Hadronization in Cold Nuclear Matter

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Model

Pythia, GiBUU, prehadronic FSI

Results

EMC@100-280
Hermes@27
CLAS@5
HARP, NA61/Shine

HIC for FAIR
Helmholtz International Center
Institut für Theoretische Physik
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

PSHP2010
Frascati, Oct 18-21, 2010

Observables, Experiments

- $$R^h(z_h,\dots) = \frac{\left.\frac{N_h(z_h,\dots)}{N_e(\dots)}\right|_A}{\left.\frac{N_h(z_h,\dots)}{N_e(\dots)}\right|_D}$$
- $$\Delta p_T^2 = \langle p_T^2\rangle_A - \langle p_T^2\rangle_D$$

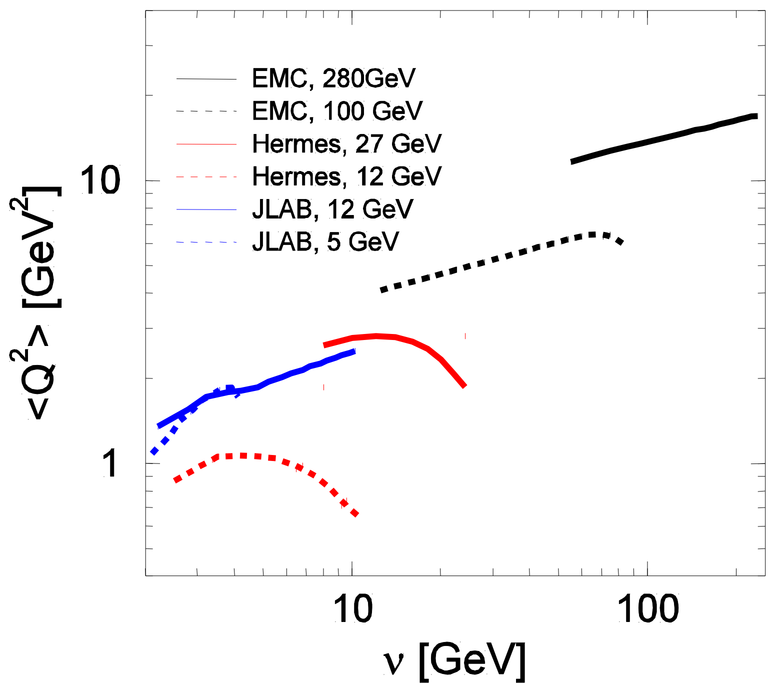
- hadronic: $z_h = \frac{E_h}{\nu}\ ,\quad p_T\ ,\cdots$
- photonic: $\nu\,,\ Q^2\,,\ W\,,\ x_B\,,\dots$

- Experiments

  E_{lepton} =

  - EMC **100…280 GeV**
  - Hermes **27 GeV**
    12 GeV
  - CLAS 12 GeV (upgrade)
    5 GeV
  - EIC e.g. 3+30 GeV

…multiple combinations of targets

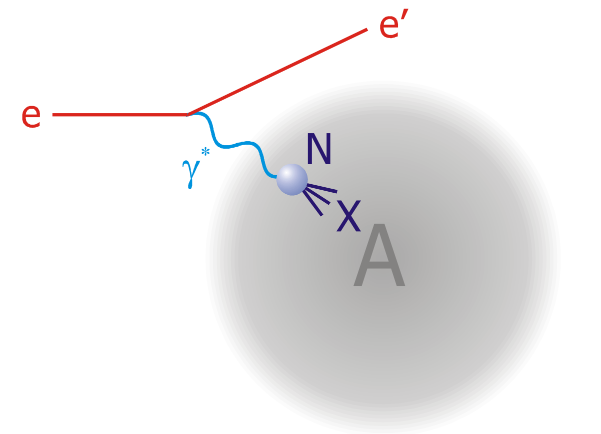


Model

- $\gamma^* N \rightarrow X$ using PYTHIA

  additional:
  - binding energies
  - Fermi motion
  - Pauli blocking
  - coherence length effects

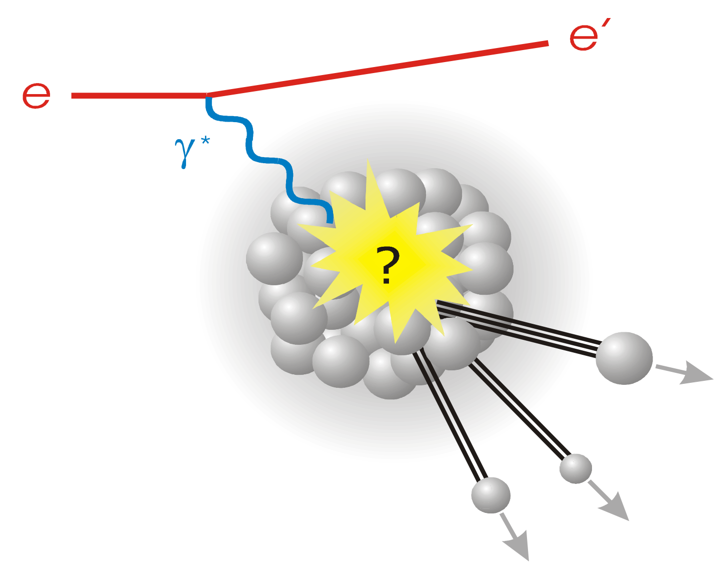
  extended for exclusive channels



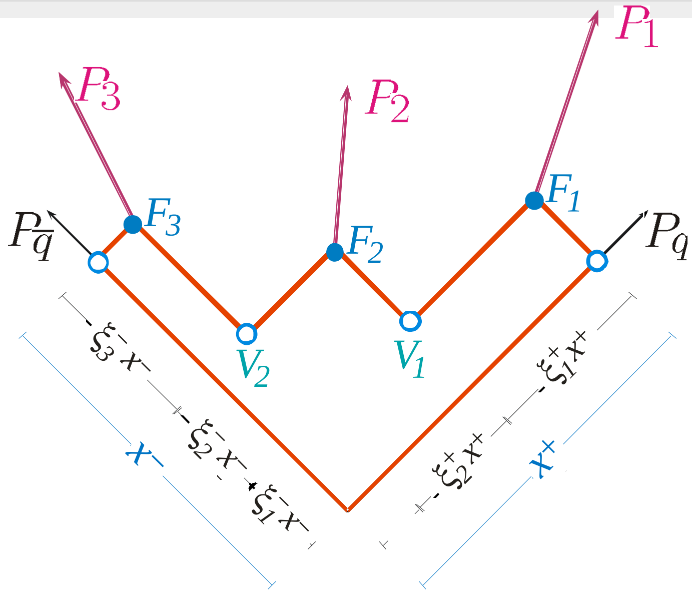
- propagation of final state X within GiBUU transport model

http://gibuu.physik.uni-giessen.de

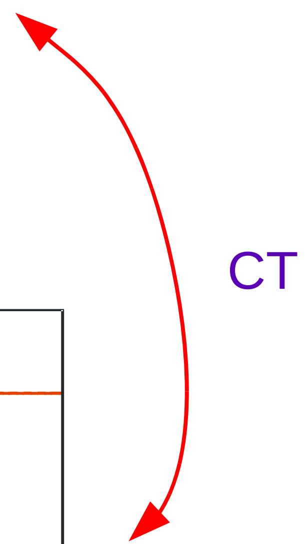
  - elastic/inelastic scatterings (coupled channels)
  - experimental acceptance



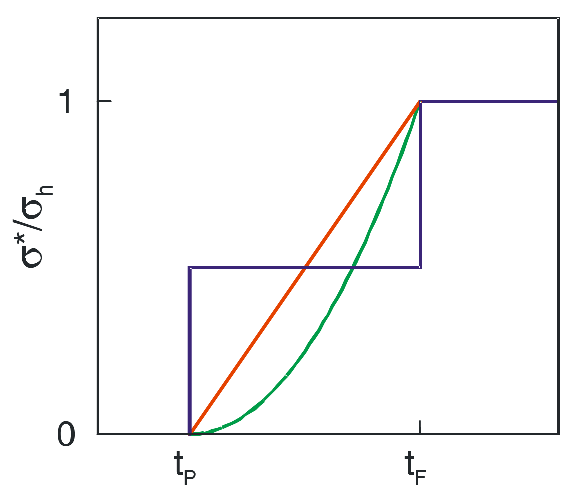
Model: Hadronization in String Model (Pythia/Jetset)

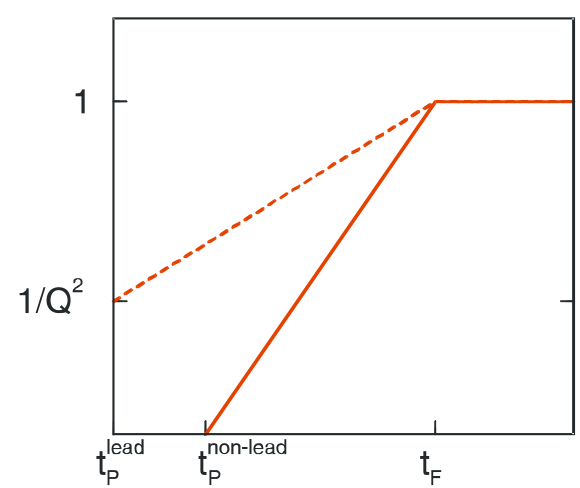


- 3 times/points per particle:
  - „Production 1“ *String-Breaking*
  - „Production 2“ *String-Breaking*
  - „Formation“ *Line Meeting*
- leading vs. non-leading



