Hadronization studies in e-A Colliders

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Outline

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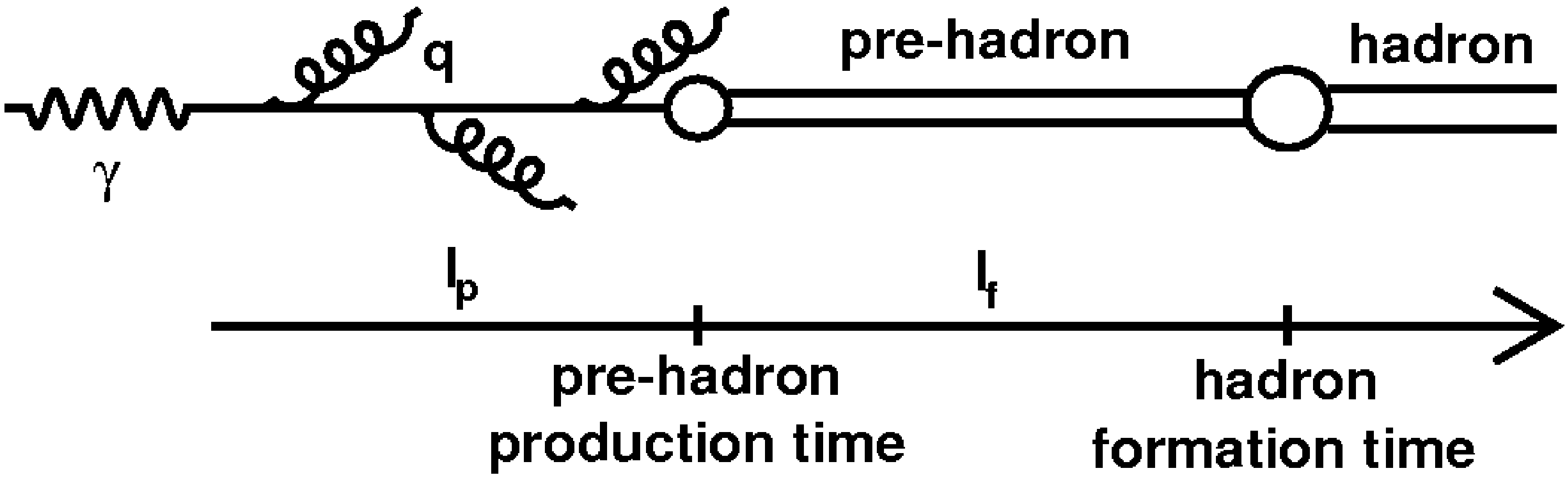
- Physics Motivation
- Possibilities at EIC
- Summary

Introduction



- Production time:
  - How long does it take to the quark to neutralize its color?
- Formation time:
  - How long does it take to the colorless object to form a full hadron?

