Recent Developments in Geant4

Calice Collaboration Meeting

10 March 2010

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(on behalf of the Geant4 hadronic working group)

Outline

- **Geant4 and Calice**
- **Geant4 Validation**
- **Physics Lists and Simplified Calorimeter results**
- **Recent model developments**
  - **EM**
  - **hadronic**
- **Plans**
- **Summary**

Geant4 and Calice

- Geant4 philosophy
  - combine several models into physics lists which cover full range of HEP energies
  - test each model using single-particle beams on thin target measurements
    - sensitive to first interaction
    - can isolate final state multiplicity, energy, angular distribution, etc.
  - test physics list against measured shower shapes, energy deposits in calorimeters
    - indicates how showers develop

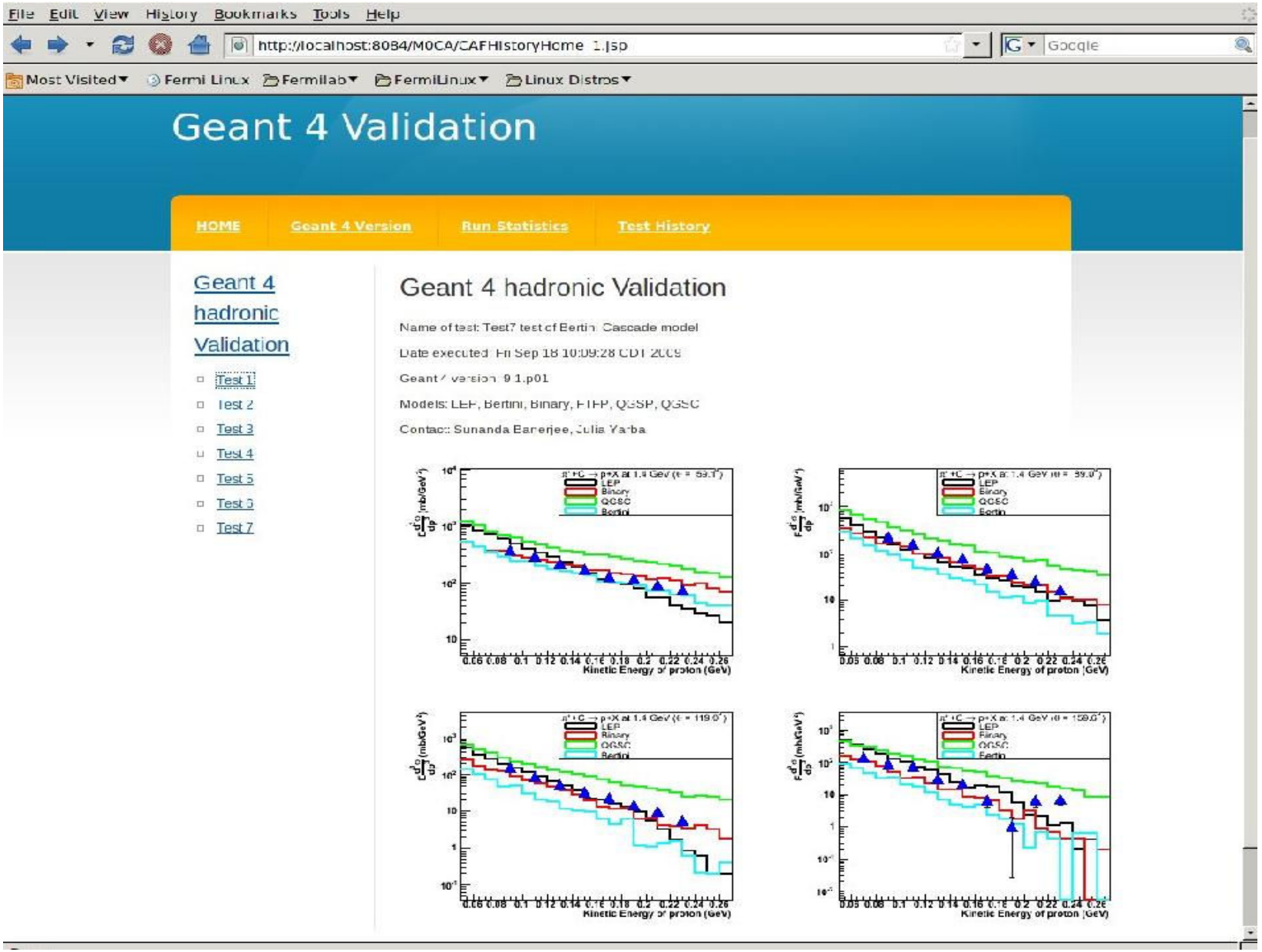
Geant4 and Calice

- Calice beam tests
  - fine grained/highly segmented calorimeters
    - sensitive to first interaction
  - provide detailed information about shower development
- Calice results provide a critical test of Geant4 physics
  - data quite well-matched to quantities required for Geant4 validation
  - feedback will guide model and physics list development
- Geant4 eagerly looking forward to Calice data

Geant4 Validation

- Validation now takes up more than half our effort
  - EM and hadronic validation suites now exist and continue to be developed/expanded
  - see validation web pages at
    - geant4.fnal.gov/hadronic_validation/validation_plots.htm
    - geant4.web.cern.ch/geant4/collaboration/working_groups/electromagnetic/tests.shtml
  - mostly thin target validations presented
  - some full-setup and test beam comparisons (CMS, ATLAS simplified test beam detectors and calorimeters)
- Would like to collaborate on validation
  - extracting “thin-target” information
  - simplified Calice set-up to be run with each Geant4 release?

