Toward Quantitative Answers for PAC

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Fermilab

MIPP Upgrade Collaboration Meeting

Fermilab,

April 28, 2007

OUTLINE

- Hadron-nucleus interaction and cascade simulation.
- Experimental data on inclusive particle production.
- Hadronic Shower Code Inter-Comparison and Verification.
- Proposal for quantifying MIPP data utility

See AIP CONFERENCE PROCEEDINGS 896. HADRONIC SHOWER SIMULATION WORKSHOP

Simplified cascade model

$P(S,E_0,x)$ - probability to obtain signal S due to interaction particle with energy E_0 with block of matter (thickness x)

$$P(S,E_0,x) = \int_0^{E_0} dE\, f_c(E_0,E,x) P_c(S,E_0,E,x) e^{-\Sigma_d x} + \int_0^x dx_0 \Sigma_d e^{-\Sigma_d x_0}$$

$$\int_0^{E_0} dE\, f_c(E_0,E,x_0) \sum_{n=1}^{n_{max}} \int \prod_{i=1}^{n} d\varepsilon_i W(E,n,\varepsilon_1,\ldots,\varepsilon_n) \int dS_0 \left[\prod_{i=1}^{n} dS_i P(S_i,\varepsilon_i,x-x_0) \right]$$

$$P_c(S_0,E_0,E,x_0)\delta(S-\sum_{i=0}^{n} S_i),$$

where $f_c(E_0,E,x)$ - probability to lose energy $E_0 - E$ on length x in "continuous" collisions, $P_c(S,E_0,E,x)$ - probability to get signal S in such collisions.

$W(E,n,\varepsilon_1,\ldots,\varepsilon_n)$ - probability to create n particles with energies $\varepsilon_1,\ldots,\varepsilon_n$ in discrete interaction with primary energy E.

Moments of Additive Signal

By definition

$$\int_0^\infty dSP(S,E_0,x) = 1$$

$$\sum_{n=1}^{n_{max}} \int d\varepsilon_1 ... d\varepsilon_n W(E,n,\varepsilon,\varepsilon_2,...,\varepsilon_n) = 1$$

Average signal of cascade - $\bar{S}(E_0,x) = \int_0^\infty dSSP(S,E_0,x)$

$$\bar{S}(E_0,x) = \int_0^{E_0} dE f_c(E_0,E,x)\bar{S}_c(E_0,E,x)e^{-\Sigma_d x} + \int_0^x dx_0 \Sigma_d e^{-\Sigma_d x_0} \int_0^{E_0} dE f_c(E_0,E,x_0)$$

$$\{\bar{S}_c(E_0,E,x_0) + \int_0^E d\varepsilon H^{(1)}(E,\varepsilon)\bar{S}(\varepsilon,x-x_0)\},$$

where

$$\bar{S}_c(E_0,E,x) = \int_0^\infty dSSP_c(S,E_0,E,x)$$

$H^{(1)}(E,\varepsilon) = \sum_{n=1}^{n_{max}} n \int d\varepsilon_2 ... d\varepsilon_n W(E,n,\varepsilon,\varepsilon_2,...,\varepsilon_n)$ - one-particle inclusive spectra.

Moments of Additive Signal

Second moment of cascade signal

$$\bar{S^2}(E_0,x) = \int_0^\infty dS S^2 P(S,E_0,x).$$

$$\bar{S^2}(E_0,x) = \int_0^{E_0} dE f_c(E_0,E,x)\bar{S_c^2}(E_0,E,x)e^{-\Sigma_d x} + \int_0^x dx_0 \Sigma_d e^{-\Sigma_d x_0}$$

$$\int_0^{E_0} dE f_c(E_0,E,x_0)\{\bar{S_c^2}(E_0,E,x_0) + \bar{S}_c(E_0,E,x_0)\int_0^E d\varepsilon H^{(1)}(E,\varepsilon)\bar{S}(\varepsilon,x-x_0)\}$$

$$+ \int_0^E d\varepsilon_1 d\varepsilon_2 H^{(2)}(E,\varepsilon_1,\varepsilon_2)\bar{S}(\varepsilon_1,x-x_0)\bar{S}(\varepsilon_2,x-x_0)\},$$

