
# Hadron Formation in Semi-Inclusive DIS on Nuclei at HERMES

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- √ Nuclear broadening
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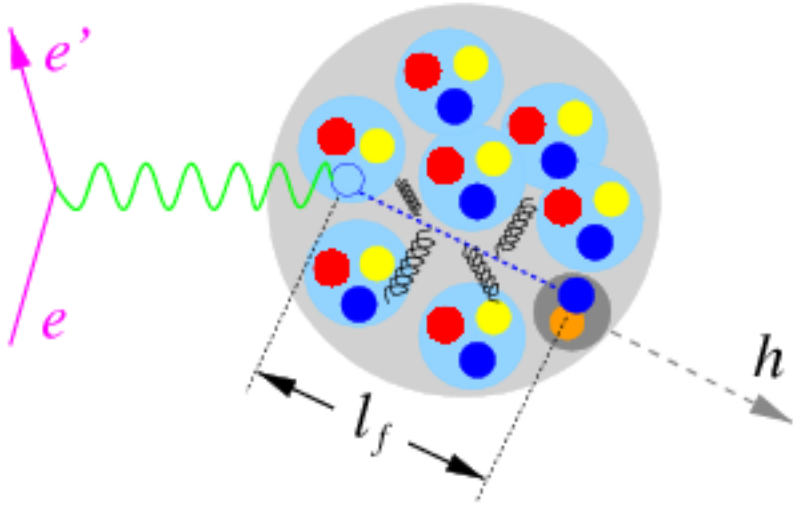
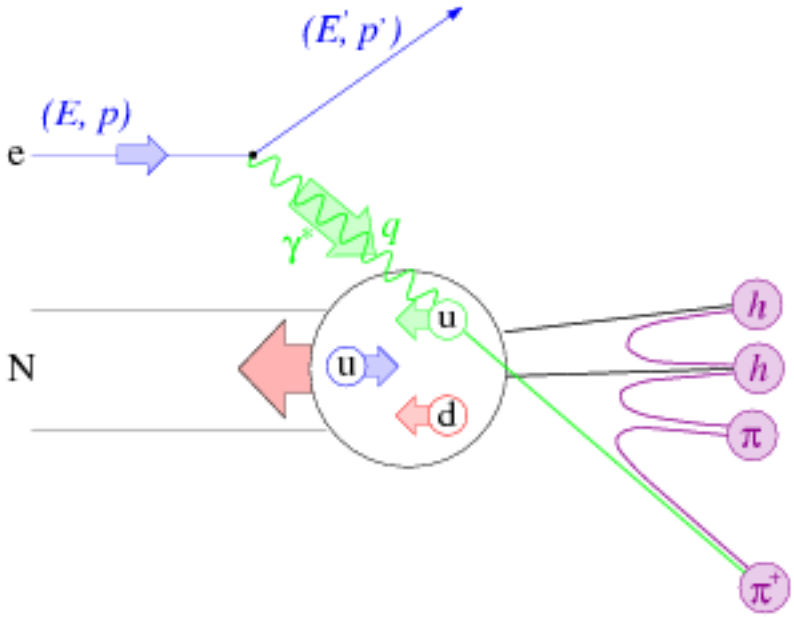
# Motivation




- **Understanding of the hadronization process:**
  - **parton energy-loss mechanism in nuclear matter**
  - **space-time evolution of the hadron formation process**
- **relativistic ion-ion collisions**

