Hadronic Physics in Geant4: Improvements and Status for LHC Start

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on behalf of the Geant4 hadronic working group

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Geant 4

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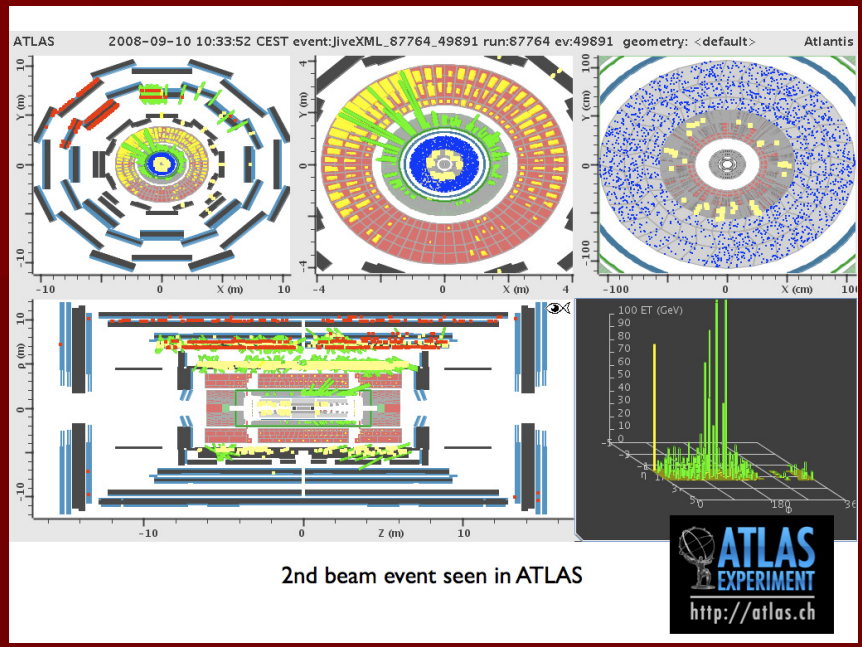
Outline

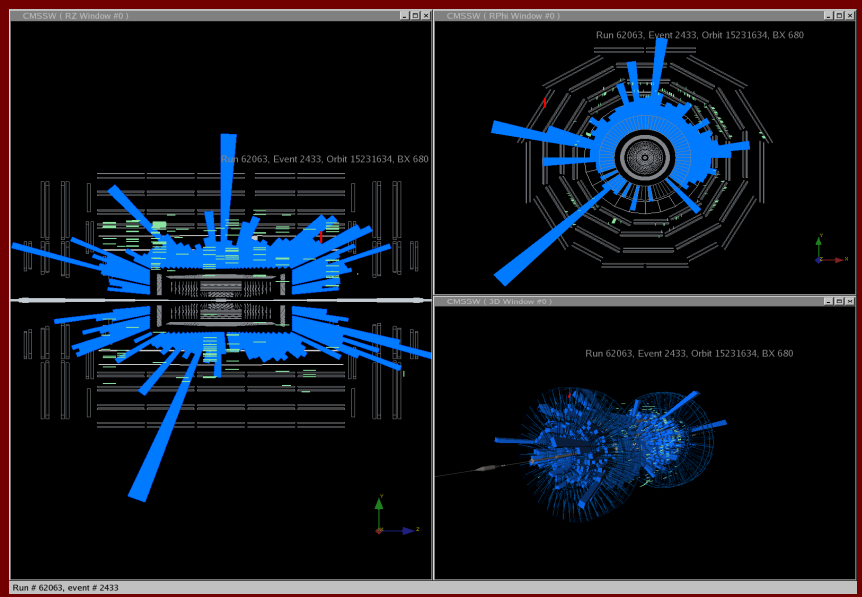
- Introduction
  - Geant4 hadronic physics overview
  - Physics Lists
- Validation of Geant4 hadronic physics
- Highlights of new developments
  - Fritiof model
  - Bertini cascade
  - Pre-Compound
  - De-excitation models
- Conclusions

Introduction

- Geant4 is used for Monte Carlo simulation of particle transport for ATLAS, CMS, LHCb since 2004
- Hadronic physics packages is an important part of Geant4 for LHC
  - Signal acceptance
  - Background estimation



