Nuclear effects in hadron production at HERMES

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for the hermes collaboration

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on
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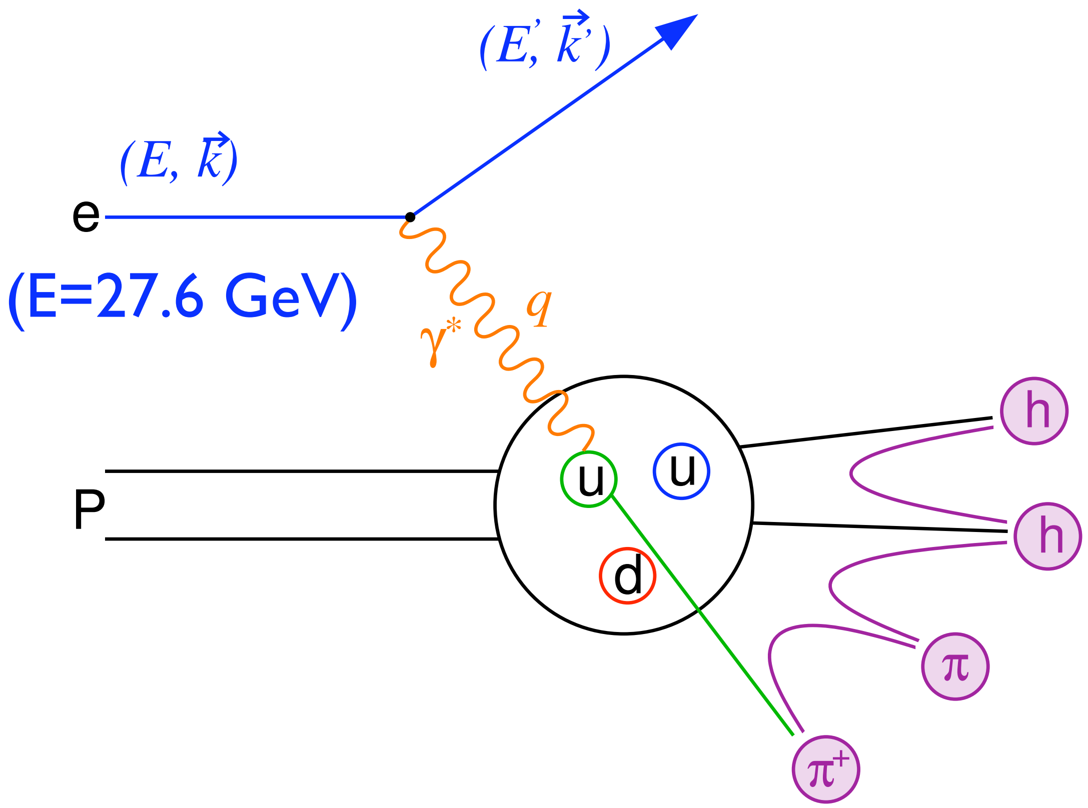
(EINN 2009)
Milos, Greece

Overview

- Measuring nuclear effects in hadronization at HERMES
- Final results on hadron attenuation
- Final results on p_t broadening

Semi-inclusive deep-inelastic scattering



$$Q^2 = -q^2 = -(k-k')^2$$

$$\nu \stackrel{lab}{=} E - E'$$

$$x = \frac{Q^2}{2M\nu}$$

$$z \stackrel{lab}{=} \frac{E_{\mathrm{had}}}{\nu}$$

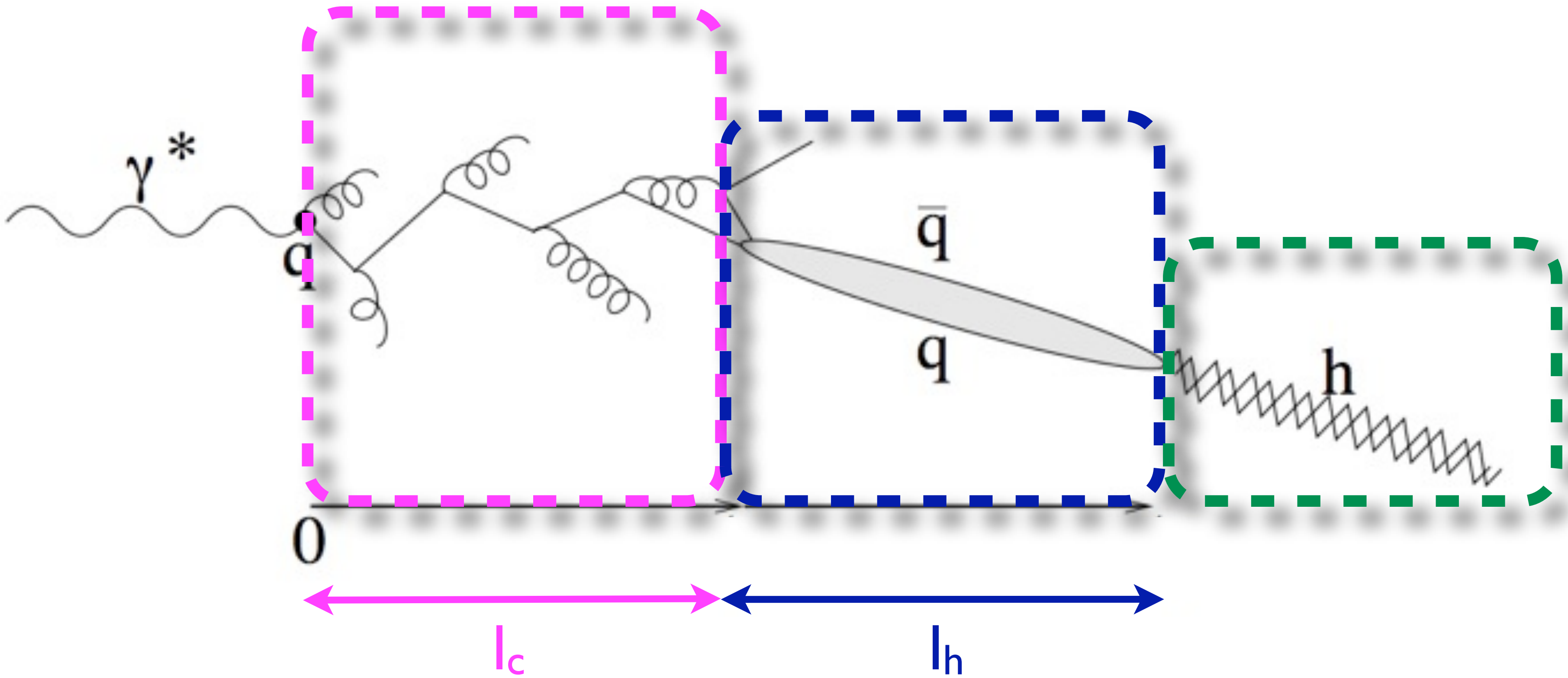
Cross section contains Distribution Functions and Fragmentation Functions:

$$\sigma^{ep\to eh} \sim \sum_q \mathrm{DF}^{p\to q} \otimes \sigma^{eq\to eq} \otimes \mathrm{FF}^{q\to h}$$