New: Geant4 Validation Framework

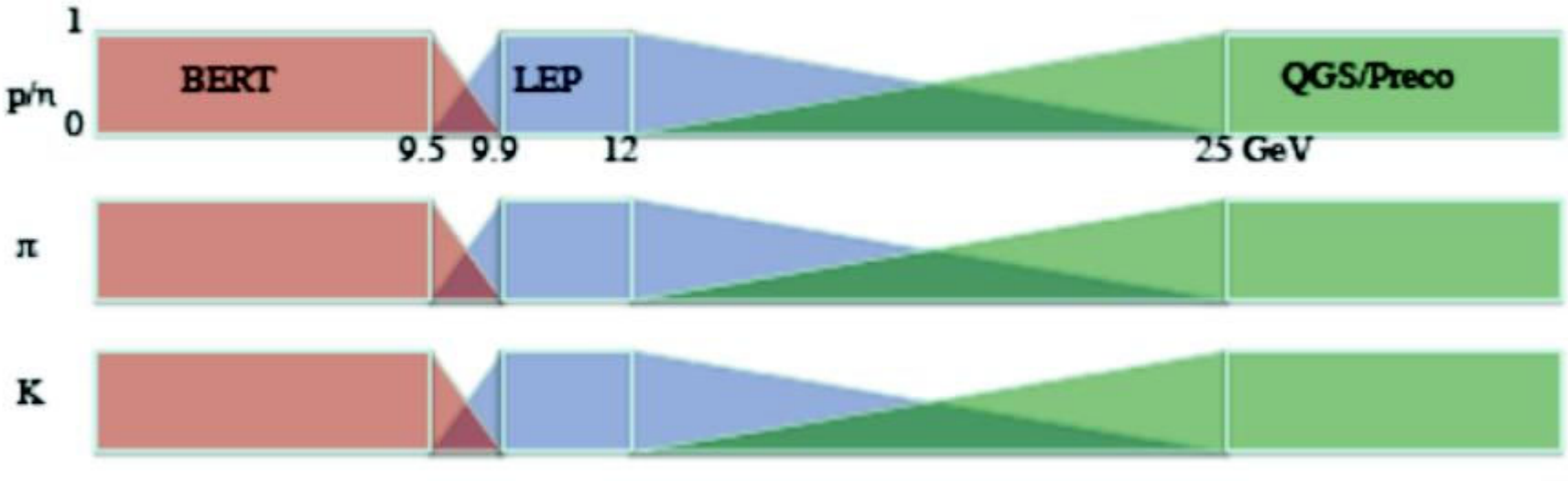


Physics Lists: Promise and Problems

- Building a complete set of physics processes from a toolkit of models and cross sections is
  - very flexible
  - very powerful
  - potentially dangerous
- Getting the models to match where they join one another
  - requires care in making sure distributions in one energy region blend smoothly into those of another region
  - requires thorough validation in regions where models overlap
- QGSP_BERT physics list has done the best job so far
  - currently used in ATLAS, CMS, LHCb production
  - good agreement with measured shower width, length
  - but it still has problems (see slide 11)

Physics Lists: QGSP_BERT

For most hadrons, the following combination of models is used:

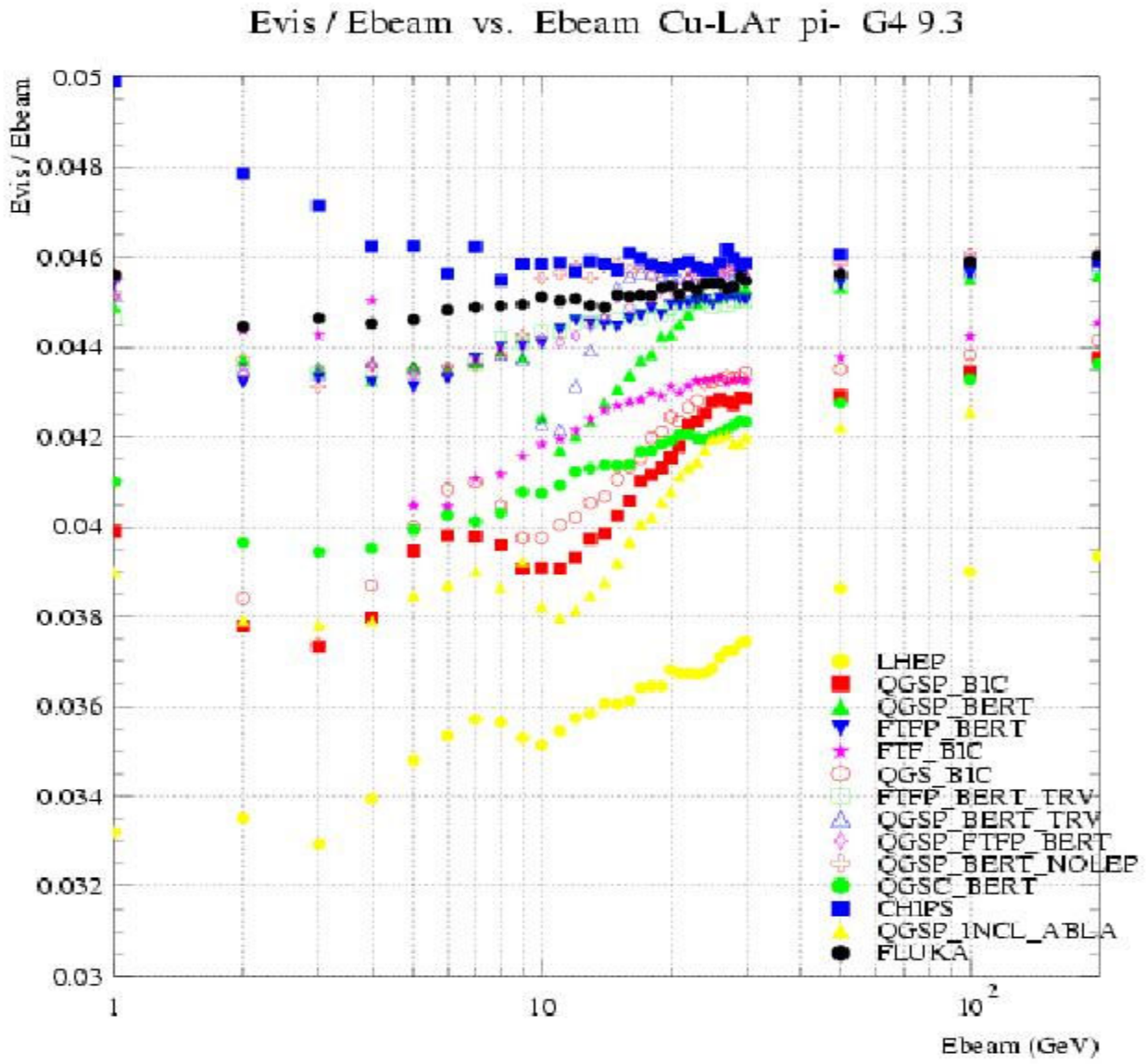


For now, LEP models (GHEISHA) are used to fill the gap between Bertini and QGS
=> not ideal due to several shortcomings in LEP