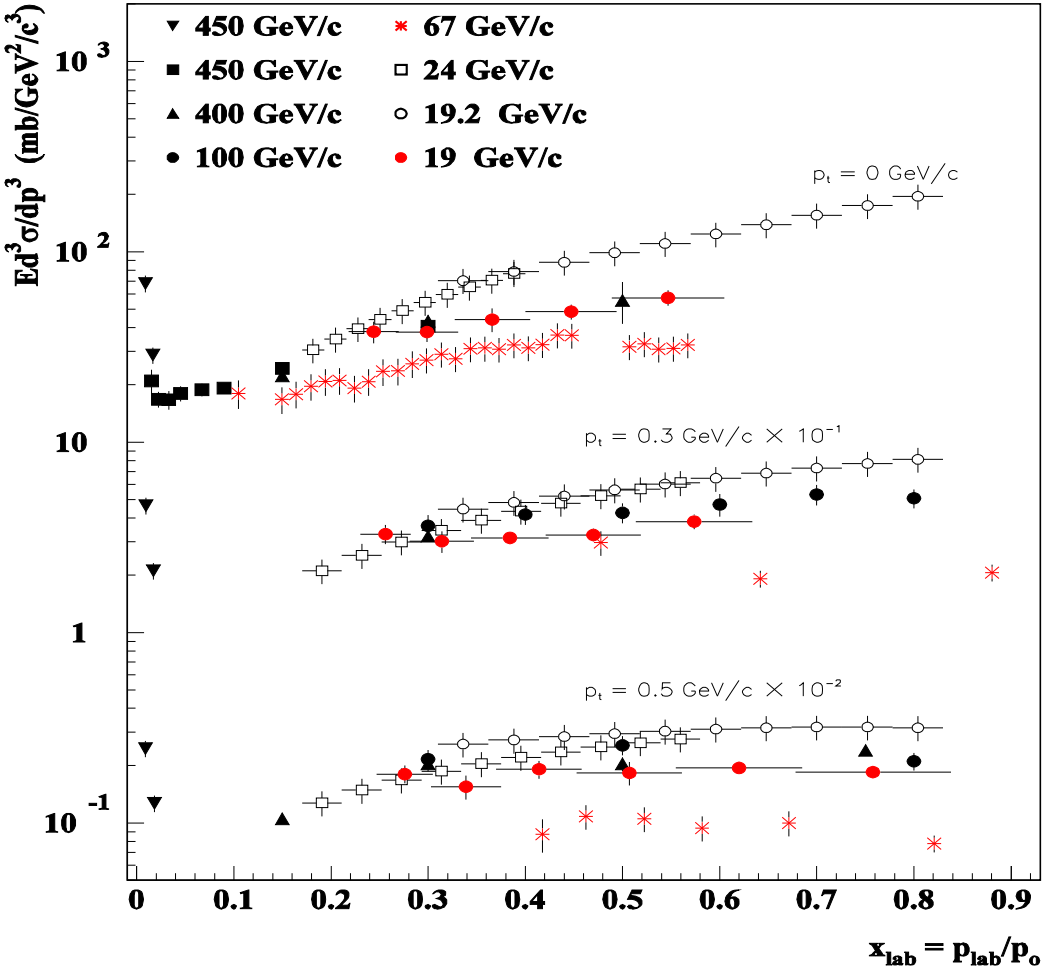
where

$$\bar{S_c^2}(E_0,E,x) = \int_0^\infty dS S^2 P_c(S,E_0,E,x)$$

$H^{(2)}(E,\varepsilon_1,\varepsilon_2) = \sum_{n=2}^{n_{max}} n(n-1)\int d\varepsilon_3 ... d\varepsilon_n W(E,n,\varepsilon_1,\varepsilon_2,...,\varepsilon_n)$ - two-particle inclusive spectra.

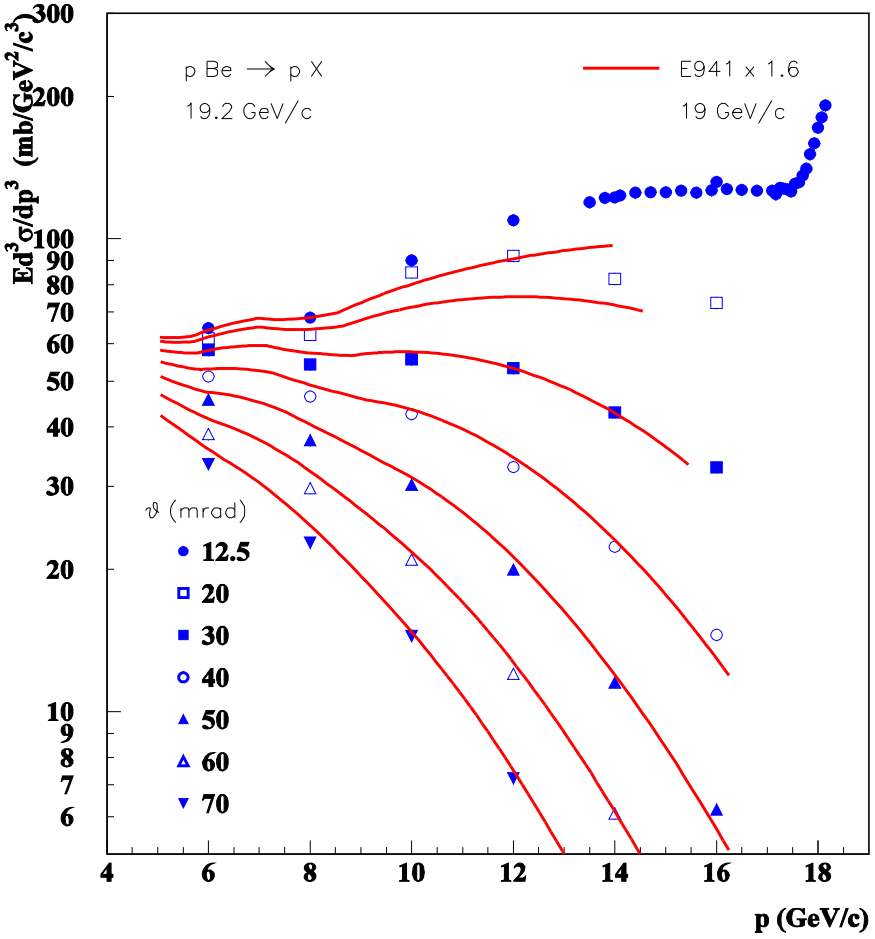
Data on proton production

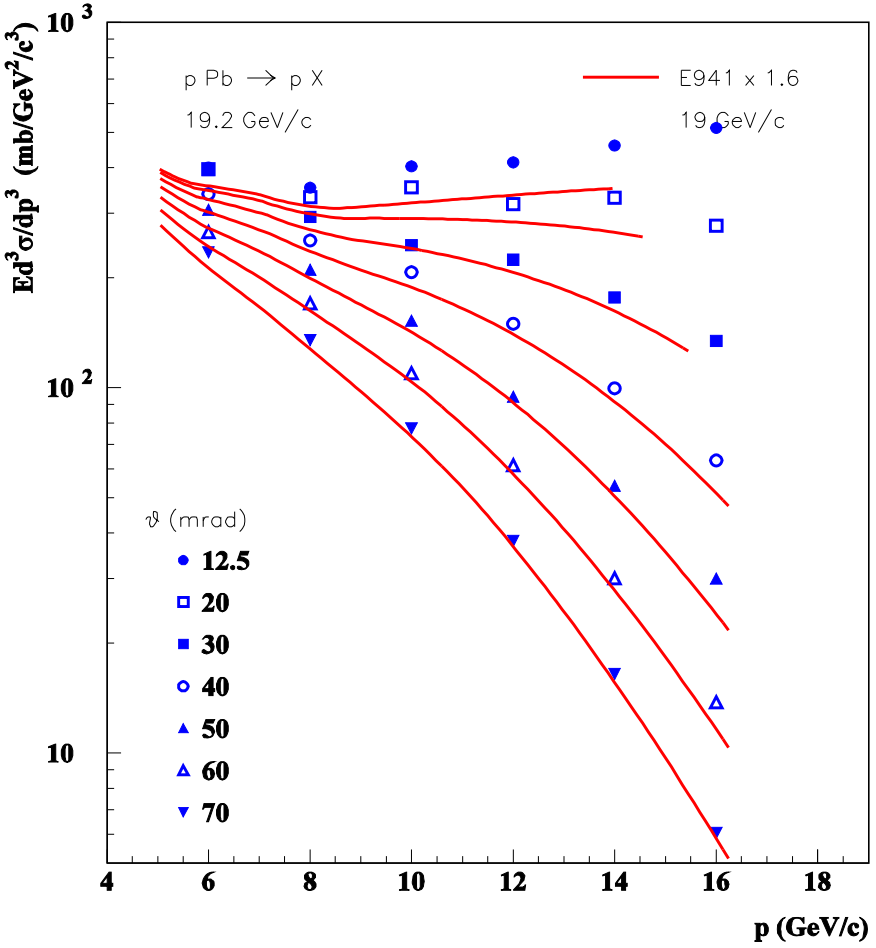
- 450 GeV/c NA44 CERN
- 450 GeV/c SPY CERN
- 400 GeV/c Atherton et al CERN
- 100 GeV/c Barton et al FNAL
- 67 GeV/c Bozhko et al IHEP
- 24 GeV/c Eichten et al CERN
- 19.2 GeV/c Allaby et al CERN
- 19 GeV/c E941 BNL (2001 !!!)



