Geant4 Advanced Examples

S. Guatelli and F. Romano

Geant4 Collaboration Meeting 2018, Lund, Sweden

Current status

Members (census 2018)

Susanna Guatelli (University of Wollongong, Australia) WG Coordinator

Francesco Romano (NPL, Teddington, UK) WG Deputy Coordinator

Barbara Caccia (ISS, Rome, Italy)
Pablo Cirrone (INFN-LNS, Catania, Italy)
Gabriele Cosmo (CERN, Switzerland)
Giacomo Cuttone (INFN/LNS, Catania, Italy)
Sebastien Incerti (CNRS/IN2P3/CENBG, France)
Francesco Longo (INFN-Ts, Trieste, Italy)
Luciano Pandola (INFN-LNS, Catania, Italy)
Ivan Petrovic (Vinca Institute, Belgrad, Serbia)
Maria Grazia Pia (INFN-Ge, Genova, Italy)
Alexandra Ristic-Fira (Vinca Institute, Belgrad, Serbia)
Giorgio Russo (CNR-Lato, Cefalù, Italy)
Bernardo Tomè (LIP, Portugal)

Examples and responsibilities (I)

Example	Responsible	Description
air_shower	B.Tomè	Detection system for cosmic ray shower simulation
amsEcal	M.Maire	Simulation of an Electromagnetic calorimeter
brachytherapy	S.Guatelli	Dosimetry for endocavitary, interstitial and superficial brachytherapy
composite_calorimeter	A. Ribon	A composite electromagnetic and hadronic calorimeter
ChargeExchangeMC	A. Radkov	Simulation of charge exchange real experiment performed at the Petesburg Nuclear Physics Institute (PNPI, Russia)
eRosita	M.G.Pia, et el.	PIXE simulation with Geant4
gammaknife	F. Romano	A device for Stereotactic Radiosurgery with Co60 sources for treatment of cerebral diseases
gammaray_telescope	F.Longo	A simplified typical gamma-ray telescope (such as GLAST), with advanced description of the detector response
hadrontherapy	G.A.P.Cirrone	Simulation of a transport beam line for proton and ion therapy
human_phantom	S. Guatelli	Internal dosimetry

Examples and responsibles (II)

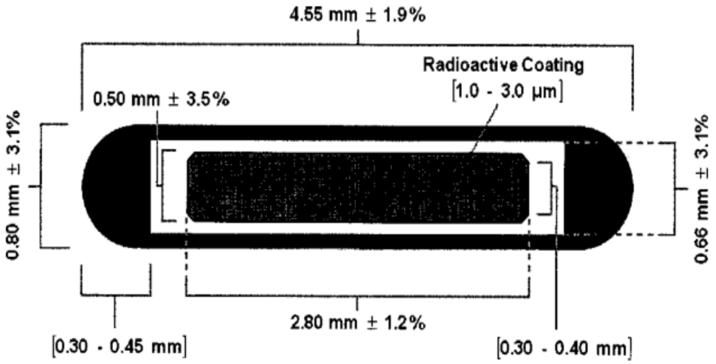
Example	Responsible	Description
Iort_therapy	G.Russo	Simulation of a IORT device
lAr_Calorimeter	A.Dotti	Simulation of the Forward Liquid Argon Calorimeter of the ATLAS Detector at LHC
medical_linac	B. Caccia et al.	A typical LINAC accelerator for IMRT,
microbeam	S.Incerti	Simulation of a cellular irradiation microbeam line using a high resolution cellular phantom
microelectronics	M. Raine	Simulation of tracks of few MeV protons in silicon
nanobeam	S.Incerti	Simulation of a nanobeam line facility
purging_magnet	J.Apostolakis	Electrons travelling through the magnetic field of a strong purging magnet in a radiotherapy treatment head
radioprotection	S.Guatelli, J. Davis	Microdosimetry with diamonds and silicum detectors for radioprotection in space missions
underground_physics	A.Howard	A simplified typical dark matter detector (such as the Boulby Mine experiment)
xray_fluerescence	A. Mantero	Elemental composition of material samples through X-ray fluorescence spectra
xray_telescope	G.Santin	A simplified typical X-ray telescope (such as XMM-Newton or Chandra)

