Improvements in the Geant4 Hadronic Physics

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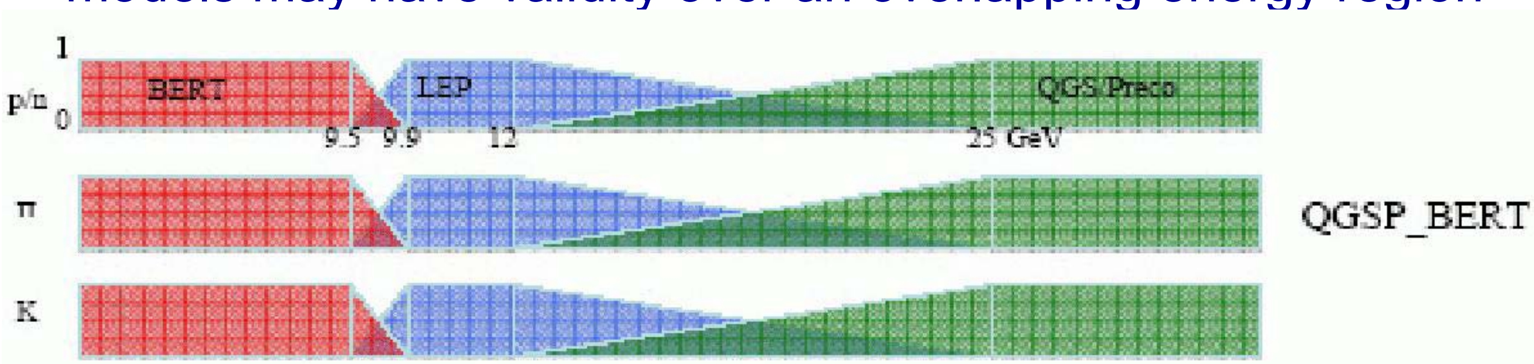
(on behalf of Geant4 Hadronic Working Group)

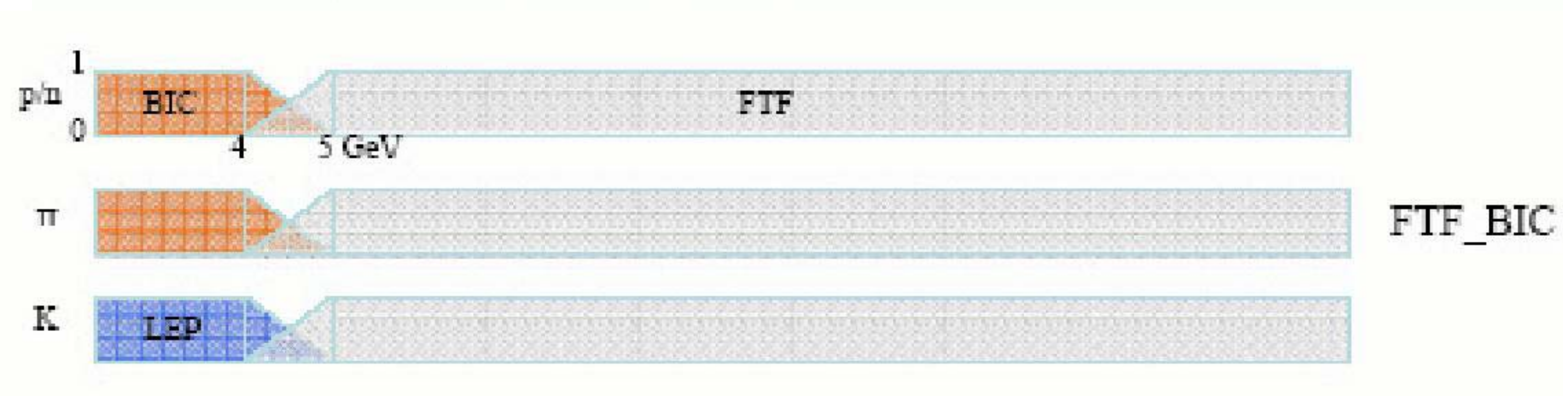
The LHC and Geant4 Hadronic Physics Improvements

- Turn-on of LHC detectors has motivated the improvement of hadronic physics models
  - in the recent past, test beam data have spotlighted flaws and driven improvements
    - ATLAS, CMS, HARP
  - in the near future data from the full detectors will provide strong tests of the models
- Development has concentrated on several inelastic models
  - string models, intra-nuclear cascades, precompound models, and elastic and inelastic cross sections
  - improvement in these models has resulted in better agreement with test beam data

Physics List

- Since none of the models within Geant4 could explain all physics processes, it is customary to register several physics processes in a list.
  - EM processes are usually valid over the entire energy domain but each discrete process is described separately, e.g., pair production, Compton scattering, …
  - Hadronic processes are valid over a finite energy domain. Two models may have validity over an overlapping energy region

