Recent Developments and Validations in Geant4 Hadronic Physics

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Geant4 Hadronic Contributors

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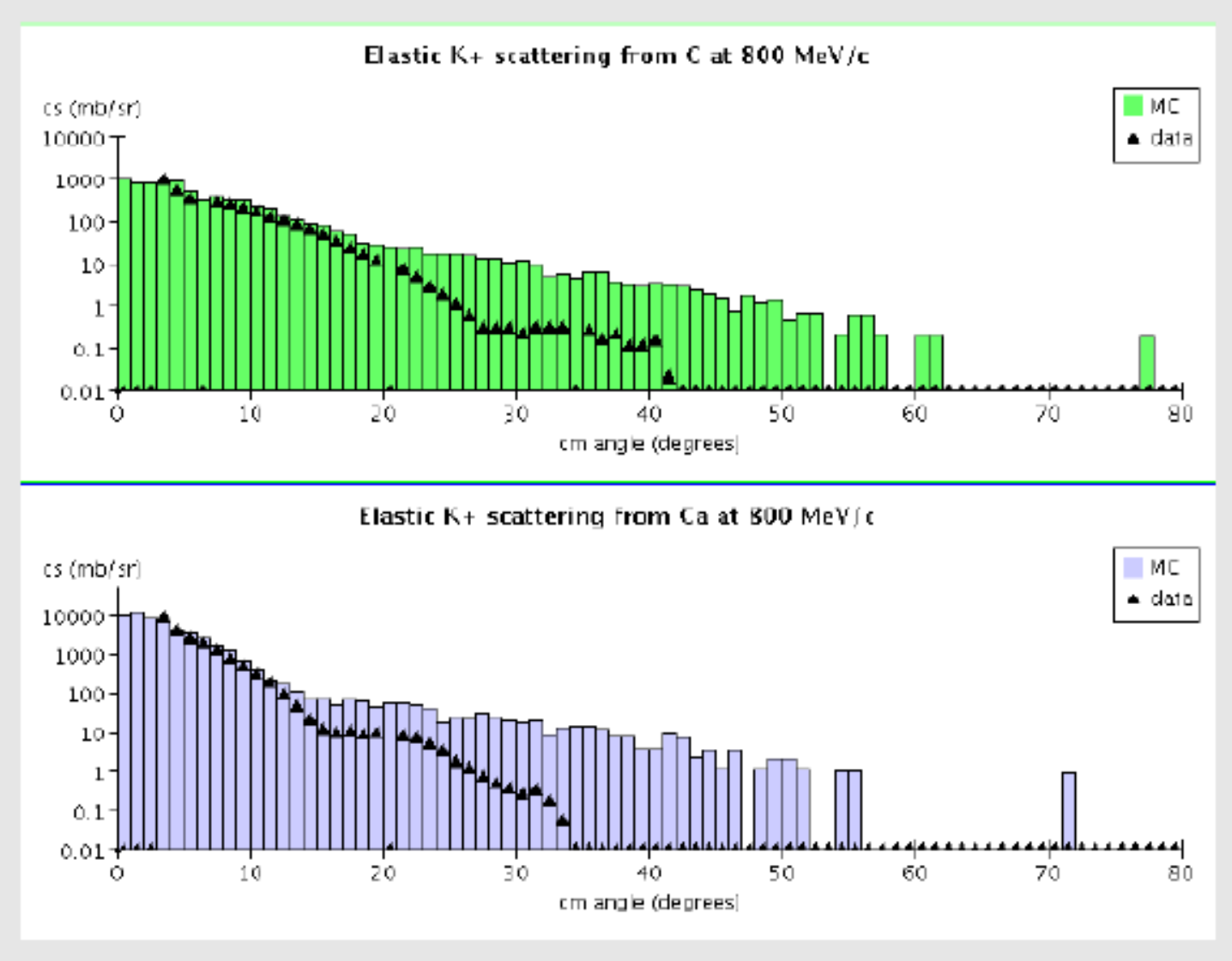
Outline

- ***Elastic scattering (improvements)***
- ***Parameterized model (improvements)***
- ***Cascade models (improvements, validation)***
- ***High energy models (cross section comparisons)***
- ***Shower shape studies (testing a combination of the above models)***

Elastic Scattering Improvements

- Elastic scattering is important for shower shapes
- Existing model is just adequate, needs improvement
  - non-relativistic kinematics, parameterized to fit mostly forward data, charge exchange included, no coherence effects
- New model and process (G4UHadronElasticProcess, G4HadronElastic) available with 8.1 release
  - high precision neutron cross sections for E < 20 MeV
  - relativistically correct
  - charge exchange removed (will be included as inelastic)
  - improved treatment of p, n scattering from p, d, α
  - coherence effects included (diffraction minima) above 1 GeV