DIS Variables

- Momentum transfer

$$Q^2 = -q^2$$

- Bjorken x

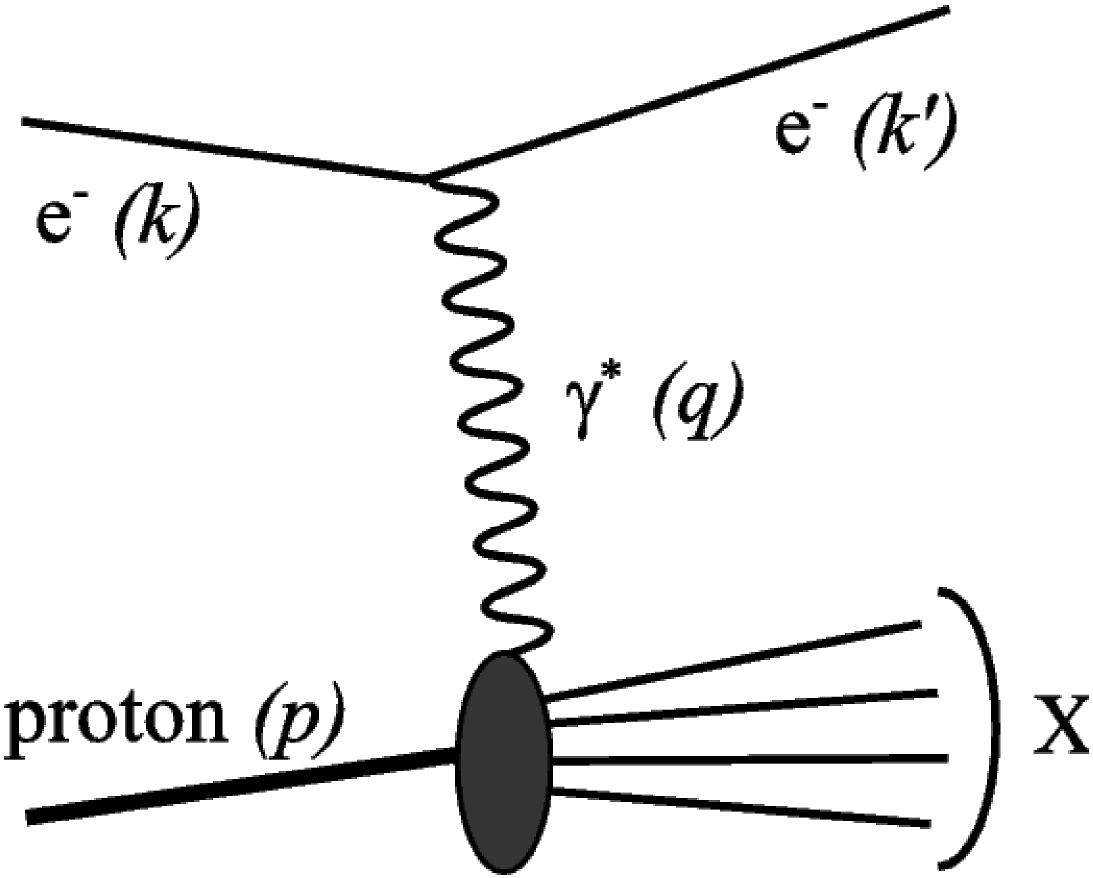
$$x_{Bj} = \frac{-q^2}{2\,p\,.\,q}$$

- Photon energy

$$\nu = E_\gamma$$

- Fraction of the energy carried by the hadron

$$z = \frac{k.p}{q.p} = E_h / \nu$$



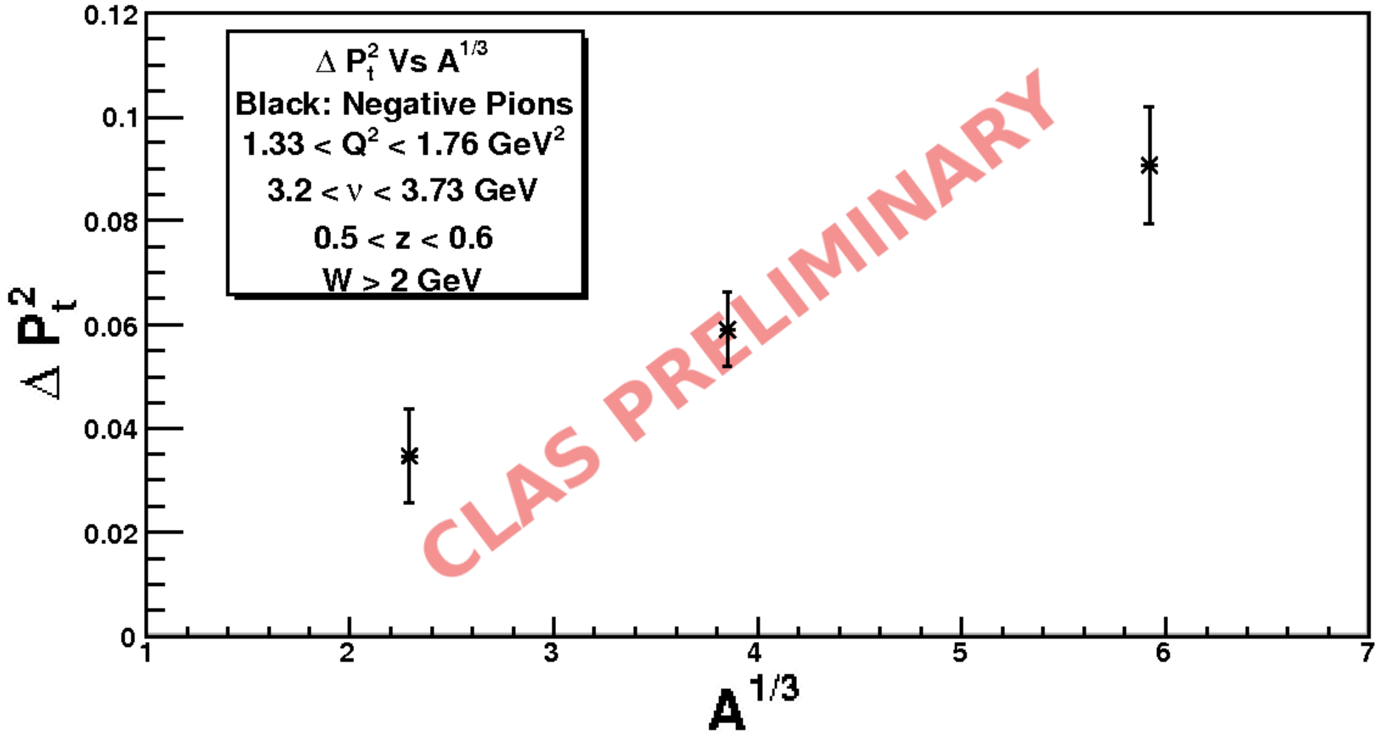
P_T Broadening

- P_T distribution broadening in Cold Nuclear Matter

$$\Delta P_T^2 = \langle P_T^2 \rangle_A - \langle P_T^2 \rangle_D$$

- Permit to extract directly quark energy loss

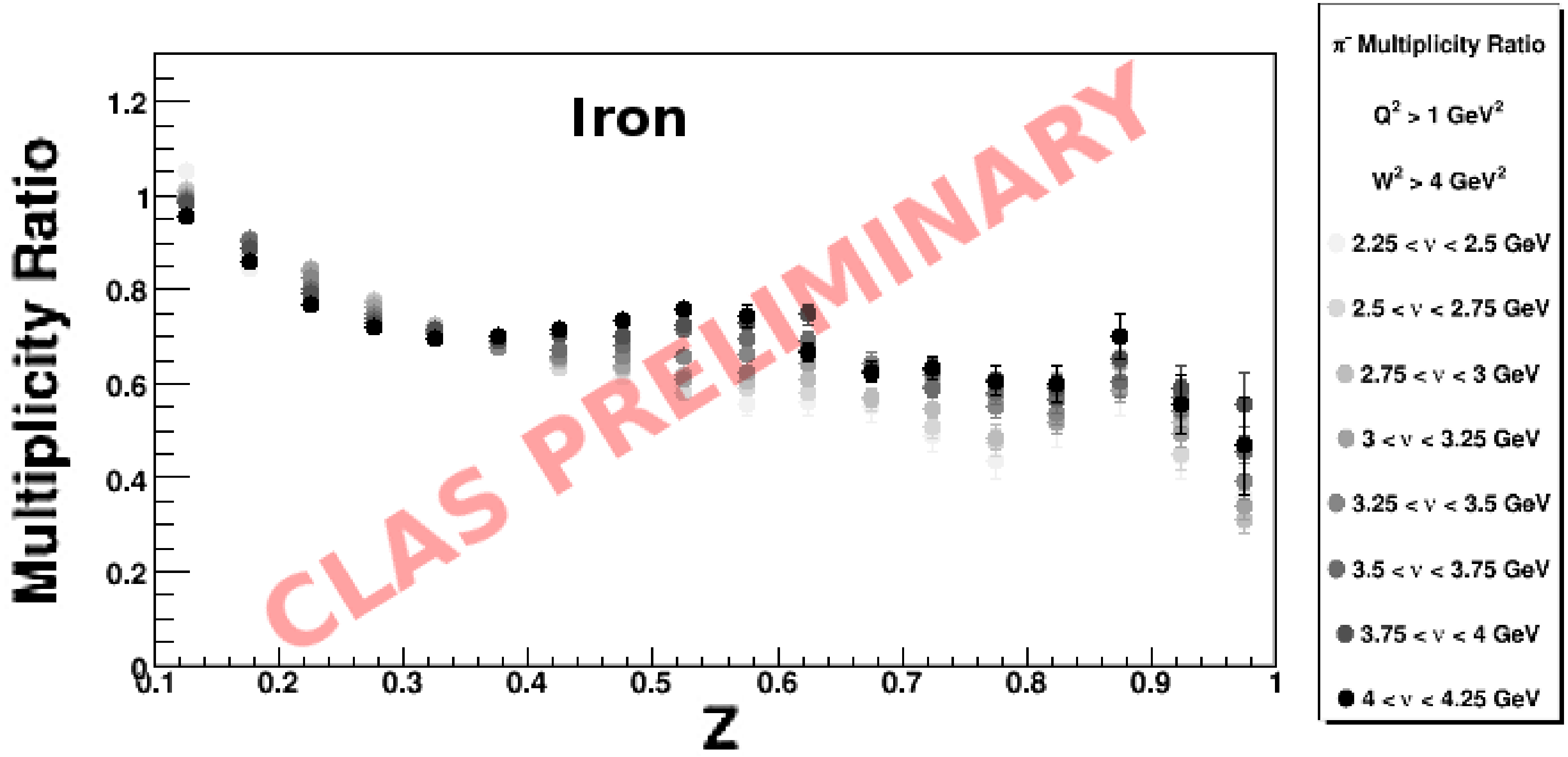
(see for exemple Domdey et al. arXiv 0812.2838)



