An Overview of Geant4 Hadronic Physics Improvements

SNA + MC2010

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on behalf of the Geant4 Hadronic Working Group

Outline

- Motivation
- Inelastic hadronic models
  - string models
  - cascades
  - precompound and de-excitation
- Other notable models
- Cross sections
- Physics lists
- Validation
- Summary

The LHC and Geant4 Hadronic Physics Improvements

- Turn-on of LHC detectors has motivated the improvement of hadronic physics models
- Most validation of G4 hadronic models done with “thin target” data -> physics can be tested in isolation
- Comparison against test beam data is a vital integration test of combined G4 models (EM + hadronic)
  - ATLAS, CMS, HARP
- Near future -> data from full ATLAS and CMS detectors will provide strong tests

The LHC and Geant4 Hadronic Physics Improvements

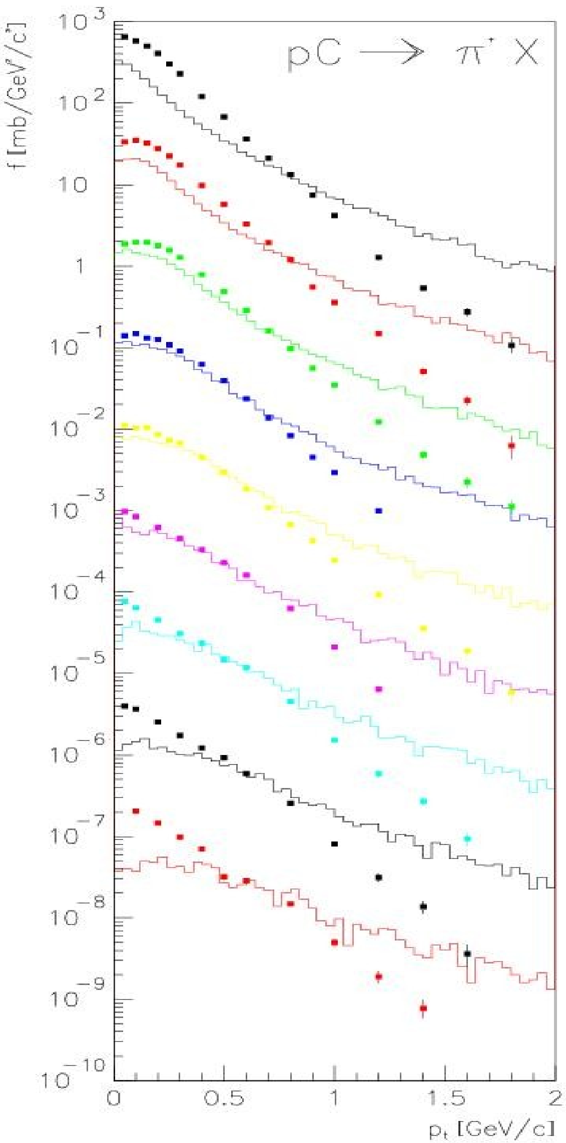
- Development has concentrated on several models
  - string models, intra-nuclear cascades, precompound models, and elastic and inelastic cross sections
  - improvement in these models has resulted in better agreement with test beam data

Fritiof Fragmentation (FTF) Model

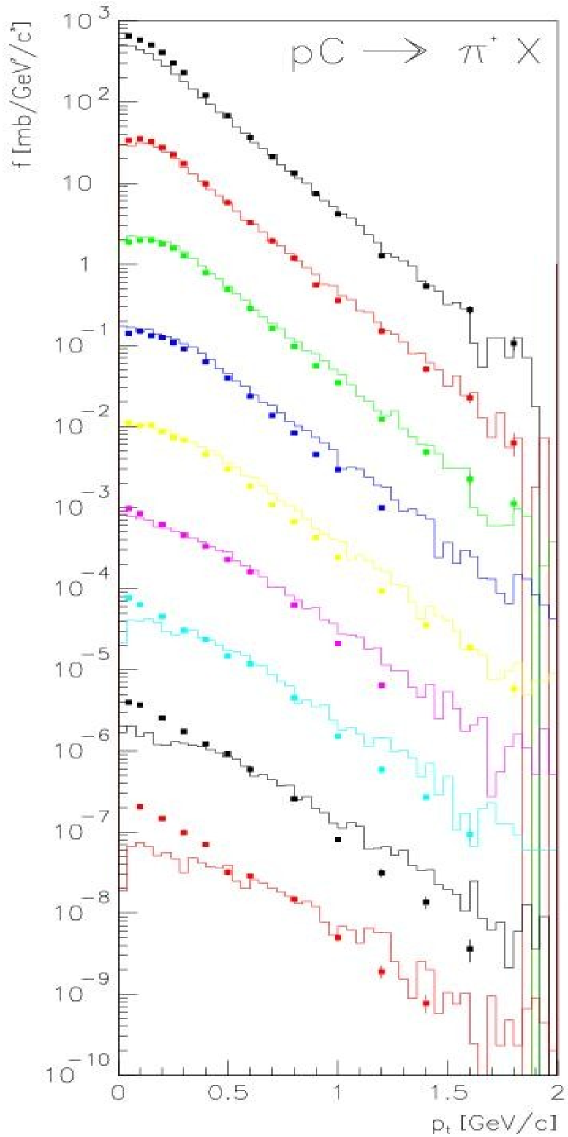
- Quark-gluon string (QGS) model has been used extensively in Geant4 physics lists
  - good performance at high energy (> 20 GeV)
  - not valid below 10- 15 GeV
- FTF model much improved during last 2-3 years (previous talk, this session)
  - single diffraction added
  - Reggeon cascading
  - model now 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

p C -> pi- X at 150 GeV/c (NA49 data)

