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CMS Physics Analysis project - Geant4

Introduction

It is important that in the simulation studies of the LHC experiments as realistic as possible information about the detectors an the physics processes is used. Detailed simulation of the CMS experiment is based on the Geant4 toolkit (See Fig.).

Geant4 is a collaboration of scientists aiming to create a detector simulation toolkit for high energy physics experiments, A variety of system requirements also come from heavy ions physics, cosmic rays physics, space science applications, and medical applications [1, 8].

Geant4 is now de facto standard tool for HEP applications. Our group participates to Geant4 testing and develops new LHC-era simulation and data-analysis-software based on it. Significant contribution has been made to the design of the hadronic cascade models. Intra-nuclear cascade models for medium energy range 0.1 - 15 GeV, are based on INUCL [7] and High Energy Transport (HETC) software. Our scientific goals include, also in future, the development of hadronic models and simulation tools.

Geant4-related workshops. We have been actively promoting Geant4 usage in Finland and in Nordic countries. Two major workshops: 1st Finnish Geant4 Workshop, 2003 and 2nd Finnish Geant4 Workshop, 2005 and several other tutorials, seminars, and demonstrations have been organized.

Collaborators. We have collaborated with various Geant4 experts from CERN, SLAC (INUCL kaon extension), TRIUMF (HETC code), INFN (physics validation) and KEK (medical applications). We will continue to work together with active Finnish Geant4 users from various fields.

Students. Geant4 activity has provided many opportunities for CERN summer students 2000-2006. Four undergraduate have spent their three month training at CERN working with Geant4. Three Geant4 M.Sc or M.Mc (Tech.) degrees are done or in preparation. One Ph.D is in preparation. We expect that hadronics physics modeling provides also in future interesting research subjects for students.

Modeling hadronic intra-nuclear cascade

Intra-nuclear cascade (INC) implementations such as HETC [R.G.Alsmiller, Jr., F.S.Alsmiller and O.W.Hermann, **The High-energy Transport Code HETC88 and comparisons with experimental data,** Nucl. Instr. and Meth. A, 295, pp. 337-343 (1990).] have traditionally a wide range of applications in shielding, dose estimation, hadronic treatment planning, hadron calorimetry and transmutation of nuclear waste materials.

Recently a renewed interest towards INC has been stimulated by Accelerator Driven Systems and spallation neutron sources. Examples of this development are improvements in Liege INC model [A. Boudard et al. Phys. Rev. C66 (2002) 044615, A. Boudard et al. Nuc. Phys. A740 (2004) 195].

Sub-models

In inelastic particle-nucleus collisions a fast phase of INC results in a highly exited nucleus is followed by fission and pre-equilibrium emission. A slower compound nucleus phase follows with evaporation. The INC model developed by Bertini solves on the average the Boltzmann equation of this particle interaction problem.

The Bertini nuclear model consist of a three-region approximation to the continuously changing density distribution of nuclear matter within nuclei. Relativistic kinematics is applied throughout the cascade and The cascade is stopped when all the particles which can escape the nucleus, have done so. Pauli exclusion principle is taken into account and conformity with the energy conservation law is checked.

Path lengths of nucleons in the nucleus are sampled according to the local density and free nucleon-nucleon cross-sections. Angles after collisions are sampled from experimental differential cross-sections. Tabulated total reaction cross-sections are calculated by Letaw's formulation.

Models included are Bertini INC model with exitons, pre-equilibrium model, nucleus explosion model, fission model, and evaporation model. Intermediate energy nuclear reactions up to 10~GeV energy are treated for proton, neutron, pions, photon and nuclear isotopes [7].

In the following figure we see main classes connecting Geant4 Bertini cascade sub-models.

Implementation

Geant4 hadronic shower framework follow the Russian dolls approach to implement framework design. Hierarchy of frameworks encapsulate the common logic of a particular use-case, so hadronics Level 4 framework allows concrete implementation of intra-nuclear scattering. It defines purely abstract class *G4VIntraNuclearTransportModel*, which implementers of concrete intra-nuclear transport code need to use.