DF: distribution of quarks in the nucleon

FF: fragmentation of (struck) quark into hadronic final state

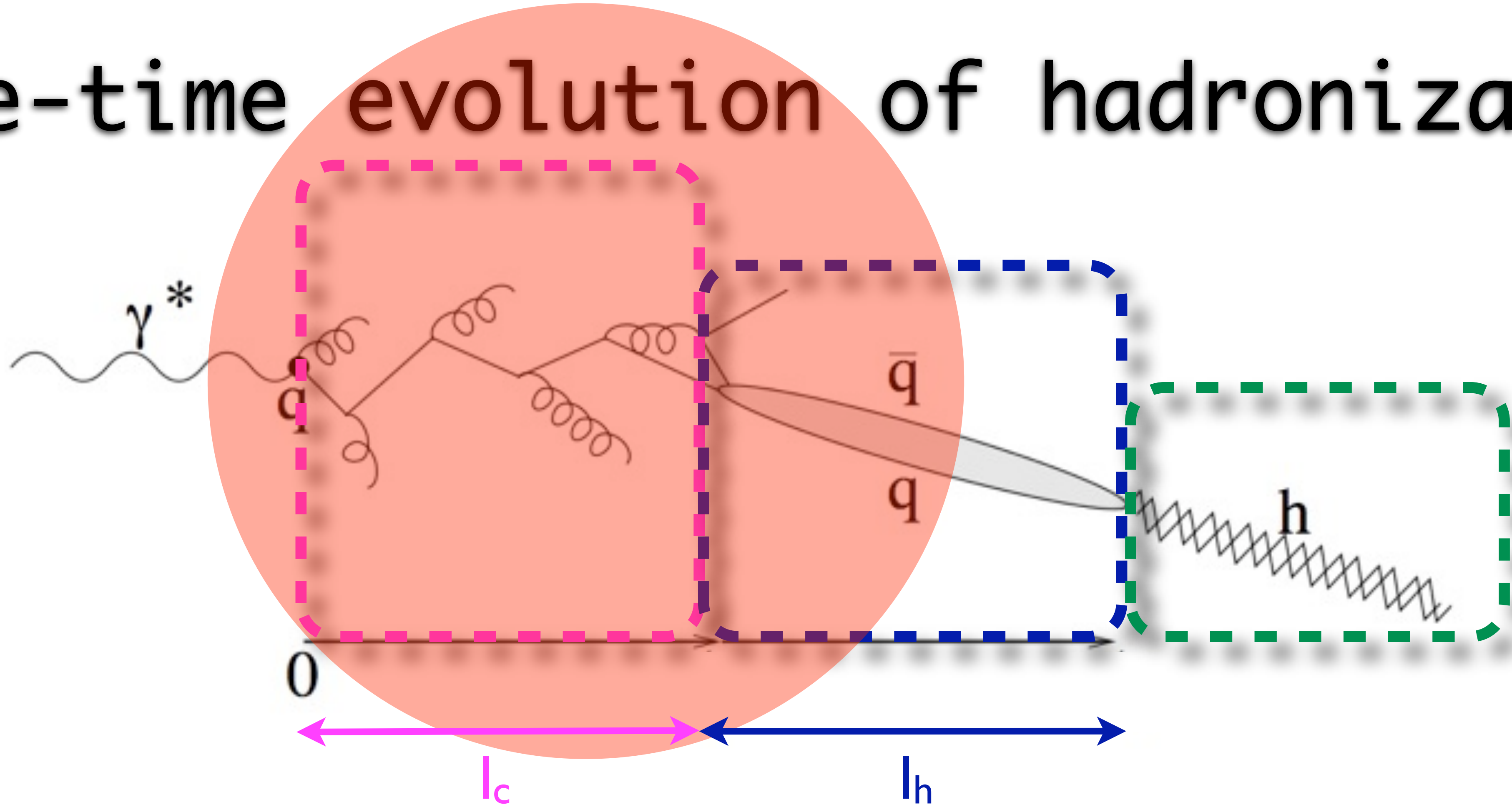
Space-time evolution of hadronization



- parton
- pre-hadron
  - colorless
  - quantum numbers of final hadron
- final state hadron

Formation length $l_c \sim$ 1-10 fm $\Rightarrow \mathcal{O}$ (size of nucleon)

Space-time evolution of hadronization

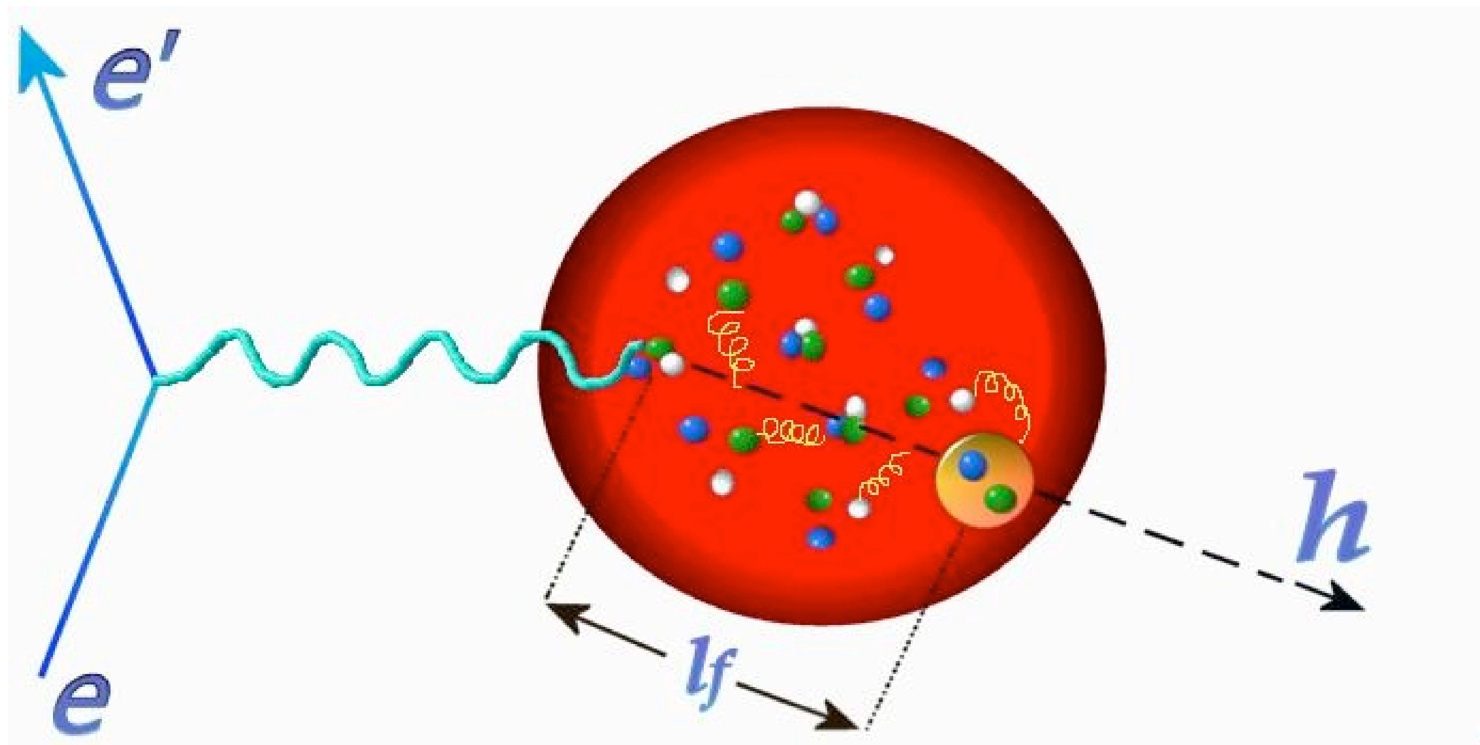


- parton ⇒ energy loss by q-q scattering and gluon radiation
- pre-hadron ⇒ hadronic final state interactions (FSI)
  - colorless
  - quantum numbers of final hadron
- final state hadron ⇒ hadronic final state interactions (FSI)

cross sections may be different!