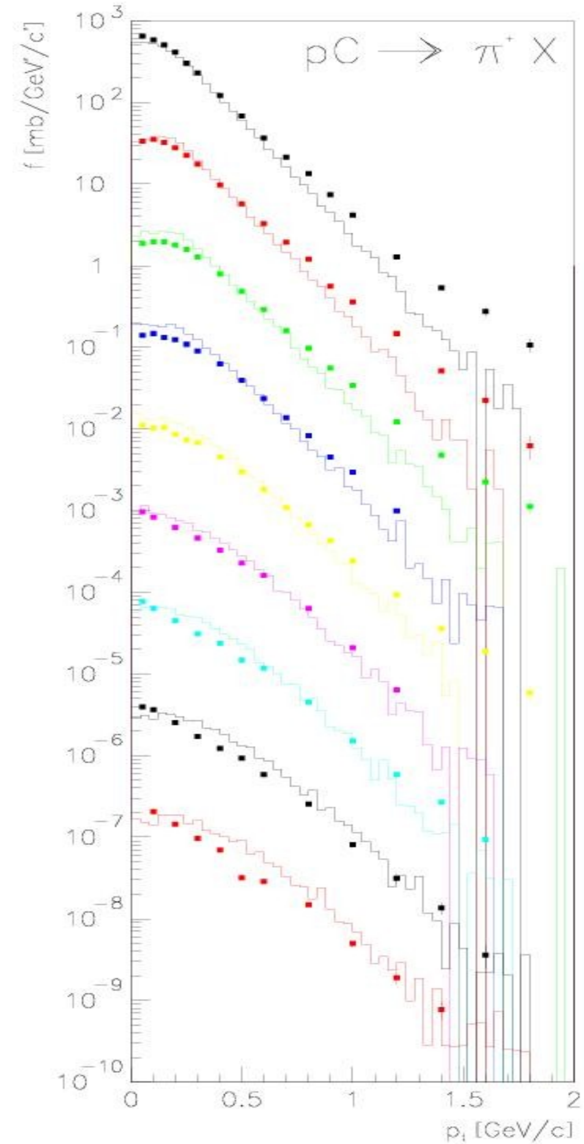
FTFP G4 8.2



FTFP G4 9.3.p01



QGSP G4 9.3.p01



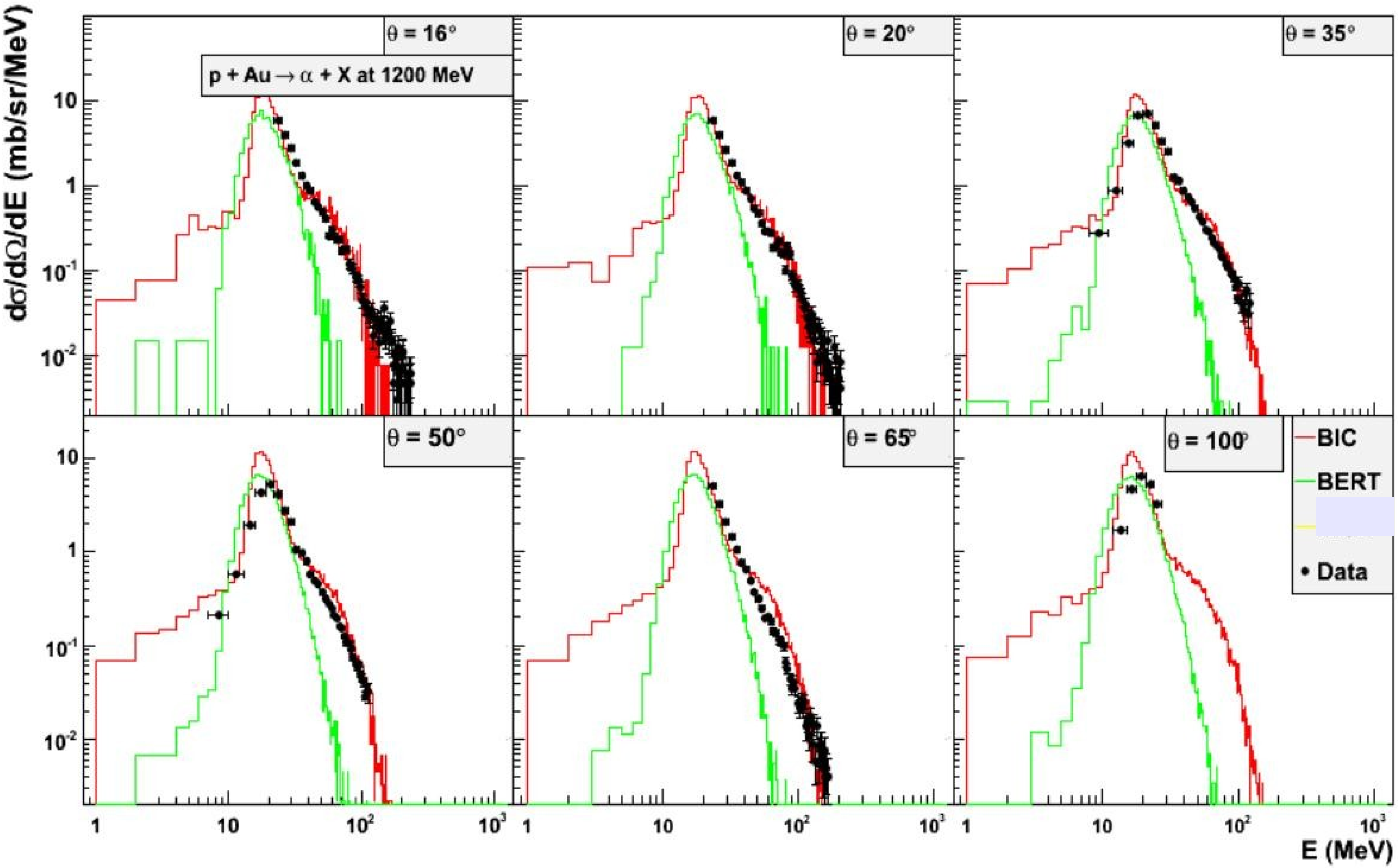
Modified INUCL (Bertini-style) Cascade

- 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

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) or FTF models