- XS evolution scenarios:





Model: Transport (GiBUU)

GiBUU: Gießen + Boltzmann-Uehling-Uhlenbeck

$$\frac{\mathrm{d}f^X}{\mathrm{d}t} = \frac{\partial f^X}{\partial t} + \frac{\partial H}{\partial \vec{p}}\frac{\partial f^X}{\partial \vec{r}} - \frac{\partial H}{\partial \vec{r}}\frac{\partial f^X}{\partial \vec{p}} = I_{\mathrm{coll}}(f^X, f^a, f^b, \cdots)$$

1 particle phase space densities

Full coupled channel

- Hamiltonian $H = H(f^X, f^a, f^b, \cdots)$

  hadronic mean fields + potentials

- Solved with „testparticle ansatz“

$$f^X = \sum_{i=1}^{n \times N^X} \delta(\vec{r} - \vec{r}_i)\delta(p - p_i)$$

local ensemble method

= local collisions

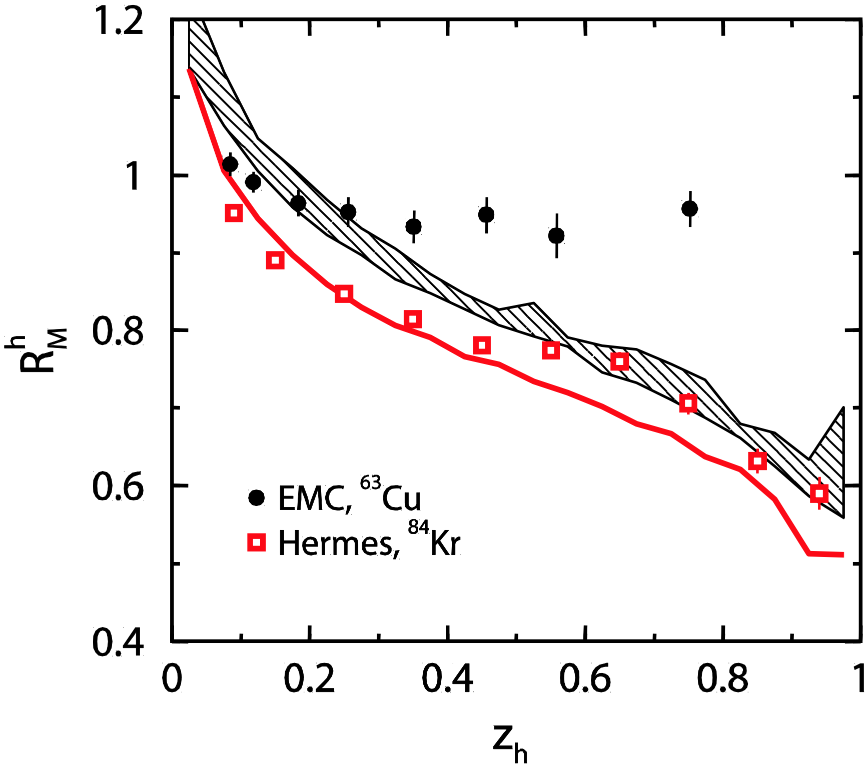
- 61 baryons, 21 mesons

Results: EMC & Hermes

- constant cross section

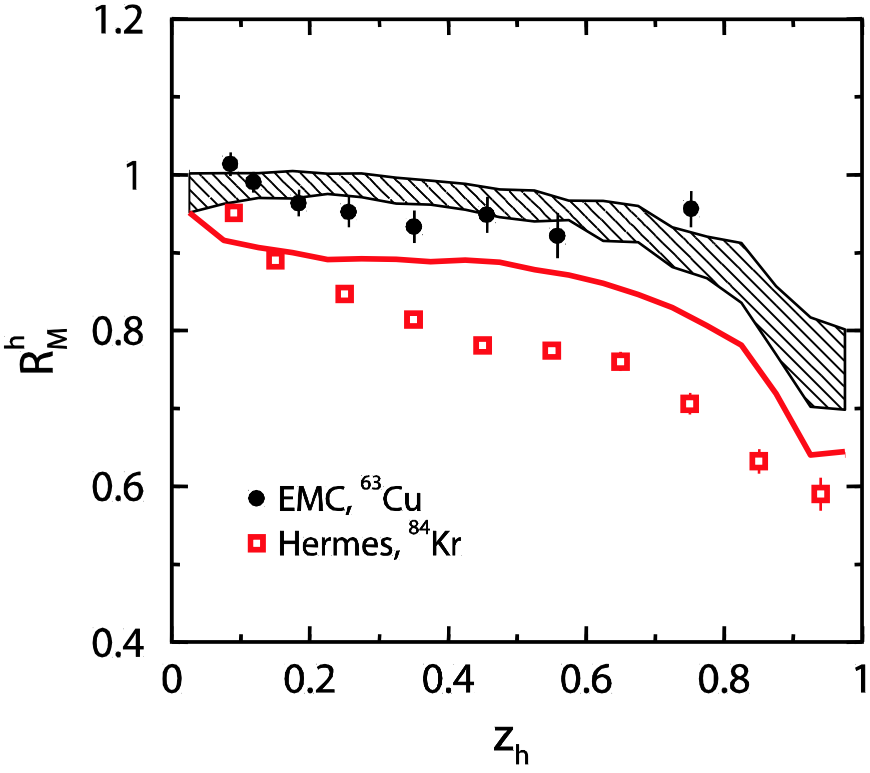
$$t = t_{\mathrm{P}} \cdots t_{\mathrm{F}} :$$

$$\sigma^* = 0.5\, \sigma_H$$



- quadratic increase

$$\sigma^* = \left(\frac{t - t_{\mathrm{P}}}{t_{\mathrm{F}} - t_{\mathrm{P}}} \right)^2 \sigma_H$$



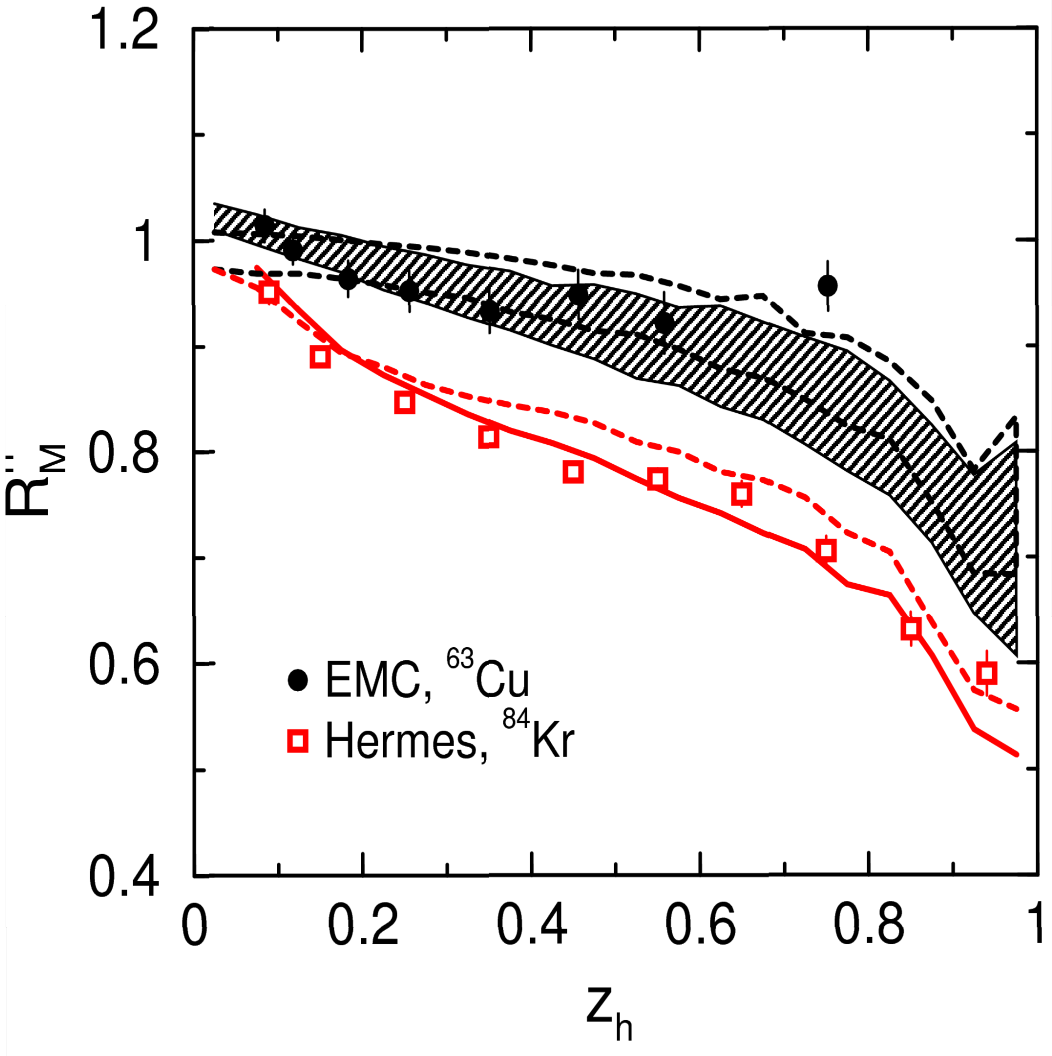
Results: EMC & Hermes

$$\frac{\sigma^*}{\sigma_H} = \frac{r_{\text{lead}}}{Q^2} + \left(1 - \frac{r_{\text{lead}}}{Q^2}\right)\left(\frac{t - t_{\text{P}}}{t_{\text{F}} - t_{\text{P}}}\right)$$

