Latest Validation Results at Intermediate Energies

Outline

- Data Used
- Validation results
  - Given reference version
  - Evolution of a model (or parameter)
- Summary

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Data Used

Data Set from ITEP: (Yu. D. Bayukov *et.al.*,)

- Measurements exist for Lorentz invariant differential cross section as a function of kinetic energy at some fixed angles
- Inclusive p and n production at 4-29 different angles in 8-9 kinetic energy bins in $p/\pi^+/\pi^-$-nucleus collision (12 targets from Be to U) with beam momenta of 1-9 GeV/c
- Statistical errors 1-10% and systematic uncertainties 5-6%

Data set from BNL E-802: (T. Abbott *et al.*)

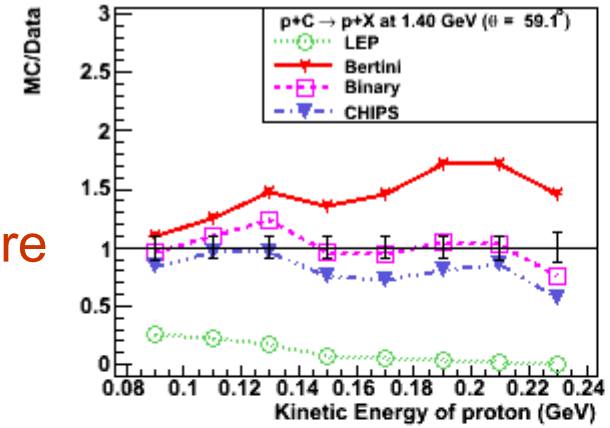
- Inclusive $\pi^{\pm}$, $K^{\pm}$ and proton production from p beams at 14.6 GeV/c on a variety of nuclear targets (Be … Au)
- Quantities measured are Lorentz invariant differential cross sections as a function of transverse mass (m_T) in bins of rapidity (y)
- Data quality: statistical error 5-30%; systematic uncertainty 10-15%

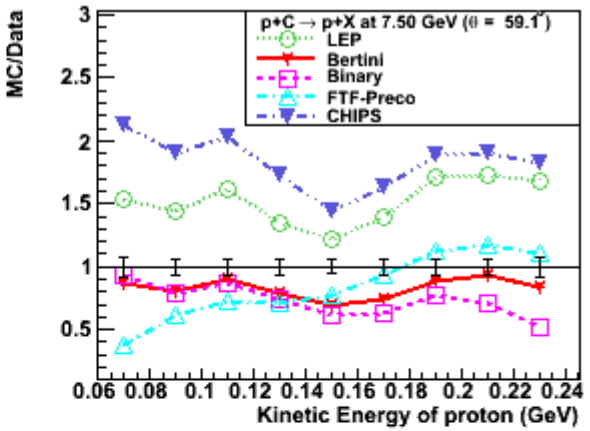
Inclusive p in p-C collisions

1.4 GeV/c

7.5 GeV/c

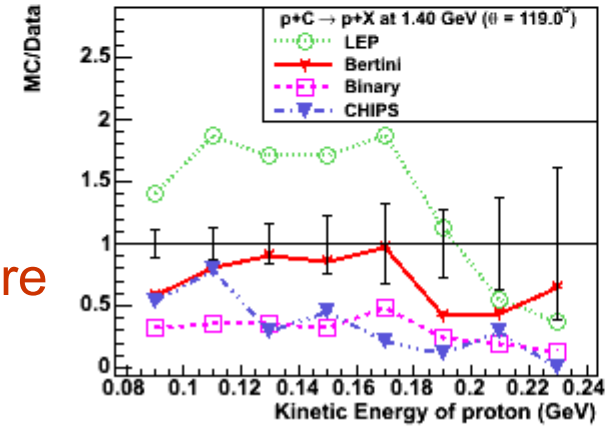
Forward Hemisphere

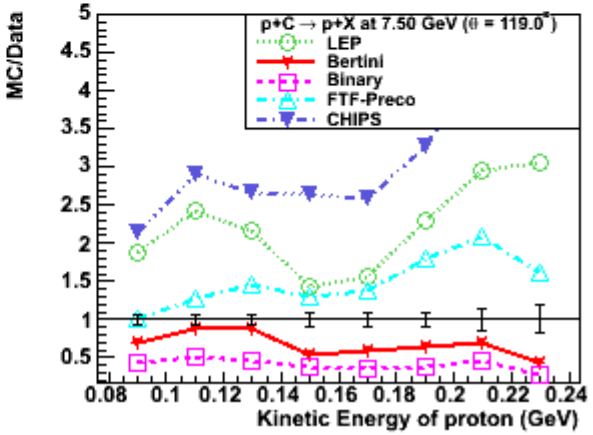




θ = 59.1°

Backward Hemisphere





θ = 119°

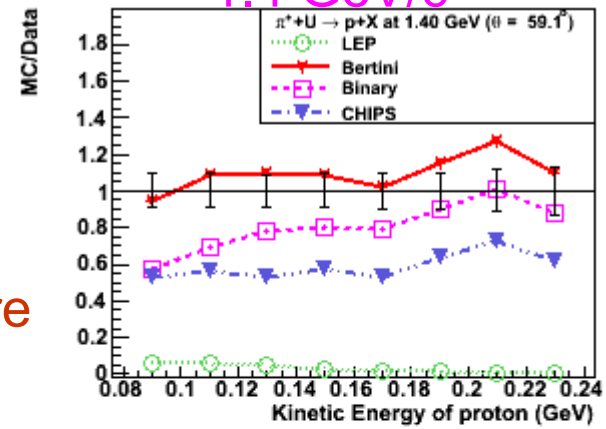
- Bertini and FTF provide reasonable agreement
- LEP over estimates at high energy & has poor agreement at low energy
- CHIPS over estimates at high energies
- Binary good in the forward hemisphere