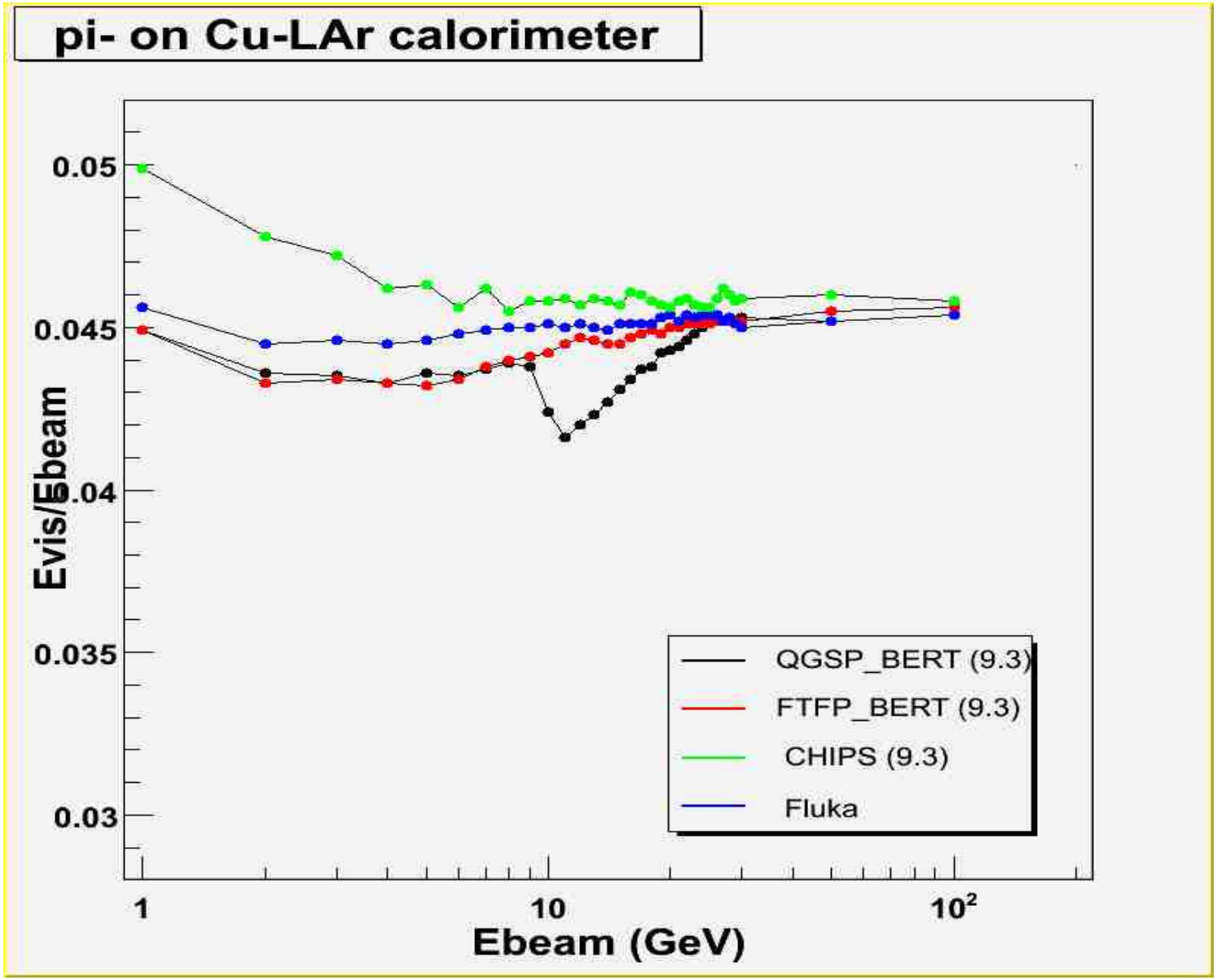
Physics Lists: Alternatives

- Goal is to eliminate LEP models for most hadrons
  - extend Bertini to higher energies
  - extend QGS to lower energies
  - try different string models (FTF)
- Alternative physics lists for HEP
  - FTFP_BERT
    - recent improvements in FTF and Bertini models make this a very promising choice: now use FTF down to 6 GeV
  - CHIPS
    - new physics list using models from Chiral Invariant Phase Space at all energies, but still being tuned
- These (and others) are being tested in simplified calorimeter models

