Hadronic Physics Updates

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Geant4 Space Users Workshop

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Outline

- Radioactive decay
- Nuclear deexcitation
- Cascade models
- Gamma-nuclear
- High energy models
- Validation package

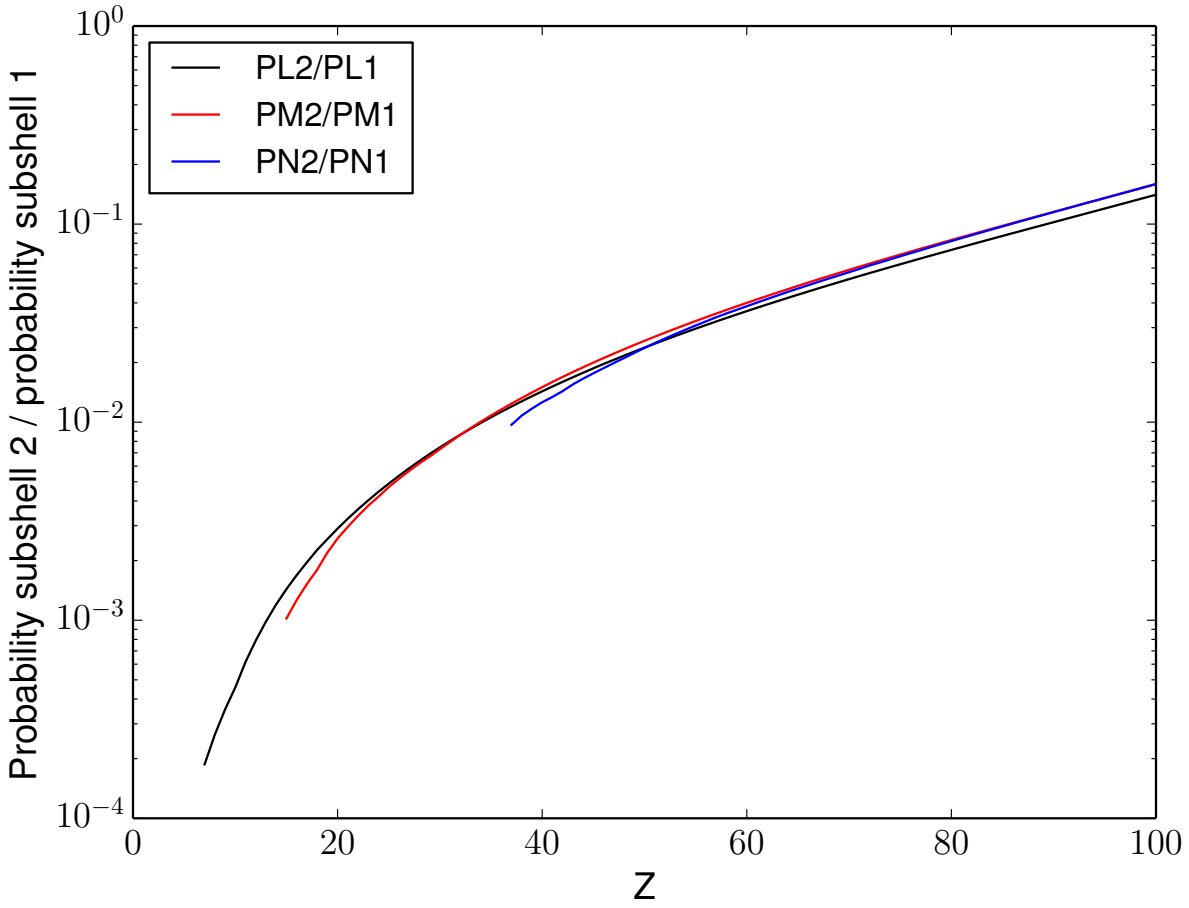
Radioactive Decay

- Completely refactored
  - biased radioactive decay now a derived class of non-biased
  - code now easier to read, maintain

- Electron capture
  - branches added for capture to N shell (previously only K, L ,M)
  - subshell capture probabilities (PL2/PL1, PM2/PM1, PN2/PN1) now tabulated for each nuclide (from Bambynek et al., calculation of electron radial wave functions)
  - previously one fixed ratio for all nuclides

