Hadronic Model Validation at Transition and High Energies

Outline

- Models validated
- Data Used
- Validation results
- Summary

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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

Data

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 from HARP experiment: (M.G. Catanesi *et al.*)

- Double differential distribution of inclusive pion production at large (0.35 – 2.15 rad) and forward (0.03 – 0.21 rad) with proton beam between 3-15 GeV/c for a number of nuclear targets from Be to Pb
- Authors quote statistical errors 1-10% and systematic uncertainties ~ 10%

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%

Data from NA49 (C. Alt *et al.*)

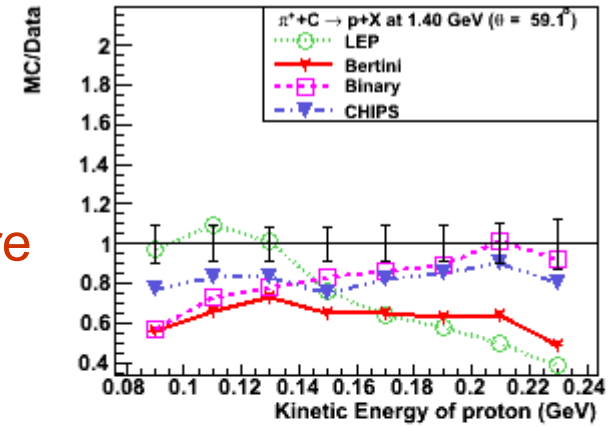
- Inclusive $\pi^{\pm}$ production in p-C interactions at 158 GeV/c in bins of x_F and p_T

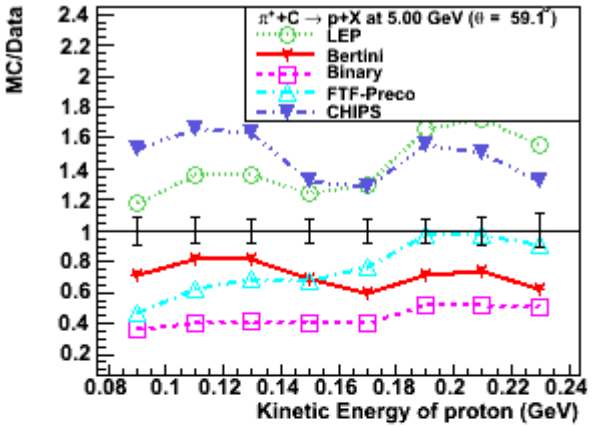
Inclusive p in π^+-C collisions

1.4 GeV/c

5.0 GeV/c

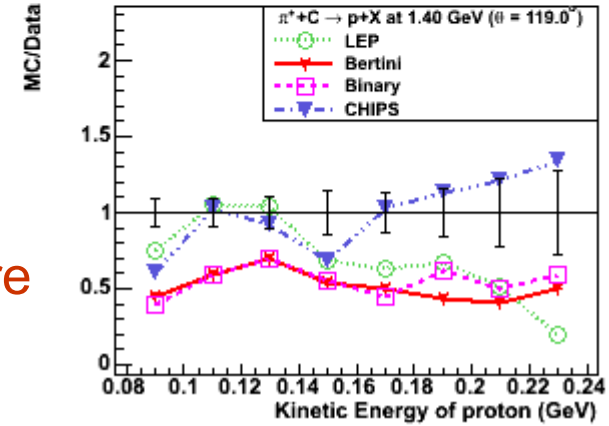
Forward Hemisphere

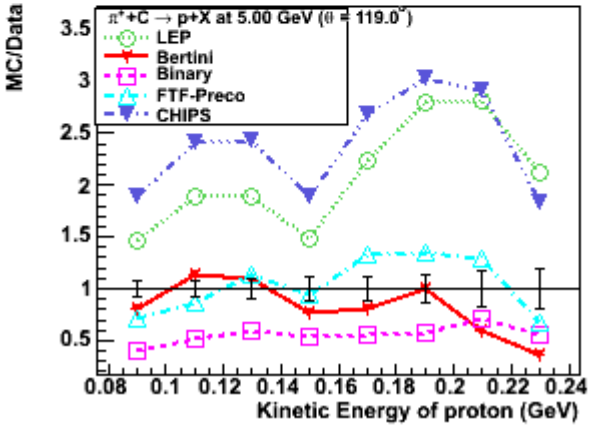




θ = 59.1°

Backward Hemisphere





θ = 119°

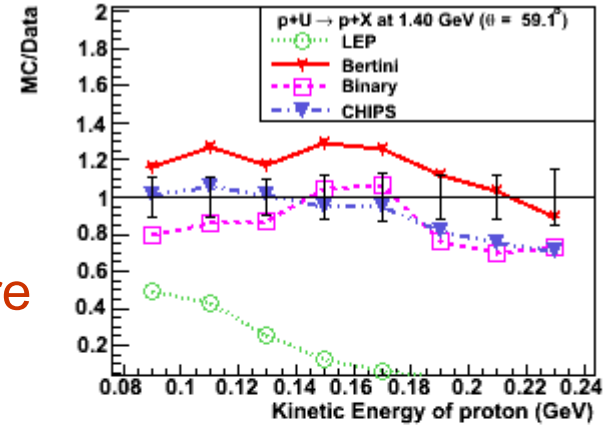
- Bertini provides reasonable agreement at higher energy
- FTF gives reasonable description at 5 GeV/c
- CHIPS over estimates at high energies
- Binary is better at lower energies