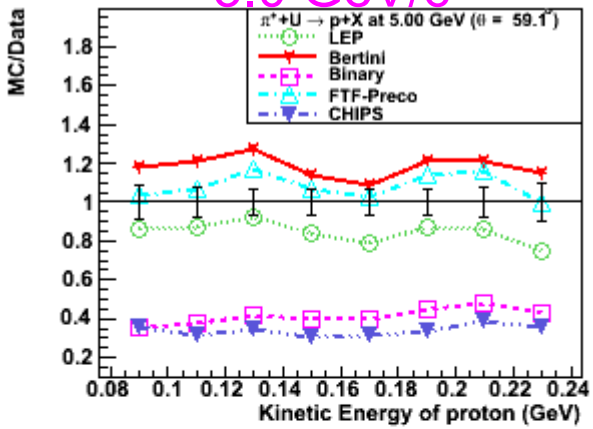
Inclusive p in π^+-U collisions

1.4 GeV/c

5.0 GeV/c

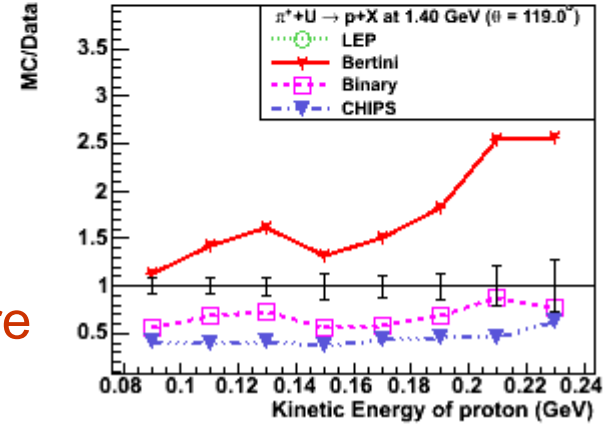
Forward Hemisphere

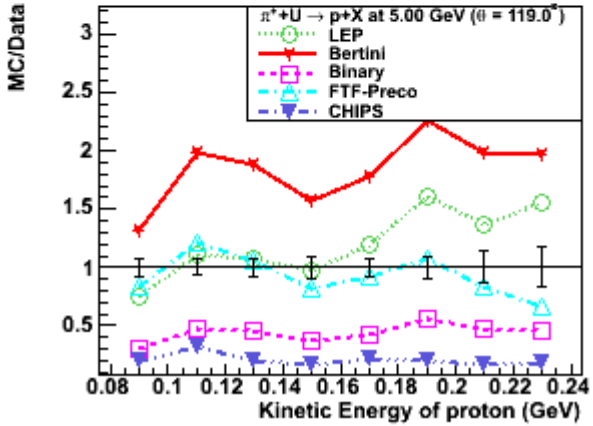




θ = 59.1°

Backward Hemisphere

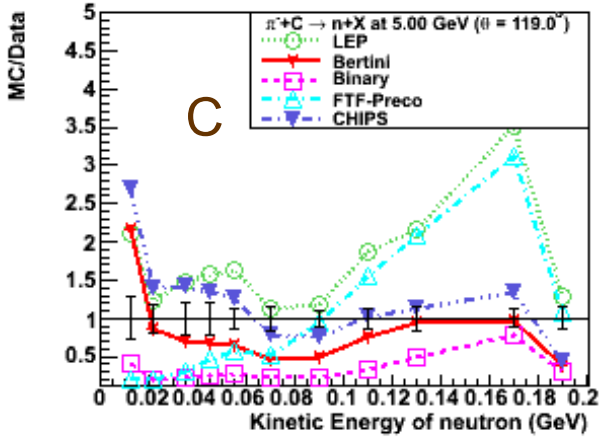


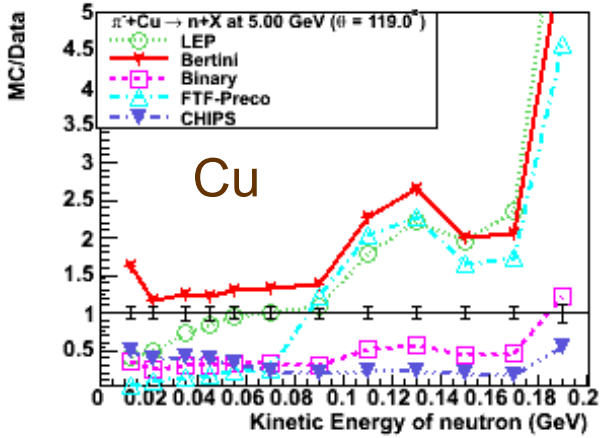


θ = 119°

- Bertini OK in forward hemisphere; overestimates in the backward
- LEP is OK at high energy
- CHIPS and Binary predictions are below the data
- FTF-Preco provides a good prediction at 5 GeV/c

Inclusive n in π⁻-A collisions





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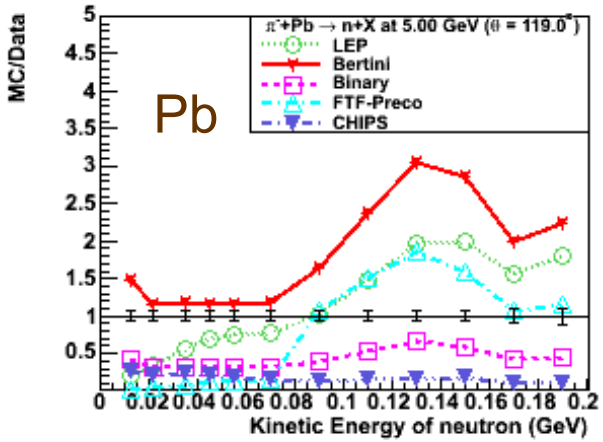
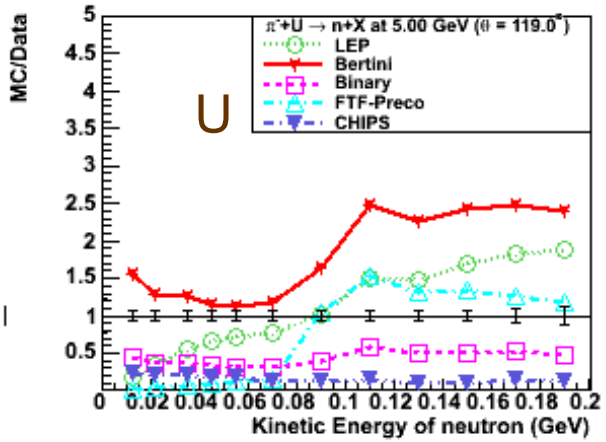
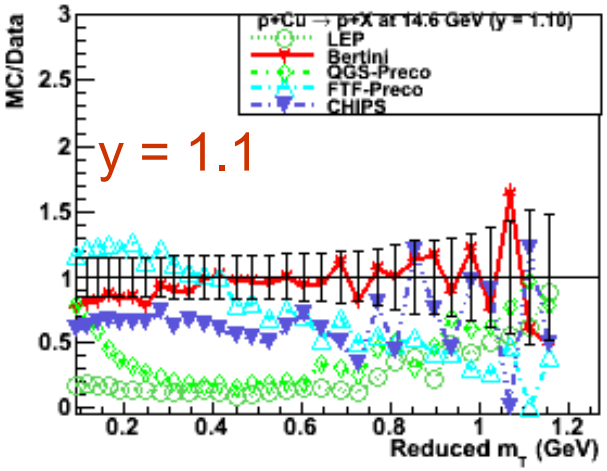