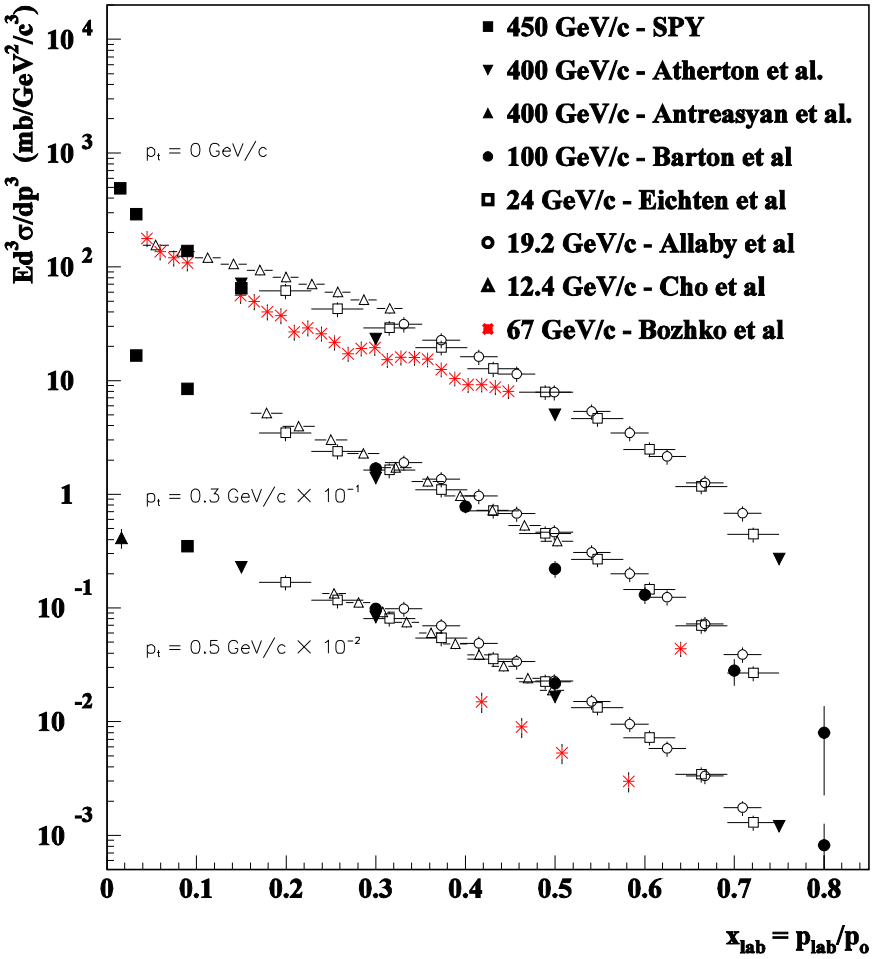
Proton production in proton beryllium interaction

