Geant4 Status and Results

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Abstract

GEANT4 is a detector simulation toolkit designed for the new generation of High Energy Physics experiments as well as for nuclear physics, astrophysics, medical and space applications and radiation background studies. An overview of its main features is presented, with emphasis on the most recent enhancements and a selection of results from Geant4-based simulations in various experimental environments.

Keywords: simulation, Geant4

1 Introduction

The Geant4 [1] Object Oriented Simulation Toolkit provides a complete set of tools for all the domains of detector simulation: geometry, tracking, detector response, run, event and track management, visualisation and user interface. An ample set of physics processes [2], many of which offer the option of different models, handle particle interactions with matter across a wide energy range. Various utilities, interfaces to event generators and to ODBMS complete the toolkit.

Geant4 exploits advanced software engineering techniques and Object Oriented technology to achieve the transparency of the physics implementation, and hence provide the possibility of validating the physics results.

2 Overview of Geant4 main features and recent enhancements

The main enhancements to the functionality of Geant4 in recent production releases are outlined in the following sections; more complete overviews of Geant4 can be found in references [1] and [3]-[5]. Only a few results from Geant4-based applications are highlighted; a wider collection of results is available in [6].

2.1 Geometry

The detector geometry is described by creating a hierarchy of the different elements and specifying their positions and orientations. Geant4 also exploits the concept of "positioned" volume, useful for saving memory when describing complex or repeated structures. Different kinds of solids are supported: "Constructed Solid Geometry (CSG) solids", for simple shapes; "Boundary REPresentation Solids" (BREPs) for those defined by complex surfaces.

A significant addition to solid modelling is the ability to do Boolean operations on solids, starting from CSG solids. Union, intersection or subtraction can be used to produce more complex shapes. Geant4 provides an interface to CAD systems through the ISO STEP [7] compliant solid modeller, built-in to the toolkit. The default STEP reader provided in Geant4 is the one developed

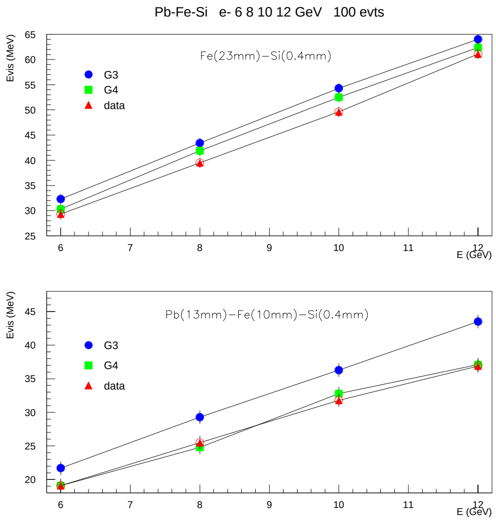

Figure 1: Visible energy versus incident energy: data from [9], Geant3 and Geant4 simulations.

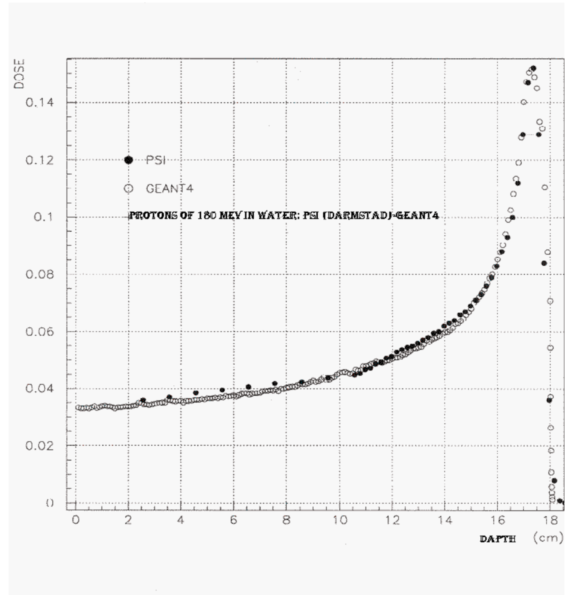

Figure 2: Comparison between Geant4 simulation and experimental data for medical applications

by NIST [1]. It is one of the most widely used STEP readers, and conforms to the EXPRESS (ISO 10303-11) data specification.

Geometrical propagation of tracks for charged particles in a magnetic field is also handled in the Geometry module of Geant4. Several integrators have been developed, to enable the correct and efficient transport in a variety of fields, analytic and interpolated.