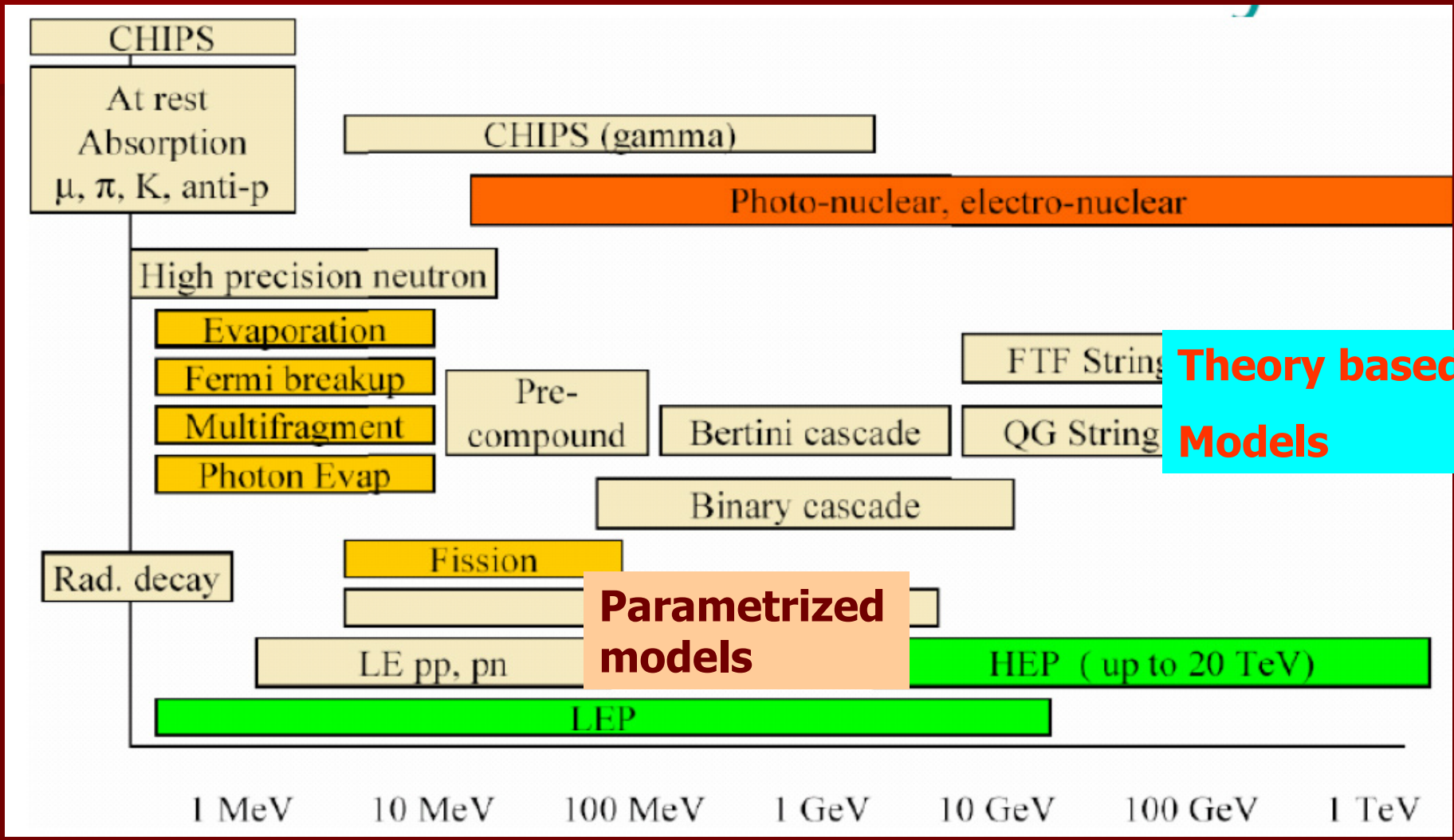
2nd beam event seen in ATLAS



Geant4 hadronic physics

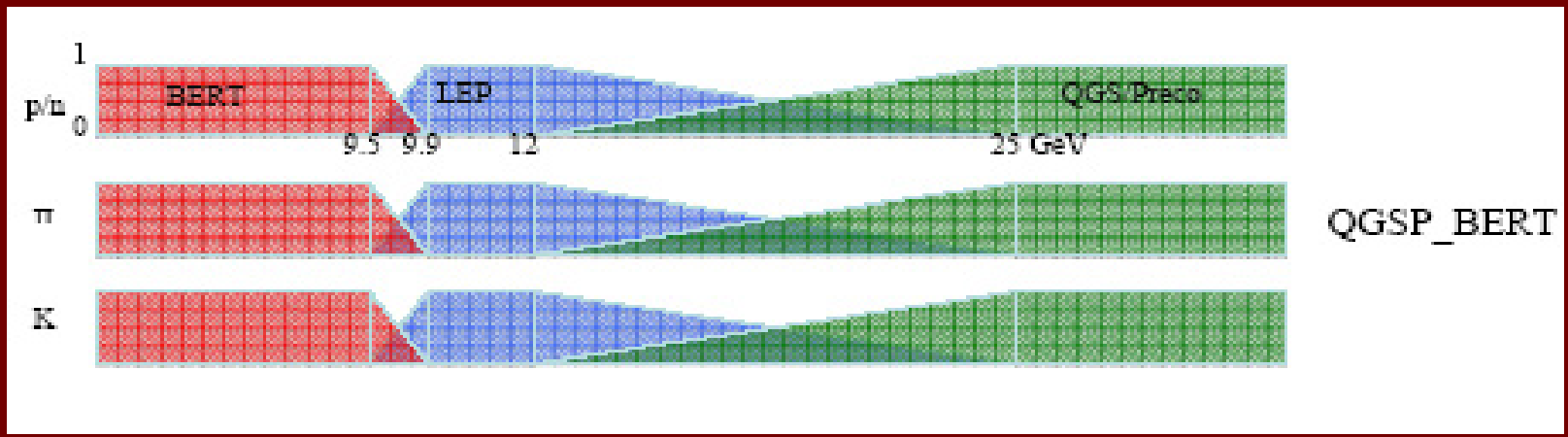
- General hadronic processes:
  - Elastic
  - Inelastic
  - Neutron capture
  - Neutron fission
  - Lepton-nuclear
  - Capture at rest
  - Charge exchange
- G4VProcess is the main interface to Geant4 kernel
- Two main components of a hadronic process defined for particle type:
  - Cross section
  - Models == secondary generators

Geant4 hadronic models



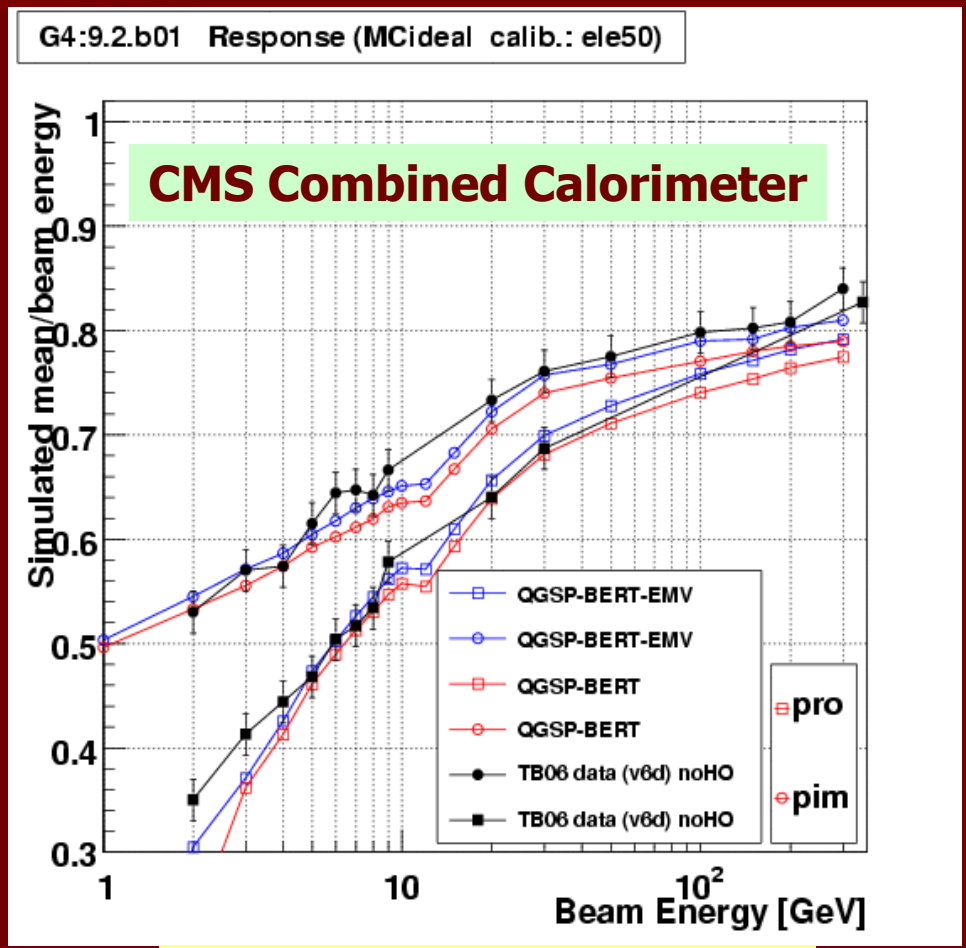
Physics List

- Combination of processes, cross sections and models
  - In general, user responsibility
- Reference Physics Lists
  - Provided with the Geant4 toolkit
  - Used for Geant4 validation and comparisons with test-beam data of LHC experiments
- QGSP_BERT is current recommended Physics Lists for simulation productions for LHC experiments



Simulation of responses of hadron calorimeters

- Important requirements of LHC experiments
- Needs detailed simulation of
  - Quasi-elastic scattering
  - String formation
  - Intra-nuclear cascade
- Main problem – intermediate energy region between cascade and string models