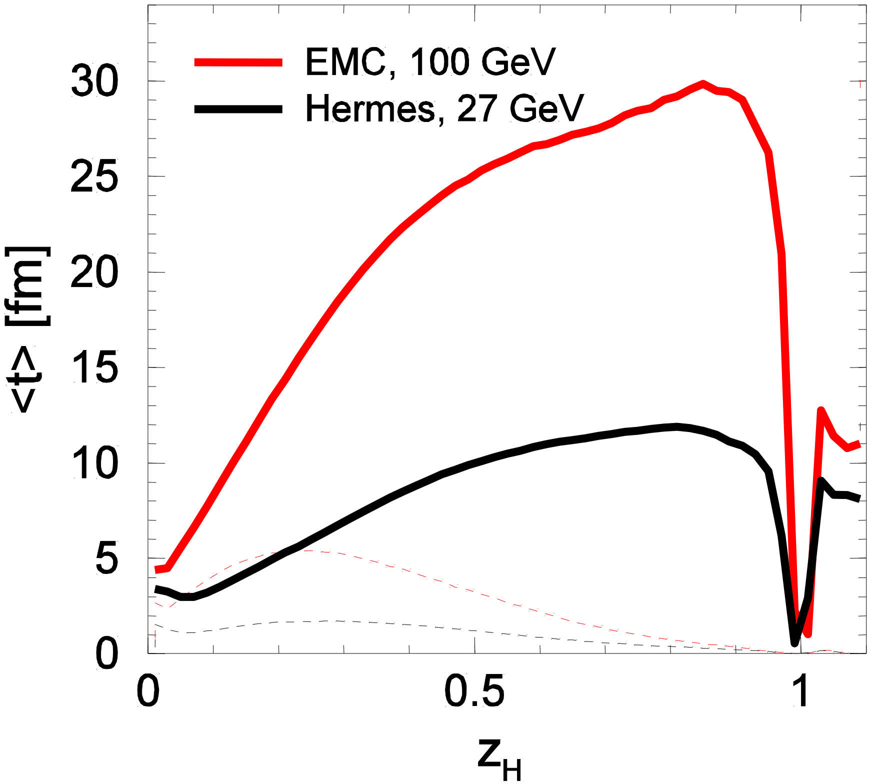
!

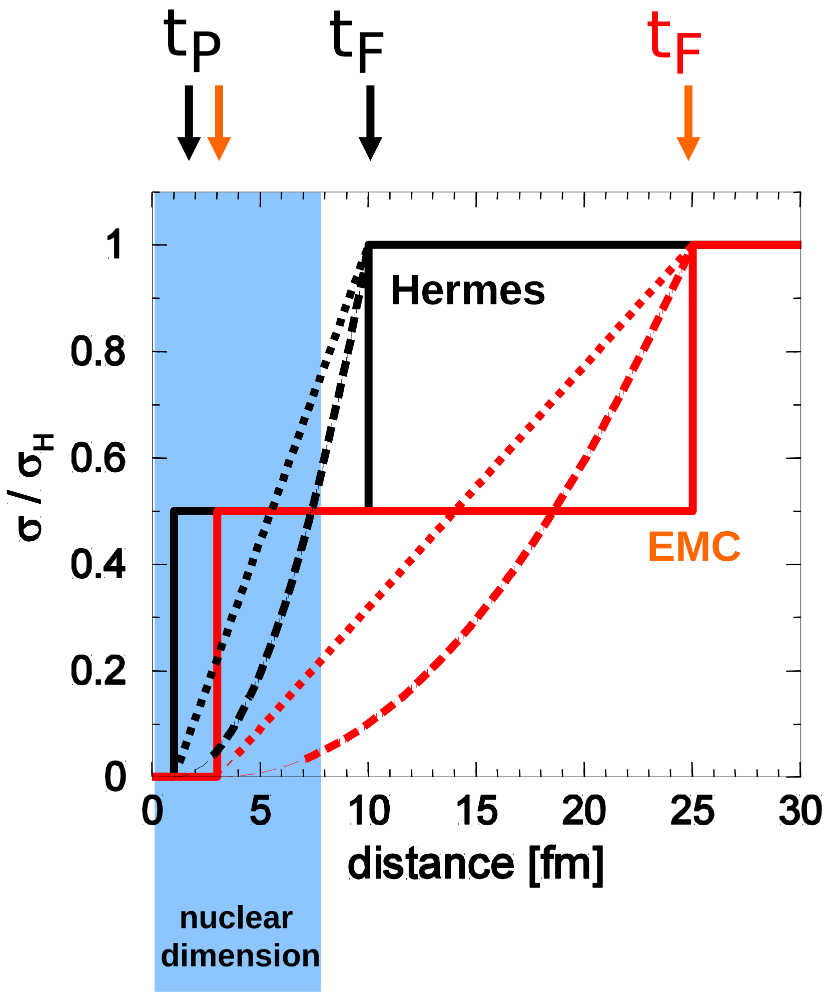
EMC@100...280 GeV
and
Hermes@27 GeV
described simultanously

pedestal value?
…small effect!



