Validation Effort at Fermilab

(SB, Daniel Elvira, Julia Yarba)

Outline

- Intermediate Energy Validation (test47)
- Validation of Stopping Particles (test48)

14th Geant4 Workshop, Catania
October 20, 2009

Sunanda Banerjee
Fermilab

Scope of Validation

- Test47 package focuses on validating hadronic models in the intermediate energies (incident momenta between 1-20 GeV/c)
- Test48 package validates physics models of stopping particles (stable negatively charged hadrons)

Models Validated in test47

- We have compared data with the predictions of several models using Geant4 version 9.2.ref08 (9.3.b01)
- 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
- The limits are results of validations and compromises
- In recent validation with LHC calorimeters, it was found that existing physics lists ought to be improved in the energy range 5-25 GeV. So some of the models are tested beyond their validity range

Data used in test47

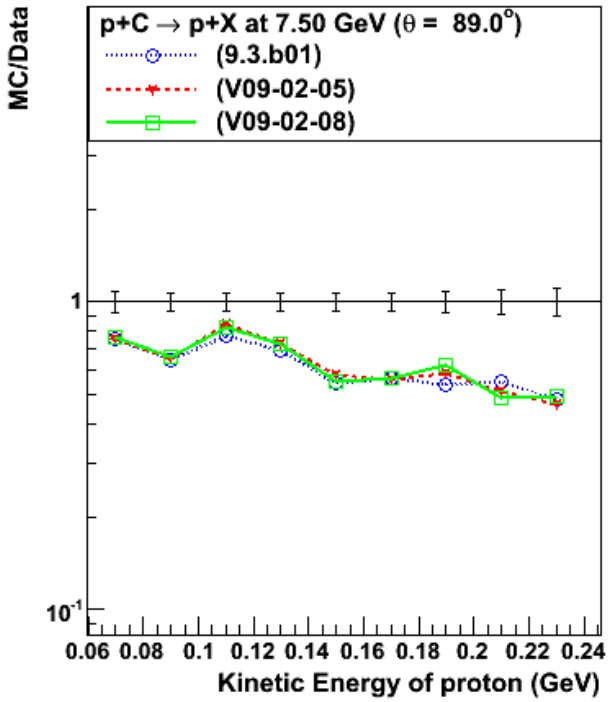
Data Set from ITEP: (Yu. D. Bayukov *et.al.*, Preprint ITEP-148-1983, Sov. J. Nuclear Physics 42, 116)

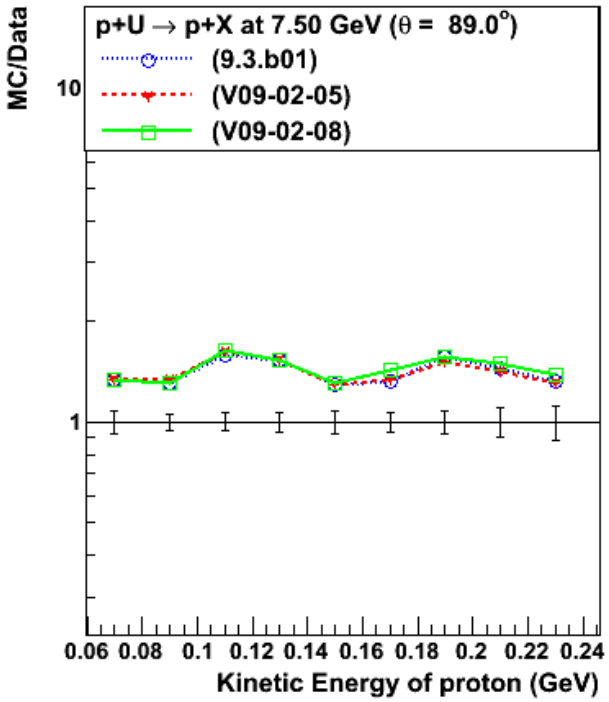
- Measurements exist for Lorentz invariant differential cross section as a function of kinetic energy at some fixed angles
- Inclusive proton and neutron production at 4-29 different angles in 8-9 kinetic energy bins in $p/\pi^+/\pi^-$-nucleus collision (12 targets from Be to U) with beam momenta of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

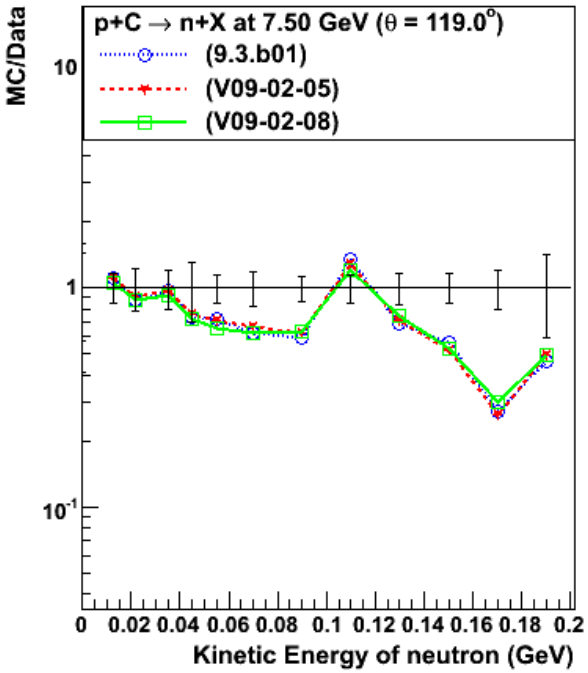
Data set from BNL E-802: (T. Abbott *et al.*, Phys. Rev. D45, 3906)

