Validation of Geant4 Hadronic Generators vs Thin Target Data

Outline

- Motivation
- Models validated
- Data Used
- Validation results
- New validation framework
- Summary

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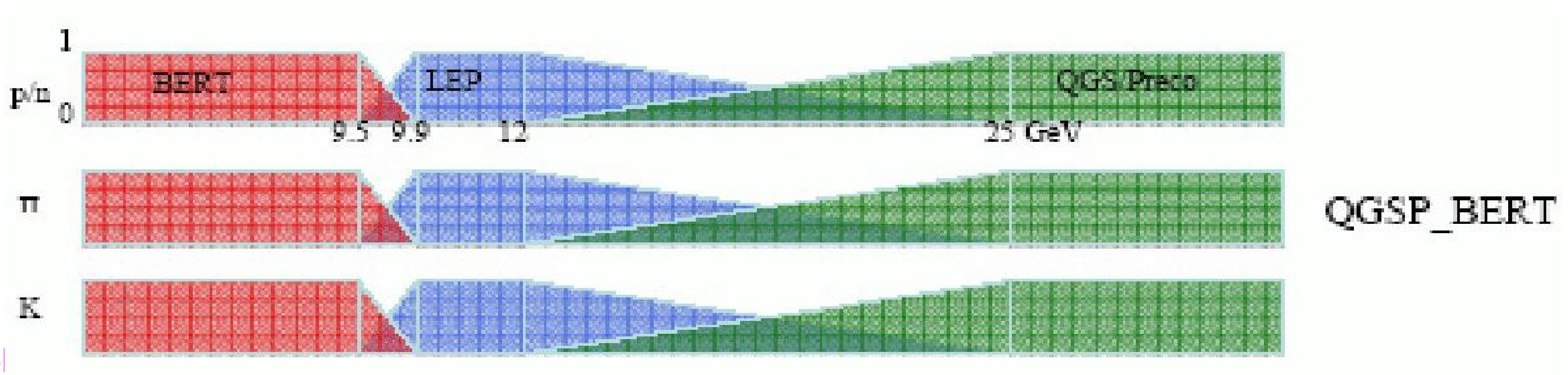
(slides prepared by Sunanda Banerjee
on behalf of Geant4 Hadronic Working Group)

Motivation

- Geant4 provides a large number of models to describe hadronic interactions over the entire energy spectrum
  - Quark-gluon string models which are valid for high energy interactions (E > 10 GeV): QGS, FTF
  - Cascade models to describe medium to low energy interactions (E: 1-10 GeV): Bertini, Binary
  - Precompound and de-excitation model for low energy interactions: Preco
  - Parametrized models describing broad energy domains: LEP, HEP
- It is essential to find the range of application of these models.
- Validation of physics models is an integral part of commissioning the models in Geant4 applications and is done by comparing their predictions with published thin target data.

Physics List

- Since none of the models within Geant4 could explain all physics processes, it is customary to register several physics processes in a list.
  - EM processes are usually valid over the entire energy domain with each process described separately, e.g., pair production, Compton scattering, …
  - Hadronic processes are valid over a finite energy domain. Two models may have validity over an overlapping energy region
- LHC experiments have chosen QGSP_BERT physics list as the default physics list
  - Uses Bertini, LEP, QGSP for $\pi^{\pm}$, K and p/n
  - LEP/HEP (GHEISHA) for all others



Models Validated

- We have compared data with the predictions of several models using Geant4 version 9.3.p01
- Primary set:
  - QGS: Quark gluon string model and is intended for incident energy above 12 GeV
  - Bertini Cascade: Bertini intra-nuclear cascade model intended for incident energy below 9 GeV
  - LEP: Low energy parametrized model derived from GHEISHA and is intended for incident energies below 25 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 (works at all energies)
  - 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

Data from Saturne (S. Leary *et al.*); GSI Synchrotron (C. Villagrasa-Canton *et al.*)

- Double differential cross section for neutron production
- Isotope production

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.*)