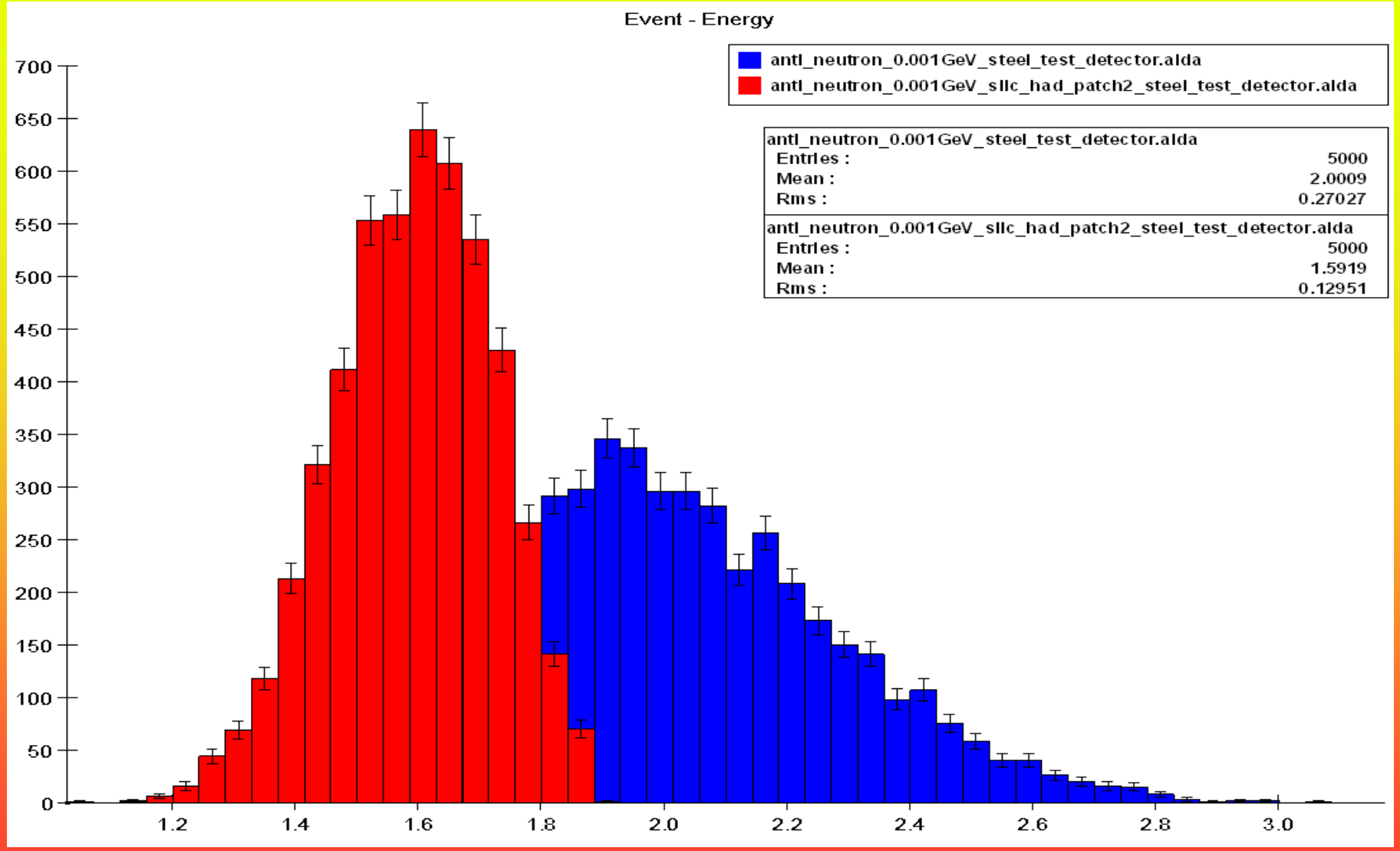
Elastic Scattering



Parameterized Model Improvements

- Parameterized model (low energy and high energy parts) is a re-engineered version of GHEISHA
  - based on fits to data with some theoretical guidance
  - can be used for all long-lived hadrons + light ions
  - not originally intended to conserve most quantities on an event-by-event basis, but rather on average (does well in showers)
- Improvements for 8.1 release include better energy conservation, nucleon counting in low energy part (< 25 GeV)
- Similar improvements to high energy part in release 9.0

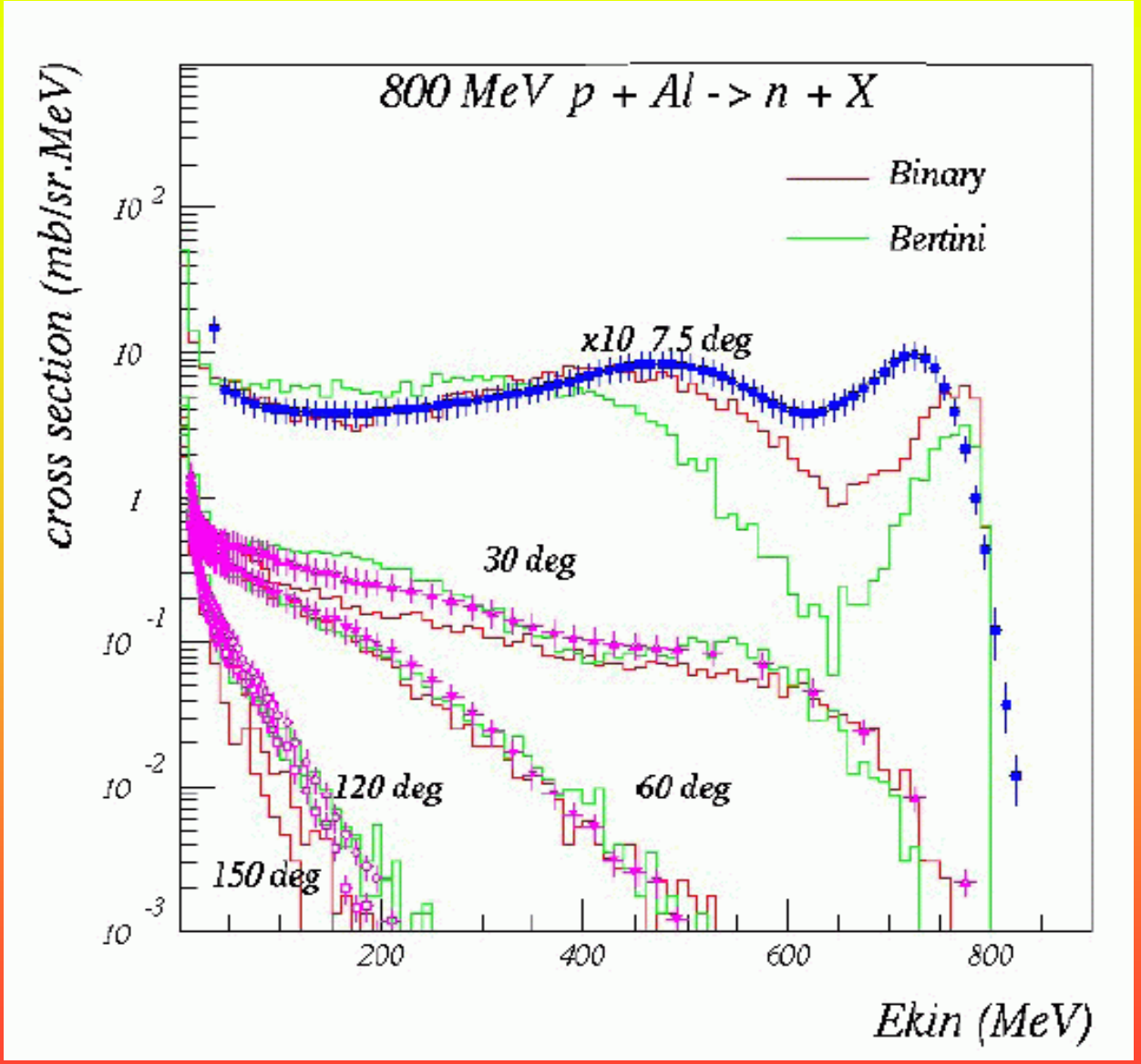
Parameterized Model Test in ILC Calorimeter (Ron Cassell - SLAC)



Cascade Model Improvements

- Two cascade models offered by Geant4
  - binary: two particle collisions only, with resonance formation and decay, for p, n, π (< 3 GeV)
  - Bertini: based on INUCL code, scattering based on free-space cross sections (< 10 GeV)
- Binary model extended to heavy ions ($A_{projectile}$ < = 12) or (A_{target} < = 12), E < 10 GeV/A
- Bertini cascade extended to kaons, hyperons
  - planned extension to elastic scattering and heavy ions