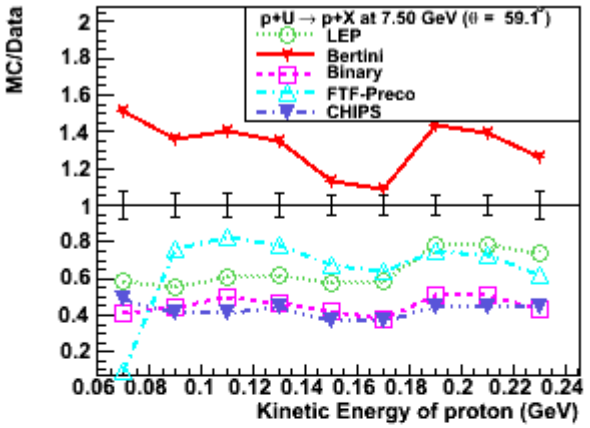
Inclusive p in p-U collisions

1.4 GeV/c

7.5 GeV/c

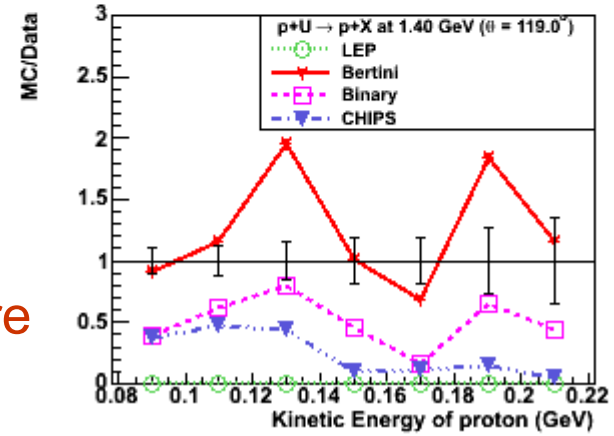
Forward Hemisphere

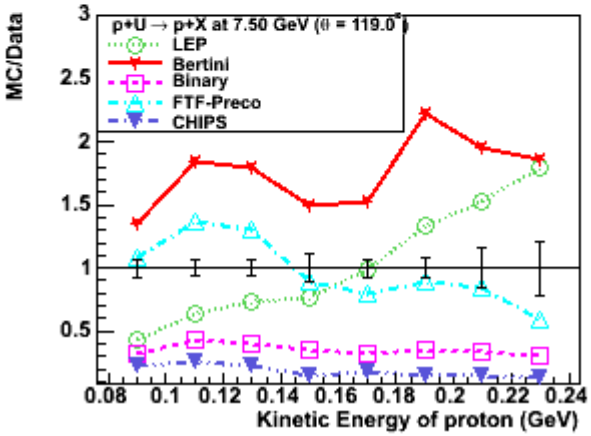




θ = 59.1°

Backward Hemisphere

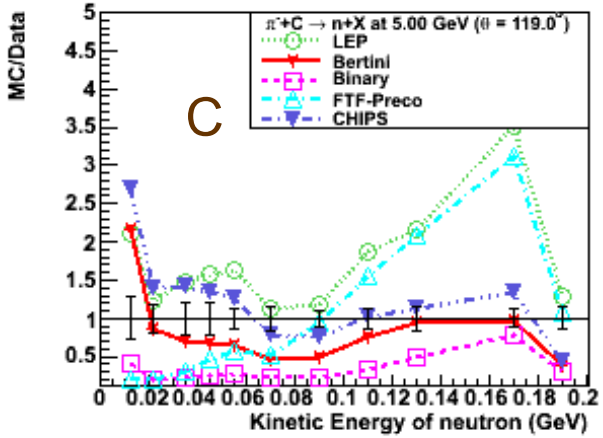


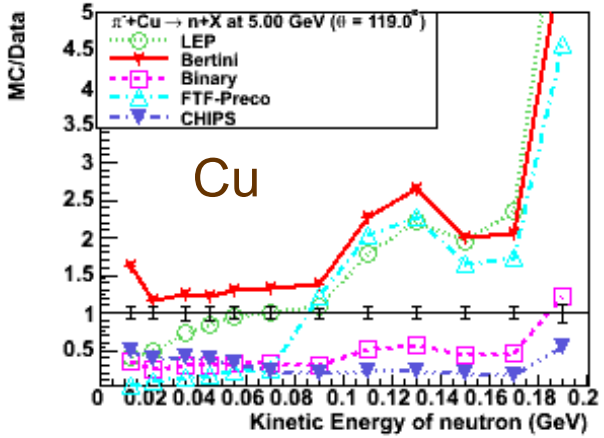


θ = 119°

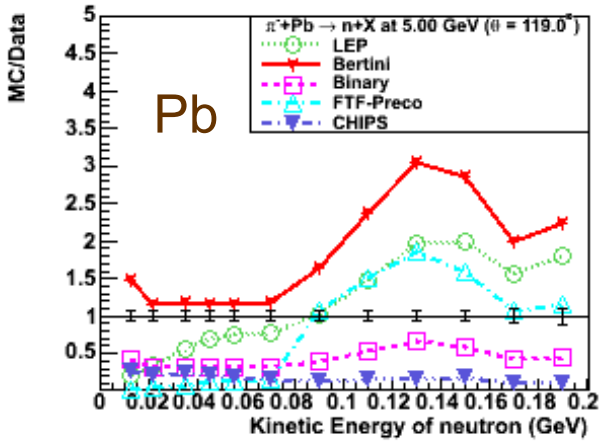
- Bertini is quite reasonable
- LEP is better at high energy
- CHIPS and Binary predictions are below the data
- FTF-Preco provides a good prediction at 5 GeV/c