Allaby et al (1970) vs BNL E941 (2001) x 1.6

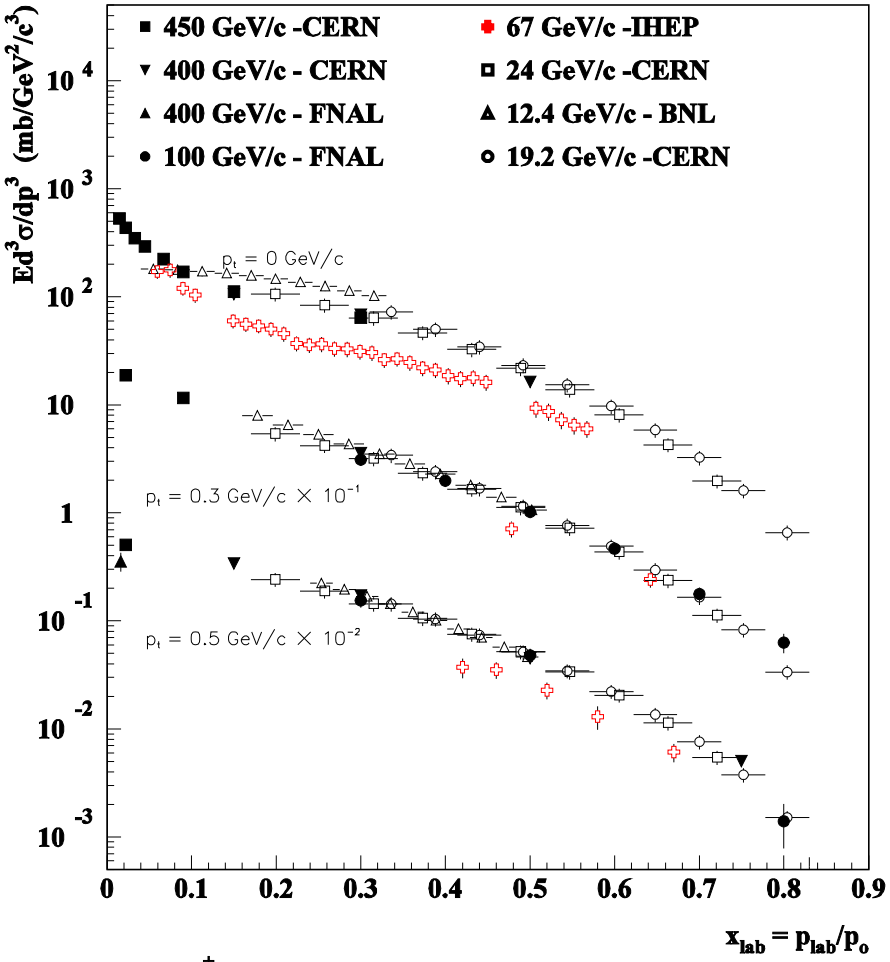




Charged pion production

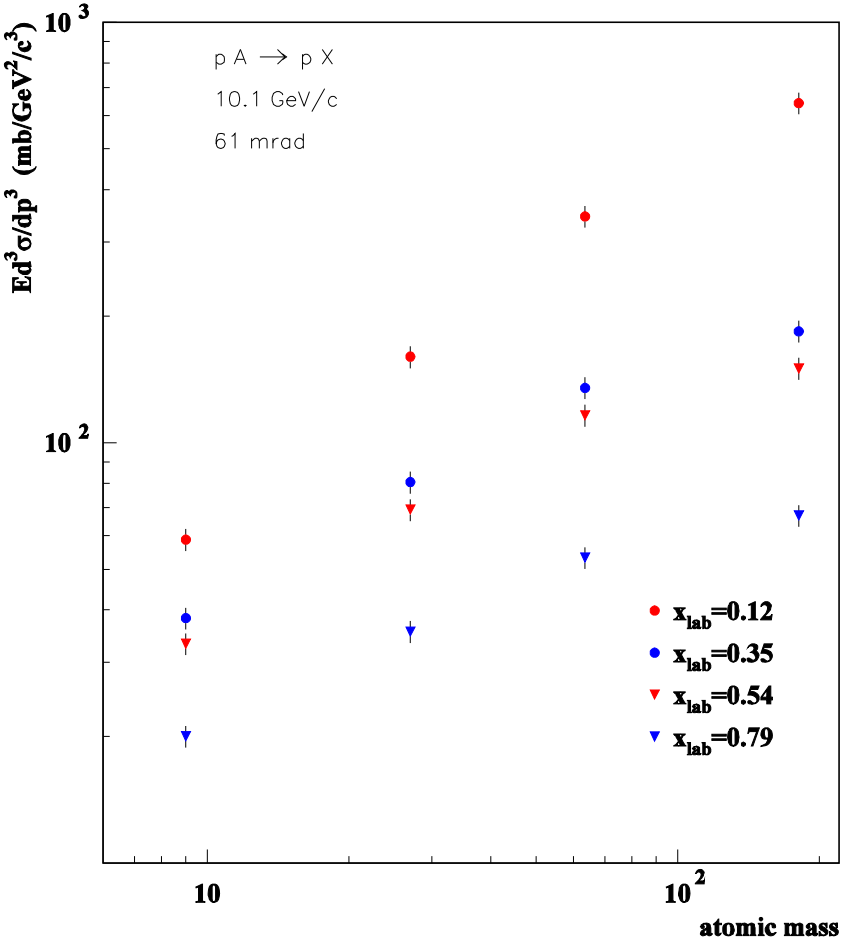


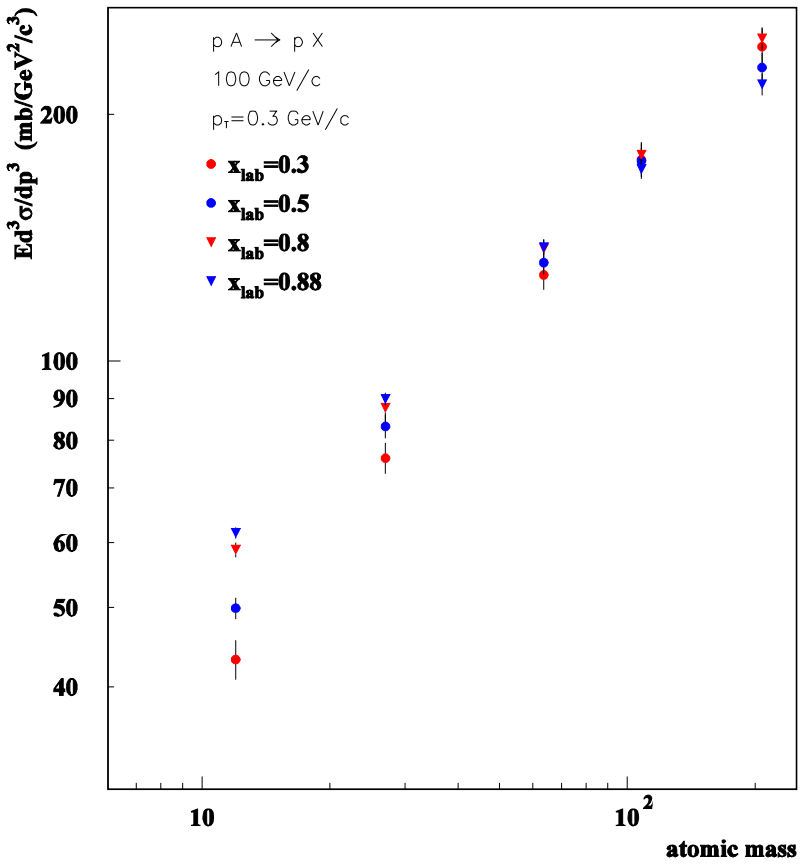
π^- production in proton beryllium interaction



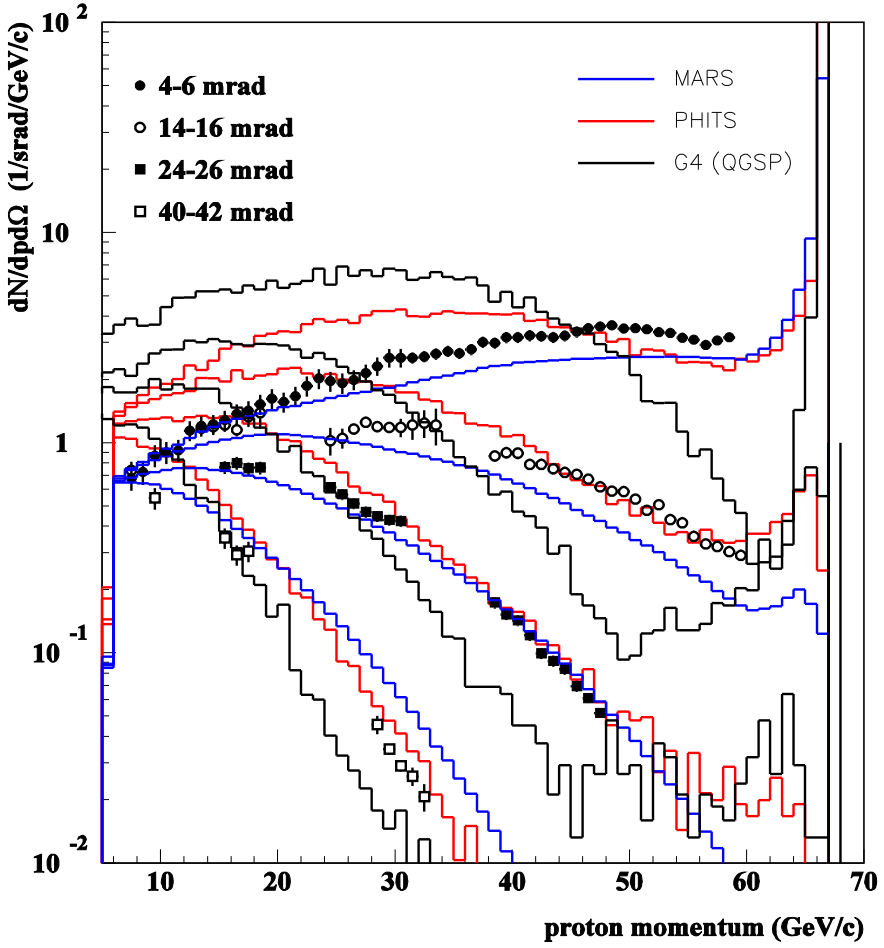
π^+ production in proton beryllium interaction

Nuclear effects: A physics?