2.2 Electromagnetic physics

Extensive comparisons of the Geant4 “standard” electromagnetic physics [2] to experimental data are collected in [8]. An example is shown in figure 1, where experimental data derive from reference [9]. A new powerful algorithm has been implemented to optimise the tracking of ionising particles [10].

Geant4 “Low Energy” electromagnetic physics has been extended to handle the interactions of electrons and photons down to 250 eV [11] and to provide a variety of alternative models for hadrons [12] and ions [13], based on Ziegler [14] and ICRU [15] data and parameterisations. Figure 2 shows the comparison of experimental data with a Geant4-based simulation [16] utilising the new “Low Energy” electromagnetic processes in the framework of studies [17] for medical physics applications.

Further improvements relevant to the simulation of high energy muons, such as the correction of nuclear screening to the multiple scattering of particles, have also been implemented. Figure 3 shows a comparison of Geant4 and Geant3 [18] simulations against experimental data for high energy muons, resulting from studying [19] their deviation due to multiple scattering traversing the L3 [20] detector and the production of secondaries.

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2.3 Hadronic physics

The use of object oriented technologies in Geant4 has allowed us to offer an ample choice of complementary and alternative hadronic physics models [21], including parameterisation- and data-driven ones and a powerful set of theory-driven models. The framework of Geant4 hadronic physics and some recent developments are described extensively in other papers to this Conference [22]-[25].

2.4 Space-specific modules

Various space-specific modules are developed in Geant4, including a radioactive decay module, a sector shielding analysis tool, a CAD tool front-end and a general source particle utility. The Geant4 radioactive decay module is being developed to continue simulation of the long-term ionising events resulting from radioactive nuclei (e.g. produced by nuclear spallation products). Treatment of such physics is crucial in background calculations for scientific missions such as the future gamma ray observatory INTEGRAL. Further applications of this module in other fields are also foreseen. The sector shielding analysis tool provides the user with the facility to obtain a first-order estimate of radiation shielding characteristics and calculation of doses by determining the amount and distribution of shielding using ray-tracing techniques. The results of a recent Geant4-based extensive analysis on the effects of low-energy protons on the ESA X-ray Multi-Mirror (XMM) mission are reported in another paper of this Conference [26]; the geometry of the Chandra [27] telescope modelled with Geant4 is shown in figure 4.

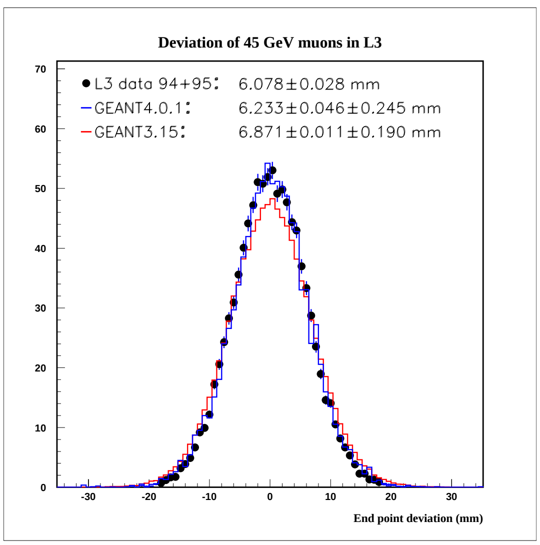

Figure 3: Deviations of 45 GeV μ in L3: experimental data, Geant3 and Geant4 simulations.

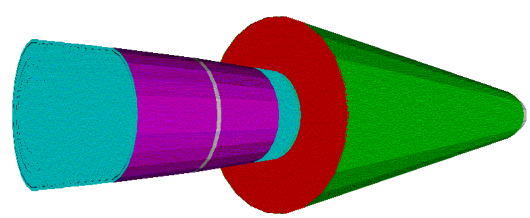

Figure 4: The model of the Chandra X-ray telescope simulated with Geant4.

2.5 Recent software enhancements

Since the Geant4 1.0 release, the C++ Standard Template Library (STL) is required as a base foundation library. The whole code has been migrated to ISO-ANSI C++ and will be available from the next release. It will allow the use of 'native' STL on systems/compilers supporting the Standard.

3 Conclusions

The Geant4 Toolkit has been in production for approximately one year at the time of the CHEP2000 Conference. Since the beginning of the production phase, many Geant4-based applications have produced a wide set of successful results in a variety of experimental set-ups and physics domains. Several enhancements to Geant4 functionalities have been provided by the most recent releases, and further developments to extend Geant4 capabilities are in progress.

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