  - 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 parameterizations (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

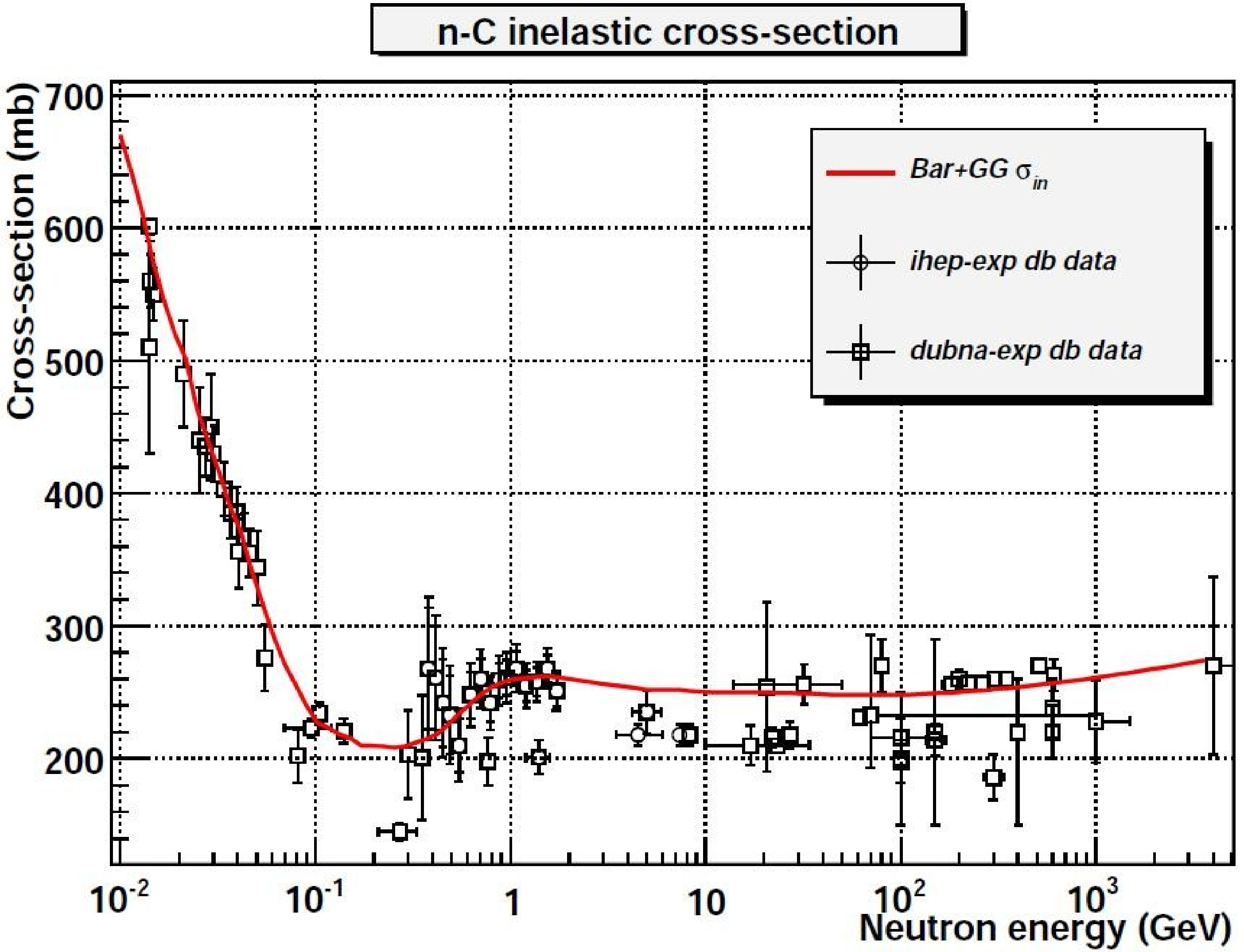
Precompound and De-excitation Models vs. IAEA Data for p+Au -> alpha X