- 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%

Recent Updates to Bertini Code

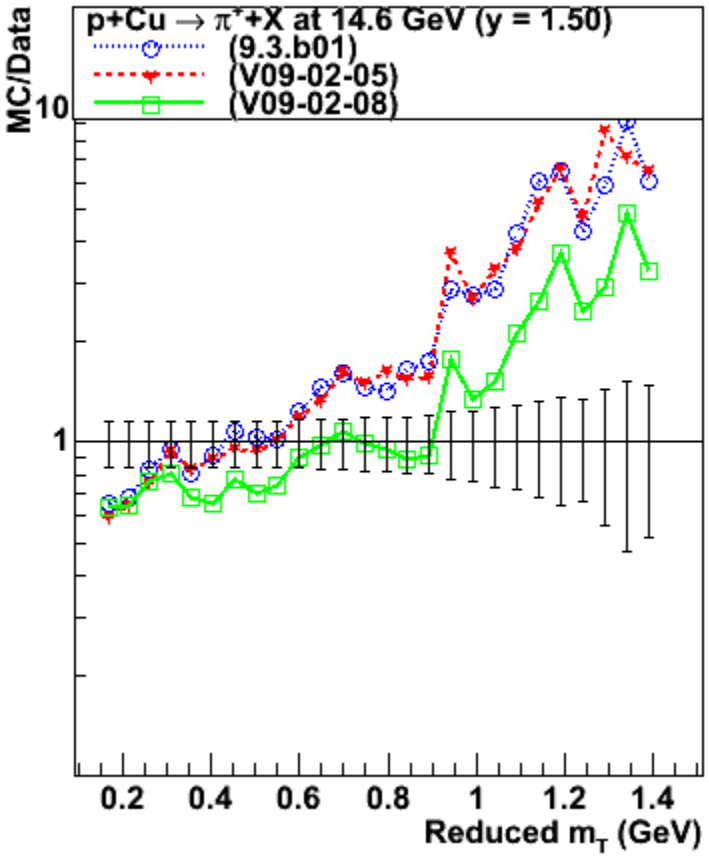


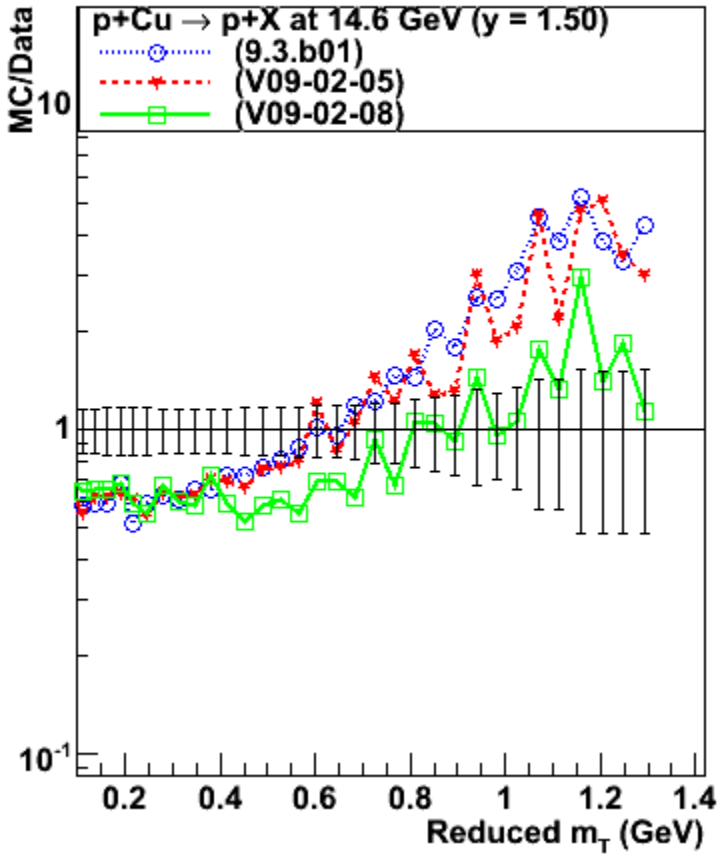




- No appreciable difference in inclusive p/n production in pA interactions up to 7.5 GeV/c. The same is true for p/n production in $\pi^{\pm}$A interactions up to 5 GeV/c.

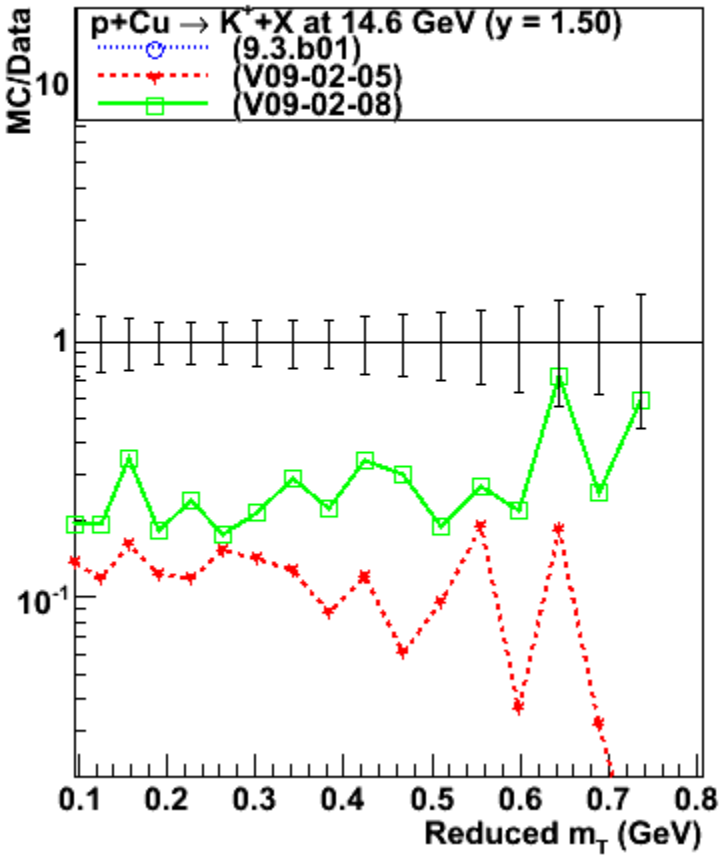
Bertini Model at higher energies

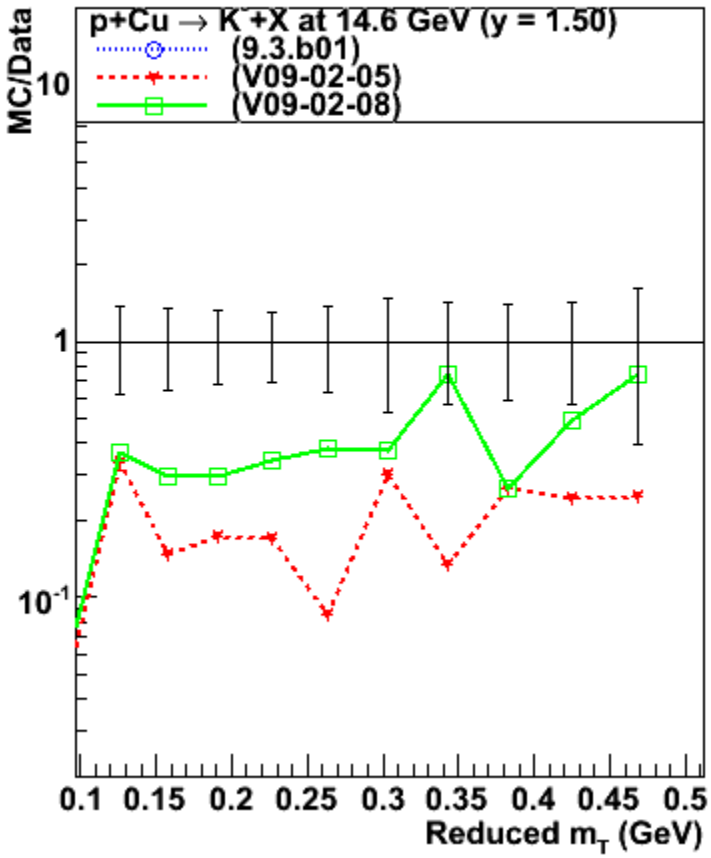




- Changes in inclusive π^+/p production in pA interactions at 14.6 GeV/c. Changes are in the right direction.