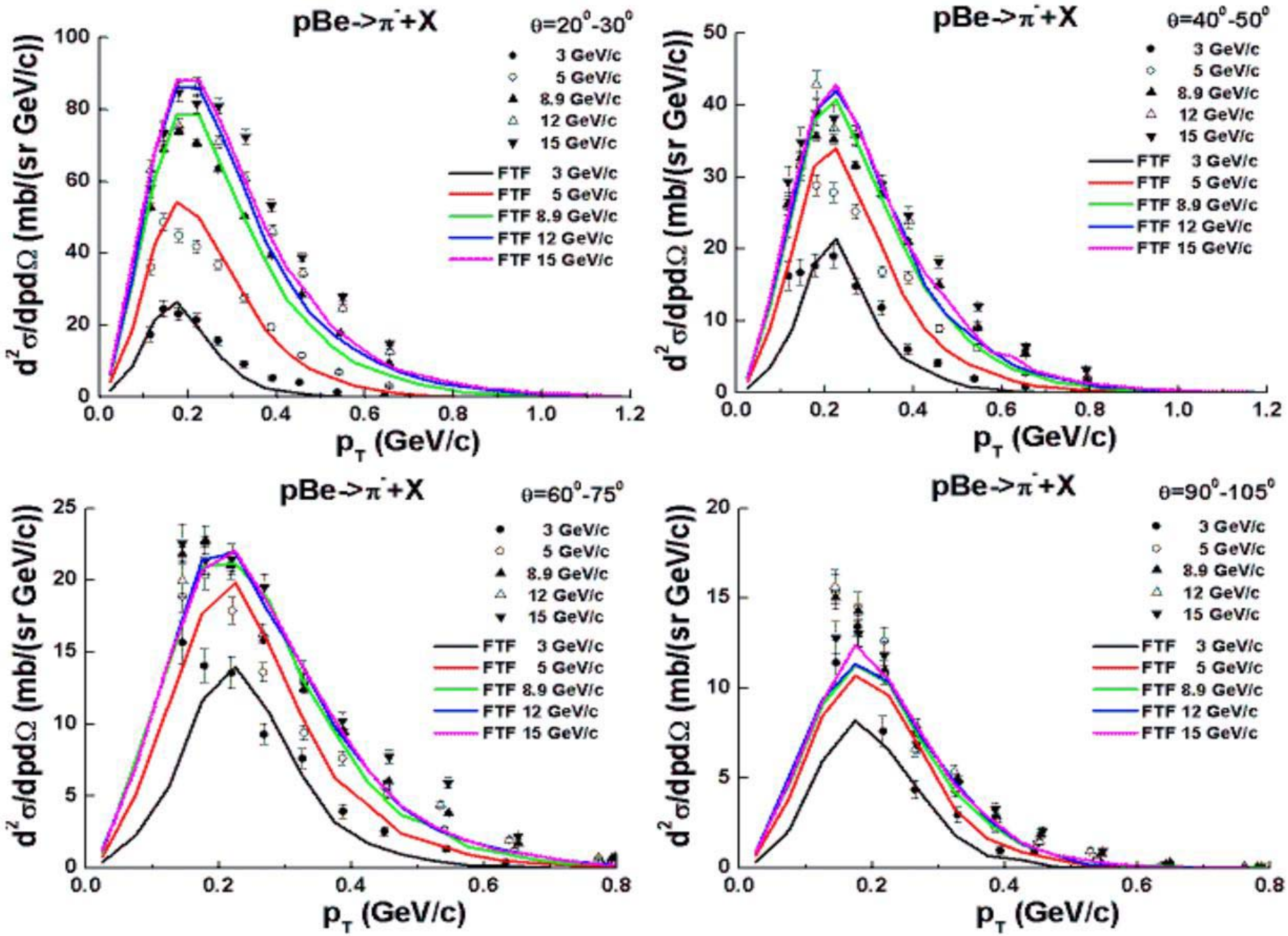




Fritiof Fragmentation (FTF) Model

- Quark-gluon string (QGS) model has been used extensively in Geant4 physics lists
  - good performance at high energy (> 20 GeV)
  - not valid below 10–15 GeV
- The FTF model is much improved during last 2-3 years
  - single diffraction added
  - cascade model motivated by Reggeon theory included
  - model now performs well down to 5–10 GeV
- Now possible to join FTF model directly to Bertini cascade at $5 < E < 10$ GeV
  - intervening GHEISHA-based models no longer needed
  - reduced discontinuity in detector response

