Geant4 Low Energy Electromagnetic Physics

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Abstract

Geant4 Low Energy Electromagnetic package provides a precise treatment of electromagnetic interactions of particles with matter down to very low energies (250 eV for electrons and photons, ¡ 1 keV for hadrons and ions). It includes a variety of models for the electromagnetic processes of electrons, photons, hadrons and ions, taking into account advance features, such as shell effects and effects due to charge dependence. The comprehensive set of particle types it can handle, the variety of modeling approaches and the extended coverage of energy range make this package a unique tool among Monte Carlo codes on the market, and of relevance to several experimental domains in HEP, astroparticle physics, space science and biomedical studies.

Keywords: Simulation, Object Oriented, Physics

1 Introduction

Geant4 includes a series of packages for electromagnetic physics, specialised for different particle types, energy range or approach in the physics modeling. Among them, the "Low Energy" package provides models extended down to low energy for electrons, photons, hadrons and ions. It addresses requirements of interest for astroparticle experiments, space radiation background studies and medical physics, as well as requirements for precise simulation of high energy physics detectors.

2 Object Oriented Analysis and Design

Object Oriented design provides the possibility to implement or modify any physics process in Geant4 without changing other parts of the software. This feature makes Geant4 open to the extension of its physics capabilities and to the implementation of alternative physics models.

The architectural design of Geant4 "Low Energy" electromagnetic package is shown in figure 1. Processes for photons inherit from *G4VDiscreteProcess*, while processes for electrons, hadrons and ions inherit from *G4VContinuousDiscreteProcess*. Both categories of processes are handled transparently by Geant4 kernel through their abstract interfaces. For each process the generation of the final state is independent from the access and use of the cross sections.

Throughout the package other abstract interfaces handle the concepts of "physics model" and "data source". Strategy patterns [2] are used to make models and algorithms interchangeable.

The Object Oriented design of Geant4 contributes to the transparency of physics implementation, thus facilitating the validation of experimental results.

3 Physics models

A variety of models is implemented in Geant4 "Low Energy" electromagnetic package, depending on the type of physics process, particle type and energy range. The package makes ample use

of public evaluated databases, distributed by a variety of sources; this feature also contributes to the reliability and the transparency of the physics implementation.

3.1 Electrons and photons

The current implementation of Geant4 Low Energy electron and photon processes [3] covers the energy range from 100 GeV down to 250 eV for elements with atomic number between 1 and 99. It includes photoelectric effect, Compton scattering, Rayleigh effect, Bremsstrahlung and ionization; for completeness, a photon conversion process has also been implemented based on the same data sources as the other Low Energy ones. In addition, fluorescence emission from excited atoms is also generated; the implementation of the Auger effect is in progress. The implementation is based on the exploitation of evaluated data libraries (EPDL97 [4], EEDL [5] and EADL [6]), that provide data for the determination of cross-sections and the sampling of the final state. A simulation based on Geant4 Low Energy processes for photons and electrons is compared with experimental data in figure 2, with evidence of shell effects.

The development of a set of processes taking into account polarisation is in progress; the first of the series, for polarised Compton scattering, has been released with Geant4 3.2.

3.2 Hadrons and ions

A Low Energy process is available in Geant4 to handle the ionisation by hadrons and ions [7] [8]. It adopts different models depending on the energy range and the particle charge. In the high energy ($E > 2\ MeV$) domain the Bethe-Bloch formula and in the low energy one ($E < 1\ keV$ for protons) the free electron gas model are applied respectively. In the intermediate energy range parameterised models based on experimental data from the Ziegler [9] and ICRU [10] reviews are implemented; corrections due to the molecular structure of materials [11] and to the effect of the nuclear stopping power [10] are taken into account. The Barkas effect is taken into account [12]; a specialised quantum harmonic oscillator model [13] for negative charged hadrons, valid down to 50 keV, is available; this model has been compared to experimental data for a set of materials, for which data are available; further extensions are in progress. Figure 3 shows a comparison with experimental data for ions.

4 Software process

A rigorous approach to Software Engineering plays a fundamental role in Geant4 Low Energy Electromagnetic package.

