Geant4 Hadronic Physics Update

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Outline

- Recent improvements (2007)
  - handling of user-defined isotopes, G4NDL extension, others
- Improved models
  - precompound, FTF string
- New models
  - high precision neutrons replacement
  - INCL/ABLA alpha version
  - RPG
  - QMD alpha release, JQMD interface, DPMJET interface
- Validation
  - low and intermediate energy

Handling of User-defined Isotopes

- Before Geant4 8.3
  - users could define elements with specific isotope abundances
  - hadronic process would ignore this and use natural abundances
  - HP neutron code always treated isotopic composition correctly
- Now
  - hadronic code will use abundances specified by user to calculate mean free path and select nucleus for interaction
  - Note: in most cases there is no isotopic cross section data, so A dependence is calculated by $A^{2/3}$ or $A^{3/4}$

Extension of G4NDL Database

- 7 new elements added during last year
  - Ag, Br, Ge, Hg, La, Ra and associated isotopes added
  - Cd isotopes added from JENDL
- High energy data from JENDL cross sections
  - up to 3 GeV neutron data for shielding calculations
  - to be added in next release
- Environment variable pointing to G4NDL changed
  - now use G4NEUTRONHPDATA
  - done in order to be consistent with other G4 environment variables

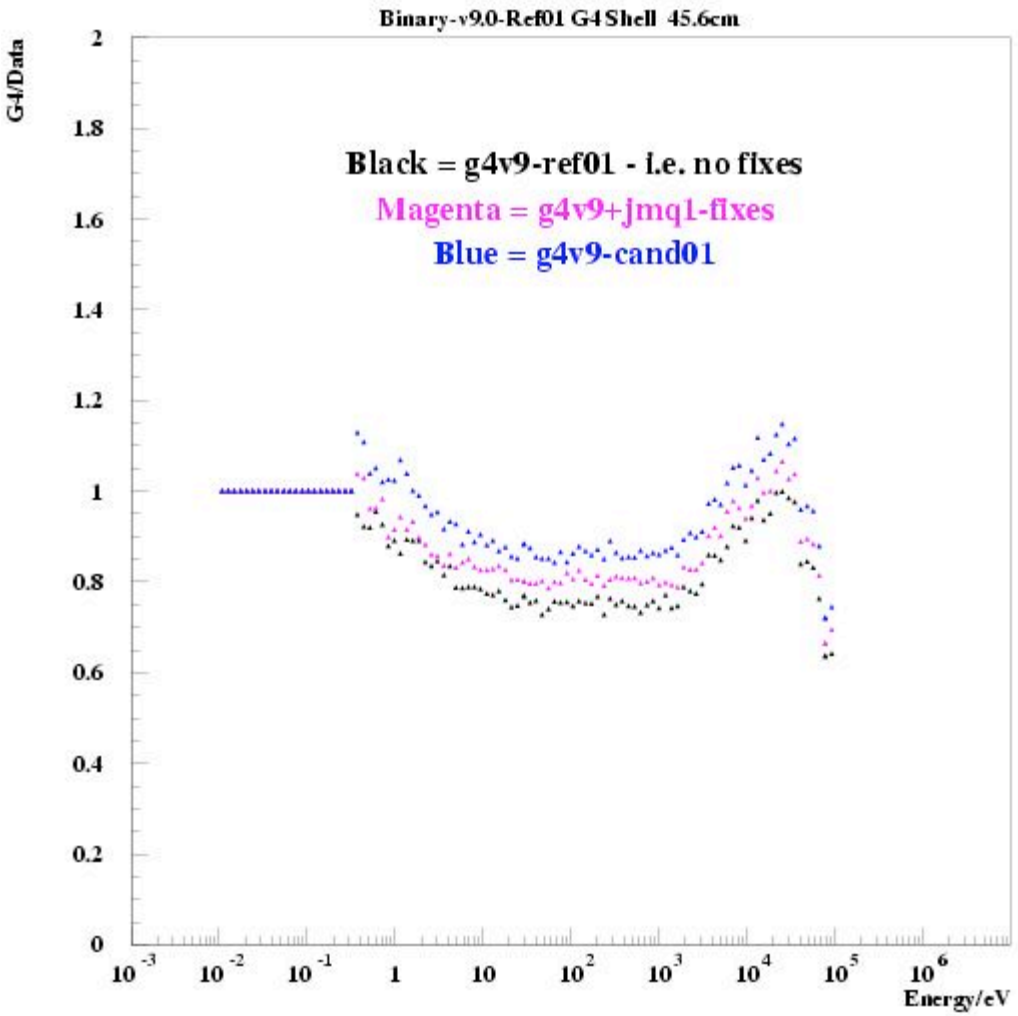
Other Updates

- Correct secondary times now used (9.1)
  - previously global time was used
  - users of HP neutrons most affected
- Model name included in hadronic error reporting (8.3)
  - previously, only process name was included

Precompound/De-excitation

- G4PreCompound model
  - improvements of the exciton model based on a study of the literature
    - improved probability calculations
    - improved Pauli-blocking calculation
    - making number of charged particles decrease when exciton number decreases
  - several bug fixes
- Evaporation
  - supplied missing calculation of factor used to calculate evaporation probabilities
    - particles affected: p, n, d, t, 3He, alpha
  - suppressed warning message when no gamma level exists
    - user must now set flag