Inclusive $K^{\pm}$ Production





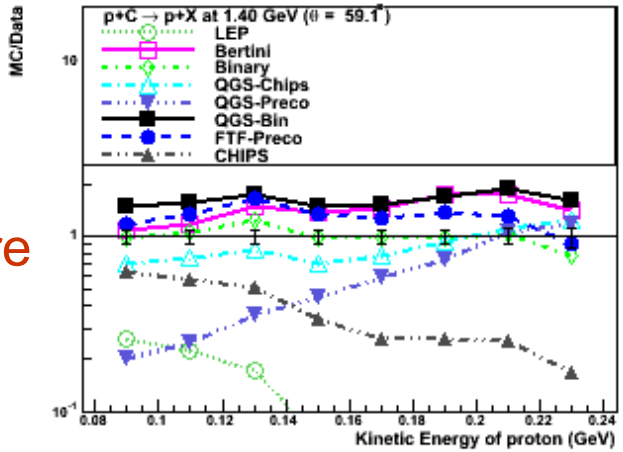
- The new version gives some $K^{\pm}$ production in pA interactions. But the production cross section is still small

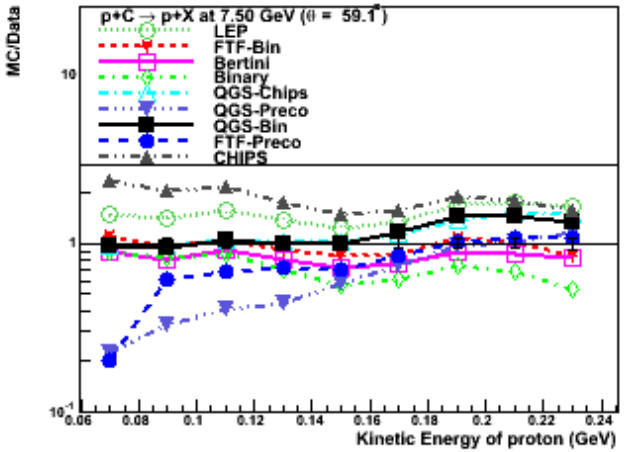
Inclusive p in p-C collisions

1.4 GeV/c

7.5 GeV/c

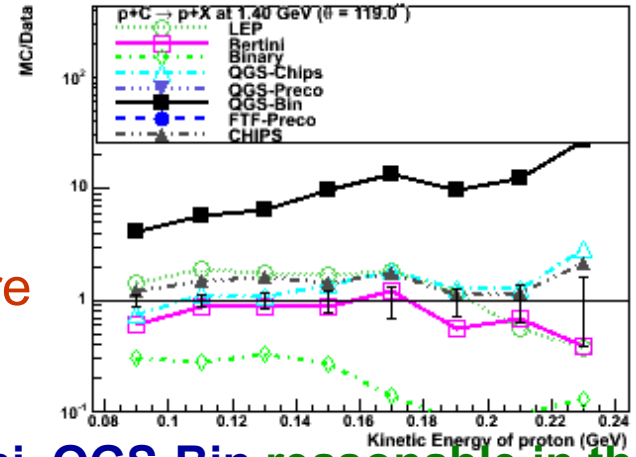
Forward Hemisphere

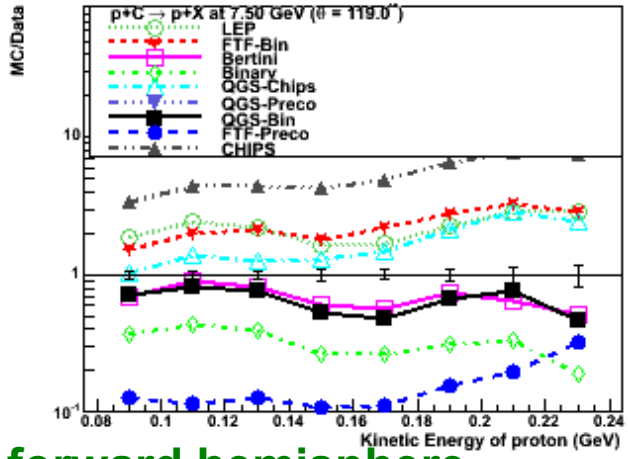




θ = 59.1°

Backward Hemisphere





θ = 119°

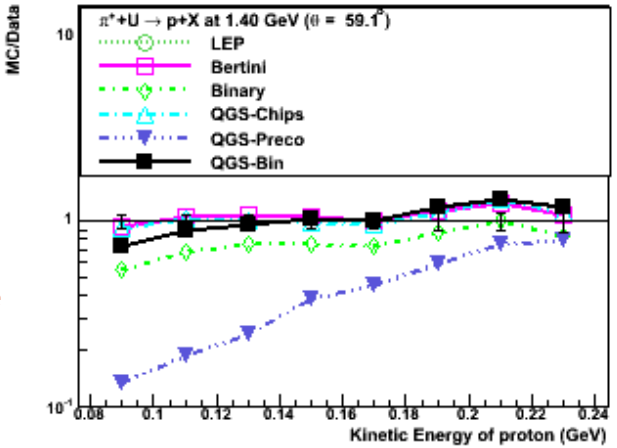
- Bertini, QGS-Bin reasonable in the forward hemisphere
- LEP over estimates at high energy and underestimates at low energy in the backward hemisphere
- QGS-CHIPS has large difference at low energies; CHIPS is reasonable
- FTF-Preco under estimates in backward hemisphere
- Binary good at low energy in forward hemisphere

