A Software Toolkit to Study Systematic Uncertainties of the Physics Models of the Geant4 Simulation Package

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Challenge

Particle physics experiments make heavy use of the Geant4 simulation package (http://geant4.cern.ch) to model interactions between subatomic particles and matter. Geant4 employs a set of validated physics models that span a wide range of interaction energies. These models rely on directly measured cross-sections and phenomenological models with physically motivated parameters, and are tuned to cover a very wide range of possible experiments. This raises a critical question of what systematic uncertainties are associated with a particular parameter set of one or another Geant4 physics model, or a group of models, involved in modeling and optimization of a detector design. The challenge has motivated the Geant4 collaboration to start a new initiative to develop a toolkit to study the effects of varying model parameters on the simulated results, and to explore the associated errors.

Software Features

- User-friendly API to vary one or multiple parameters of Geant4 physics models involved in the simulation studies
- Flexible run-time configurable workflow
- Comprehensive bookkeeping
- Collective analysis of multiple variants of the resulting physics observables of interest
- Modular, easy to extend software design
- Based on the following software:
  - Art Framework: http://art.fnal.gov
  - Open source toolkit RooMUHistos: https://github.com/ManyUniverseAna/RooMUHistos

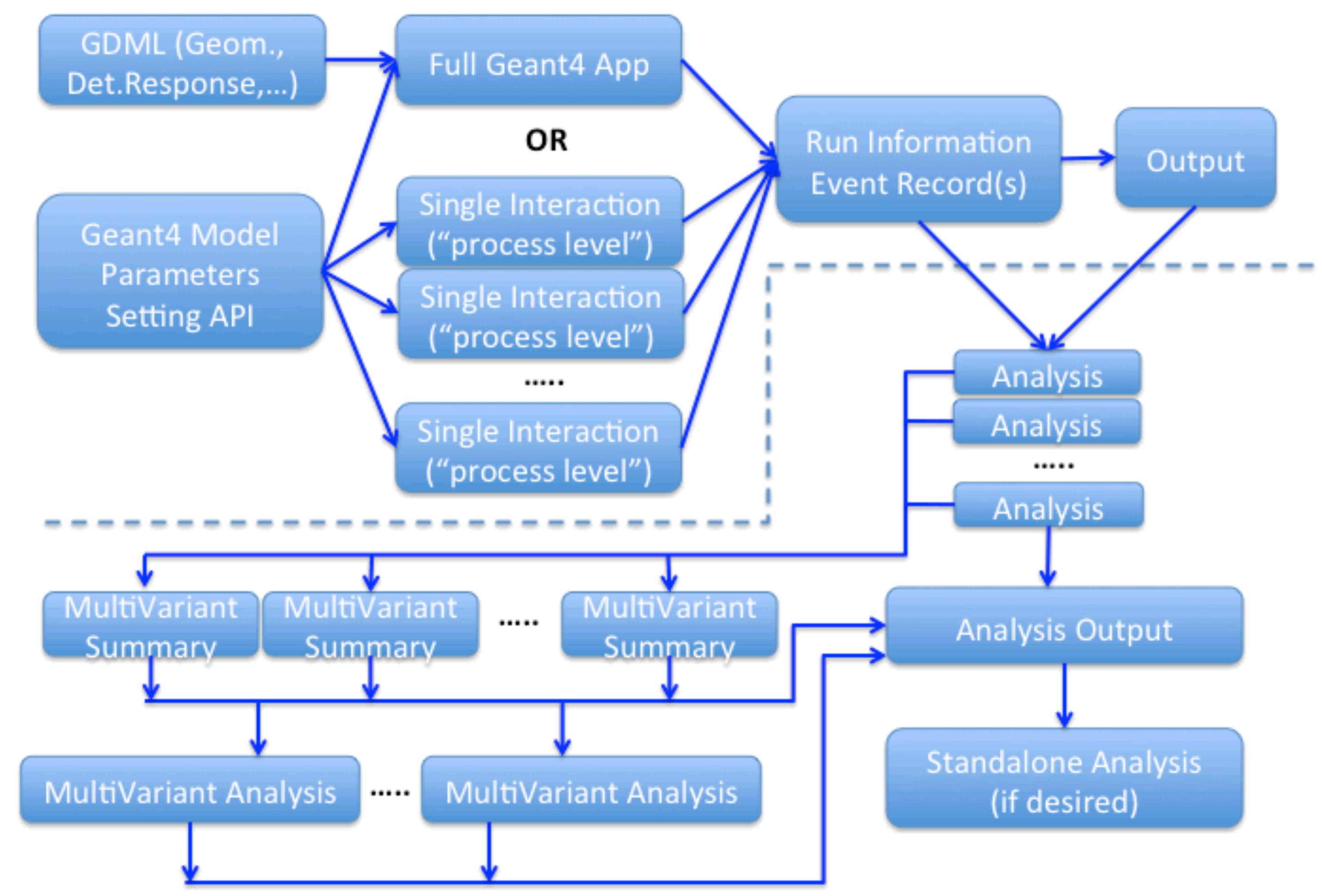

Diagram 1. Software Components and Workflow

Toolkit Components

Diagram 1 show representation of the software components and the workflow. The event processing chain can be executed in one step, or can be subdivided into multiple steps, if desired. Geant4.10.1.patch02 version or later is required.

- **Geant4 model parameter setting API:** allows to change one or several parameters of one or several models. This recently developed component can be used with a bare Geant4 or with any application based on modern event processing framework
- **Run-time configurable Geant4 application module:** flexible geometry and detector hits setup in GDML format, run-time choice of physics list. Only one instance of this module can be used in the event processing chain, due to technical details of Geant4 physics list composition. However, events simulated by different variants can be chained in the same output file, for further collective analysis.
- **Single interaction simulation:** can be run-time configured to use Geant4 model of user's choice to simulate a single beam-nucleus interaction. Beam and nucleus are also chosen by a user at run time. Multiple instances of this module can be executed in the same event processing chain.
- **Example analysis modules:** easy to expand collection of run-time configurable components, to perform event-by-event analysis. Multiple modules of this type can run in the same chain.
- **Example end-of-job summary analysis modules:** easy to expand collection of run-time configurable components, to perform end-of-job combination of different variants, for further multi-variant analysis, if desired. Multiple modules of this type can run in the same chain.