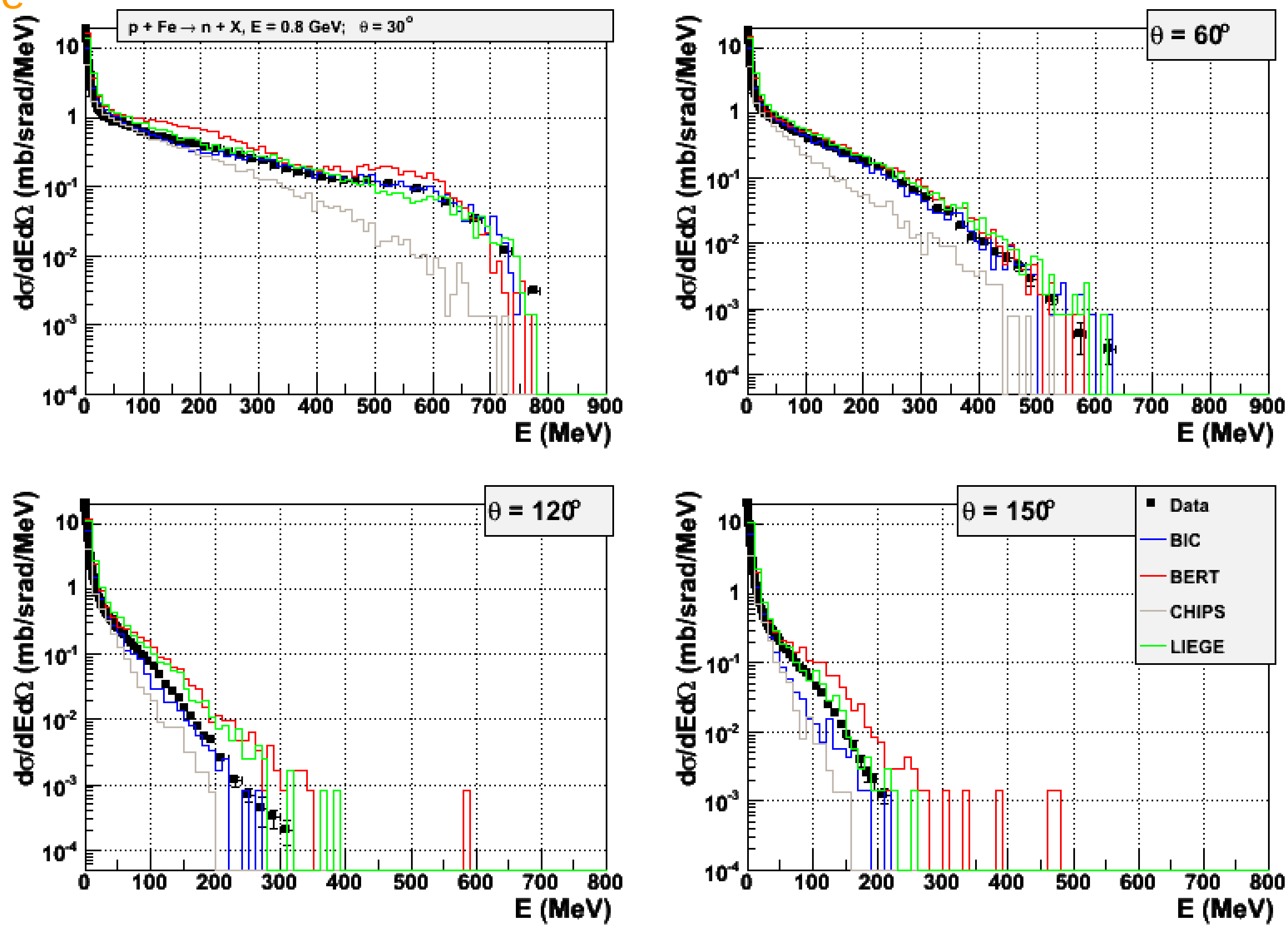
- Double differential distribution of inclusive pion production at large (0.35 – 2.15 rad) and forward (0.03 – 0.21 rad) with proton, $\pi^\pm$ beam between 3-15 GeV/c for a number of nuclear targets from Be to Pb
- Authors quote statistical errors 1-10% and systematic uncertainties ~ 10%