FTF Model Predictions vs HARP-CDP Data



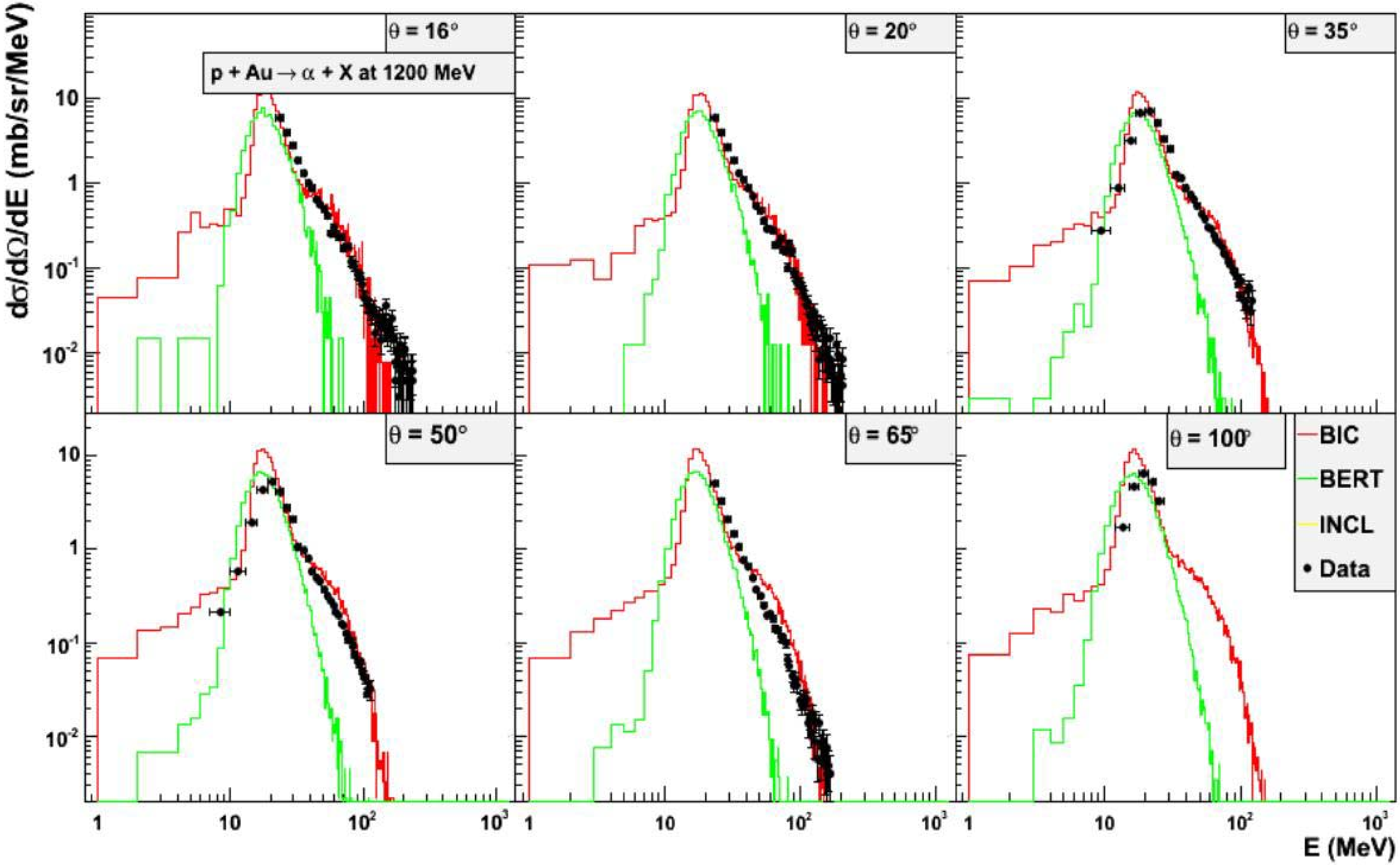
Bertini-style Cascade

- Used in QGSP_BERT physics list (and others) to handle inelastic collisions from 0–10 GeV
  - good performance below 5–6 GeV
  - may be responsible for part of the discontinuity in calorimeter response seen ~10 GeV by ATLAS, CMS and HARP
- Physics improvements
  - almost all energy-momentum non-conservation removed
  - old and inaccurate pi-nucleon and nucleon-nucleon angular distributions replaced with new ones
- Performance improvements
  - reduction in object creation and deletion by factor ~10
  - increased CPU speed

Precompound and De-excitation Models

- The Geant4 precompound model is used in the QGSP_BERT (and other) physics lists
  - Responsible for de-exciting the nucleus after high energy interaction of the Quark Gluon String (QGS) model
  - valid for energies below ~200 MeV
- Improvements during last 2 years include:
  - Improved density-of-states calculation
  - Emission probabilities had been based on very old data (pre-1960s) – use of modern data has improved these significantly
  - Hybrid use of both Weisskopf-Ewing and GEM models improves nuclear fragment spectra from decay

