New Developments for Bertini Cascade

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Geant4 Collaboration Workshop

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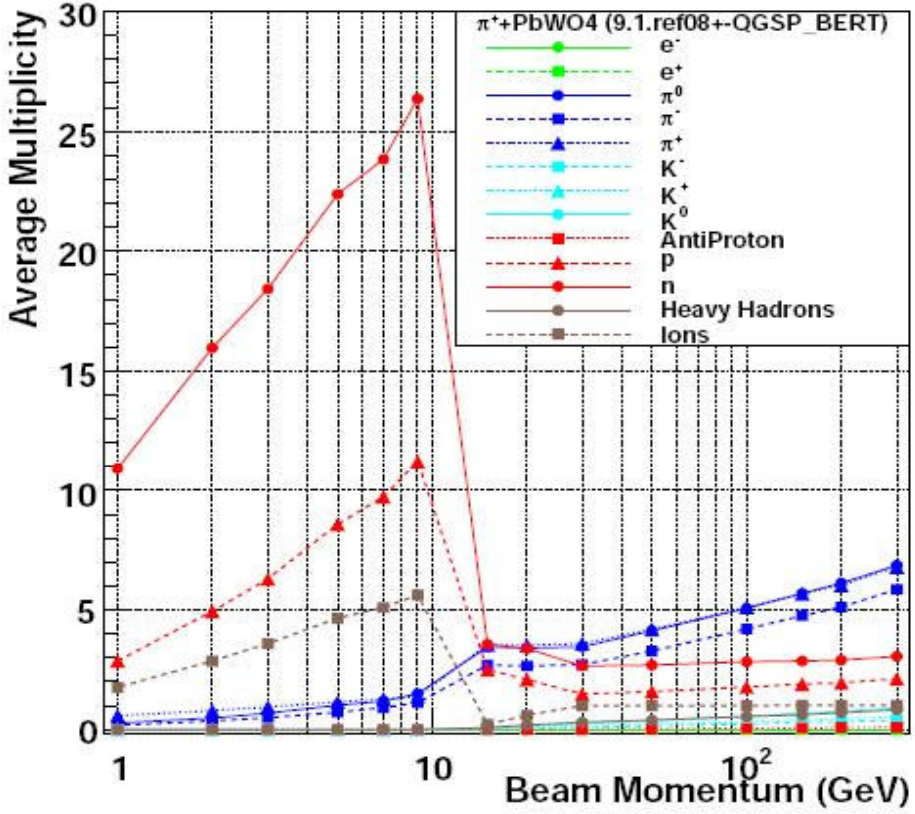
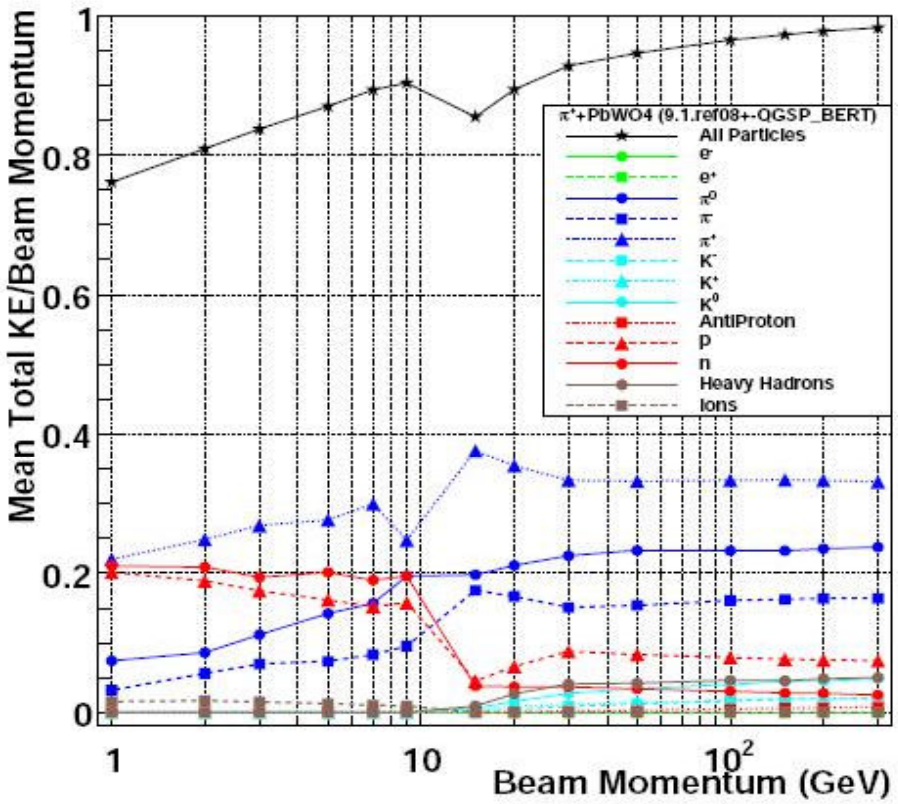
Motivation

- Bertini cascade is part of physics lists in all LHC experiments
  - used in other fields as well
- Works reasonably well with some major exceptions:
  - showers still too short, too narrow
  - at least partly responsible for discontinuities in multiplicity, mean energy, etc.
- Address these problems with a two-fold plan:
  - find model shortcomings and fix them
  - extend model capabilities in energy and in physics features