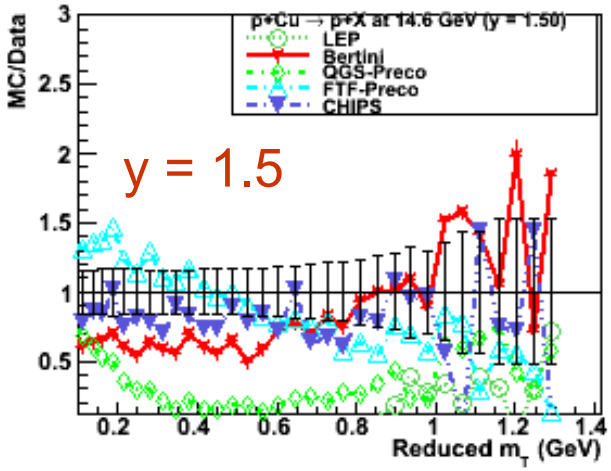


5.0 GeV/c

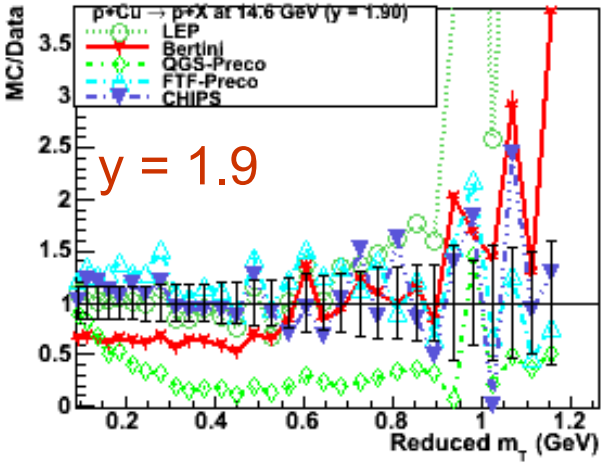
- Bertini gives reasonable predictions for soft neutrons
- LEP does not provide a good description of the data
- CHIPS provides reasonable agreement for light targets
- Binary predicts smaller cross section
- FTF-Preco predicts smaller cross section for soft neutrons

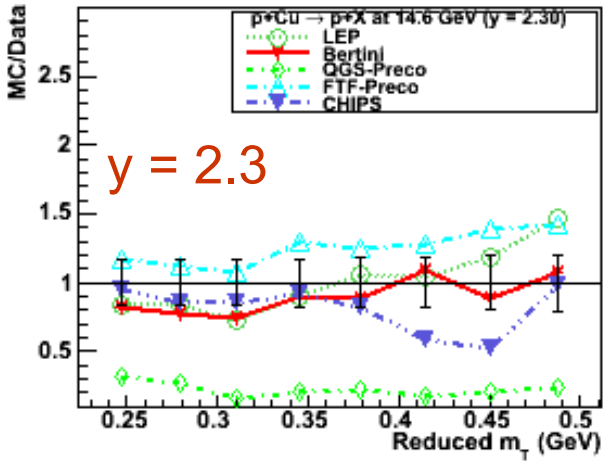
p + A → p + X at 14.6 GeV/c





Cu Target





- FTF is good for at large y values and under-predicts at small y, large m_T
- LEP predicts smaller cross sections
- CHIPS provides reasonable agreement for y values above 1.5
- Bertini gives a fair description of the data

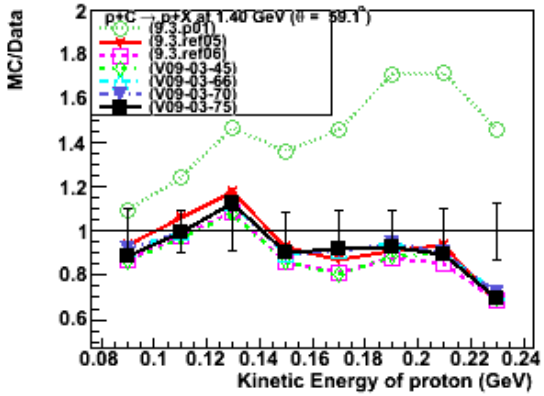
Evolution of Bertini Cascade Model

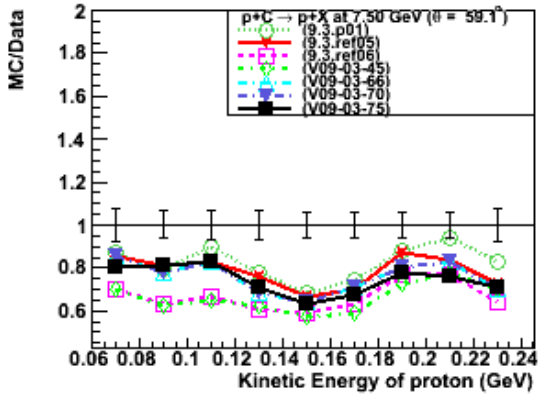
- Several versions of Bertini Cascade models examined to monitor the evolution of the code and test goodness of its predictions. Seven versions of Bertini cascade code are tried
  - As in 9.3.p01
  - As in 9.3.ref05
  - As in 9.3.ref06 (observed large changes in the predictions)
  - As in V09-03-45
  - As in V09-03-66
  - As in V09-03-70
  - As in V09-03-75