Attenuation of hadrons

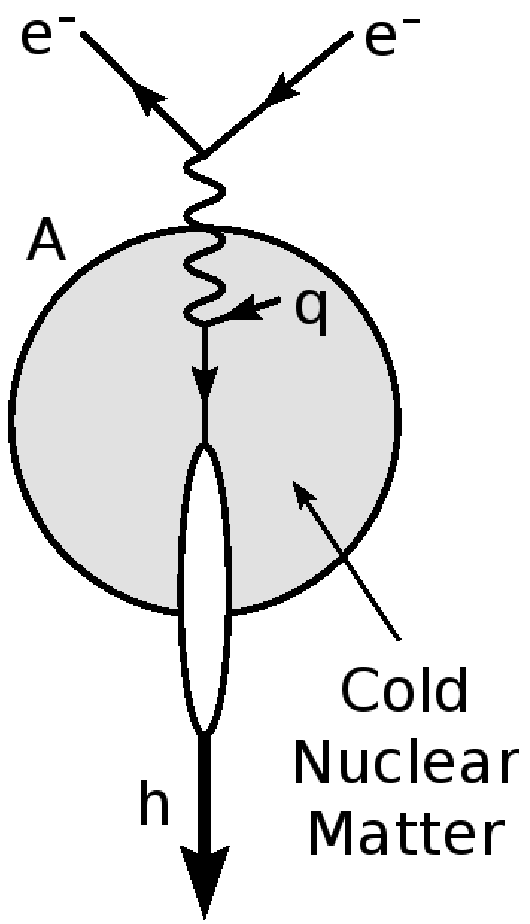
- Measured in Cold Nuclear Matter with

$$R_A^h(Q^2, x_{Bj}, z, P_T) = \frac{N_A^h(Q^2, x_{Bj}, z, P_T) / N_A^e(Q^2, x_{Bj})}{N_D^h(Q^2, x_{Bj}, z, P_T) / N_D^e(Q^2, x_{Bj})}$$

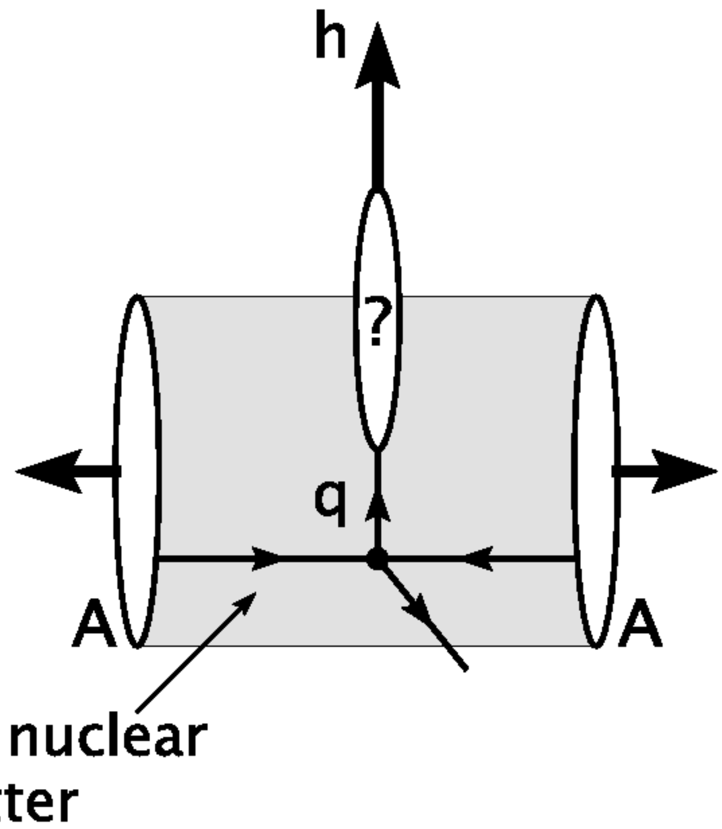


Hadronization in Cold Nuclear Matter

- Comparison between different nuclei
  - Known environment
- Measure
  - Nuclear modifications of fragmentation functions
  - Quark energy loss
  - Absorption



Hadronization in Hot Nuclear Matter



- Comparison hadron production between d+A and A+A
- Goal is to characterize the medium
- Models need benchmark from cold nuclear matter

Models applied to Cold Nuclear Matter (1)

- No quark interaction (Gallmeister et al. NPA 801(2008) 68)
  - No quark energy loss
  - Parametrization of pre-hadron cross section
- Pure energy loss (Arleo EPJ C30(2003)213)
  - Energy loss during quark life time
  - Attenuation due to lower energy of fragmenting quark
  - Pre-hadron interaction neglected

Models applied to Cold Nuclear Matter (2)

- Combination of both (Kopeliovich et al. NPA 740 (2004) 211)
  - Energy loss during quark life time
  - Absorption of pre-hadron in medium
- All those models can describe actual data
  - High statistics permit use of multidimensional binning and therefore more constraint on models

Physics Motivation

How Long is Quark Life Time?