Kinks in Multiplicity and Energy



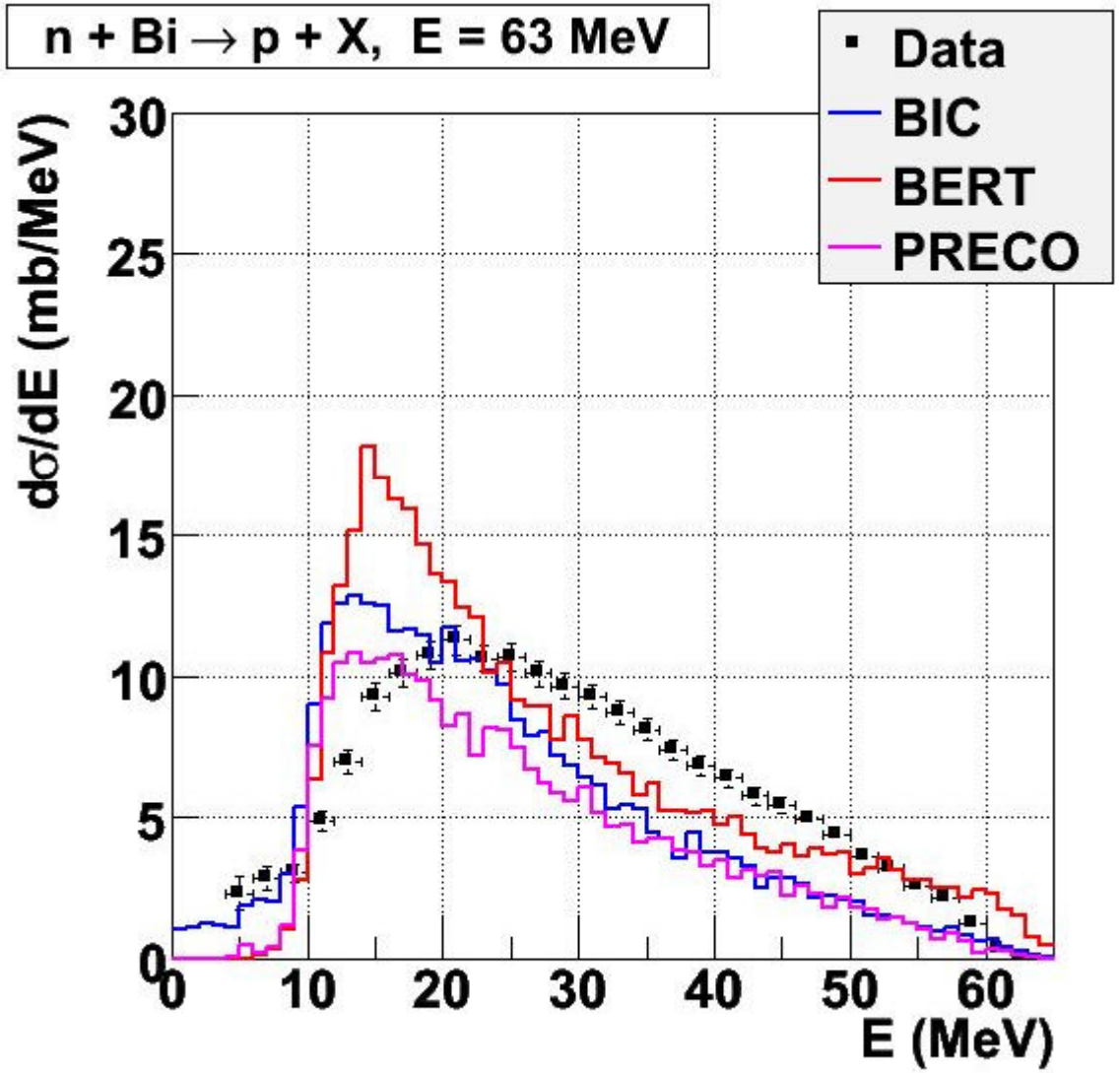


- Mean multiplicity/mean total kinetic energy per particle have 2 discontinuities

Changes to Code

- past
  - addition of strange particle interactions
  - over-estimate of quasi-elastic scattering fixed
  - Coulomb barrier added
- present
  - cross section review and correction
  - addition of 7-, 8-, and 9-body final states to elementary interaction
  - strange pair production
  - formation length
- future
  - precompound interface
  - trailing effect
  - coalescence model
  - anti-proton, anti-neutron interactions