**HERMES offers suitable energy range, set of nuclear targets, PID for hadrons; clean initial state**

# Hadronization in a nucleus

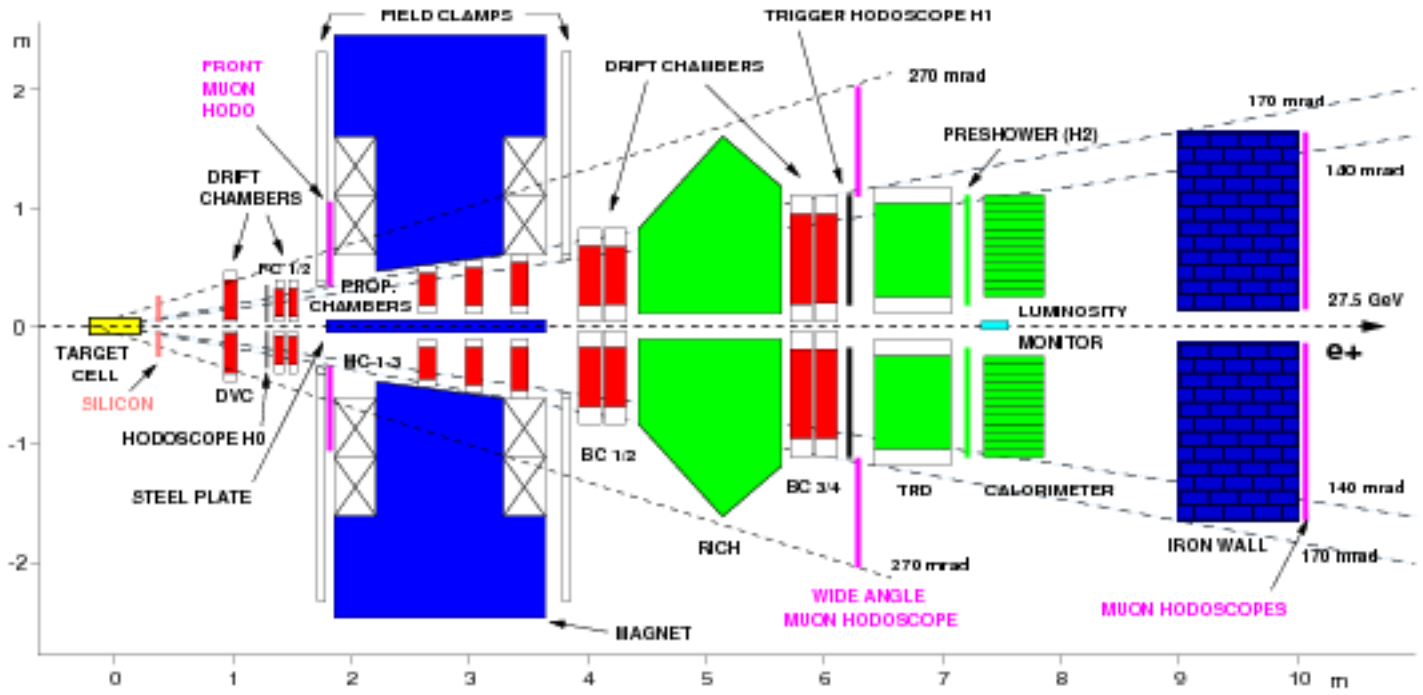



- Experimental access to the hadronization process through the measured multiplicity ratio:

- $\nu = E - E'$
- $Q^2 = -q^2 = -(p - p')^2$
- $z = E_h/\nu$

$$R_M^h(\nu, Q^2, z, p_T^2) = \frac{\left(\frac{N_h^{SIDIS}(\nu,Q^2,z,p_T^2)}{N_e^{DIS}(\nu,Q^2)}\right)_A}{\left(\frac{N_h^{SIDIS}(\nu,Q^2,z,p_T^2)}{N_e^{DIS}(\nu,Q^2)}\right)_D}$$