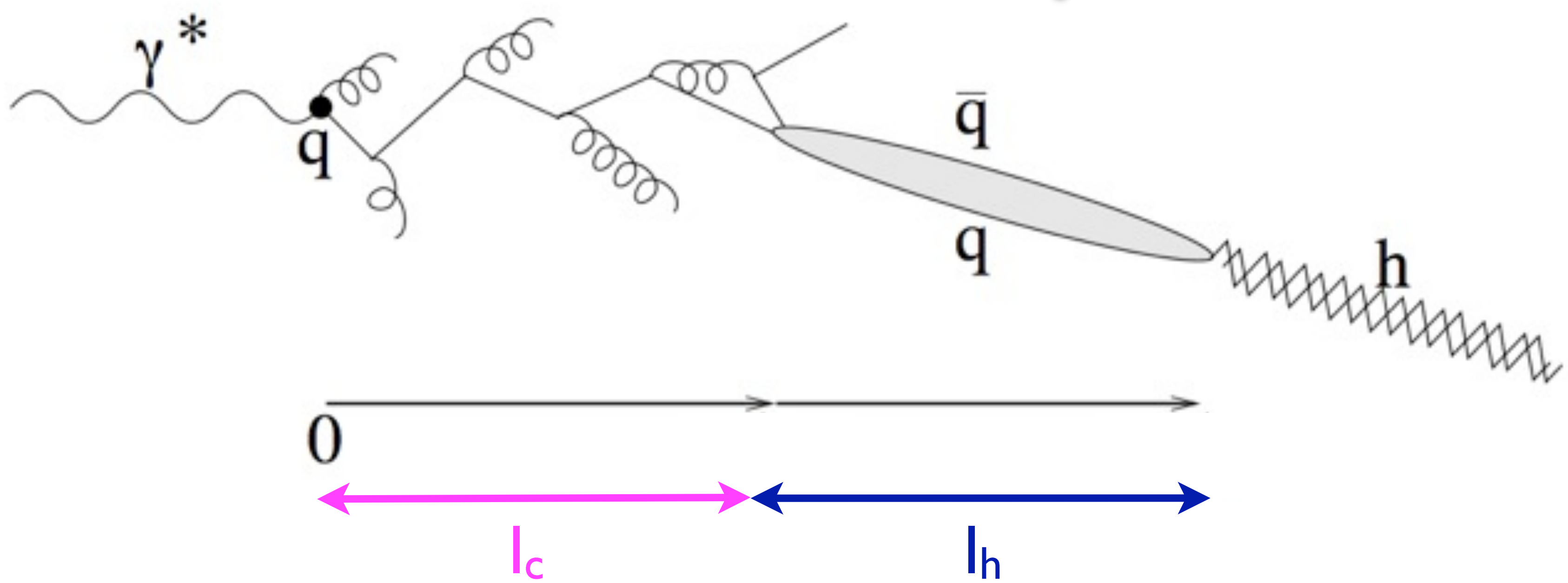
Formation length l_c ~ 1-10 fm ⇒ $\mathcal{O}$ (size of nucleon)

Nuclear effects in SIDIS



- use targets of different nucleon number A for different length scales to investigate space-time development of hadronization
  - HERMES: D, He, Ne, Kr, Xe
- nuclear effects:
  - hadron attenuation
  - p_t broadening

Hadron attenuation & p_t broadening



hadron attenuation

$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t)}{N^e(\nu,Q^2)}\right)_D}$$

Caused by partonic and hadronic effects:

- shift to lower energy
- absorption

⇒ sensitive to l_c and l_h

p_t broadening

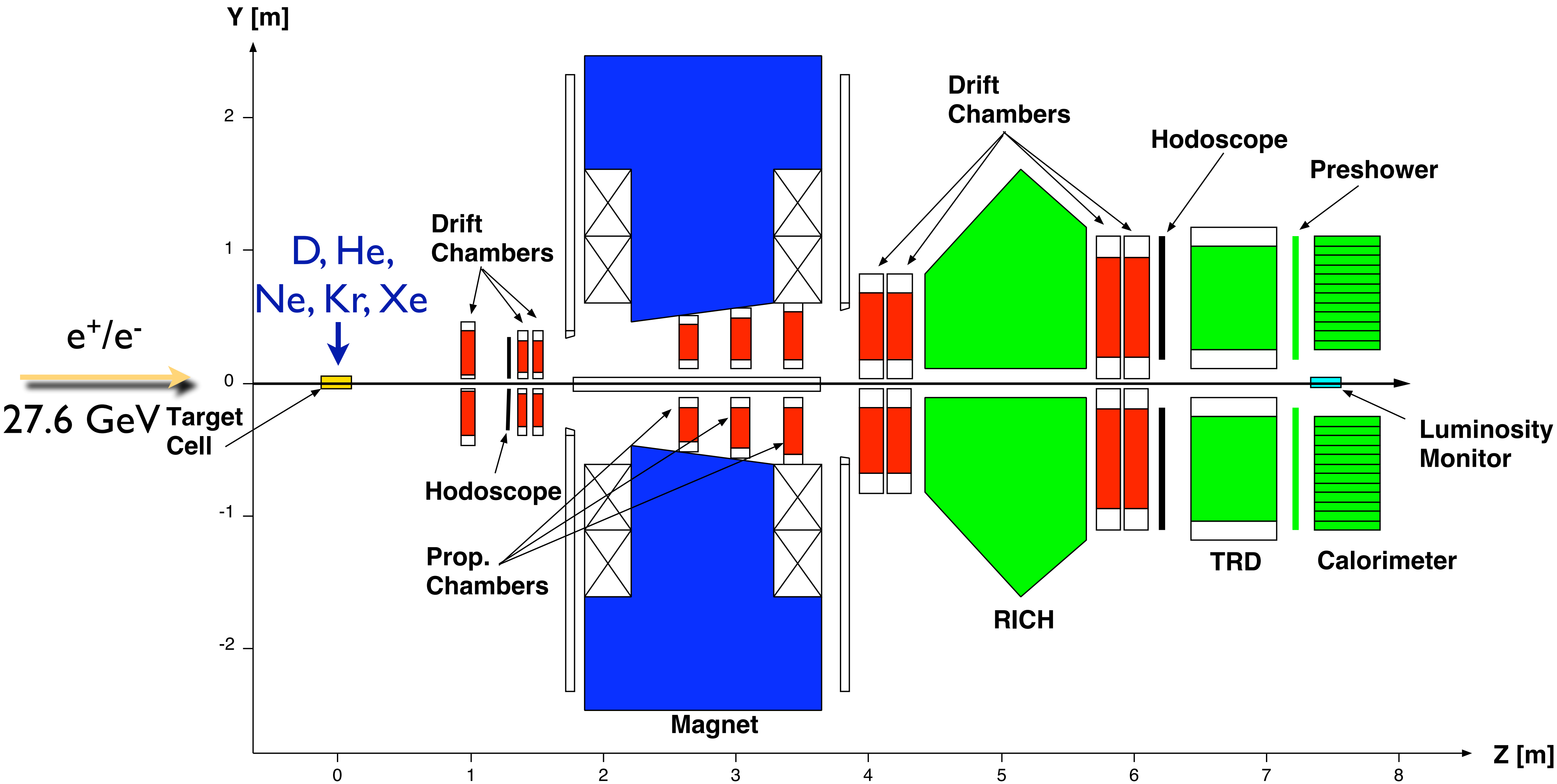
$$\Delta\langle p_t^2\rangle_A^h = \langle p_t^2\rangle_A^h - \langle p_t^2\rangle_D^h$$