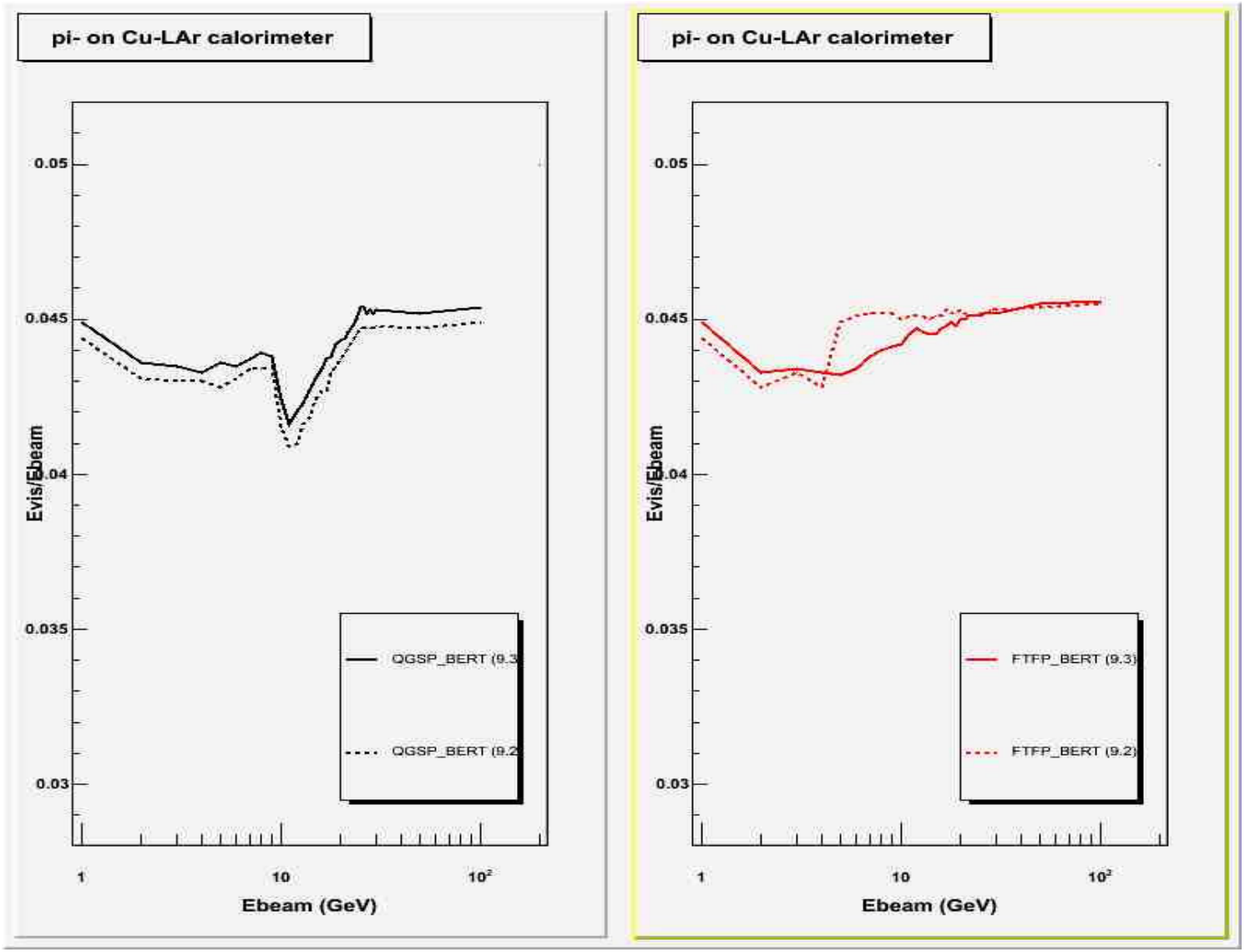
Visible Energy in Simple Calorimeter



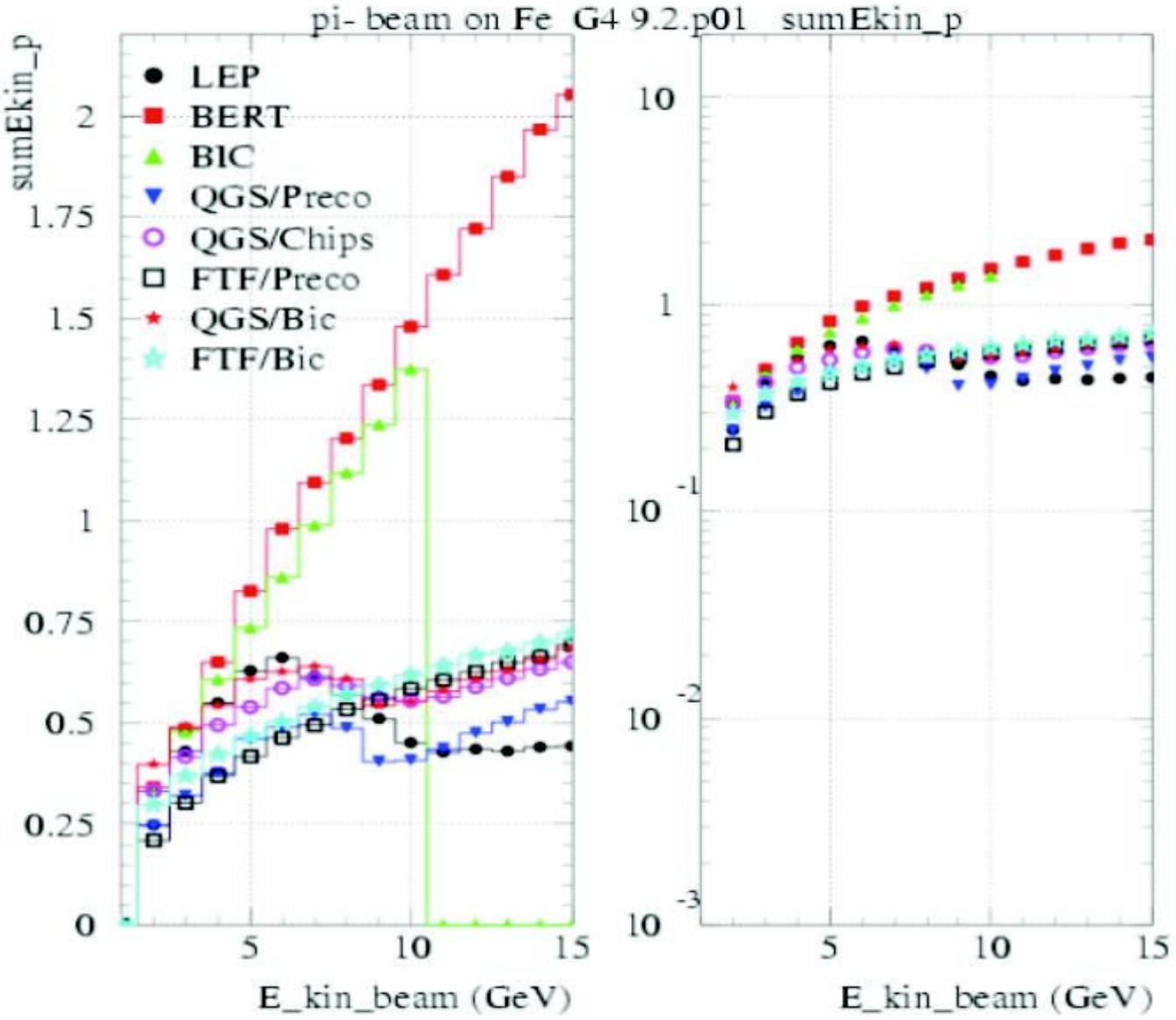
Visible Energy for 4 Physics Lists (9.3)



Visible Energy for 2 Physics Lists (9.3 vs. 9.2)



Model Performance



EM Physics Developments

- Low energy and standard EM processes now have a common design
  - no longer two different classes for same physics process (e.g. G4LowEnergyPhotoElectric and G4PhotoElectricEffect)
  - all EM processes now follow “model approach” which allows different models to be assigned to a process (e.g. standard, Livermore and Penelope models)
- G4MultipleScattering replaced by specialized versions:
  - G4eMultipleScattering for e+/e-
  - G4MuMultipleScattering for mu+/mu-
  - G4hMultipleScattering for charged hadrons and ions
- Old code kept for backward compatibility until Geant4 10.0
  - new processes already included in reference physics lists