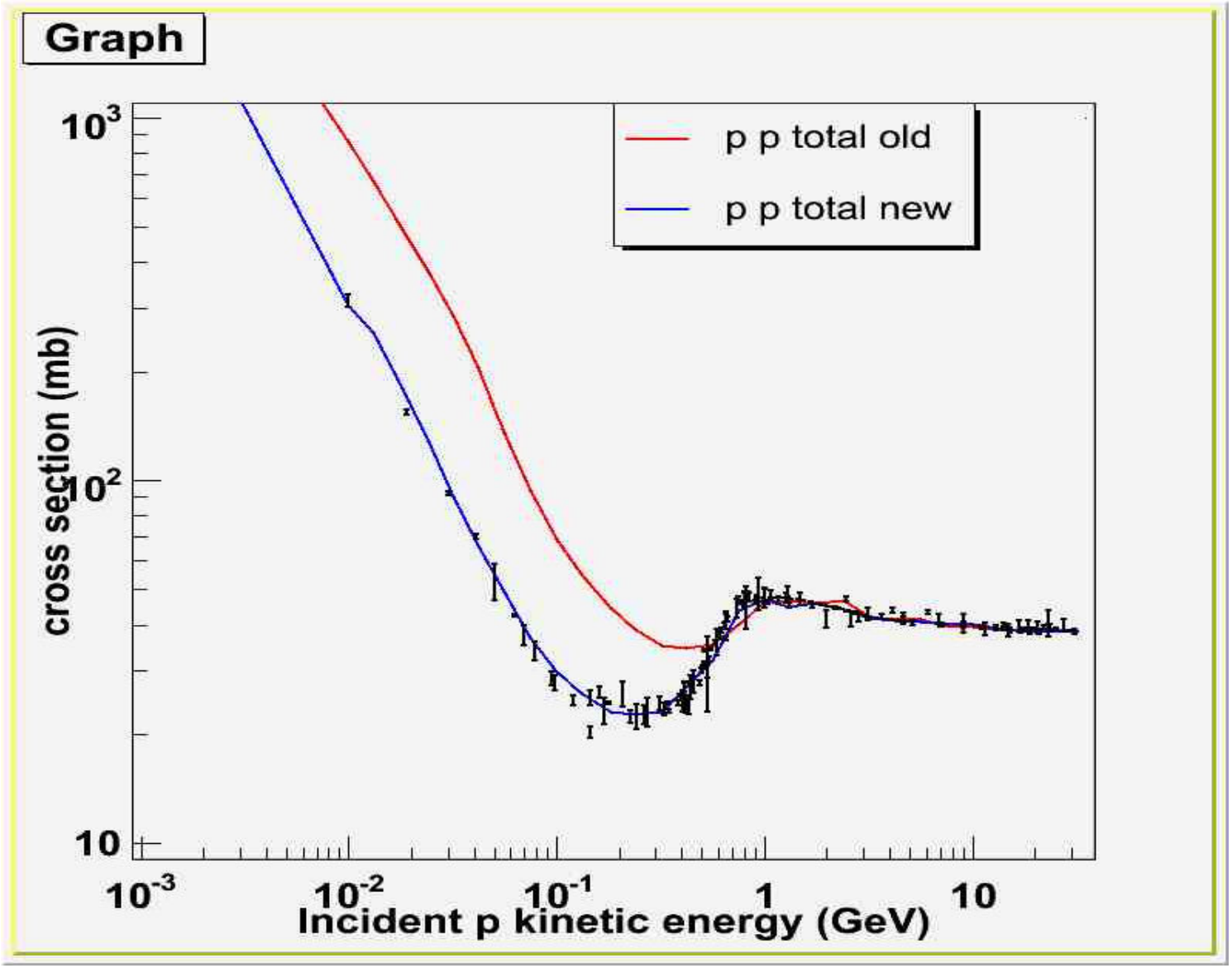
Coulomb Barrier



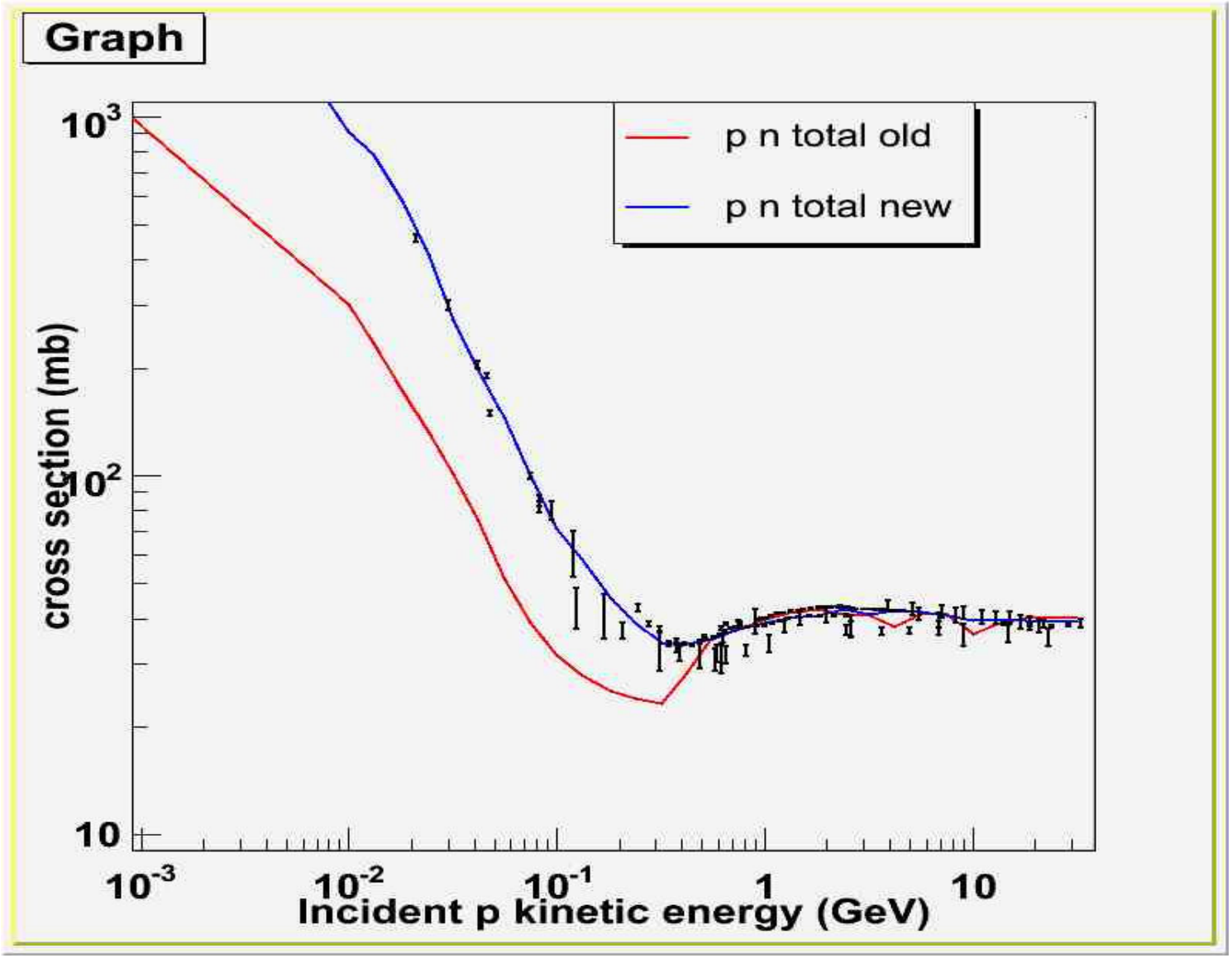
Cross Section Review and Correction

- Earlier examinations had found differences between the cross sections used in Bertini and data
  - compared to PDG and CERN catalogs
- All total and partial nucleon and pion cross sections were examined and compared to data
  - 95 partial cross section channels
  - 5 total cross sections
  - significant differences found
- Where measured data was available, existing Bertini cross sections were always changed to agree with it
- Not much guidance for π^0 incident channels (no data)
  - $(\pi^+ + \pi^-)/2$ was used in some cases (total c.s. at high energy)
  - in other cases, educated guesses were made

p p Total


Graph
p p total old
p p total new
cross section (mb)
10^3
10^2
10
10^{-3}
10^{-2}
10^{-1}
1
10
Incident p kinetic energy (GeV)