Inclusive p in p-C collisions

1.4 GeV/c 7.5 GeV/c

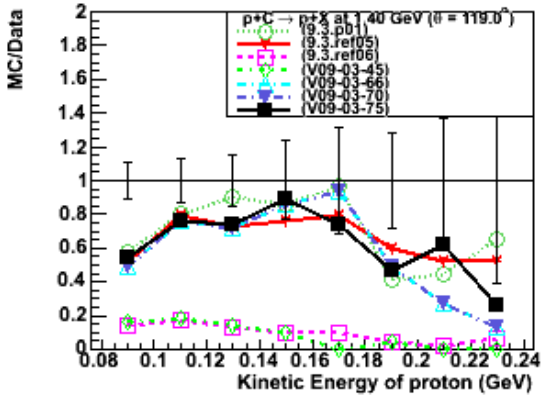
Forward Hemisphere

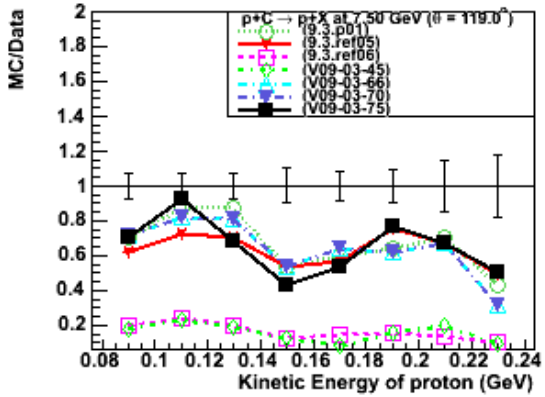




θ = 59.1°

Backward Hemisphere





θ = 119°

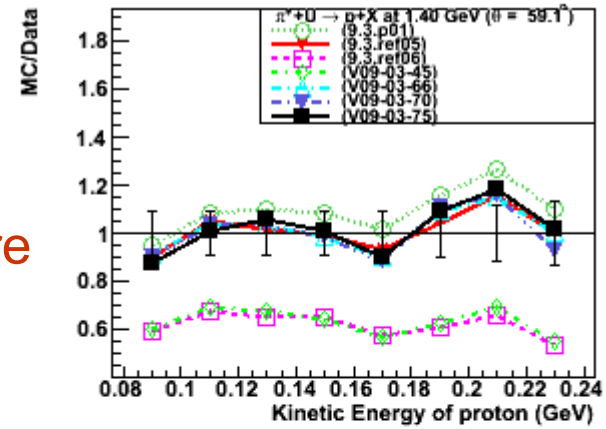
- Drop observed in 9.3.ref06 (V03-09-45) is restored back to the original level
- Level of agreement is reasonable (~20%)

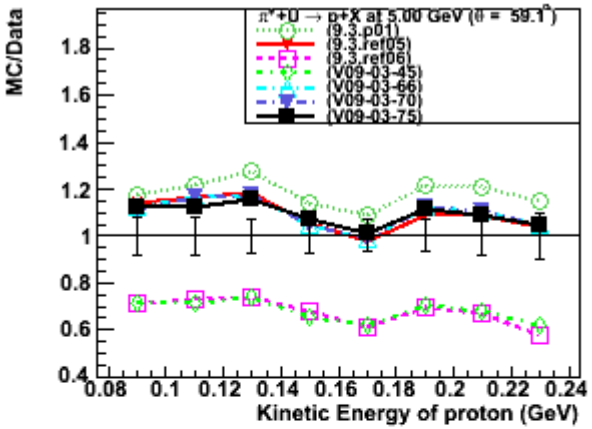
Inclusive p in π^+-U collisions

1.4 GeV/c

5.0 GeV/c

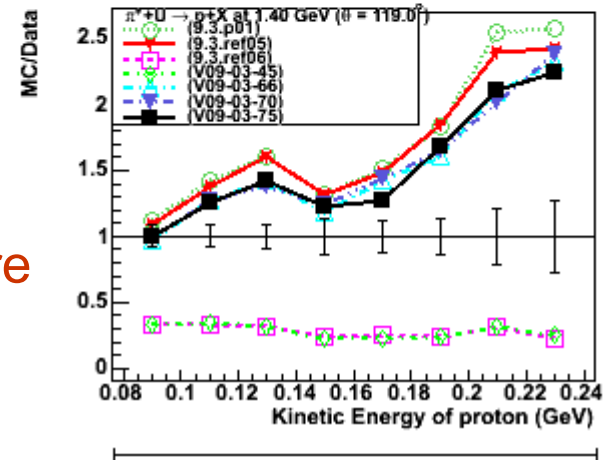
Forward Hemisphere

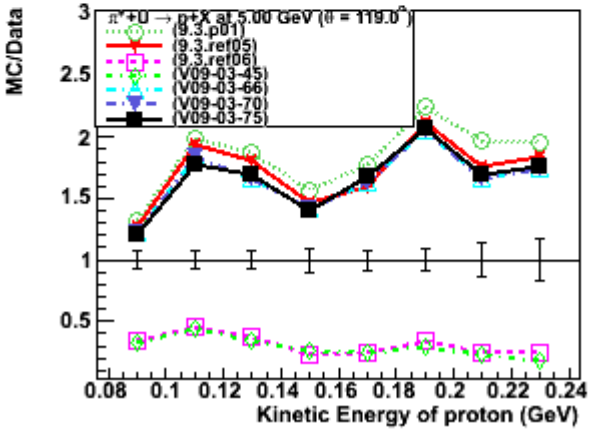




θ = 59.1°

Backward Hemisphere

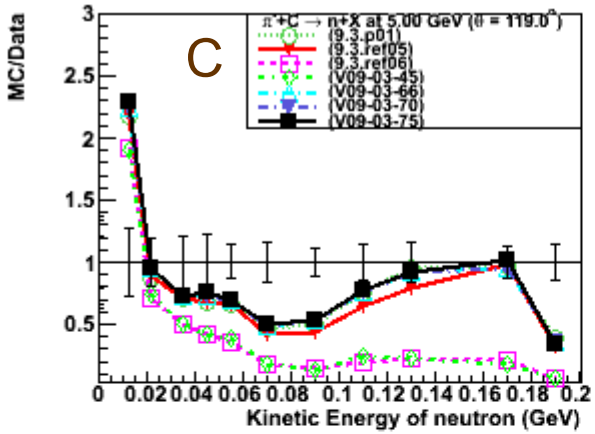


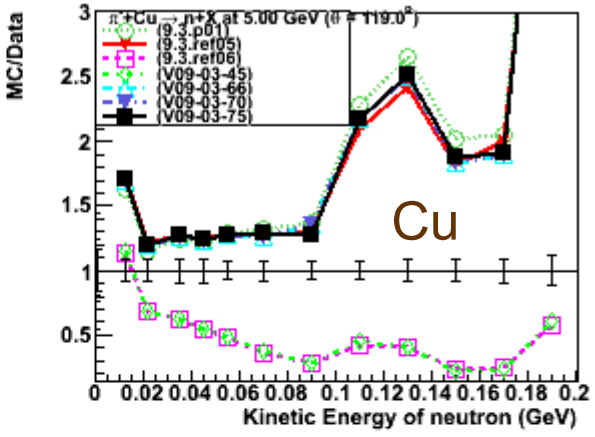


θ = 119°

- Bug fix is working fine – there may be slight improvements in the predictions for the backward hemispehere.