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%

Neutron production in p+Fe at 0.8 GeV

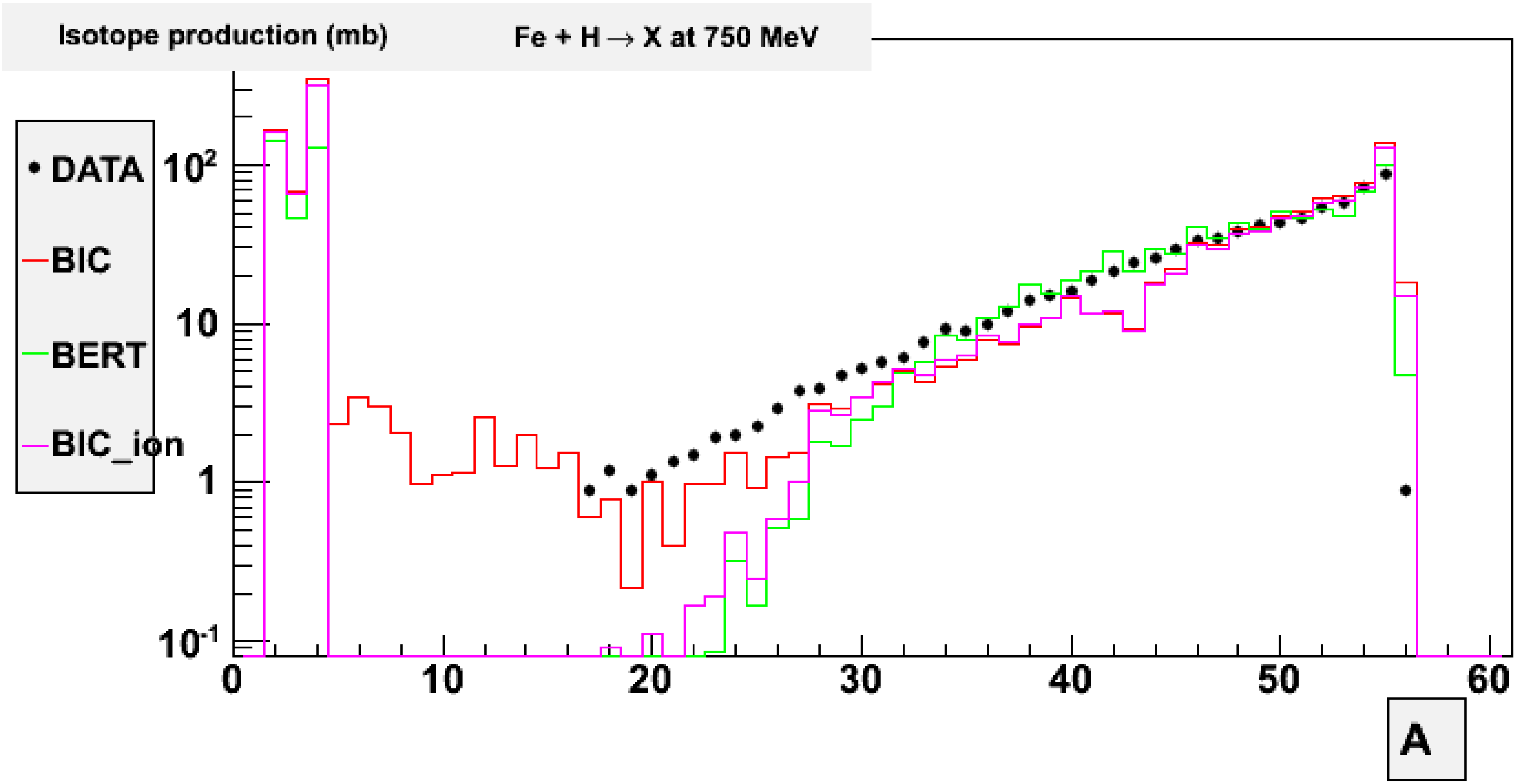
Saturne



- The cascade models and in particular Binary (and Liege, a cascade model from that origin) describe the data rather well at all angles

Isotope Production in p+Fe at 0.75 GeV

GSI



- Three cascade models, BIC (binary cascade with multi-fragmentation model on), BERT (Bertini Cascade) and BIC_ion (binary cascade model with multi-frgmentation off) are compared.