- Can be evaluated within pQCD (31 and 34)

Estimate	kinematics	π	K	p	D	B
pQCD	HERMES	36 fm	11 fm	4 fm	1 fm	0.2 fm
	RHIC	26 fm	10 fm	4 fm	1 fm	0.2 fm
Lund	HERMES	13 fm	8 fm	25 fm		
	RHIC	7 fm	5 fm	14 fm		

from “Parton propagation and fragmentation at the EIC” A. Accardi et al.

- Can be evaluated from data within the various models
  - Fit of z and ν dependence of R_h^A or ΔP_T

Quark Life Time Extraction

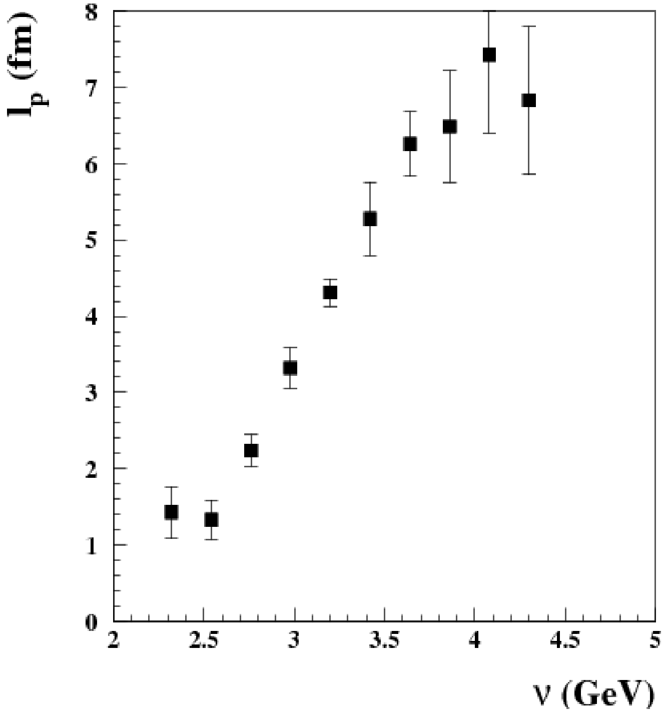


Figure 5. Results of model-independent extraction of the production length l_p using Eq. 9 from data depicted in Fig. 4.

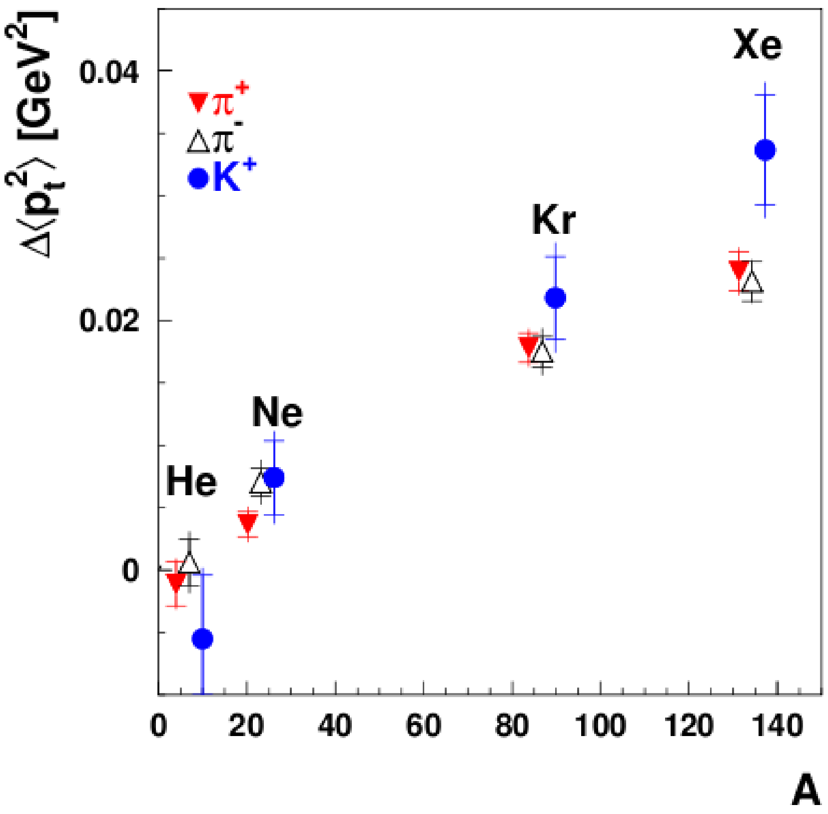
- Model independent extraction of production length with

$$\Delta p_T^2 = \frac{2Cz_h^2}{A} \int d^2b \int_{-\infty}^{\infty} dz\, \rho_A(b,z) \int_{z}^{z+l_p} dz'\, \rho_A(b,z')$$

(from Kopeliovich et al. NPA 782 (2007) 224)

- Use CLAS preliminary data

Flavor Scaling?