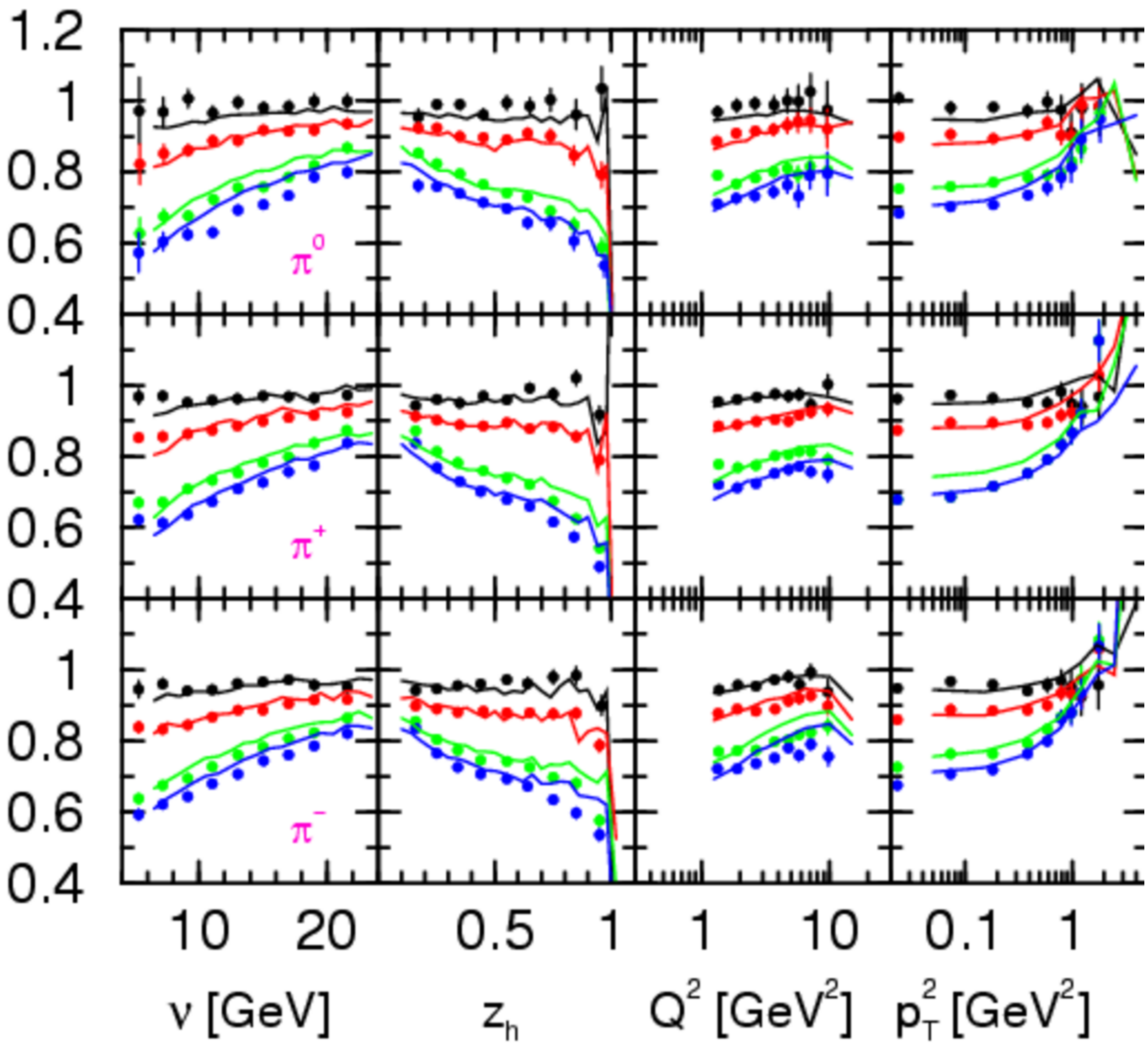
Times





here: averaged times
in code: individual times

Hermes@27: A.Airapetian et al., NPB780(2007)1



Pions

$^{2}d_{1}$

$^{4}He_{2}$

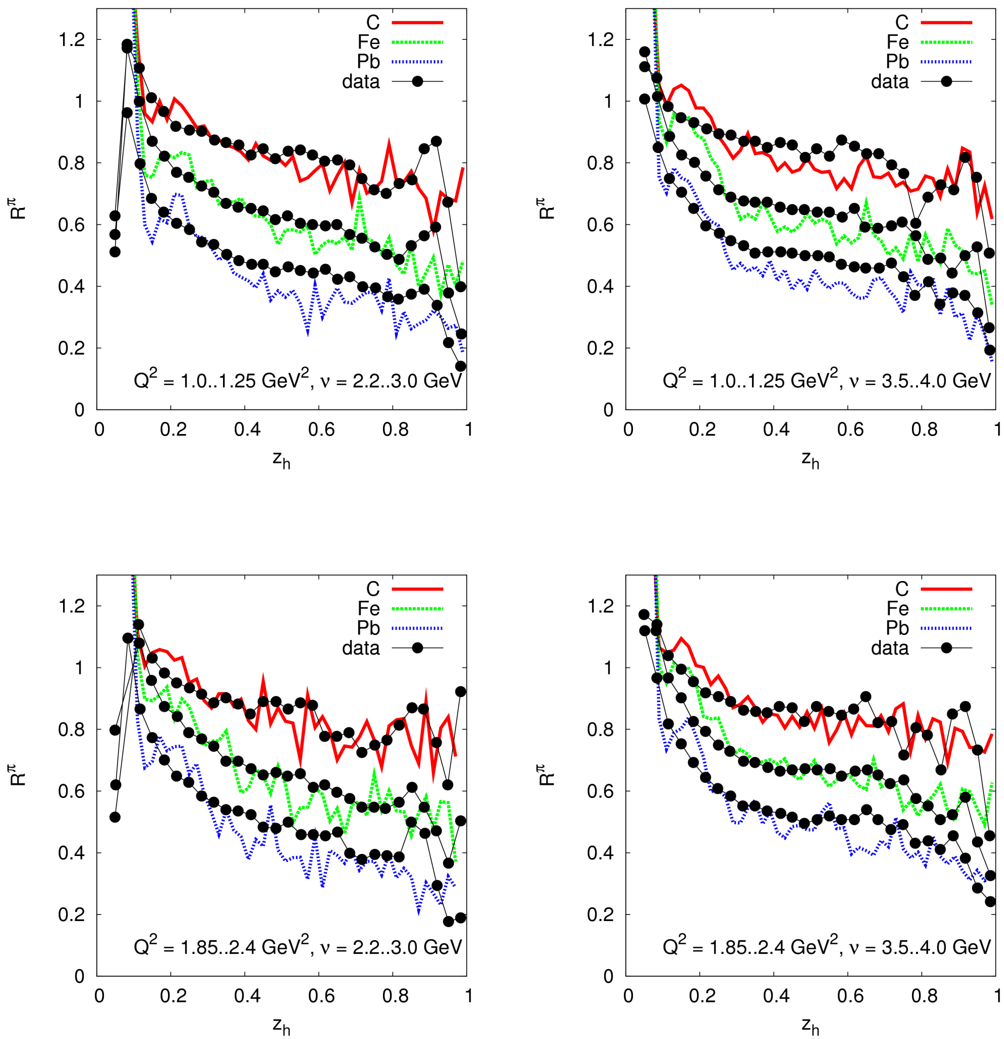
$^{20}Ne_{10}$

$^{84}Kr_{36}$

$^{131}Xe_{54}$

no diffractive

CLAS@5, π^+ : selected (ν,Q^2) bins



Data:

- CLAS preliminary
- no error bars shown

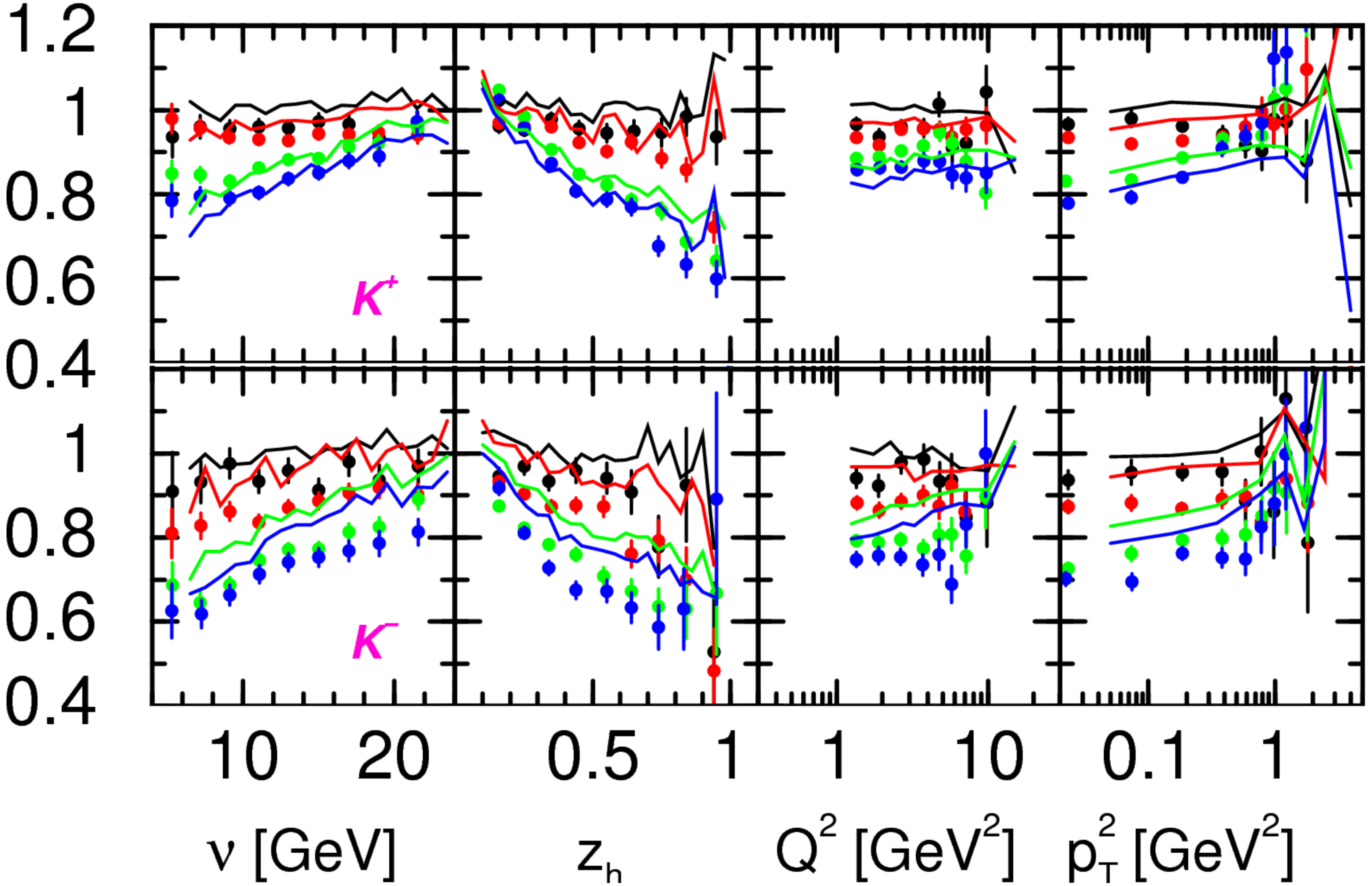
Calculations:

- not tuned !!!
- no Fermi Motion (W<2 GeV possible)
- no potentials

As good as at higher energies !