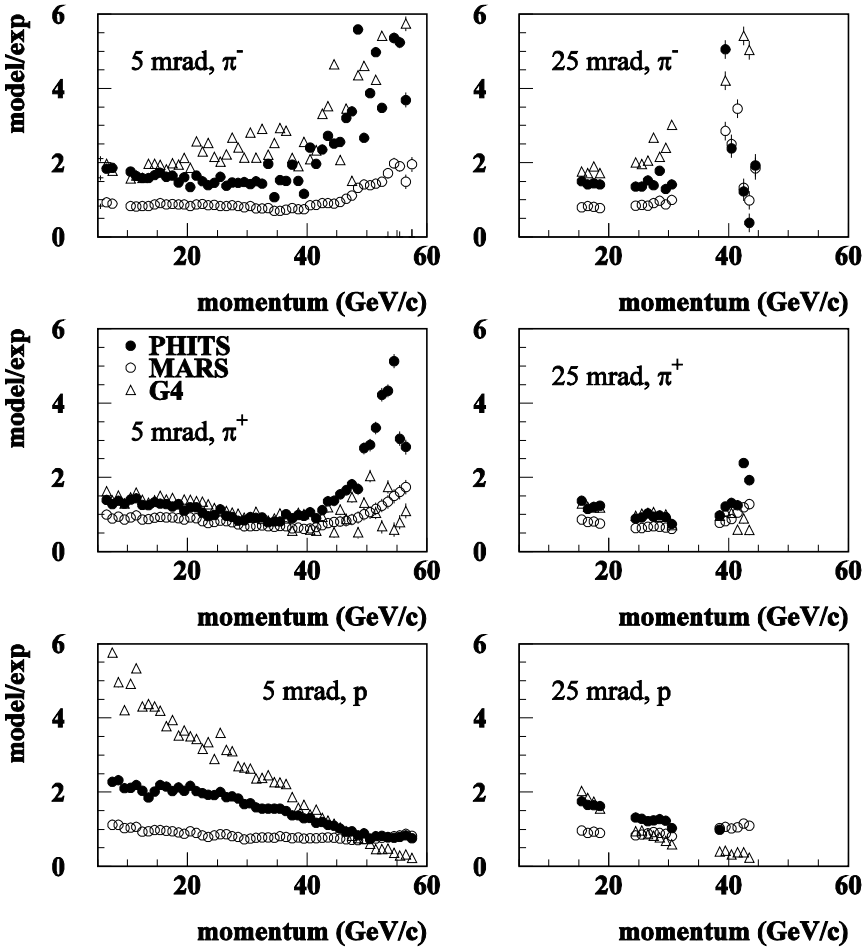




IHEP thick target data v.s. models

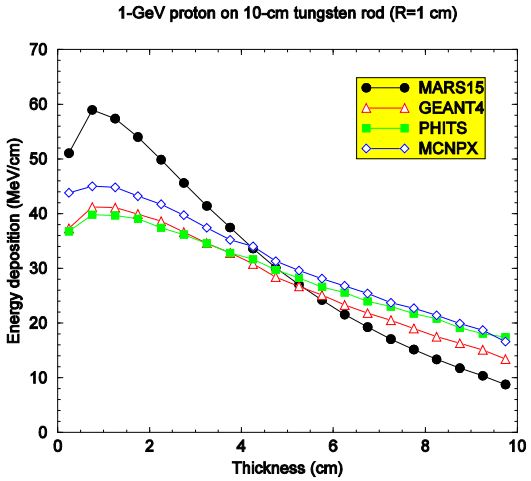


Proton production from thick aluminum target at 67 GeV/c

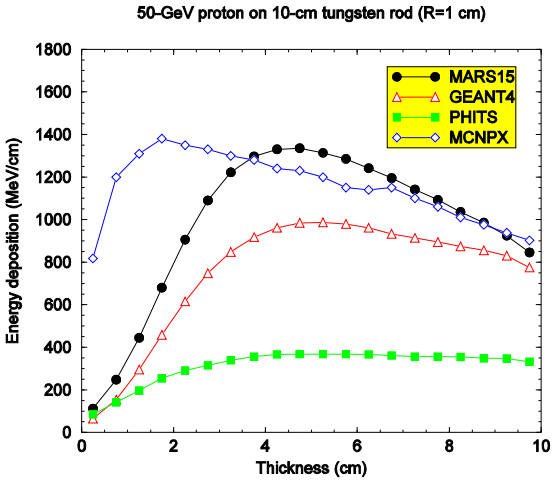


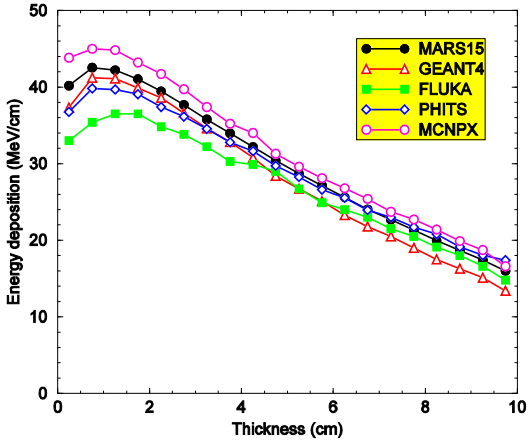
Ratio of calculated and measured cross sections

Energy deposition in cylindrical tungsten target

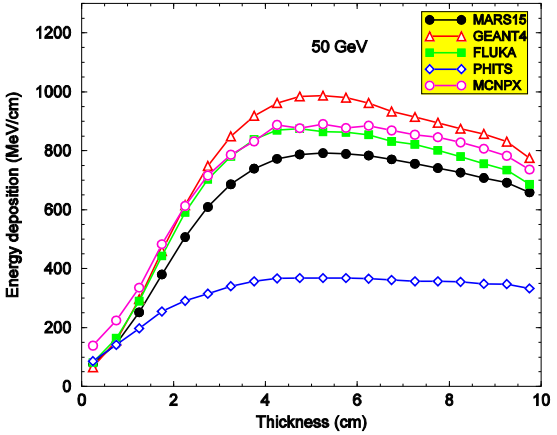


Before workshop





After workshop



Raja proposal

Proposal for quantifying MIPP data utility

Thin target simulations to be compared between various generators used in shower simulations in MARS, Geant4, FLUKA, PHITS and MCNPX.