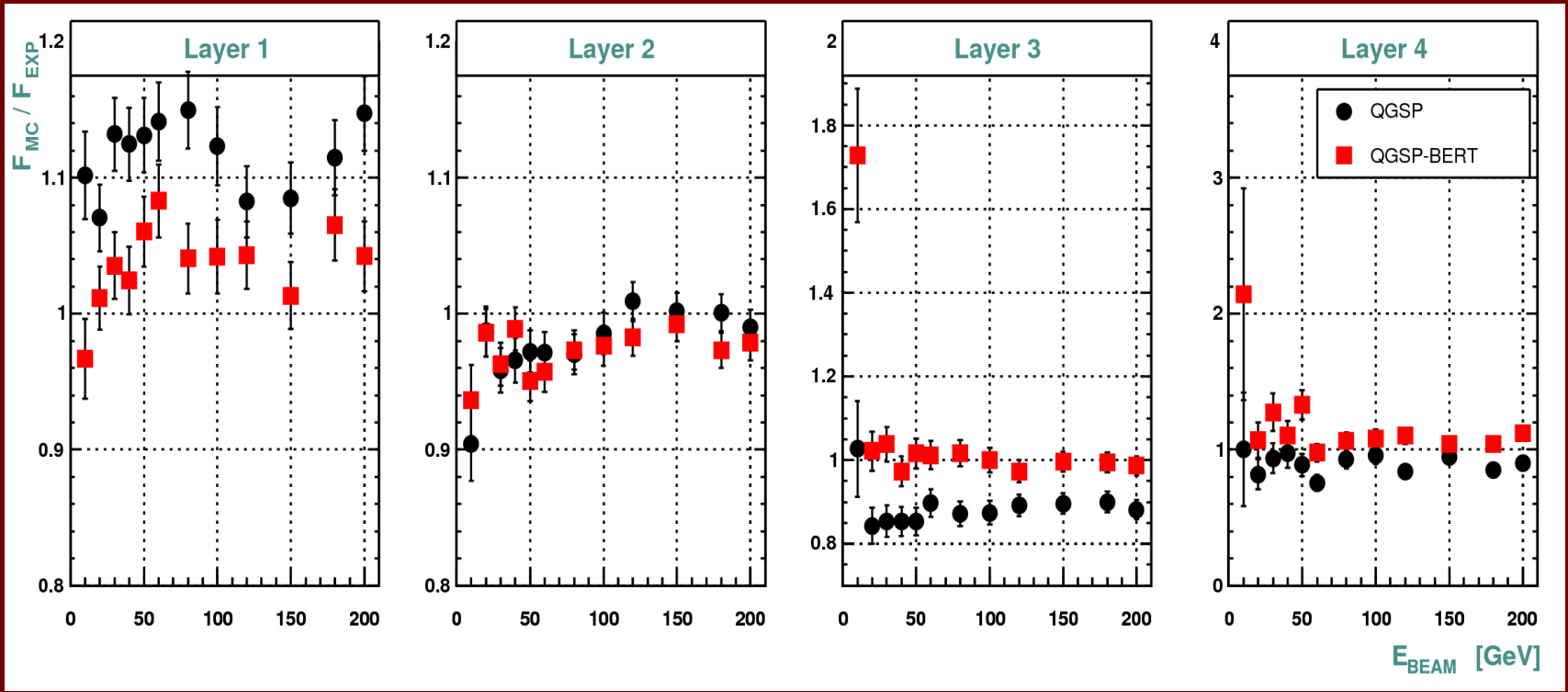
S.Piperov, IEEE NSS 2008

Pion longitudinal shower profile in ATLAS HEC

Four HEC longitudinal layers: 8/16/8/8 LAr gaps, 1.5/2.9/3.0/2.8 λ

$F = < E_{LAYER} > / E_{SUM}$, where $E_{SUM} = \Sigma < E_{LAYER} >$

G49.0



QGSP starts/ends too early, QGSP_BERT with ±10 % (still a bit too early)
Problem at 10 GeV. Courtesy A.Kirunin, P.Strizenec, LCG Validation

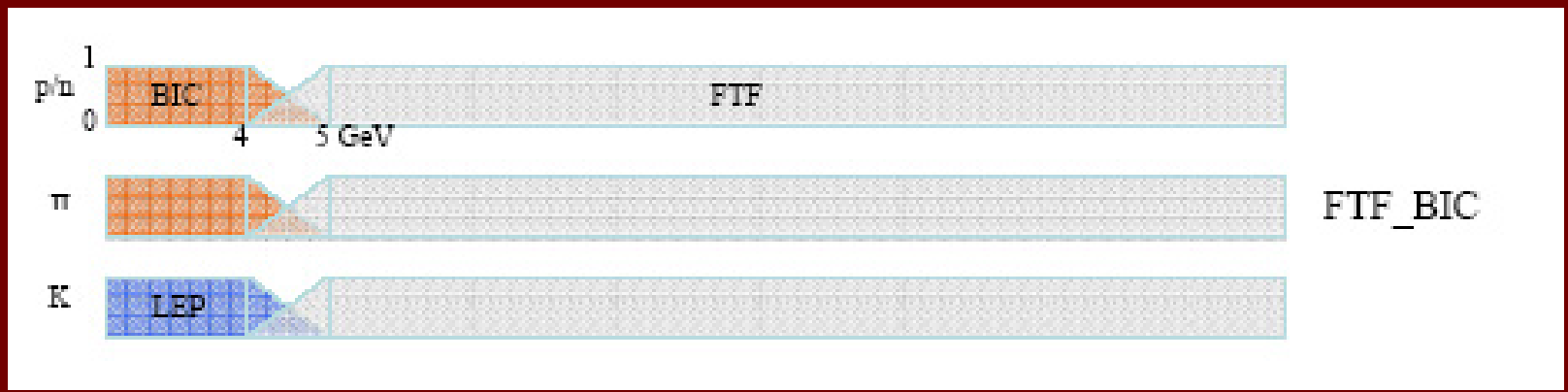
Validation strategy of Geant4 hadronic group

- Unit tests by developers
- Integration tests by Geant4 system testing
  - Reproducibility, Nan checks
- Validation and tuning mainly versus thin targets data
  - Inclusive production of neutrons, protons, pions
- Extended software and CPU resources
  - Testing suites at CERN, SLAC, FNAL
  - High statistic testing using GRID
- LHC experiments validation feedback
  - Robustness
  - Test-beam studies

Highlights of new developments

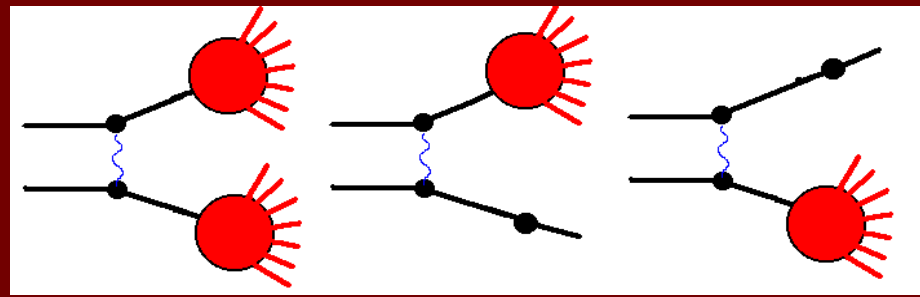
Geant4 hadronics for LHC

- Main recent developments focused on LHC test-beam problems:
  - Quasi-elastic for longitudinal shower shape
  - FTF model review
  - Bertini cascade
  - PreCompound
  - Deexcitation
- QGS_BIC, FTF_BERT and FTF_BIC are alternative Physics Lists, which includes recent improvements