Radioactive Decay - Electron Capture

- Probability to L3,M3,N3 and above is 0
  - Valid for allowed transitions

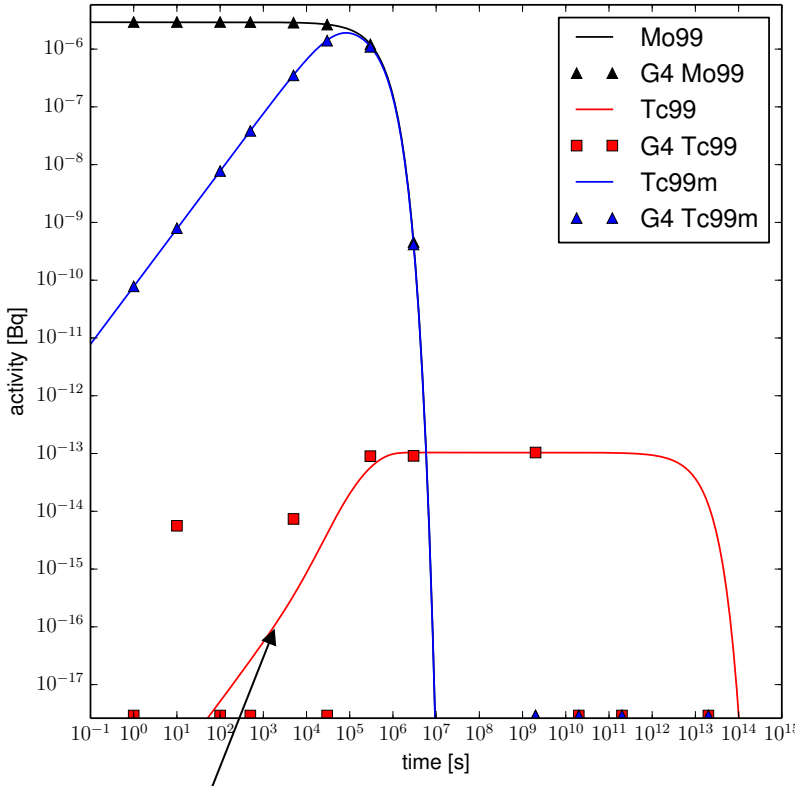


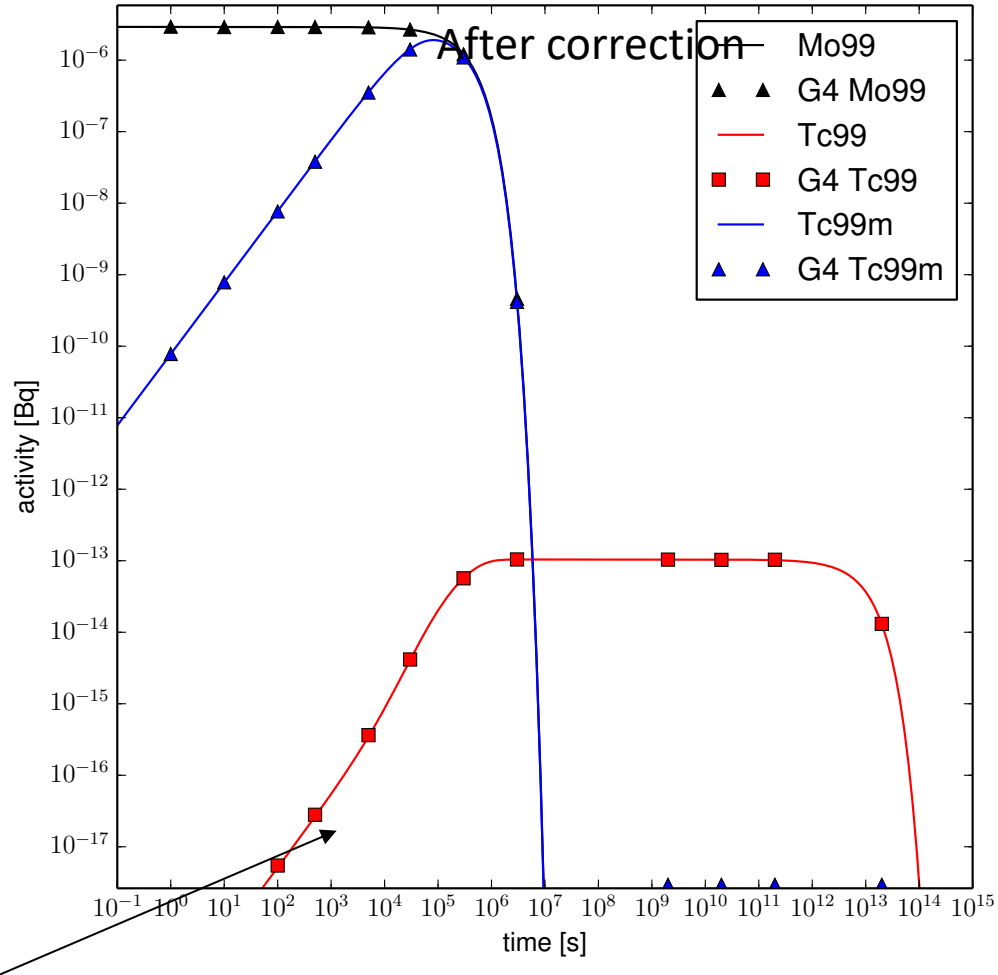
Radioactive Decay

- Long-standing biasing bugs fixed
  - activation curves had strange behavior, incorrect time profiles

- Radioactive decay validation program begun
  - currently no RD plot repository
  - will populate all major decay modes (α, β, EC, IT)

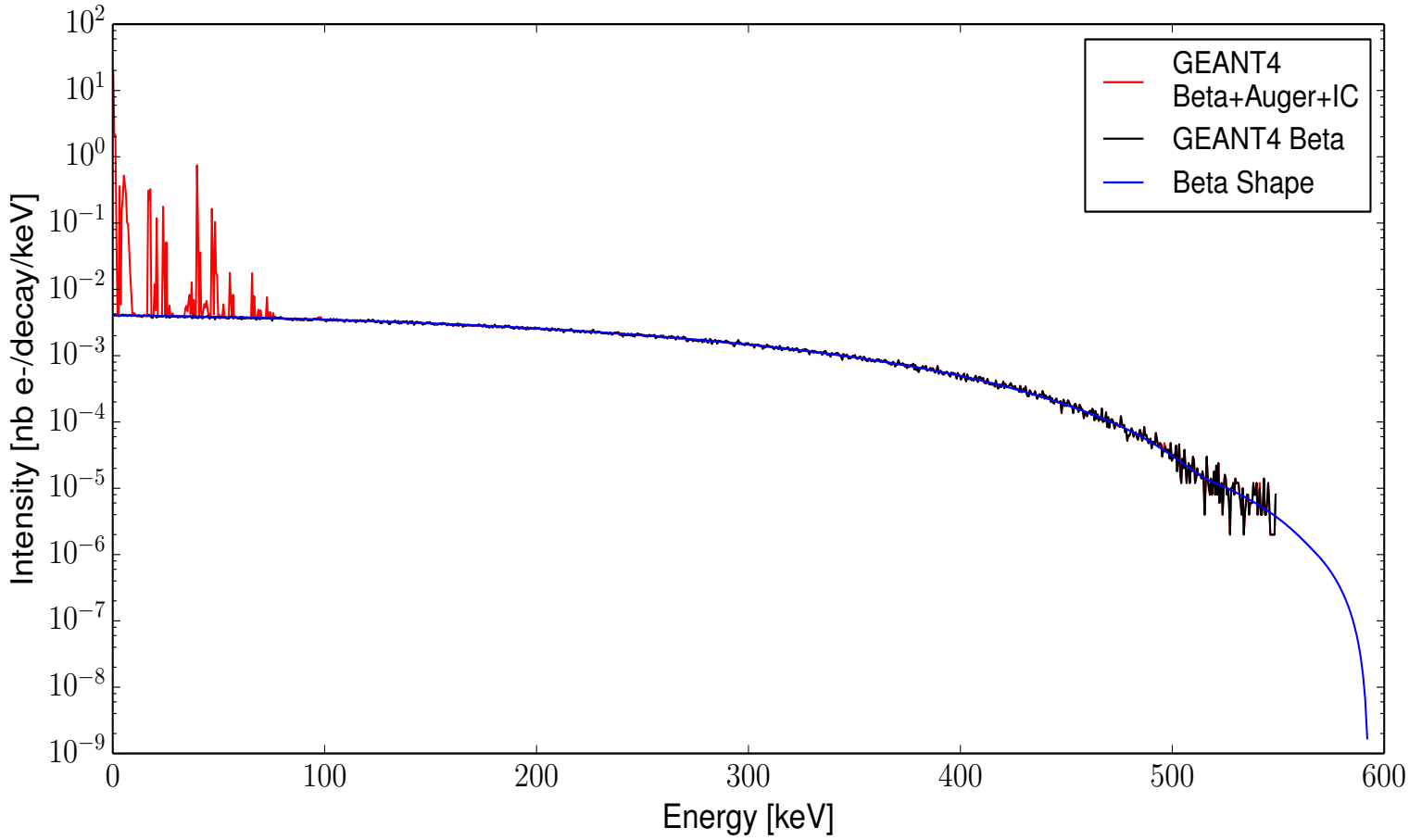
Biased Mode Validation of G4RadioactiveDecay