p n Total


Graph
p n total old
p n total new
cross section (mb)
10^3
10^2
10
10^{-3}
10^{-2}
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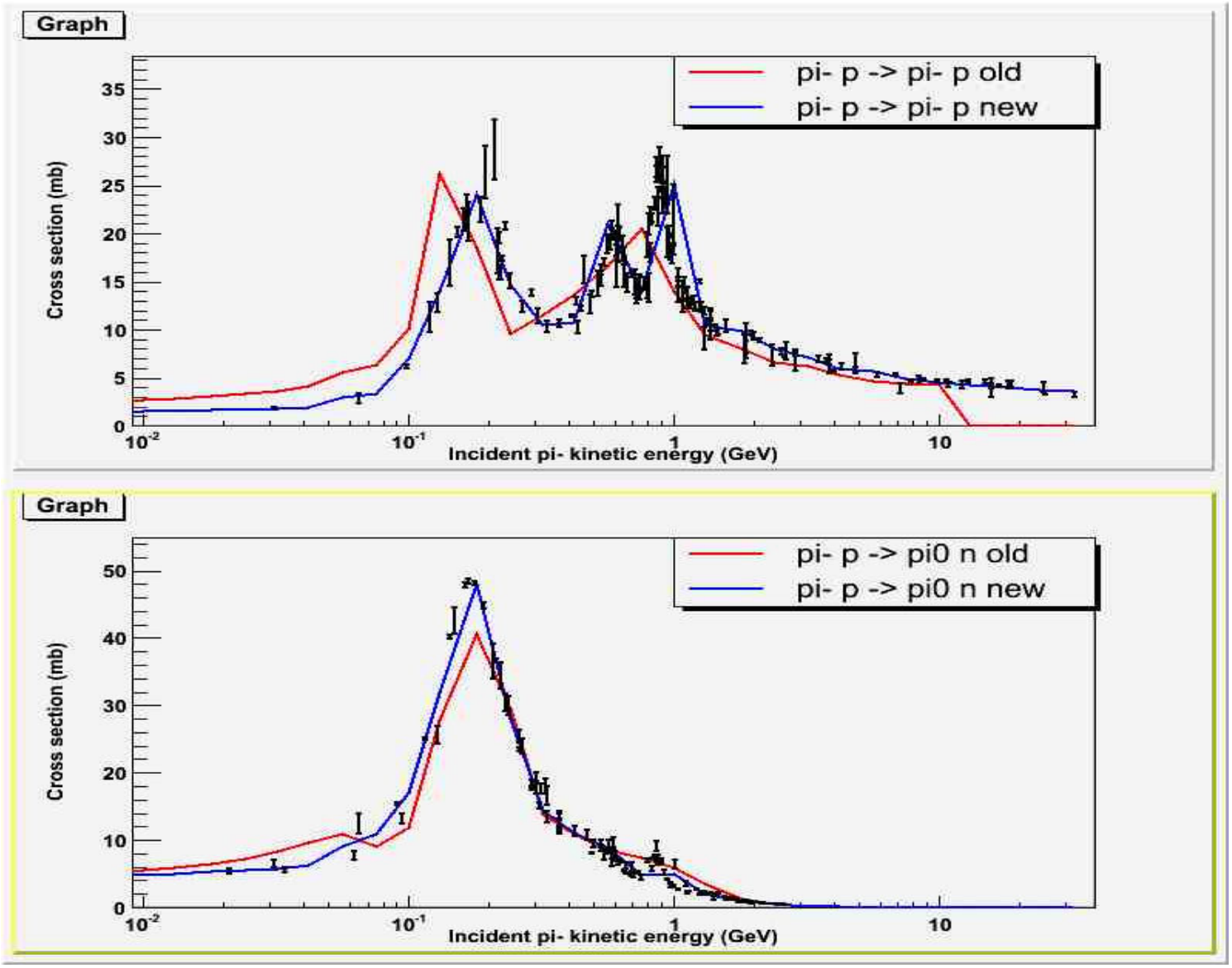
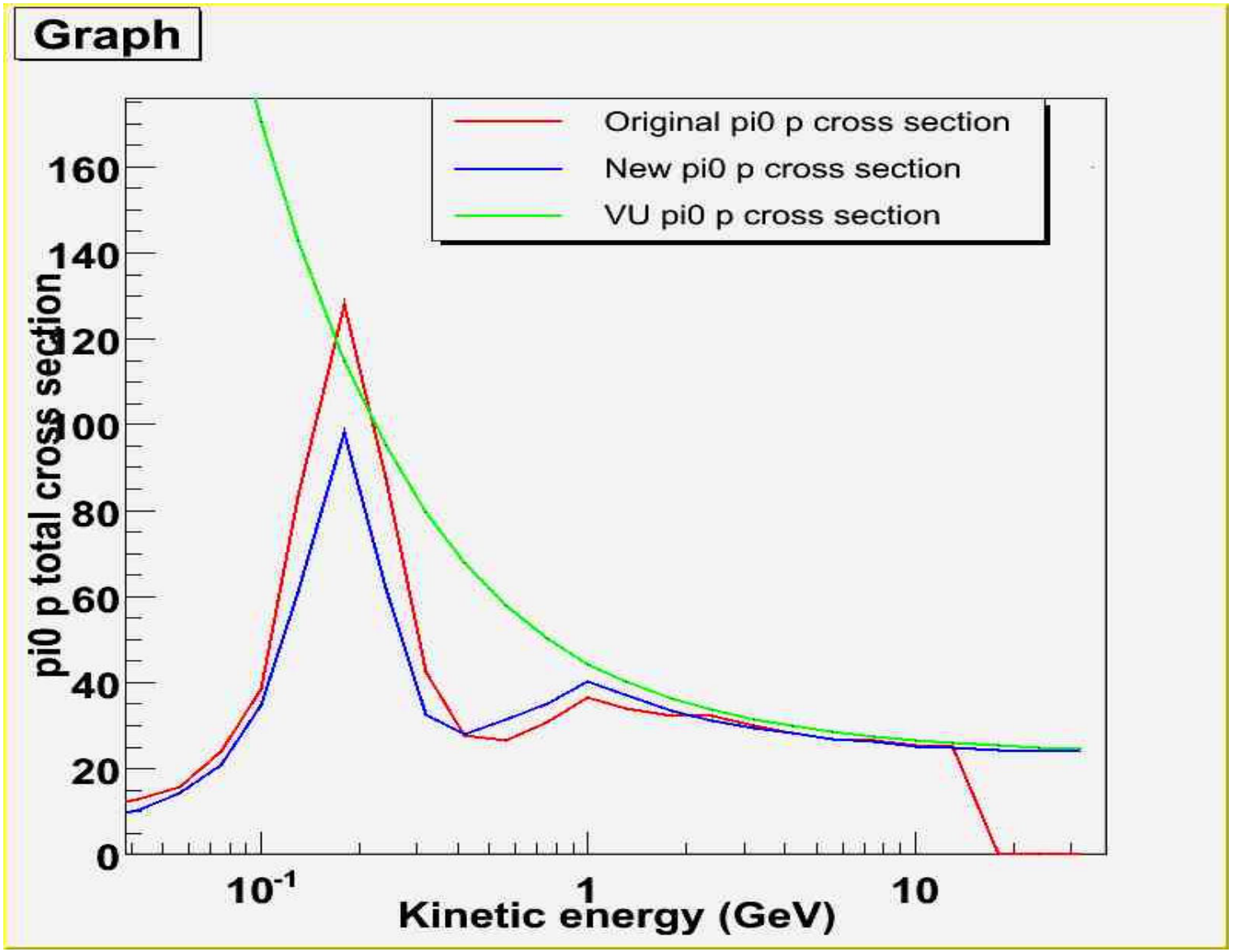
1
10
Incident p kinetic energy (GeV)