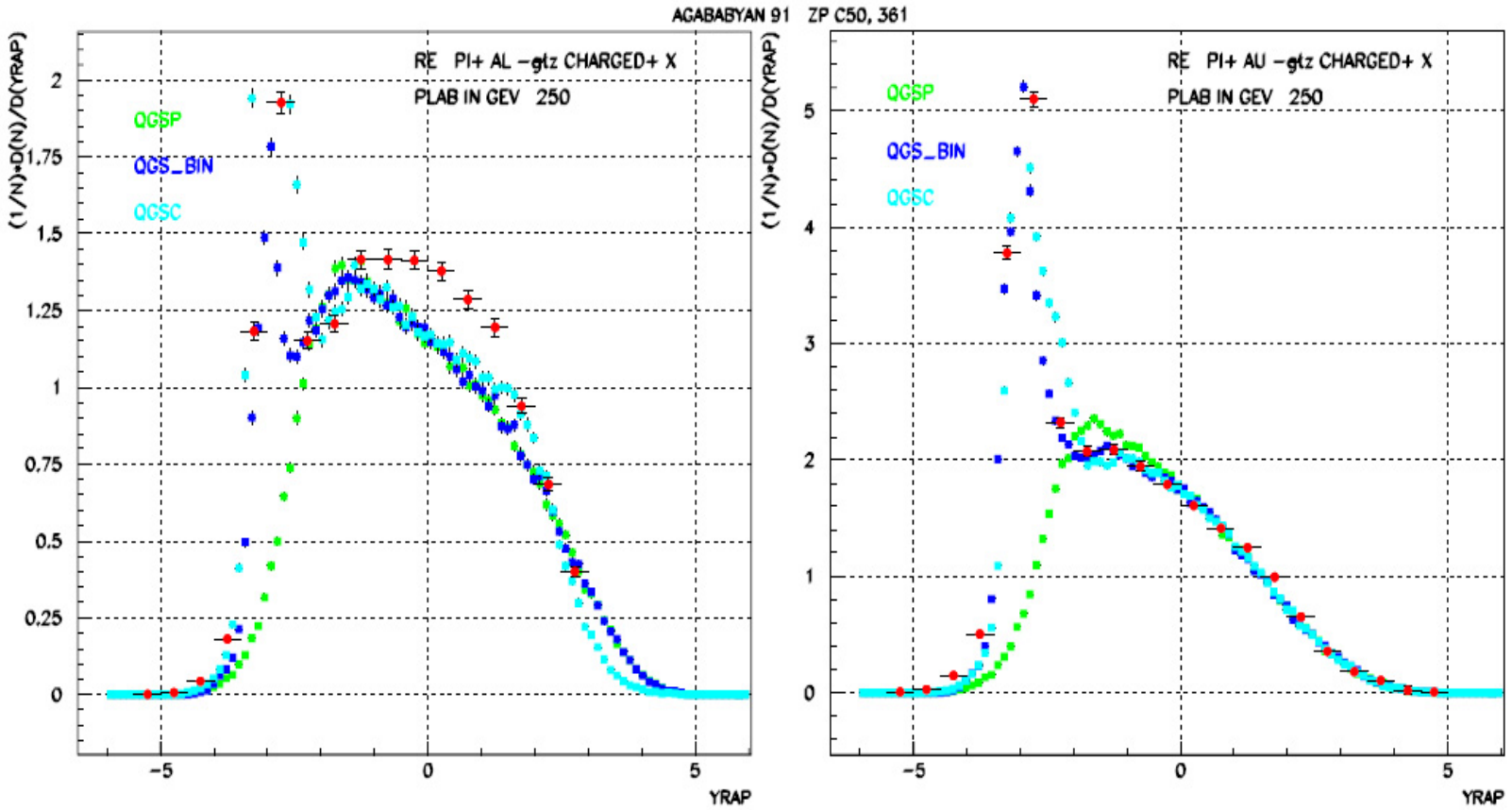
FTF model review and update

- FTF (Fritiof) is a classical string model
  - B. Andersson et al., Nucl. Phys. B281 (1987) 289
  - B. Nilsson-Almquist and E. Stenlund, Comp. Phys. Commun. 43 (1987) 387
  - V.Uzhinsky et al. Yad. Fiz.
- Naturally includes:
  - quasi-elastic model
  - diffraction



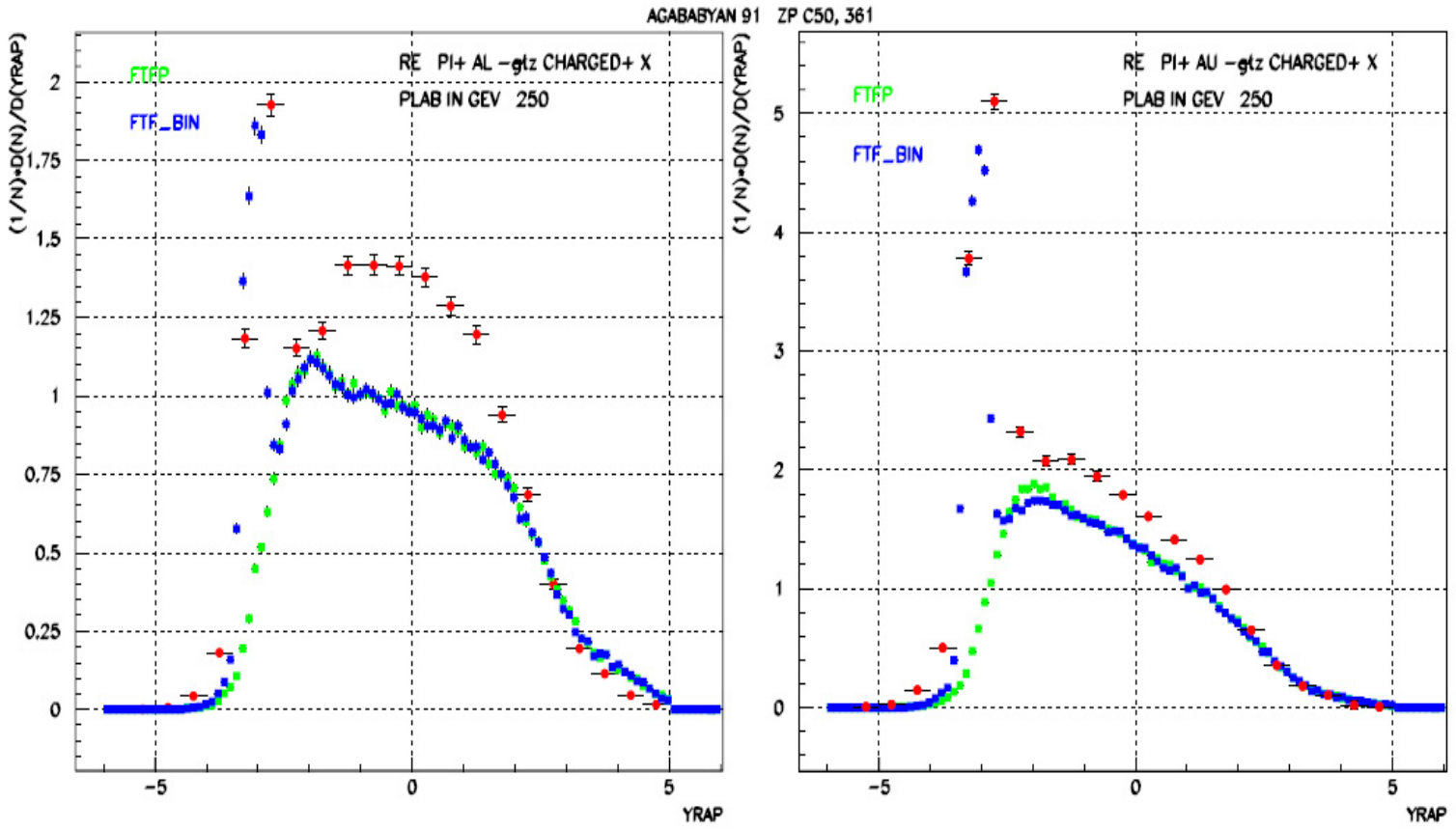
- Validity range can be extended down to 3-5 GeV
- Recent development was focused on
  - Implementation of the Fritiof native model
  - Tuning of parameters to the hadron/nucleon data
  - Combining FTF string model with the Binary cascade model for sampling of re-scattering

Inclusive charged hadron production by 250 GeV π^+ beam



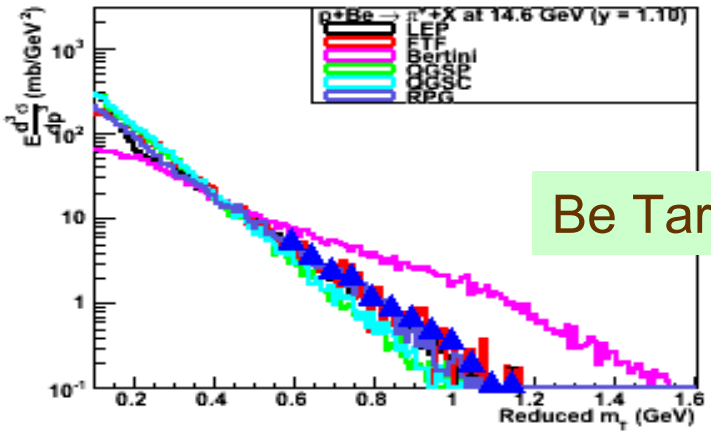
Cascade model required for simulation of re-scattering inside the target