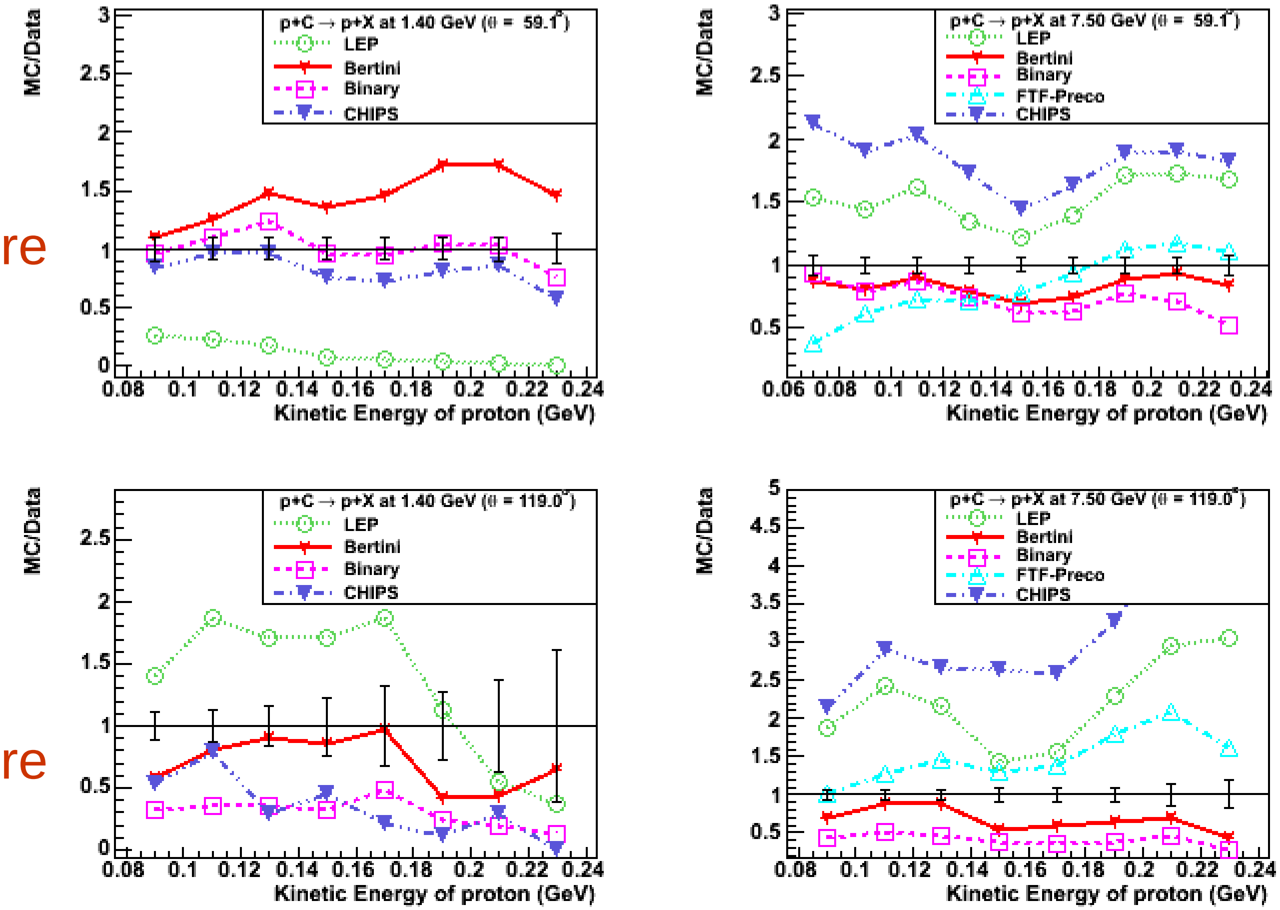
Inclusive p in p-C collisions

ITEP

1.4 GeV/c — 7.5 GeV/c

Forward Hemisphere — $\theta = 59.1^o$

Backward Hemisphere — $\theta = 119^o$



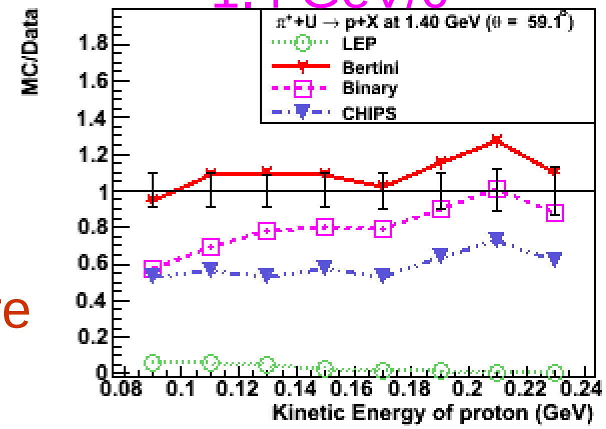
- ❑ Bertini and FTF provide the best agreement
- ❑ LEP over-estimates at high energy and has poor agreement at low energy
- ❑ CHIPS over-estimates at high energies
- ❑ Binary good only in the forward hemisphere