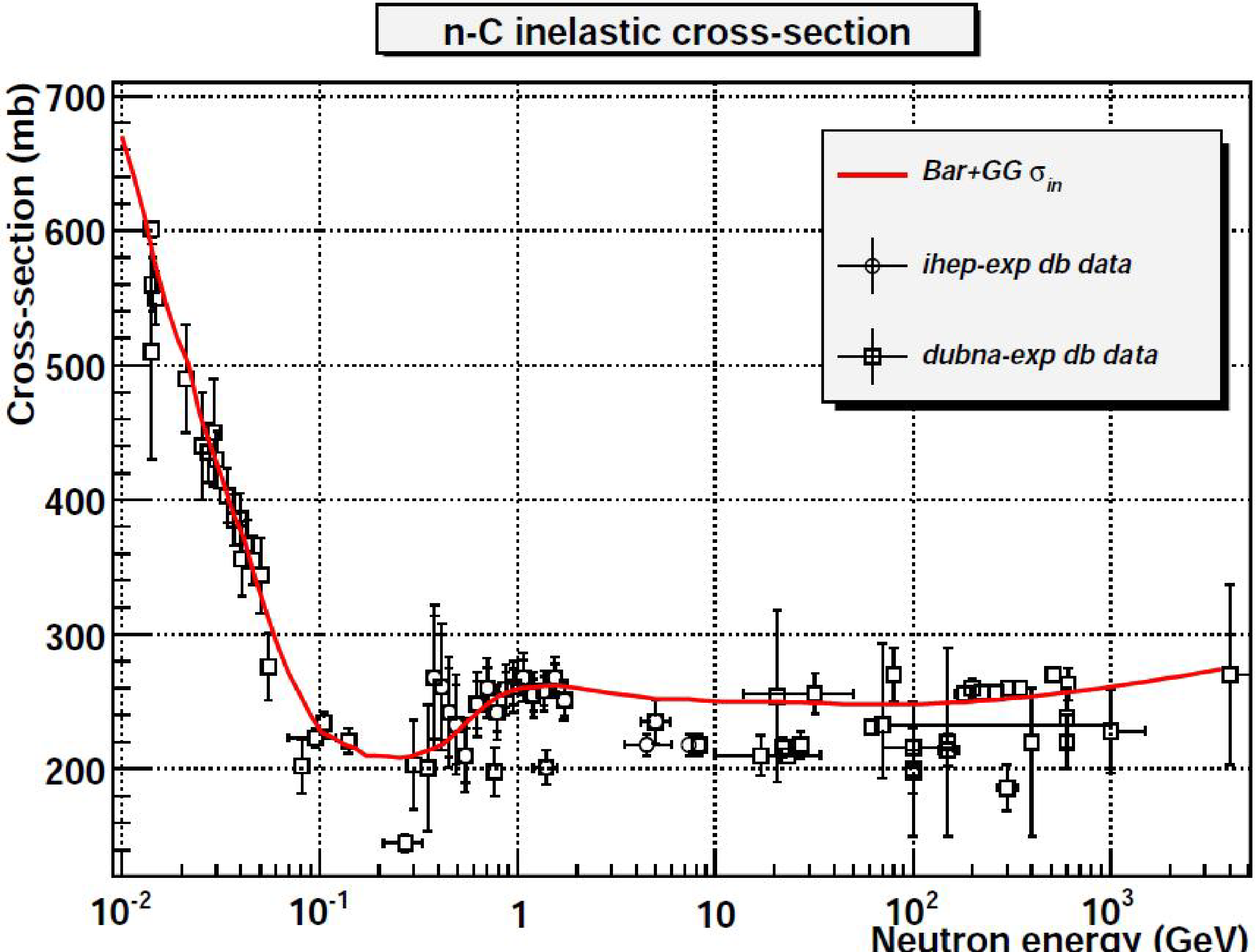
Model Predictions vs. IAEA Data for p+Au→α+X



Hadronic Cross Sections

- Barashenkov, Axen-Wellisch, and GHEISHA parameterized cross sections are widely used in Geant4 physics lists
  - generally good performance in the range 1–90 GeV
  - problems:
    - no high energy rise in the Barashenkov parameterization
    - little resonance detail at low energies
    - kaon and anti-nucleon cross sections not well treated
- Several alternative cross sections are developed as alternatives
  - CHIPS elastic and inelastic parameterizations treat more particle types
  - Parameterizations based on Glauber-Gribov theory to include high energy rise

IHEP and Dubna Data



- The new parameterization gives a good description of the measured cross sections

