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

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CHEP 2016, San Francisco, CA
10/11/2016

Presentation delivered by S.Y.Jun (Fermilab)

General Information

- Particle physics experiments extensively use Geant4 package to model interactions between 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

Challenge

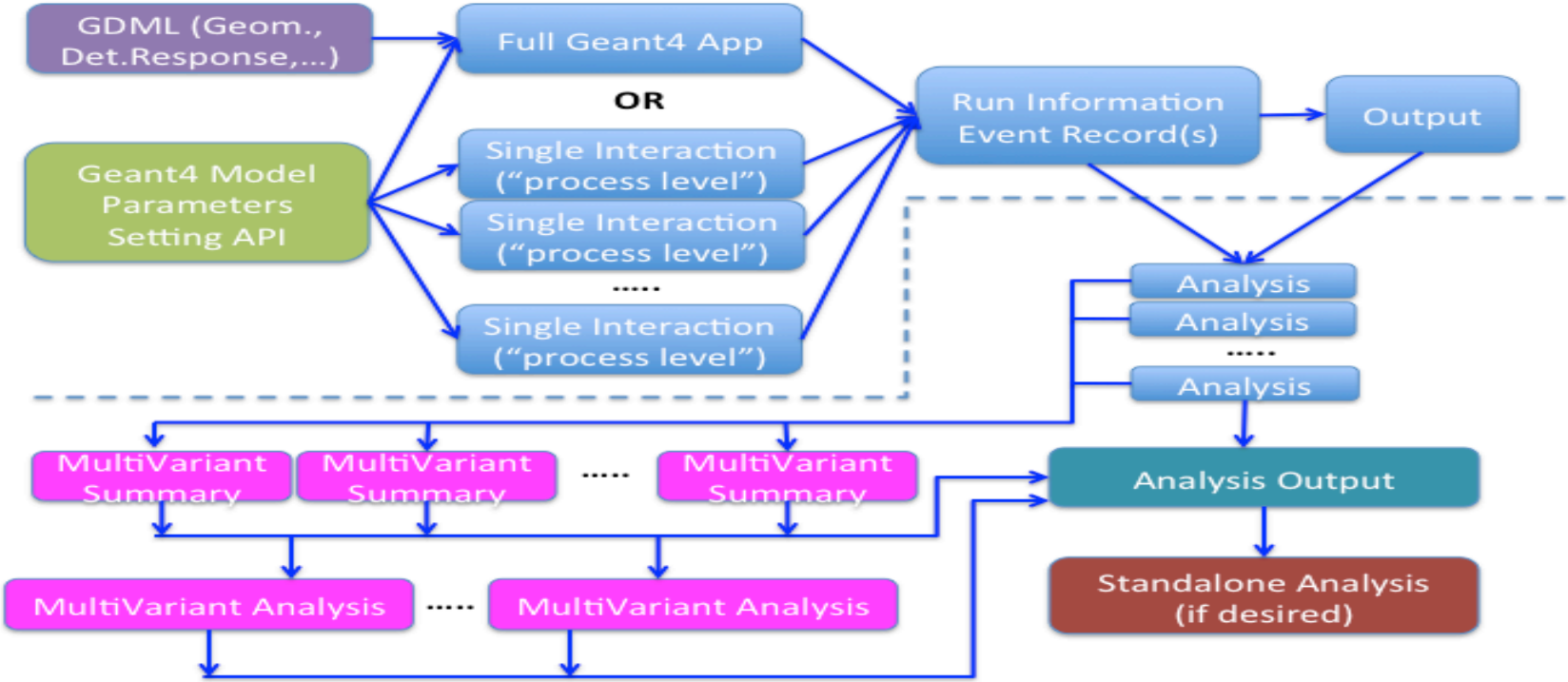
- Critical question: what systematic uncertainties are associated with a Geant4 physics model, or a group of models, involved in modeling and optimization of a detector design
- The challenge has motivated the Geant4 collaboration to start a new initiative and develop a toolkit to study the effects of varying model parameters on the simulated results, and to explore the associated uncertainties

Toolkit Features

- Documented, with step-by-step instructions and examples
- 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
- Programmatic (C++) access to the DoSSiER Repository, to extract experimental data for benchmarking and/or statistical analysis:
  - http://g4devel.fnal.gov:8080/DoSSiER (see also poster by A.Dotti et al.)
- Based on the following external software packages:
  - Art Framework: http://art.fnal.gov
  - Open source toolkit RooMUHistos: https://github.com/ManyUniverseAna/RooMUHistos

Software Components and Workflow

The event processing chain can be executed in one step, or it can be subdivided into multiple steps, if desired



Toolkit Components (I)