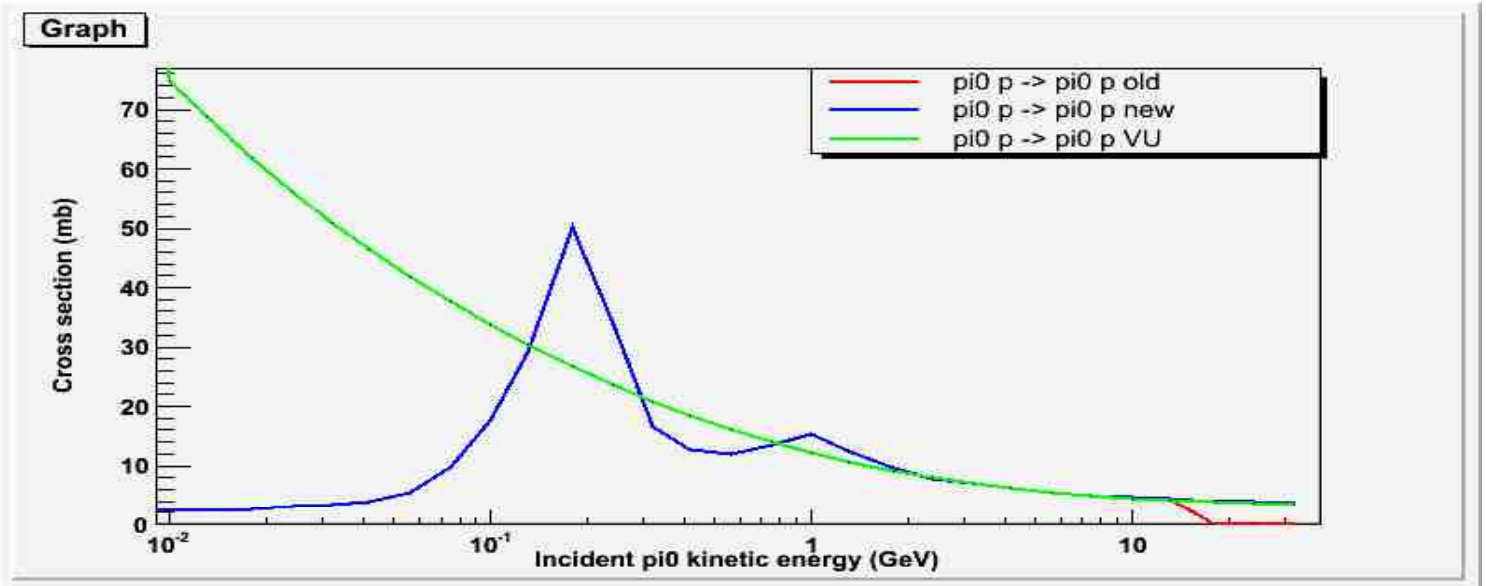
π^- p -> 2 body

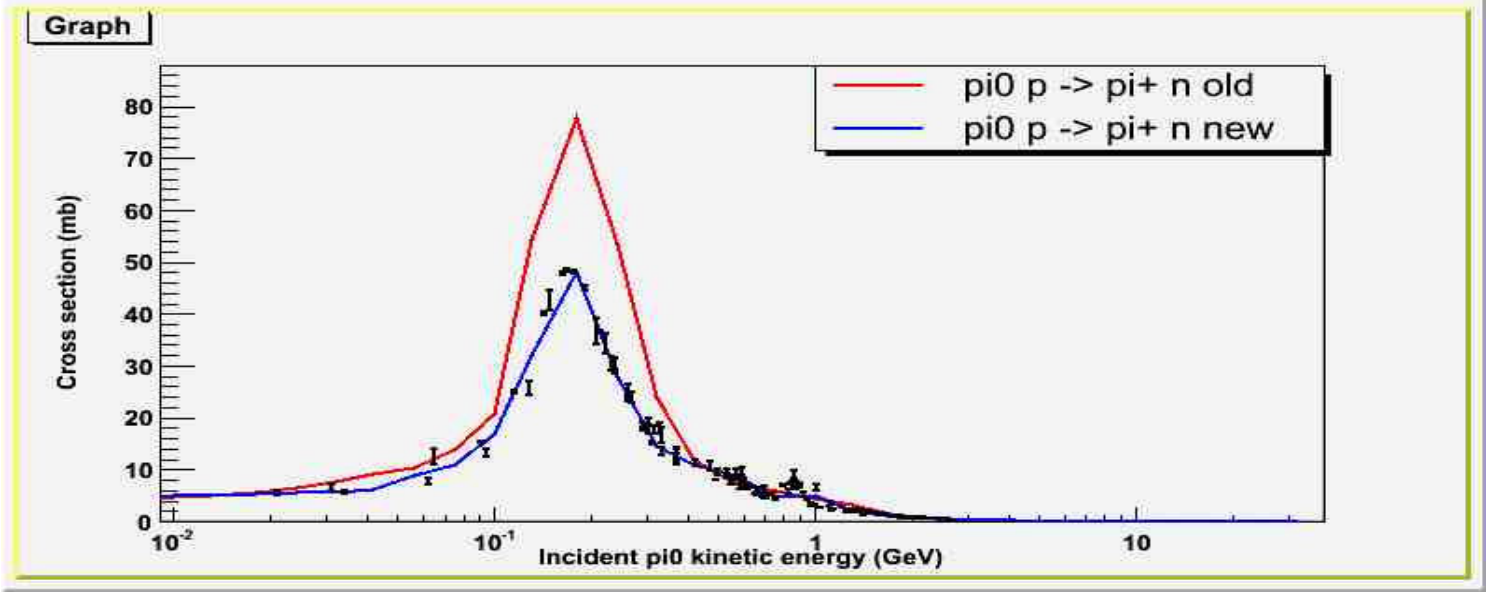

Graph
pi- p -> pi- p old
pi- p -> pi- p new
Cross section (mb)
Incident pi- kinetic energy (GeV)
Graph
pi- p -> pi0 n old
pi- p -> pi0 n new
Cross section (mb)
Incident pi- kinetic energy (GeV)

π^0 p Total Cross Section



π^0 p -> 2 body


Graph
pi0 p -> pi0 p old
pi0 p -> pi0 p new
pi0 p -> pi0 p VU
Cross section (mb)
Incident pi0 kinetic energy (GeV)


Graph
pi0 p -> pi+ n old
pi0 p -> pi+ n new
Cross section (mb)
Incident pi0 kinetic energy (GeV)

Early Validation Results

- Corrected/improved cross sections implemented for incident pions
- Results from A. Ribon and S. Banerjee:
  - no change in shower shapes
  - little or no change in cross sections at 1.5 GeV
  - some improvement at 14.6 GeV
  - reduction in mean energy to protons, neutrons, pi0s : 10%, 9%, 6%, resp.
  - increase in mean energy to light ions, pi-, pi+ : 7%, 3%, 2%
  - ratio 2pi0/(pi+ + pi-) closer to one
  - kaons, hyperons now produced
- From V. Ivantchenko
  - at low energy (730 MeV) change in shape for forward pion spectra

Summary of Cross Section Review

- Bad news: many large differences in cross sections found
- Good news: corrections do not appear to make a big difference in results

Strange Particle Interactions

- Interactions of incident kaons and hyperons added to Bertini in 2005
  - however, no strange pair production from nucleon-nucleon and pion-nucleon collisions
- Added partial cross sections to original Bertini p-p and π–p cross sections
  - ΛK, ΣK, KK pairs, up to 5-body final states
  - data from CERN catalog
  - residual hyper-nucleus not created