Hadronic Physics Validation

- During the past two years much effort has been devoted to improve Geant4 hadronic validation
- Hadronic working group now participates in regular validation efforts comparing Geant4 to other codes
  - IAEA (wide range of spallation data $0 < E < 3$ GeV)
  - SATIF (shielding application comparisons)
- A large number of validation suites test Geant4 hadronic physics over all energy ranges
  - a combined hadronic validation suite will soon be made publicly available

New Hadronic Validation Web Page

Geant 4

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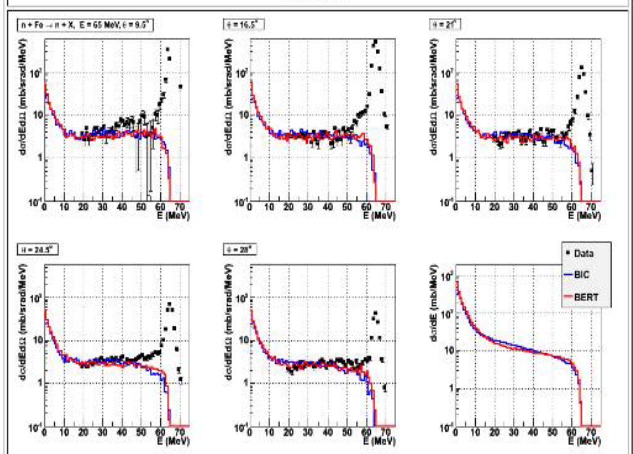
Name of the Test:	test30
Responsible:	V. Ivanchenko
Description:	Test of hadronic generators of inelastic processes

Geant4 Version:	9.3.ref06
Observable:	dsigma/dEdOmega
Reaction:	n + Fe ->n+X

Test Conditions	
Name	**Description**
Target	Iron
Particle	n
Energy	65 MeV
Model	Bertini (Bert)
Model	Binary Cascade (BIC)
Angle	9.5 deg
Angle	16.5 deg
Angle	21.0 deg
Angle	24.5 deg
Angle	28.0 deg
y-scale	logarithmic
Score:	passed
Type:	expert