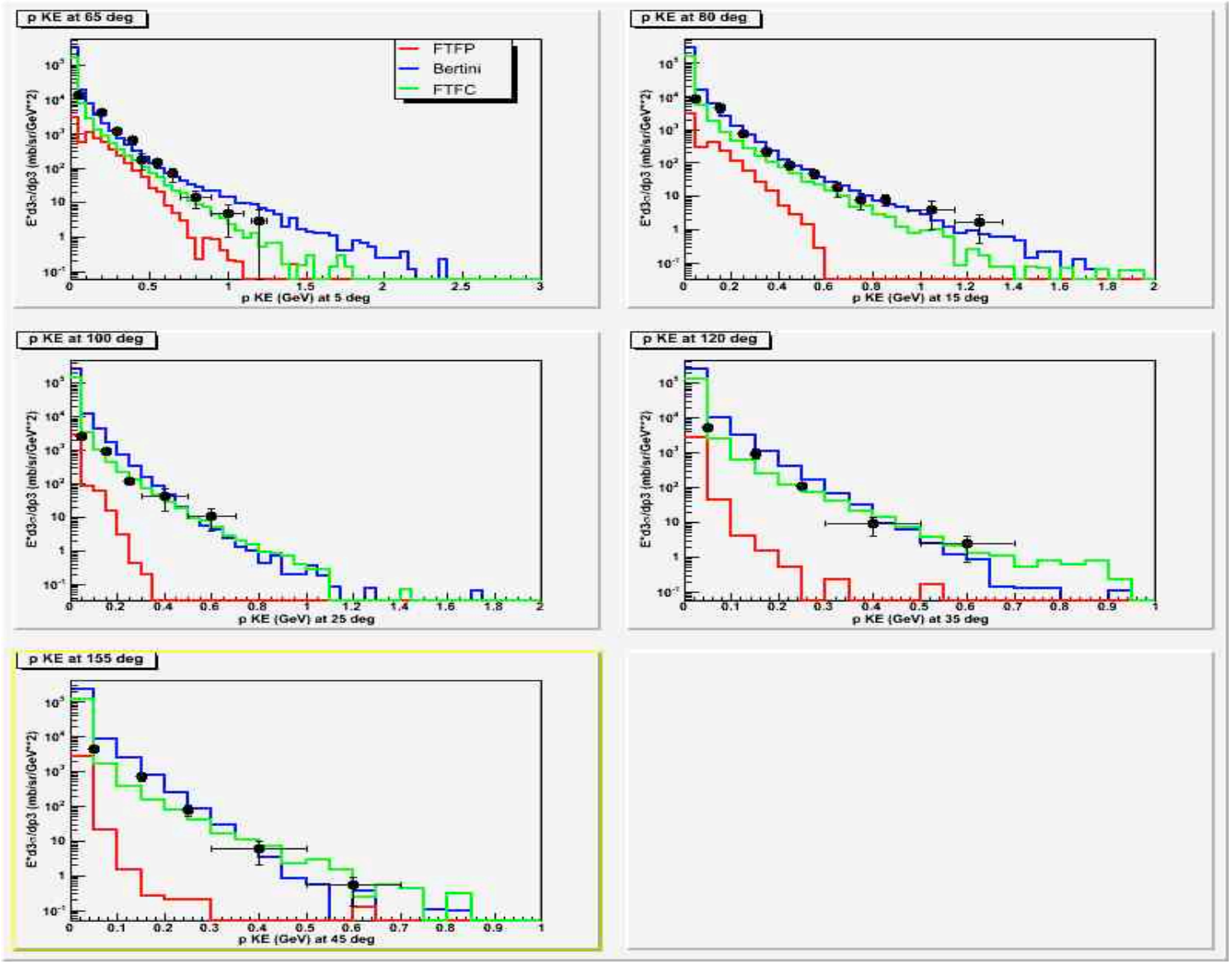
Precompound Compared to TARC data



FTF String Model

- Geant4 has two string models, QGS and FTF
  - usually valid above 20 GeV
- For many years FTF gave poor performance
  - program undertaken by V. Uzhinsky to fix/improve FTF model
  - go back to original model, add missing physics and make other improvements
- Recently FTF is now performing better than QGS in many cases
  - FTF has improved tuning, improved treatment of diffraction
- FTF can also be used at lower energies
  - possible down to 5 GeV
  - makes possible a smooth join to cascade models

FTF Model: 10 GeV/c p on Ta



Other Model Fixes and Improvements

- Bertini cascade
  - fixed angular distribution for E > 2.3 GeV
    - was causing large over-estimate of high energy tails
  - model does not currently have a Coulomb barrier
    - effort now underway to implement this (June 2008)
- LEP (low energy GHEISHA)
  - fix of several bugs in charge exchange code, based on comparison with GHEISHA Fortran
- HEP (high energy GHEISHA)
  - very high energy (300 GeV) backward particles arising from ~TeV incident particles – could mimic exotic particle
    - was a mistake in choice of leading particle - now fixed

High Precision Neutron Alternative

- Currently using G4HPNeutron models for thermal up to 20 MeV neutrons
  - based on G4NDL database
  - over time bug reports have accumulated which require serious overhaul of the code
  - G4NDL database has several gaps in isotope data
  - G4NDL is also subject to export control restrictions
- G4ENDL models will replace G4HPNeutron models
  - based on Lawrence Livermore National Lab neutron database ENDL
  - ENDL is more complete and not subject to export control
  - new models will provide correct kinematics and interface to Livermore database
  - elastic models ready for June 2008, inelastic, capture, fission by December 2008