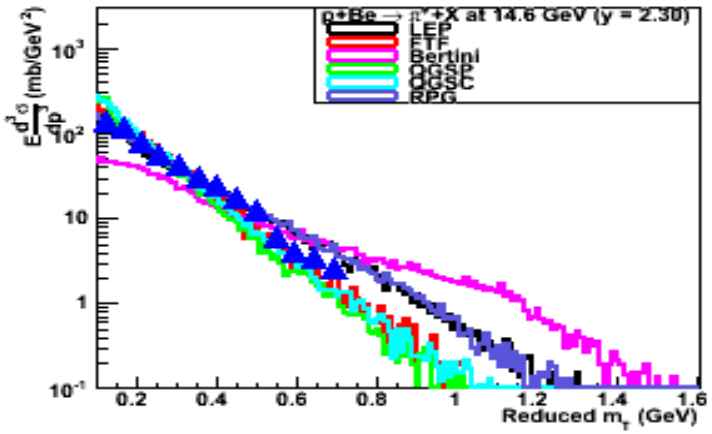
Inclusive charged hadron production by 250 GeV π^+ beam



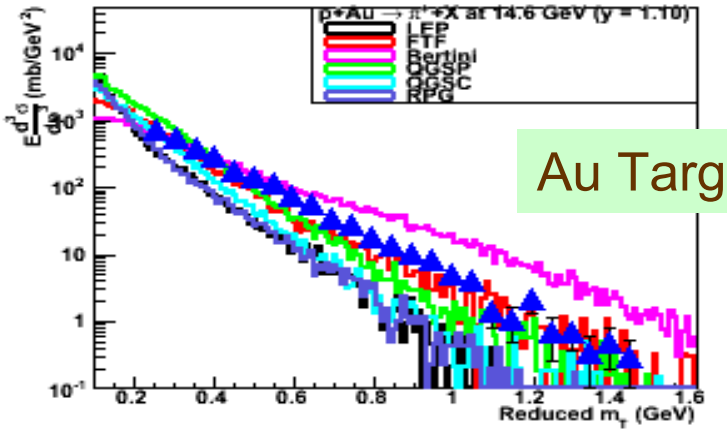
FTF underestimates charge particle production

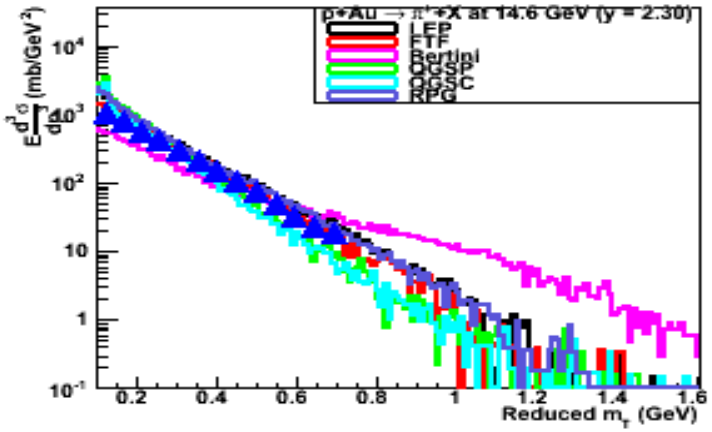
Inclusive π^+ production by 14.6 GeV/c proton beam