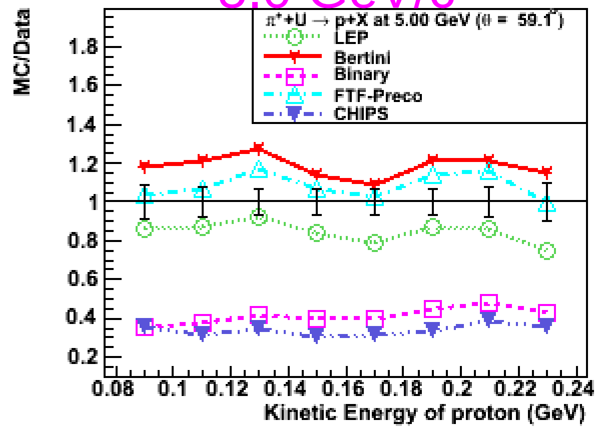
Inclusive p in π^+-U collisions

ITEP

1.4 GeV/c | 5.0 GeV/c

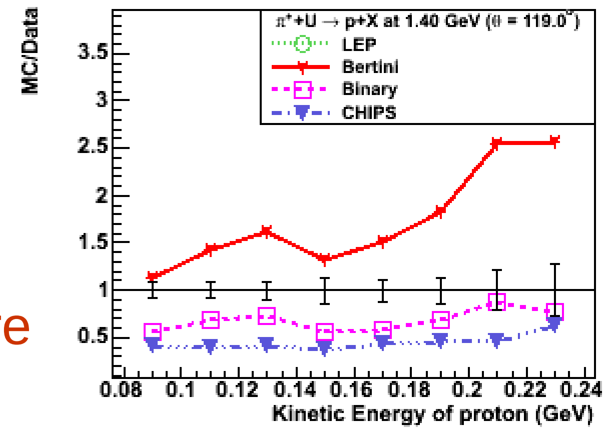
Forward Hemisphere

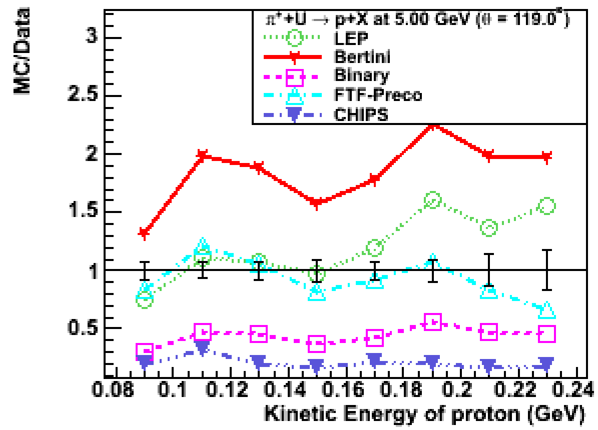




θ = 59.1°

Backward Hemisphere





θ = 119°

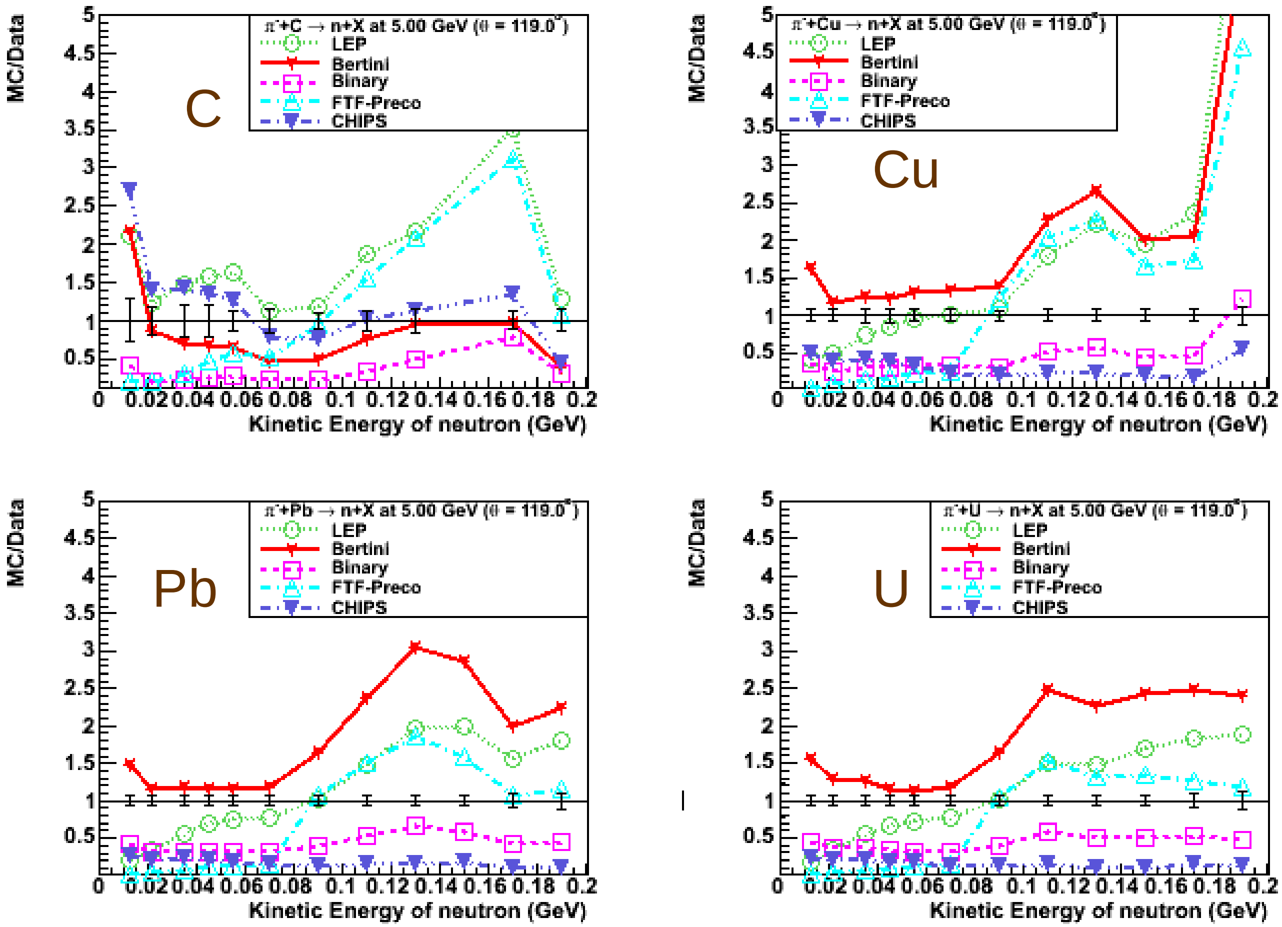
- Bertini OK in forward hemisphere; over-estimates in the backward
- LEP is OK only at high energy
- CHIPS and Binary predictions are below the data
- FTF-Preco provides the best prediction at 5 GeV/c