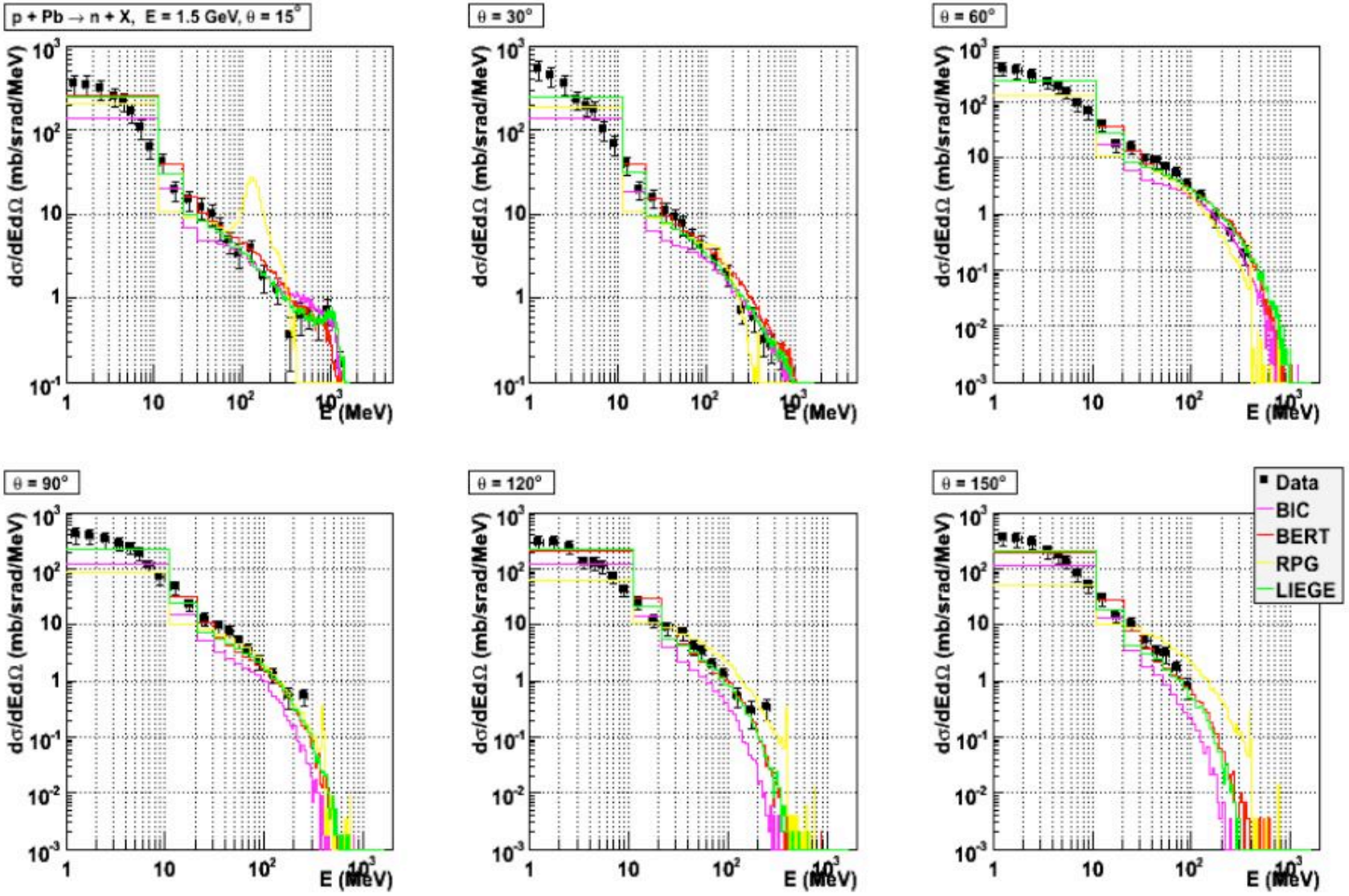
RPG Model

- Original hadronic models in Geant4
  - Low Energy Parameterized (LEP), High Energy Parameterized (HEP)
  - both based on H. Fesefeldt's GHEISHA Fortran code
  - very fast, but not very detailed
  - based on parameterization of older data
  - many bugs in both original code and in translation
  - does not conserve energy, baryon number or strangeness
- Replacement models being developed
  - RPG (re-parameterized-GHEISHA) models
  - conservation of E,Q and S will be required
  - new parameterization of more recent data
  - nucleon and pion models ready by December 2008

Liege INCL/ABLA Models

- Liege INCL cascade and ABLA de-excitation models are very successful Fortran models for p, n, and π
  - allowed projectile energy up to 3 GeV
  - good p, n, nuclear fragment spectra
- Last year Helsinki group began translation of code to C++
  - translation now complete, some bugs remain
  - alpha version now available
  - validation in progress
  - full released version by June 2008
- Will provide an alternative to Binary and Bertini cascades now in Geant4