Selected Preliminary Results from the Ongoing Study

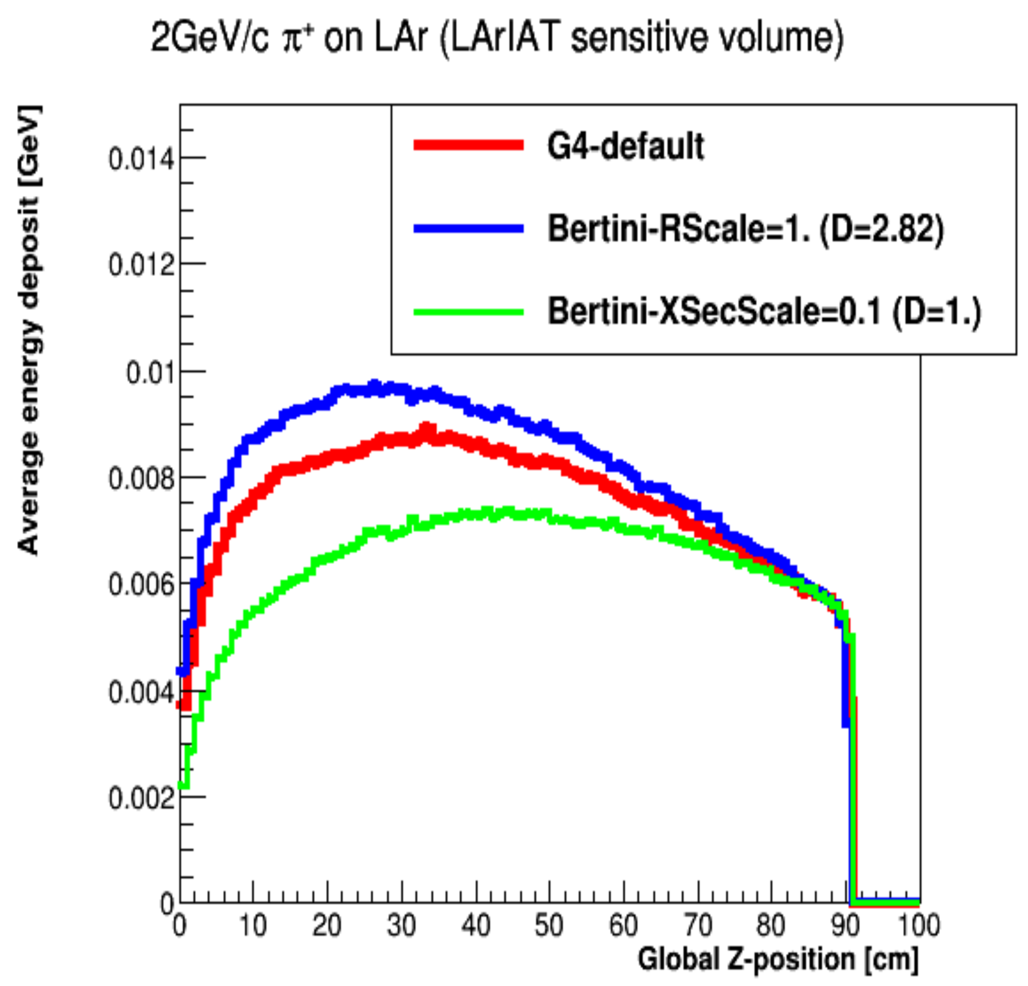

Figure 1. Longitudinal profile of a simulated hadronic shower induced by 2 GeV/c π^+ incident on Liquid Argon detector volume of the LArIAT setup (http://lariat.fnal.gov). Energy deposit is shown as a function of shower depth in the volume. Simulation is using QGSP_FTFP_BERT physics list which includes Bertini cascade model to cover energy range from 0. to 9.9 GeV. Simulated results of Bertini variants are compared with Geant4 default predictions. Variations of Bertini parameters are larger than 1σ; they have been exaggerated to make effects of changes easy to see.

