

# From HEP computing to bio-medical research and vice versa: technology transfer and application results

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## Abstract

We present a series of achievements associated to the transfer of simulation technologies to the bio-medical environment. We show also how the novel collaborative organization built around Geant4 has changed the traditional concept of technology transfer between the HEP domain and the bio-medical environment, configuring a two-way interaction.

Keywords: simulation, technology transfer, medical

## 1 Introduction

The transfer of technologies originally developed for HEP experimental applications to other scientific environments has proven to be a fruitful fall-out from the investments in HEP, besides the primary scientific goals of the experiments. In this paper we briefly illustrate examples of transfer of technologies from the domain of HEP simulation to medical physics and radiobiology. We also show how advanced software engineering methods in general, such as rigorous methodologies for the software process and object oriented technologies, represent a valuable contribution from HEP to software applications in the bio-medical field.

An open collaboration with medical and biological domains is also fruitful to the HEP software, providing contributions such as testing and validation of simulation software, user requirements stimulating new models and developments also relevant to HEP applications, scientific expertise in evaluations of hazards in the space experimental environment.

## 2 Requirements of software techniques and methodologies

A powerful and suitable tool for studies of particle production and transport in biological matter is offered by the simulation with Monte Carlo procedures. Monte Carlo techniques are used in nuclear medicine, X-ray diagnostics, radiotherapy physics, dosimetry and radiation protection.

The usage of a software system in a sensitive domain such as medical physics imposes attention to various requirements, beyond the provision of functionalities of interest for the application.

Transparency of the software is of fundamental importance in medical physics. Recent evolutions in the HEP software domain, such as the adoption of the object oriented technology, contribute to the transparency of the underlying physics implementation. The public distribution of the code from a unique source is also a key issue. Other features contributing to transparency are the independence of the code from any system of units, the absence of hard-coded numbers in the algorithms, the distinction between the access to data and their use in the code, the adoption of ISO and de facto standards.

The adoption of a rigorous software engineering approach throughout the whole life of a software product is of great importance for applications in medical physics. In particular, Quality Assurance and validation methodologies are especially relevant. Key practices include: testing at various levels - granular unit, integration and acceptance; the adoption of documented procedures; a software process based on recognised international standards and regularly monitored. The usage of evaluated databases, acknowledged as the state of the art in their domain, contributes to the reliability of the physics implementation.

Openness to the extension with new functionalities and easy interface to other software components are significant features for medical applications, that are met by the adoption of the Object Oriented technology.

Last but not least, the solidity of the maintenance and user support of a software tool is important to the medical physics environment.

The Geant4 Simulation Toolkit [1] provides a wide set of tools of interest for medical physics applications: accurate and flexible geometry and material description; particles tracking within any geometry, material and field; an ample variety of physics processes, interface to powerful visualisation, GUI and analysis tools. Particularly relevant to medical applications are the physics functionalities provided by Geant4, such as extensions of electromagnetic interactions down to low energies [3] and a powerful hadronic physics toolkit, suitable for particle cancer treatments such as Boron Neutron Capture Therapy or Hadrontherapy.

A peculiar feature of Geant4 consists in a fast parameterisation framework integrated with the full simulation, allowing simplified descriptions of the set-up and direct production of hits. This feature is interesting to simulate treatment planning: full simulation can be applied to inhomogenous parts, while fast simulation can be applied to homogeneous media.

### **3 Simulation for radiotherapeutic applications with Geant4**

Because of its advanced functionalities and its response to all the requirements listed above, Geant4 has attracted the interest of medical physics communities. A sample of applications in the bio-medical domain is presented in the following sections.

#### **3.1 Brachytherapy applications**

Monte Carlo simulation in Brachytherapy is devoted mainly to obtain complex physical parameters used in treatment planning which are not directly available by experimental measurements. A project at the National Institute for Cancer Research [4] simulated with Geant4 a commercial  $^{192}\text{Ir}$  source, to verify the anisotropy function and the dose distribution in a tissue equivalent phantom and to compare the simulated air kerma strength with the measured value. Figure 1 shows the anisotropy function obtained at 6 cm distance from the axis by sampling in polar coordinates the available data with nearest neighbour interpolation.

#### **3.2 Dosimetric studies**

Thanks to its physics performance and the flexibility to manage complex geometries, Geant4 is suitable for electron and photon beam studies. At INFN Torino a simulation of a pixel ionization chamber to measure the relative dose with therapeutical photon beams has been developed. A preliminary comparison between experimental data and simulation is shown in Fig. 4. Studies have been performed for proton beams as well; the Bragg peak reconstructed from experimental data taken at PSI by the same group shows a good agreement with the simulation [6].

Characterisation of Thermoluminescent Detectors, used in in-vivo dose estimation in radiological examinations, is also in progress in collaboration with the Italian Institute for Cancer

Research and Treatment.

### 3.3 CT image interface

To simulate a full radiotreatment planning it is necessary to have the complete geometrical description of the patient; this is done through a CT scan image. An activity is in progress to interface Geant4 with the DICOM CT format to perform direct simulation in an *ad hoc* described tissue, with the definition of organs at risk and target tumor volume.