Hermes@27: A.Airapetian et al., NPB780(2007)1

Kaons



$^{2}d_{1}$

$^{4}He_{2}$

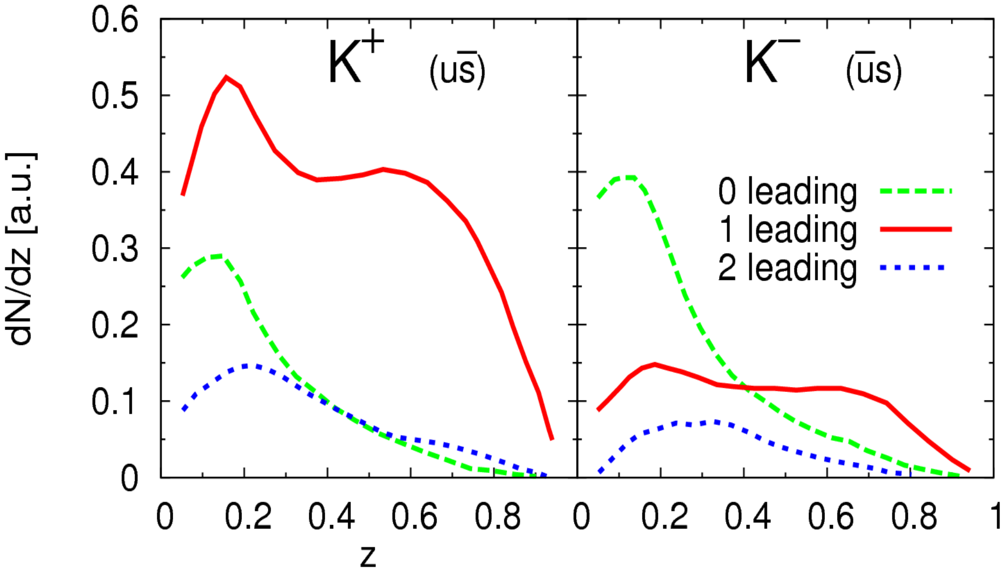
$^{20}Ne_{10}$

$^{84}Kr_{36}$

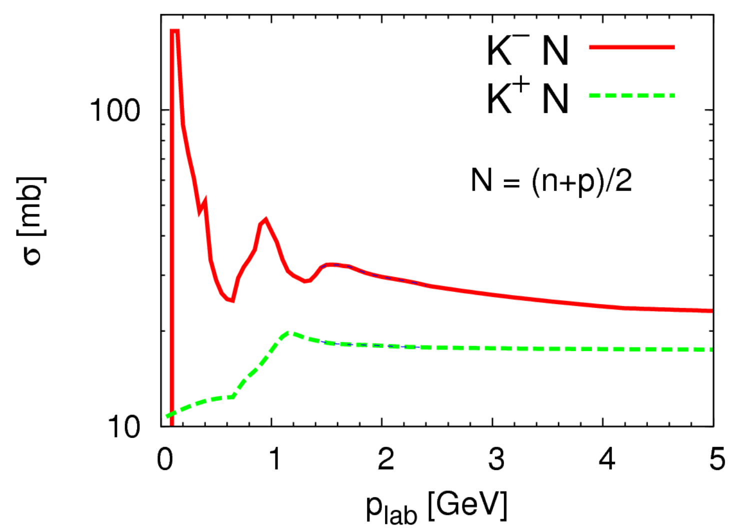
$^{131}Xe_{54}$

Hadronic FSI

- Leading

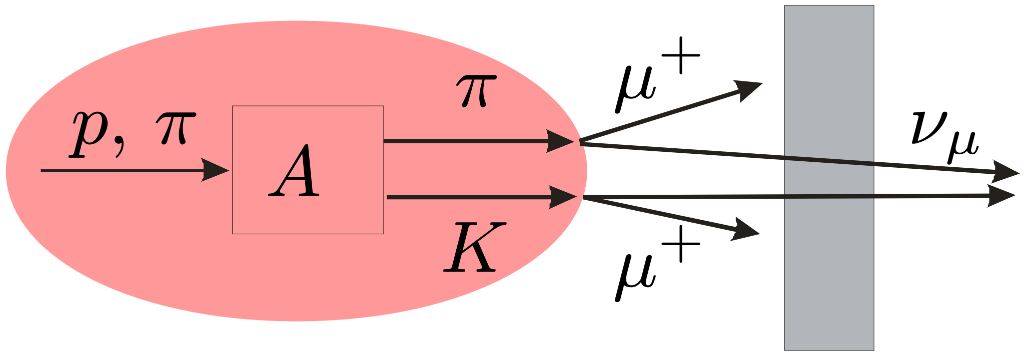


- FSI cross section



- Large z: diffractive φ
- Low/moderate z: production of secondaries

HARP, NA61/Shine



aim: adjust flux for …

- MiniBooNE
- SciBooNE
- K2K

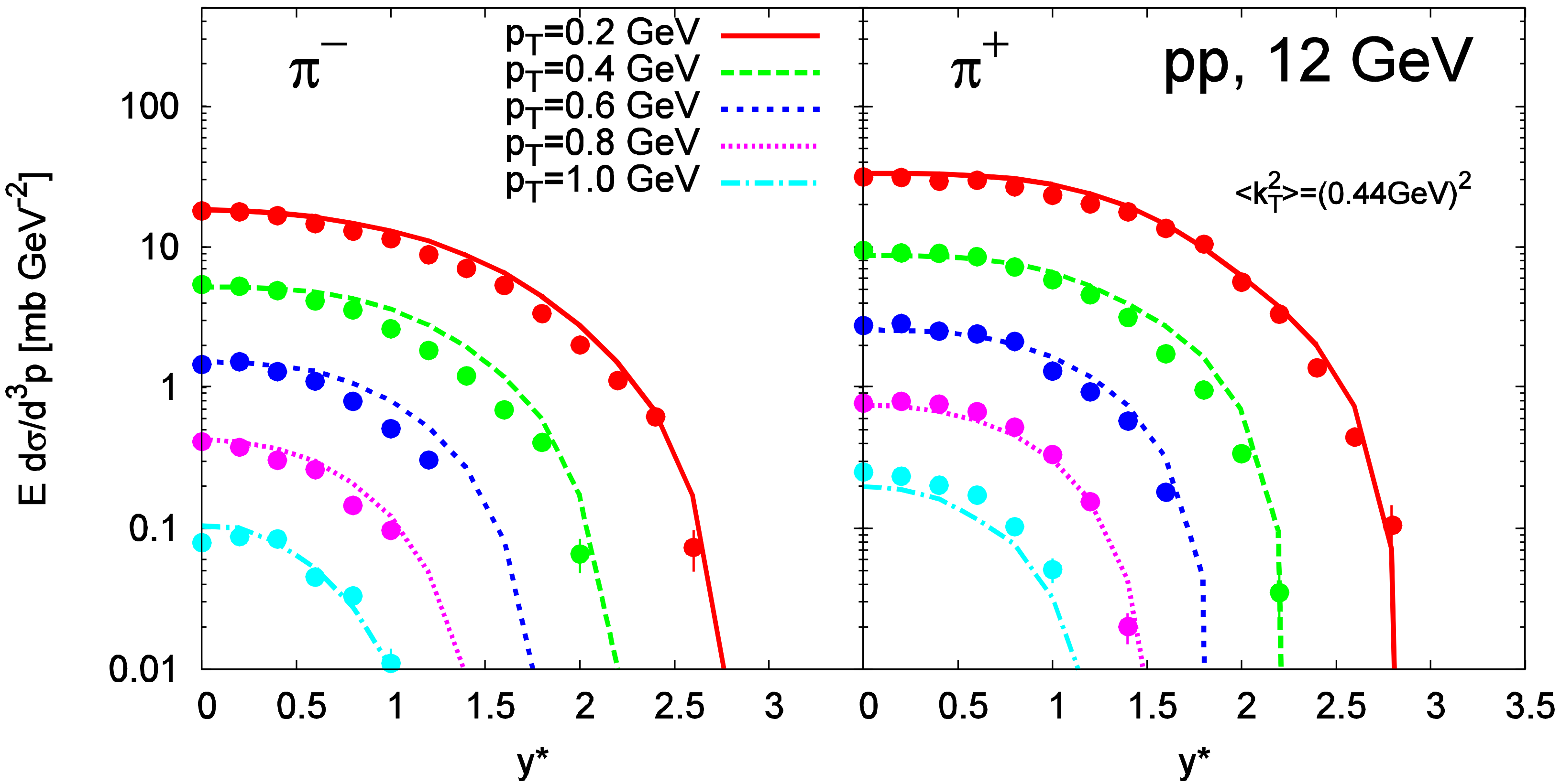
understand hadronic FSI

- proton, pion beam
- beam energies: 3 – 30 GeV/c

- critical test for hadronic fsi

elementary: $pp \to \pi^{\pm} X$

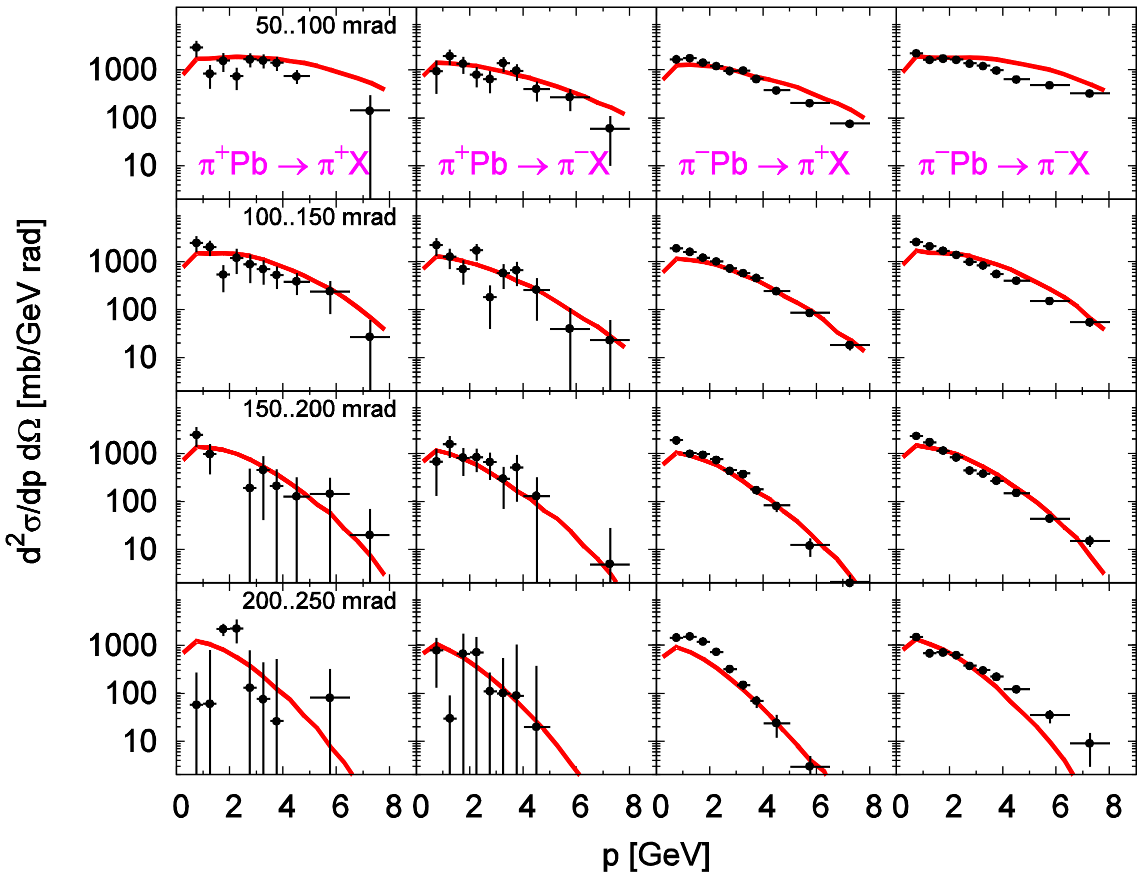
data: V. Blobel et al., Nucl. Phys. B69 (1974) 454