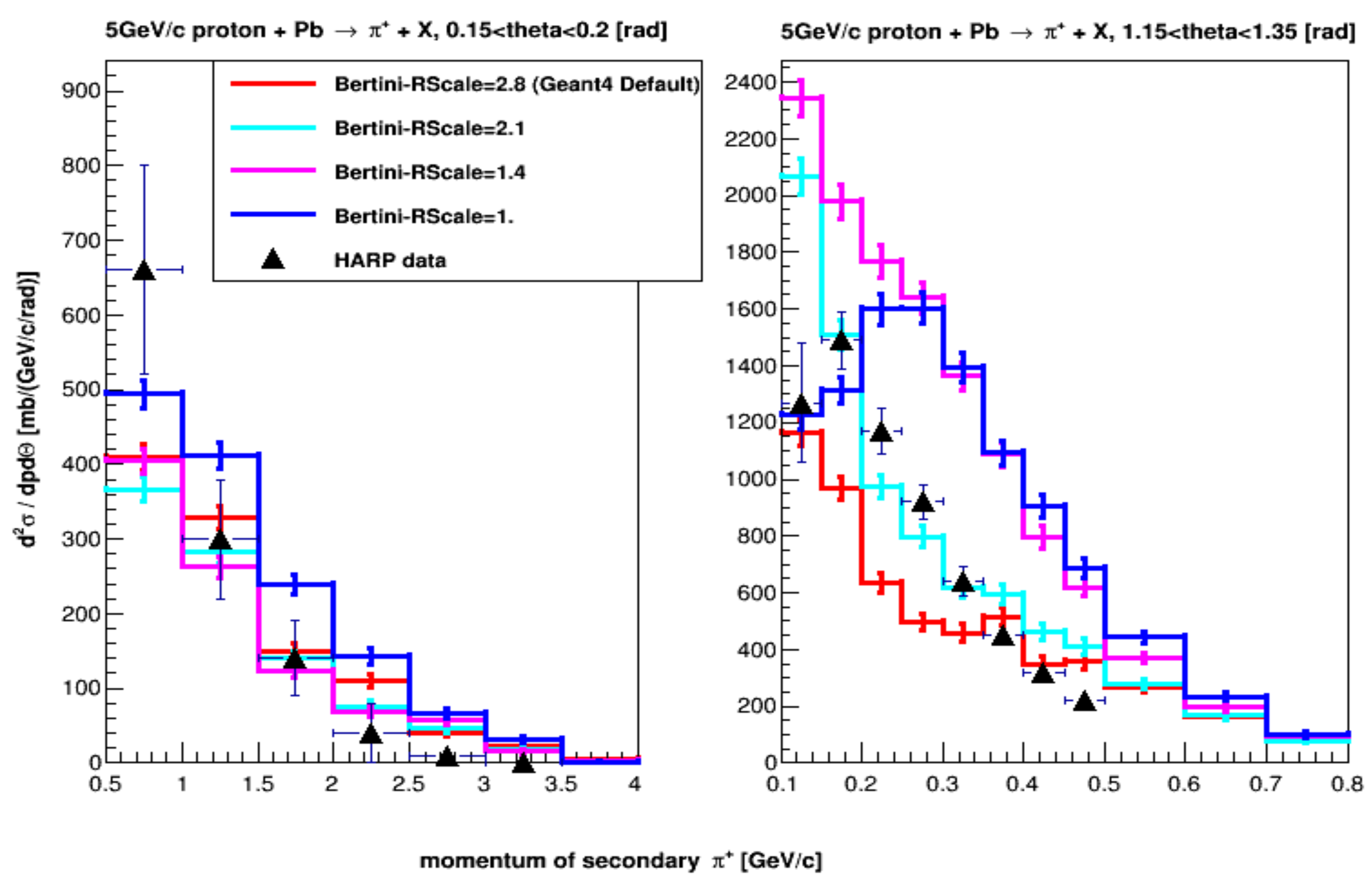

Figure 2. Production of pi+ by a 5GeV/c proton beam interacting with a Lead nucleus as simulated by Geant4 Bertini cascade model. Production cross section is shown as a function of momentum of secondary pion in different bins of the polar angle of the outgoing particle. Bertini default predictions are compared with results from several variants. Variations of Bertini parameter RadiusScale are larger that 1sigma; they have been exaggerated to make effects of changes easy to see.
Simulated results are compared with experimental data from HARP:
M.G. Catanesi et al., Phys.Rev.C77 055207, 2008
M. Apollonio et al., Phys.Rev.C80 035208, 2009

Conclusions

In response to requests from the users community, we are developing a software toolkit to explore the impact of varying Geant4 models parameters on the simulated physics results.
Geant4 Bertini cascade model and its variants are the 1st use case in the study.
The toolkit has been used to study effects of varying selected parameters of the Bertini cascade on simulated observables, including energy deposit in the LArIAT Liquid Argon detector or hadron production in hadron-nucleus interactions; the later also involved comparison with data from experiments such as HARP and initial statistical analysis. Selected results are shown in this presentation to illustrate the case.
Further development of the toolkit and inclusion of other key Geant4 models in the study are planned for the near future.

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