Beta Spectrum Validation

^{161}Tb electron spectrum



Activation Measurement from Hitomi Satellite

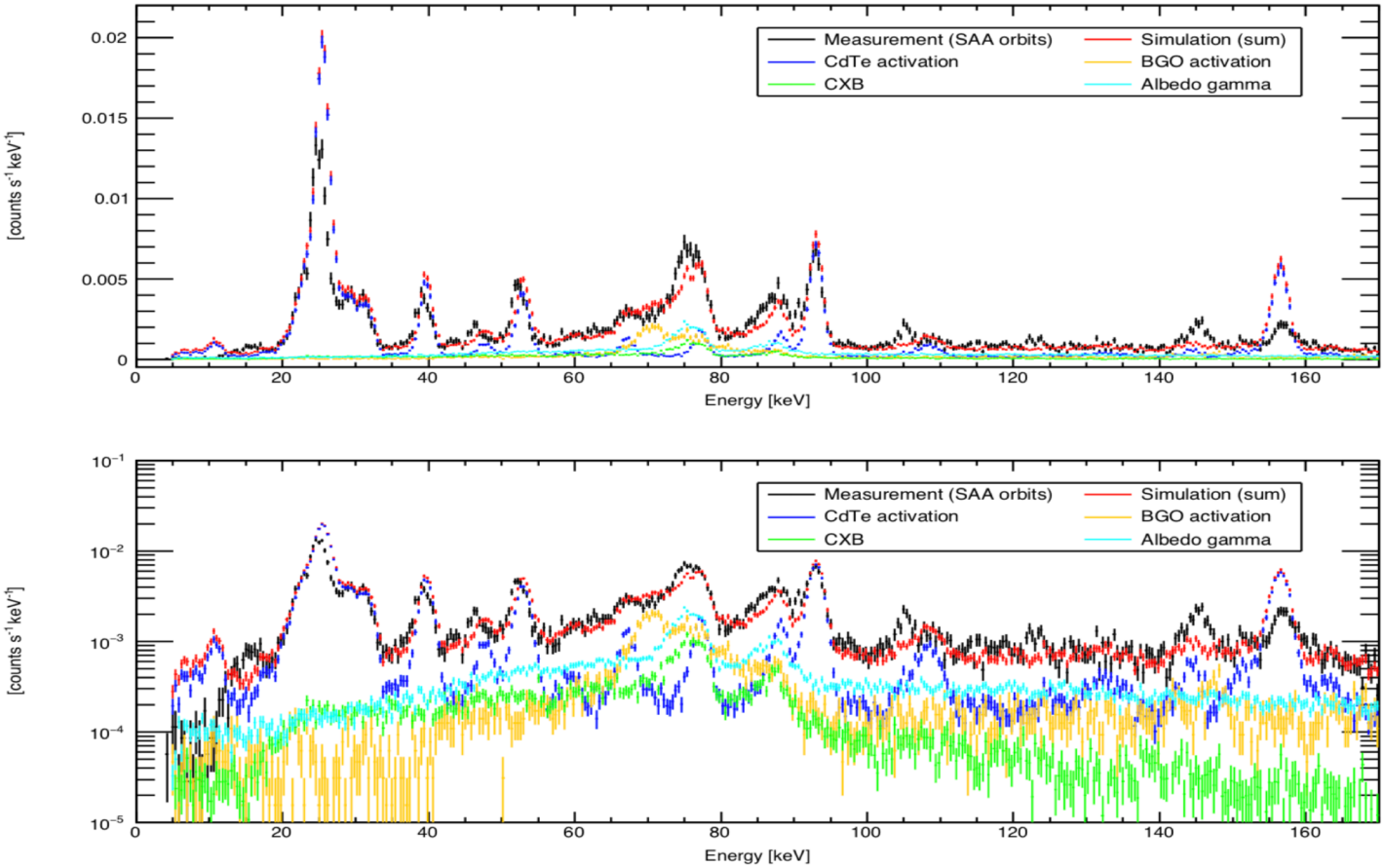


Figure 11: Background spectrum (black) of the HXI CdTe-DSD measured during the SAA orbits compared with simulation (red). All simulation components are also shown: radioactivation in CdTe (blue), radioactivation in BGO (yellow), CXB (green), and albedo gamma rays (cyan). The top panel is shown in linear scale, while the bottom is logarithmic. Although the data points are shown in the range of 5–170 keV, efficiency of readout rapidly declines below ∼10 keV due to trigger thresholds and above ∼160 keV due to limited analog-to-digital converter ranges (see §6).

Nuclear Deexcitation

- Correlated gamma emission
  - before 10.4 successive gamma emissions were uncorrelated and isotropic
  - now take into account J^{π} of levels to determine multipolarity of transition
  - γ angular distributions now governed by Legendre polynomials
  - off by default – too time-consuming, especially for high J

- Production and transport of long-lived nuclides
  - between gamma transitions the intermediate nuclides that live long enough (1000 s) are produced as recoils and tracked in Geant4 (1 μs if radioactive decay is used)

Nuclear Deexcitation

- New experiment-derived electron binding energies
  - whenever possible, BEs taken from LBL (XDB) X-Ray Data Booklet
  - all others from theory
  - up to Z = 120
  - this version is still optional – old (all theory) version still the default

- Auger emission and fluorescence are switched off by default
  - too time-consuming
  - automatically switched on when radioactive decay is used

- Removed obsolete FermiBreakup model

INCL++ Cascade

- Extension to strange sector
  - K, Λ, Σ production and interaction now included
  - Hypernuclei produced but still not handled in Geant4