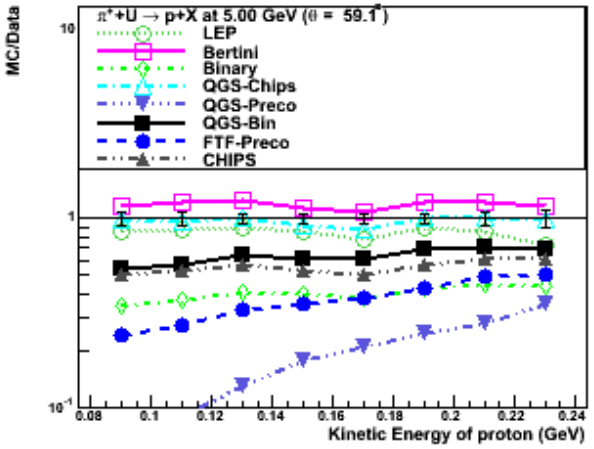
Inclusive p in π^+-U collisions

1.4 GeV/c

5.0 GeV/c

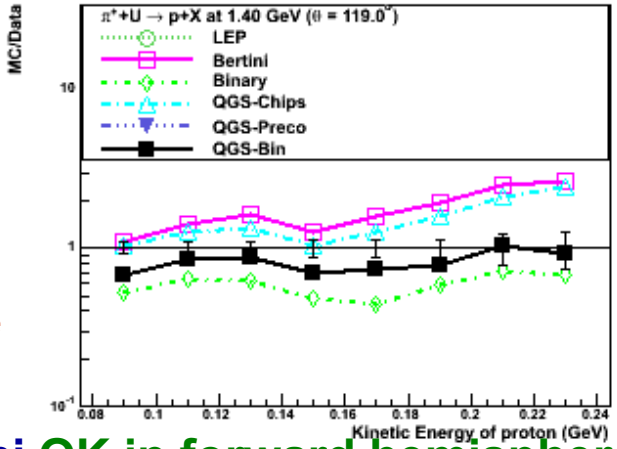
Forward Hemisphere

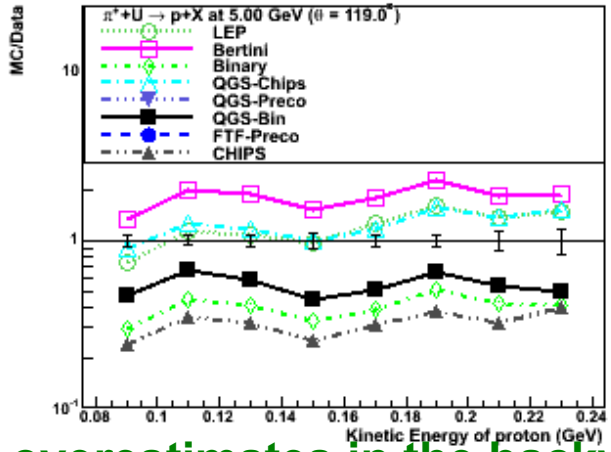




θ = 59.1°

Backward Hemisphere

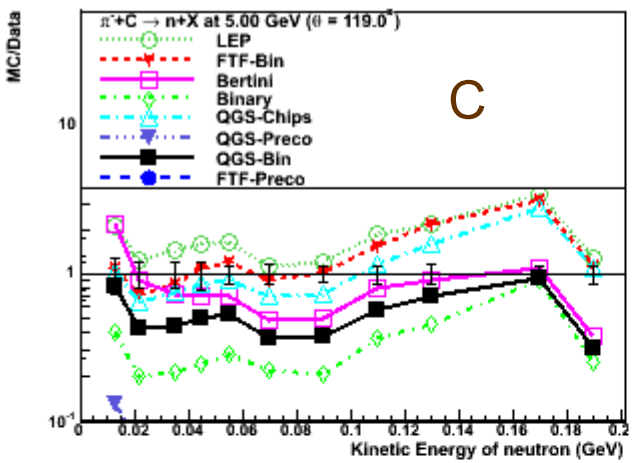


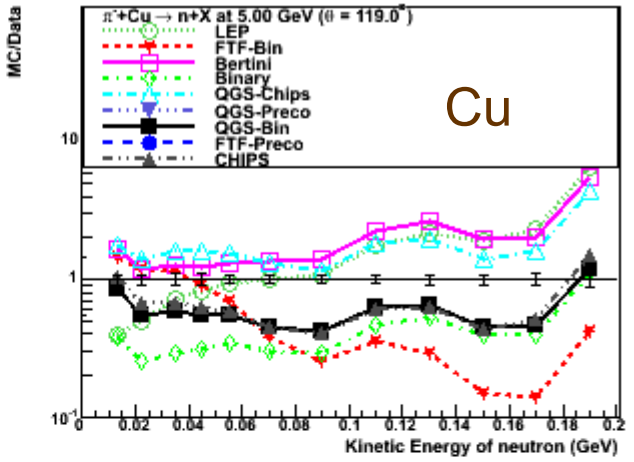


θ = 119°

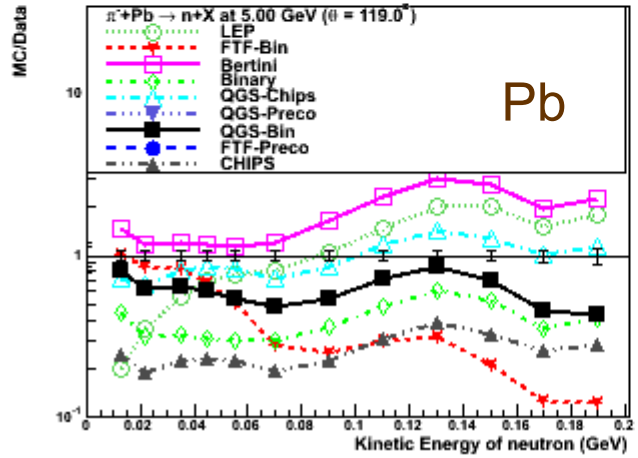
- Bertini OK in forward hemisphere; overestimates in the backward
- LEP is OK at high energy
- QGS-CHIPS provides reasonable prediction
- Binary predictions are below the data
- FTF-Preco cannot provide a good prediction

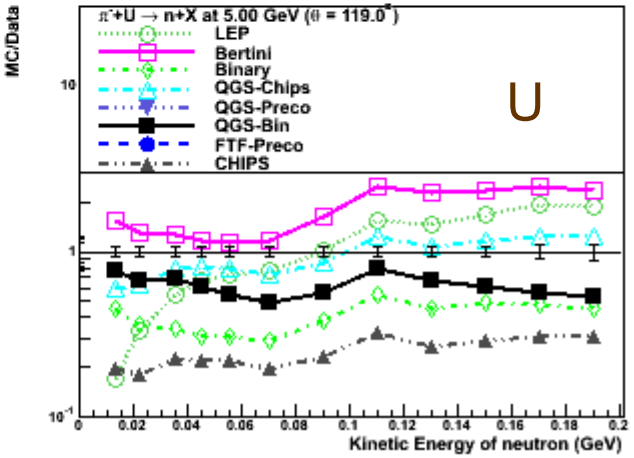
Inclusive n in π⁻-A collisions





θ = 119°





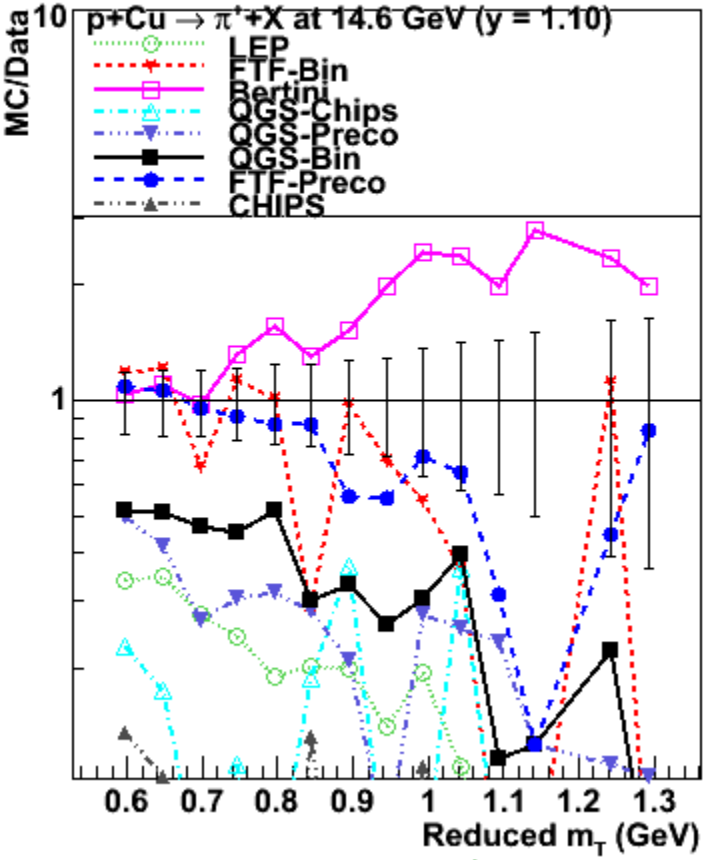
5.0 GeV/c

- Bertini gives reasonable predictions only for light targets
- LEP predicts larger cross sections for heavier targets
- QGS-CHIPS provides reasonable agreement
- Binary predicts smaller cross section
- FTF-Preco predicts smaller cross section