- Pythia v6.4 decribes elementary data very well

$\pi^\pm$ *Pb* $\to$ $\pi^\pm$ *X* (forward, 12 GeV/c)

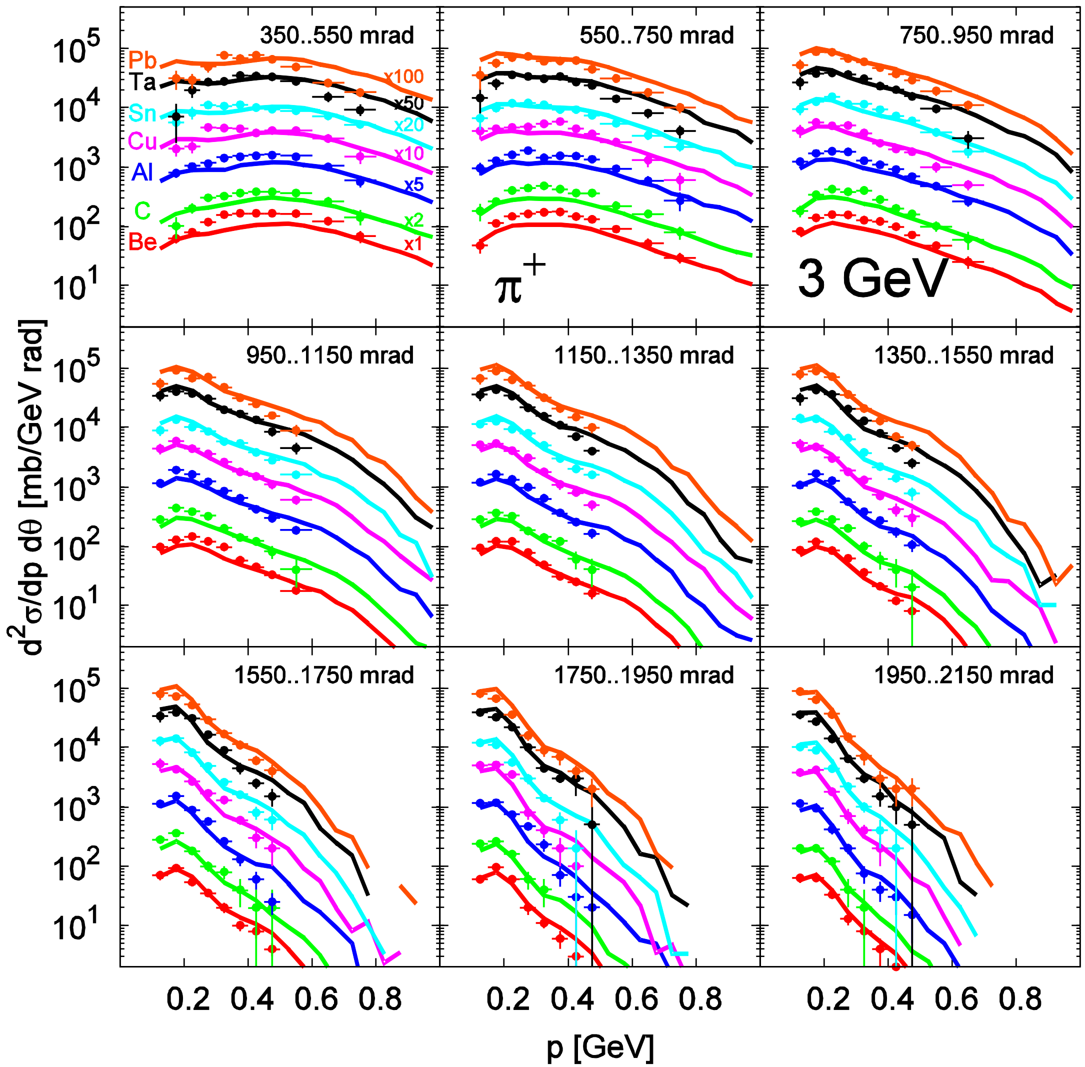
data: M.G. Catanesi et al. (HARP), arXiv:0902.2105 [hep-ex]



- forward production described very well
- pion beam slightly better described than proton beam

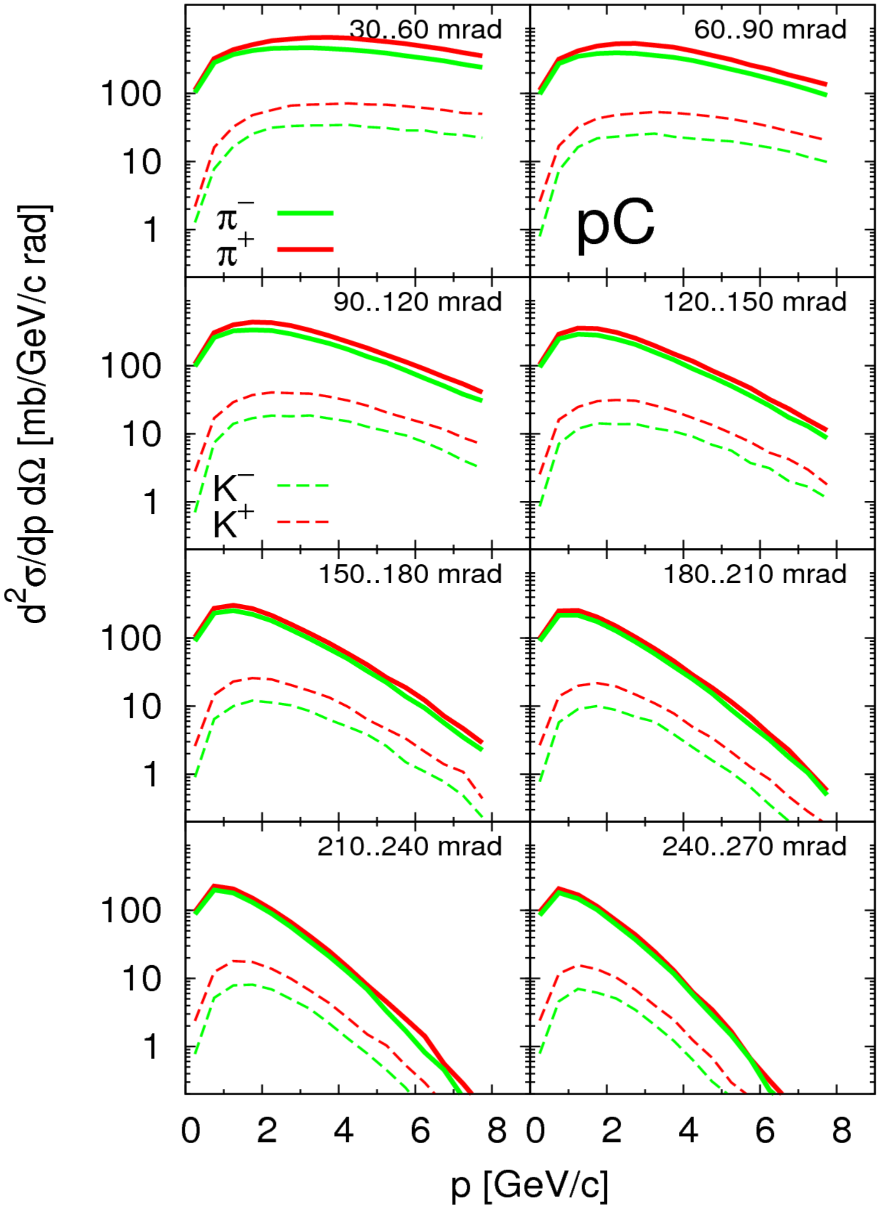
$pA \rightarrow \pi^+ X$ (backward, 3 GeV/c)