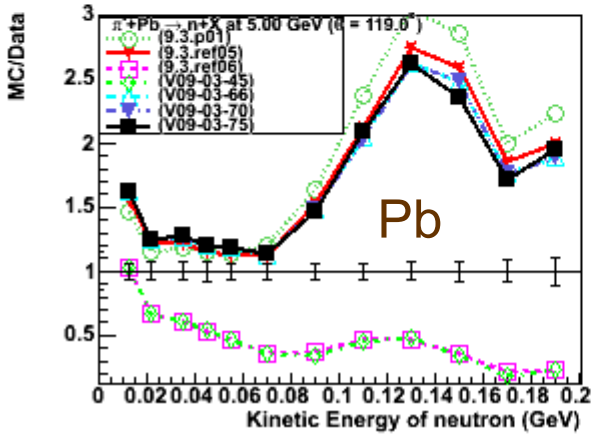
Inclusive n in π⁻-A collisions

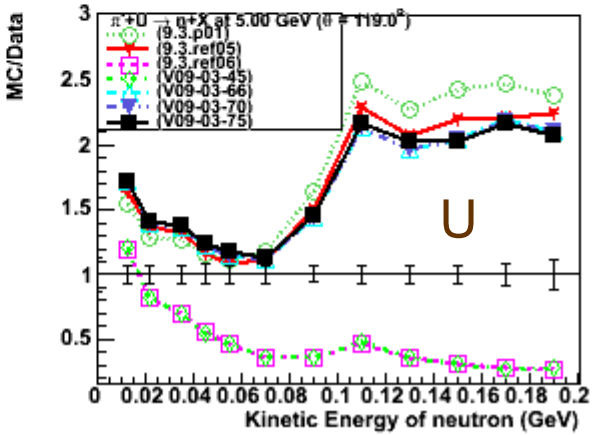




θ = 119°

5.0 GeV/c





- Level of agreement is restored – may be a small improvement at larger KE values. Similar level of over-prediction at KE values of 120 MeV or higher

Variation in Bertini Model

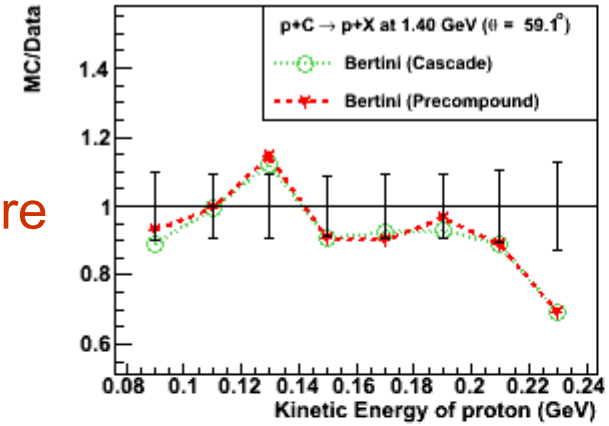
- Since the tag V09-03-78, possibility (Julia, Mike) exists to have standard de-excitation model to work after the cascading is done by Bertini model – more in Mike's presentation