Results



List of HAD Tests

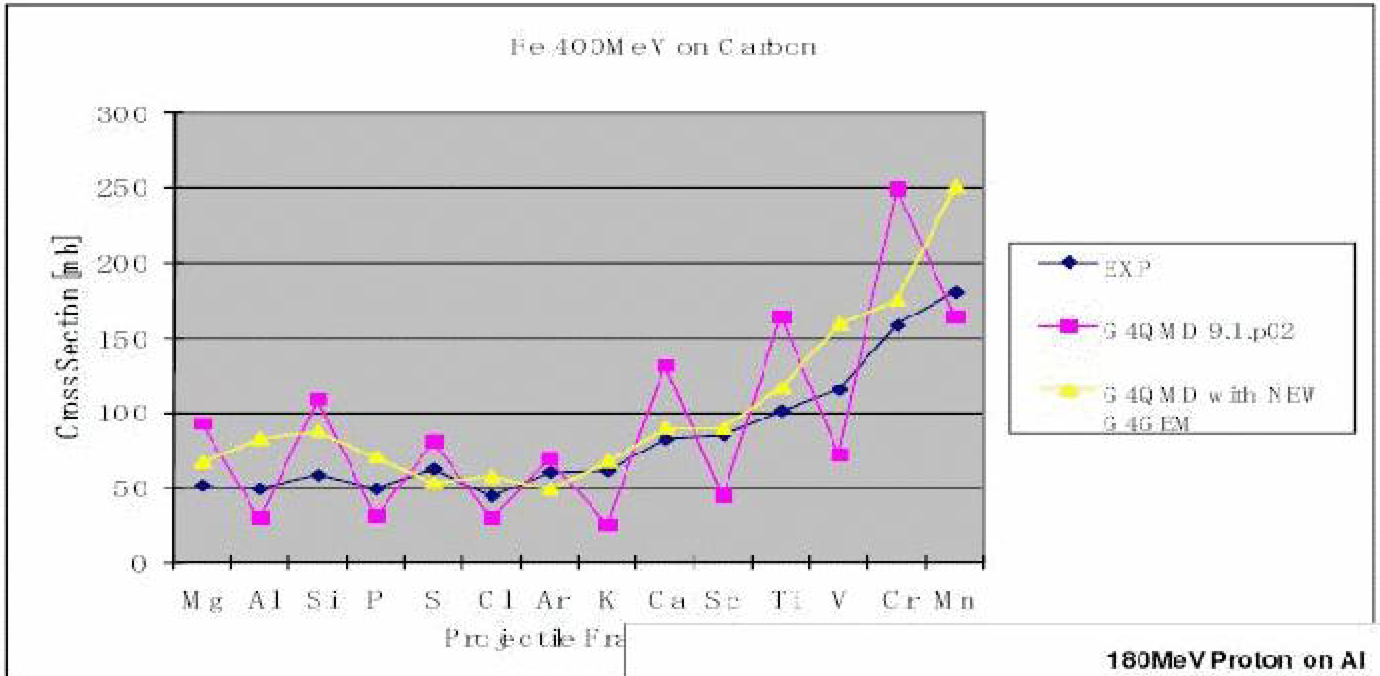
List of hadronic Tests

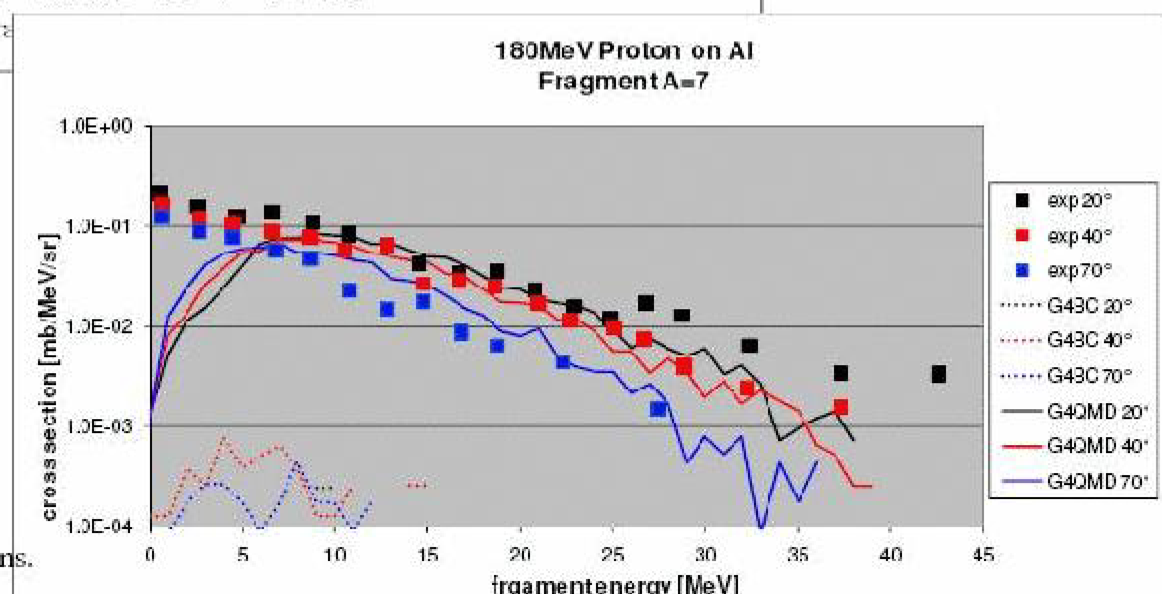
- Hadrcap
- Ndata
- Test30iaea
- test30
  - 9.3.ref02
  - 9.3.ref03
  - 9.3.ref04
  - 9.3.ref05
  - 9.3.ref06
- test35
- test45
- test47

Other Notable Models

- INCL/ABLA
  - C++ translation of CEA/Saclay code
  - cascade (INCL) + de-excitation (ABLA) used for nucleon, pion, nuclear projectiles of E < 3 GeV
  - tuned to spallation data
- QMD nucleus-nucleus collision model
  - quantum molecular dynamics code developed wholly within Geant4
  - valid for all nuclear targets and projectiles in the energy range 0.2 GeV < E/A < 5 GeV
  - higher energy version (RQMD) being developed