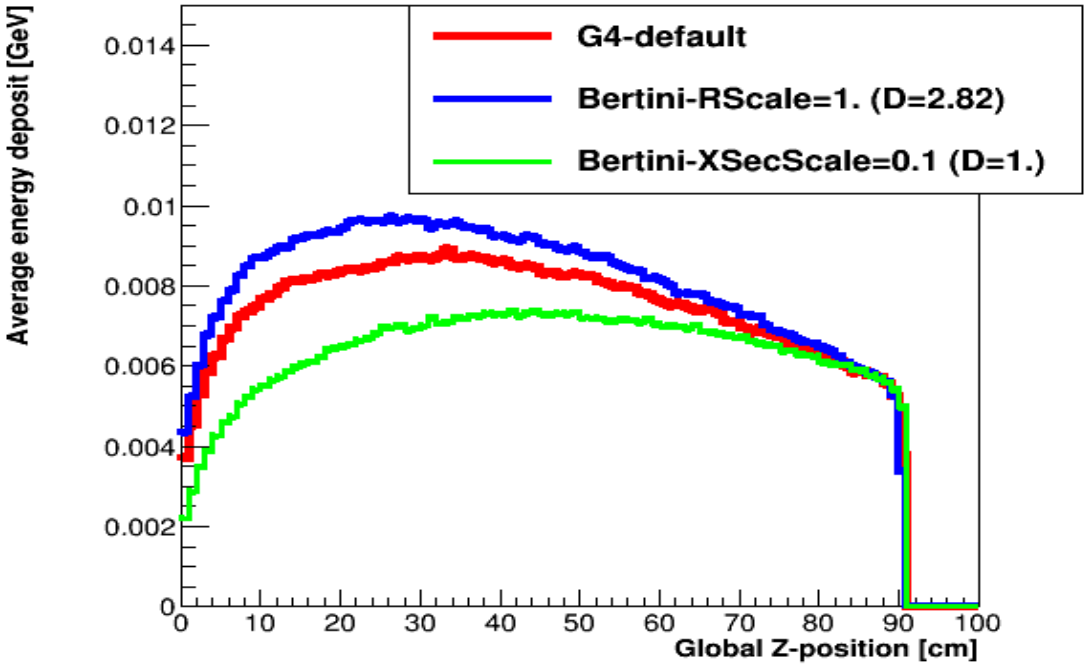
- **Geant4.10.1.p03 or later is required**
- **Geant4 model parameter setting API:**
  - recently developed component that can be used with a bare Geant4 application or with any application based on modern event processing framework
  - allows to change one or several parameters of one or several models
- **Run-time configurable Geant4 application module:**
  - flexible geometry and sensitive detector setup in GDML format
  - run-time choice of physics list
  - events simulated by different variants can be added to the same output file, for collective analysis

Toolkit Components (II)

- **Single interaction simulation:**
  - run time choice of Geant4 hadronic model to simulate a single beam-nucleus interaction
  - beam and nucleus are also chosen by 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 components to perform event-by-event analysis
  - multiple analysis modules can run in the same job
  - analysis can be done in a separate step, if desired
- **Example end-of-job summary analysis modules:**
  - easy to expand collection of run-time configurable components (based on RooMUHistos), to perform end-of-job combination of different variants, for further multi-variant analysis
  - multiple modules of this type can run in the same job

Preliminary Results (I)

Longitudinal profile of a simulated hadronic shower induced by 2 GeV/c π^+ incident on Liquid Argon detector volume of the LArIAT setup