- First hint from HERMES
- Future CLAS 12 experiment will permit to analyze this effect

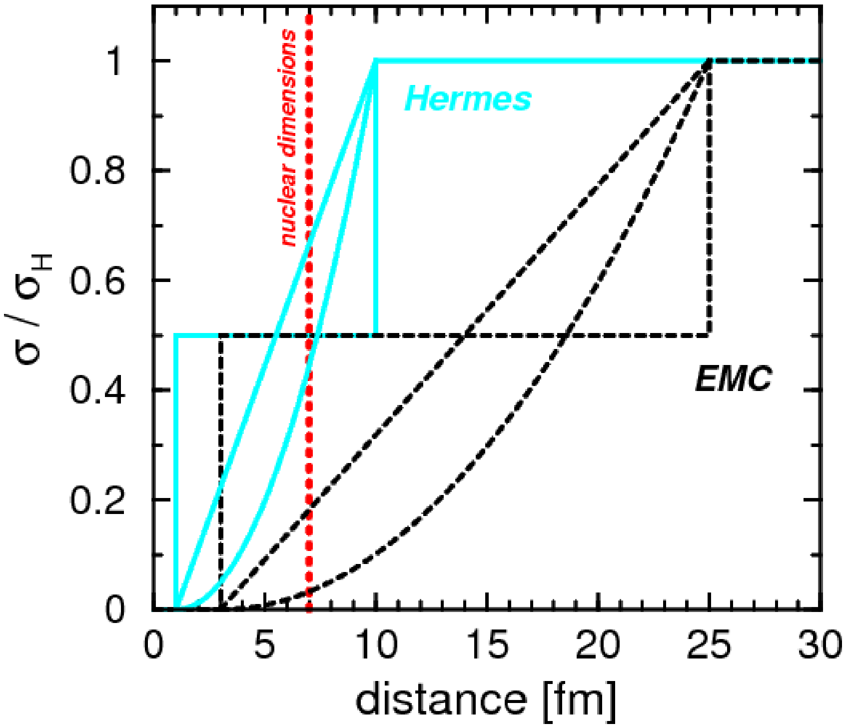
from HERMES
arXiv:0906.2478v1

Time evolution of pre-hadrons (1)

- In the models that do not neglect pre-hadron cross section (fig. From Gallmeister et al.)

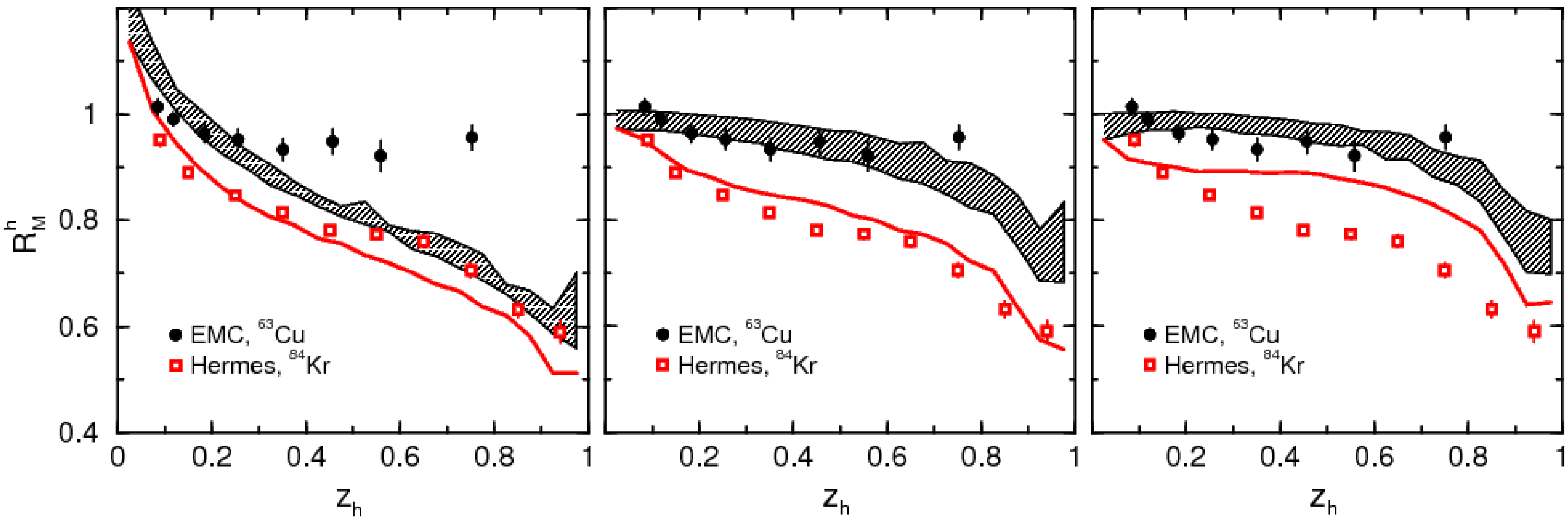
σ = prehadron cross section

σ_h = hadron cross section



- High precision measurement can constrain the cross section evolution of the pre-hadron

Time evolution of pre-hadrons (2)



- Fit of EMC and HERMES data by Gallmeister et al.
- From left to right: constant, linear and quadratic growth of the pre-hadron cross section

Possibilities at EIC

What EIC energies have to offer?

- Quark energy loss can be extracted from ΔP_T
- Scaling between quark flavors is expected
- Fitting the data models give transport coefficient