- Extended to higher incident energies (15 GeV)

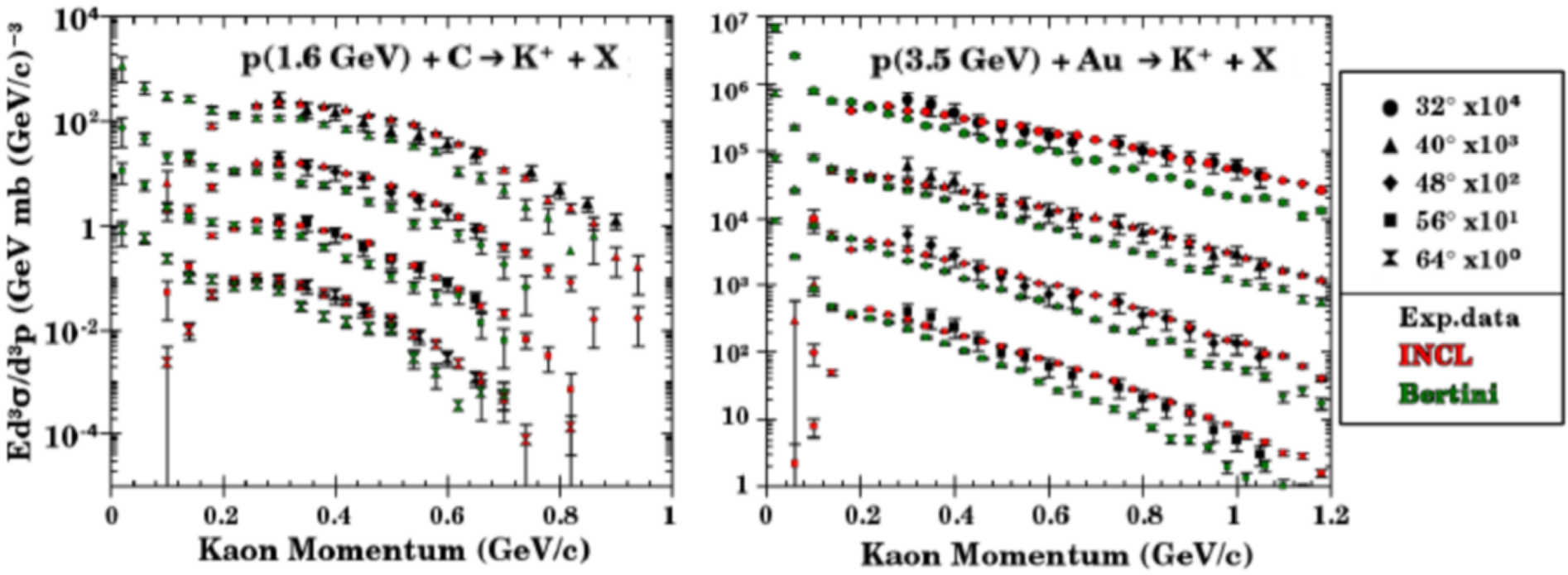
- New version of ABLA++ (deexcitation for INCL++)
  - not yet used in Geant4 (currently use Geant4 deexcitation)

Bertini Cascade

- Added high multiplicity final states for kaon-induced reactions
  - now up to 9-body final state (was only 5-body before)
  - result: more strange and fewer non-strange reactions above 10 GeV
  - goes in right direction for LHC validations
- Bug in pion absorption on quasi-deuterons fixed
  - did not respect charge conservation before
  - also goes in right direction for LHC validation
- Currently tackling long-standing problem in Bertini: phase space generation for multi-particle final states
  - existing generator not very good above 4 GeV