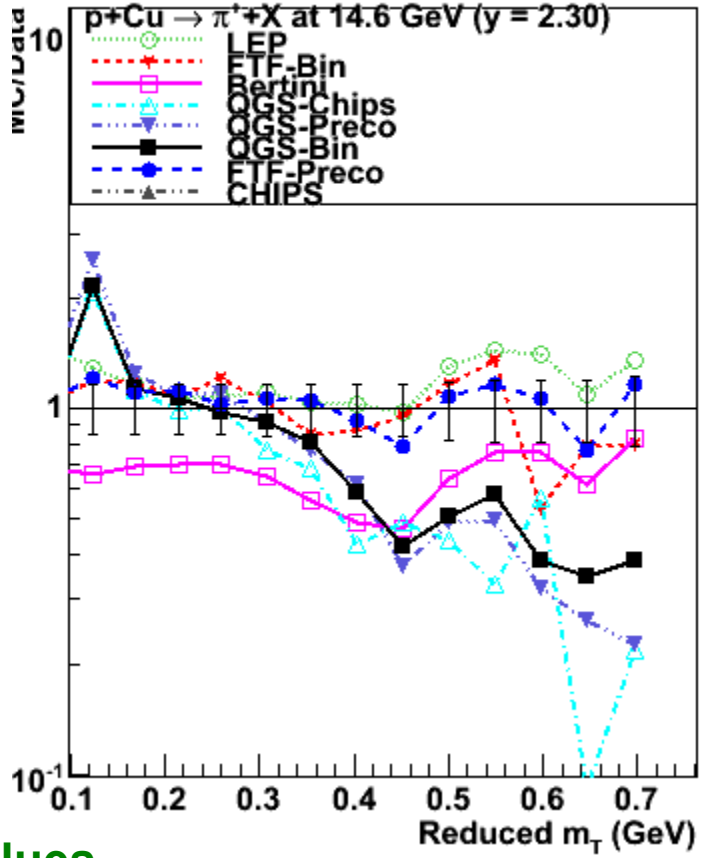
$p + A \rightarrow \pi^+ + X$ at 14.6 GeV/c

Cu Target

y = 1.1



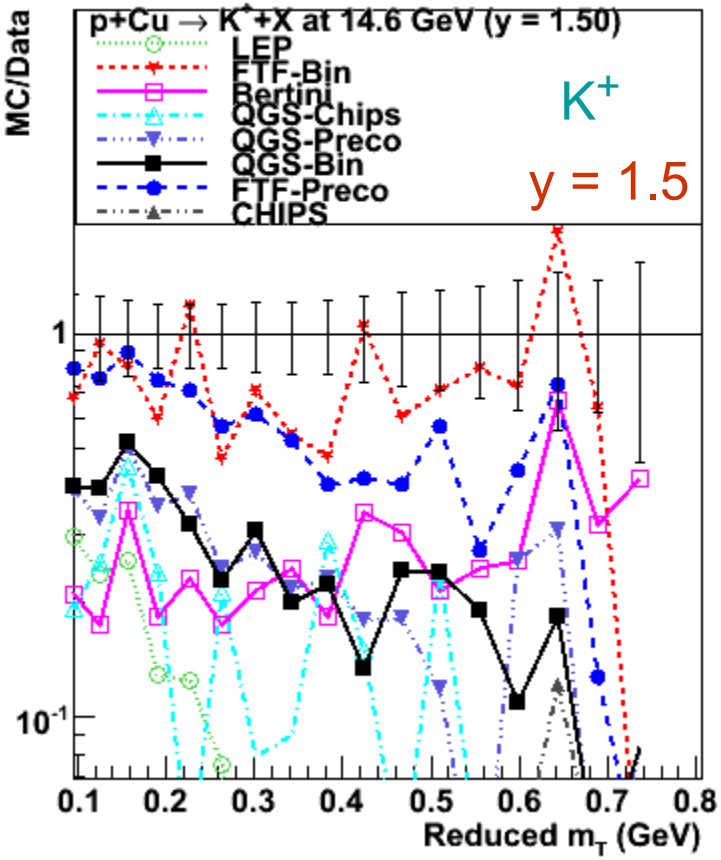
y = 2.3

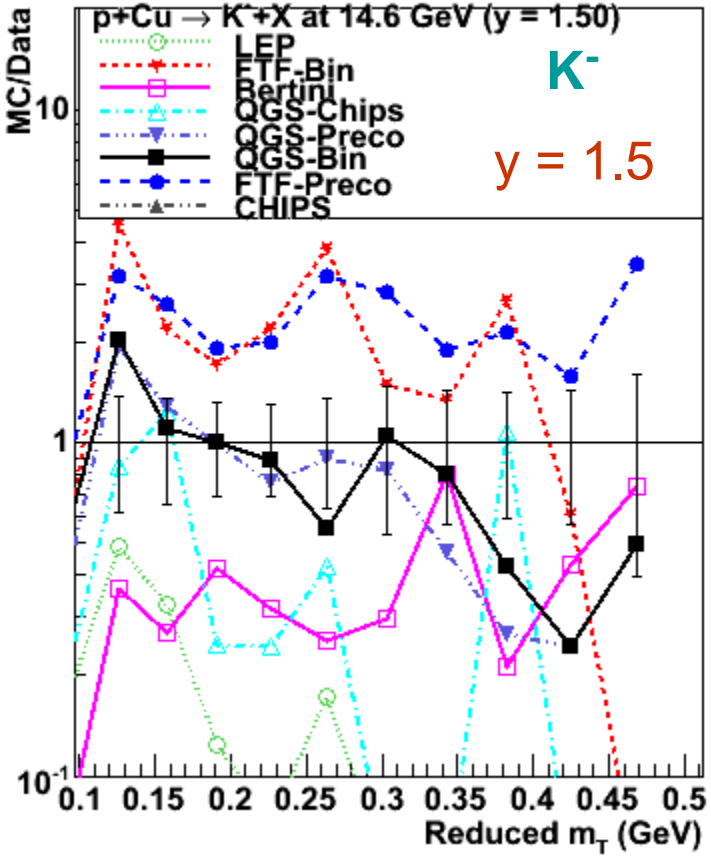


- Bertini prediction is poor for small y-values
- LEP predicts smaller cross sections at small y
- QGS-Preco and QGS-CHIPS predict smaller cross sections at large m_T
- FTF-Preco (FTF-Binary) good for all y and m_T values