# The HERMES Setup

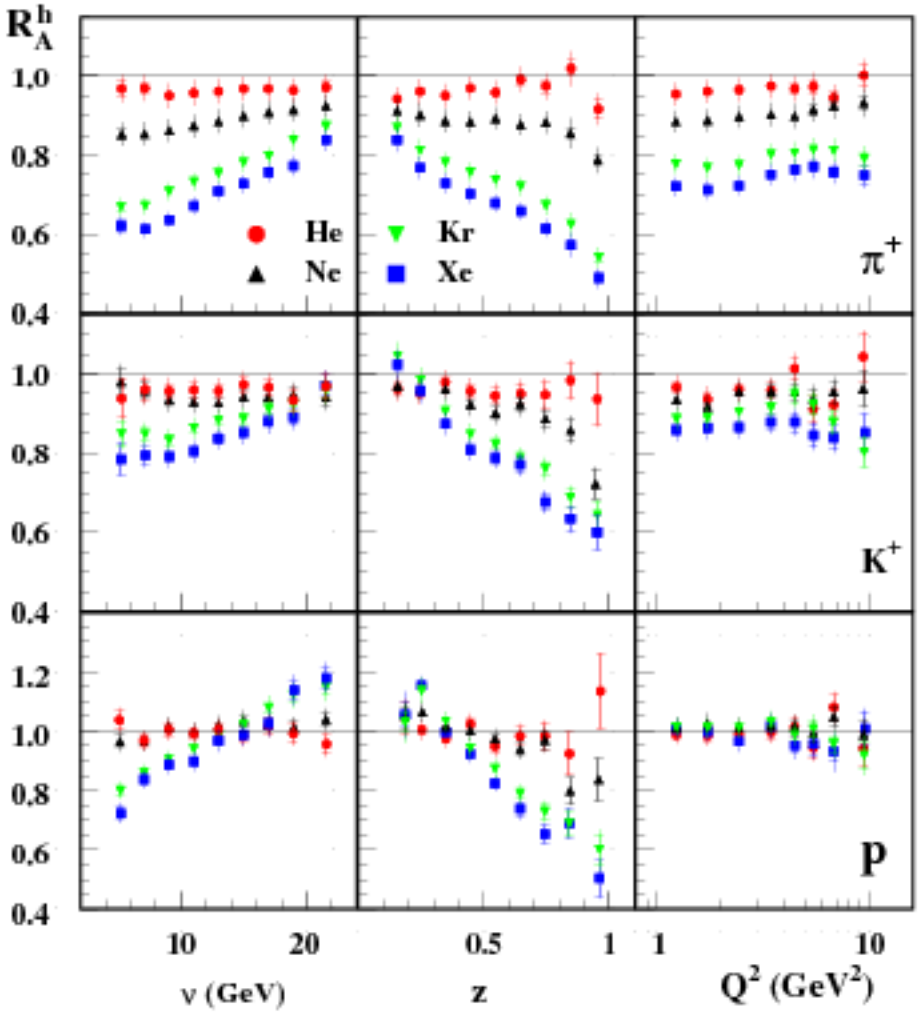


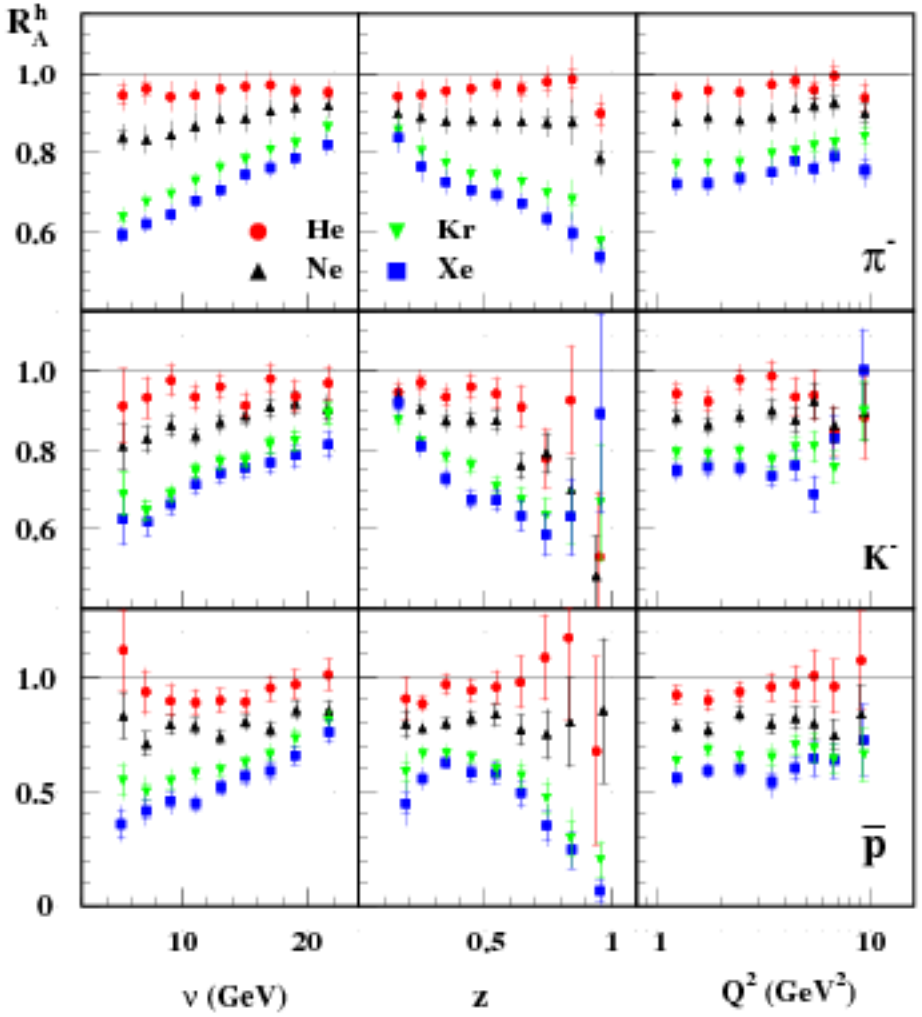

- **Beam:** $e^{\pm}, E_{beam} = 27.6\ GeV$
- **Acceptance:** $\theta_h = \pm 170\ mrad$