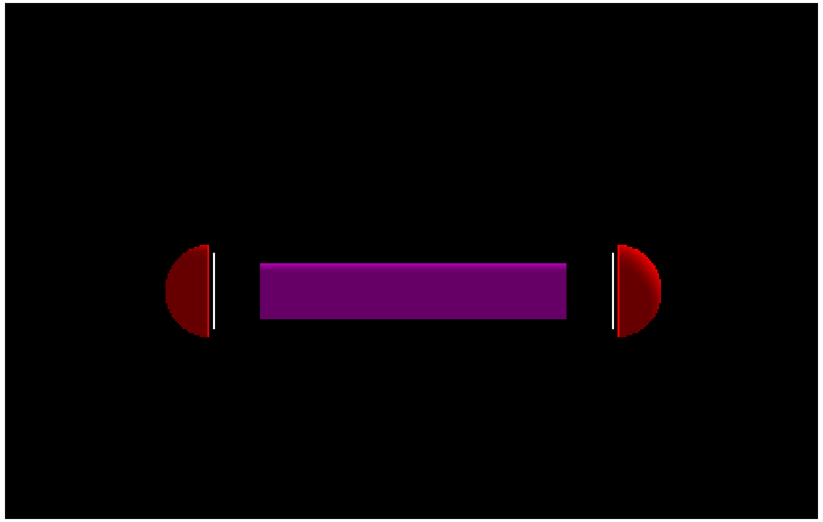
Recent developments since last public release

- **Migration to MultiFunctionalDetector/scoring mesh– remove RO Geometry**
  - IORT_therapy
  - Medical_linac
  - Migration by S. Guatelli together with
    - G. Russo, P. Pisciotta (IORT therapy)
    - B. Caccia, S. Pozzi (Medical linac)
  - This should be released in the next public release
  - Next stage: MT
- **GammaRayTelescope**
  - https://bugzilla-geant4.kek.jp/show_bug.cgi?id=1981: solved
  - Authors: L. Pandola and F. Longo
- **Hadrontherapy**
  - See the talk by G. Petringa

