

# Applications of Geant4 Hadronic Physics Models in Simulation for Neutrino Experiments

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## The Aim

Provide FNAL Neutrino Community  
with best possible hadronic physics  
modeling tools within Geant4  
by improving hadronic models and  
Physics Lists



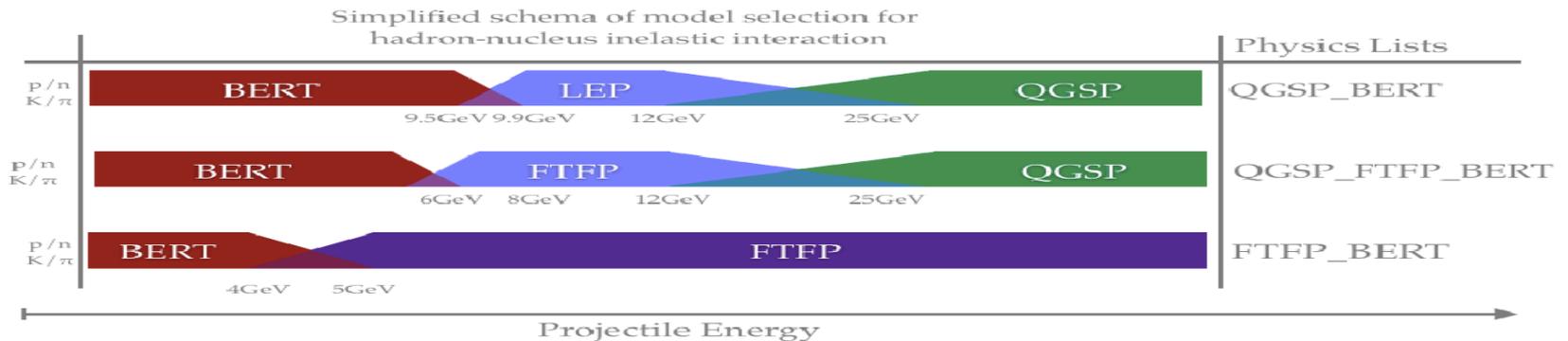
## Geant4 Hadronic Physics - General Remarks

- There is NO “unified” hadronic model
- Hadronic models are valid (or better fit) for combinations  
particle type - energy ( - target material)
- Need to choose a set of hadronic models to cover all possible interactions - Physics List (what a user typically sees)
- The choice is **NOT** a “black box” but depends on use-case:
  - The particles in simulation
  - The energy scale
  - The compromise between accuracy and CPU
- Collection of ready-to-use physics lists exists
- Users can also tailor any of those, or write their own



## Physics Lists Composition and Transition Between Models

- Hadronic models may overlap in their validity range - this is also reflected in the composition of Physics Lists



- Choice is based:
  - General Validation (benchmarking vs exp.data)
  - Use-case(s)