  $\theta_v = \pm(40 - 140)\ mrad$
- **Identified charged hadrons (RICH):** $\pi^{\pm}$, $K^{\pm}$, $p$, $\overline{p}$
- **Momentum range:** $2 < p < 15\ GeV$
- **Internal storage cell gas targets:**

  $D, {}^4He, N, Ne, Kr, Xe$

# Multiplicity ratios




NP B780 (2007) 1-27

- Influence of the nuclear environment on hadron formation
  - Dependence of $R_M^h$ on the hadron type and charge

# Formation length dependence

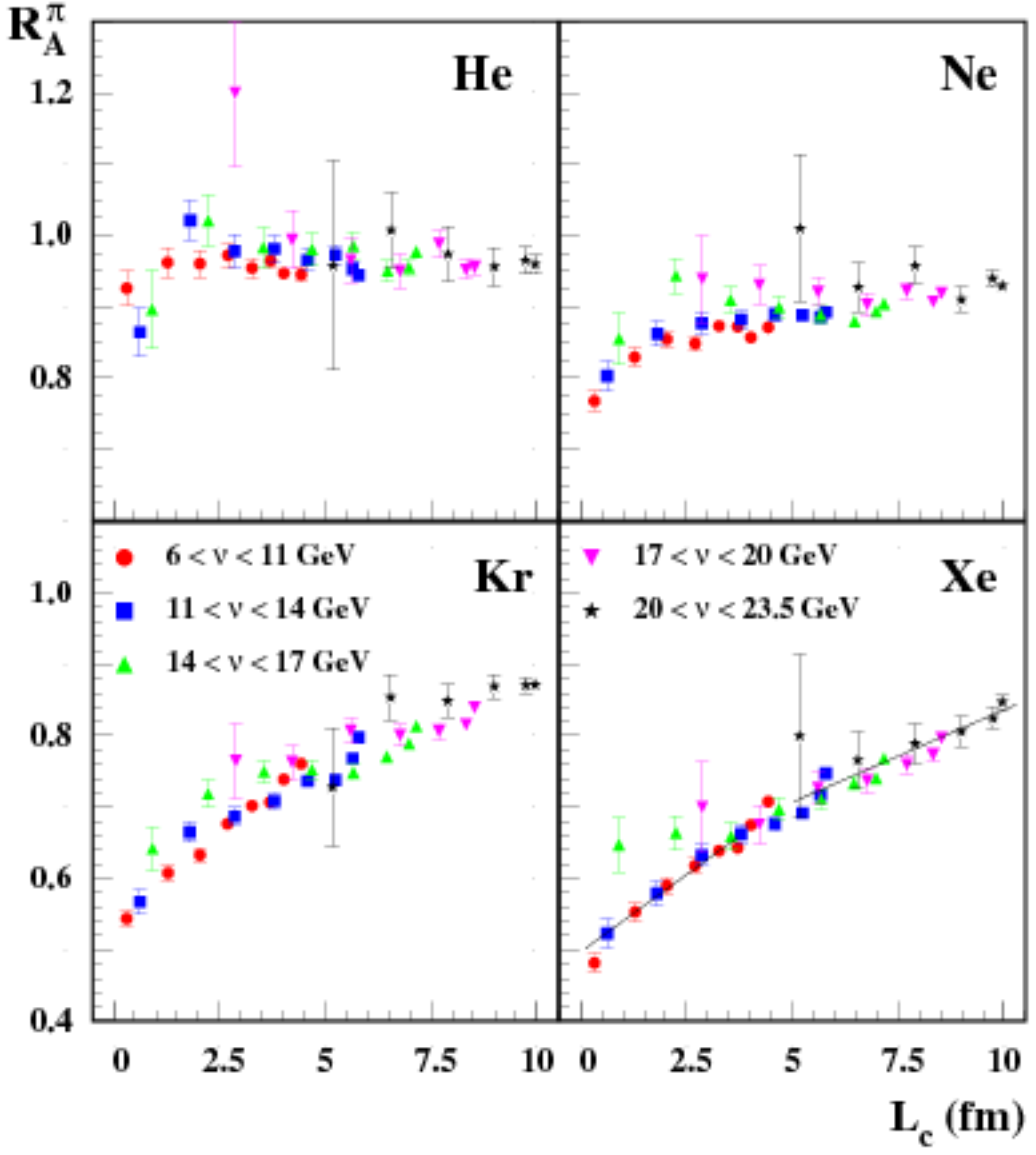
**Average value of formation length $l_c$ - $L_c$**