Hadronic Cross Sections

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

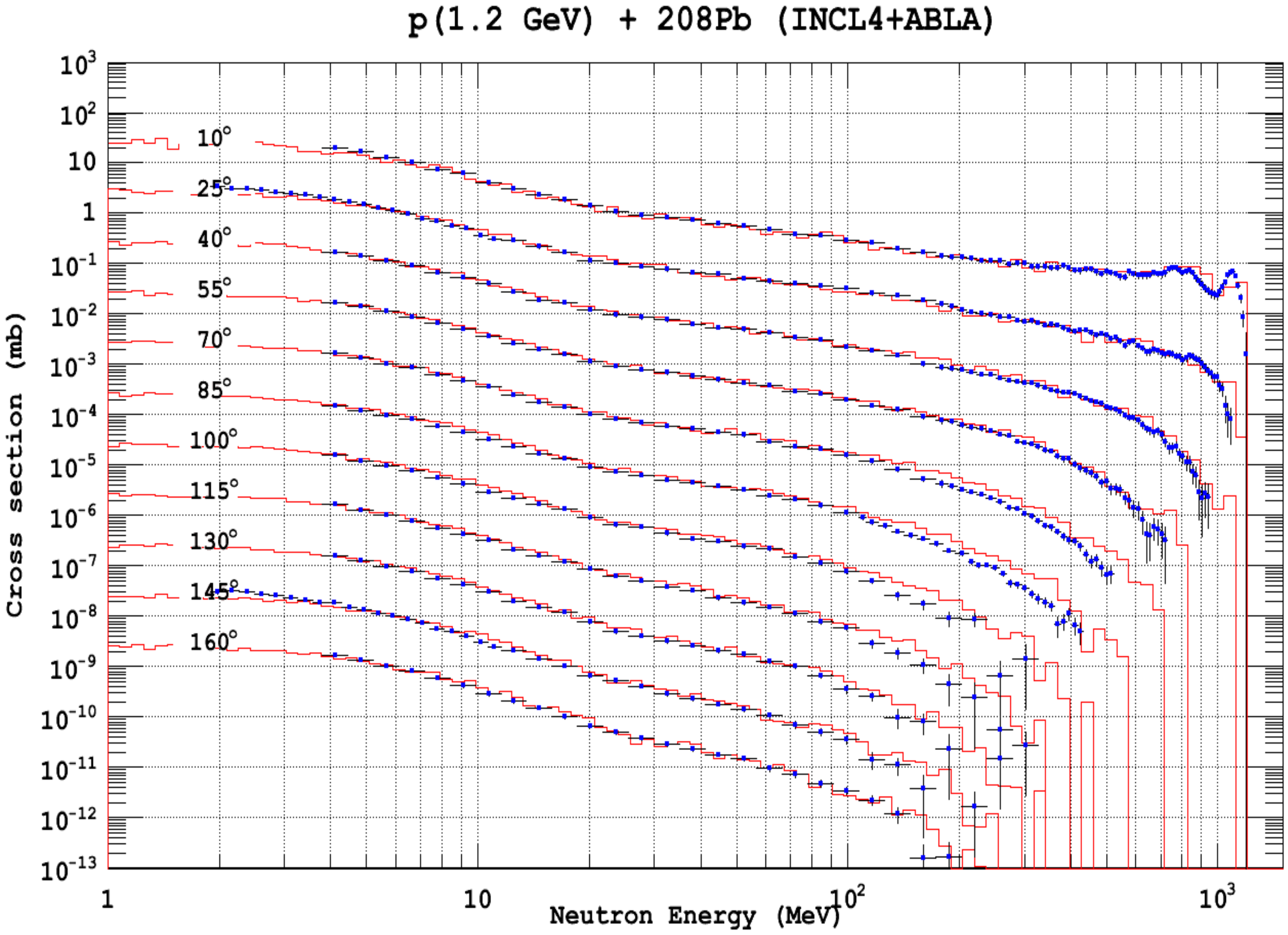
Parameterized Cross Section Based on Glauber-Gribov Model vs. IHEP and Dubna Data