Dominated by partonic effects:

- inelastic scattering suppressed
- elastic cross section small

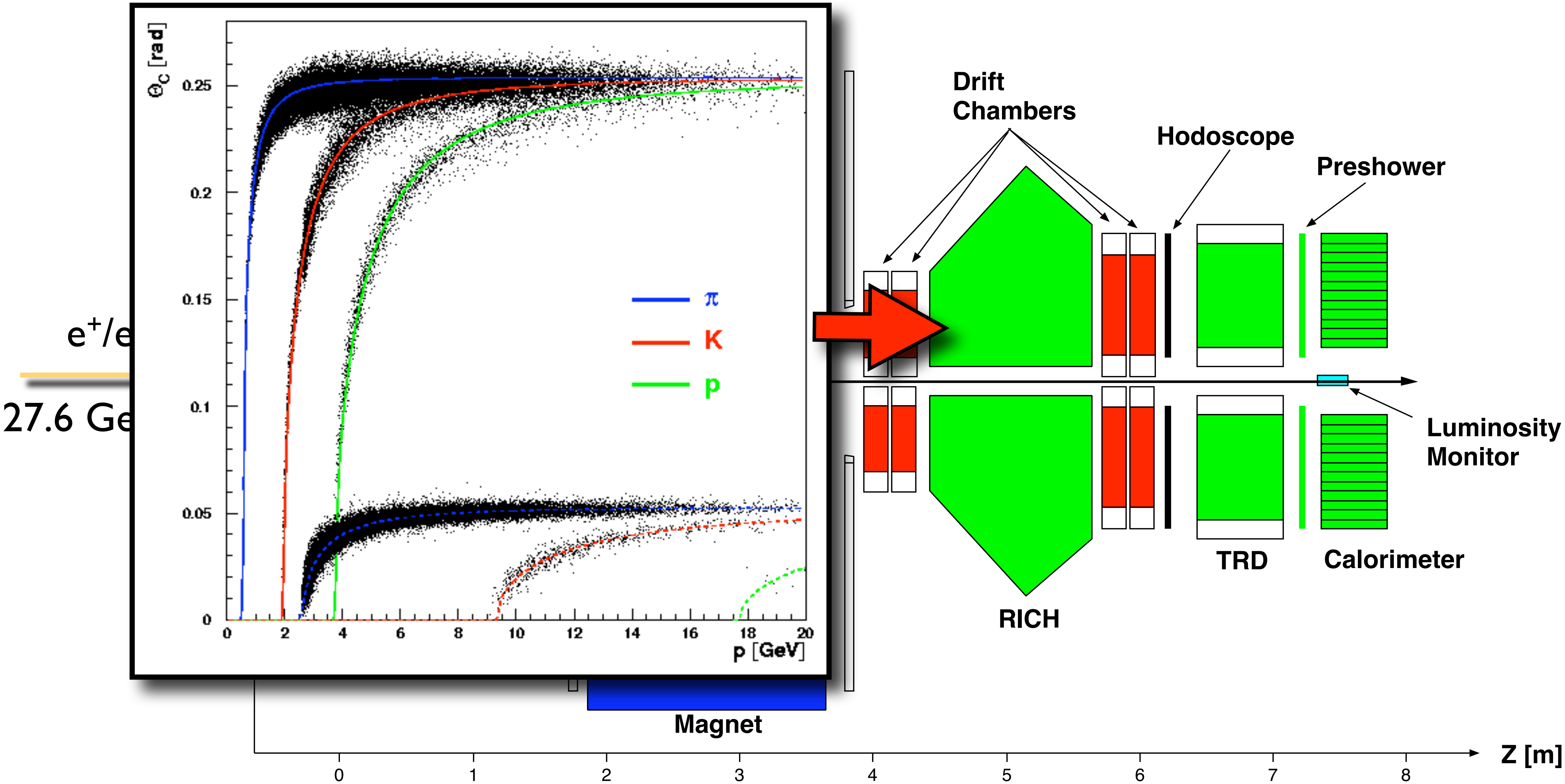
⇒ sensitive to l_c

HERMES Spectrometer



- Forward acceptance spectrometer: 40 mrad ≤ Θ ≤ 220 mrad
- Kinematic coverage: $0.02 \leq x_{Bj} \leq 0.8$ for $Q^2 > 1$ GeV^2 and $W > 2$ GeV
- Tracking: $\delta P/P$ = 0.7% - 2.5%, $\delta\Theta \leq 1$ mrad
- PID: TRD, Preshower, Calorimeter, RICH (Cherenkov before 1998)