## Simulation for Neutrino Experiments - Use-Case (the way we see it)

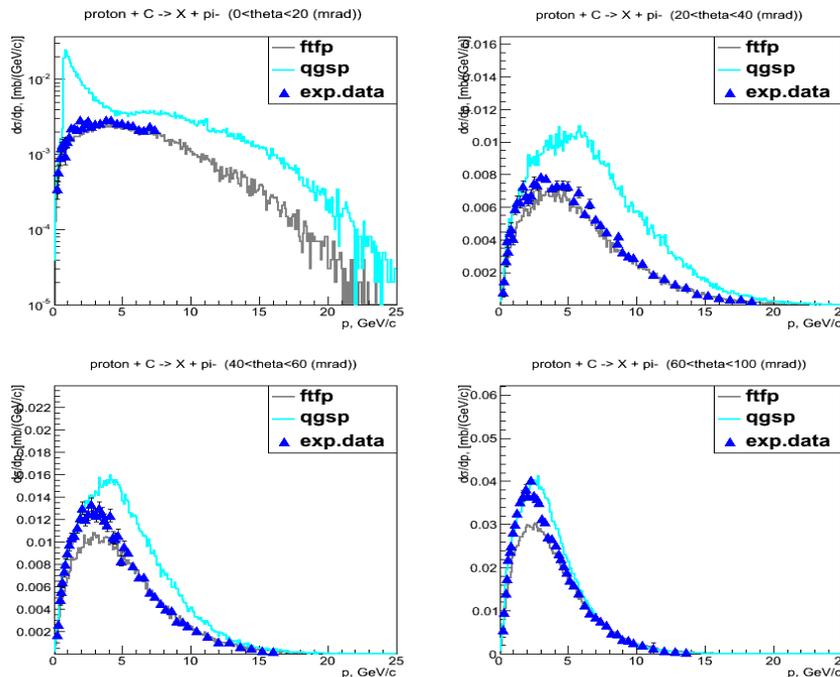
- Two distinct cases:
  - Modeling interaction of **high energy** proton beam with primary target and neutrino flux prediction
  - Modeling of neutrino-induced hadronic showers in the detector
    - **lower-to-intermediate energy** range
- Available Geant4 models:
  - High energy - FTF (from  $\sim 3\text{GeV}$  up), QGS (from  $\sim 15\text{GeV}$  up)
  - Intermediate energy - Intra-nuclear cascade models (from 0 to 5-30GeV): Bertini, Binary, INCL++ (under development), partially FTF
  - PreCompound model to treat excited nuclei
- Questions:
  - How to compose models together for this specific use-case
  - How to improve models (for this specific use-case or in general)

## Elements of Geant4 Validation Suite (I)

- High energy validation:
  - FTF(P) and QGS(P) models
  - Single interaction simulation

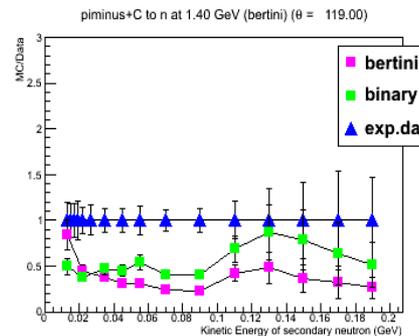
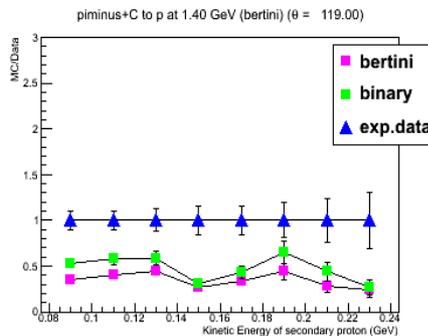
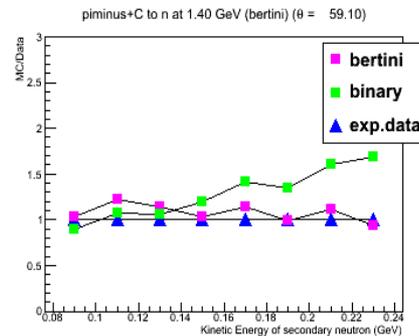
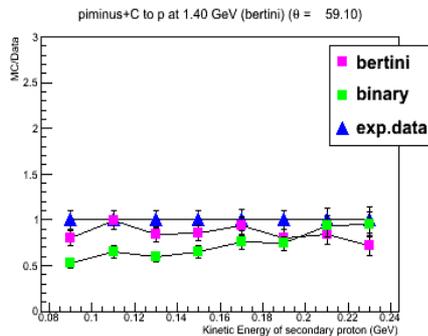
Experimental data:  
 NA61 (31GeV/c p+C, various p+p)  
 NA49 (158GeV/c p+C, p+p)  
 MIPP (56-120GeV/c p on various targets)

Sample plots:  
 Momentum distribution of pi+  
 produced in 31GeV/c p+C interaction,  
 in different theta-bins



## Elements of Geant4 Validation Suite (II)

- Lower-to-Intermediate energy:
  - Bertini, Binary, (part) FTF, INCL++
  - Single interaction simulation



### Experimental data:

[www-pub.iaea.org](http://www-pub.iaea.org) (22MeV to 3GeV p on various targets)