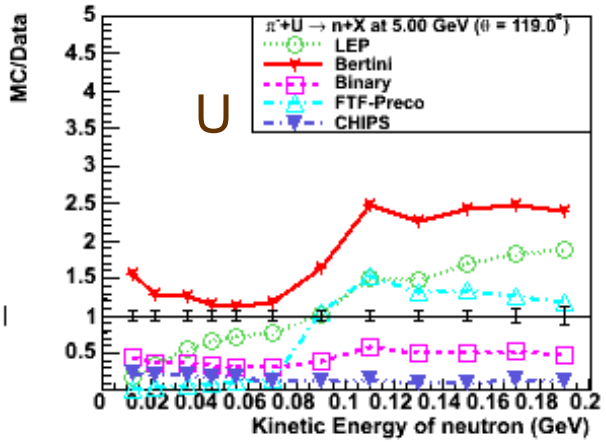
Inclusive n in π⁻-A collisions





θ = 119°

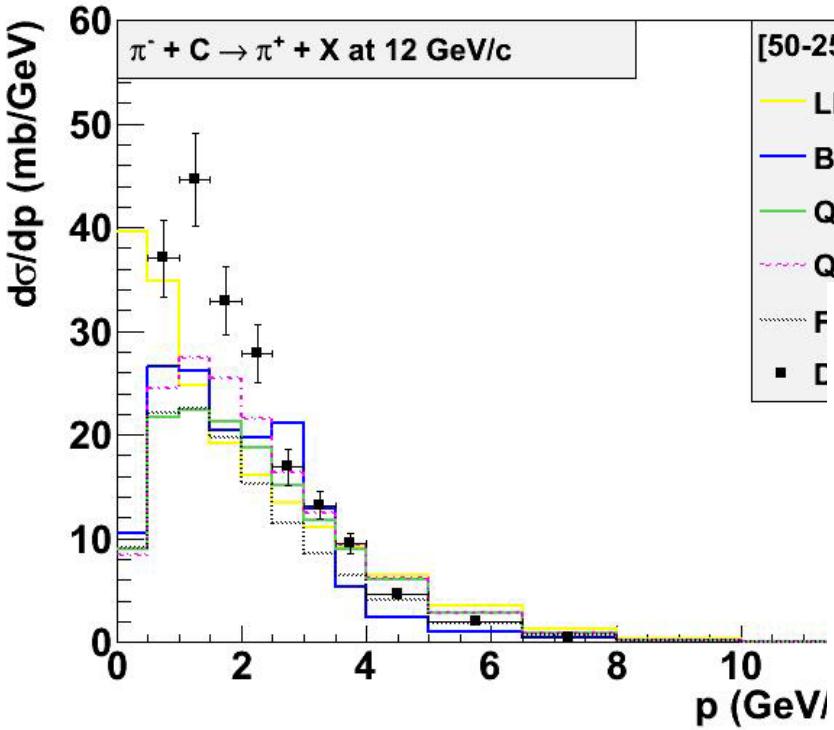


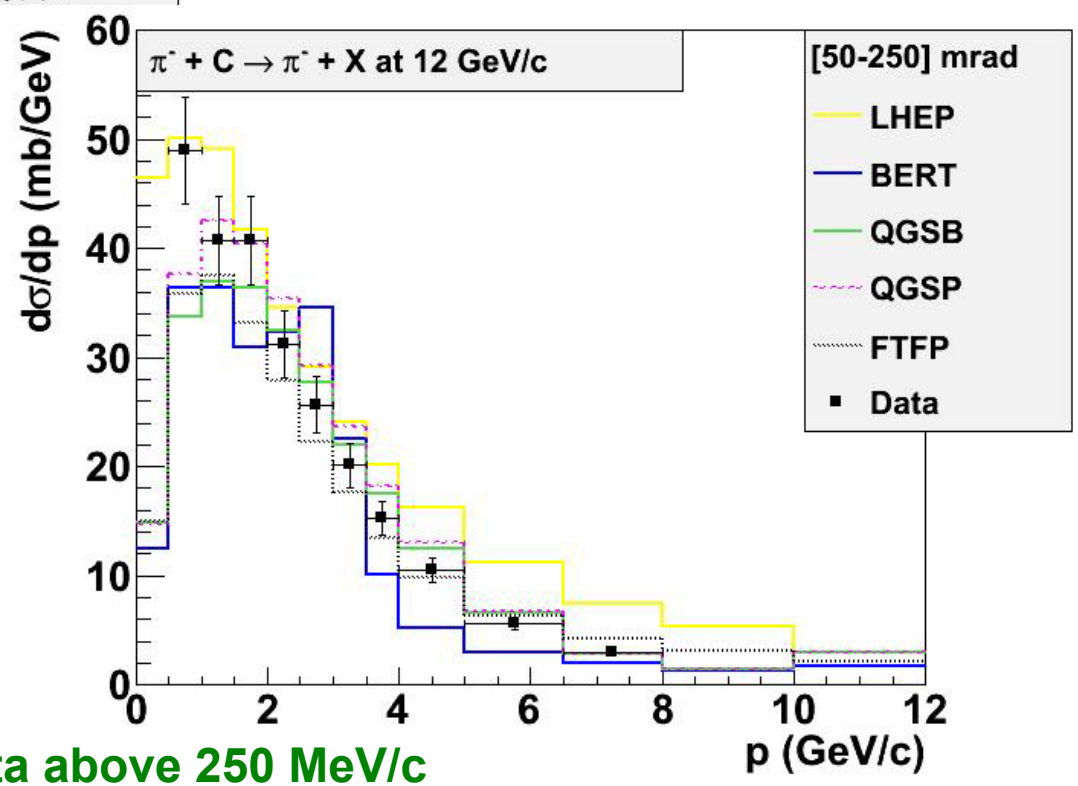


5.0 GeV/c

- **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**

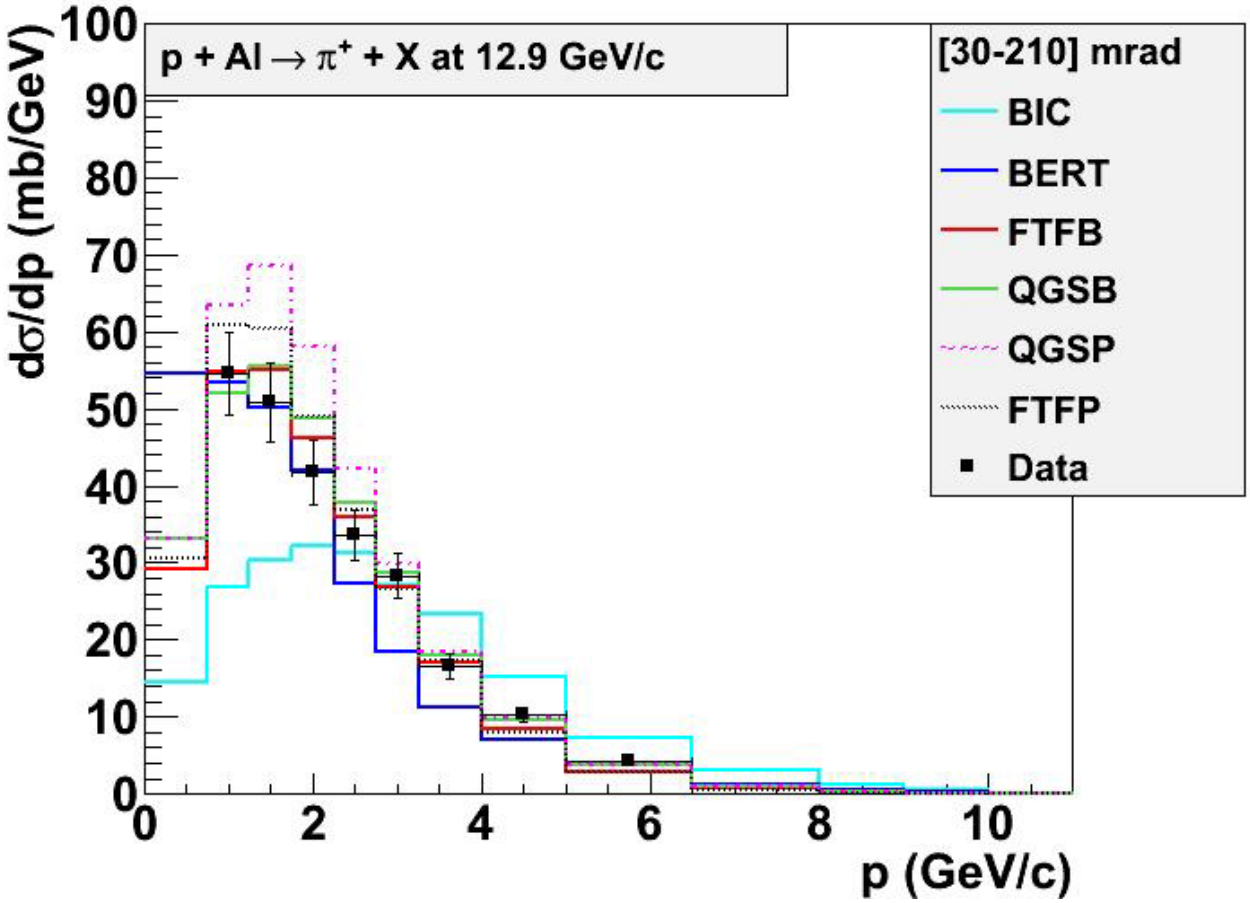