$p + A \rightarrow K^{\pm} + X$ at 14.6 GeV/c

Cu Target

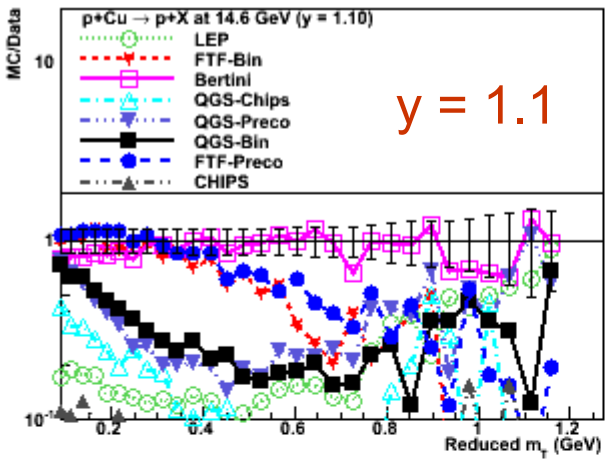


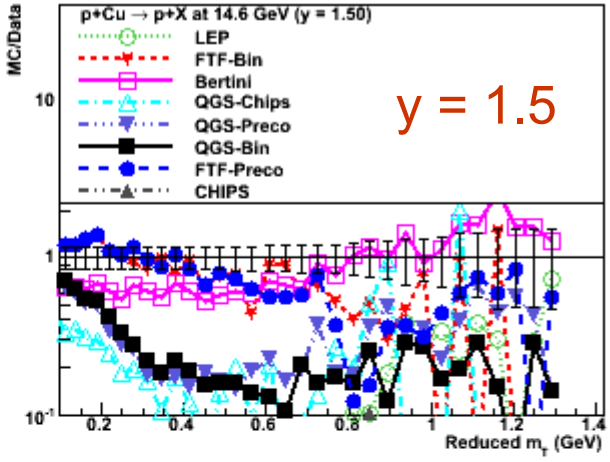


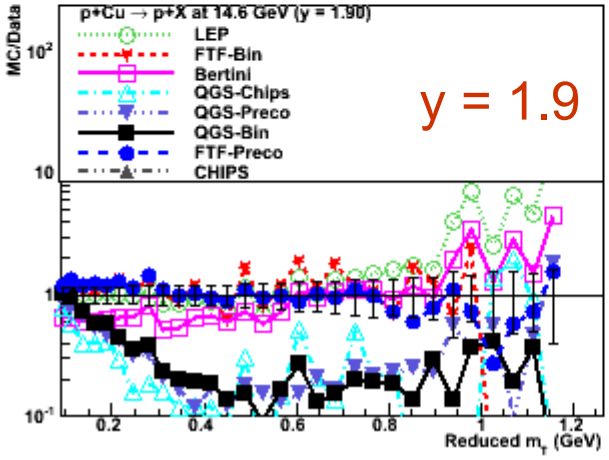
- FTF-Bin(Preco) good for moderate y and under-predicts at small y values
- LEP, QGS-Preco and QGS-Chips models predict smaller cross sections over the entire space of y and m_T

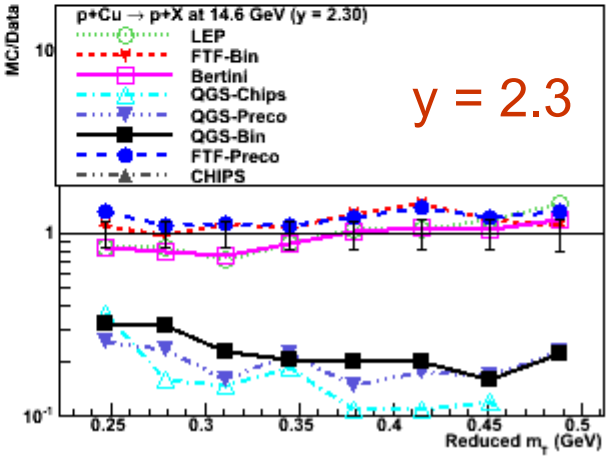
p + A → p + X at 14.6 GeV/c

Cu Target







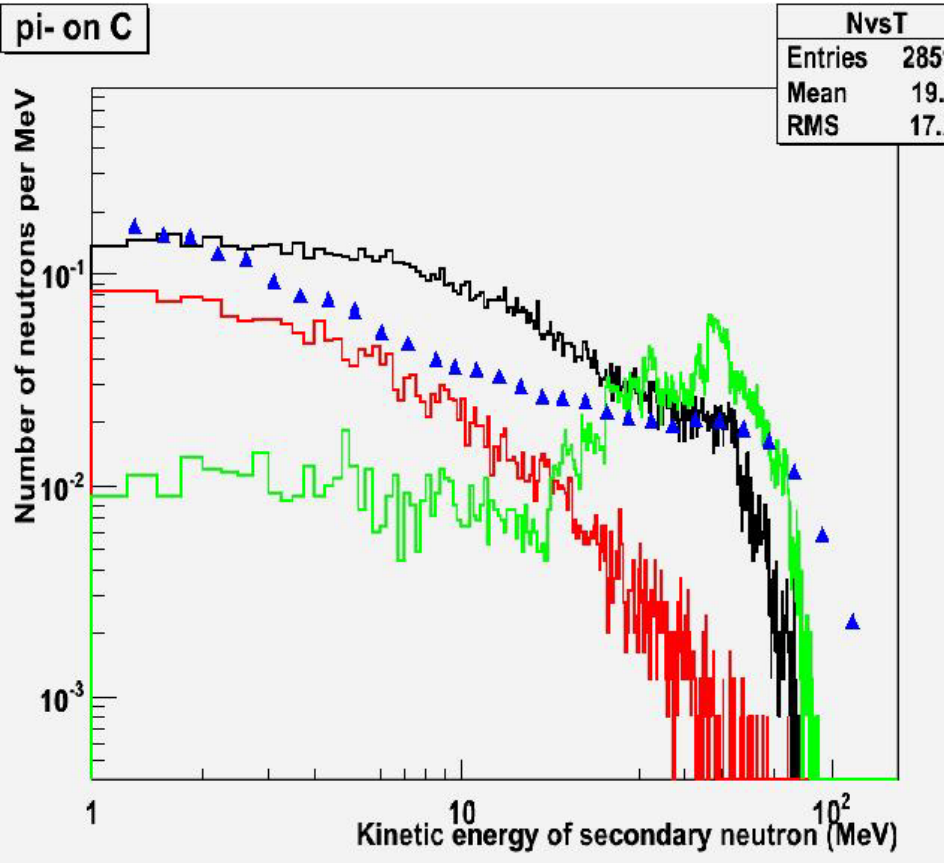


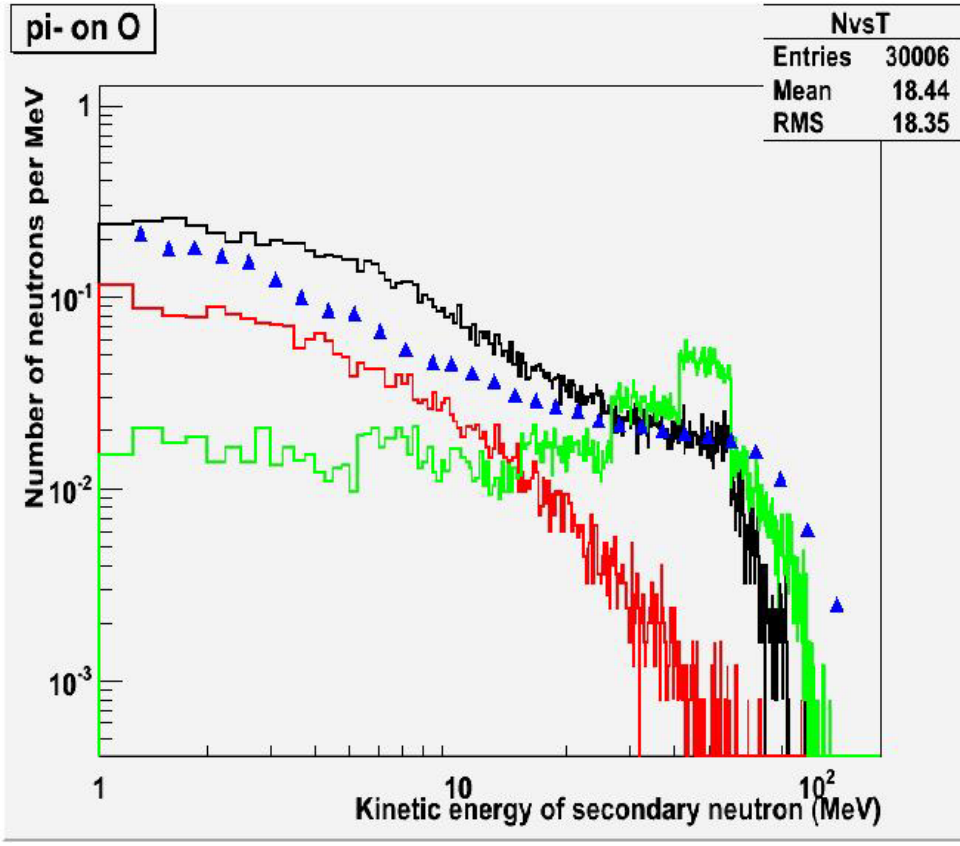
- FTF is good for at large y values and under-predicts at small y, large m_T
- LEP predicts smaller cross sections for small y and larger cross sections for large y and m_T
- QGS-Preco and QGS-Chips predict smaller cross section at small m_T
- Bertini gives a fair description of the data