$$\hat{q}\,(GeV^2/fm)$$

→ Information on the medium

- Long production length help to isolate contributions from quark energy loss

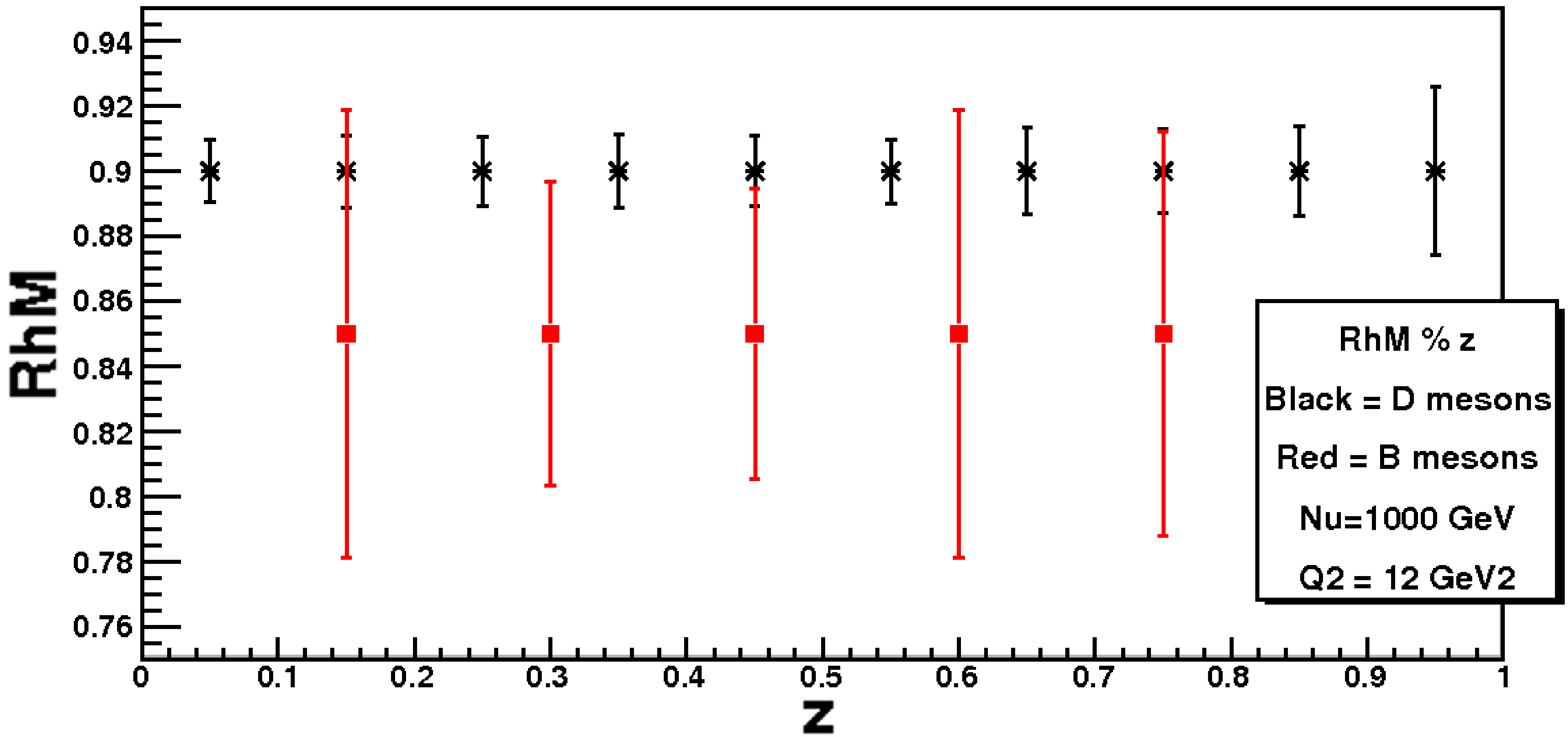
Simulation conditions

- We explore some possibilities at EIC energy in "Parton propagation and fragmentation at the EIC" A. Accardi et al.
- The following projections were done with
  - Ee = 7 GeV and E_A = 75 GeV/charge
  - Luminosity: $4\ 10^{34}\ cm^{-2}s^{-1}$ during 25 weeks
- To evaluate rates we use Pythia 6.4