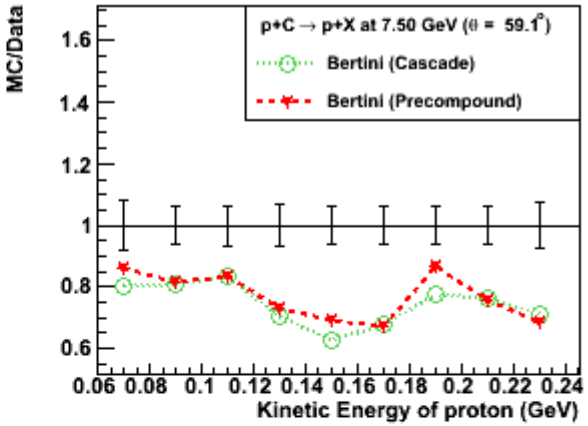
Inclusive p in p-C collisions

1.4 GeV/c

7.5 GeV/c

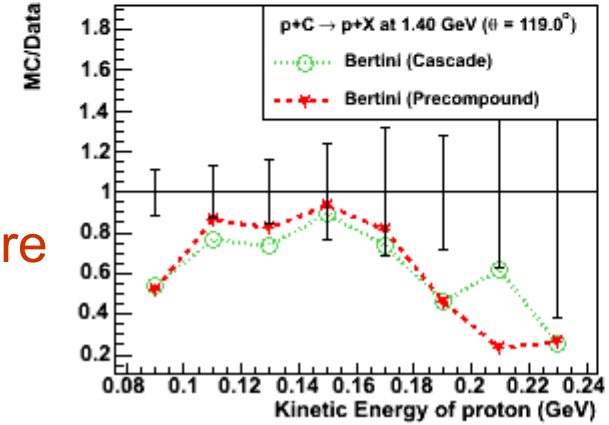
Forward Hemisphere

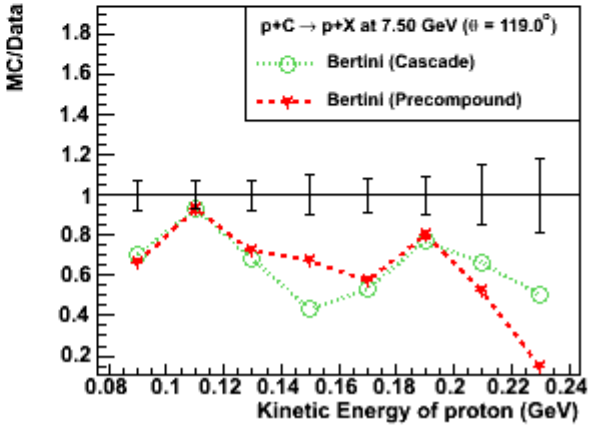




θ = 59.1°

Backward Hemisphere





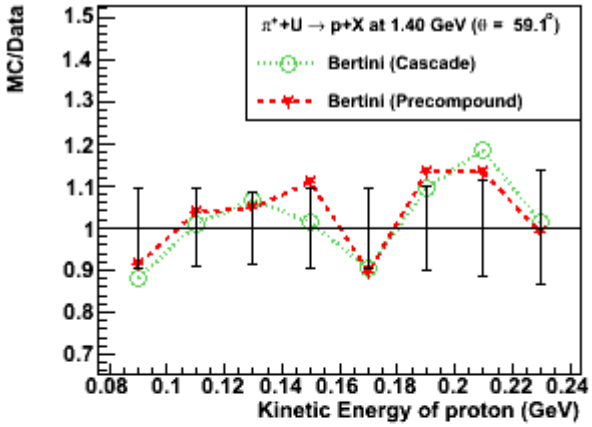
θ = 119°

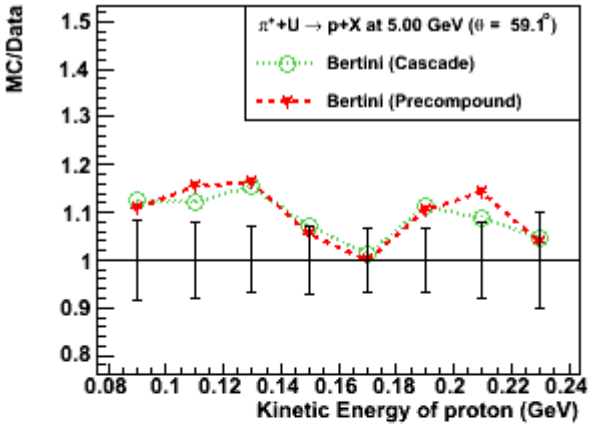
- The new option works fine. Same level of agreement with this option of using Precompound model.

Inclusive p in π^+-U collisions

1.4 GeV/c 5.0 GeV/c

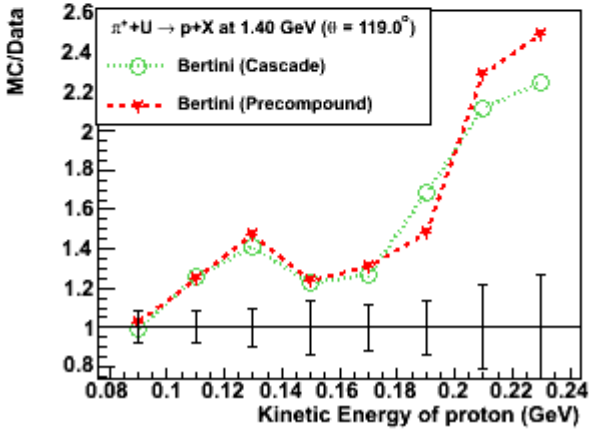
Forward Hemispher

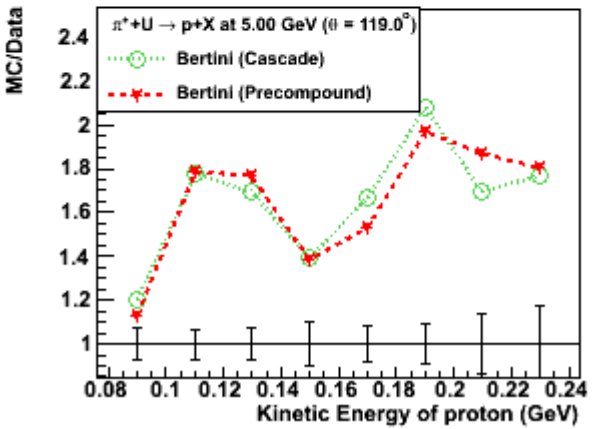




= 59.1°

Backward Hemispher

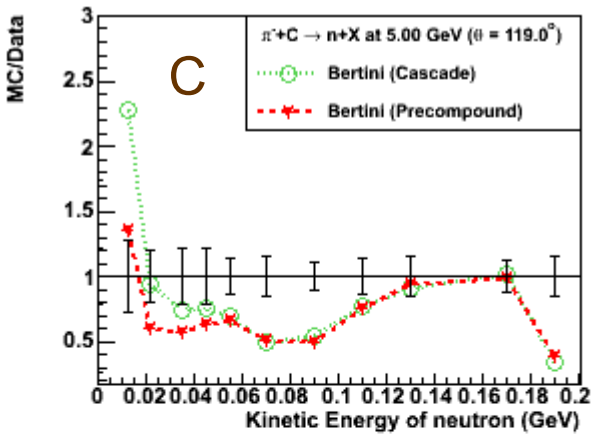


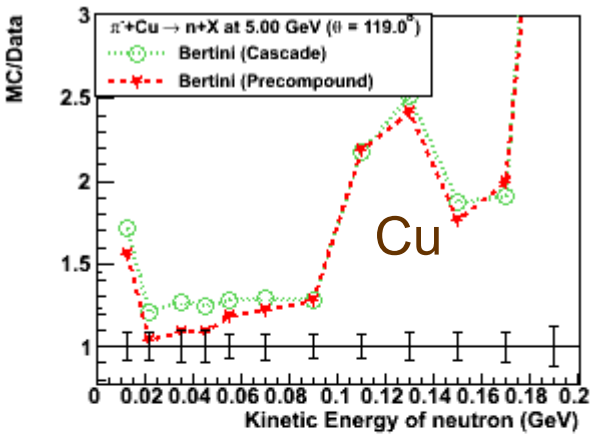


= 119°

- The two de-excitation models give similar level of agreement,

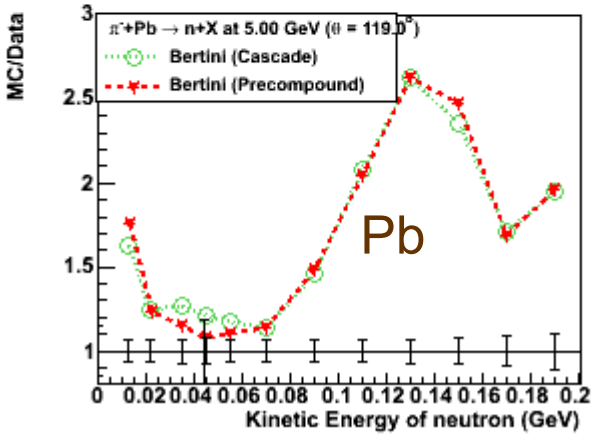
Inclusive n in π⁻-A collisions

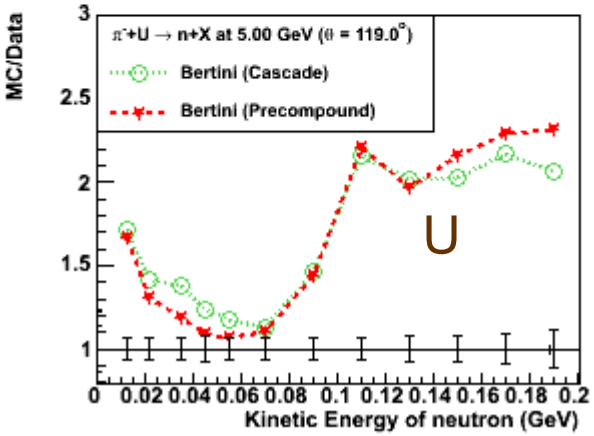




θ = 119°

5.0 GeV/c





- Small difference in soft neutron production – native de-excitation model produces more soft neutrons.