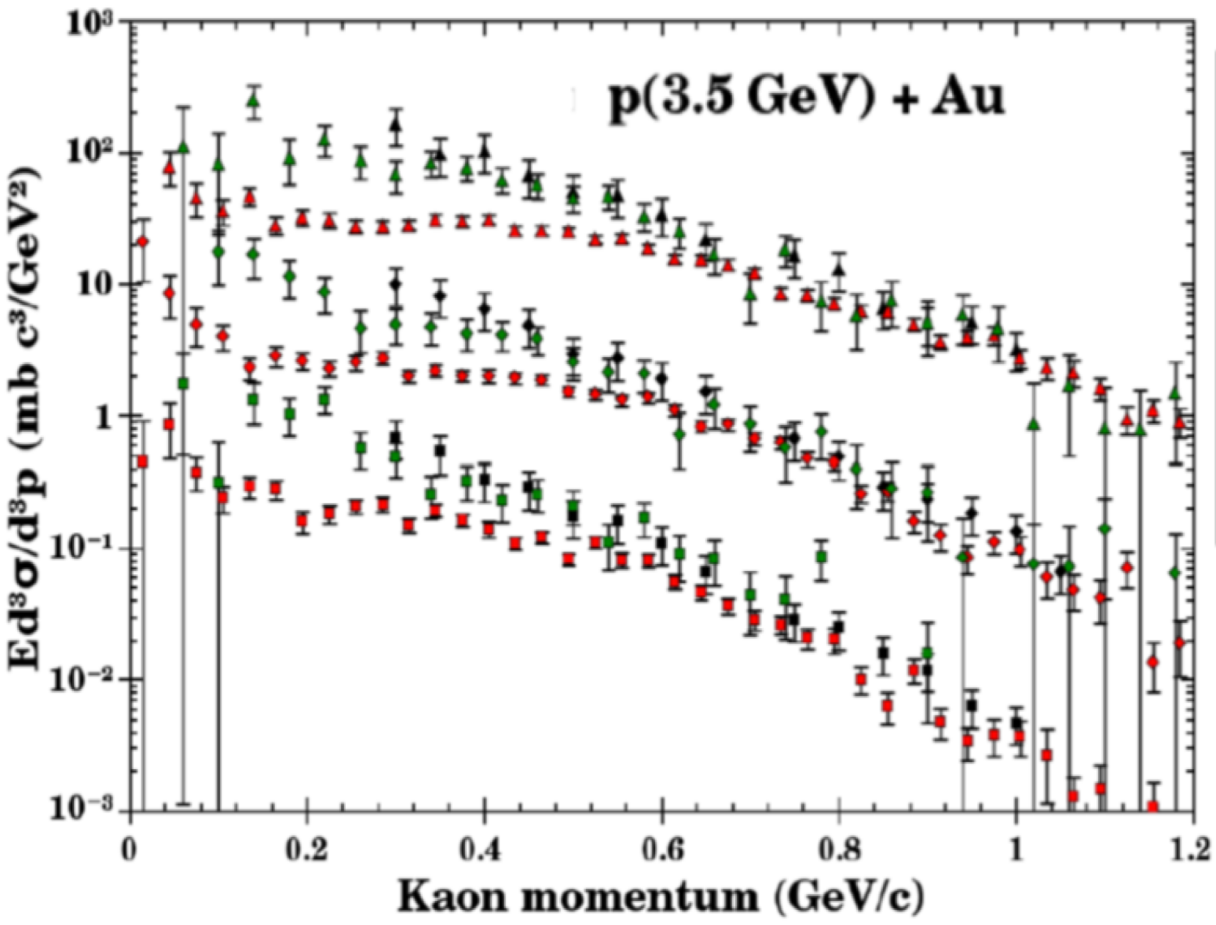
Results - K^+ production

KAOS - W. Scheinast et al., PRL 96, 072301 (2006)



Most of the time K^+ production well simulated...

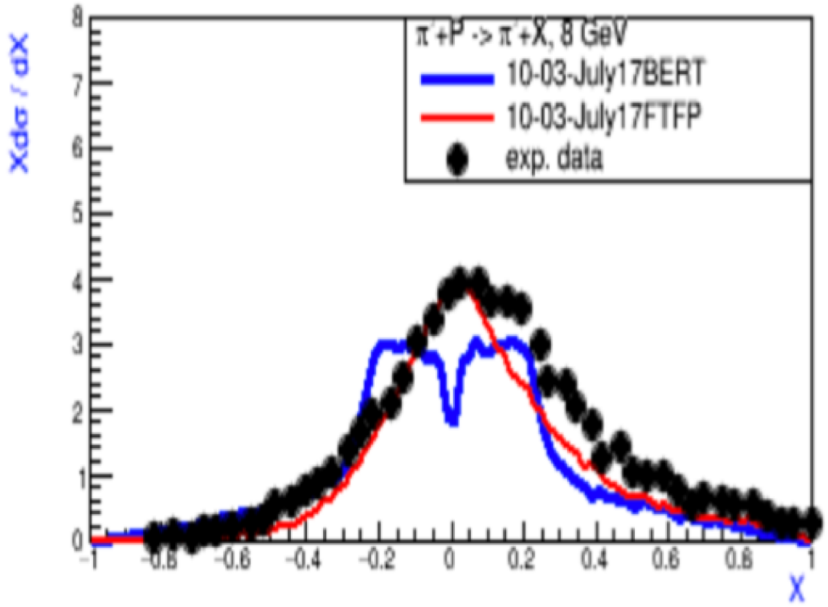
Results - K^- production

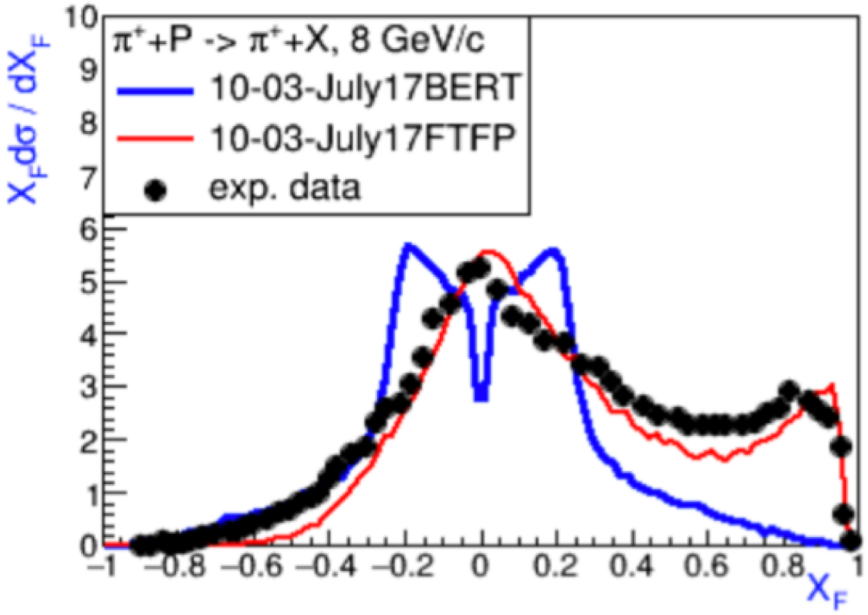


A word about K^- production

Relatively bad results, notably at low energy

$\pi^- p \rightarrow \pi^- X$ @ 8 GeV/c





$\pi^+ p \rightarrow \pi^+ X$ @ 8 GeV/c

“High Precision” Gamma-nuclear Model

- G4LENDorBERTModel now available
  - G4LEND is a database-driven model used mainly for neutrons
    - uses Generalized Nuclear Data (GND)
    - up to 100 MeV
    - large number of targets
    - also has data for gammas

- Perfect solution for current problem of poor agreement of Bertini gamma reactions at low energy
  - Bertini not intended flor low energies, but with GND nuclear structure effects can be simulated
  - Hybrid: G4LEND + Bertini → G4LENDorBERT