HERMES Spectrometer



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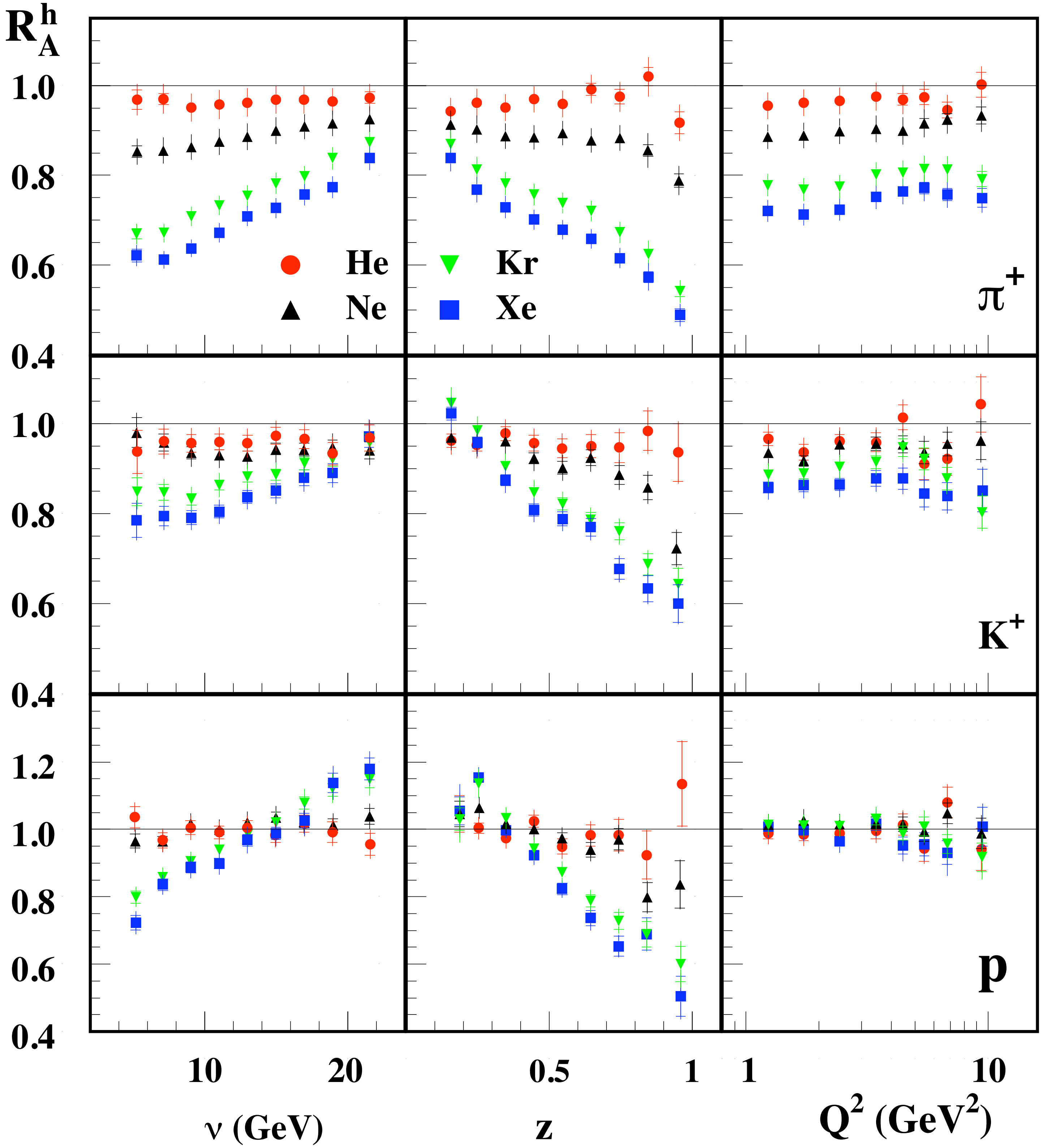
Hadron attenuation



$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t)}{N^e(\nu,Q^2)}\right)_D}$$

- attenuation: strong dependence on A
- large ν:
  - longer l_c (Lorentz boost)
  - less absorption
- z dependence:
  - partonic: Δz from energy loss & z dependence of FF
  - hadronic: decrease in h formation length & h absorption

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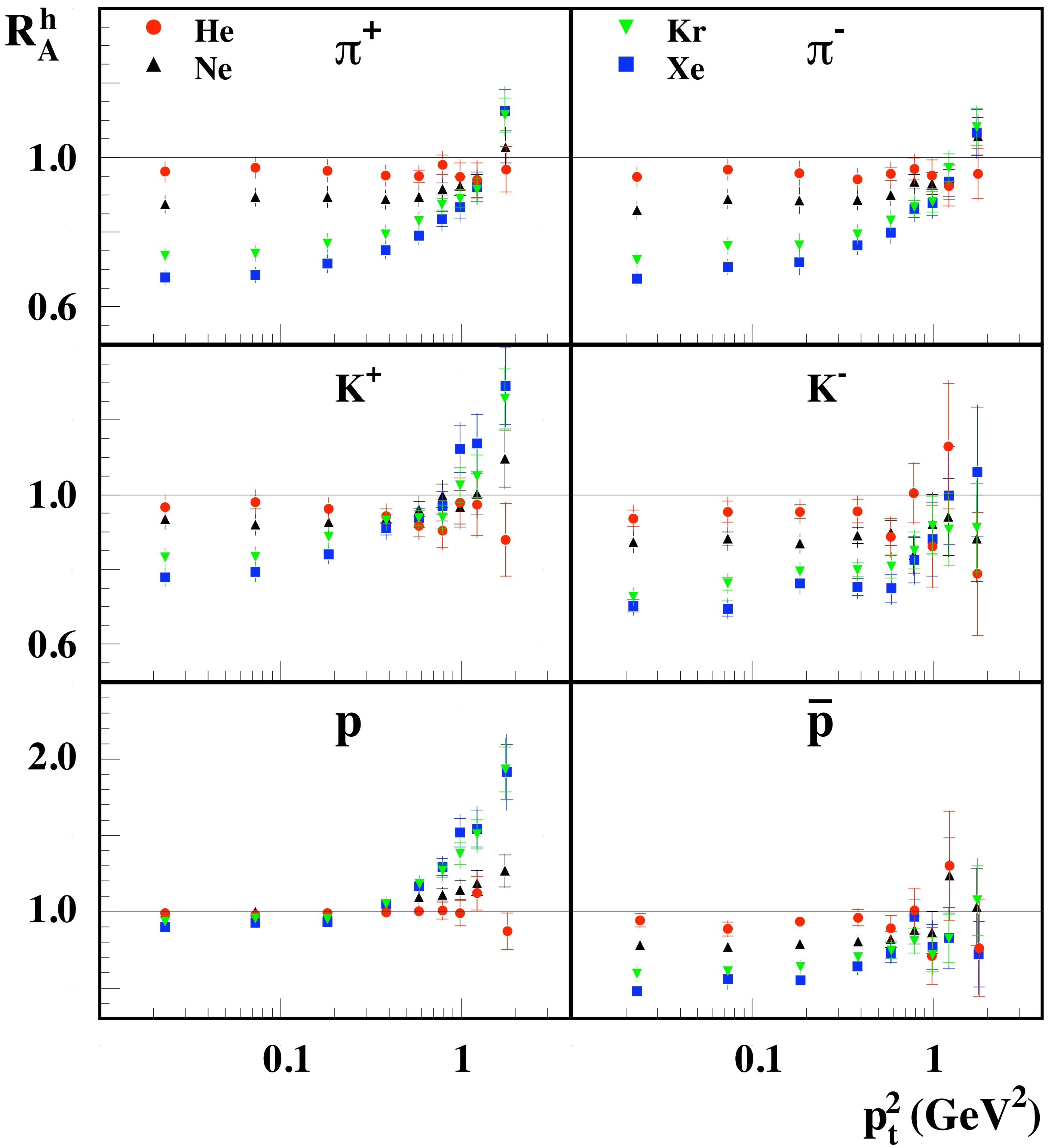
Hadron attenuation: p_t



$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t)}{N^e(\nu,Q^2)}\right)_D}$$

- for heavier nuclei: rise at high p_t^2
- Cronin-effect in DIS (no ISI)
- rise is attributed to a broadening of the p_t distribution