Inclusive $\pi^{\pm}$ in π-C collisions





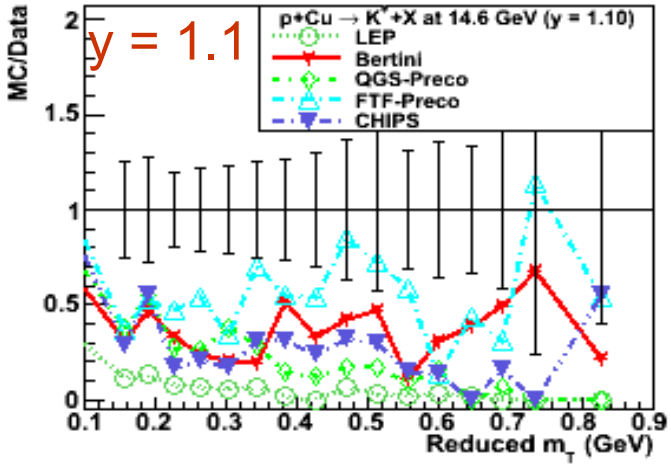
- QGS-Binary is closest to data above 250 MeV/c
- LEP predicts larger cross sections at higher momenta
- QGS-Preco and Bertini predict smaller cross sections

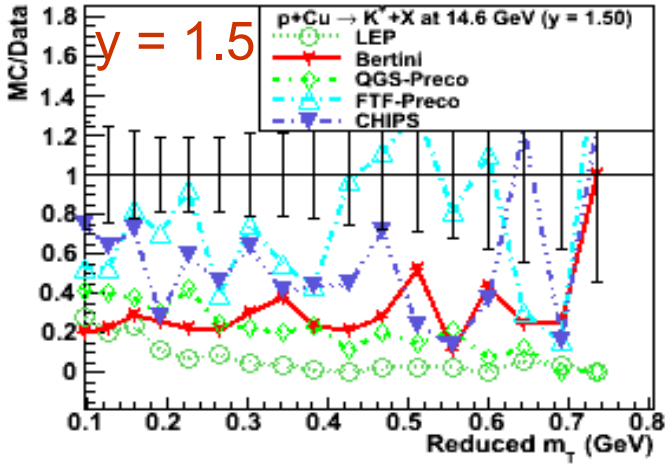
Inclusive π^+ in p-Al collisions



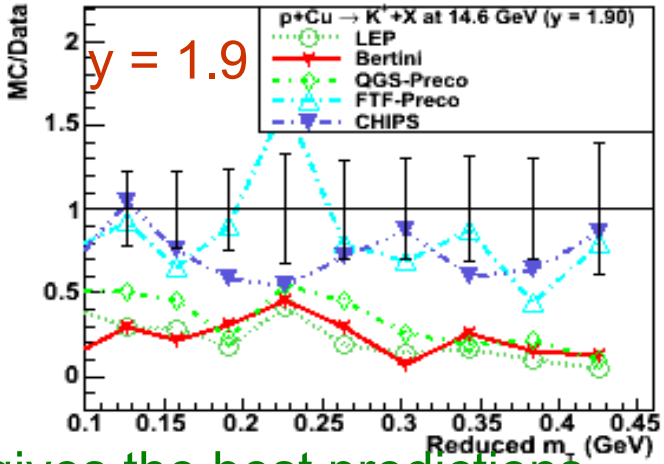
- QGS-Binary, Bertini, FTF-Preco give reasonable description of the data
- QGS/Preco predicts larger cross section while Binary provides a much broader spectrum