User Requirements have been formally collected, and are systematically reviewed and updated following the ESA PSS-05 framework [16] Standards. Object-Oriented methods (and the respective tools) have been employed for the analysis and design of the software, and to produce the corresponding deliverables. The spiral iterative approach adopted for the design and development process demonstrated to be very effective throughout the various phases of the software product, allowing to apply successive refinements to the existing architecture, and experienced solutions to OOAD iterations. Software Processes have been monitored by following the ISO/IEC 15504 (SPICE) exemplar model [17]. By adopting OOP methodologies through the use of Software Engineering CASE tools and Quality Assurance techniques one guarantees that the code quality will not degrade with time; a coherent development is also assured, where coupling will not increase with the complexity of the software. Testing procedures are applied extensively, both at granular unit level and integration level. Physics validation is performed by comparison to experimental data, over a wide set of use cases.

The software process is complemented by a goal-directed project management. Extensive interaction with the user communities ranges from the collection of user requirements to

collaboration in validation of the simulation models and code by comparison to experimental data.

5 Conclusions

A set of physics processes is available in the Geant4 Toolkit to extend the simulation of electromagnetic interactions of electrons, photons, charged hadrons and ions down to low energies.

The Object Oriented technology plays a key role to achieve transparency of physics implementation and openness to extension to new physics processes and models. A rigorous software process is applied.

The source code of Geant4 Low Energy Electromagnetic package is publicly distributed from the WWW [18], as part of the Geant4 Toolkit, together with ample documentation. Enhancements of existing processes, as well as new physics models, are still in progress and will be released in future versions of Geant4.

Geant4 Low Energy Electromagnetic physics is exercised in a variety of simulation domains; a selection of astroparticle and medical applications is presented elsewhere in these Proceedings [19] [20].

References

[1] Geant4: LCB Status Report/RD44, CERN/LHCC-98-44, 1988.

[2] E. Gamma, R. Helm, R. Johnson and J. Vlissides, "Design Patterns: elements of reusable object-oriented software", Addison-Wesley, 1995

[3] J. Apostolakis *et al.*, CERN-OPEN-99-034 and INFN/AE-99/18 (1999)

[4] D. Cullen *et al.*, EPDL97, the Evaluated Photon Data Library, 97 version, UCRL–50400, Vol. 6, Rev. 5 (1997)

[5] S.T. Perkins *et al.*, Tables and Graphs of Electron-Interaction Cross Sections from 10 eV to 100 GeV Derived from the LLNL Evaluated Electron Data Library (EEDL), UCRL-50400 Vol. **31** (1997)

[6] S.T. Perkins *et al.*, Tables and Graphs of Atomic Subshell and Relaxation Data Derived from the LLNL Evaluated Atomic Data Library (EADL), Z=1-100, UCRL-50400 Vol. **30** (1997)

[7] S. Giani *et al.*, CERN-OPEN-99-121 and INFN/AE-99/20 (1999)

[8] S. Giani *et al.*, CERN-OPEN-99-300 and INFN/AE-99/21 (1999)

[9] H.H. Andersen and J.F. Ziegler, The Stopping and Ranges of Ions in Matter, Vol.3, Pergamon Press (1977)

[10] ICRU (A. Allisy et al), ICRU Report 49 (1993)

[11] J.F. Ziegler and J.M. Manoyan, NIM **B35** 215 (1988)

[12] S. Chauvie *et al.*, INFN/AE preprint, in preparation

[13] P. Sigmund, Light-ion stopping near the maximum, NIM **B85**, 541-550 (1994)

[14] R. Shimizu *et al.*, J. Phys. **D9** 101 (1976)

[15] H. Paul, http://www.uni-linz.ac.at/fak/TNF/atomphys/STOPPING/welcome.htm

[16] ESA, Guide to User Requirements Definition Phase, ESA PSS-05 (1994)

[17] T. Rout Project Editor, ISO/IEC DTR 15504 Software Process Assessment

[18] The Geant4 Collaboration, http://cern.ch/geant4/geant4.html

[19] A. De Angelis *et al.*, Simulation for astroparticle experiments and planetary explorations: tools and applications, These Proceedings

[20] S. Chauvie *et al.*, From HEP computing to bio-medical research and vice versa: technology transfer and application results, These Proceedings