Giant Dipole Resonance in Si

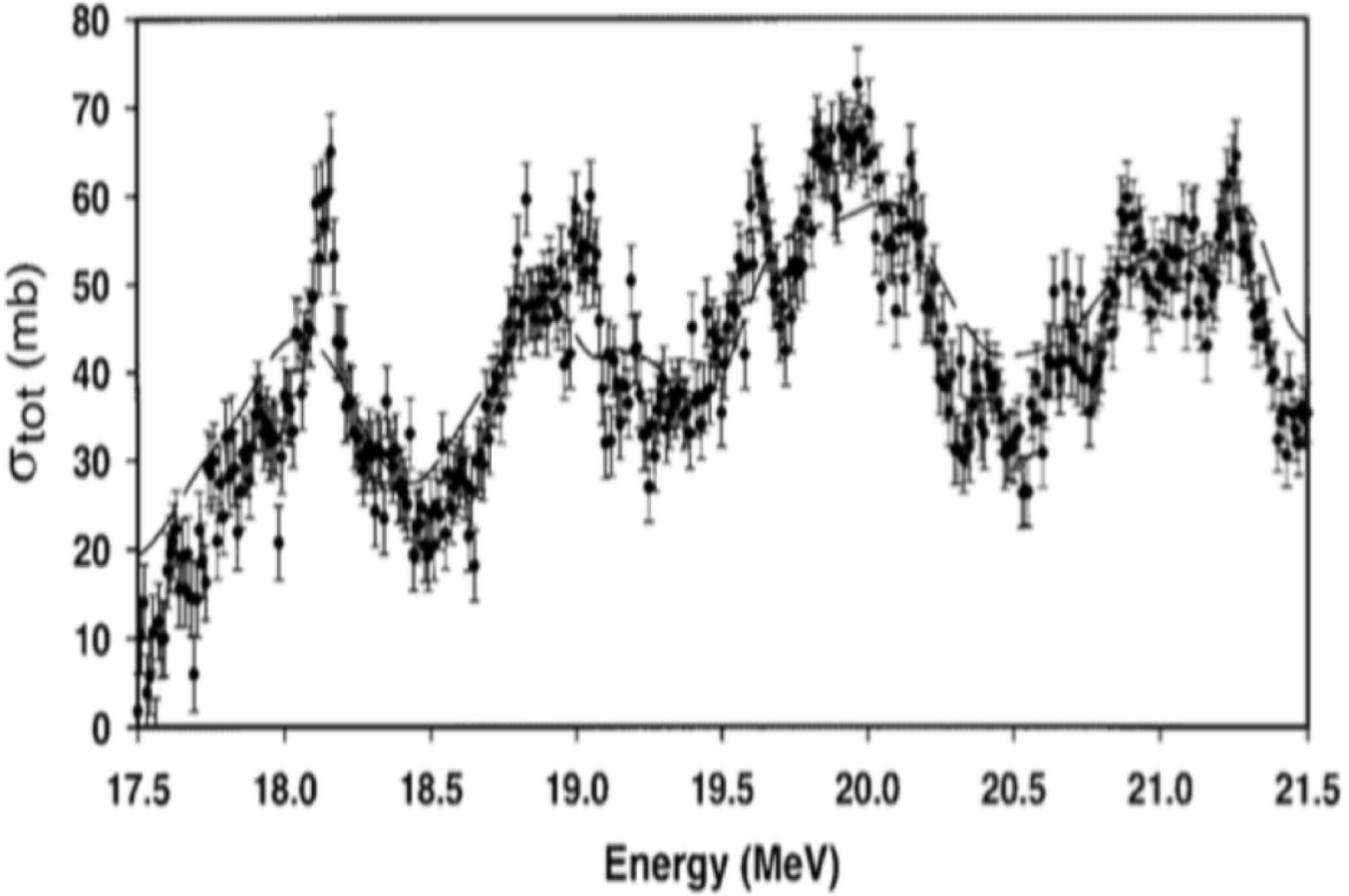


Fig. 2 The observed ^{28}Si(γ, abs) cross section (•) in the energy range 17.5–21.5 MeV

QGS (Quark Gluon String) Model

- Has been in Geant4 for a long time
  - but not often used due to superior physics performance of FTF

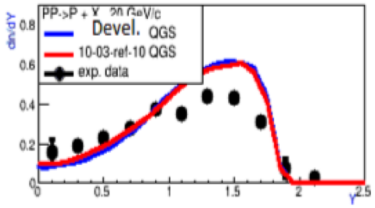
- Model as originally developed (outside of Geant4) has been used elsewhere with good results (LAQGSM)
  - resume development of Geant4 version
    - more theory-based than FTF
    - in principle more predictive power
    - can reach higher energies (few TeV) than FTF

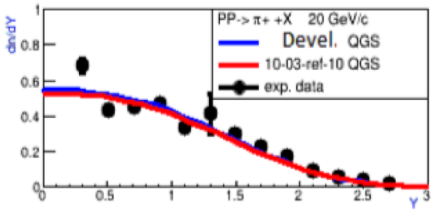
- With recent developments, good agreement with thin target data and closer to FTF results

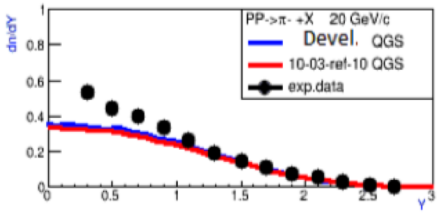
QGS (Quark Gluon String) Model

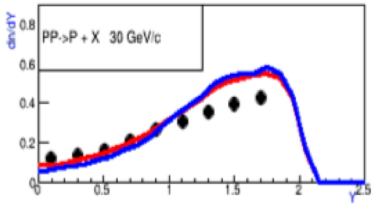
- Recent improvements (V. Uzhinsky)
  - added Reggeon cascade (as in FTF)
  - added multi-Pomeron exchange (to access higher energies)
  - use Reggeon/Pomeron parameters as prescribed by Kaidalov and Poghosyan
    - closer to those of original model
  - added constituent quark masses
    - were 0 before
    - helps low energy behavior
  - tuning of QGS string fragmentation
  - improved Fermi motion of target nucleons
  - improved treatment of the remnant nucleus