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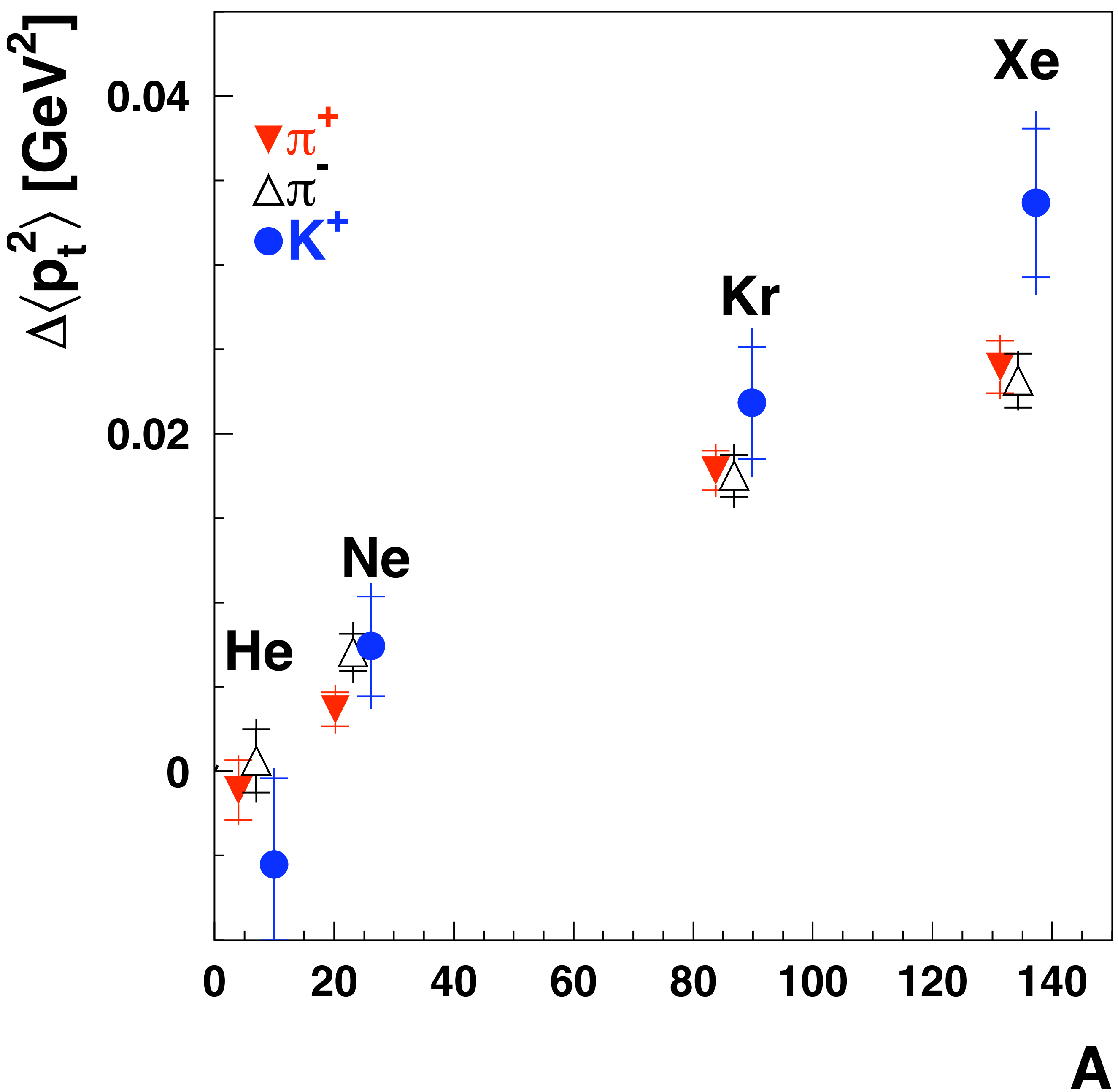
p_t broadening vs A



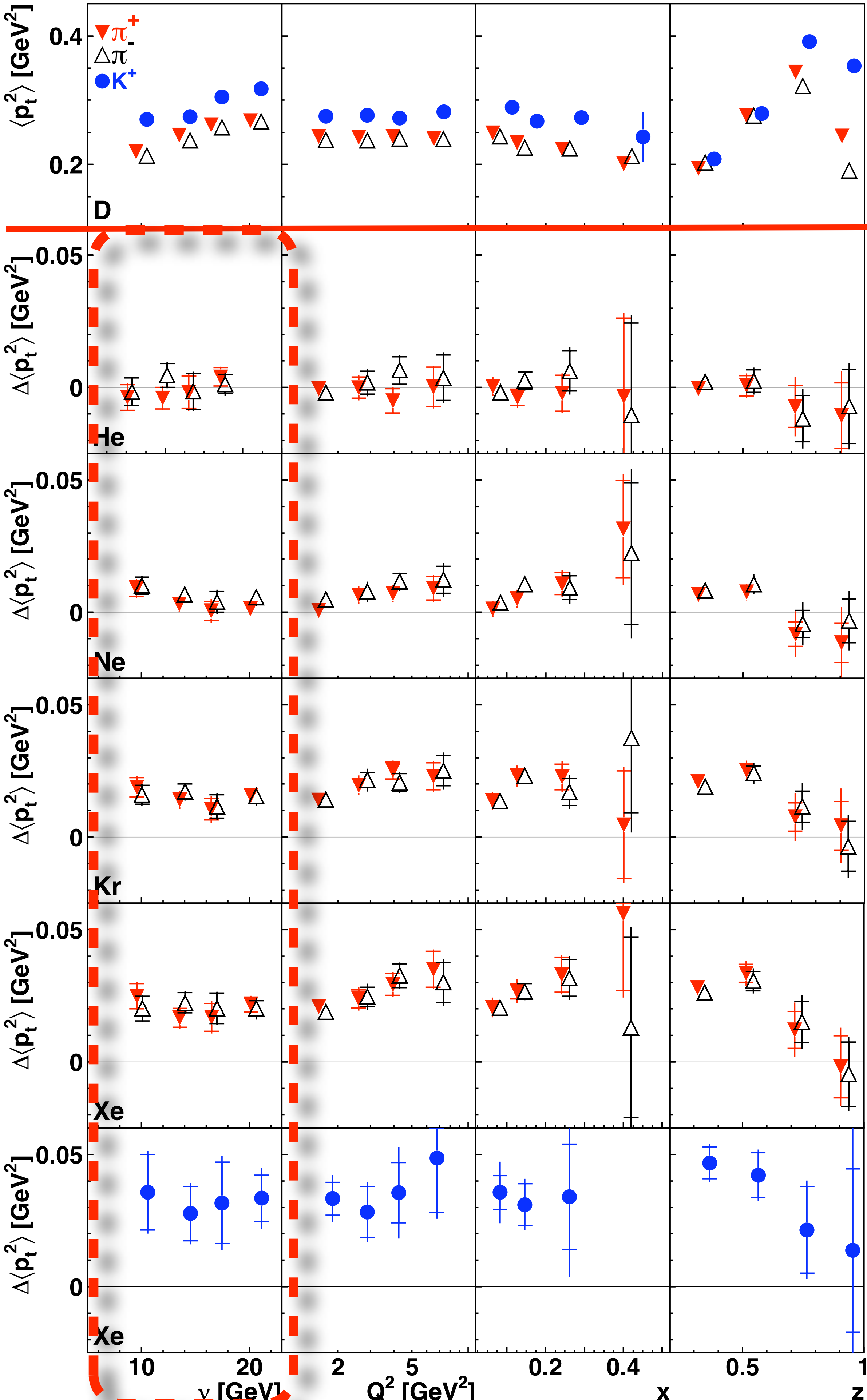
$<Q^2>=2.4$ GeV^2

$<\nu>=14.5$ GeV

$<z>=0.39$

- broadening increases with mass number A
  - similar for $\pi^{+/-}$
  - seems systematically higher for K^+
- precision does not allow firm conclusion about functional form of the increase with A
- no saturation observed
  - p_t broadening due to effects in the partonic stage
  - pre-hadron formation near/ outside surface