Electromagnetic Physics Developments

- EM code in HEP physics lists has been fairly stable since V8.0
- There are now HEP physics lists with options for different collections of EM processes
  - default (standard HEP EM physics)
  - EMV (faster but less precise)
    - uses multiple scattering code from Geant4 V7.1
  - recommended options for HEP using these lists:
    - QGSP_BERT, QGSP_BERT_EMV
    - FTFP_BERT, FTFP_BERT_EMV
- Other options exist, but are mostly for low/medium energies
  - EMX (sub-cutoff secondary generation for ionization)
  - EMY (most precise models for low/intermediate energies)

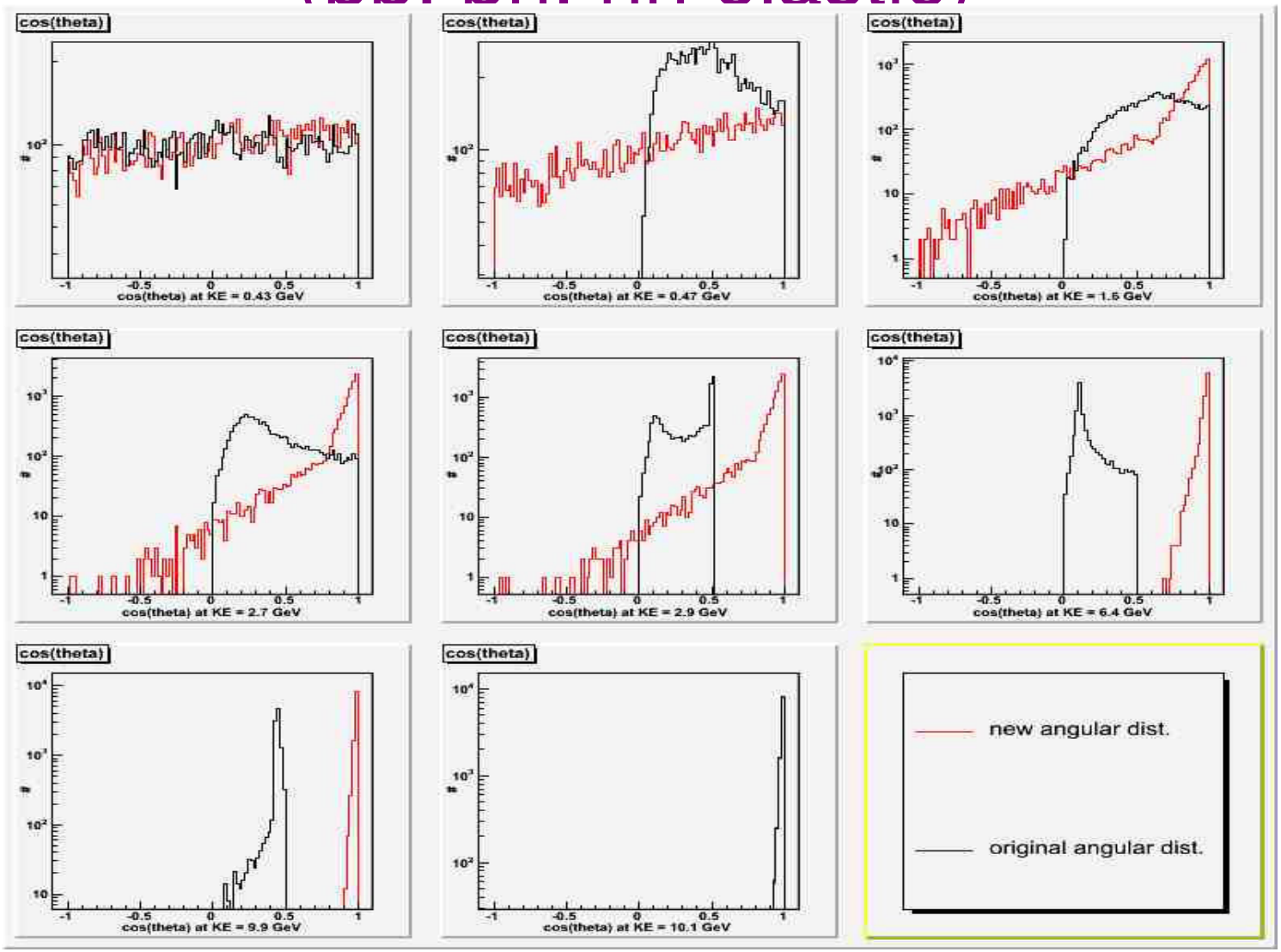
Hadronic Physics: Fritiof Fragmentation (FTF)

- Before 9.3 model produced too much energy to secondaries at energies below 10 GeV (see slide 12)
- The following fixes improved this situation significantly
  - added reggeon cascade
    - particles resulting from initial high energy interaction can initiate cascade in nucleus
    - cascade is performed with reggeons instead of p, n, pi, etc.
  - direct pion absorption
    - previous cross section was factor ~4 below measured pion absorption data
  - charge exchange added for pn -> np
    - previously treated only as elastic

Hadronic Physics: Bertini Cascade

- Cross section review
  - discovered significant differences from PDG values in internal hadron-nucleon cross section code
  - all cross sections reviewed and re-implemented
- Angular distribution review
  - currently underway
  - significant corrections already included in 9.3 for pp, pn, nn elastic scattering (see slide 18)
  - effect is a slight lengthening of shower
- Extension to higher energies
  - addition of 7-, 8- and 9-body final states in intra-nuclear collisions improves behavior slightly between 5 and 10 GeV