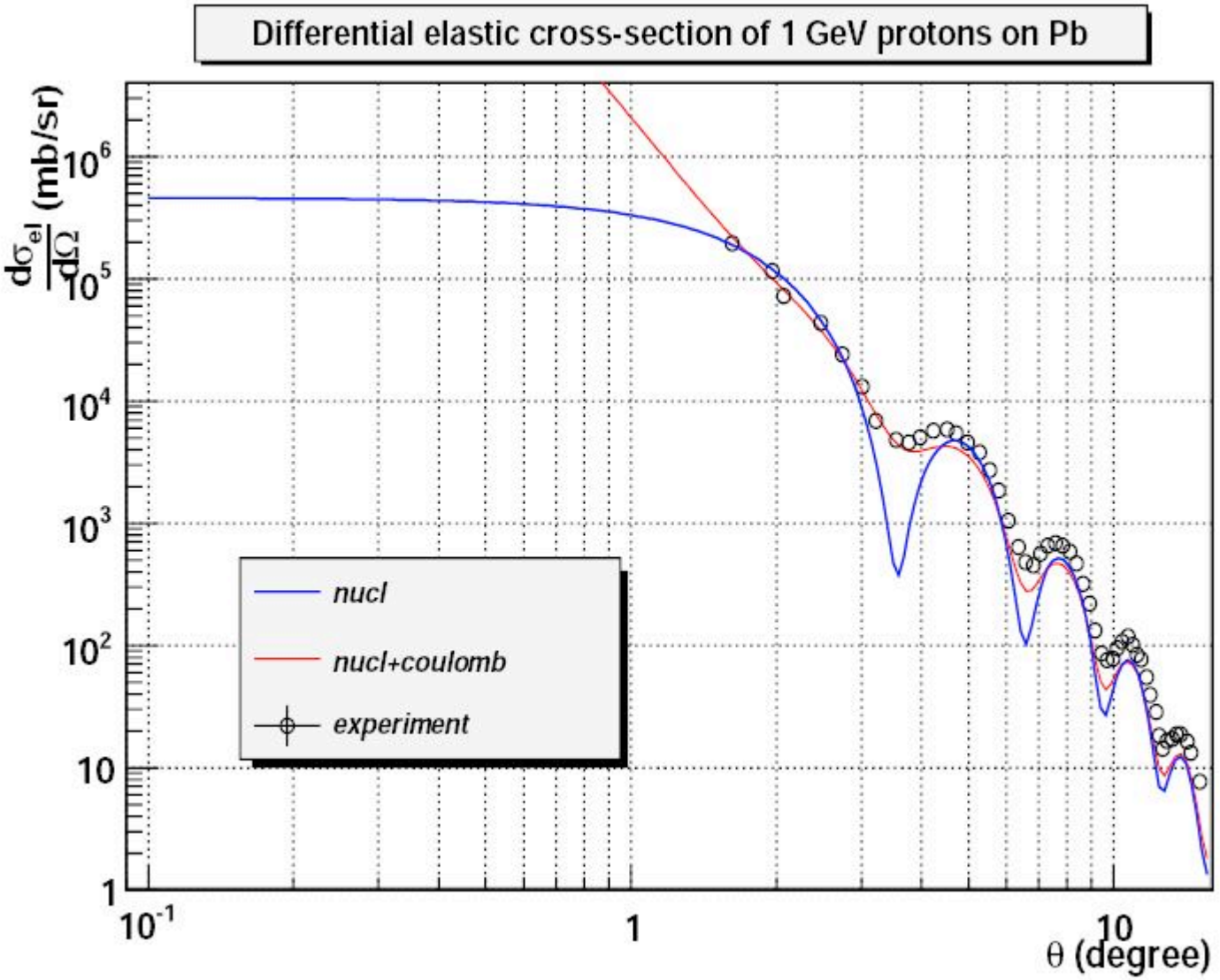
INCL/ABLA (green) Compared to (p,n) Data at 1.5 GeV