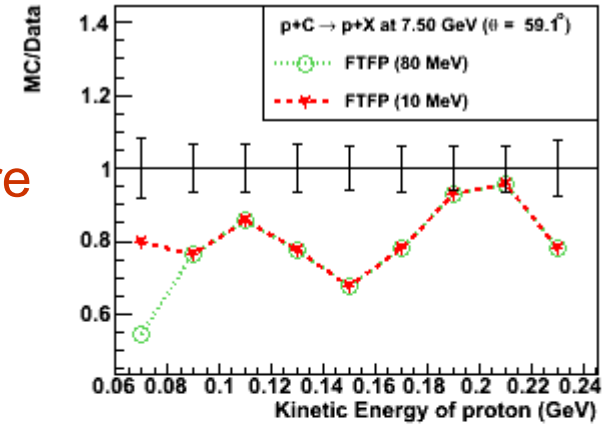
Possible Improvements for FTF

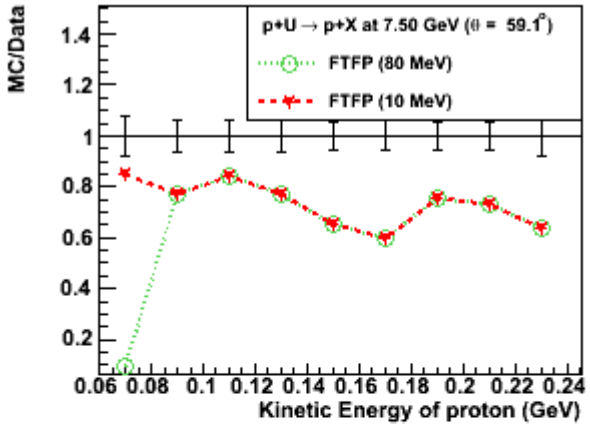
- There is a recent suggestion by Vladimir to lower the capture threshold in the Precompound model for the FTF interface. The old default is 60 MeV – the suggested value is to use 10 MeV.

p+A → p+X at 7.5 GeV/c

C-Target U-Target

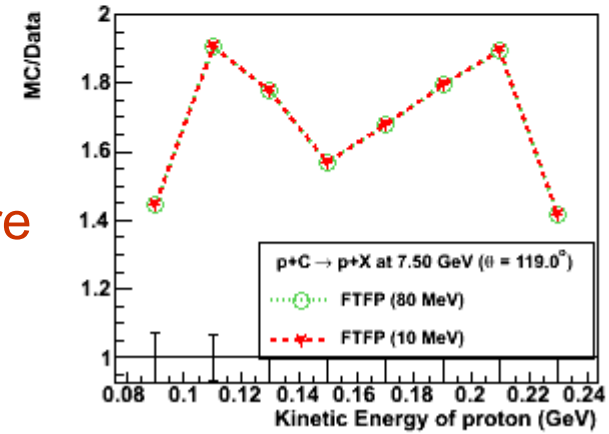
Forward Hemisphere

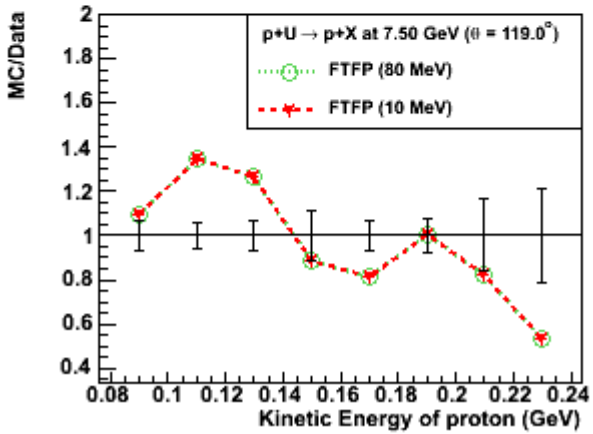




θ = 59.1°

Backward Hemisphere





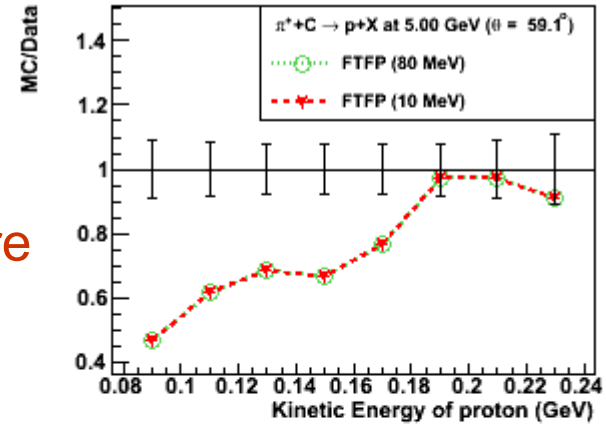
θ = 119°

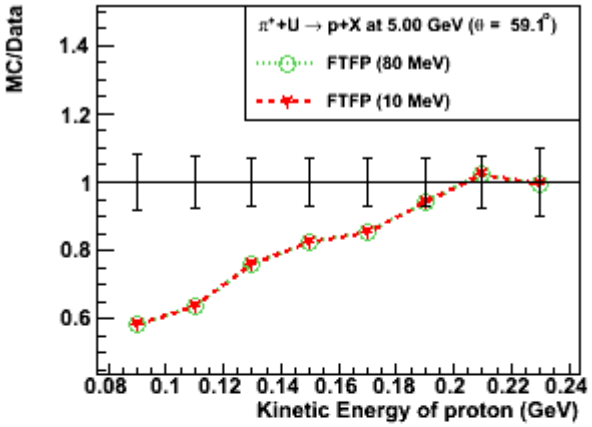
- Improvement seen in the soft proton production in the forward hemisphere