### 3.4 Radiation interactions at the cellular and DNA level

Estimating cancer risk for human exposure to space radiation is a challenge which involves a wide range of knowledge in physics, chemistry, biology and medicine. The future activities on the International Space Station impose a greater attention to such effects. Traditionally, the biological effects of radiation are analyzed in top-bottom order, i.e. the evaluation of the absorbed macroscopic radiation dose at a given location in the biological tissue is translated to the degree of danger it presents, and dose limits are consequently set that are considered to be acceptable. A novel approach that proceeds in a reverse order, from bottom to top, by analyzing the nano-scale effects of energetic particles at the cellular and DNA molecule level, has been started [2] by a multidisciplinary European Collaboration of biologists, physicians, physicists, space scientists and software engineers. User requirements for such studies have been collected, analysed and specified. In the framework of this project, nanodosimetric studies are in progress, involving the application of Geant4 Low Energy Electromagnetic processes. Figure 2 shows an  $\alpha$  particle of 5.3 MeV from a  $Po^{210}$  source producing  $\delta$  electrons traversing a cylindrical volume inside a modelled cell nucleus.

## 4 Contributions from the medical physics environment

The novel organization around the Geant4 Toolkit has stimulated a fruitful close interaction with medical user communities. Medical user groups actively contribute to the testing and validation of simulation software of general interest. For instance, a significant contribution to the validation of Geant4 photon processes has come from the Italian National Institute for Cancer Research; simulation results of the photon attenuation coefficient  $\mu/\rho$  are compared to IST [5] reference experimental data in figure 3. Similar tests for validation against experimental data are shown in figure 4.

Particularly significant is also the contribution of the medical physics environment to the collection of user requirements, that are successively found relevant for HEP and astroparticle experiments as well.

## References

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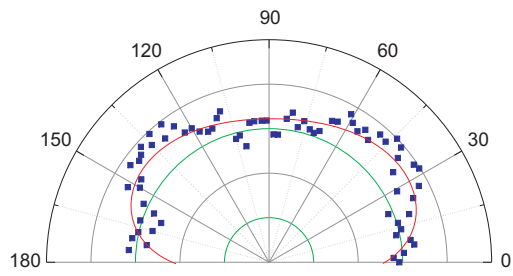


Figure 1: Anisotropy function.

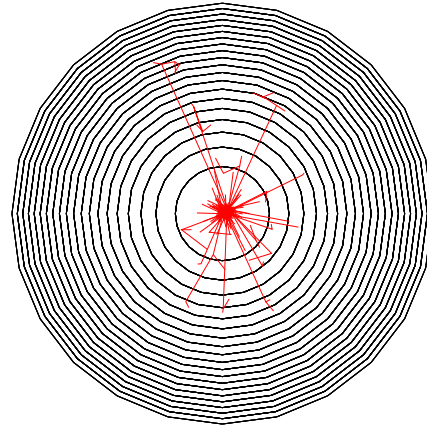


Figure 2: 5.3 MeV  $\alpha$  particle in a cylindrical volume inside the cell nucleus. The inner cylinder has radius 50 nm.

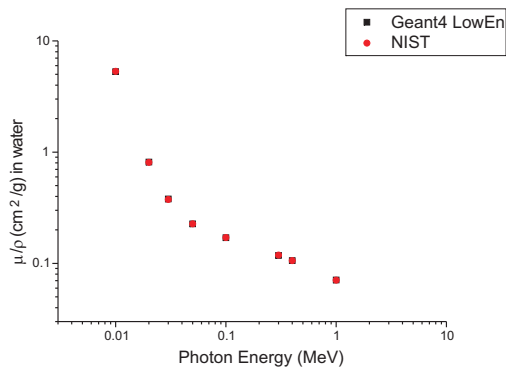


Figure 3: Photon attenuation in water: Geant4 versus NIST tabulated values; the statistical error on simulated points is  $< 1\%$ .

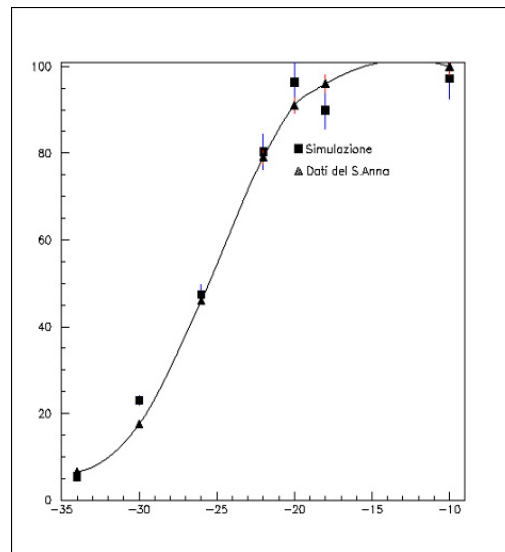


Figure 4: Deposited energy versus depth in water: comparison of experimental data and simulation.