HARP & HARP-CDP (3-15GeV/c p, pi+, pi- on various targets)

ITEP (1.4-7.5GeV p, pi+, pi- on various targets)

### Sample plots:

Momentum distribution of p and n produced in 1.4GeV/c pi- on C interaction, in different theta-bins



## Elements of Geant4 Validation Suite (III)

- A variety of other validation tests:
  - Geometry/navigation/transportation
  - EM processes
  - Cross sections
  - Full Physics Lists
    - these tests are somewhat LHC/Calorimetry biased
    - we would like to introduce other types of testing, also with the focus on the needs of Neutrino Program



## Tests Conducted in Experiments vs Geant4 Validation

- **More complex/specific geometry**
  - Single interaction
  - Particles may re-interact
- **Use of complete Physics List vs single model**
  - A good chance to land in the area of models overlap
- **A variety of observables:**
  - Production of individual particles (inclusive/exclusive)
  - More complex observables such as shower shapes, resolutions, etc.
- **This is an excellent source for identifying issues**
  - In models themselves
  - In how the models are combined together



## What Is in the Plans of the Neutrino Community ?

- **Specific interests:**
  - Particle types ?
  - Energy range ?
- **What datasets to use for tuning:**
  - Existing/published data ?
  - Ongoing measurements ?
  - Future test beam plans ?
- **What are the testing applications in the Neutrino Community:**
  - Beam-target configuration ?
  - Physics Lists in current use or of potential interest ?
  - Specific observables ?



## Not a Summary but...

- Your feedback is vital for improving Geant4 hadronic models and their composition into Physics Lists !!!
- We can serve as liaison between Fermilab Neutrino Community and the Geant4 collaboration



## Just FYI: large collection of Geant4 hadronic validation materials is available: <http://g4validation.fnal.gov:8080/G4ValidationWebApp/G4ValHAD.jsp>

The screenshot shows the Geant4 validation web application interface. At the top, there is a navigation bar with links for Home, Validation Overview, Release Highlights, Electromagnetic, Hadronic, LHC-feedback, and Expert. The main content area displays details for a specific test, 'test30', including its name, responsible person (V. Ivanchenko), and description. Below this, there are 'Test Conditions' and 'Results' sections. The 'Test Conditions' table lists parameters such as Name, Description, Target, Particle, Observable, Energy, Upload date, Description, Data Source, last modified, Score, and Type. The 'Results' section contains four plots showing differential cross-sections (dσ/dΩ) in mbarn/MeV versus energy (E) in MeV for different angles (θ = 30° and θ = 60°). The plots compare experimental data points with various Geant4 models: BIC, BERT, BERTP, and INCL. A 'List of hadronic Tests' sidebar on the right provides a dropdown menu for selecting different tests, with 'geant4-09-05-ref-10' and 'geant4-09-06-ref-00a' highlighted in green.

<b>Name of the Test:</b>	test30
<b>Responsible:</b>	V. Ivanchenko
<b>Description:</b>	Test of hadronic generators of inelastic processes

<b>Geant4 Version:</b>	geant4-09-06-ref-00
<b>Observable:</b>	pn, c, 113
<b>Reaction:</b>	p + C -> n + X, 113 MeV/c, LOG
<b>Status:</b>	public

Test Conditions	
Name	Description
Target	Carbon
Particle	proton
Observable	dSigma/dEdOmega
Energy	113 MeV/c
Upload date	Fri Nov 29 16:18:05 CET 2012
Description	Neutron spectra
Data Source	Meier et al., Nucl. Sci. Eng. 104, 1990
last modified	2012-12-08 21:32:53 CST
Score:	passed
Type:	expert

Results	
dσ/dΩ (mbarn/MeV)	E (MeV)

- geant4-09-05-patch-01
- geant4-09-05-ref-09
- geant4-09-05-ref-10
- p + C -> n + X, 113 MeV/c, LOG
- geant4-09-06-ref-00a
- 9.3.ref02
- 9.3.ref03
- 9.3.ref04
- 9.3.ref05
- 9.3.ref06
- test35
- test45