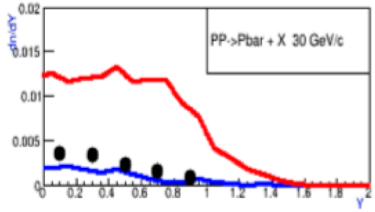
PP interactions, NA61 data

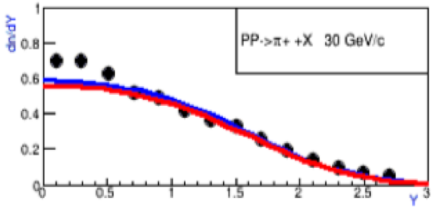


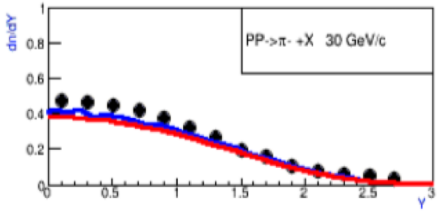


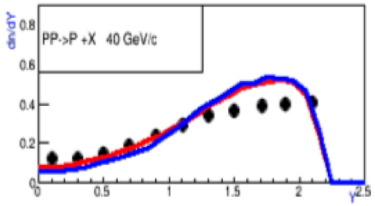


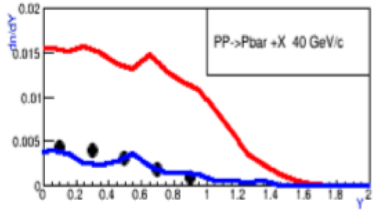


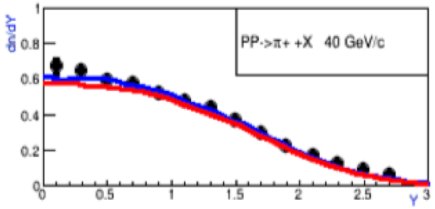


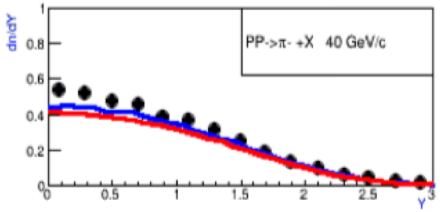


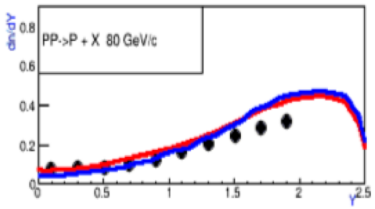


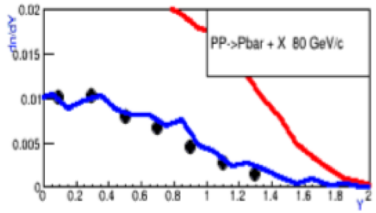


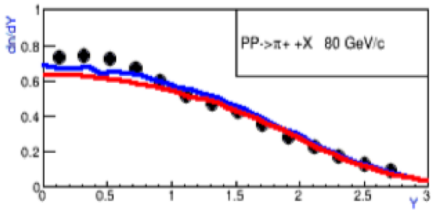


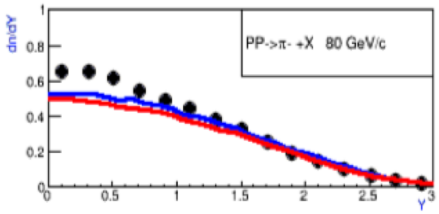


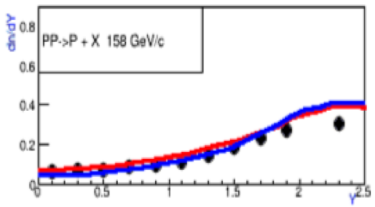


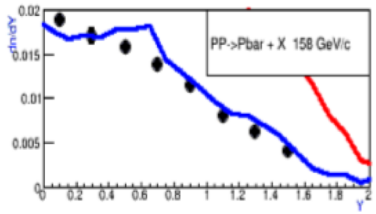


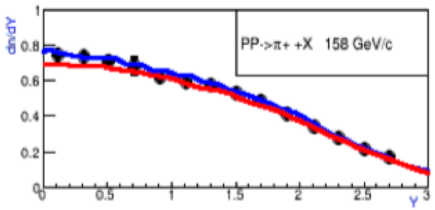


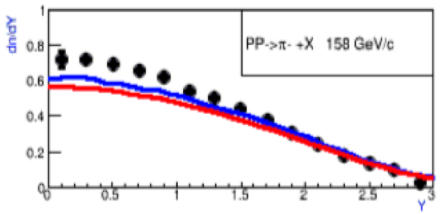












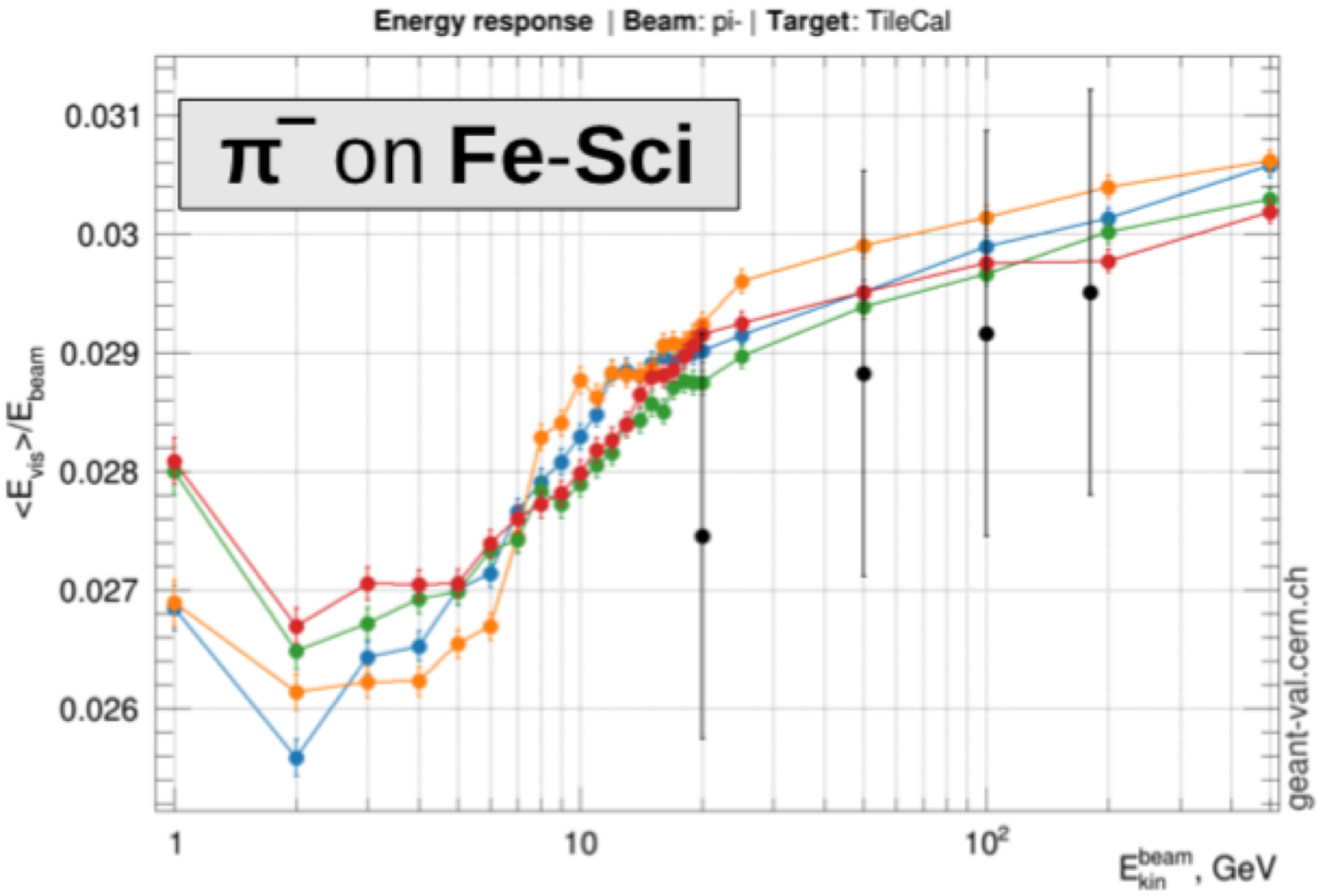
FTF

- Several improvements
  - added rotating QCD strings → broadens resonances (Δ and ρ)
  - improved version of Lund string fragmentation
  - new tuning of model parameters

- Have begun to use Professor
  - application which allows efficient tuning of multiple parameters by fits to data
  - useful now that there are many tunable model parameters

- Good agreement to thin target data
  - but agreement with LHC shower shapes gets worse. Why?
  - likely a large under-estimate of Birks quenching by the experiments

Energy Response ATLAS TileCal