Be Target

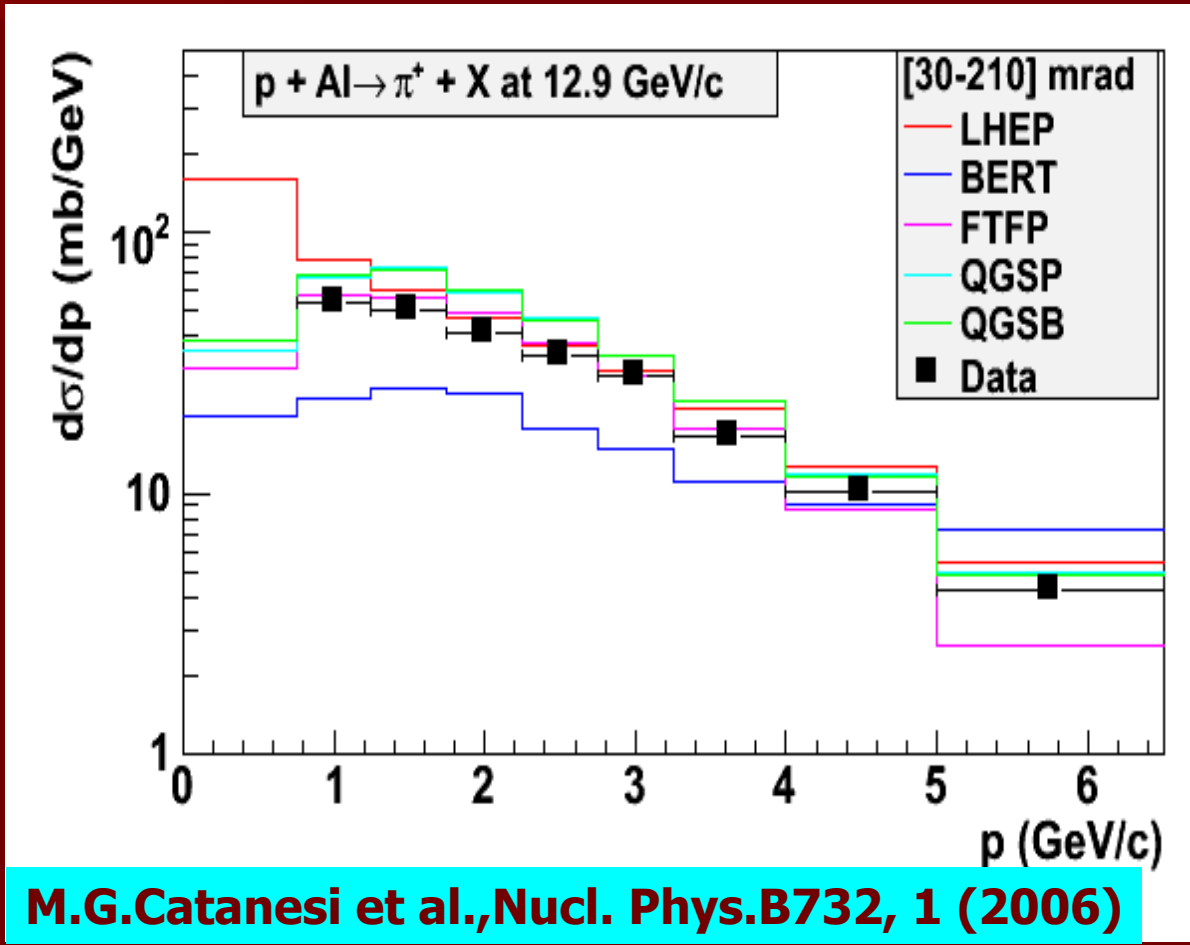




Au Target

Inclusive forward π^+ production by proton 12.9 GeV/c beam

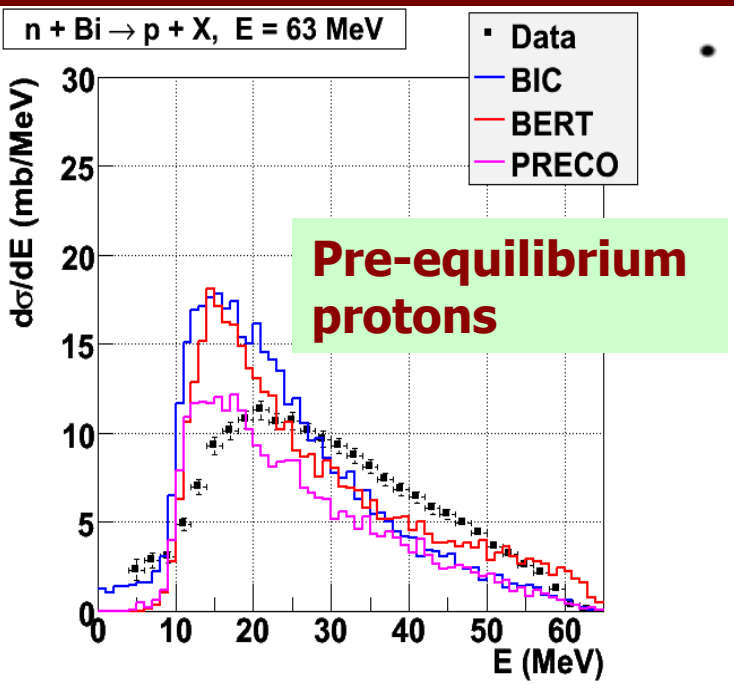
- QGS more close to the data at high energies
- FTFP more close to the data at moderate energies
- Cascade models not applicable above 10 GeV
- LHEP overestimate π^+ yield



M.G.Catanesi et al.,Nucl. Phys.B732, 1 (2006)

Bertini cascade improvements

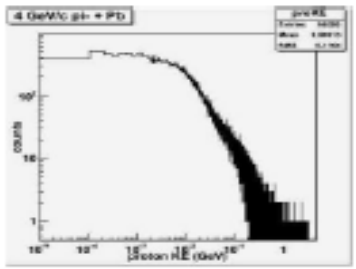
- Extension to strange particles
- Coulomb barrier properly introduced
- Angular distributions
- Internal cross sections



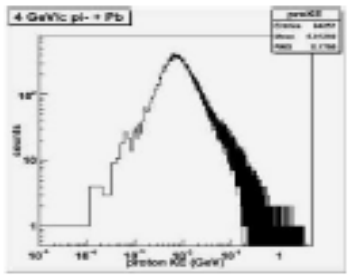
Pre-equilibrium protons

- Coulomb barrier added

– without barrier

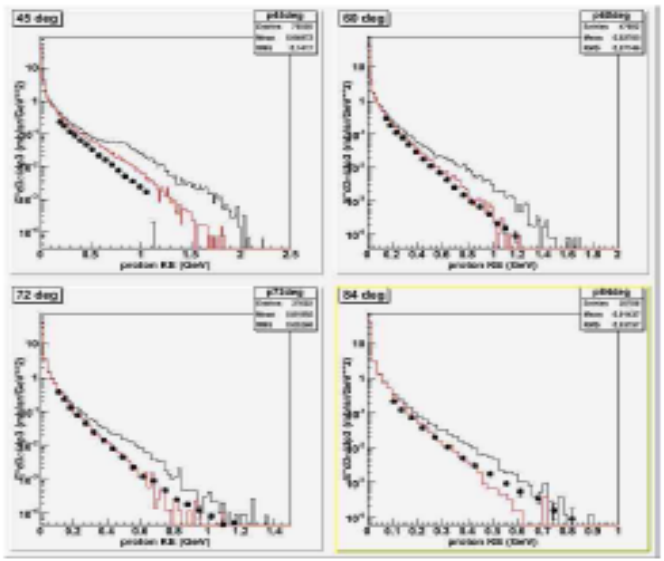


– with barrier

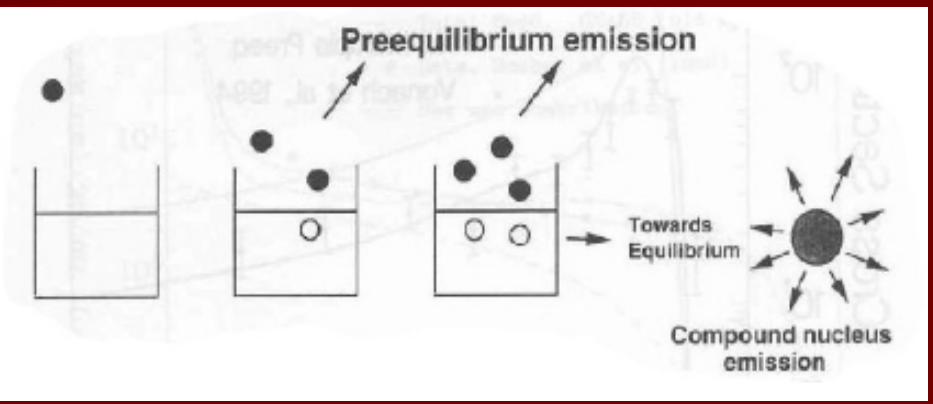


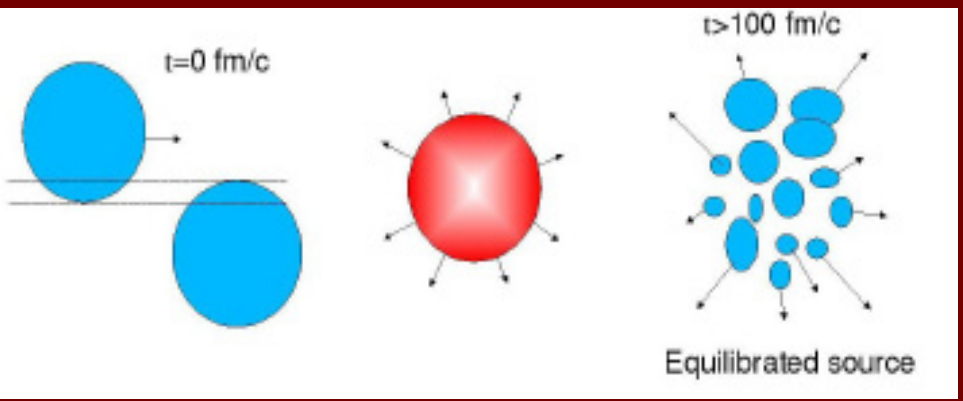
- High energy angular distributions fixed: 4 GeV p+Al