p + A → p + X at 14.6 GeV/c



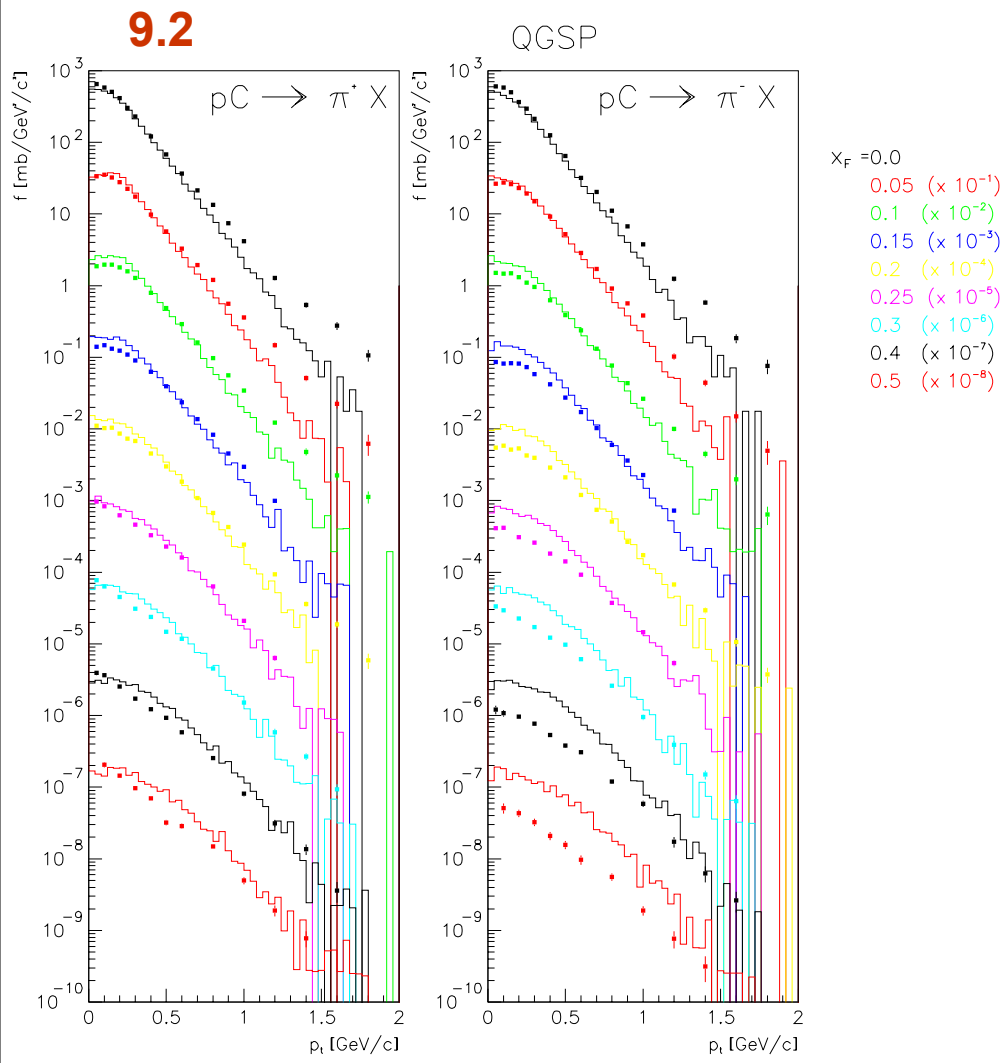


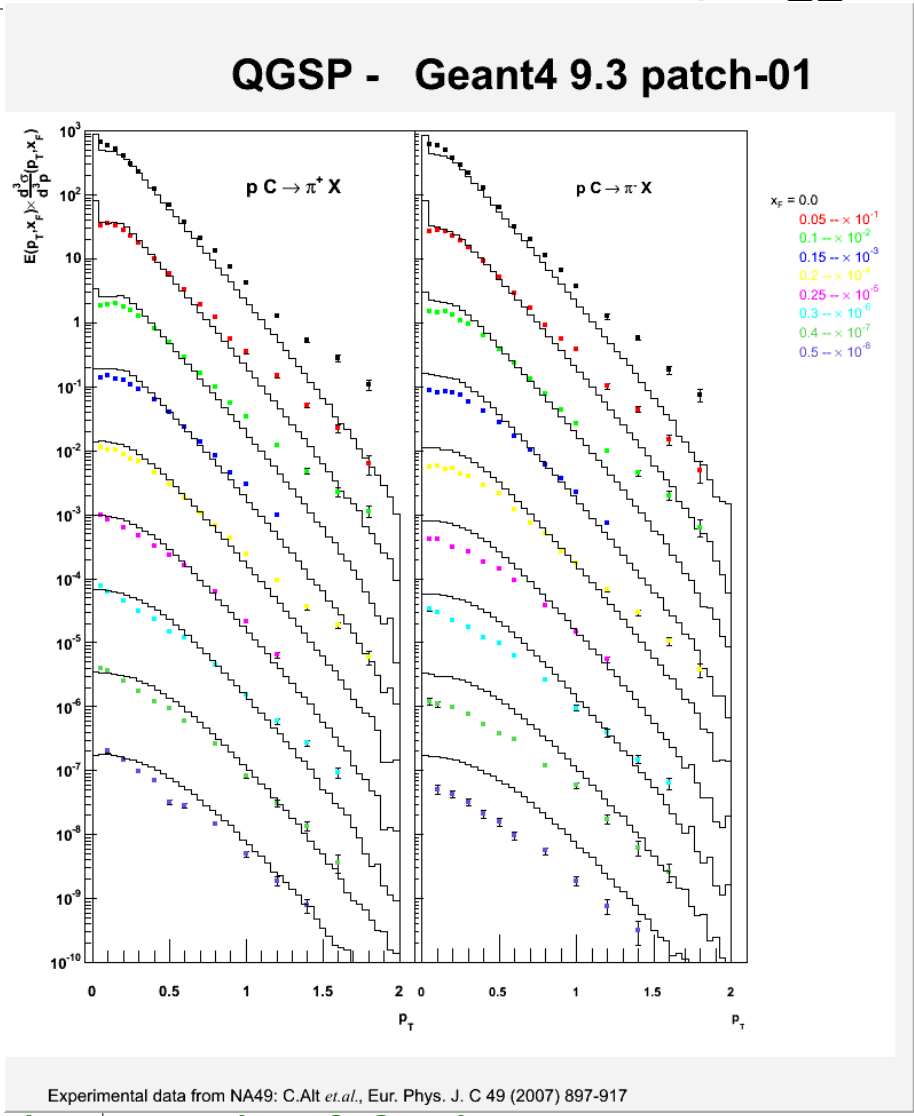
Cu Target



- FTF gives the best predictions
- LEP predicts smaller cross sections