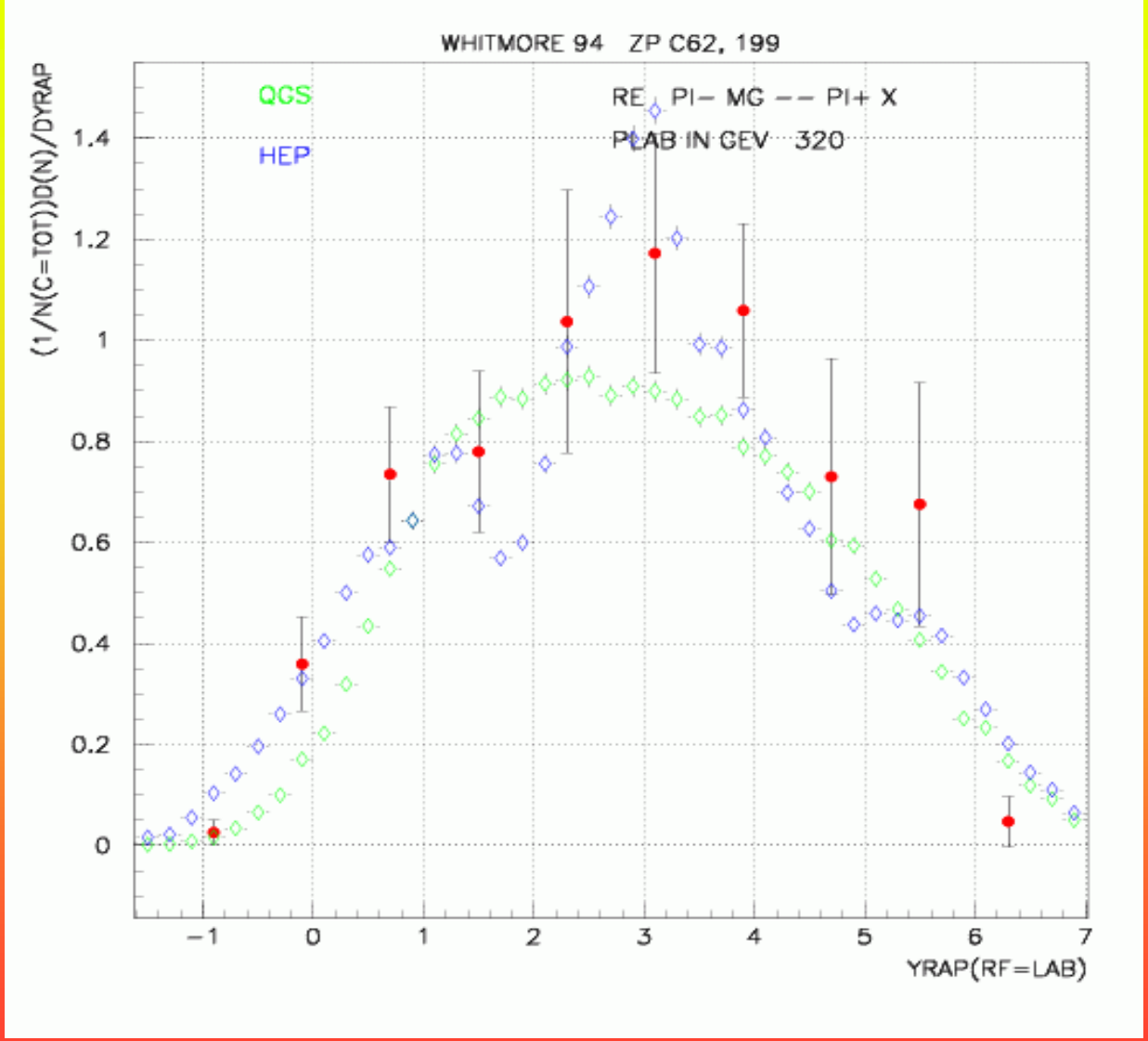
Cascade Validation



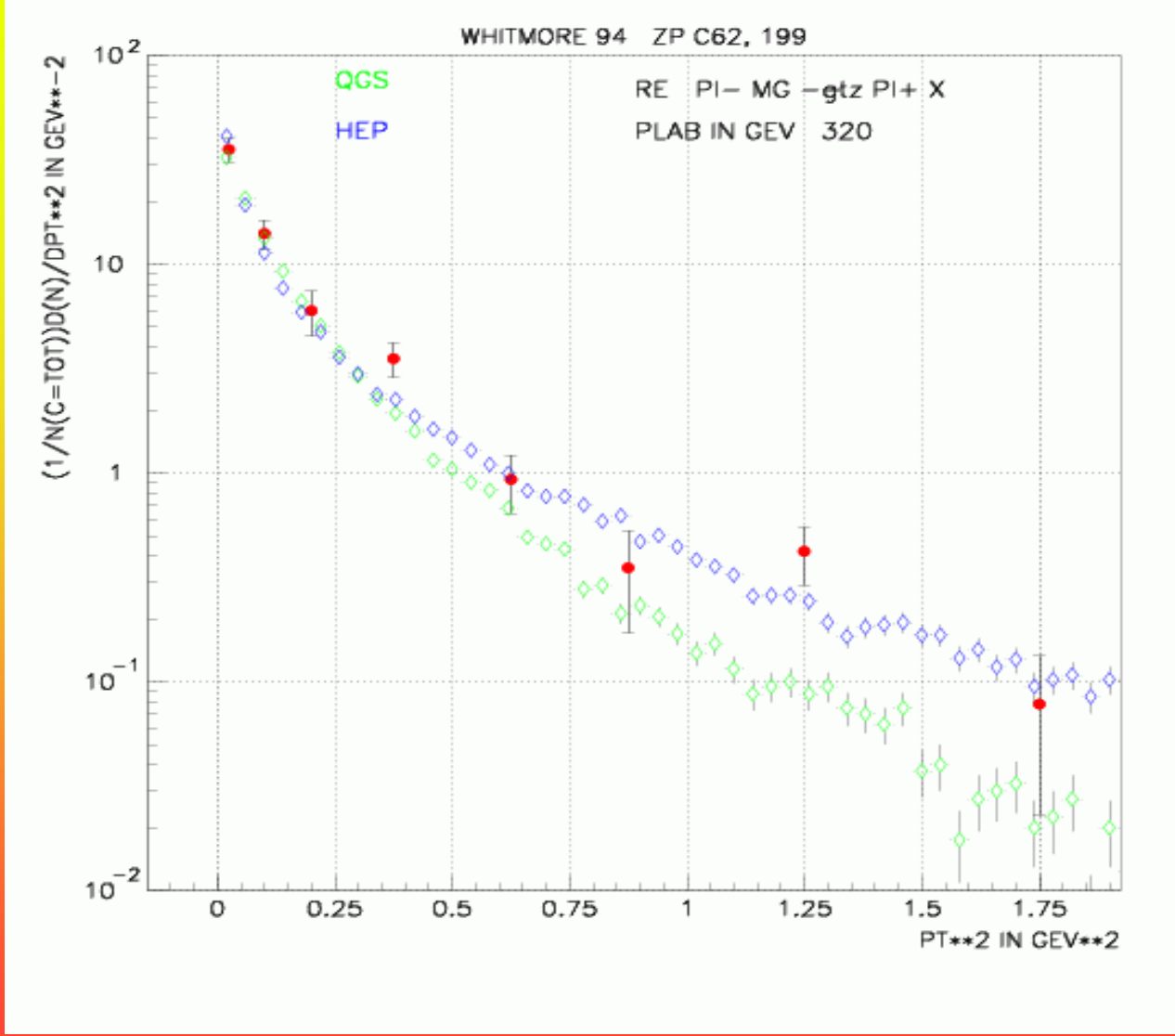
High Energy Models

- Geant4 has three models for high energies (15 GeV < E < ~10 TeV):
  - high energy parameterized (HEP) : derived from GHEISHA, depends mostly on fits to data with some theoretical guidance
  - quark-gluon string (QGS) : theoretical model with diffractive string excitation and decay to hadrons
  - Fritiof fragmentation (FTF) : alternate theoretical model with different fragmentation function
- Of the two theoretical models (QGS and FTF) QGS seems to work better in most situations
- Most used and tested models are HEP and QGS