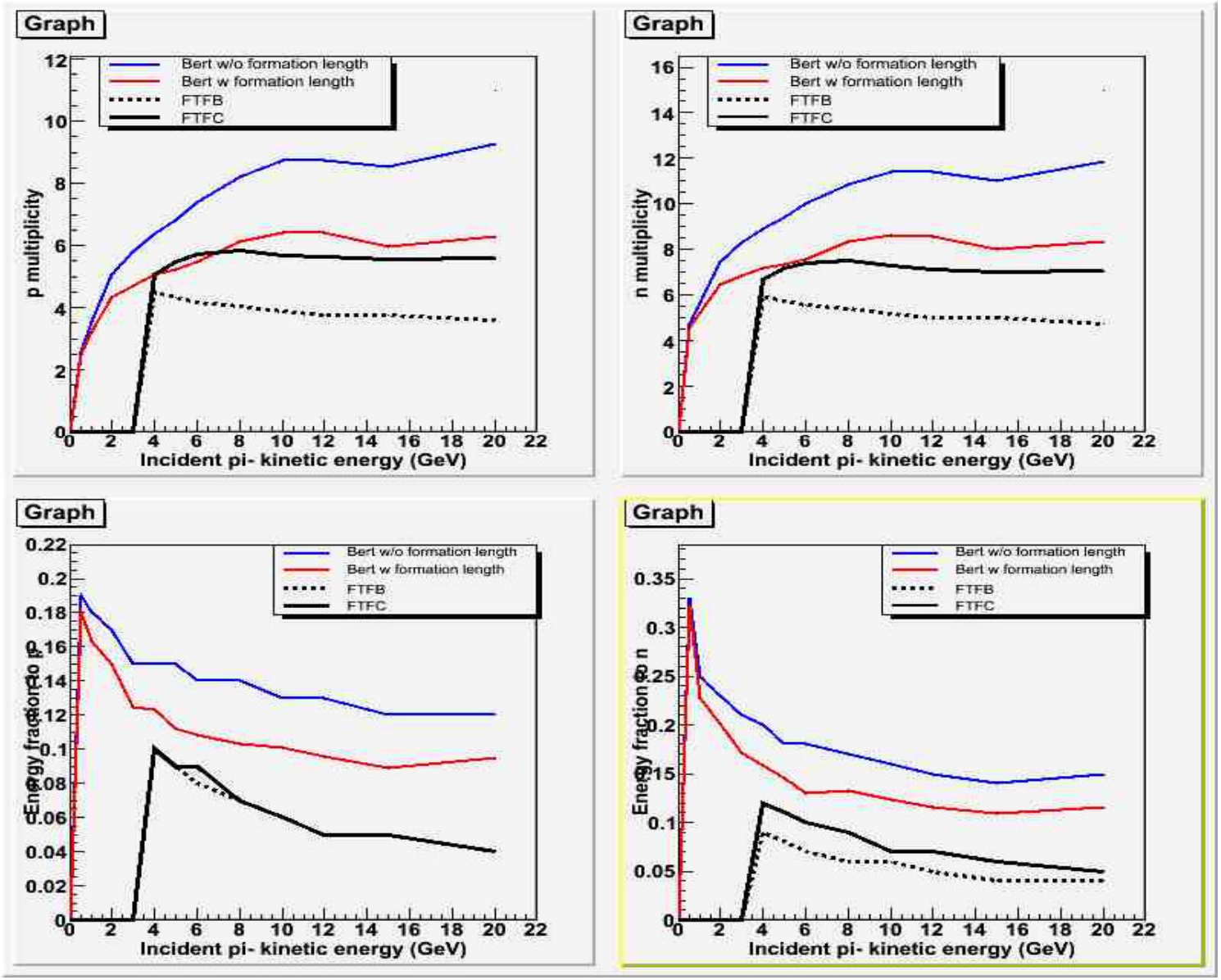
High Multiplicity Final States

- Original Bertini model includes up to 6 final-state particles for elementary interactions within a nucleus
  - for example, p p -> p n π^+ π^+ π^- π^0
  - the sum of 2 – 6 body final state partial cross sections were normalized to total cross section
  - this is OK as long as energy is below 3 - 4 GeV
  - above that > 6-body final states are important
- 7-, 8-, and 9-body final state partial cross sections added
  - effect on measured cross sections does not appear to be very large
  - but multiplicities are correct up to ~ 6 GeV

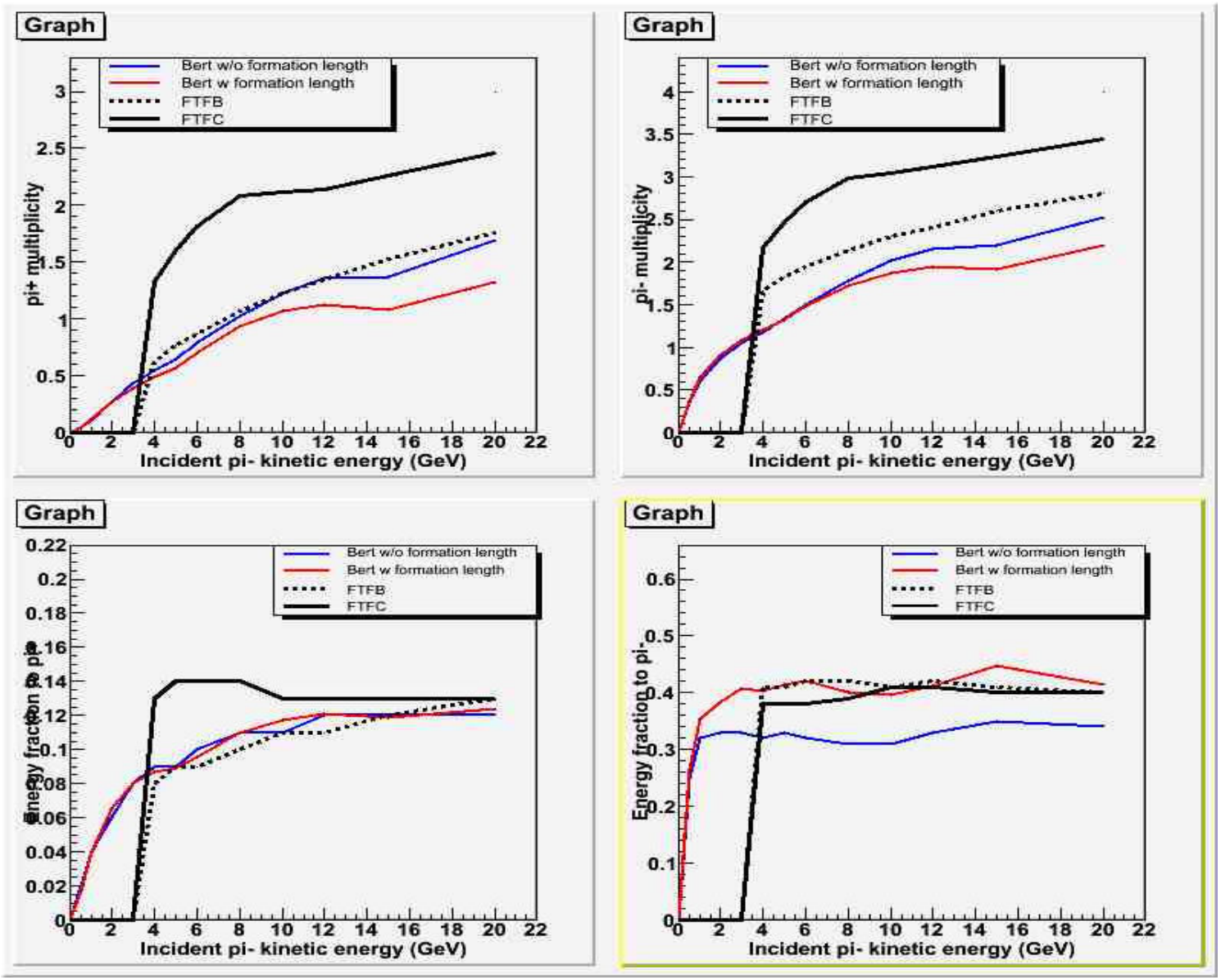
Formation Length

- Bertini code assumes intra-nuclear interactions can be represented by free-space cross sections, but nuclear matter and quantum effects can modify them:
  - Pauli blocking (included)
  - short-range nucleon-nucleon repulsion (not included)
  - trailing/trawling effect (sort-of included, but not really)
  - formation time/length (not included)
- Formation time/length already used in EM, HEP code
  - distance it takes for secondaries to become distinct from one another and therefore be able to interact
  - if distance > path length in nucleus => no interaction
  - $L_f \sim \text{hbar } p / (p_T^2 + m^2)$