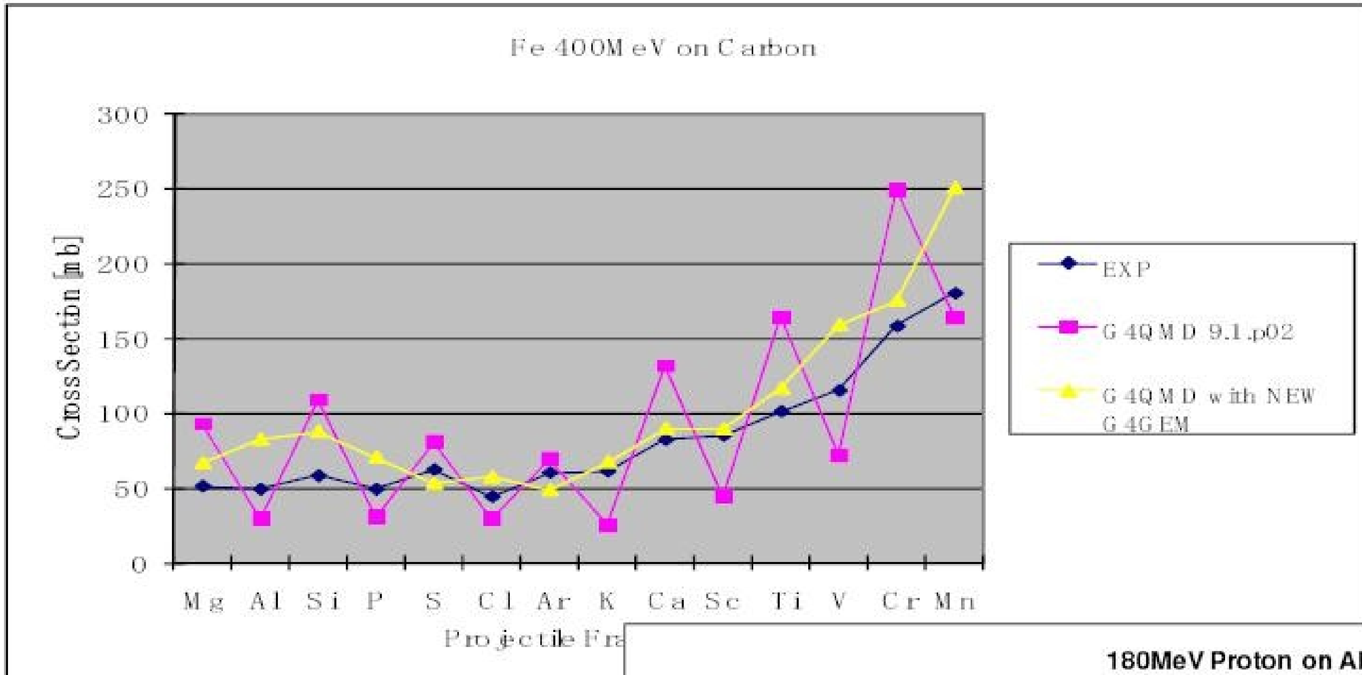
Other Notable Models

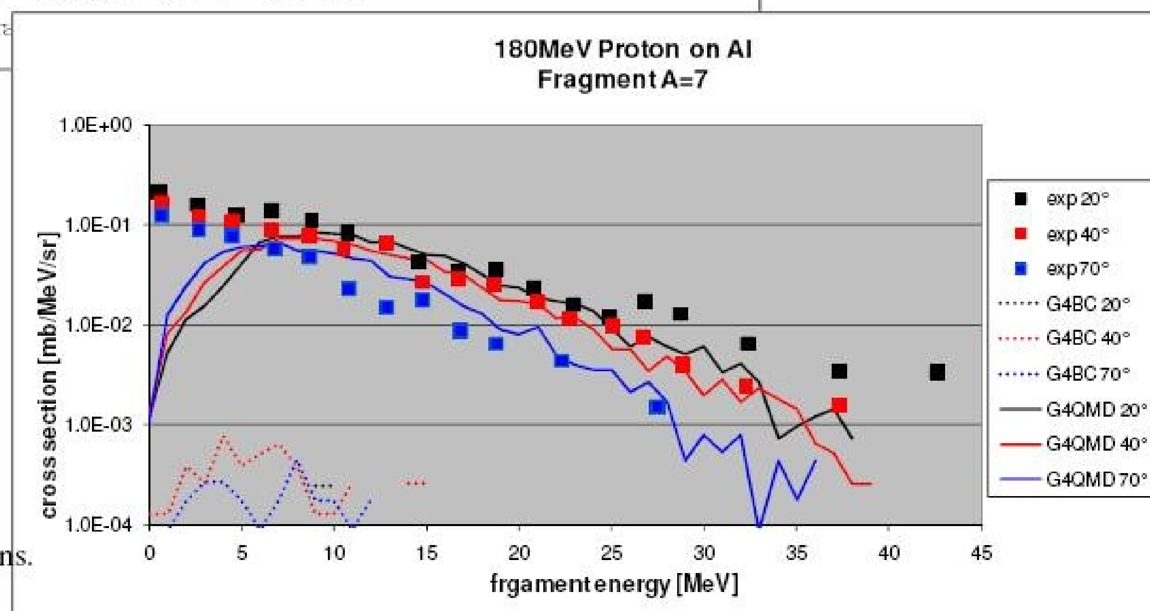
- INCL/ABLA (see 1st talk this session)
  - C++ translation of CEA/Saclay code
  - cascade (INCL) + de-excitation (ABLA) used for nucleon, pion, nuclear projectiles of E < 3 GeV
- QMD nucleus-nucleus collision model (see talk in session J1 Monday)
  - quantum molecular dynamics code valid for all nuclear targets and projectiles, 0.2 GeV < E/A < 5 GeV
- CHIPS intermediate and high energy (experimental)
  - previously used for stopped particle reactions, nuclear de-excitation, gamma- and lepto-nuclear
  - recently extended to medium and high energy reactions

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



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.