Brachytherapy: Addition of 6711 I-125 Source

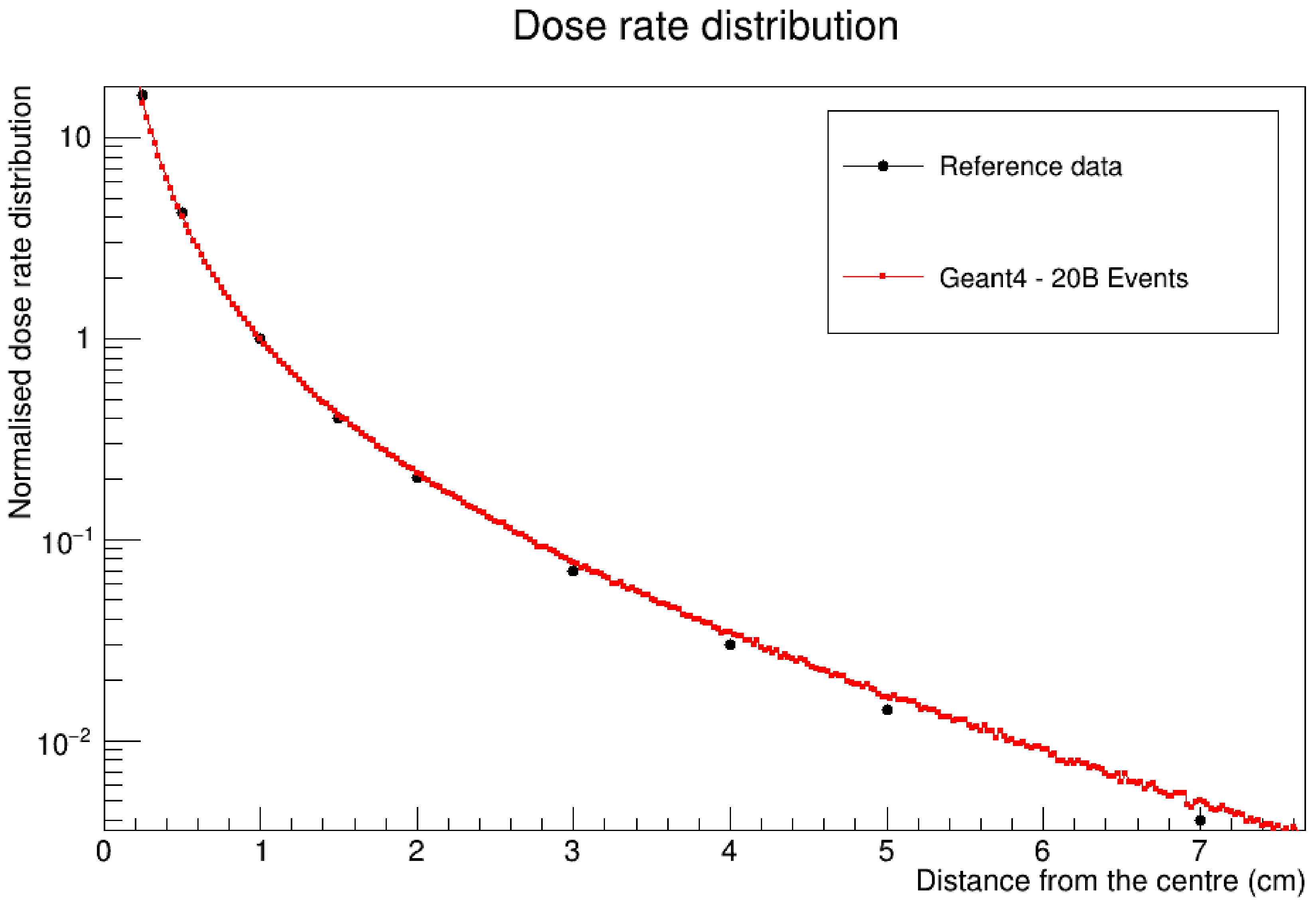
- Authors: A. Lee (PhD), D. Cutajar and S. Guatelli, CMRP, UOW, Australia
- Addition of Oncura 6711 I-125 source model used for low dose rate brachytherapy
- Implementation of source geometry into the example
- Particle generation through use of radioactive decay module





Dolan, J., Li, Z., & Williamson, J. F. (2006). Monte Carlo and experimental dosimetry of an I125 brachytherapy seed. Medical Physics, 33(12), 4675–4684

Comparison to reference data (TG43)



Update of TG43 Dose Parameters Macro

$$\dot{D}(r,\theta) = S_K \cdot \Lambda \cdot \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} \cdot g_L(r) \cdot F(r,\theta)$$

- Allows for the generation of radial dose function data, $g_L(r)$, and anisotropy function, $F(r,\theta)$, from simulation root files
- Will allow users to implement their own source models into the brachytherapy example and determine the parameters from the macro

New proposed example

- Nuclear medicine/PET
- Authors:
  - M. Safavi & A. Ahmed, Australian Nuclear Science Technology and Organisation
  - A. Chacon and S. Guatelli, University of Wollongong
- Maintenance in Geant4: S. Guatelli
- T. Yamaya, H. Tashima, E. Yoshida, G. Akamatsu, A. Mohammadi, NIRS, supported the study by providing the technical details of the PET scanner