Nucleus-nucleus: G4QMD vs Data





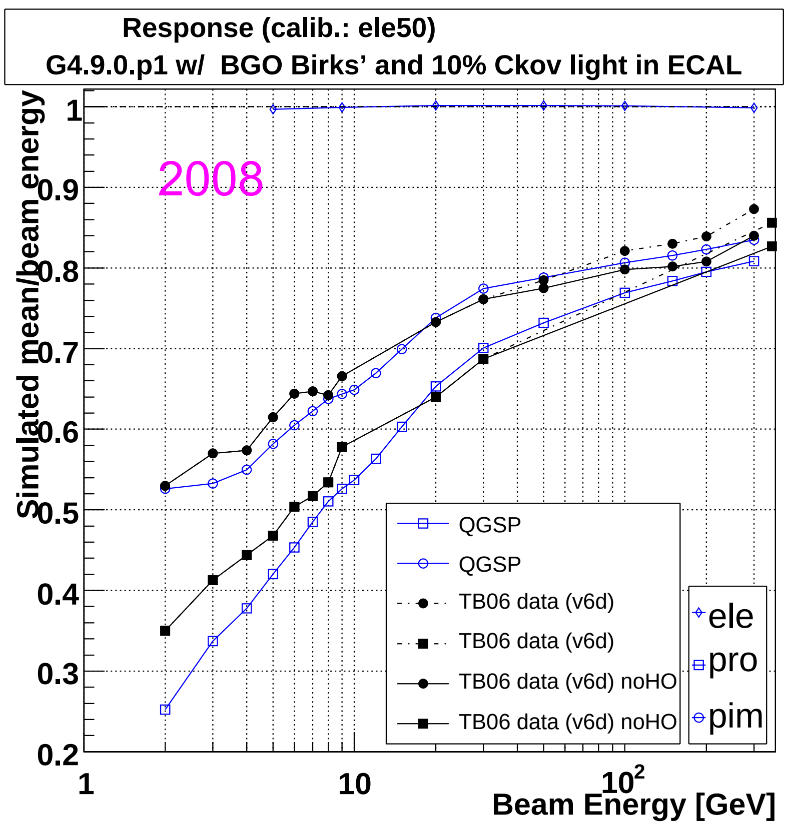
"Energy deposition in intermediate-energy nucleon–nucleus collisions," *Kwiatkowski* et al., *Phys. Rev. Lett.*, *vol. 50*, no. *21*, pp. 1648–1651, *1983*

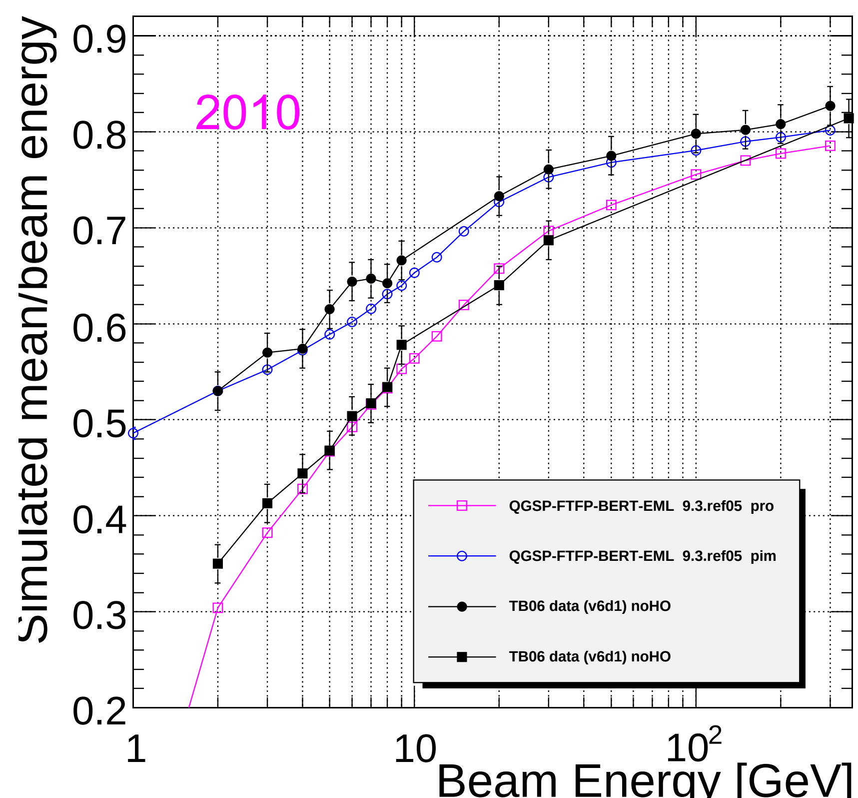
This result includes some but not all recent corrections.

Impact on LHC Experiments

- CMS and ATLAS did extensive tests of their calorimeters with test beams and the experiments monitored the improvements of Geant4 hadronic models over years