Coherent Elastic Scattering Models

- Two models now available:
  - G4ElasticHadrNucleusHE, for hadrons 1 – 300 GeV
  - G4DiffuseElastic, for hadrons 10 MeV – 1 TeV
- G4ElasticHadronNucleusHE
  - uses Glauber approach
  - calculates differential cross sections and then parameterizes them
- G4DiffuseElastic
  - uses optical model approach
  - diffraction plus refraction from nuclear surface

Diffuse Elastic Comparison with Data



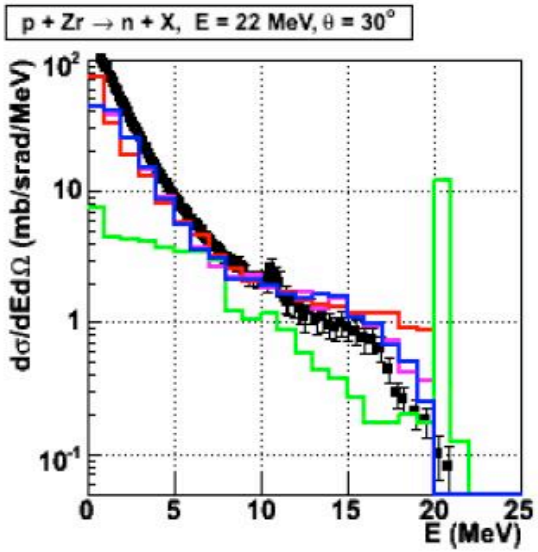
Ion-ion Interactions

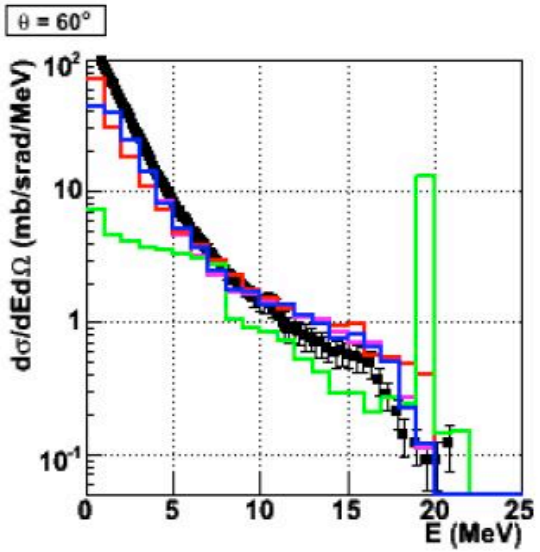
- QMD native Geant4 model
  - see talk by T. Koi
- Interfaces to Geant4
  - JQMD/PHITS – see talks by K. Niita and T. Koi
  - DPMJET – see talk by D. Wright

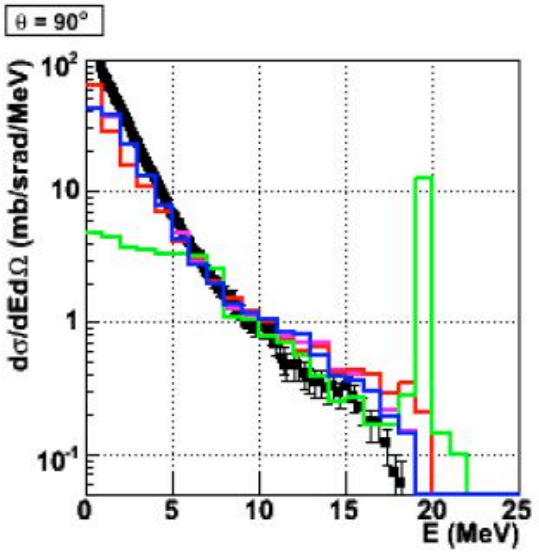
Validation (1)