Inclusive n in π^--A collisions

ITEP

$\theta = 119^o$

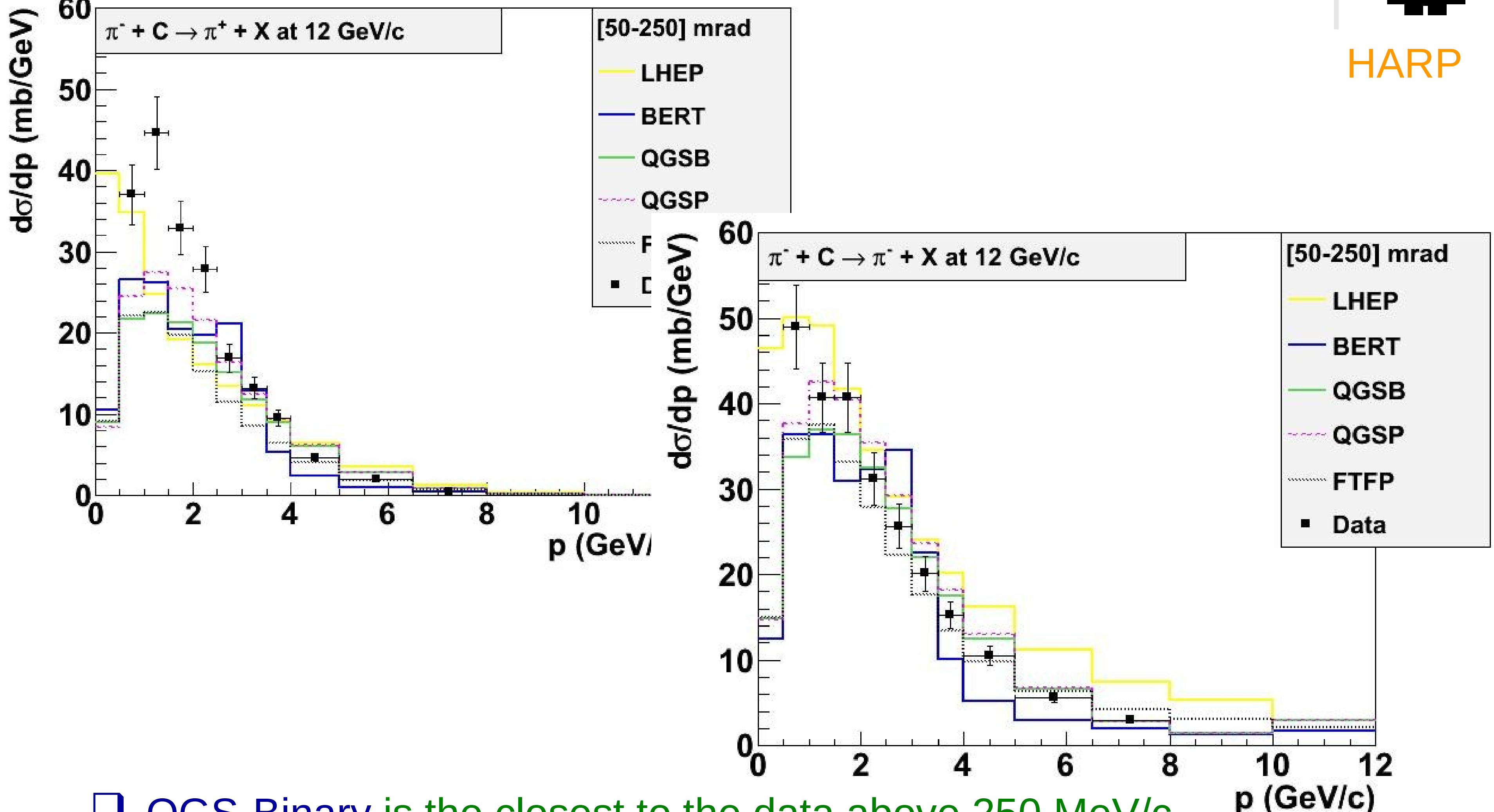
5.0 GeV/c



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

Forward Production of $\pi^{\pm}$ in π-C collisions

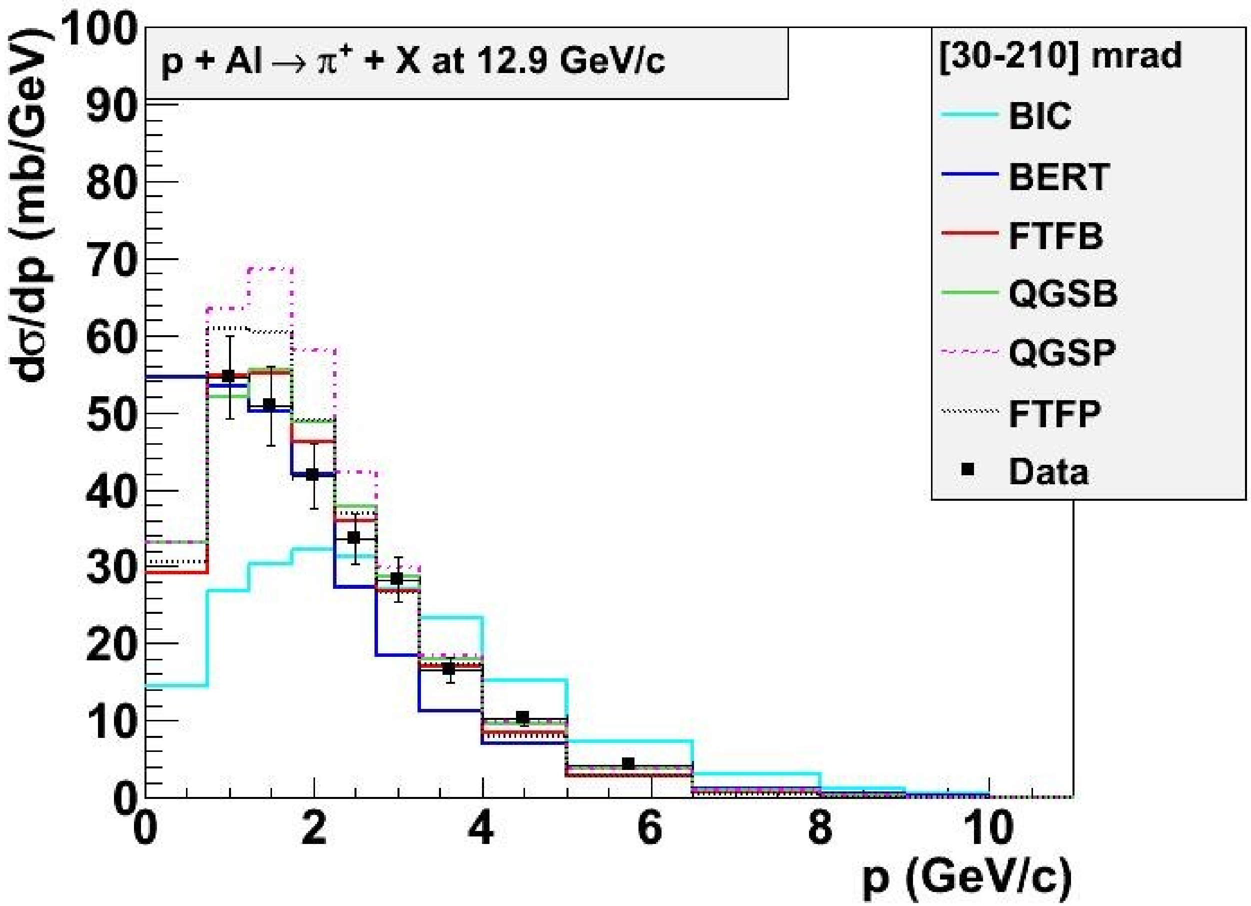
HARP



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

Forward Production of π^+ in p-Al collisions

HARP

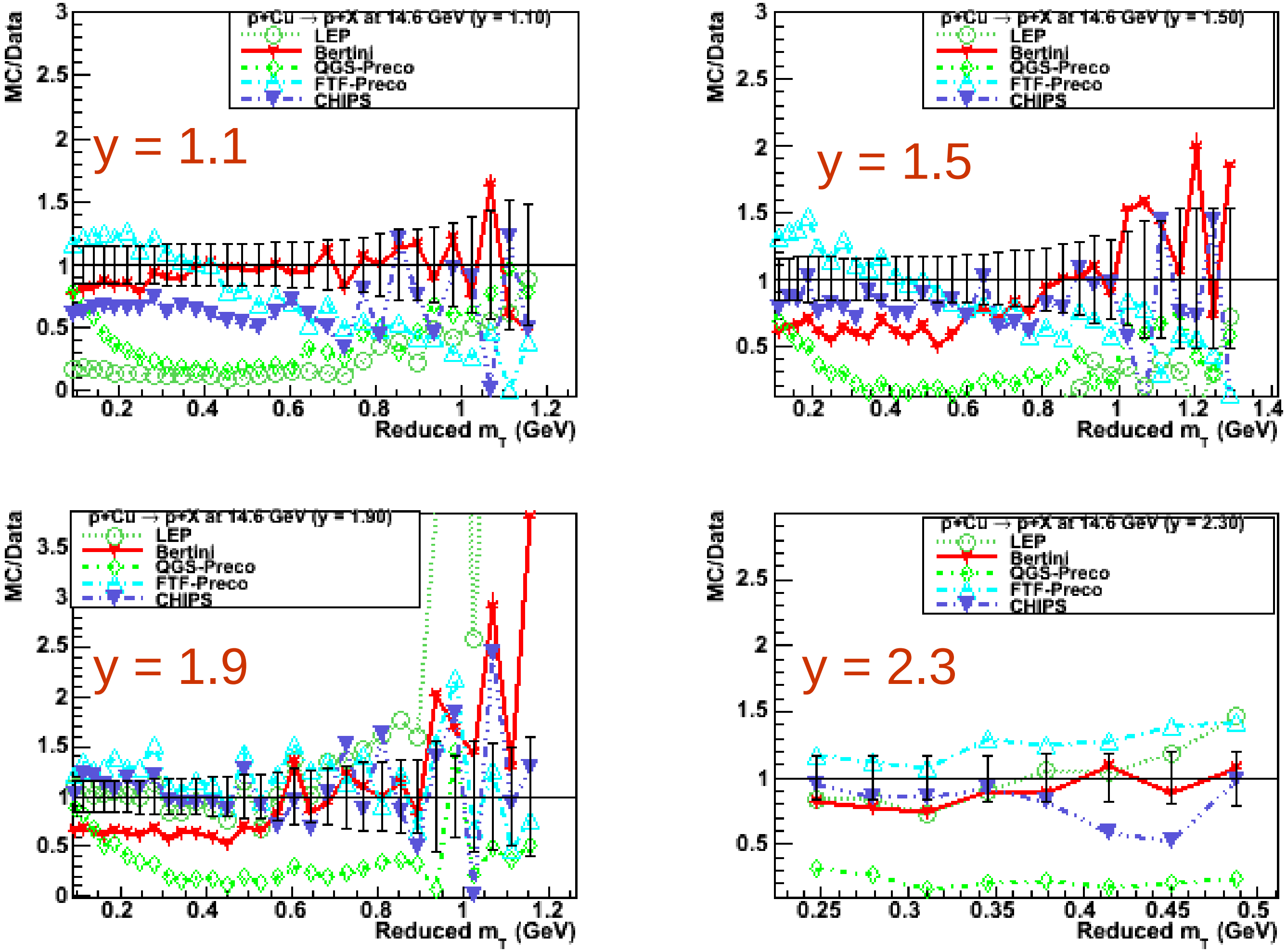


- QGS-Binary, Bertini, FTF-Preco give reasonable description of the data
- QGS/Preco predicts larger cross section while Binary provides a much broader spectrum

p + A → p + X at 14.6 GeV/c

BNL

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

Validation Framework

- Results from validation are of high interest to the user community:
  - how good is the agreement with experimental data
  - how is the modeling software evolving/improving
- BUT !!! Current access and exposure of results is rather "non-uniform"
- Develop a validation framework
  - improve the consistency of the tests