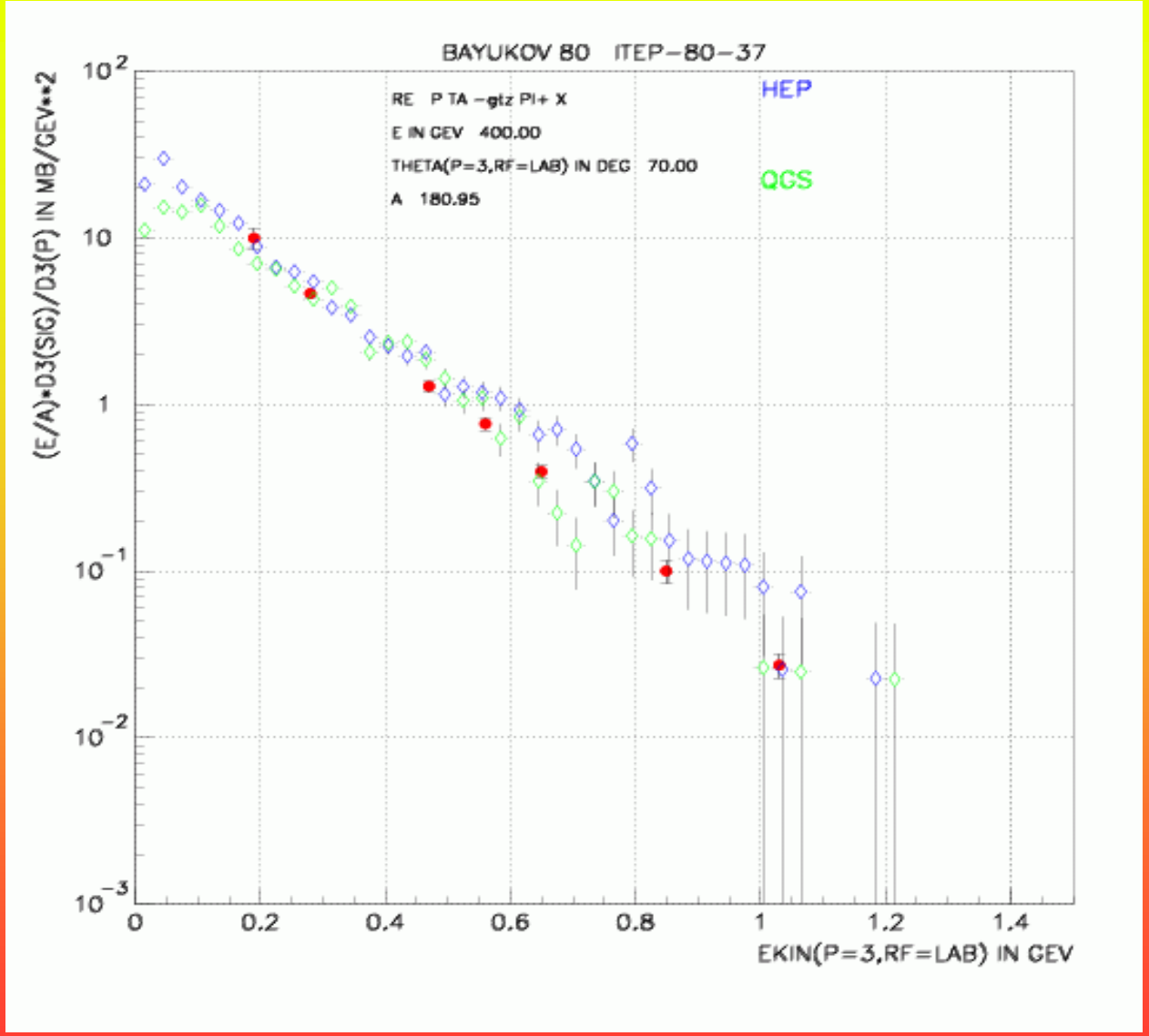
High Energy Model Validation: rapidity



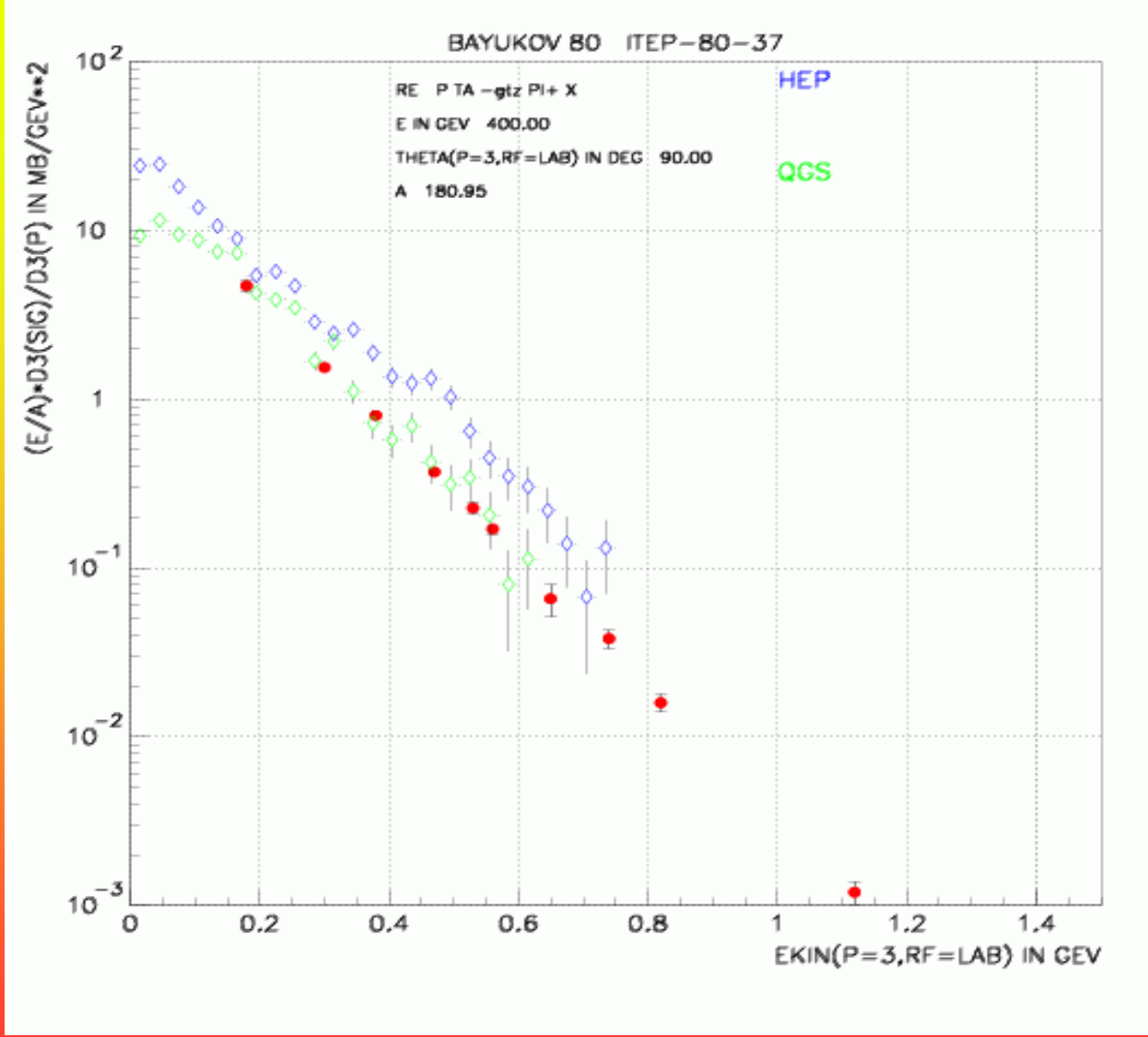