data: M.G. Catanesi et al. (HARP), Phys. Rev. C 77 (2008) 055207



Official HARP
vs.
HARP-CDP

NA61/Shine



T2K neutrino flux

30 GeV (40, 50 GeV)

- critical test for kaonic FSI

Conclusions

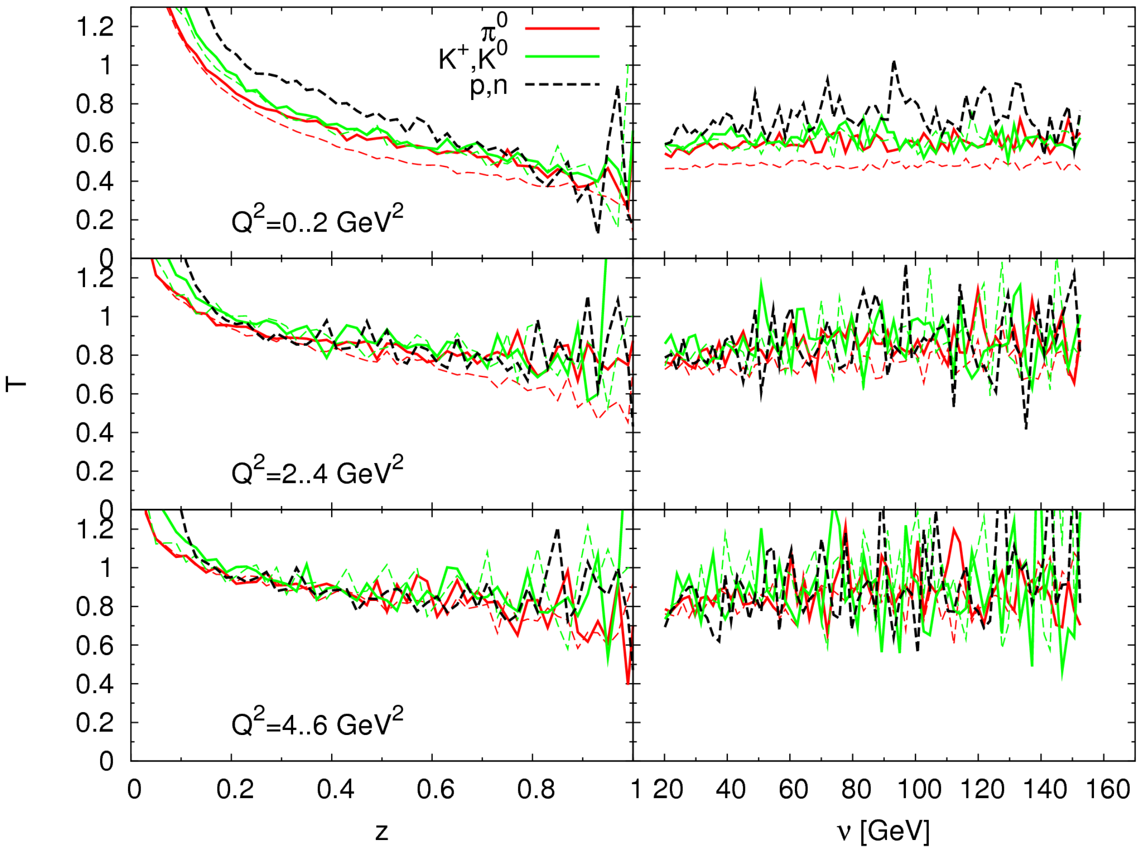
- GiBUU:
  - coupled channel transport code (semi classical)
  - from some MeV to tens of GeV (Pythia v6.4 for high energy)
  - multi purpose: p, π, γ^*, ν – induced reactions
    Heavy Ion Collisions

- pre-hadron cross section: linear in time
  (EMC,Hermes,CLAS)

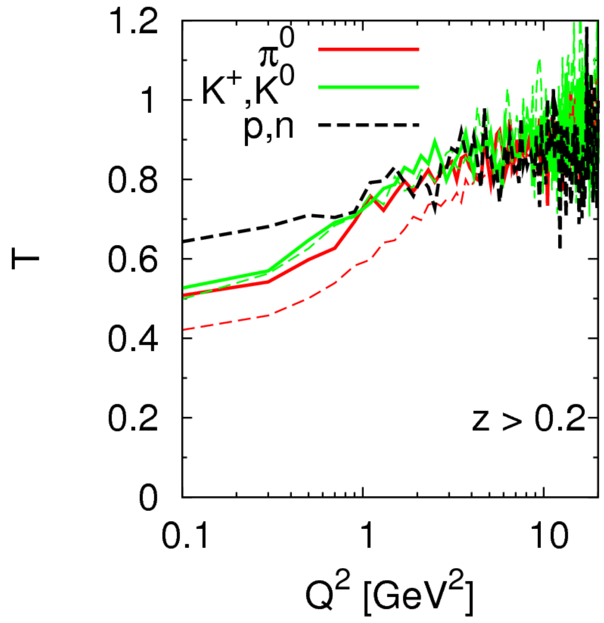
- Kaons/Antikaons critical test of interaction scenario
  - Different production mechanism (leading/non-leading)
  - Different hadronic FSI cross section

- HARP, NA61/Shine: important for testing hadronic FSI

EIC@3+30: hadrons



- Strong dependence on Q2



EIC@3+30: π° vs. η

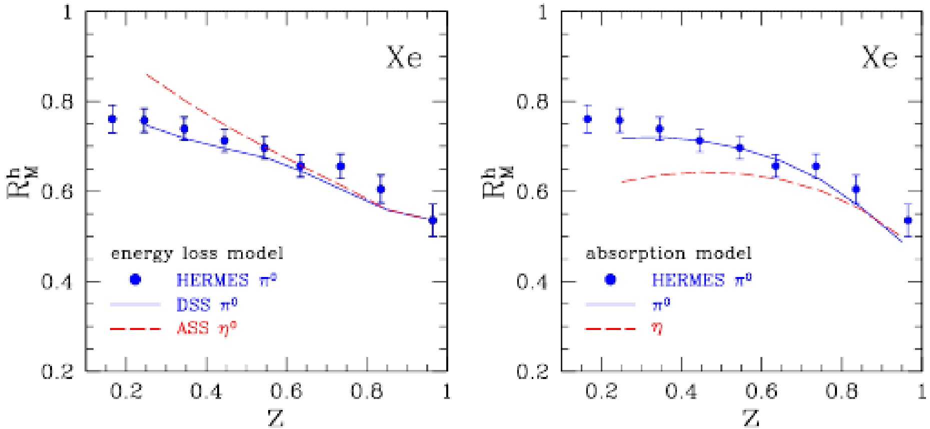
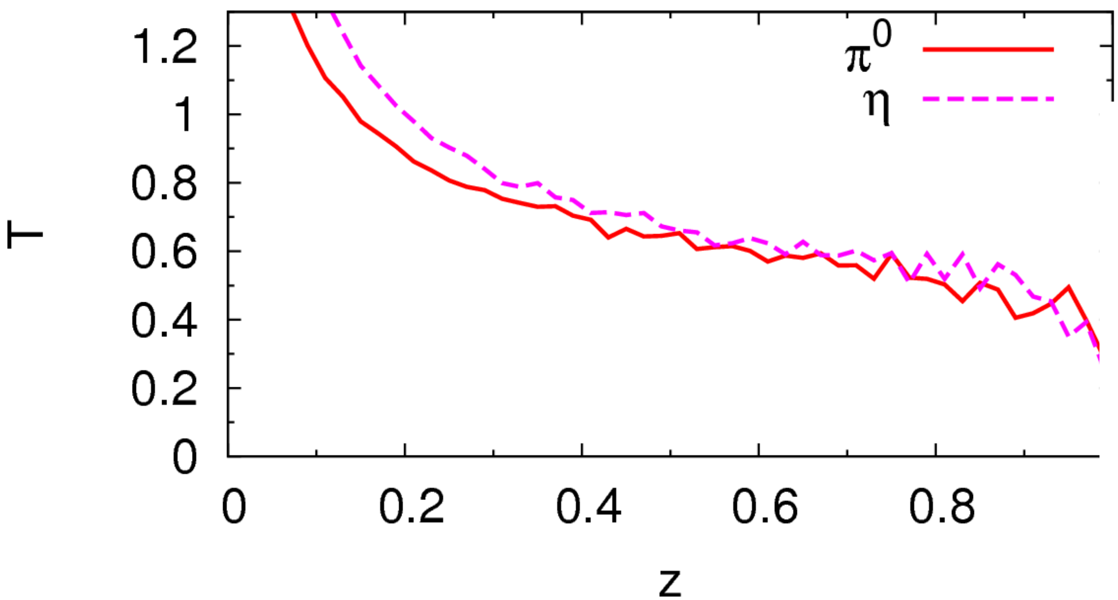
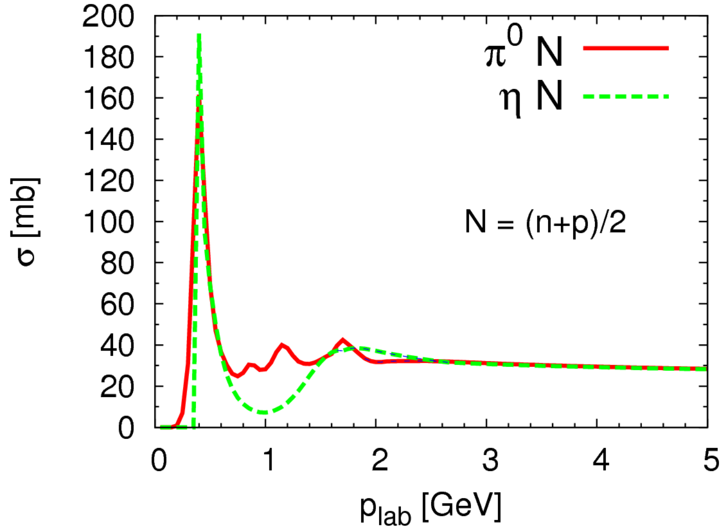
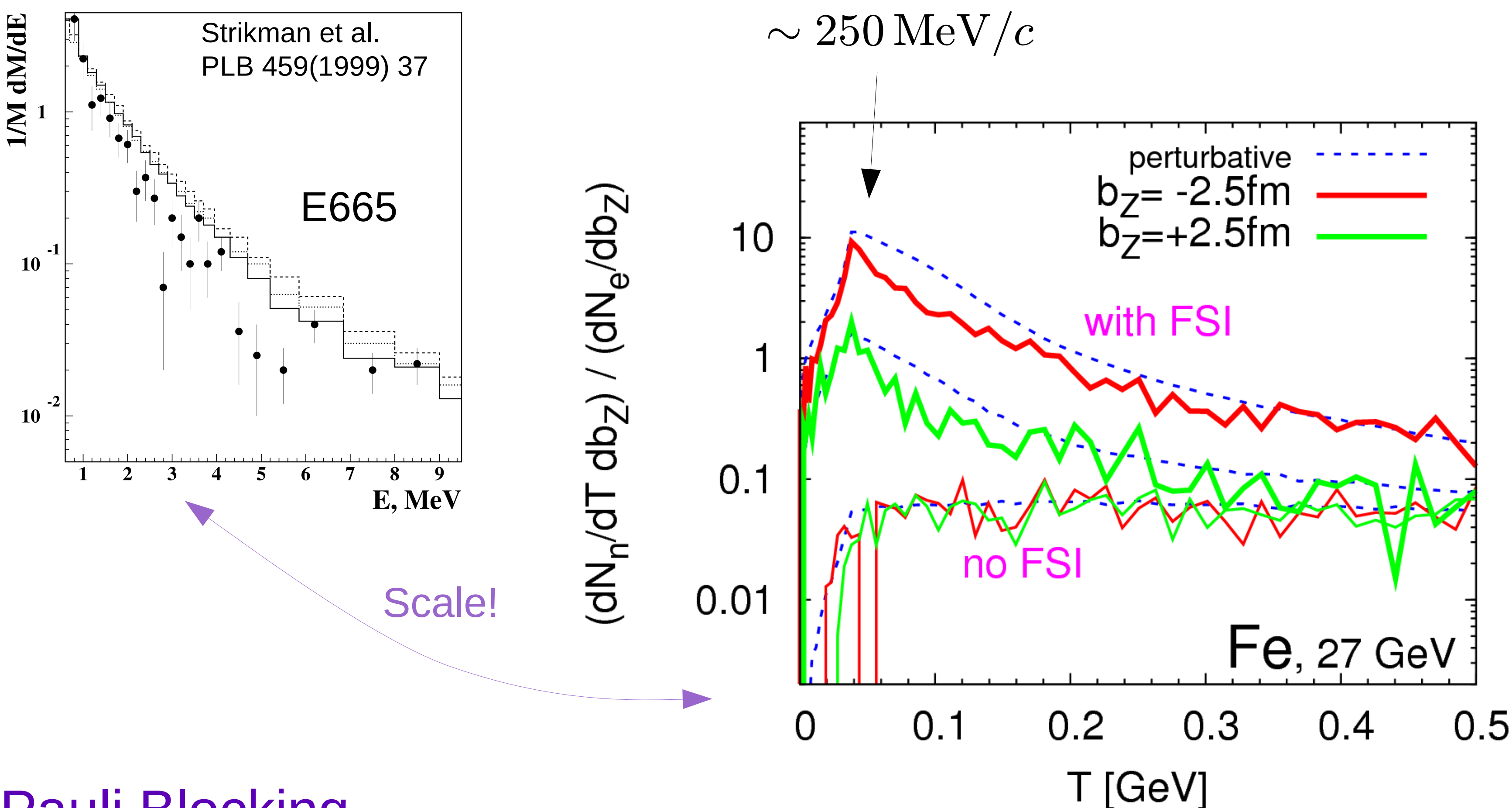