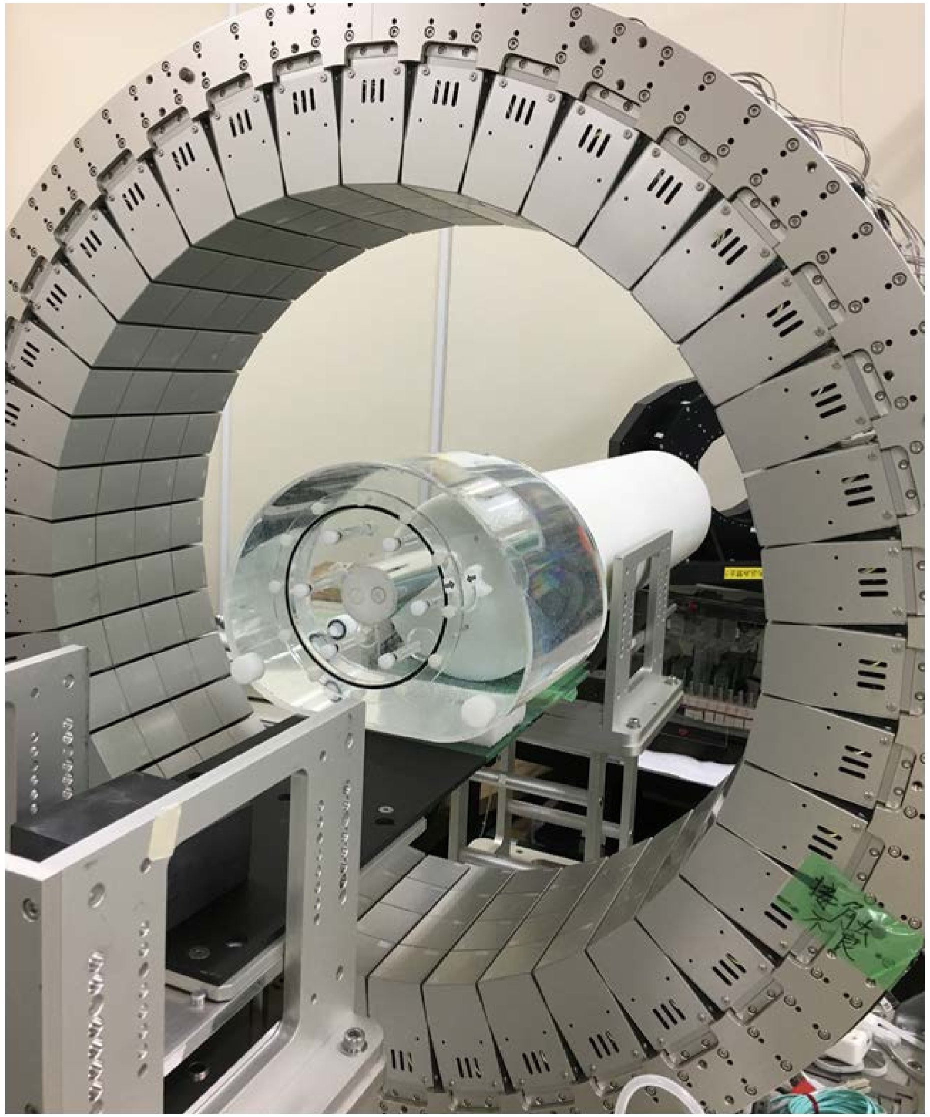


Fig. DOI-enabled whole-body PET scanner (image from Taiga-lab, NIRS, Japan)

