Legre Y., Donnarieix D., "Parallelization Of Monte Carlo Simulations And Submission To A Grid Environment", Parallel processing letters, Volume 14, N°2, pp. 177-196.

Hellekalek, P. Don't trust parallel Monte Carlo !. Proceedings of the 12th workshop on Parallel and distributed simulation. Banff Canada. May 26 - 29, 1998, pp. 82-89.

Hill D., "URNG: A portable optimisation technique for every software application requiring pseudorandom numbers", Simulation Modelling Practice and Theory, Vol. 11, pp. 643-654.

# Geont4 2005

CNRS / IN2P3 - Université Bordeaux 1

Chemin du Solarium = Le Haut-Vigneau = B.P. 120 = 33175 GRADIGNAN
Tél. 05 57 12 08 04 = Fax : 05 57 12 08 01 = http://www.cenbg.in2p3.fr





IN2P3