arXiv:0906.2478



$$\Leftarrow \langle p_t^2 \rangle_D^h$$

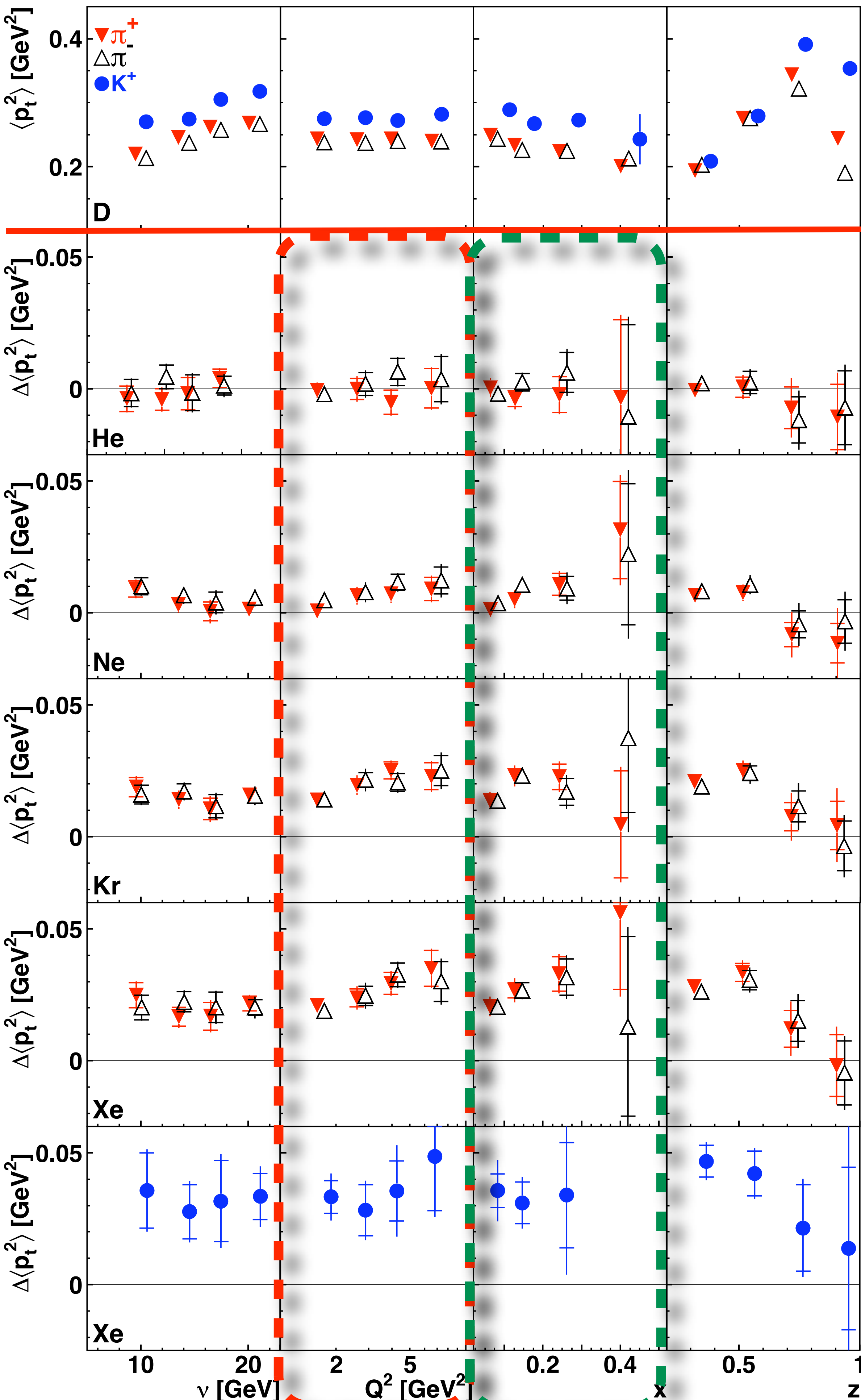
$$\Delta\langle p_t^2 \rangle_A^h = \langle p_t^2 \rangle_A^h - \langle p_t^2 \rangle_D^h$$

... vs. ν :

- in models commonly connected with the formation length
- flat behavior

supports the notion that color neutralization mainly happens at the surface/outside of the nucleus

arXiv:0906.2478



$\Leftarrow \langle p_t^2 \rangle_D^h$

$$\Delta\langle p_t^2 \rangle_A^h = \langle p_t^2 \rangle_A^h - \langle p_t^2 \rangle_D^h$$

... vs. Q^2 / vs. x_B

- similar behavior vs. Q^2 and x_B (strong correlation in HERMES kinematics)
- slight increase with both variables
- direct interpretation difficult
- different model predictions

  $\Rightarrow$ result helps to distinguish models

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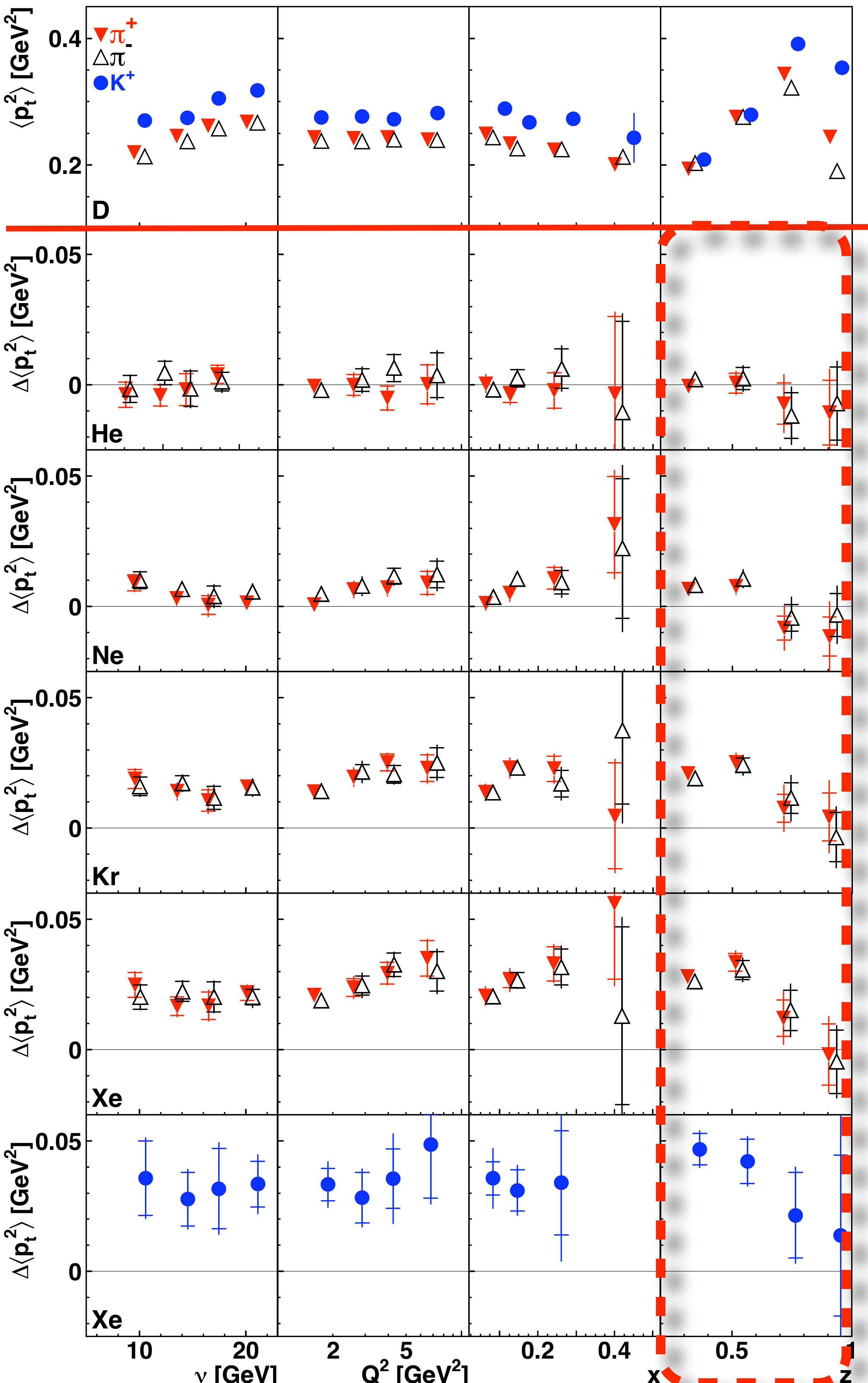