Bertini Angular Distribution Improvement (pp, pn, nn elastic)



Hadronic Physics: Nuclear De-excitation

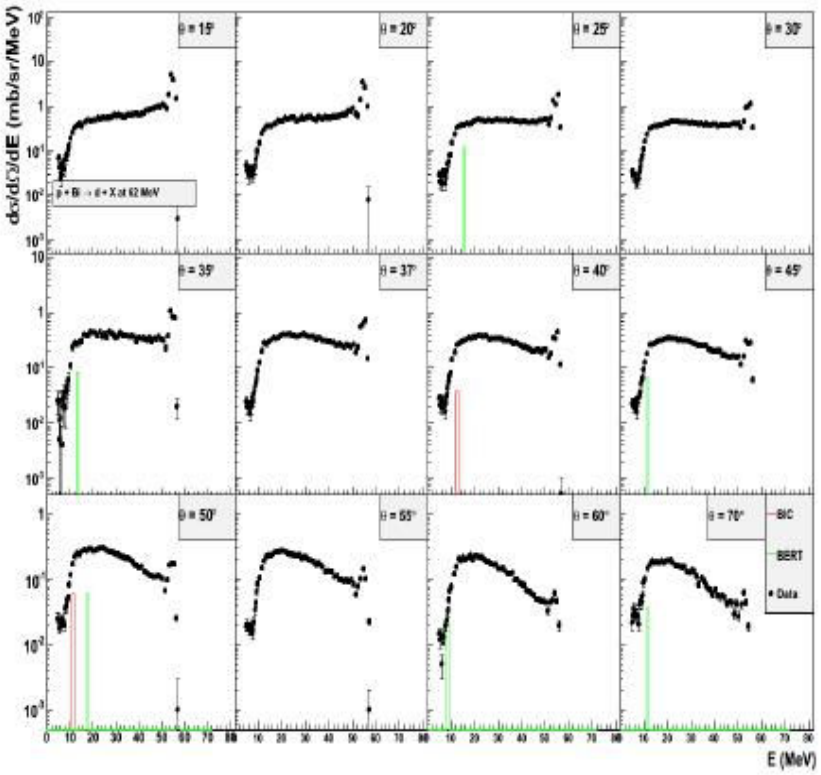
- Precompound model
  - Δn = +/- 2 particle-hole transition probabilities were factor 5 too low – now fixed
  - bugs fixed: negative transition probabilities for light elements
- Nuclear evaporation models
  - improved inverse cross sections
  - fixed several evaporation probabilities
  - more detailed evaporation channels
- Fermi breakup and fission models
  - fixed unit conversion errors (keV vs. MeV)
- All of the above significantly improved agreement of precompound and binary cascade with low energy data (< 1 GeV)

Low Energy Validation (precompound)

Pb (p, d) at 63 MeV

BEFORE

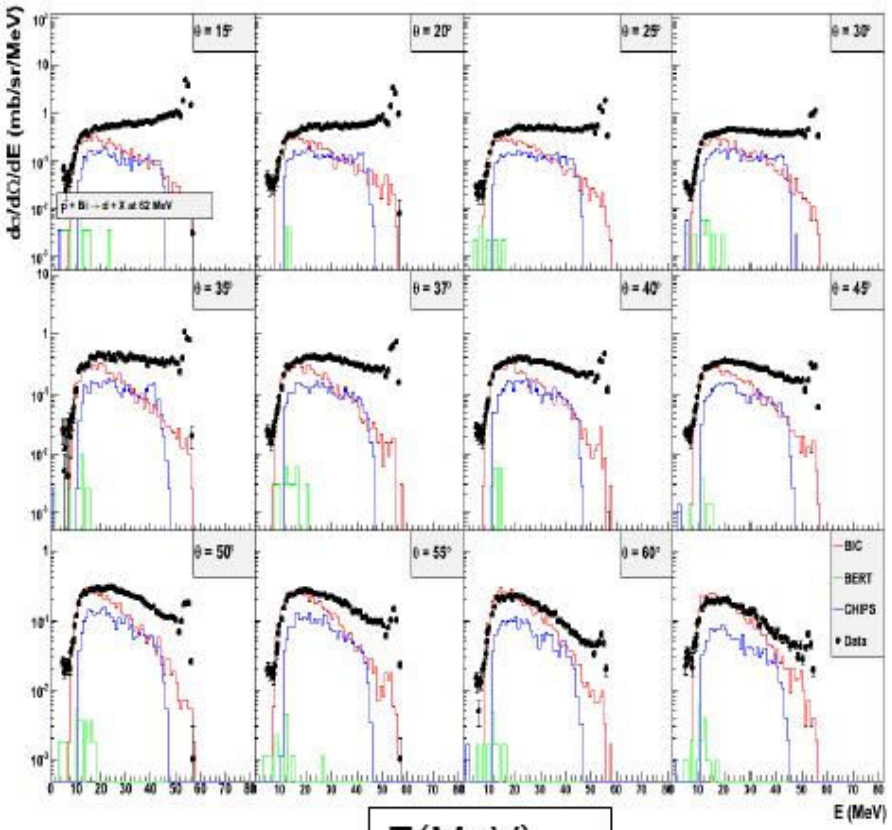
9.2



E(MeV)