black: original, red: fix



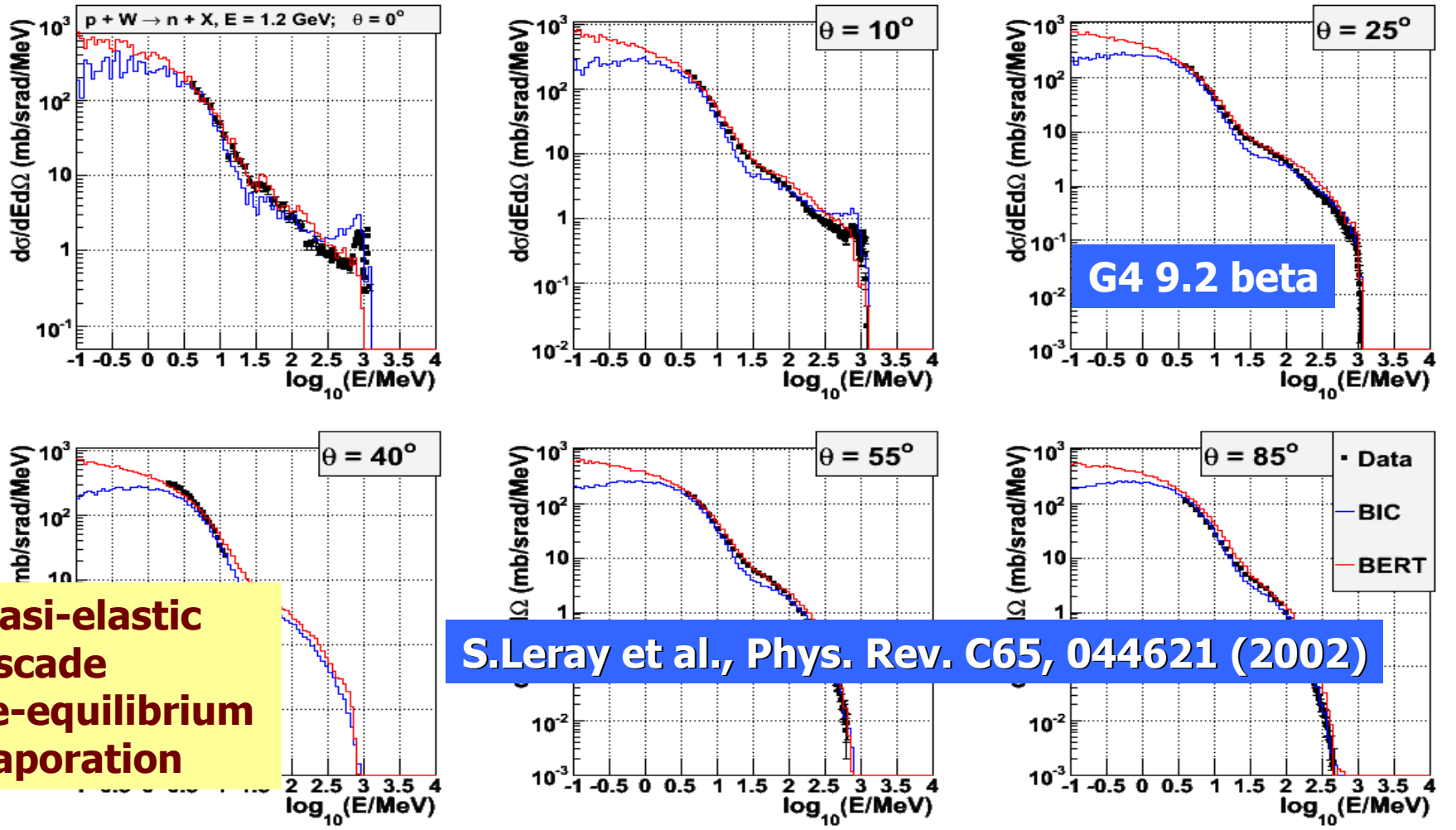
Modifications in Pre-Compound and De-excitation models





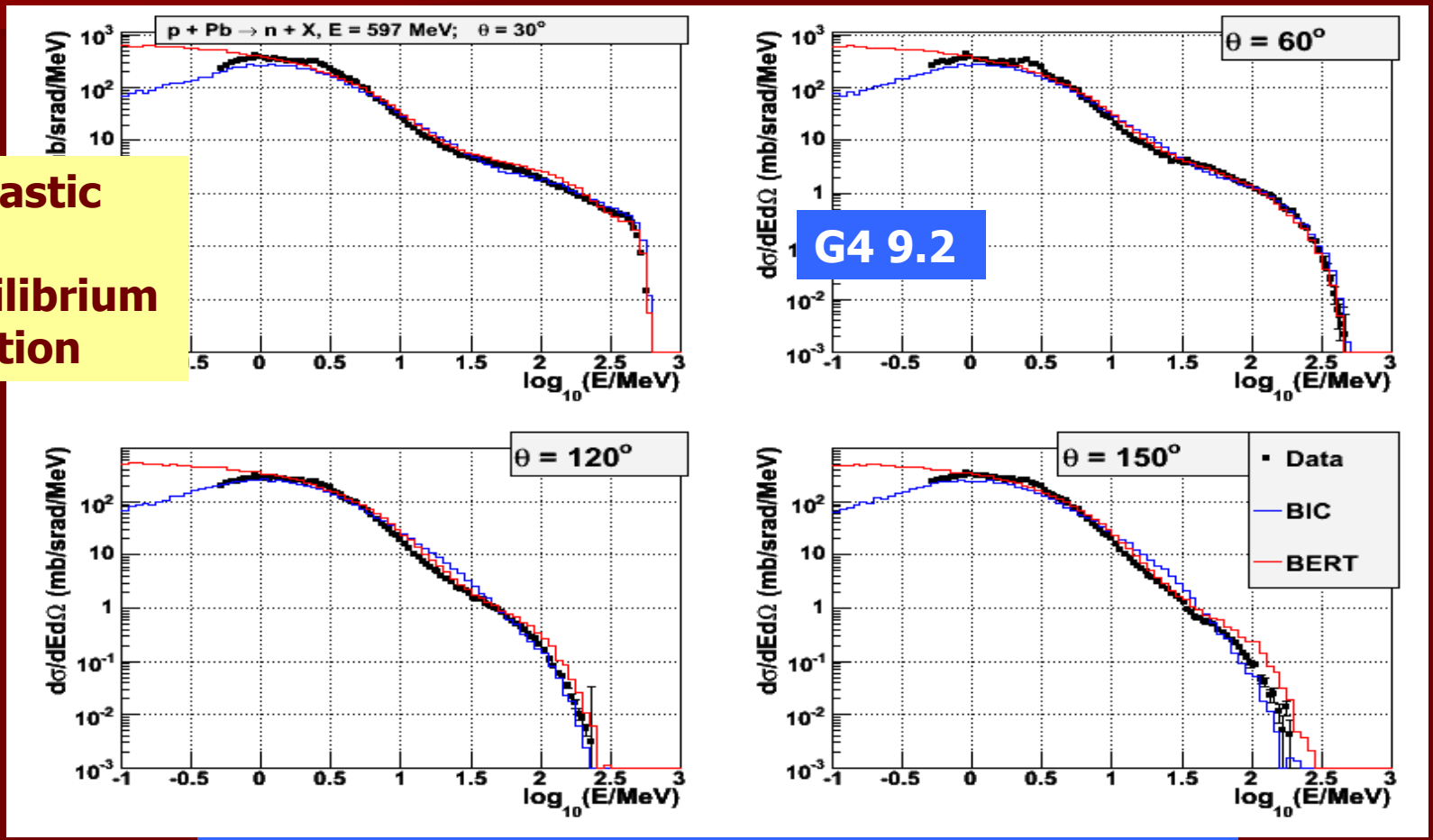
- Pre-compound:
  - more realistic probabilities of particles emission
- De-excitation:
  - Improved evaporation probabilities
- Activation of options
  - Fermi BreakUp (A<18, Z<10)
  - Multi-fragmentation ($E^*/A > 3$ MeV)
  - Light fragments production