Beam Species – Use 6 beam species ($p^{\pm}, K^{\pm}, p^{\pm}$)

Beam Momenta – 1, 3, 5, 10, 20, 40, 80 100 GeV/c (This does resonance region and continuum)

Target nuclei – H2, D2, Be, C, N2, Fe, Si, U (other suggestions welcome)

As a function of beam momentum and target type generate for each model the following distributions:

1) Elastic and Inelastic cross section

2) Multiplicity distribution (ds/dn) for inelastic events.

3) Inclusive cross sections ds/dx, ds/dpT for final state particles ($p^{\pm}, K^{\pm}, p^{\pm}$) as a function of total multiplicity. This will show correlations wrt multiplicity.

4) Two particle correlations (rapidity correlations). Will specify this better shortly.

5) Neutron inclusive distributions from nuclear breakup.

We should set up a mechanism for generating these plots (in ROOT) in a semi-automatic fashion and provide ROOT macros for comparing various nuclei and models. Plots from each reaction can be in a separate ROOT folder.

A select number of these plots can be included in the white paper.

Even if the models agree with each other, they may all disagree with data. However this exercise will examine model variance in some detail.

Current status

- MCNPX (Laurie Waters), PHITS (Matsuda Norihiro) agreed to collaborate with Geant4 and MARS15 in this project. No respond from Fluka yet. Some technical problems still open.

- Exclusive generator is needed to simulate distributions (2-4). MARS15 are using inclusive generator in most cases. Exclusive generator based on recent LAQGSM model should be available soon.

- Should we use total multiplicity or charged particle multiplicity or charged particles multiplicity in some momentum range:

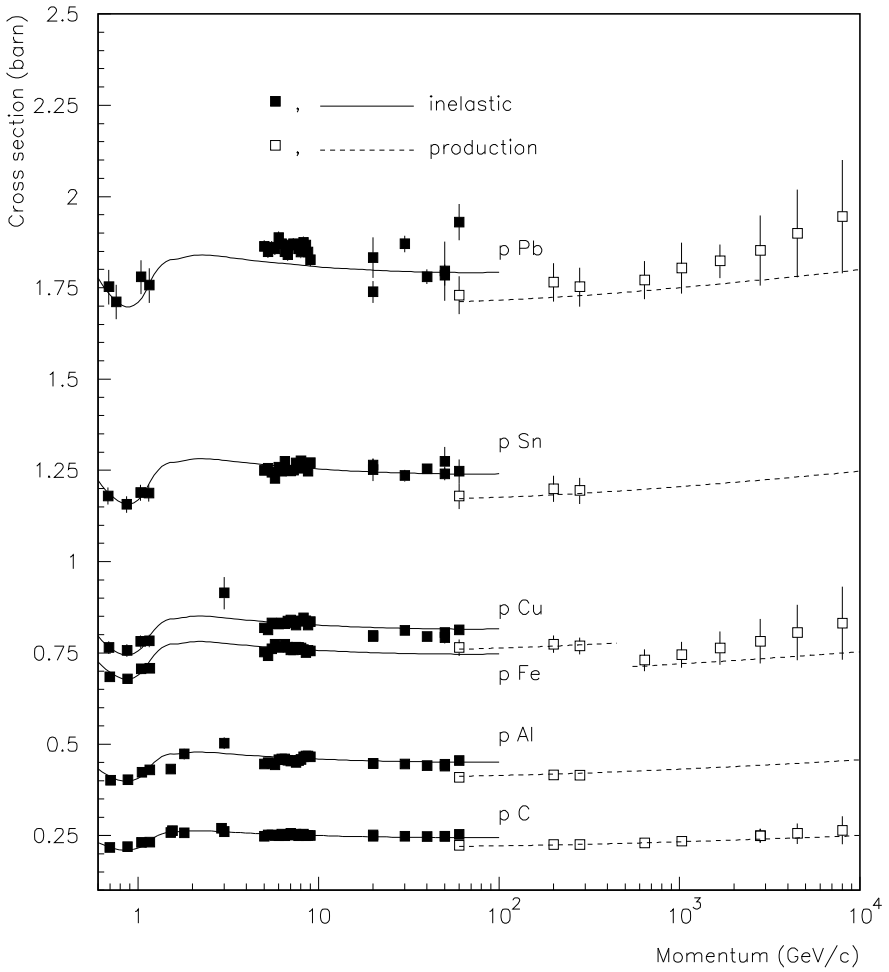
  1) Secondary protons and neutrons with momentum < 1 GeV/c are produced in "elastic" intra-nuclear cascade and breakup

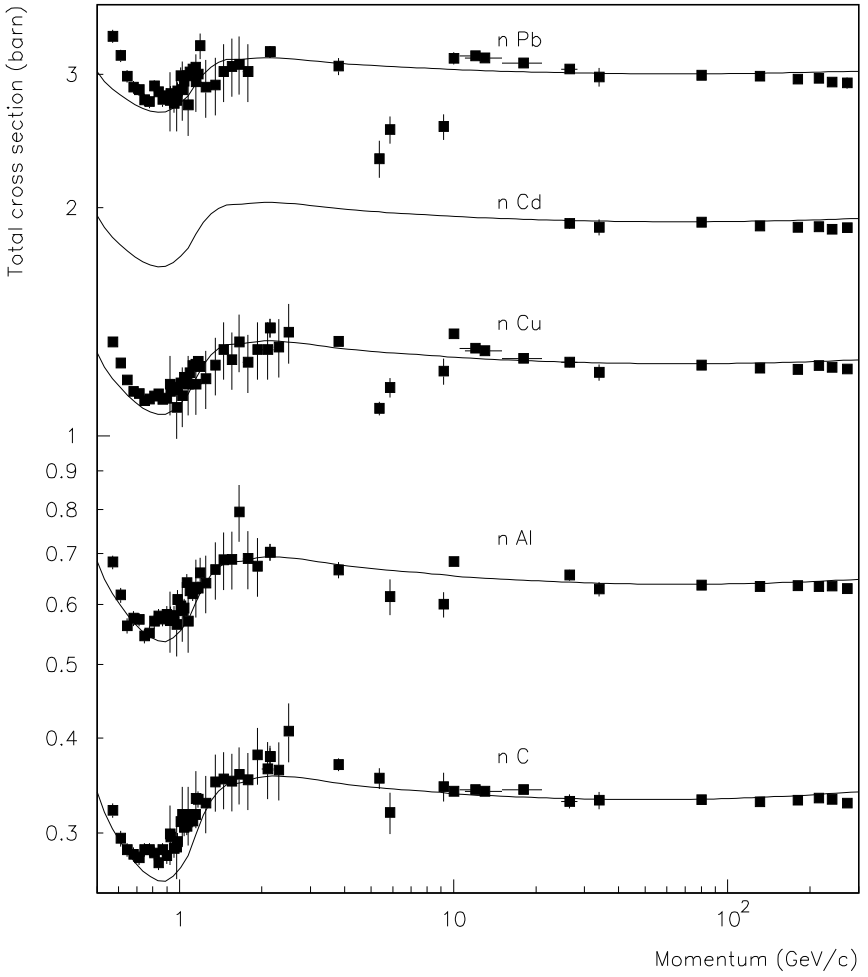
  2) Secondary mesons and other baryons are created in few high-energy interactions