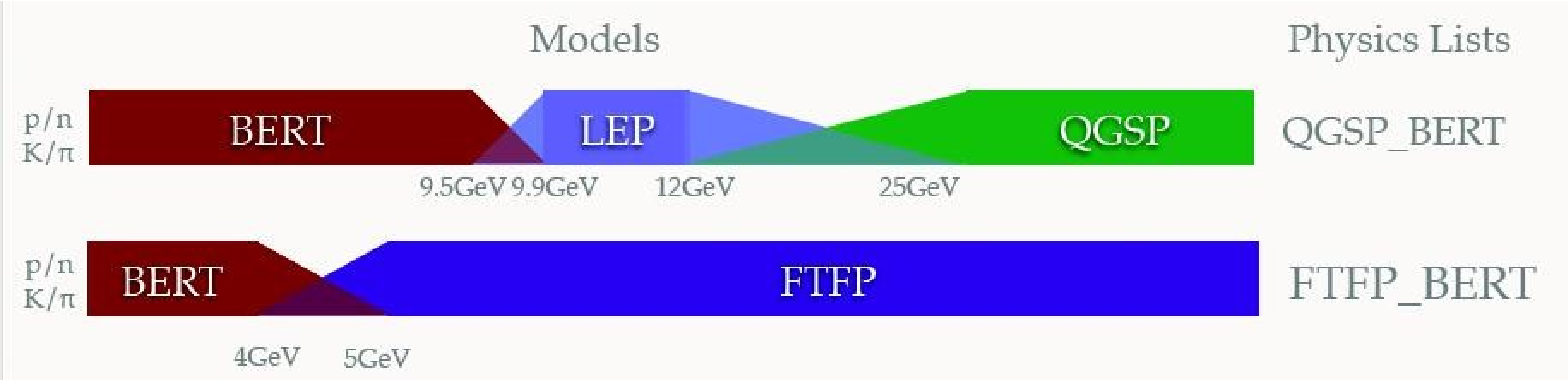
Combining the Models: Physics Lists

- Geant4 philosophy: allow physics to be user-configurable
  - no single model handles all energies for all particles
  - can choose best models and cross sections from several alternatives provided
  - “physics lists” provide this capability

- QGSP_BERT physics list (and its variants) now used by all four major LHC experiments
  - Bertini-style cascade from 0 – ~10 GeV
  - LEP (GHEISHA-derived) models from 10 GeV to ~15 GeV
  - Quark-gluon string (QGS) model used above ~15 GeV
  - some overlap provided where different models are joined together

Physics Lists (2)

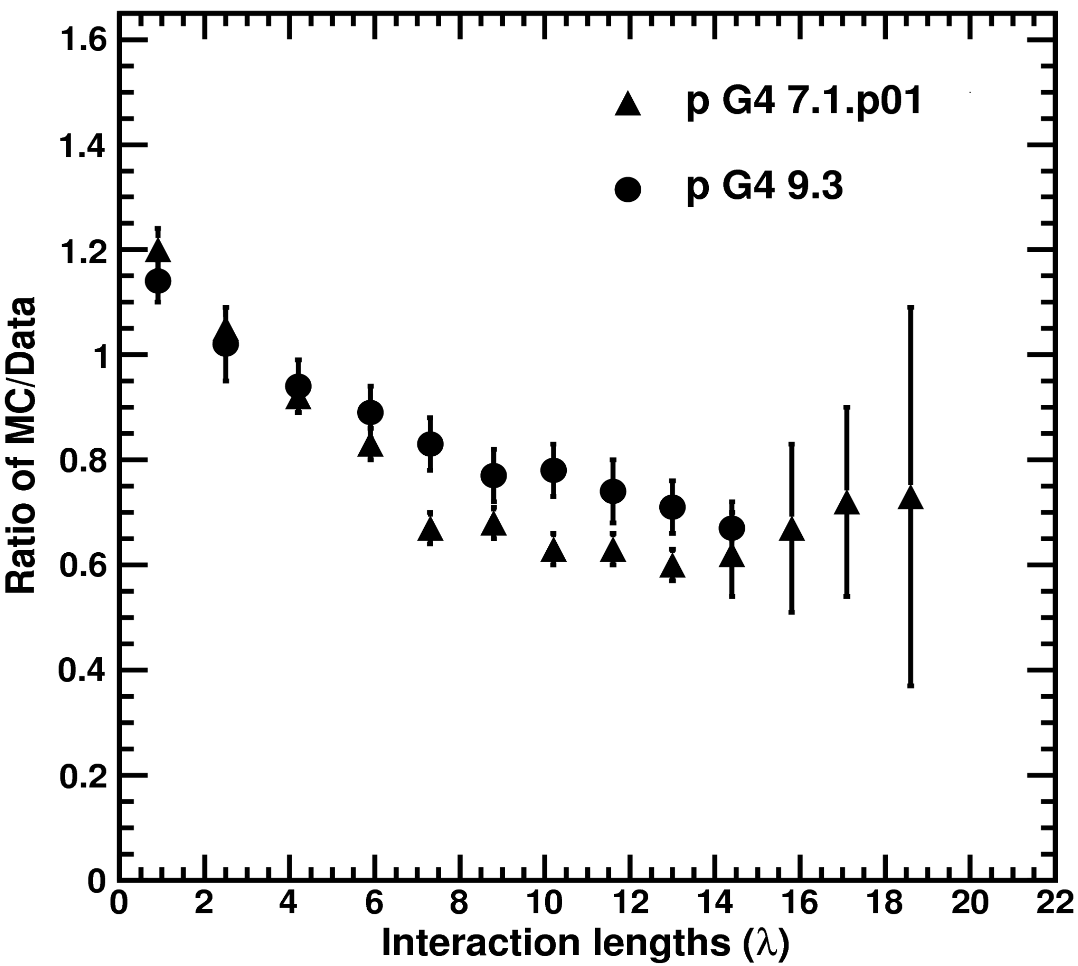
- Merging models in a physics list:



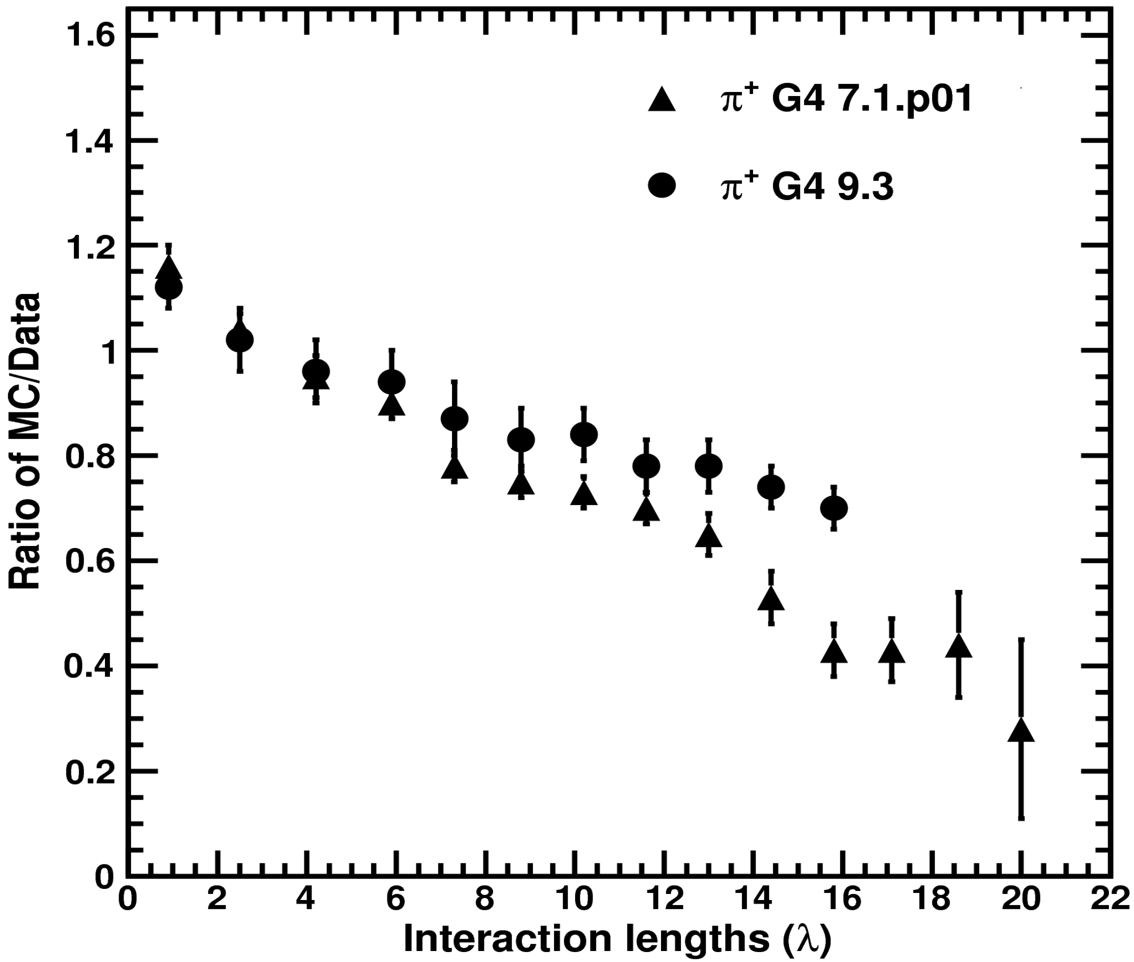
- Discontinuities can arise if:
  - models are not well-matched
  - energy span of transition from one model to next is too small

- As models are improved, new physics lists will have better behavior and replace old ones