High Energy Model Validation: transverse momentum



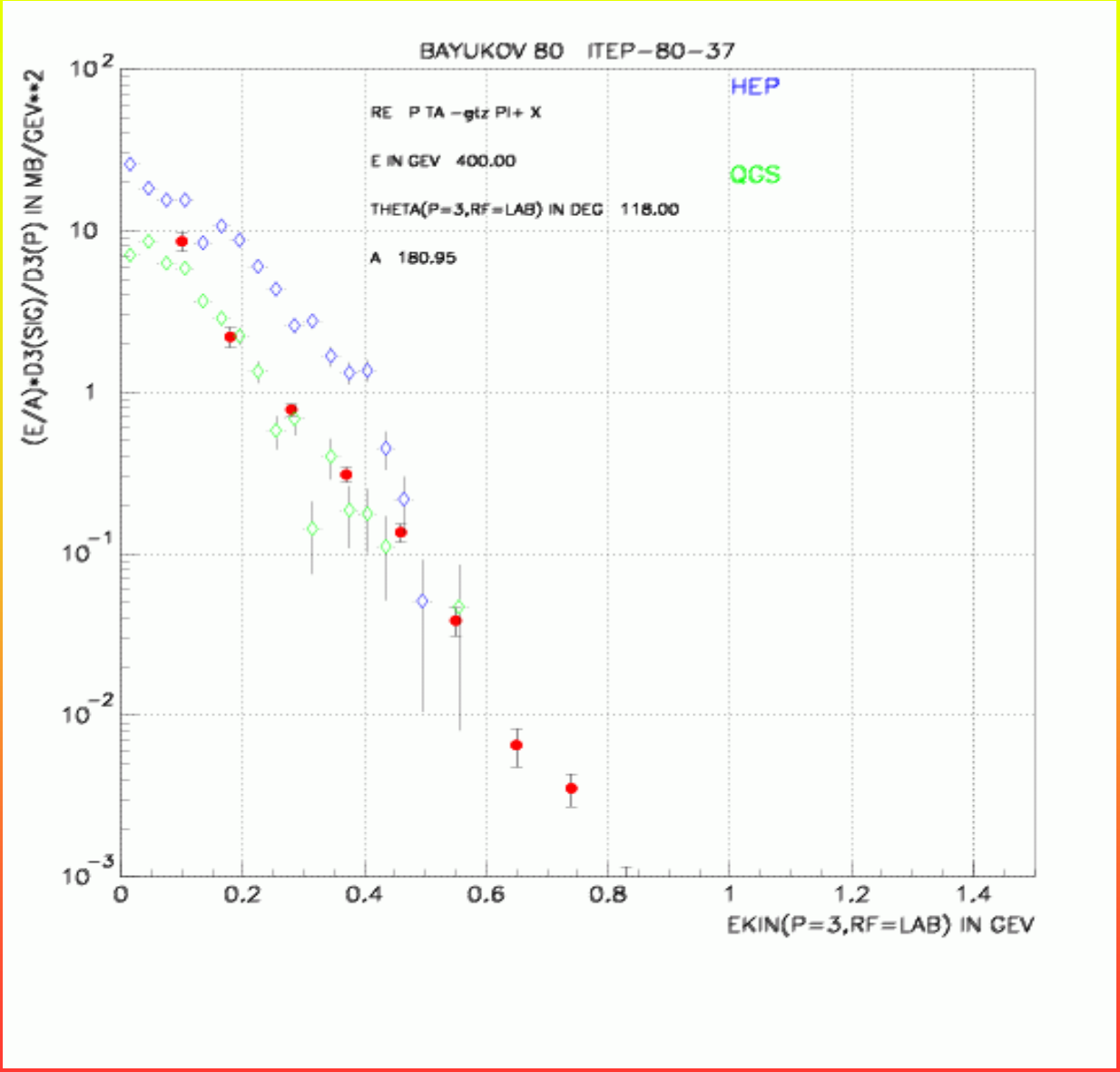
High Energy Model Validation: kinetic energy at 70 degrees