$\Leftarrow \langle p_t^2 \rangle_D^h$

$$\Delta\langle p_t^2 \rangle_A^h = \langle p_t^2 \rangle_A^h - \langle p_t^2 \rangle_D^h$$

... vs. z :

- p_t broadening vanishes as z → 1
- z=1 : no energy loss
  - no room for p_t broadening
  - except possible primordial k_t modification vs. A
- results indicates no or little dependence of k_t on the size of the nucleus
- p_t broadening not due to elastic scattering of (pre-) hadrons

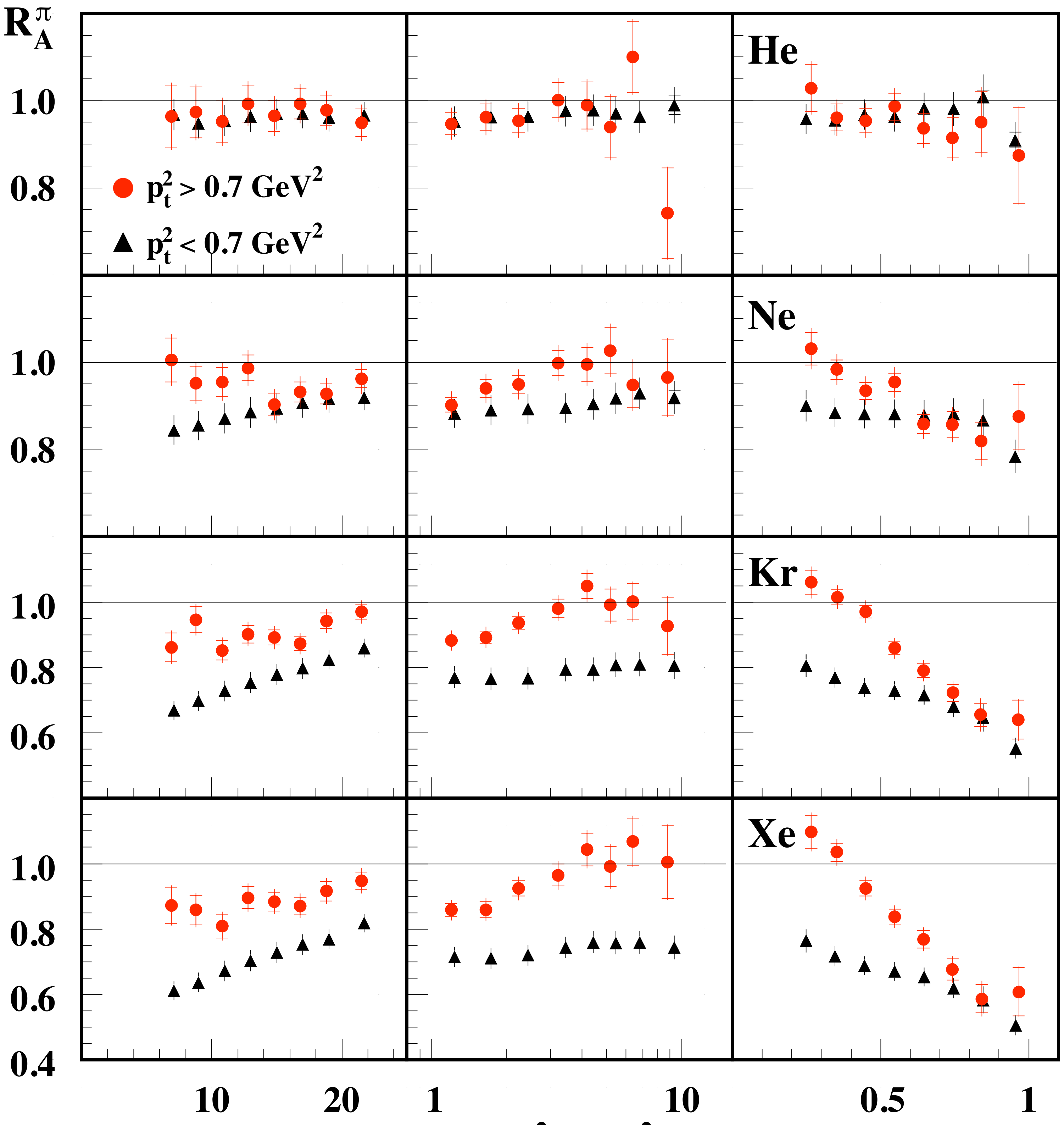
arXiv:0906.2478

Conclusions

- HERMES provides the largest data set to study space-time evolution of hadronization
- final results on hadron attenuation *(Nucl. Phys. B 780 (2007) 1)*
  - strong A dependence
  - less attenuation with larger ν and low z
  - multiplicity ratio rises at high p_t^2 (Cronin effect)
- final results on p_t broadening *(arXiv:0906.2478)*
  - p_t^2 broadening is mostly caused by partonic effects
  - color neutralization happens outside (or close to the surface) of the nucleus

Hadron attenuation

charged pions



$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t)}{N^e(\nu,Q^2)}\right)_D}$$

- stronger attenuation for larger A
- low p_t^2 bin:
  strong ν dependence
- less attenuation for large p_t (attr. to broadening of the p_t distribution, Cronin effect)
- high p_t^2 bin:
  effect vanishes for large z

⇒ consistent with the idea that rise at large p_t^2 is of partonic origin

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