- CHIPS provides reasonable agreement only at high y values
- Bertini predictions are off b a factor of 2

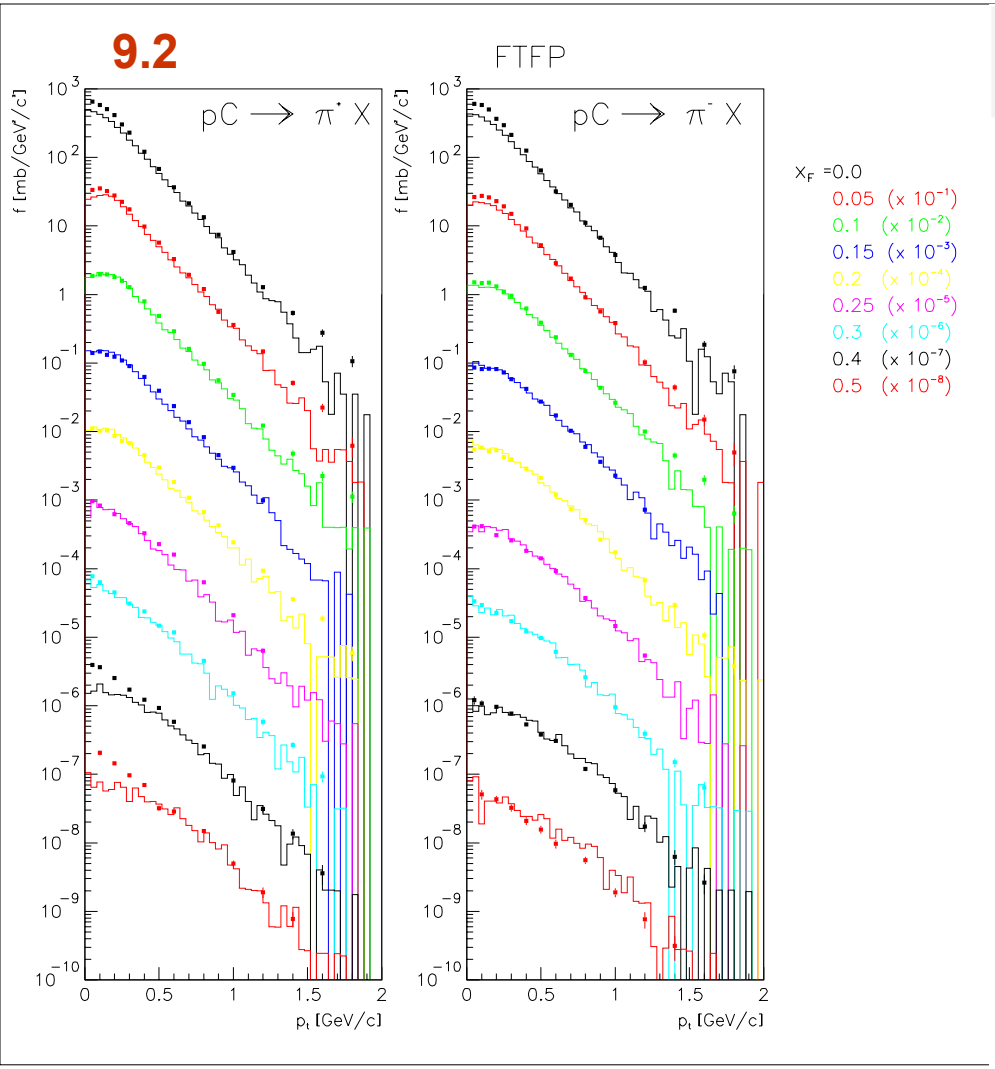
p+C→π±+X at 158 GeV/c (QGSP)