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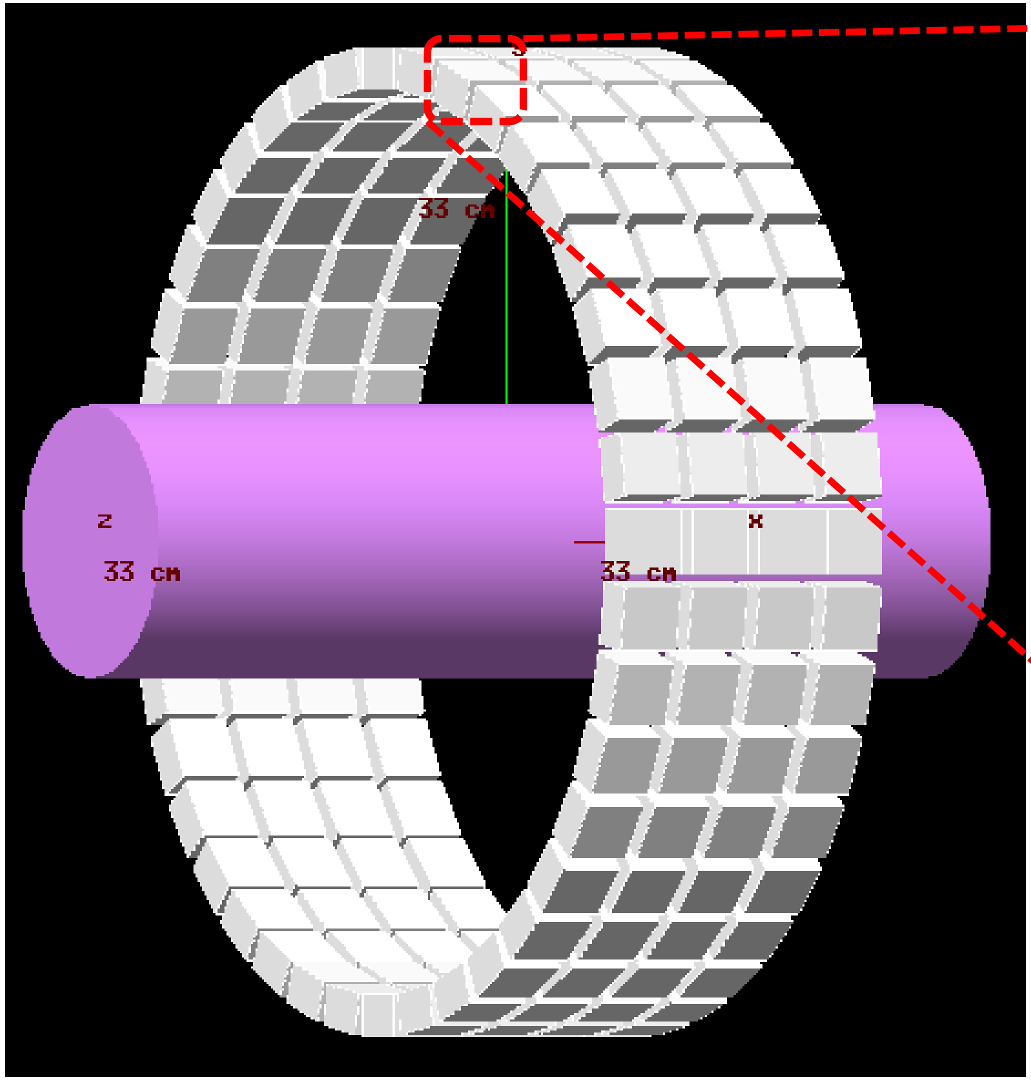
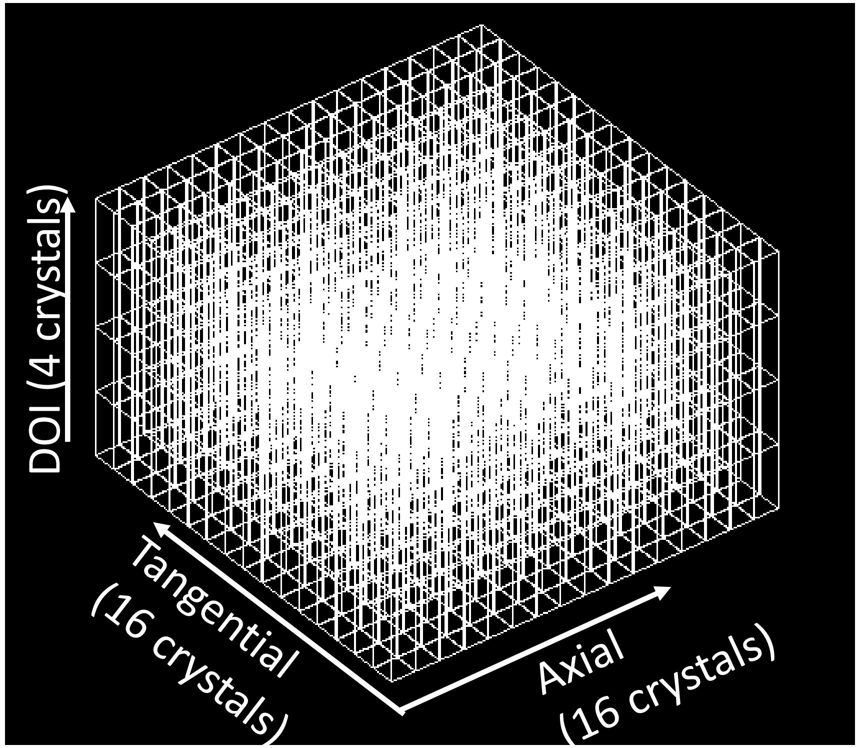
CENTRE FOR MEDICAL RADIATION PHYSICS