  - completion of tests on definite timescale
  - access to the results in the central location
  - share the tools and resources
  - share the comparison reference
  - track history as the hadronic models evolve
- The first versions for storage and publication of results have been implemented

Geant 4

First Implementation

- Validation results are stored in a database under a central server
- A web application is deployed to store and display results

Geant 4

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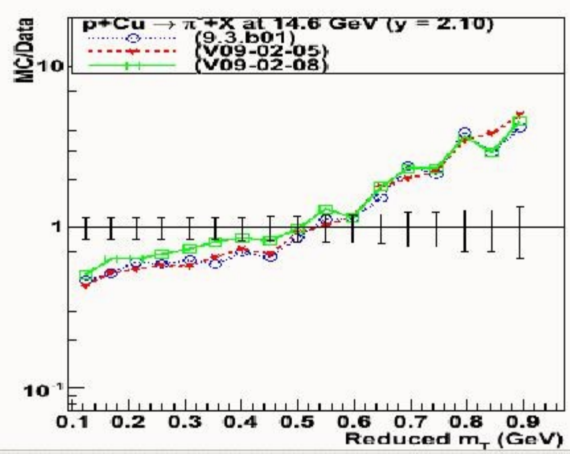
Name of the Test:	test47
Responsible:	Sunanda Banerjee, J. Yarba (Fermilab)
Description:	Intermediate energy validation is done by comparing Monte Carlo predictions vs experimental data.

Geant4 Version:	9.2.ref08
Observable:	Inclusive m_T spectrum
Reaction:	p+Cu->pi- +X

Test Conditions

Name	Description
Target	Copper
Particle	p
Energy	14.6 GeV/c
Bertini Cascade Version	9.3.b01
Bertini Cascade Version	V09-02-05
Bertini Cascade Version	V09-02-08
Rapidity	y=2.1
Score:	passed
Type:	expert

Results



List of HAD Tests

List of hadronic Tests

- Hadrcap
- Ndata
- Test30iaea
- test30
- test35
- test45
- test47
  - 9.2.ref08

Summary

- Geant4 provides a large number of models for hadronic physics each valid over a certain energy domain for a number of incident particles. These models are put together in a physics list to satisfy a given application domain
- Models are continuously improved over the years, with new features and new models being added
- 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 low-A nuclei, it under-estimates production of proton/neutron in the backward hemisphere
  - Improved version of FTF model gives good overall 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
- The FTFP_BERT physics list based on FTF and Bertini is currently being validated by LHC experiments and show promising results.
- A validation framework is being developed to keep track of results from all the comparisons