Geant4 Stopping Particles Test

- Particles: antiproton, antineutron, π^-, K^-
- Geant4 Models (use version 9.2.p01):
  - CHIPS (out of the box)
  - "Traditional" /processes/hadronic/stopping
    - 2 versions of π^- absorption code
- Data Sets:
  - π^- Absorption: R.Madey et al., Phys. Rev. C25, 3050 (1982):
    - Experimental data on neutron yield as a function of neutron's kinetic energy available in a form of table; systematic uncertainty ~6.3%
  - Antiproton annihilation: C.Amsler, Rev. Mod. Phys. 70, 1293 (1998) and reference materials:
    - Experimental data (H target) in a form of plots in papers. Extracted data from graphs, with the DigitizeIt software (www.digitizeit.de); induces ~2% systematics
    - In addition to $\pi^{\pm}$ momentum spectrum, also available plots on pion multiplicity and some angular distributions.

π^- Absorption in Light Targets

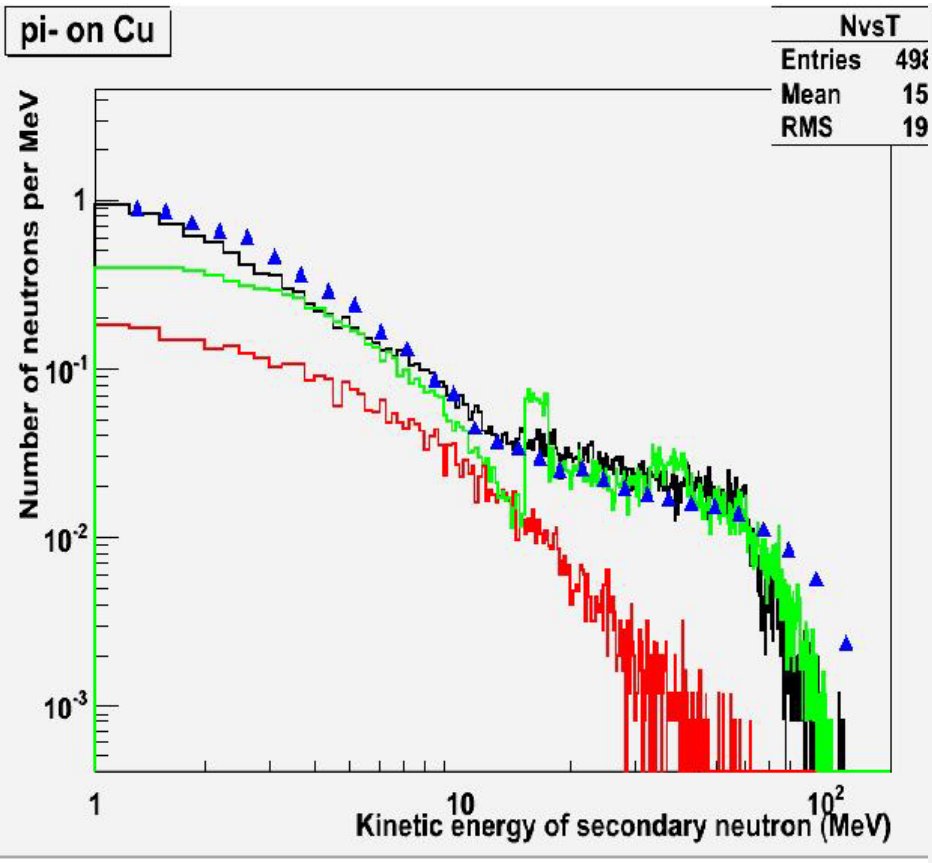


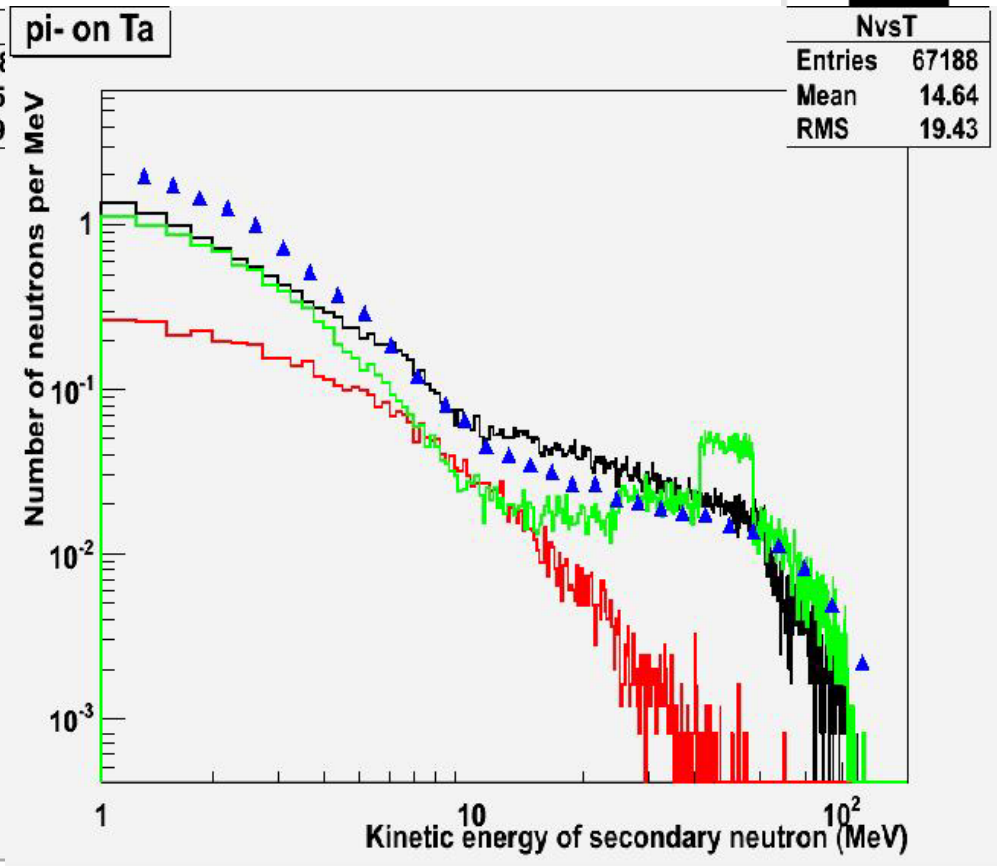


-- CHIPS, -- "traditional", -- "alternative" (M.G.P.)