High Energy Model Validation: kinetic energy at 90 degrees



High Energy Model Validation: kinetic energy at 118 degrees



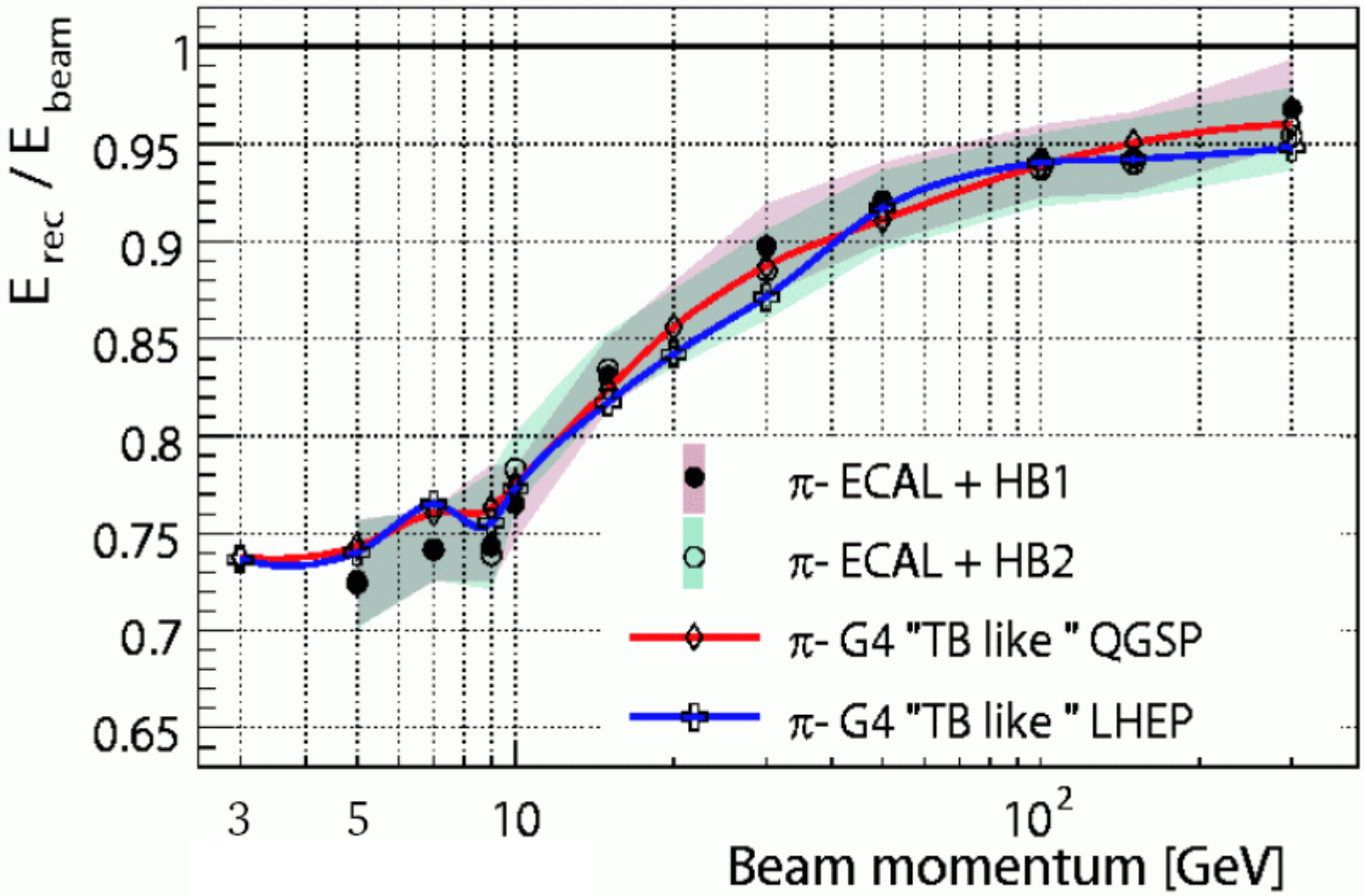
Shower Shape Studies

- To use Geant4 in a realistic simulation many models and processes must be combined in a physics list
  - two physics lists, LHEP and QGSP, are the most used and most tested Geant4 physics lists in high energy calorimetry
  - LHEP consists of the low energy parameterized (LEP) and high energy parameterized (HEP) models, plus the Geant4 standard electromagnetic package
  - QGSP consists of the Quark-gluon string model (QGS), the Precompound model and some of the LHEP models plus the Geant4 standard electromagnetic package
- Data from several test beam experiments have been compared to the predictions of these physics lists
- Shower shapes provide especially good tests

Shower Shape Studies

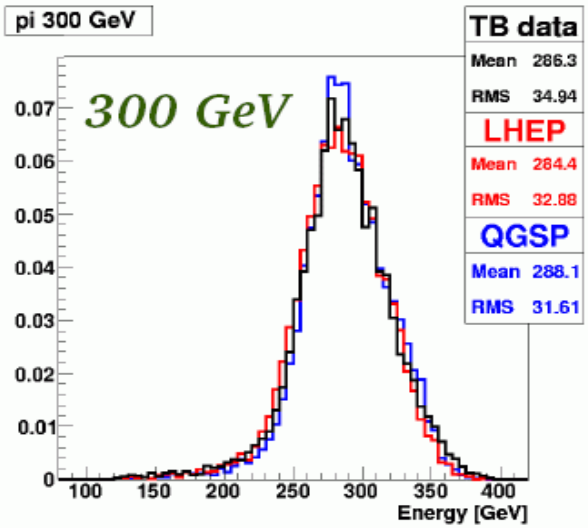
- The following comparisons are based on data from the CMS test beam
- CMS test beam setup (2004):
  - ECAL: 7 x 7 array of $PbWO_4$ crystals
  - HCAL: 2 barrel production wedges of alternating brass absorber and scintillator
  - pion beams from 2 to 300 GeV
- Simulation used Geant4 6.2 p02 and looked at:
  - recovered energy
  - pion energy spectra
  - longitudinal shower shapes

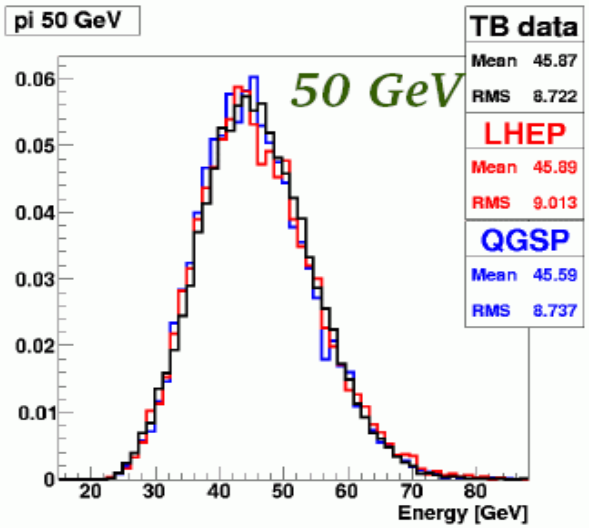
Calorimeter response to pions: ECAL+HCAL