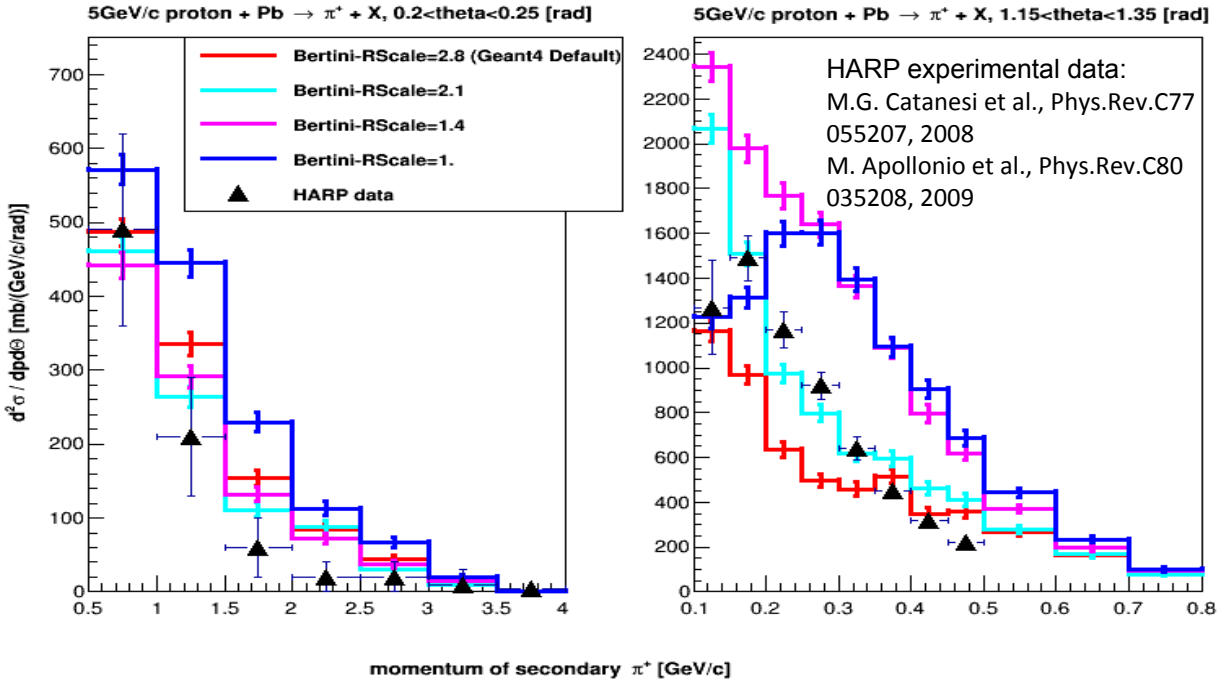


QGSP_FTFP_BERT physics list is used in the simulation.
Bertini Cascade model covers energy range from 0. to 9.9 GeV.
Bertini default predictions are compared with results from several variants.

Variations of Bertini parameters are larger than one standard deviation; they have been exaggerated to make effects of changes easy to see.

Preliminary Results (II)

Production of π^+ by a 5GeV/c proton beam interacting with a Lead nucleus as simulated by Geant4 Bertini Cascade model and its variants

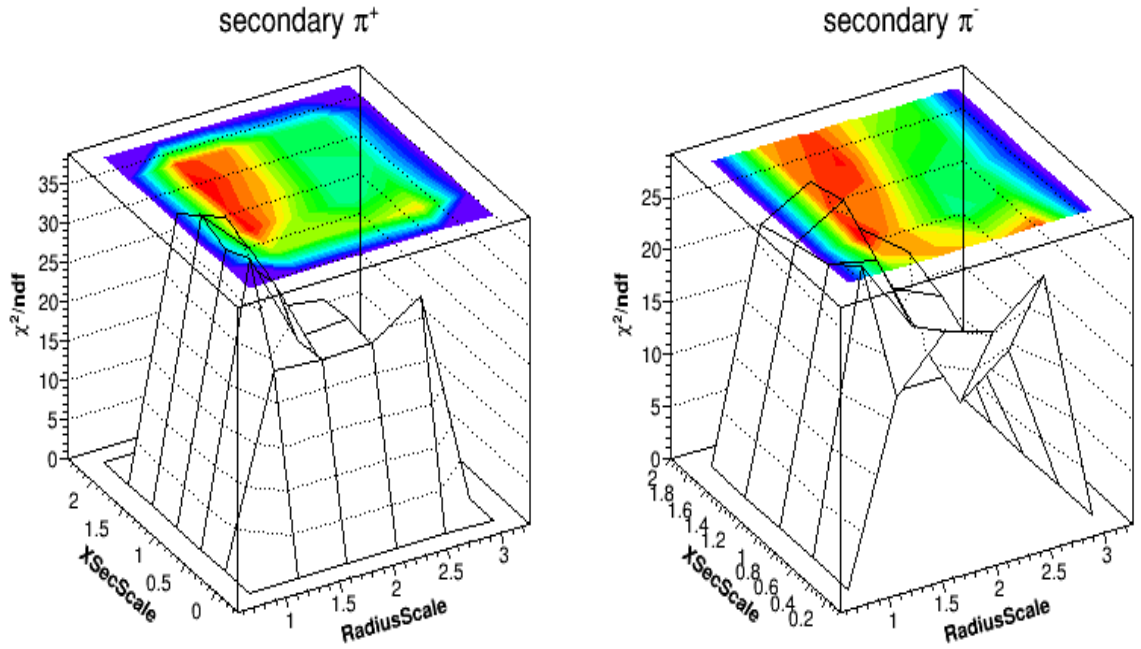


Bertini default predictions are compared with results from several variants and with experimental data.

Variations in the parameter RadiusScale have been exaggerated, in some cases more than one standard deviation, to make effects of changes easily seen.

Preliminary Results (III)

Production of π^+/π^- by a 5GeV/c proton beam interacting with a Lead nucleus as simulated by Geant4 Bertini Cascade model and its variants



Bertini default predictions are compared with results from several variants and with experimental data.

Results are obtained in a form of χ^2/ndf where χ^2 is calculated for each variant for the MonteCarlo spectrum and the corresponding data spectrum.

Variations of Bertini parameters maybe larger than one standard deviations.

Summary

- In response to requests from the user community, we are developing a software toolkit to explore the impact of varying Geant4 model parameters on the simulated physics results
- The toolkit has been used to study effects of varying parameters of the Geant4 Bertini cascade model on simulated observables
- The toolkit allows to compare simulated results with experimental data, including statistical analysis
  - Experimental data are programmatically obtained from DoSSiER repository
- Selected results and comparison with experimental data have been shown to illustrate the case
- Further development of the toolkit and inclusion of other key Geant4 models in the study are planned for in the near future