  3) Dependence of one- and two-particle inclusive distributions on TOTAL multiplicity could be inconclusive

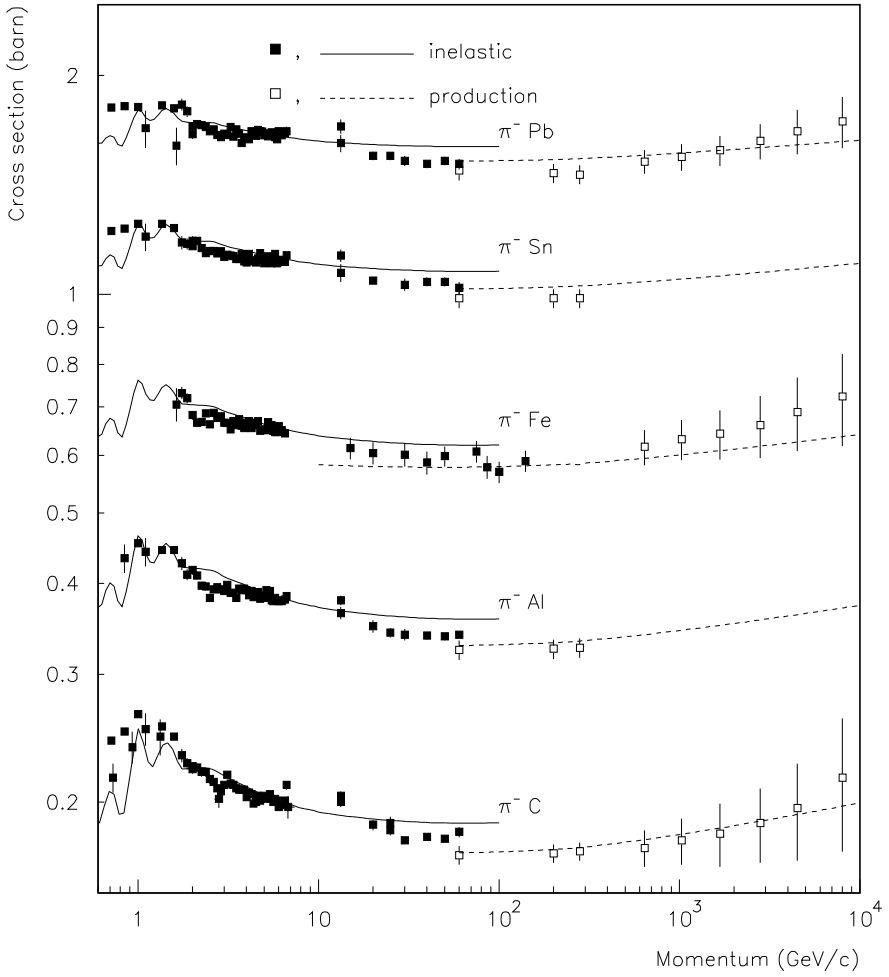
- Before MIPP data 'll appear we can use above procedure for model comparisons with existing experimental data on cross sections, two particle correlations functions, inclusive spectra of neutrons/protons from nuclear breakup