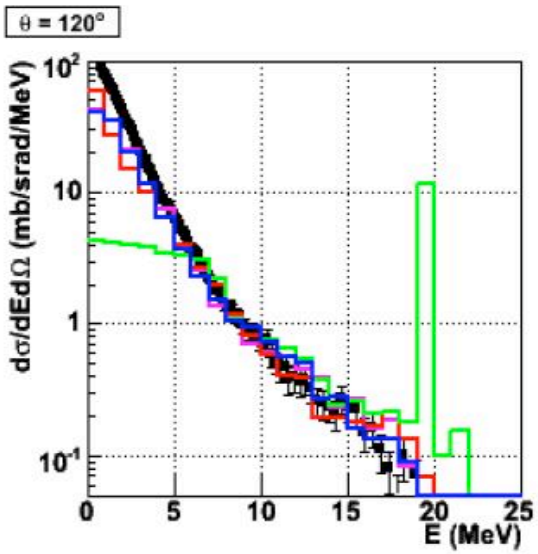
- test30 is our most extensive hadronic validation test suite
  - tests evaporation/precompound, cascade and string models
  - recently extended down to 22 MeV
  - tests for INCL/ABLA models recently included
  - includes HARP data validation (up to 12 GeV)
  - it is run for each release to check model performance

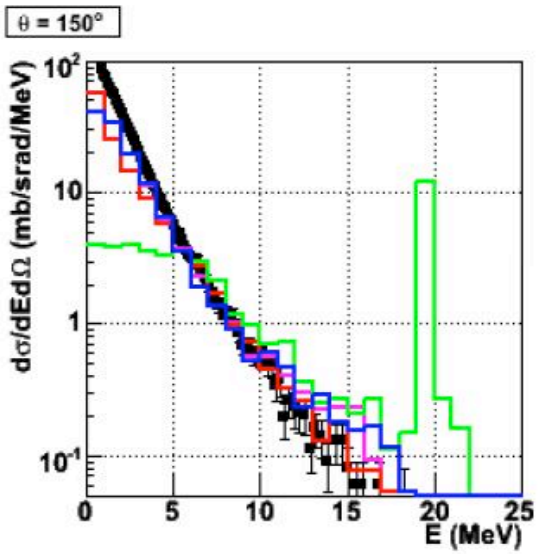
Test30

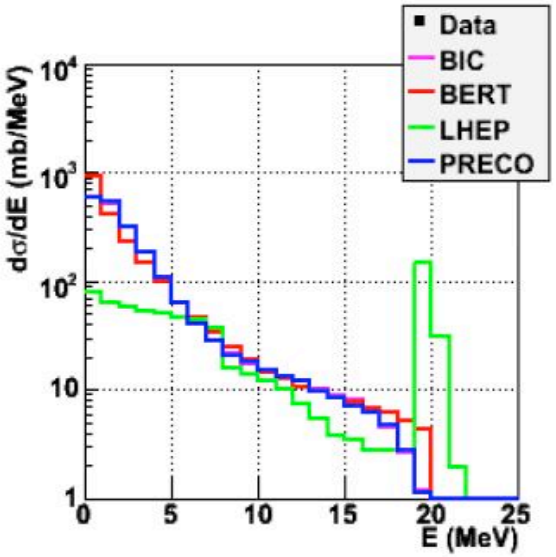

p + Zr → n + X, E = 22 MeV, θ = 30°
dσ/dEdΩ (mb/srad/MeV)
E (MeV)


θ = 60°
dσ/dEdΩ (mb/srad/MeV)
E (MeV)


θ = 90°
dσ/dEdΩ (mb/srad/MeV)
E (MeV)


θ = 120°
dσ/dEdΩ (mb/srad/MeV)
E (MeV)


θ = 150°
dσ/dEdΩ (mb/srad/MeV)
E (MeV)