**Lund model by :**

$$L_c = f(z)\frac{\nu}{k}$$

$$f(z) = z^{0.35}(1-z)$$

**Phys.Lett.B649(2007) 384-389**



# A-dependence

**The A-dependence of $R_A^h$ was fit with:**

$$R_A^h = 1 - \beta A^\alpha$$

**In parton energy-loss models is assumed:**

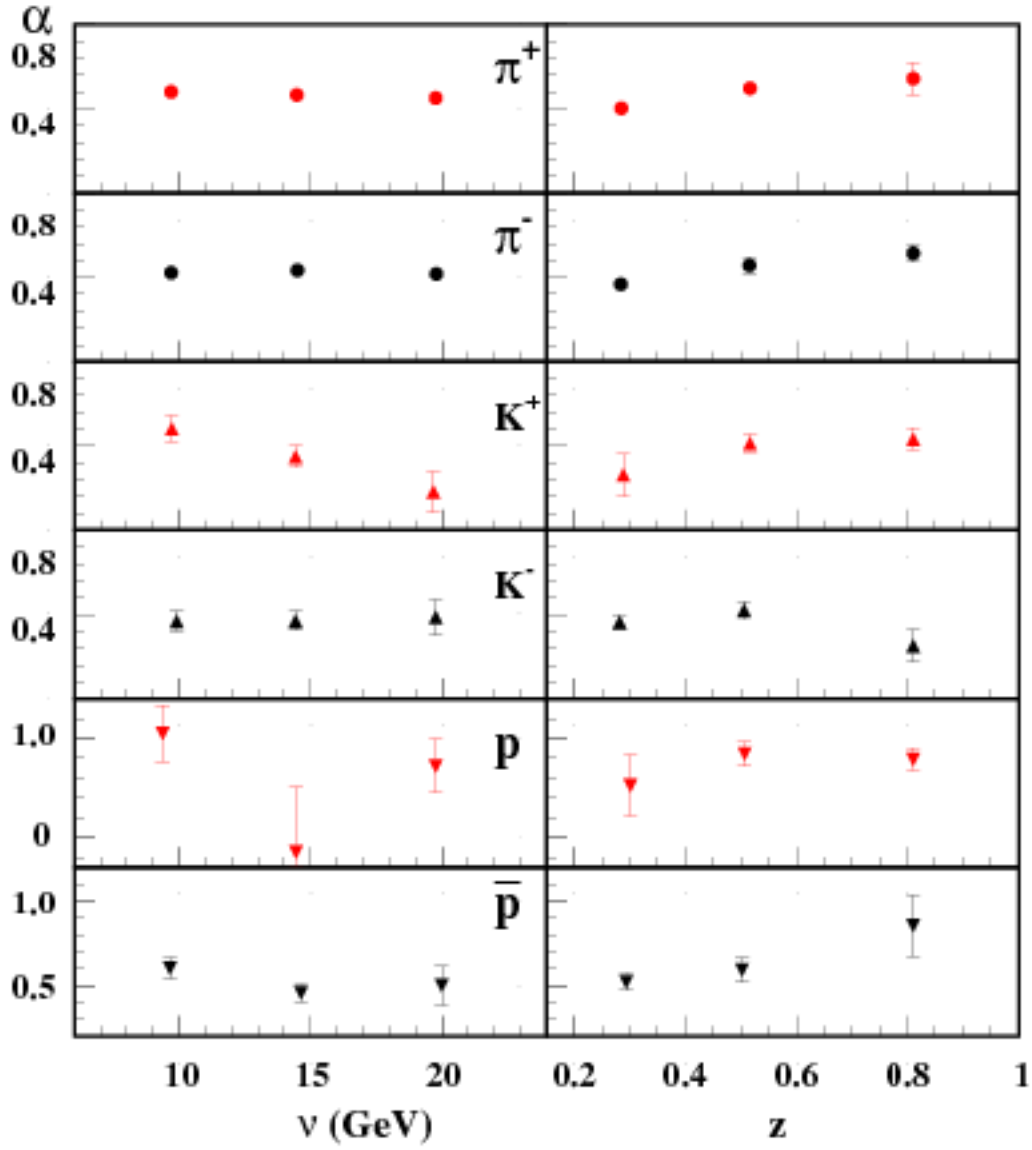
$$\text{1 - } R_A^h \sim L^2 \sim A^{2/3}$$