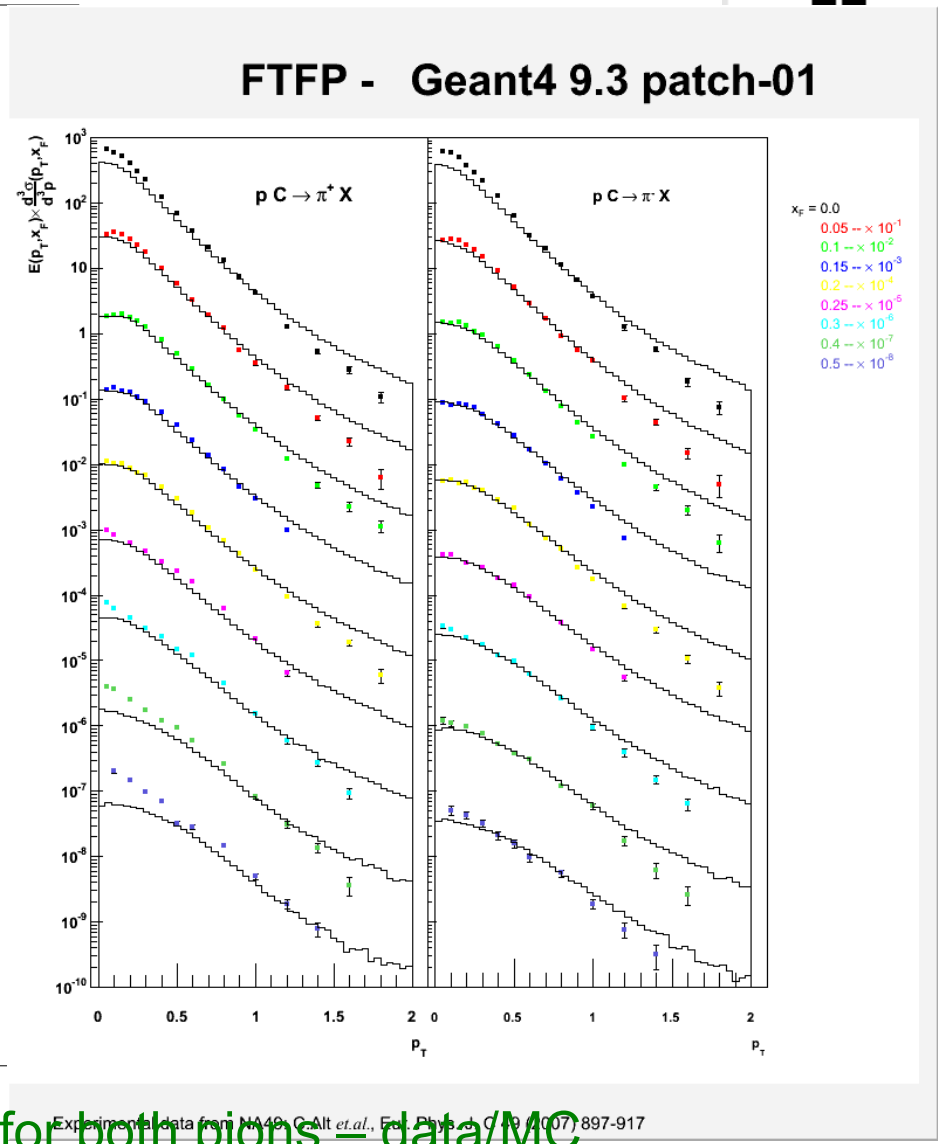




- No appreciable changes in QGSP since version 9.2 – better agreement for π^+ than for π^- and for smaller x-values

p+C→π±+X at 158 GeV/c (FTFP)





- Predictions give harder spectrum for both pions – data/MC comparisons got slightly worse

Summary

- Geant4 provides a large number of models for hadronic physics each valid over a certain energy domain for a number of incident particles.
- The models are continuously improved over the years adding new features and new models are added to the list.
- 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 lower energies.