Simulated geometry of the DOI-enabled whole body PET scanner



Each detector has 16x16x4 (1024) crystals



Types of NEMA NU phantoms included in the simulation

1. Spatial resolution: phantom for point source
2. Sensitivity: line source phantom
3. Image quality phantom for whole-body imaging (Fig. 1)
4. Image quality phantom for pre-clinical imaging (Fig. 2)
5. Cylindrical phantom for count rate measurement
6. Normalization phantom (not mentioned in the NEMA NU protocol)

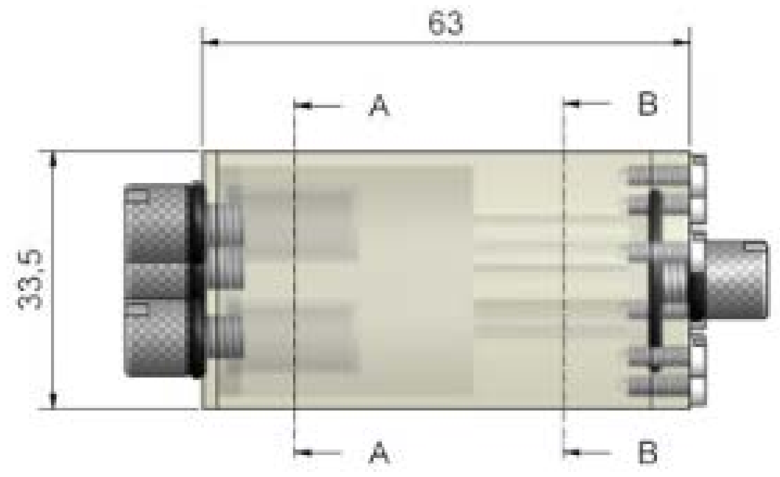


Fig. 1. Image quality phantom for small animal

Fig. 2. Image quality phantom for whole body imaging

Output of the simulation

List-mode data are obtained from the simulation either in singles or coincidence.

(a) Singles event (that can be further processed into coincidence events)

Example of event information in the list-mode data:

eventID blockID axialCrystalID tangentialCrystalID DOICrystalID timerTag EnergyDeposition

(b) Coincidence event

Example of event information in the list-mode data:

eventID1 blockID1 axialCrystalID1 tangentialCrystalID1 DOICrystalID1 timerTag1 EnergyDeposition1

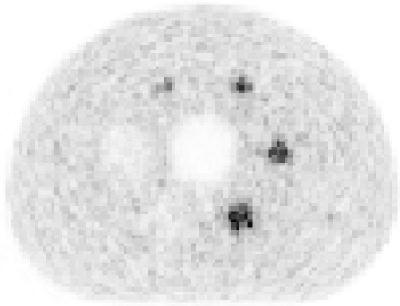
eventID1 blockID2 axialCrystalID2 tangentialCrystalID2 DOICrystalID2 timerTag2 EnergyDeposition2

Annihilation photon 1

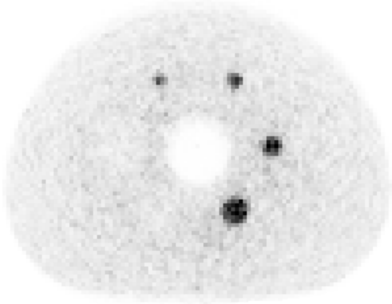
Annihilation photon 2

Conditions of the acquisition and image reconstruction	
Type of acquisition	Single based
Coincidence time window	20 ns
Energy window	400 – 600 keV
Reconstruction algorithm	List-mode OSEM
Voxel number and size	125x125x150, 3.0 x3.0 x3.0 mm^3