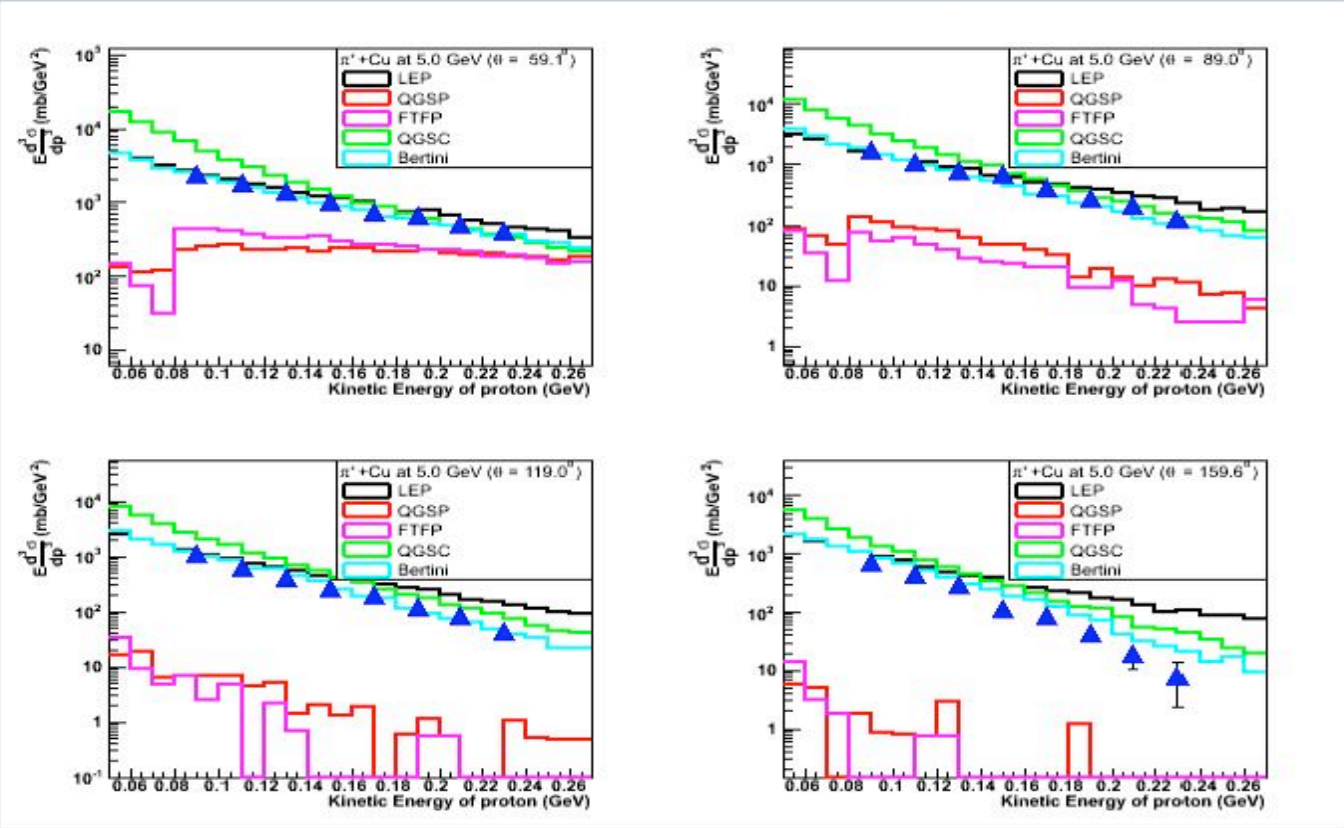

Data
BIC
BERT
LHEP
PRECO
dσ/dE (mb/MeV)
E (MeV)

Validation (2)

- Hadronic shower shapes
  - new physics lists tested (FTFP_BERT) for longer, wider showers
  - more work to come on improved FTF model may help lengthen showers
- New validation activity added for intermediate energies
  - comparing against 3 - 30 GeV data
  - important region for LHC, ILC calorimetry
  - tests LEP, FTFP, FTFC, QGSP, QGSC, Bertini, Binary models

Medium Energy Validation

pi+ Cu -> p X at 5.0GeV



Bertini OK; QGSP is worse than LEP in this case

Summary

- A lot of hadronic activity in the past year:
  - nucleus-nucleus interactions
  - hadronic shower shapes
  - low and intermediate energy validation
  - continuing model improvements
  - 5 new models, either released or about to be released