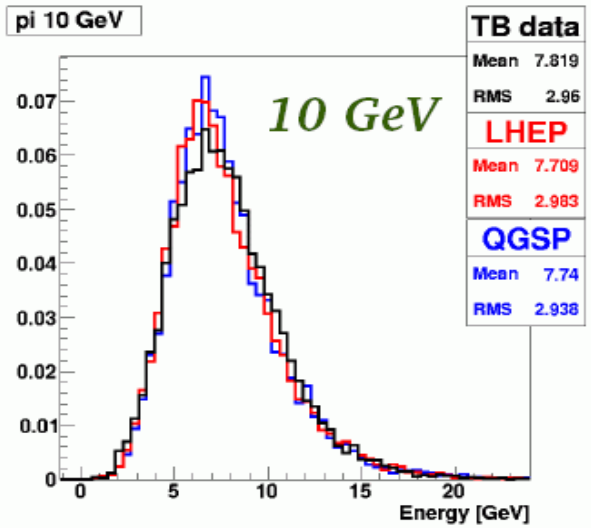


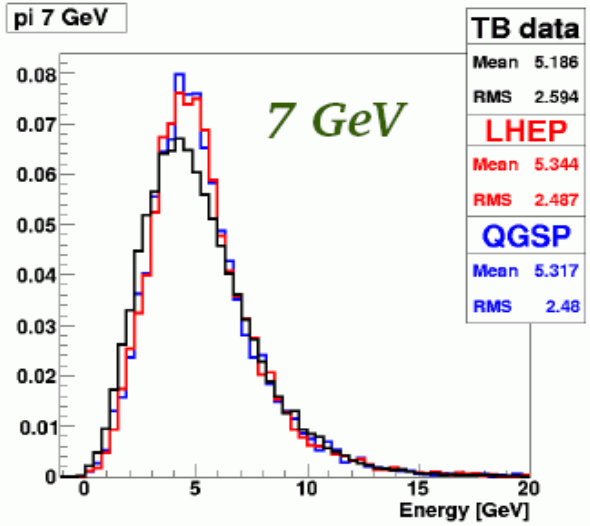
Slide courtesy of J. Damgov, S. Piperov, S. Kunori and the CMS collaboration