(a) Experimental



(b) Simulation



Oral presentation

Status of GEANT4 Advanced Examples for medical applications

B. Caccia[1], G.A. P. Cirrone[2,7], D. Cutajar[3], J. Davis[3], S. Guatelli[3], S. Incerti[4,5], I. Kiryakou[6], L. Pandola[2], G. Petringa[2,8], J. Pipek[2], P. Pisciotta[2,8,9],S. Pozzi[2], F. Romano[10,2], G. Russo[8,9]

[1]National Center for Radiation Protection and Computational Physics, Ist. Sup. di Sanità, Rome, Italy.
[2]National Institute for Nuclear Physics, Laboratori Nazionali del Sud, INFN-LNS, Catania, Italy.
[3]Centre of Medical Radiation Physics, University of Wollongong, Wollongong, NSW, Australia.
[4]Univ. Bordeaux, CENBG, UMR 5797, F-33170, Gradignan, France.
[5]CNRS, IN2P3, CENBG, UMR 5797, F-33170, Gradignan, France.
[6]Ioannina University, Ioannina, Greece
[7]Institute of Physics ASCR, v.v.i. (FZU), ELI-Beamlines Project, Prague, Czech Republic.
[8]University of Catania, Department of Astronomy and Physics, Catania, Italy.
[9]Institute of Molecular Bioimaging and Physiology, IBFM CNR, Cefalù (PA), Italy.
[10]National Physical Laboratory, Hampton Rd, Teddington, Middlesex, UK

Geant4 is a Monte Carlo code widely used in medical physics applications, spanning from radiotherapy and imaging to radiation protection. To support users, the *Geant4 Advanced Examples* include applications of the toolkit in a set of realistic application scenarios: *brachytherapy*, *gammaknife*, *hadrontherapy*, *human_phantom*, *iort_therapy*, *medical_linac*, *microbeam*, *nanobeam*, *purging_magnet*, *radioprotection*. In this work, recent developments of some *Geant4 Advanced Examples* for medical physics applications are presented.

The *brachytherapy* example provides the modelling of radioactive sources used in interstitial, endocavitary and superficial brachytherapy. The example has been recently improved by including two new ^{192}Ir brachytherapy sources; the Flexisource (Nucletron, Elekta)[1] is a source commonly used for high dose rate brachytherapy treatments. The TG186 source [2] is a generic, reference ^{192}Ir source, created to provide developers of dose engines with a method of validating new dose calculation techniques. An additional recent improvement is the option to compare simulation results with reference data.

The *hadrontherapy* example has been specifically developed for dosimetric and radiobiological studies with protons and heavy ions beams. It allows the simulation of three passive ion INFN beamlines: CATANA (INFN-LNS, Catania); the Zero-degree multidisciplinary facility (INFN-LNS, Catania); the Multidisciplinary beam line (INFN-TIFPA, Trento). Recently, the primary event generator has been optimized with the capability of generating primary particle from a phase space file. A recent development is the calculation of biological-related quantities such as averaged LET-dose and LET-track [3, 4], Relative Biological Effectiveness (RBE) [5], survival fraction and biological dose.

The *iort-therapy* example simulates intraoperative radiotherapy (IORT) devices used in clinical environment to treat breast cancer. The application also reproduces the PMMA collimator and all the passive elements, such as scattering foils used to obtain flat transversal dose profiles. This Geant4 example allows calculating the dose distributions in different clinical setups and performing radioprotection studies. Such kind of application can be very useful especially during the acceptance of a new IORT accelerator and periodical Quality Assurance as well as for treatment plan verification. During the last years, one of the most relevant improvement of the developed Geant4 example was the possibility to simulate also an innovative model of IORT devices, i.e. NOVAC11.

The *microbeam* and *nanobeam* examples describe transport beamlines for radiobiological studies, used for single-cell irradiation experiments and high-resolution irradiation of samples. The *microbeam* example implements a cellular phantom obtained from confocal microscopy including scoring of energy deposition [6]. The *nanobeam* example allows to extract beam optics parameters (e.g. aberration coefficients) and includes alternative models of quadrupole magnetic field [7].