Figure 4. Multiplicity ratio for HERMES neutral pions from a Xenon target together with calculations in an energy loss model[29] calculation from 2007 and in an absorption model[30] for neutral pions and the eta meson. These calculations suggest that the comparison of η and π^0 will distinguish between these two reaction mechanisms.





Slow Neutrons & interaction point



- Pauli Blocking
- Evaporation, Binding etc.: GiBUU afterburner (Gaitanos)

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    Heavy Ion Collisions

- pre-hadron cross section: linear in time
  (EMC,Hermes,CLAS)

- Transverse momentum broadening
  - attenuation leads to broadening
  - medium modification of fragmentation parameters **???**

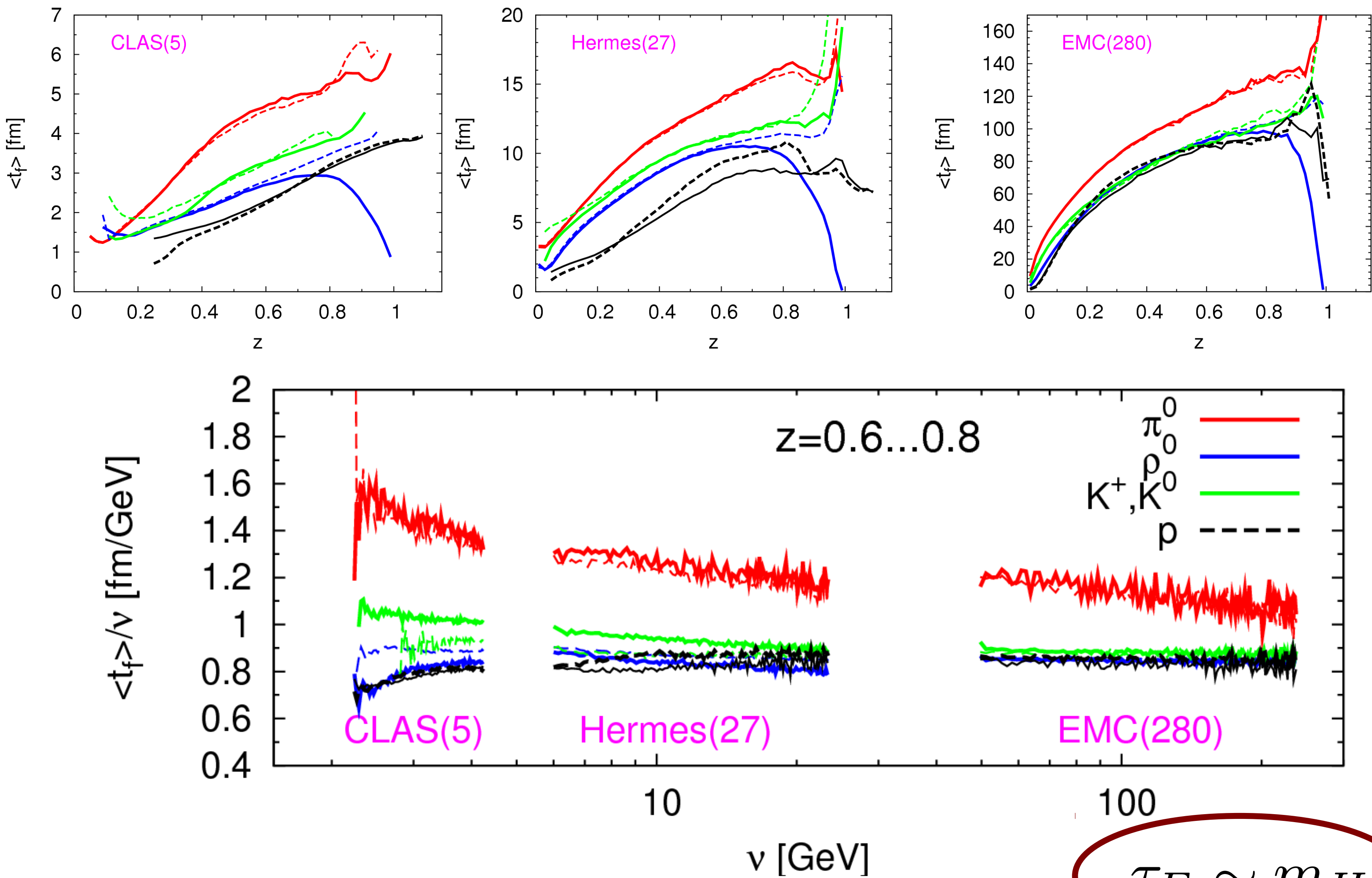
- EIC: important for testing FSI at beginning of hadronization

- **Cold Nuclear Matter as baseline for Heavy Ion Collisions**

Conclusions

- GiBUU:
  - coupled channel transport code (semi classical)
  - from some MeV to tens of GeV (Pythia v6.4 for high energy)
  - multi purpose: p, π, γ^*, ν – induced reactions
    Heavy Ion Collisions
- pre-hadron cross section: linear in time
  (EMC,Hermes,CLAS)
- Transverse momentum broadening
  - attenuation leads to broadening
  - medium modification of fragmentation parameters **???**
- HARP: Critical test for hadronic FSI
- **Cold Nuclear Matter as baseline for Heavy Ion Collisions**

Averaged Times



$$\tau_F \sim m_H$$