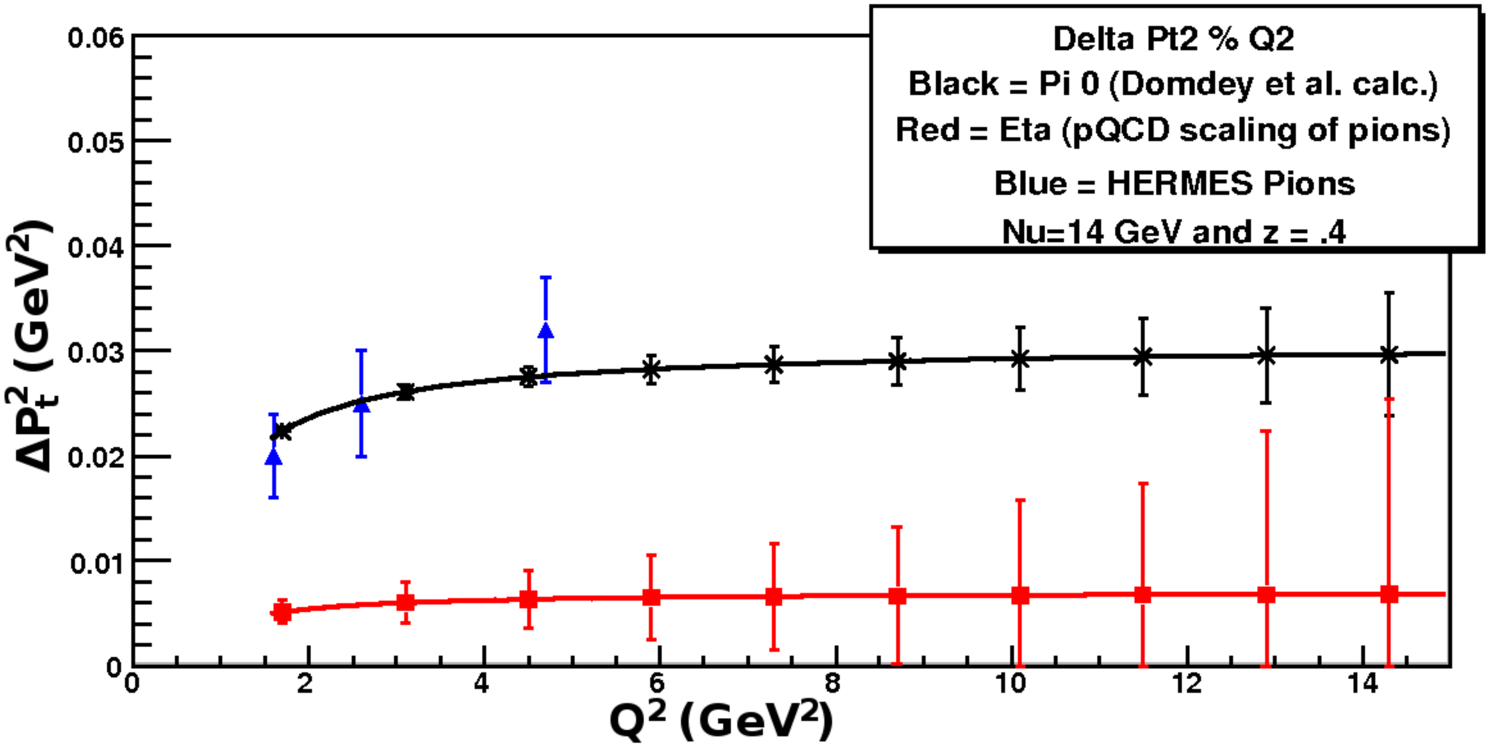
Multiplicity Ratios at EIC

- At EIC energies multiplicity ratio is expected to be close to 1 for light quark flavors
- High statistics and therefore multidimensional binning is important
  - Strong test of the models
- Formation far outside of the medium
  - Isolate quark energy loss effects for light flavors
- For heavy quarks it would be first data
  - Test the flavor dependence of models

Multiplicity Ratios at EIC

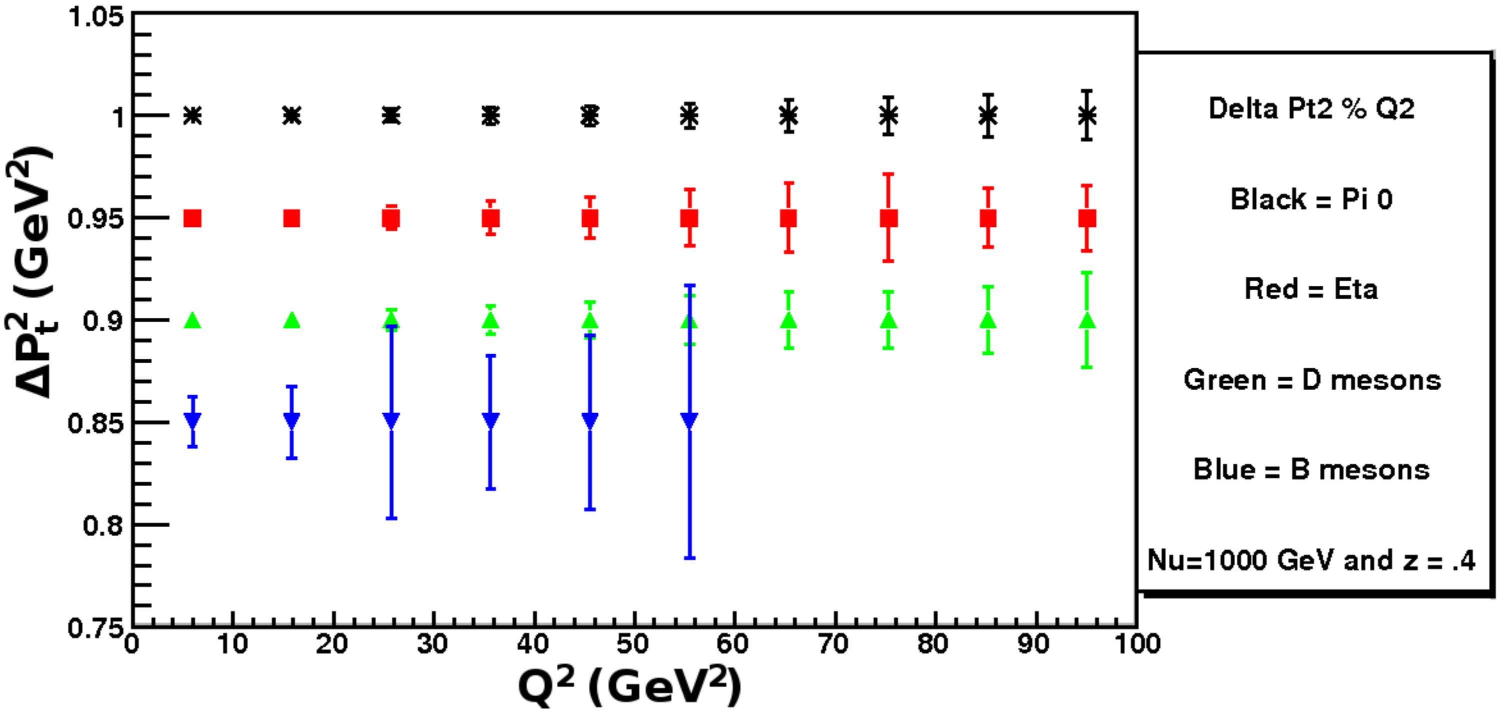


Flavor dependance of ΔP_T^2 at EIC



- Scaling between quark flavors is expected within pQCD
- To be compared with hot nuclear matter where no scaling is observed
- Q^2 dependence can be studied on a large scale

Charm and Bottom Possibilities @ EIC



- Charm mesons produced by gluon fragmentation
- An access to gluon energy loss?

What Detector Specifications are Needed?

- Heavy Flavor identification is a challenge
  - Need very good vertex tracking (100µm or better)
- ΔP_T^2 is a small quantity to measure
  - Good tracking resolution is needed for this measurement

Summary

- EIC give access to important measurement
  - Consistency of models between light and heavy quarks
  - Flavor scaling of quark energy loss
  - Quark energy loss dependence on Q^2
  - Heavy quark hadronization
- Those measurements need specific attention on vertex reconstruction
- Future investigations
  - How jet physics can apply to EIC case?
  - Gamma hadron correlation
  - etc.