Inclusive neutron production by 1.2GeV proton beam in W target



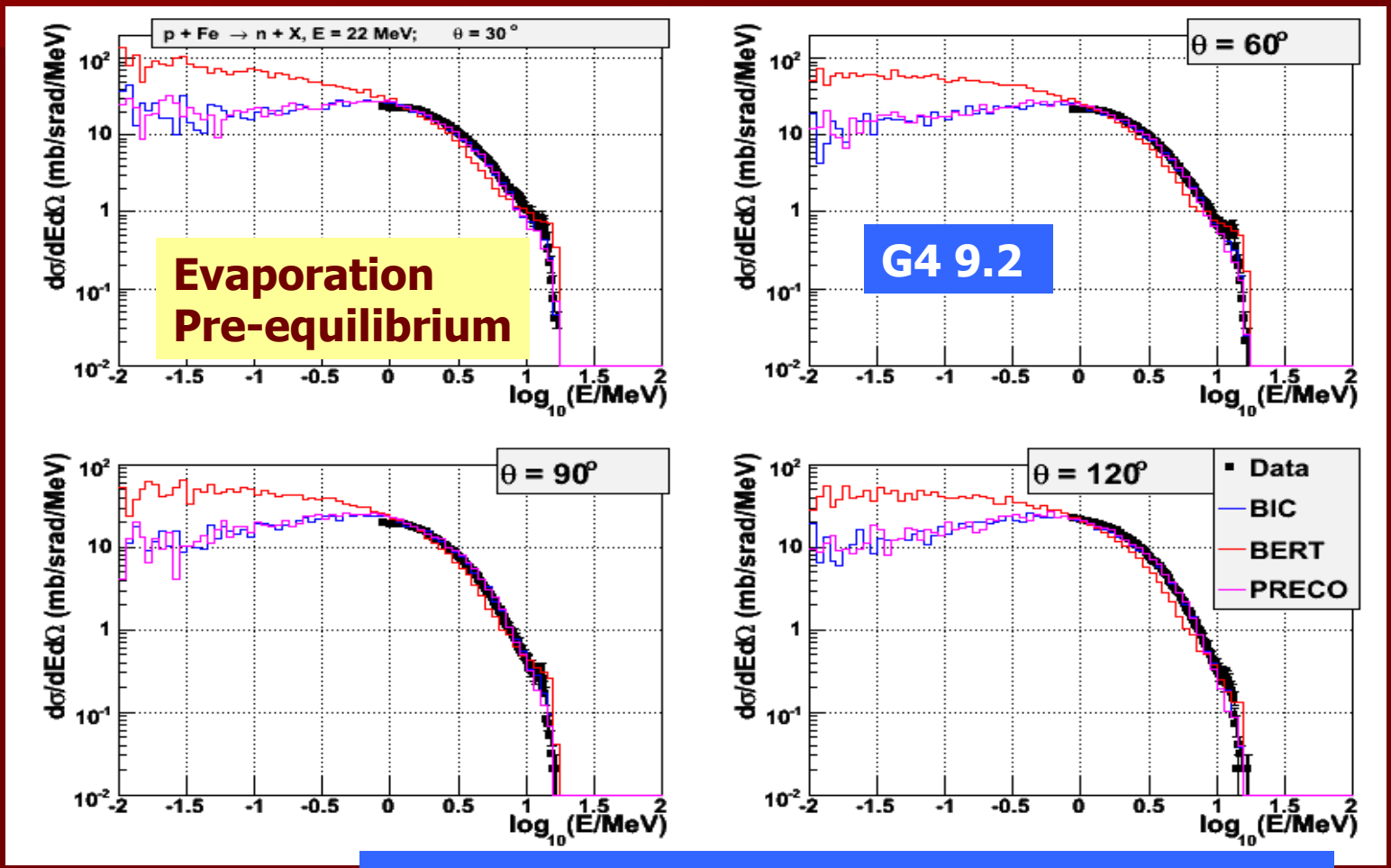
Inclusive neutron production by 587 MeV proton beam in Pb target

Quasi-elastic
Cascade
Pre-equilibrium
Evaporation



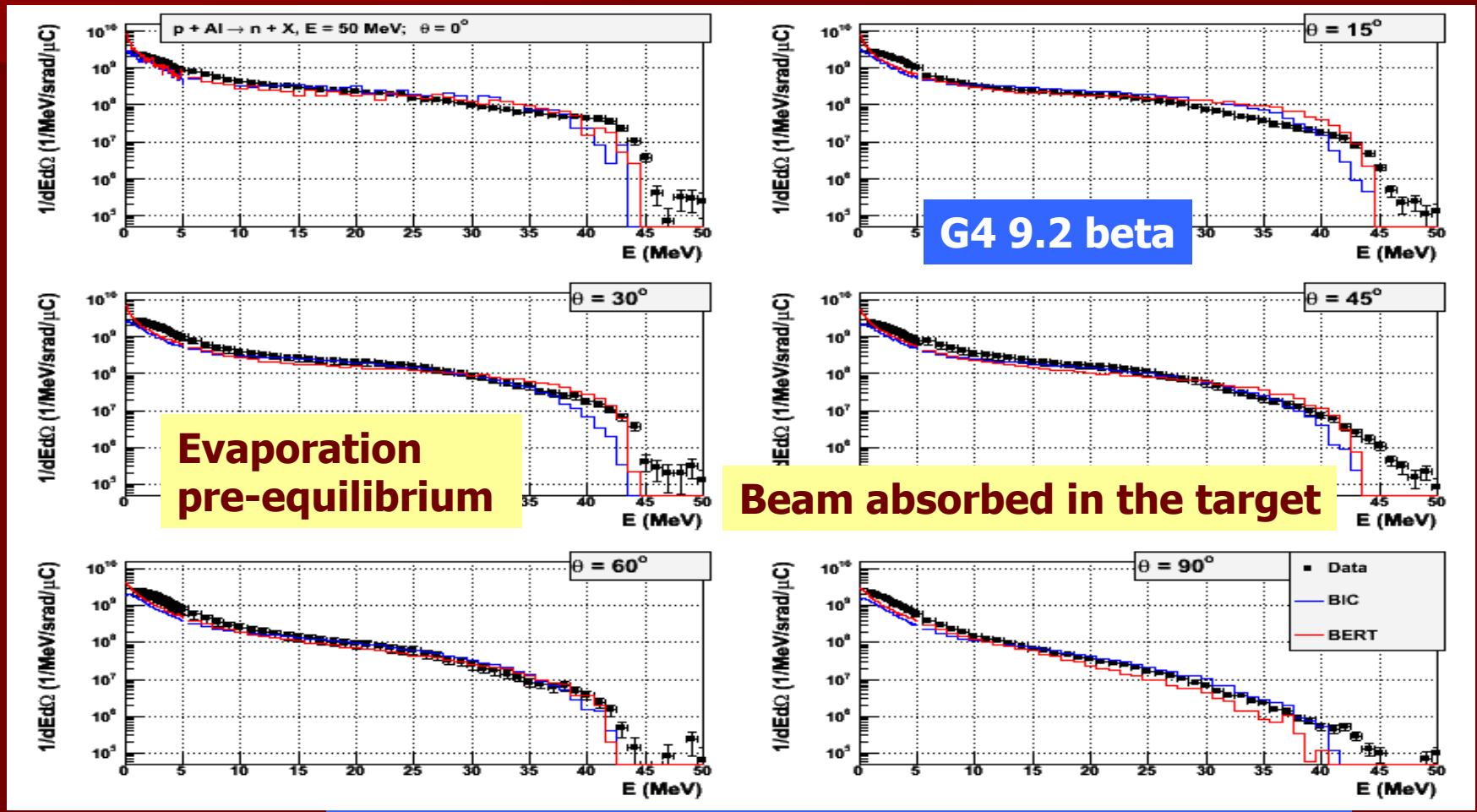
W.B.Amian et al., Nucl. Sc. Eng., 115, 1 (1993)

Neutron production by 22 MeV proton beam in Fe target



N.S.Birjukov et al, Yad. Fiz., 31, 561 (1980)

Neutron production by 50 MeV proton beam in thick Al target



T. Aoki et al, Nucl. Sc. Eng., 146, 200-208 (2004)

Conclusions

- Geant4 hadronic packages successfully used in production for LHC experiments
- There are intensive validation efforts
  - Validation software have been developed by different groups
    - Comparisons with published thin target data
    - Comparisons LHC test-beam data
- Important improvements are foreseen for coming Geant4 9.2 release (December 2008)