Following the coding guidelines provided by the hadronic framework, Bertini cascade model interface class *G4CascadeInterface* inherits from *G4VIntraNuclearTransportModel* and implements hadronic final state generator. Implementation consists of 50 classes, while most of them are are utility classes for physics models [3].

Requests from users in high energy physics community and other fields are discussed regularly at Geant4 Technical Forum. Requirements documents are used to guide design of highly complex and modular object-oriented Geant4 software.

For pion the INC cross-sections are provided to treat elastic collisions and inelastic channels (Fig. right). Multiple particle production and following s-wave pion absorption channels are implemented (Fig. left).

Browse the Geant4 cascade source code

Using Bertini cascade

Key results

Improved performance for pions. Inclusion of new Geant4 intra nuclear cascade models we have gained significant improvement compared to old Geant4 and LEP model. Improvement is particularly significant for pions (See following Figs.)

Validating isotope production. As a part of validating all new Geant4 models we have studied Geant4 Bertini cascade isotope production [5]. In the following figure 20 MeV - 1 GeV proton induced isotope production is studied for the case of 39-Y-89(p,X)40-Zr-88 and validated against experimental data.

Kaon extension. We have added to Geant4 cascade model a previously unavailable treatment for kaons [4]. In a first release, we see reasonable agreement in comparison with data (See Fig.).

Acceptance from the users and reviewers. Validated physics list provided by Geant4 collaboration and simulation project of LHC Computing Grid Project (LCG) suggest currently models developed at HIP for LHC background radiation studies and for modeling of 'general detector'. (For reference see for example J.Beringer, **(p, xn) Production Cross Sections: A Benchmark Study for the Validation of Hadronic Physics Simulation at LHC,** CERN-LCGAPP-2003-18, CERN (2004).) An example of physics performance for neutron double differential cross section is demonstrated in next Fig.

Current and future Geant4 activities (spring 2006 -)

Shower shape validation. There is very strong interest from the LHC experiments to see progress before major simulation productions start late 2006.

We are actively participating in the International Organizing Committee of the *Hadronic Shower Simulation Workshop* to be held at Fermilab September 8th-9t 2006 to bring together world experts to examine ways to improve our ability to simulate hadronic shower simulators.

Optimizing speed of Bertini cascade. Currently we have a student at Turku University working on Bertini code speed optimization.

Extending a selection of Geant4 medium energy models. Currently we are planning to include INCL [J. Cugnon et al. Nuc. Phys. A462 (1987) 751, A. Boudard et al. Phys. Rev. C66 (2002) 044615, A. Boudard et al. Nuc. Phys. A740 (2004) 195] and ABLA [A.R. Junghans et al. Nuc. Phys. A629 (1998) 635, J. Benlliure et al. Nuc. Phys. A628 (1998) 458] models into Geant4. This work will be done by original developers from CEA (Alain Boudard and Yair Yariv), Universit de Li ge, ULg (Joseph Cugnon) and GSI (Karl-Heinz Schmidt) together with Geant4 hadronics group.

We will organize a 'INCL-Geant4' mini-workshop at CERN June 19th-20th.

Co-coordinating Geant4 hadronics working group. From late 2005 Aatos Heikkinen (HIP) has been co-coordinating Geant4 hadronics working group together with Dennis Wright (SLAC).

Geant4 applications. We are using data from full Geant4 based CMS simulation to be analyzed with novel data-analysis techniques. A first paper in this line of work, studying supervised and unsupervised neural networks is just published [2]. Future work will include more detailed studies of Self Organized Maps and inclusion on boosting methods.

Using CMS data. When CMS starts producing data, comparisons with Geant4 are needed and physics models will tuned and improved. Our focus will change from hadron induced reactions (h-A) to heavy ion modeling (A-A).

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