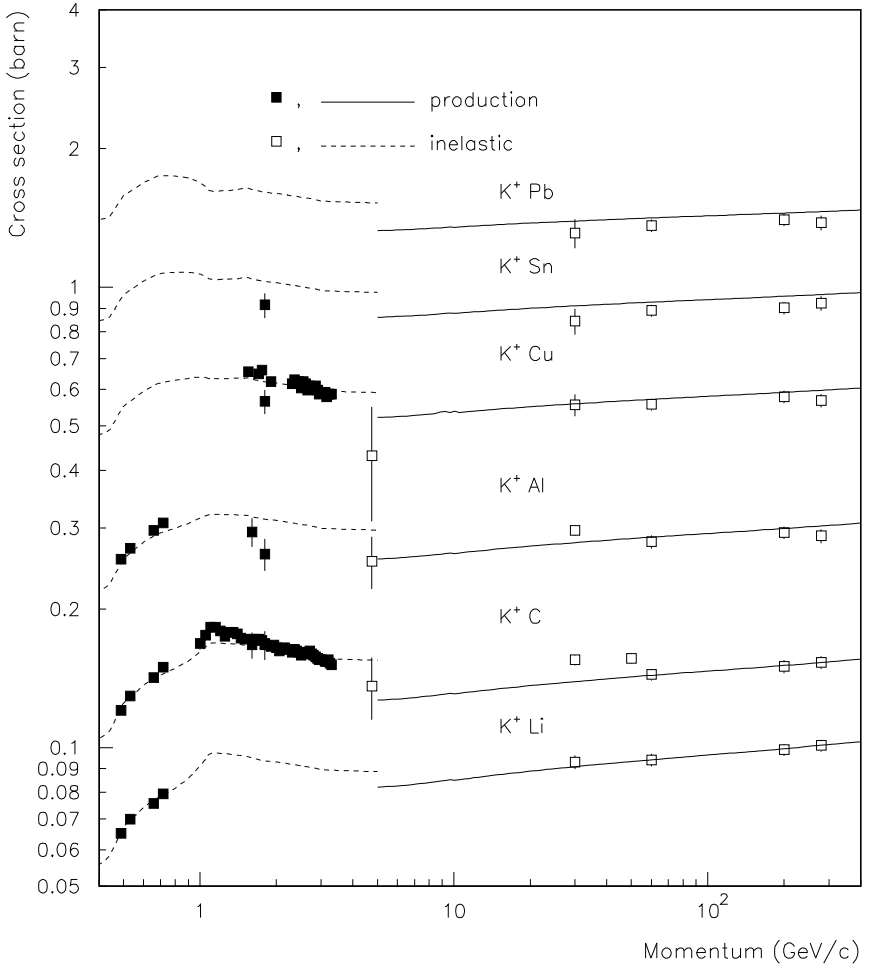
Total and inelstic cross sections



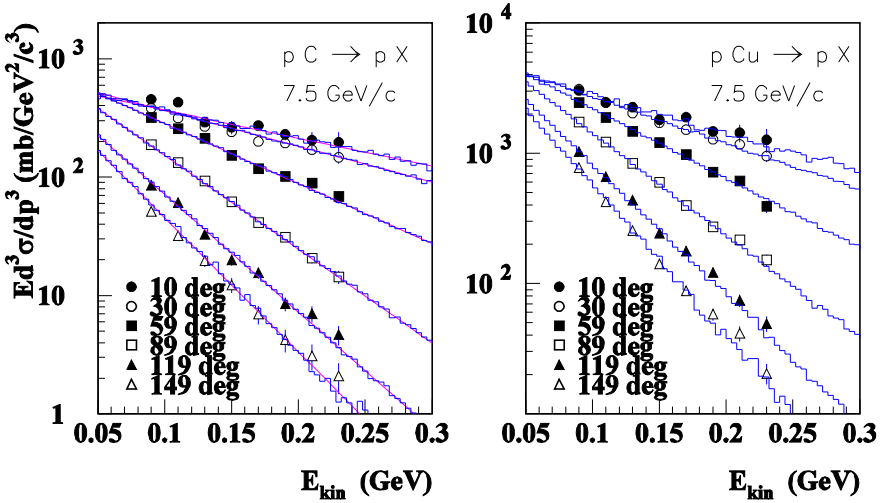


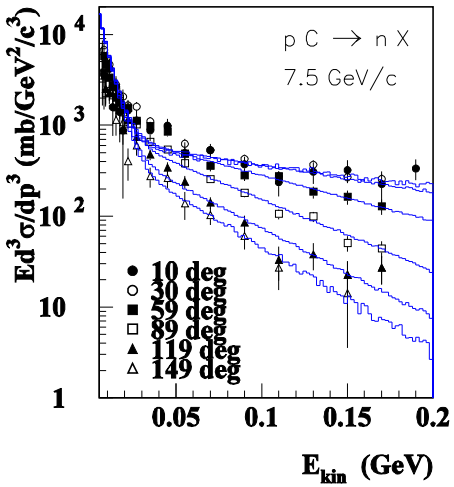
Hadron-nucleus inelastic cross sections

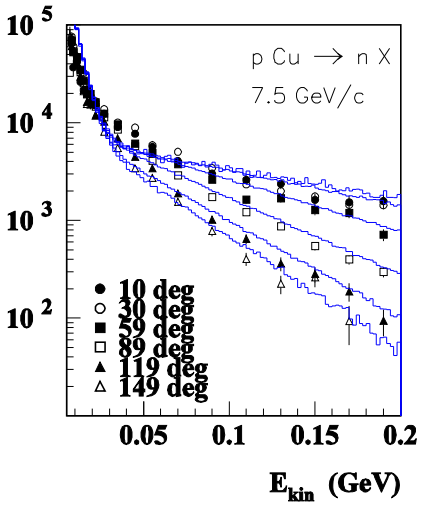


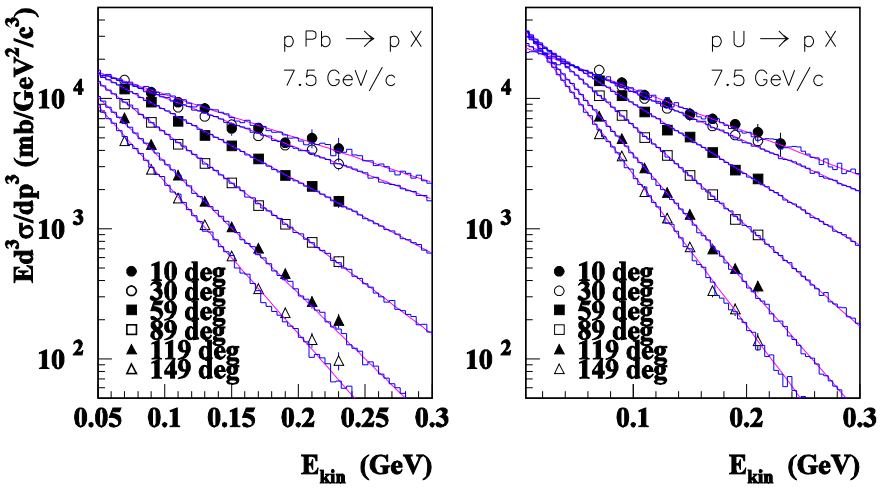


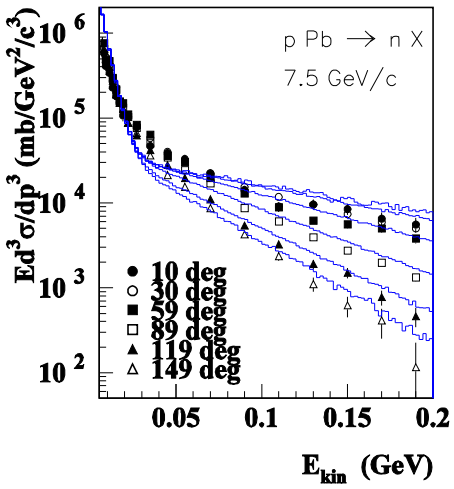
Low energy protons & neutrons spectra

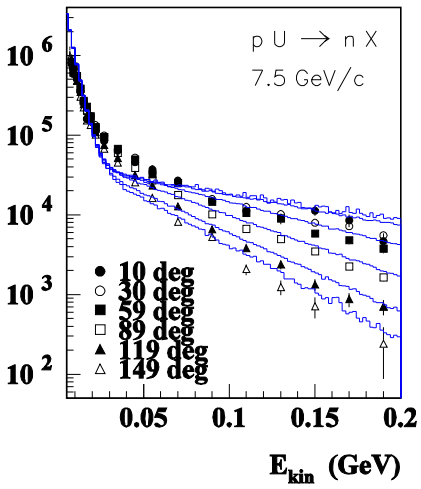












Conclusions

- *Evaluated set of experimental data is needed for verification of general purpose shower codes. New precise data are important*

  to resolve open problems with cross section normalization and complicated A-dependence at energies < 100 GeV.

- *All code development groups perform their code verifications, but recent hadronic shower code inter-comparison help to find serious problems. Systematic code inter-comparison could be useful to increase predictive power and reliability of shower simulations.*

- *Development of semi-automatic procedure for generation of some important distributions using different codes can be useful:*

  - *to simplify code inter-comparison;*
  - *to quantify connection between systematic errors in description of microscopic hA collisions and systematic errors in global shower simulations;*
  - *to find out where new measurement are most important;*