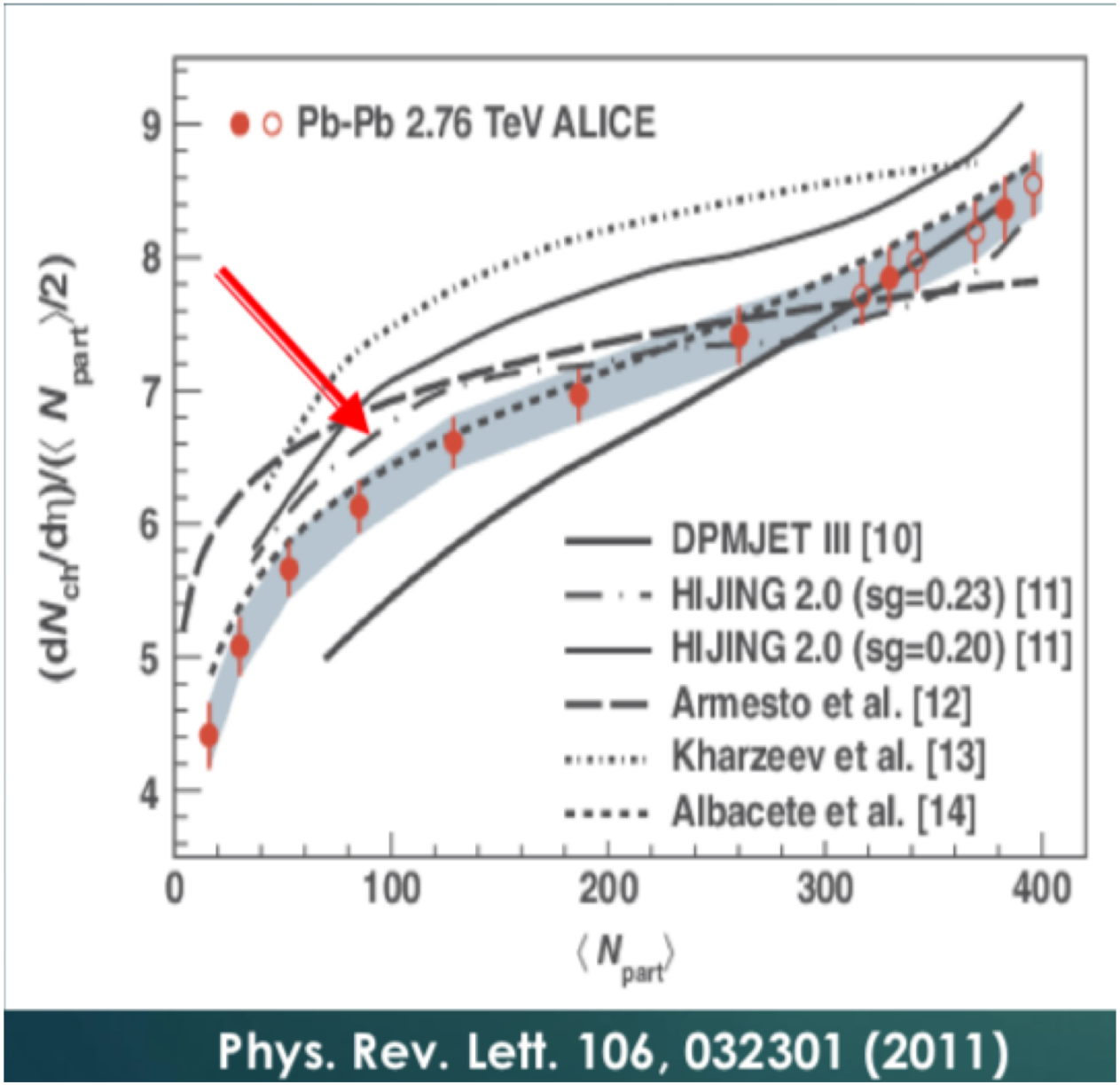
HIJING++

- Heavy Ion Jet Interaction Generator
  - microscopic transport model built to work at RHIC and LHC energies
  - uses Pythia 5.3 to generate kinetic varaibles for easch scattering
  - uses JetSet 7.2 for string and jet fragmentation
  - uses Fritiof (FTF) for string interactions

- Being developed in part by one of our collaborators, Khaled Abdel-Waged (Saudi Arabia)

- C++ version, so can be used with Geant4.

HIJING++



Phys. Rev. Lett. 106, 032301 (2011)

Validation Suite

- Main hadronic validation suite is down
  - sorry about that
  - old site now obsolete
  - new site was being developed (FNAL) but work has stopped (funding)

- CERN developing one, but hadronic plots not migrated yet
  - big job

- For now most plots are on individually maintained systems
  - ask us if have questions

Summary

- Radioactive decay (re-designed and upgraded, validation begun)
- Nuclear deexcitation (correlated gamma emission, tracking of long-lived nuclides)
- Cascade models (extensions to higher energy, phase space generator work)
- New low energy model for gamma-nuclear
- High energy models (new QGS development, HIJING HZE model)
- Validation package being replaced (under development)