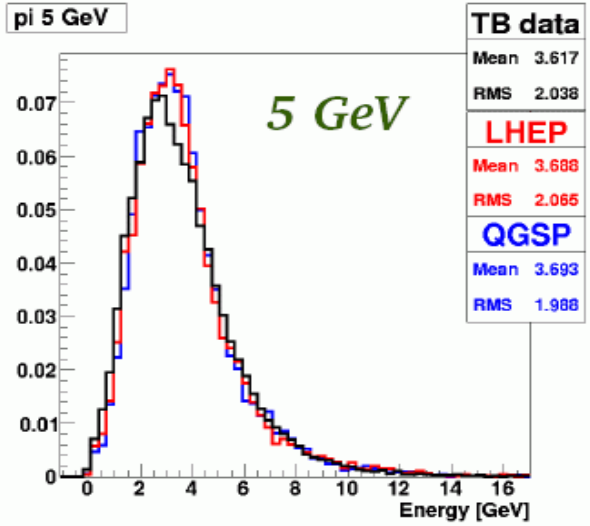
Energy spectrums: data vs GEANT4





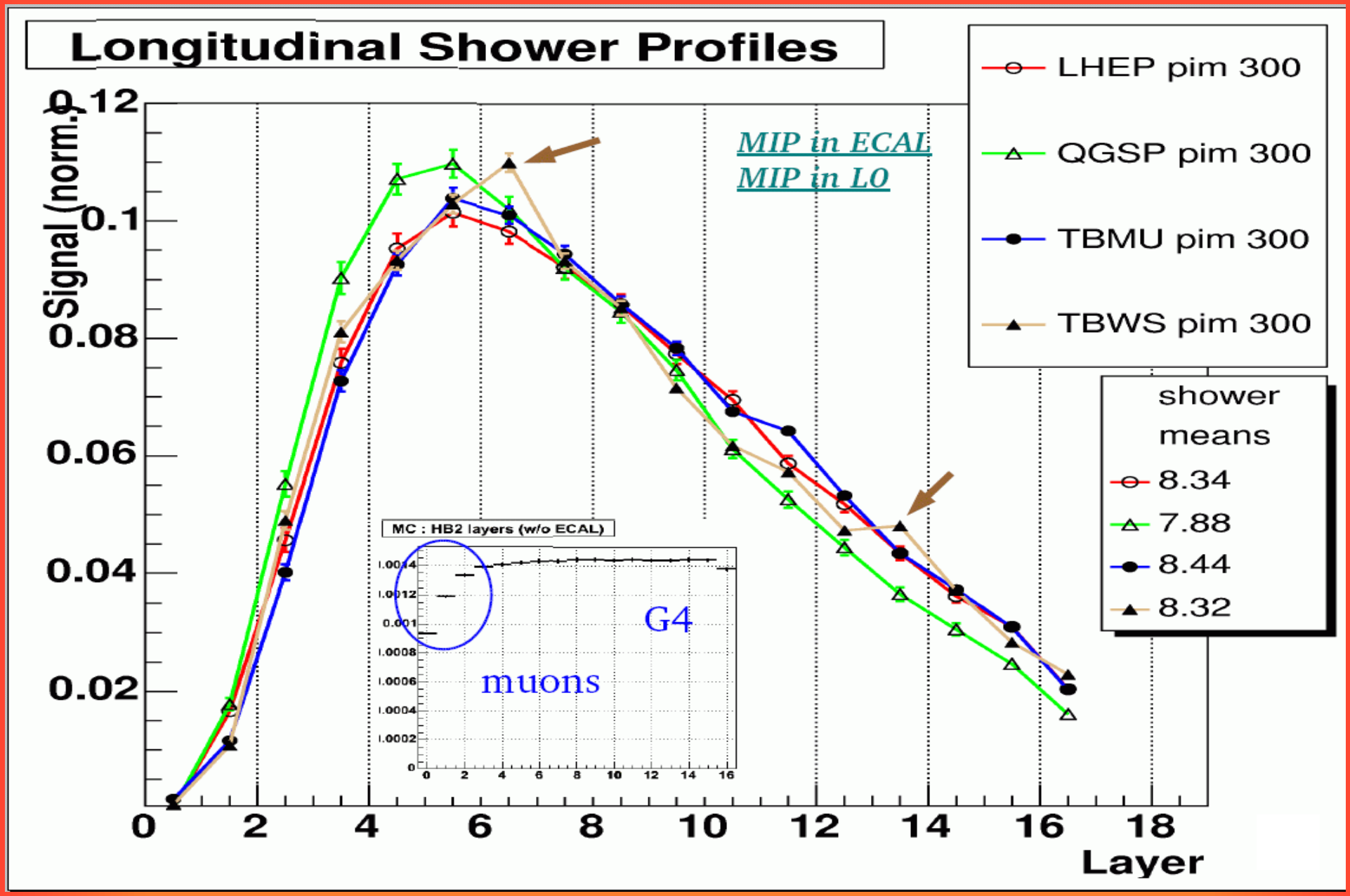






7-10 GeV
is the transition
region between
low and high
energy
parametrization

Slide courtesy of J. Damgov, S. Piperov, S. Kunori and the CMS collaboration



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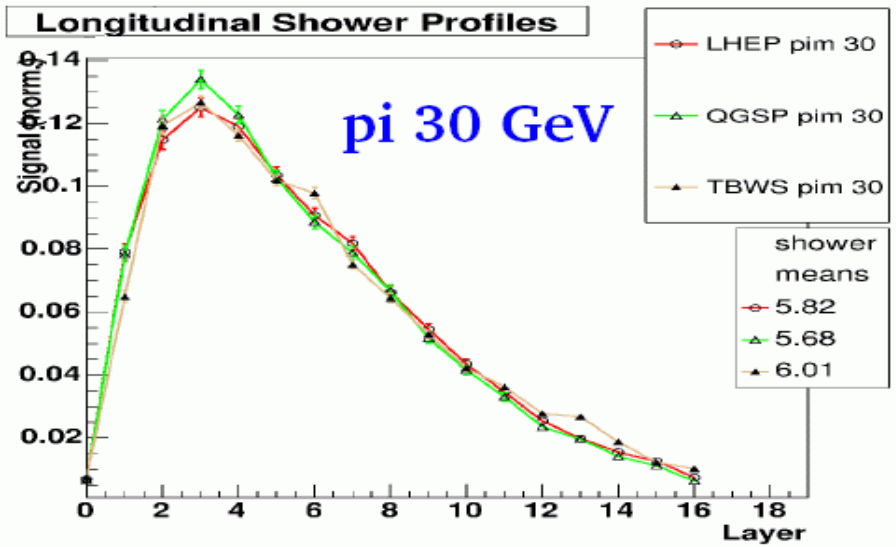
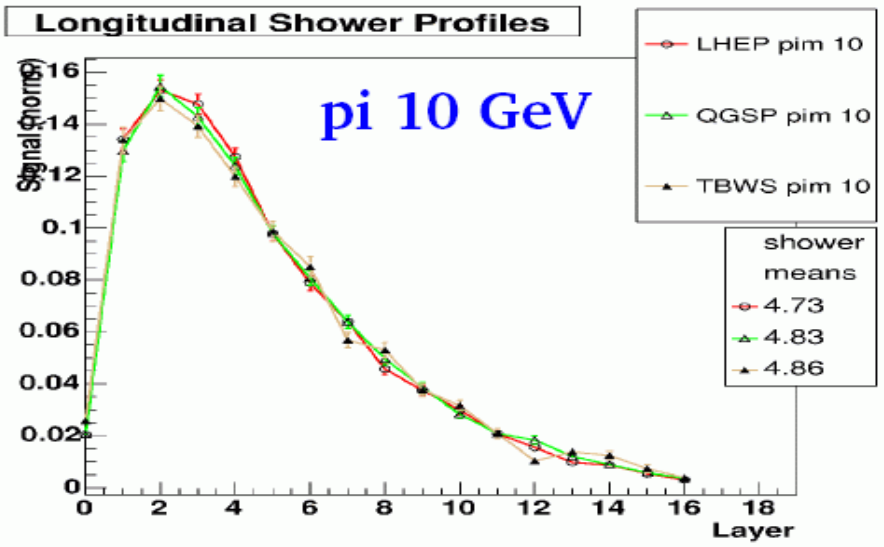
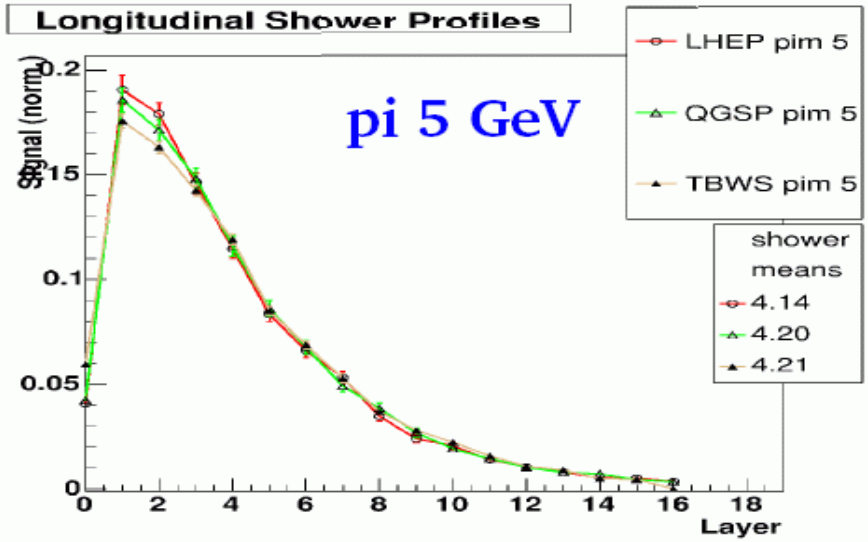
Longitudinal shower profiles (cont.)







LHEP and QGSP show good agreement with test beam data at low and intermediate energies

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Other Developments and Validations

- HARP data to be published soon
  - 1 – 15 GeV test beam data (p, n, π)
  - very useful for cascade model validation
- Alternate physics list: LCPHYS
  - used in linear collider studies
  - test beam validation within the year?
- Geant4 cross section review
  - all hadronic cross sections to be checked and updated
  - internal cross section in QGS model already improved -> possible improvement in shower shapes at high energy

Summary

- Many improvements to the Geant4 hadronic models are being made in order to improve calorimeter response and shower shape agreement
- Elastic scattering was found to be important to shower shape – improvements being made
- Cascade models are important for calorimetry – both Geant4 models are being validated – more data needed
- Shower shapes measured in CMS test beam show good agreement at low to medium energies – high energy models may need improvement