Effect of Formation Length on pi- Fe



Effect of Formation Length on pi- Fe



Formation Length

- This is a very recent change and testing has just begun, but:
  - big reduction (10-30%) in p, n multiplicities, energy fractions
  - pion multiplicities almost unchanged
  - energy fraction for π^+ unchanged, increased 20% for π^-
  - improved agreement with FTFB and FTFC offers the possibility that the discontinuities around 9 GeV might get much smaller => try a FTFB/C-BERT physics list
- Still need to look at detailed effects:
  - currently no “correction factors” applied to formation length calculation

Future Projects (1)

- Precompound/evaporation
  - Bertini uses its own precompound and evaporation models
  - can we remove these and substitute G4Precompound, for example?
- Need an interface connecting cascade to G4Precompound, evaporation
  - would allow:
    - cascade part of code to be used separately
    - comparative studies of different precompound/evaporation models
  - S. Banerjee now taking over this project

Future Projects (2)

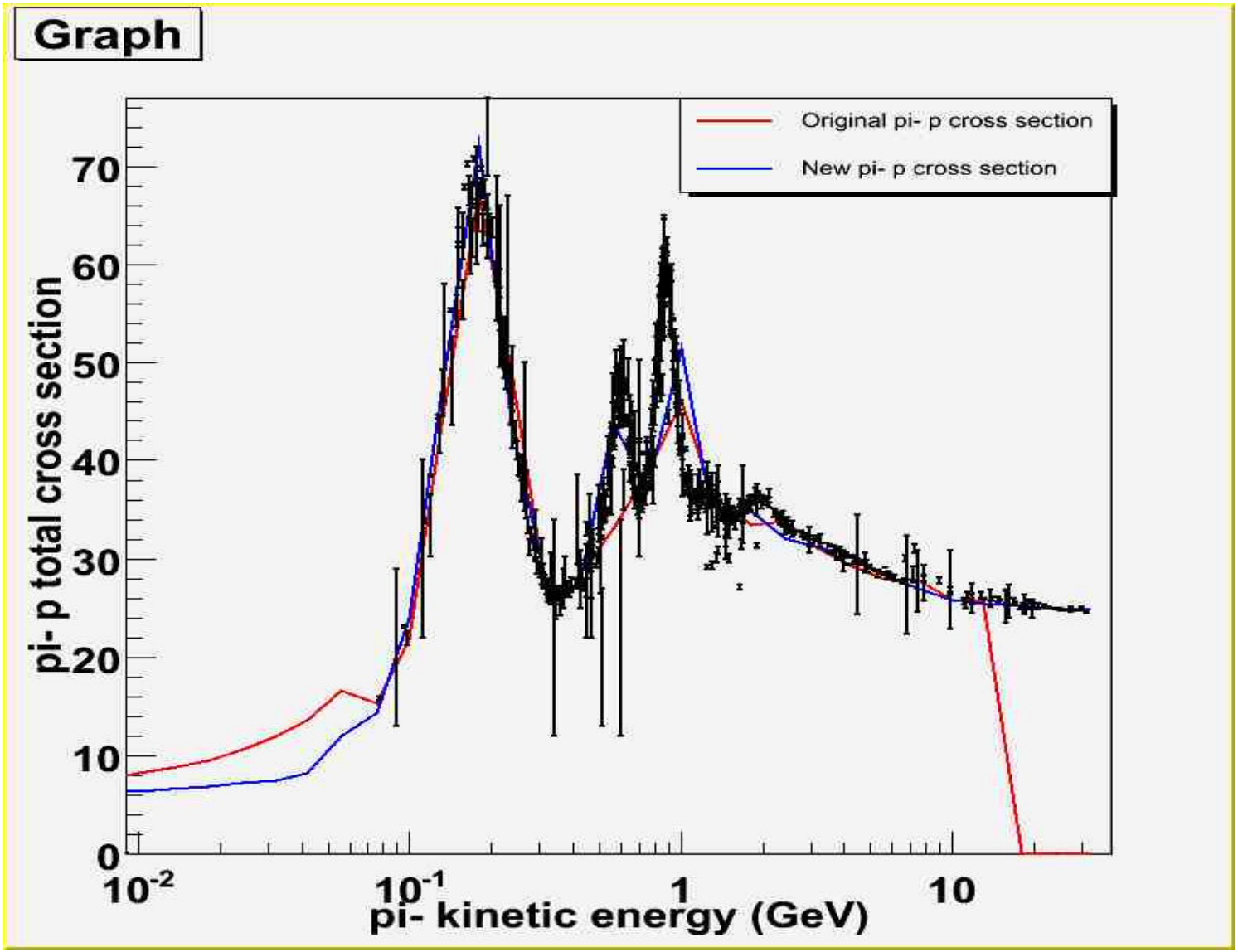
- Trailing effect
  - reduction of local nuclear density following an intra-nuclear interaction
  - lower nuclear density makes it possible for slower particles which follow interaction to escape nucleus
    - means fewer intra-nuclear cascade particles
    - can increase valid energy range of cascade
  - has always been included in model, but density change is global => small effect in medium and heavy nuclei
    - need to change to local effect
    - crude early attempts make a large difference in nucleon multiplicity

Future Projects (3)

- Coalescence model
  - IAEA validation results showed that Bertini does not produce light ions, except in the evaporation stage
  - need to add this in both cascade and precompound stages
  - typically done by coalescing 2, 3, and 4 final-state nucleons into d, t, ^{3}He, α
- anti-proton, anti-neutron interactions
  - sufficient data exists to add these partial cross sections to model

Backup Slides

π^- p Total


Graph
Original pi- p cross section
New pi- p cross section
pi- p total cross section
0
10
20
30
40
50
60
70
10^{-2}
10^{-1}
1
10
pi- kinetic energy (GeV)

Effect of Formation Length on pi- Fe