- None of the models is good for lighter targets (C, N, O)

π^- Absorption in Heavier Materials

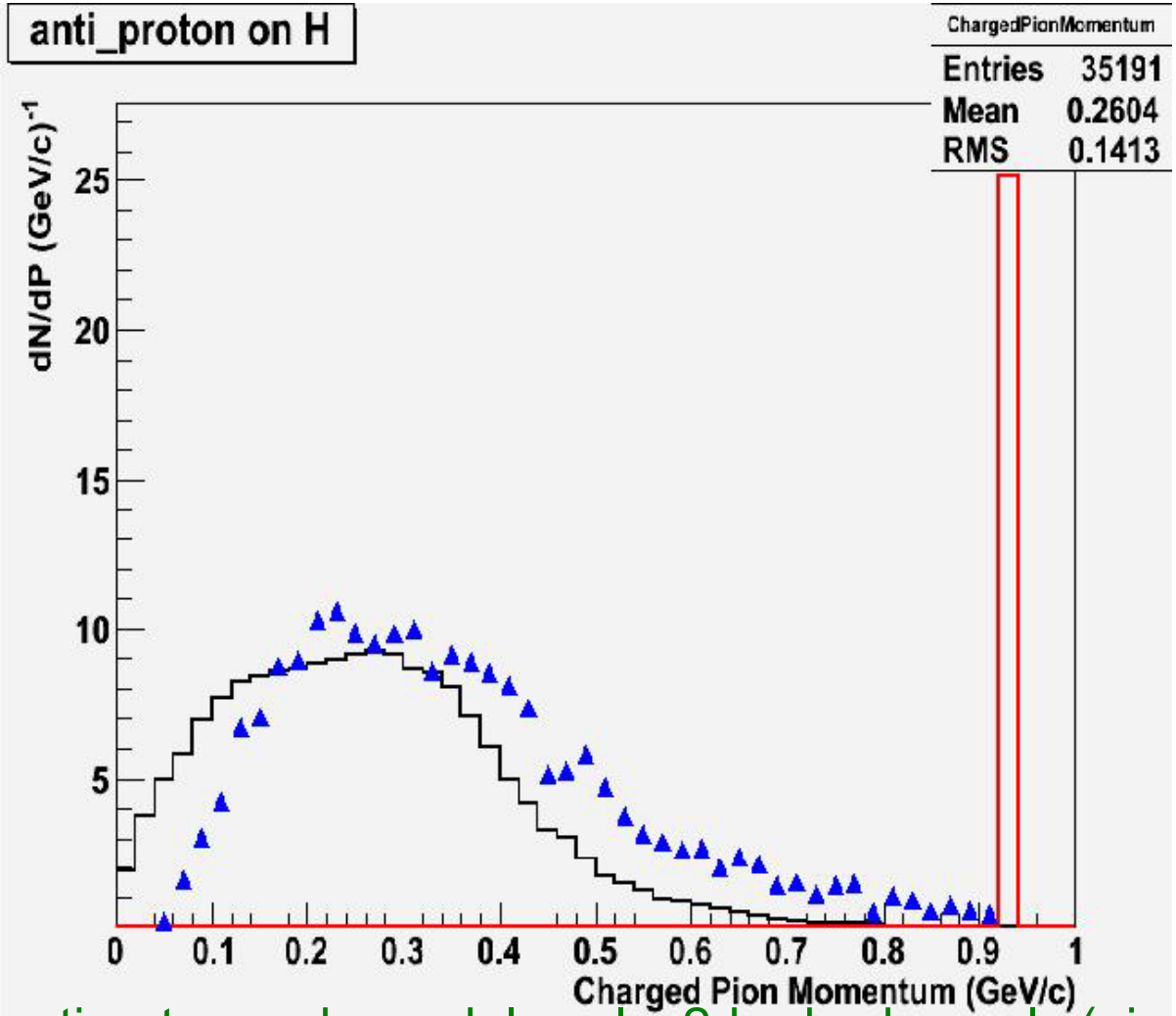




-- CHIPS, -- "traditional", -- "alternative" (M.G.P.)

- CHIPS results are reasonably close to the data starting from Al target
- "Traditional" PionMinus results significantly deviate from the data
- "Alternative" PiMinus gives "strange" structures
- CHIPS is ~700 times slower than PionMinus;
- PiMinus is ~200 times slower than PionMinus

Antiproton Annihilation



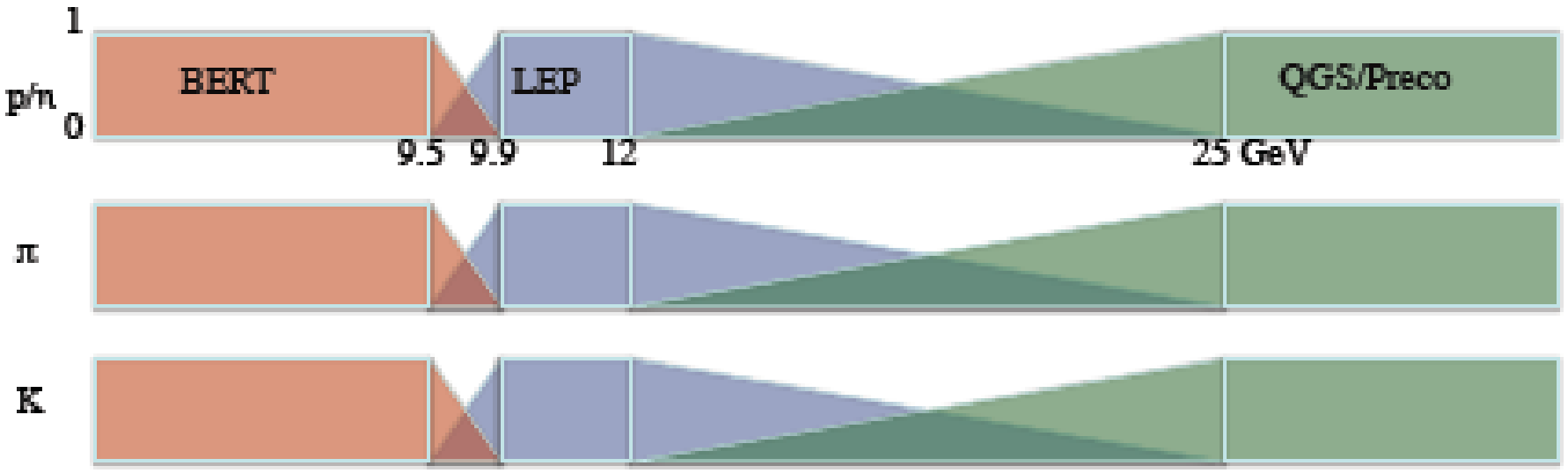
- Traditional antiproton code models only 2-body channels (pion channels and gamma) - comparison doesn't make much sense.
- CHIPS doesn't match the data well but obviously is more sensible

Summary and Outlook

- We now have a validation package of hadronic models in the form of test47 for energy region between 5 and 15 GeV.
- Basic infrastructure in test48 for stopping particles with the application software, ASCII data files, analysis Root macro and a minimal README.
- Hopefully, more experimental data can be extracted from published graphs for both the applications and the tests can be extended.
- The package test47 is also used as a prototype for automatic validation procedure.

Backup

Geant4 Models



- At present the best physics list for the LHC experiments is QGSP_BERT_EMV.
- This list utilizes 3 Geant4 models to describe interactions of the hadrons
  - Bertini cascade model at low energies
  - LEP at intermediate energies
  - QGS/Preco at high energies
- These 3 models need to be examined in more detail.

Summary on test47 Results

- Systematic studies are being made by comparing results from several thin target experiments with predictions from different models of hadronic interactions
- The models showed their strengths and weaknesses in these comparisons. These could guide us to have the right choice of models for HEP application.
- For example, Bertini cascade model gives good overall description of data below 9 GeV. However for low-A nuclei, it under-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.