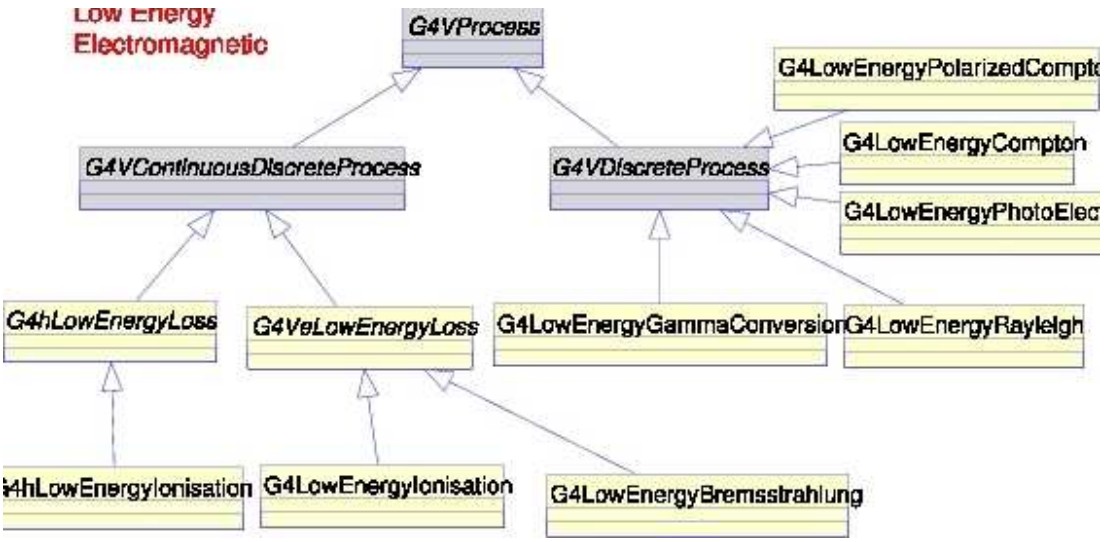

Figure 1: Class diagram of electromagnetic processes

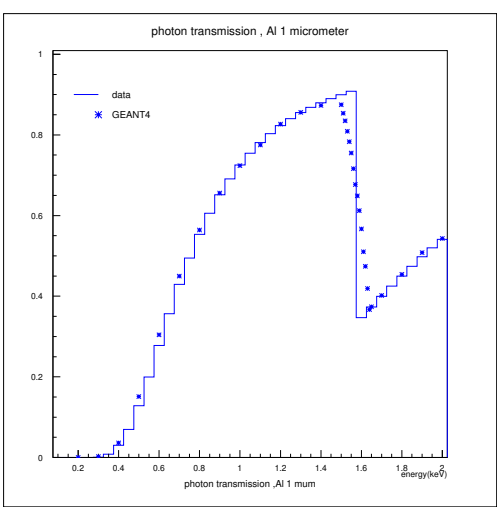

Figure 2: Comparison of the Geant4 Low Energy photon simulation and experimental data, with relevance of shell effects: photon transmission in 1 μm Al; data from [14]

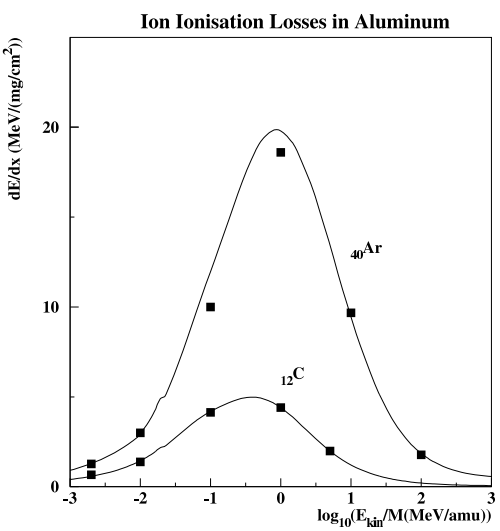

Figure 3: Electronic stopping power of ions in Al, simulated with Geant4 Low Energy Electromagnetic package; the accuracy of the data is approximately 5%; experimental data from [15]