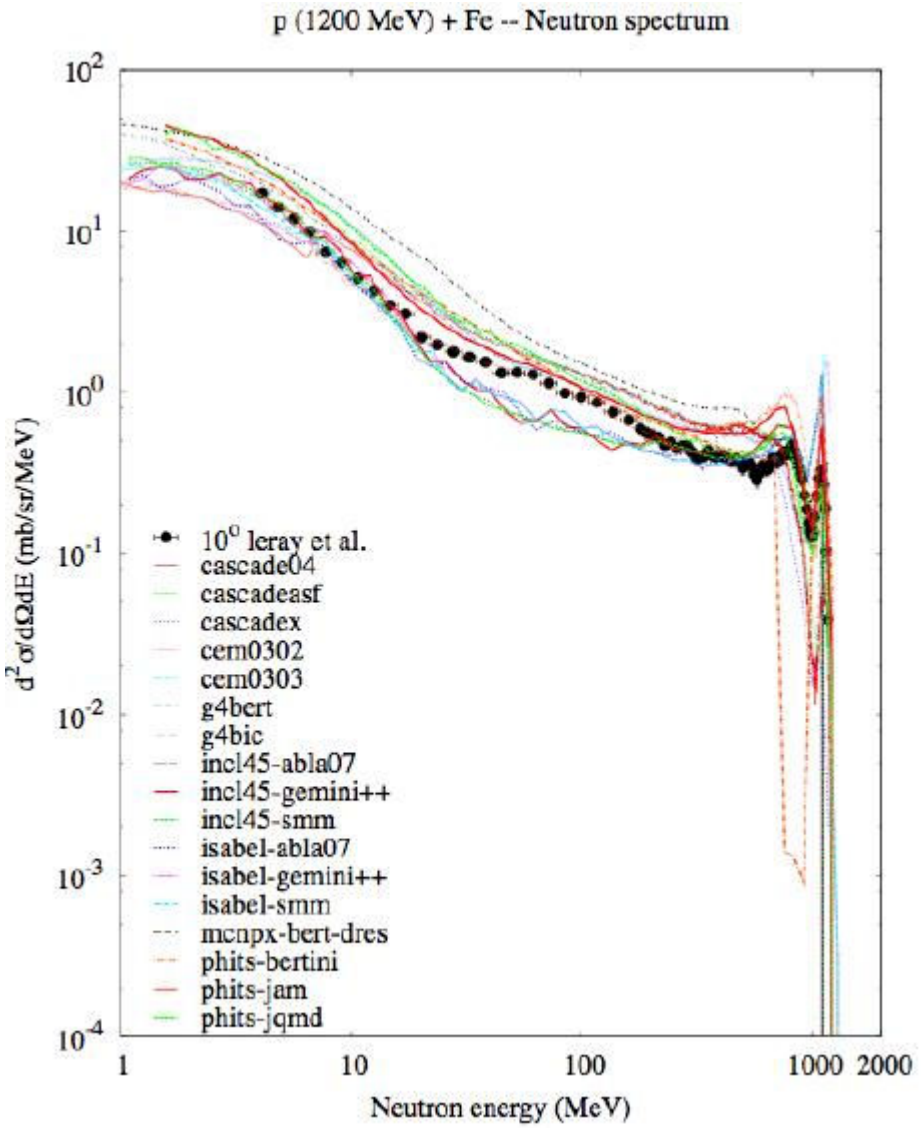
NOW

9.2p01



E(MeV)

Low and Medium Energy Validation (IAEA)



Plans (1)

- Quark-gluon string (QGS) model: add reggeon cascade
  - will extend model validity down to 5-10 GeV
  - LEP models will no longer be needed for p, n , pi
- Bertini cascade
  - need to find a way to shut down the runaway cascade above 5 GeV => implement trailing effect
  - implement formation time?
  - complete angular distribution review for pions, inelastic reactions
- Find better way to make transition between string model and cascade model
  - currently use energy blending (see slide 8)
  - formation time is a possibility

Plans (2)

- Fast neutron capture
  - especially important for calorimeters with plastic scintillator
  - beta version exists which emits a single gamma following n capture, 4-momentum conserved
  - uses simplified low energy cross sections to save time
- Hadron-nuclear cross section re-design
  - many new and improved cross sections have been made available in the last two years => confusing
  - simplified code design
  - cross section documentation and validation
- Expanded validation effort
  - new hadronic validation framework (slide 6)
  - new cross section, ion-ion, stopping processes validations

Summary (1)

- Model improvements have led to better behavior
  - shower shapes
  - visible energy
  - agreement with low energy thin-target data
- Further model improvements will allow:
  - simpler physics lists
  - the elimination of the LEP (GHEISHA) physics models
  - smoother transition from cascade to string models
- Increased validation effort
  - already a large number of validation plots to browse
  - new validation framework will add more

Summary (2)

- Looking forward to closer collaboration with Calice
  - use data to validate Geant4
  - perhaps develop a simplified Calice model for regular Geant4 validations
- Thanks for the invitation – I'm looking forward to the rest of the meeting