ATLAS Tile Cal Test Beam
Shower Length from Incident Protons

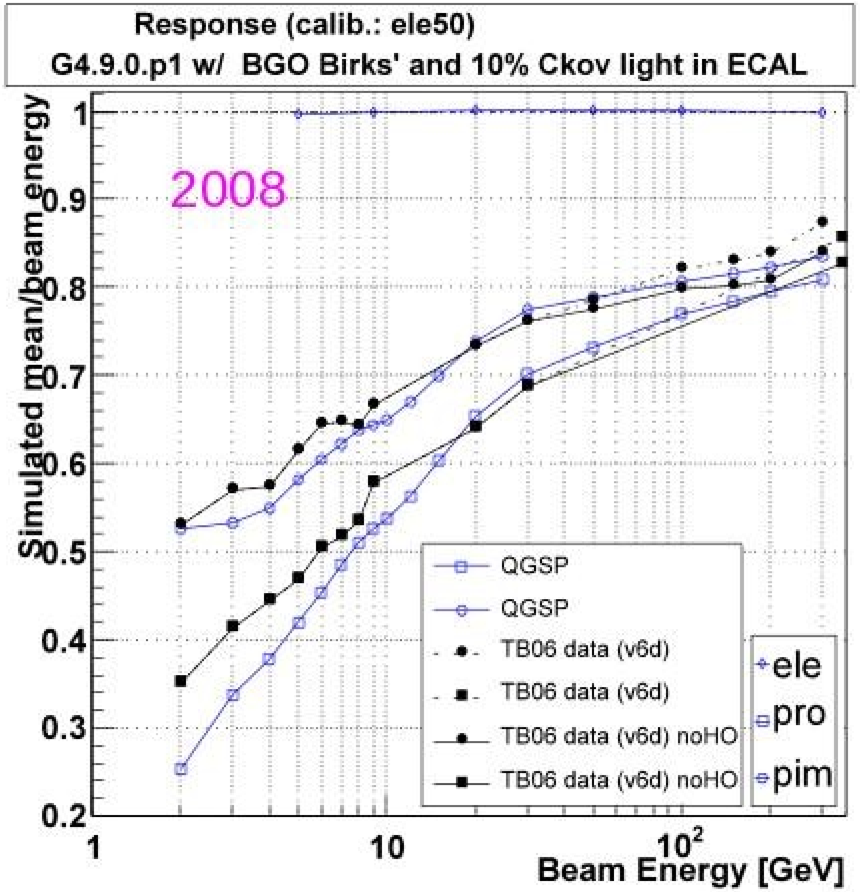


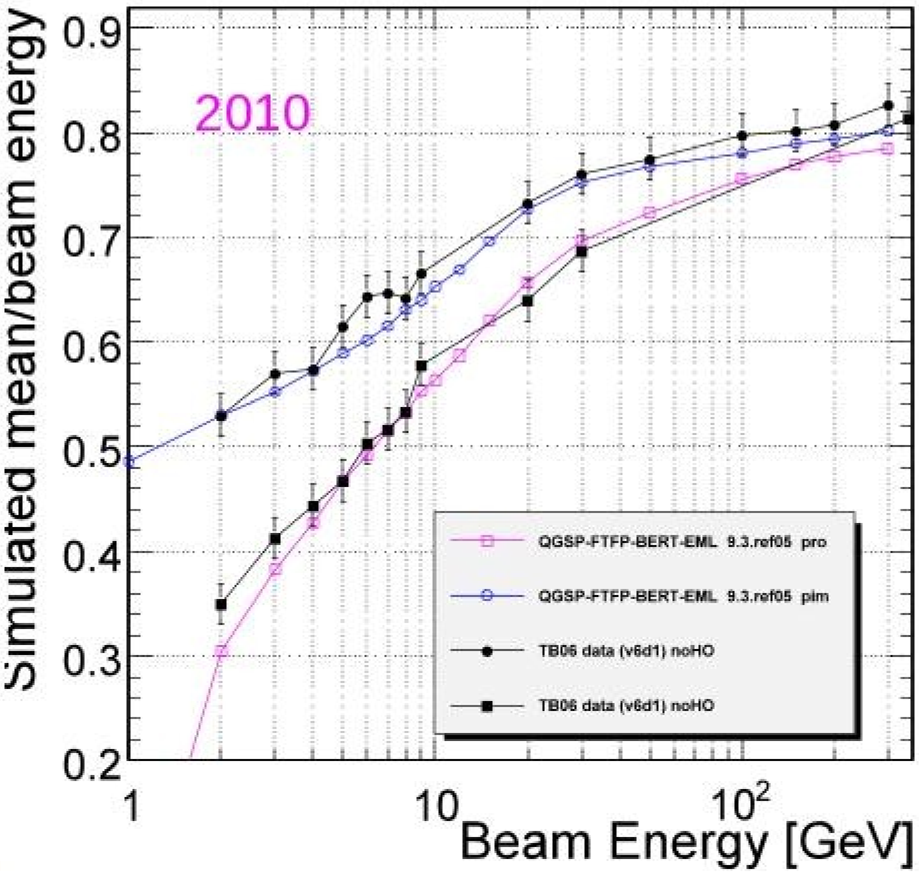
ATLAS Tile Cal Test Beam
Shower Length from Incident Pions



CMS Combined Calorimeter Response to vs. Hadronic Models (2008 and 2010)

protons: bottom curves, pions top curves





Hadronic Physics Validation

- During the past two years much effort has been devoted to improving Geant4 hadronic validation
  - according to the January 2009 Review of the Geant4 project: "An impressive program of systematic physics validation has been carried out."

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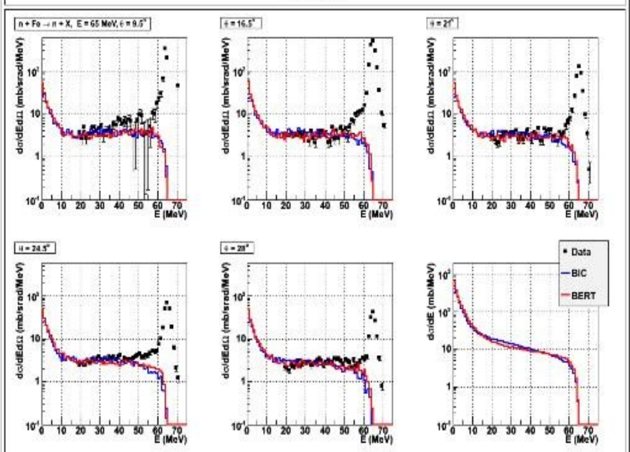
Name of the Test:	test30
Responsible:	V. Ivanchenko
Description:	Test of hadronic generators of inelastic processes

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

Summary

- Geant4 hadronic models have improved significantly during the past 5 years
  - test beam data from ATLAS, CMS and HARP have played a central role
- Hadronic code development has focussed on string, cascade and precompound models
  - improved physics
  - improved speed
- Hadronic cross section parameterizations have been improved

- Hadronic models now regularly validated and validations soon to be made easily accessible to public