π^++A → p+X at 5.0 GeV/c

C-Target U-Target

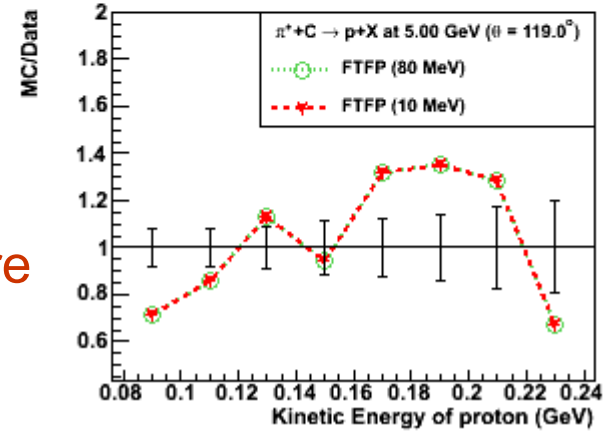
Forward Hemisphere

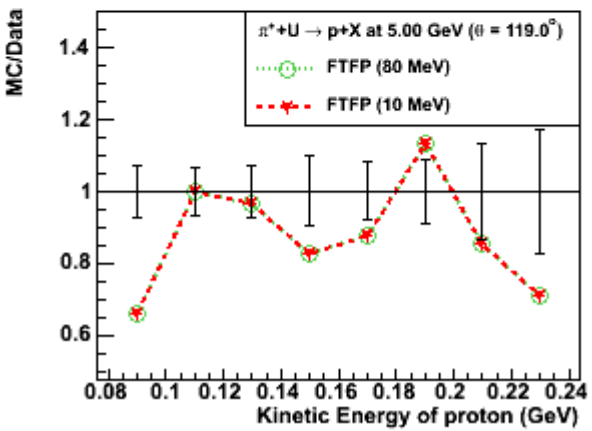




θ = 59.1°

Backward Hemisphere



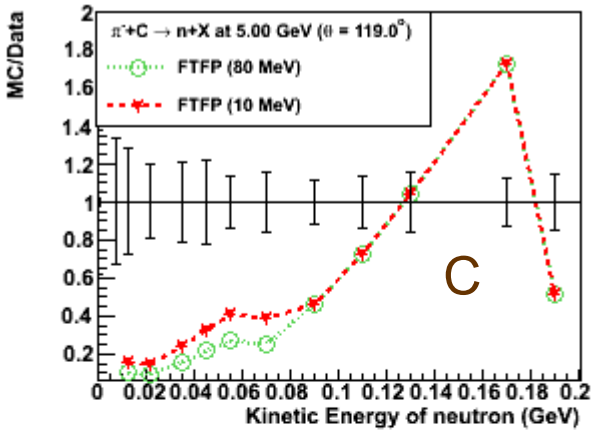


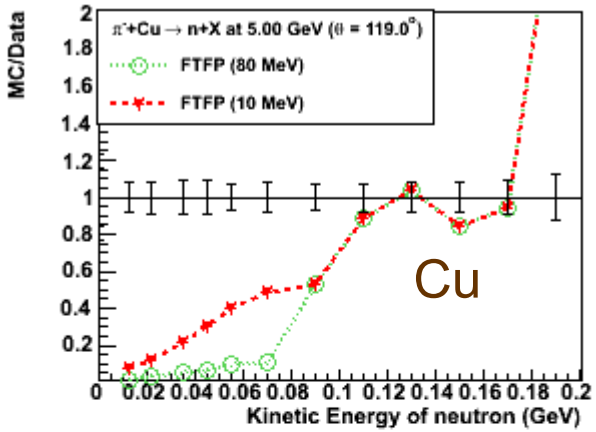
θ = 119°

- No appreciable changes observed in pion induced interactions

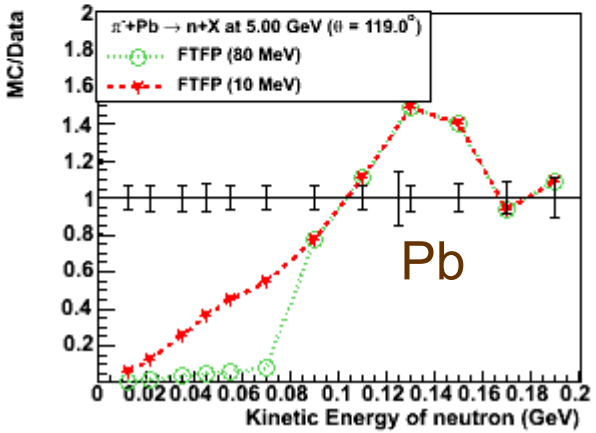
Inclusive n in π⁻-A collisions

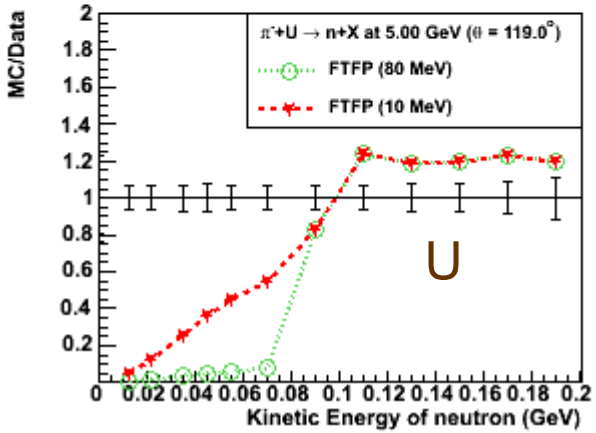
θ = 119°





5.0 GeV/c





- Soft neutron production is enhanced with the lowered threshold – better agreement with the data.

Summary

- The hadronic models within Geant4 are continuously improved over the years adding new features and new models are added to the list. The extension of Bertini cascade model with de-excitation from precompound model gives an interesting alternative.
- The models are validated against data obtained from thin target experiments as well as from thick targets and calorimeters.
  - Bertini cascade model gives good overall description of data below 9 GeV. However for high-A nuclei, it over-estimates production of proton/neutron in the backward hemisphere.
  - The modified version of FTF model gives good over all description of data above 5 GeV. It has some deficiency in predicting inclusive proton and neutron production for heavier targets at energies below 5 GeV. Lowering of the capture threshold gives some significant improvement.

Models Validated

- We have compared data with the predictions of several models using Geant4 version 9.3.ref07 + (hadr-casc-V09-03-75, hadr-string-diff-V09-03-03, hadr-hadronization-V09-04-02)
- Primary set:
  - LEP: Low energy parametrized model derived from GHEISHA and is intended for incident energies below 25 GeV
  - Bertini Cascade: Bertini intra-nuclear cascade model intended for incident energy below 9 GeV
  - QGS: Quark gluon string model and is intended for incident energy above 12 GeV
- Auxiliary set:
  - Binary Cascade: An intra-nuclear cascade model intended for incident energy below 5 GeV
  - CHIPS: Quark level event generator based on Chiral Invariant phase space model
  - FTF: Fritiof model implementation intended for incident energy above 4 GeV