The *medical_linac* example performs the dosimetry of a typical medical linear accelerator for Intensity Modulated Radiation Therapy (IMRT), such as Varian Clinac 2100 accelerator. Nowadays, dose calculation algorithms based on the Monte Carlo method are generally regarded as the most accurate tools for radiotherapy and an independent Monte Carlo simulation can be used to validate commercial treatment planning systems for radiotherapeutic treatments. This example is addressed to disseminate and encourage the use of Geant4 in oncological radiotherapy allowing to simulate in an adequate flexible way a linear accelerator for radiotherapy and to evaluate the dose distributions. Medical linac allows selecting and choosing two different dosimetric phantoms and the generation of a phase space. The example is under revision to work in multi-threaded mode and to offer a wider range of medical linear accelerators models, dosimetric phantoms and experimental data to be used for the validation of the user' simulations.

Third Geant4 International User Conference

The Geant4 toolkit at the Physics-Medicine-Biology frontier

The **Third** Geant4 International User Conference

at the **Physics-Medicine-Biology frontier**

will take place on **October 29-31, 2018** in Bordeaux, **France**.

NSS-MIC2018

- Accepted as poster in NSS03, NSS 03 - Computing, Software and Simulations for Experiments

Recent developments of Geant4 for medical physics applications

S. Guatelli, P. Arce, M. Bandieramonte, D. Bolst, M. C. Bordage, J. Brown, B. Caccia, G.A.P. Cirrone, D. Cutajar, J. Davis, M. Cortés-Giraldo, G. Cuttone, P. Dondero, V. Giacometti, S. Incerti, V. Ivanchenko, I. Kyriakou, N. Lampe, A. Mantero, S. Meylan, P. Nieminen, M. Novak, L. Pandola, G. Petringa, S. Pozzi, F. Romano, A. B. Rosenfeld, G. Russo, D. Sakata, G. Santin, H. Tran, C. Villagrasa

Abstract— **Geant4 is a particle transport Monte Carlo code in continuous evolution and refinement. Recent developments in terms of physics models, related validations and examples, to address medical physics applications, are presented.**

Index Terms—**Geant4, medical physics.**

I. Introduction

GEANT4 [1] is a Monte Carlo (MC) code toolkit describing particle interactions with matter, originally developed for

based on the EPICS2014 data for shell cross sections. The Compton scattering modelling uses the G4KleinNishinaModel above 20 MeV and the G4LowEPComptonModel below [3]; the G4PenelopeGammaConversion model is used for gamma conversion below 1 GeV; the Livermore model is adopted to describe the Rayleigh scattering.

Ionization and multiple scattering of charged particles have recently been improved by the adoption of the theory-based Goudsmit-Saunderson (GS) model, including Mott corrections, for electron/positron multiple scattering [2]. Both electronic and nuclear stopping powers are considered for protons, alpha

Paper….

- Idea: write a paper from the seed of this contribution
  - It looks like an extremely ambitious and giant work

- Maybe start with a paper on the Advanced Examples for medical physics ?

Recent developments of Geant4 for medical physics applications

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Summary

In progress

- Mainteinance and bux fix (1,2)
- Introduction of some C++11 specific features/utilities in the examples (2)
- Migration of medical_linac to parallel geometry (1)
- Code review (e.g. implementation of the extended examples coding guidelines) in selected examples (1,2)
  - S. Guatelli – Brachytherapy for the public release.
- Developments of alternative approaches for LET calculation in hadrontherapy (2)
  - See the Talk by G. Petringa
- Revision of analysis, geometry and validation scripts for hadrontherapy
  - See the Talk by G. Petringa

Something to think about/discuss

- Wide experimental coverage:
  - HEP (15%), Space science/astrophysics (20%), Medical physics and radiobiology (40%), Detector technologies and others (25%)
  - For the future maybe we could think to offer more examples in HEP and space science
- The Advanced Examples may be published
  - In themes (med phys, space science, High Energy Physics)
  - The papers should go through the Geant4 Editorial Board
- We need to promote the Advanced Examples in conferences/workshops
  - The abstracts need to go through the Geant4 Editorial Board
- We need regular Geant4 Advanced Examples meetings
  - I propose every 3-4 months
  - Maybe one before the deadline for the Geant4 Release?
- Comments/recommendations?