Combined CMS calorimeter response to π^- and p

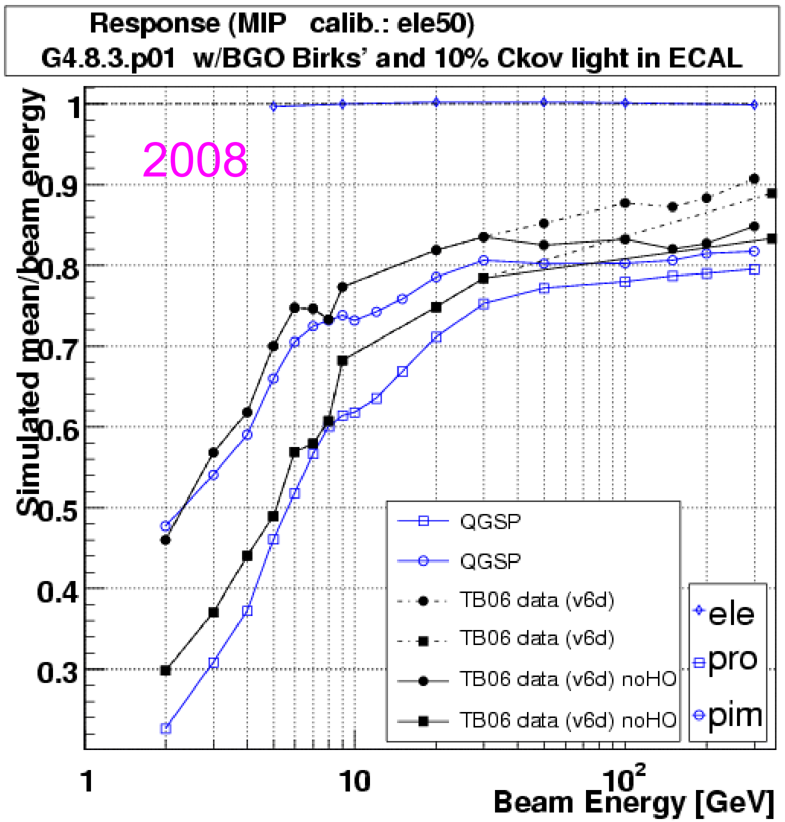


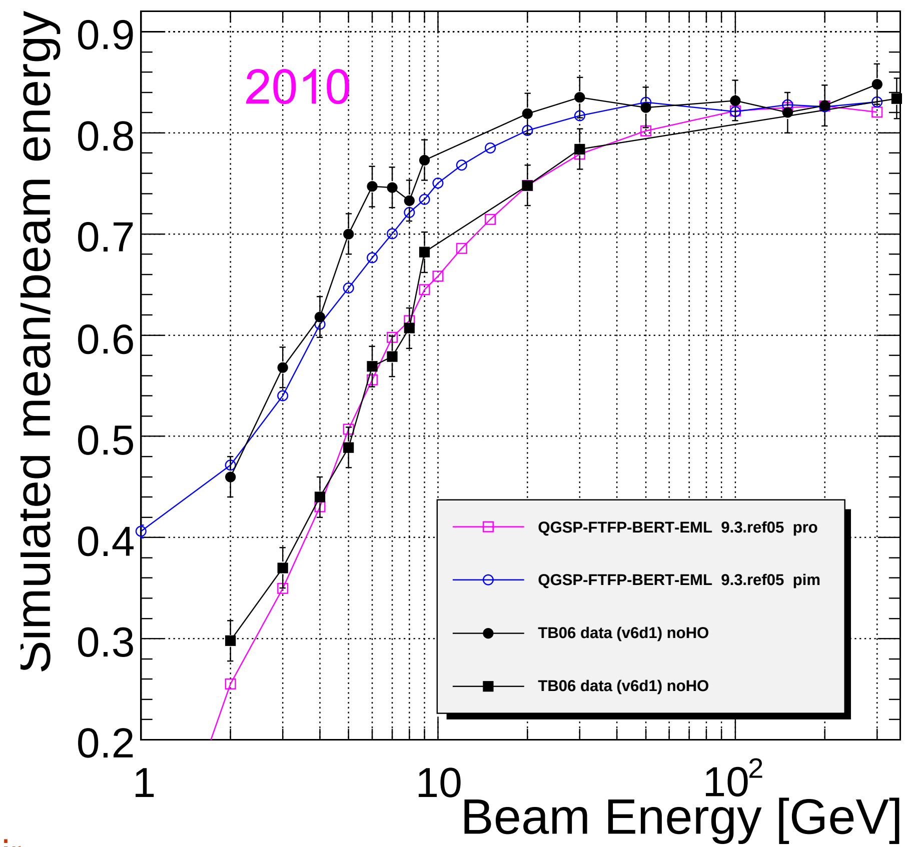


Impact on LHC Experiments (II)

- The experiments adopted newer Geant4 versions and newer physics lists (current default is QGSP_BERT)

Response of CMS Hadron Calorimeter to π^- and p





Summary

- Geant4 provides a large number of models for hadronic physics each valid over a certain energy domain for a number of incident particles. These models are put together in a physics list to satisfy a given application domain.
- The models are continuously improved over the years adding new features and new models are added to the list.
- The models are validated against data obtained from thin target experiments as well as from thick targets and calorimeters. A validation framework is being developed to keep track of results from all the comparisons.
- LHC experiments have successfully deployed Geant4 physics list to model the performance of the detectors. Hadronic models are successfully used for space and medical applications.

Backup Slides

INCL/ABLA (data in blue, model in red)