Backup slides

GiBUU Parametrization

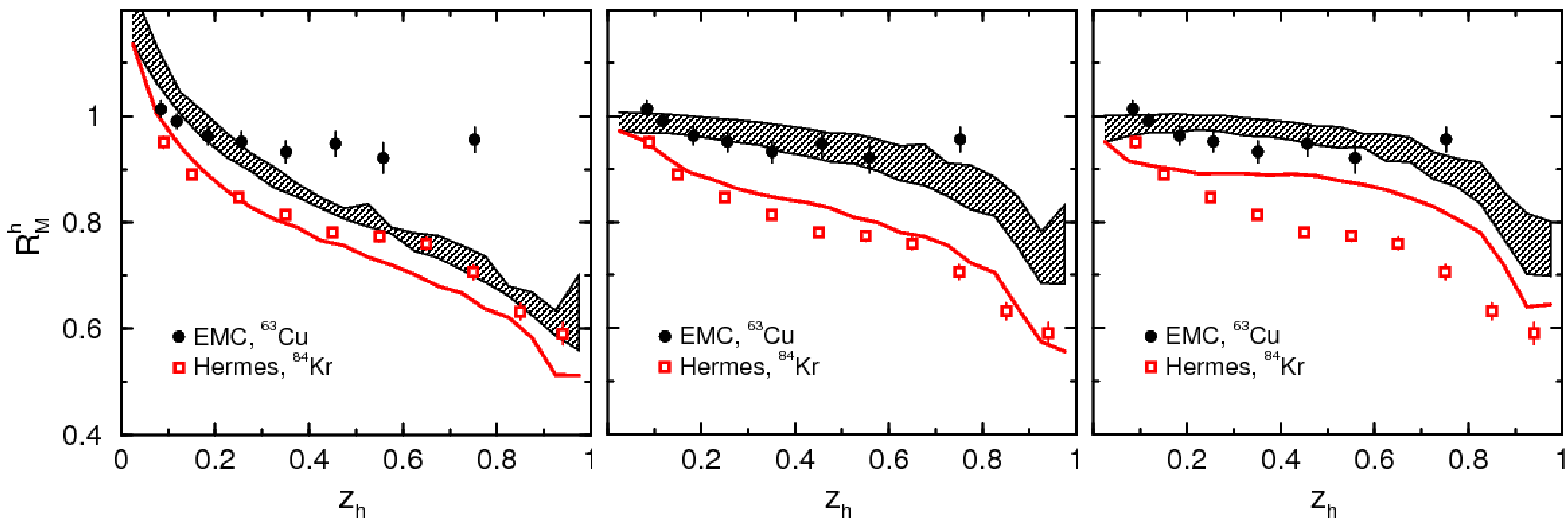


Fig. 1. *Nuclear modification factor for charged hadrons. Experimental data are for HERMES@27*GeV *(16) and EMC@100/280*GeV *(17). The predictions for the two EMC energies are given by the lower and upper bounds of the shaded band. The cross section-evolution-scenarios in the calculations are: constant, linear, quadratic (from left to right).*

RHIC Pi^0 and Eta suppression

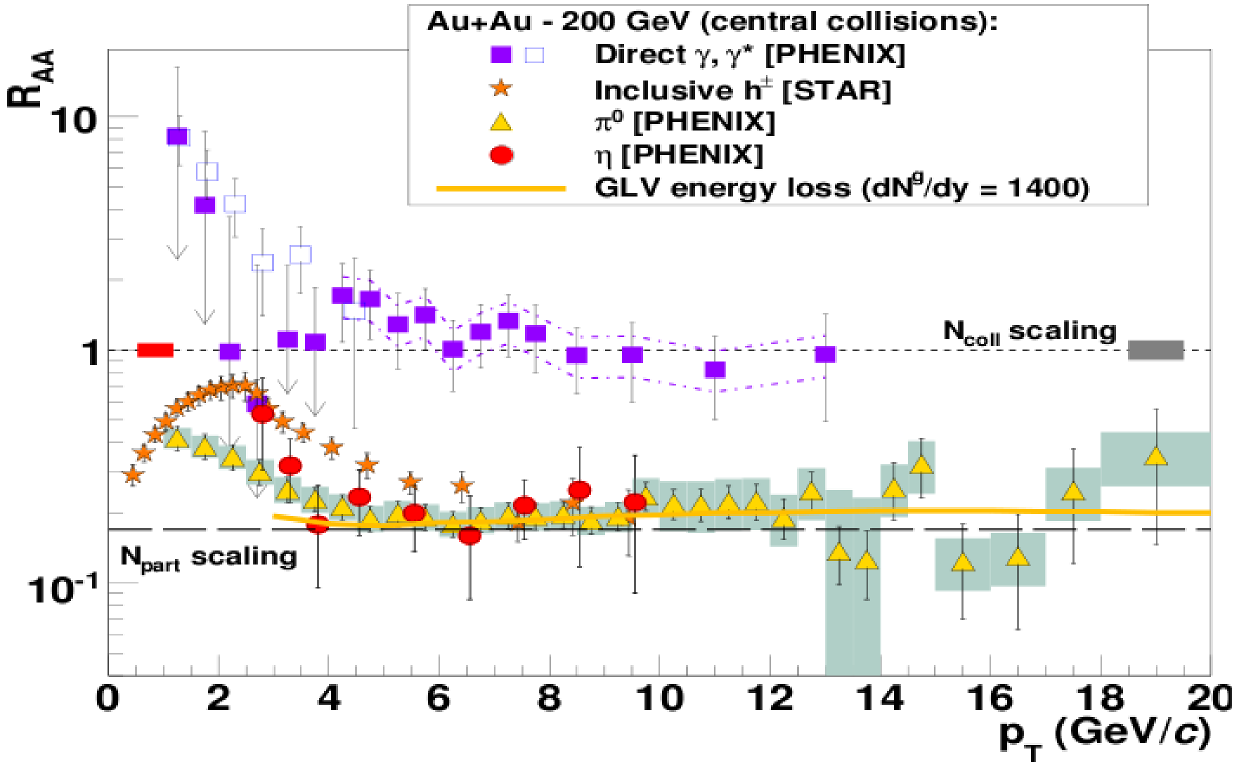


Fig. 16. $R_{AA}(p_T)$ measured in central *AuAu* at 200 GeV for π^0 [89] and η [135] mesons, charged hadrons [114], and direct photons [136, 137] compared to theoretical predictions for parton energy loss in a dense medium with $dN^g/dy = 1400$ (yellow curve) [138].

from d'Enterria "Jet Quenching" arXiv 0902.2011v2

Covered Distance by D Mesons at EIC Energies