Phys.Rev.Lett.85(2000) 3591
Phys.Rev.Lett.89(2002) 162301

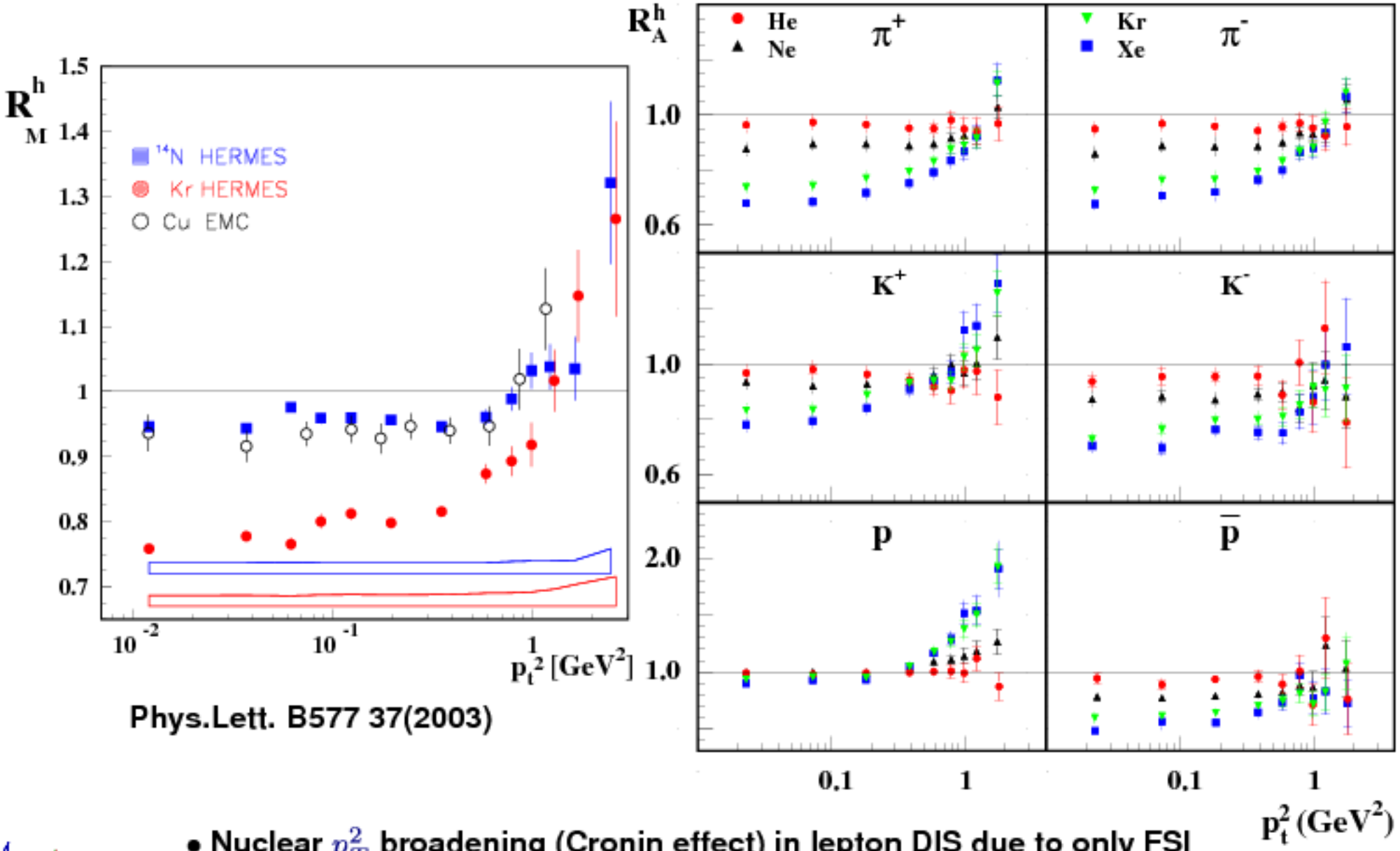
**In absorption models is assumed:**

$$\text{1 - } R_A^h \sim L \sim A^{1/3}$$

NP A761 (2005) 67-91



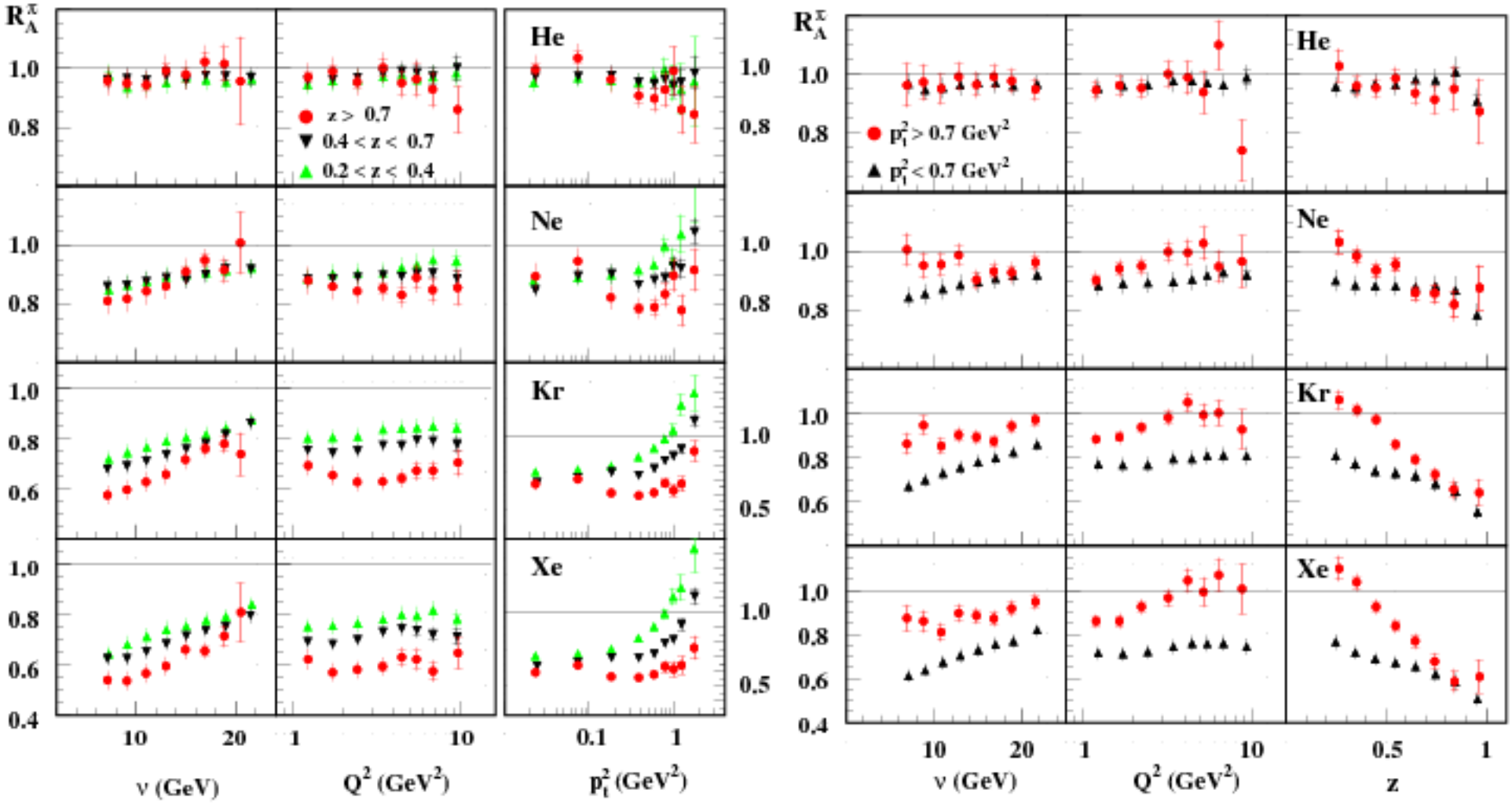
# Cronin effect




Phys.Lett. B577 37(2003)

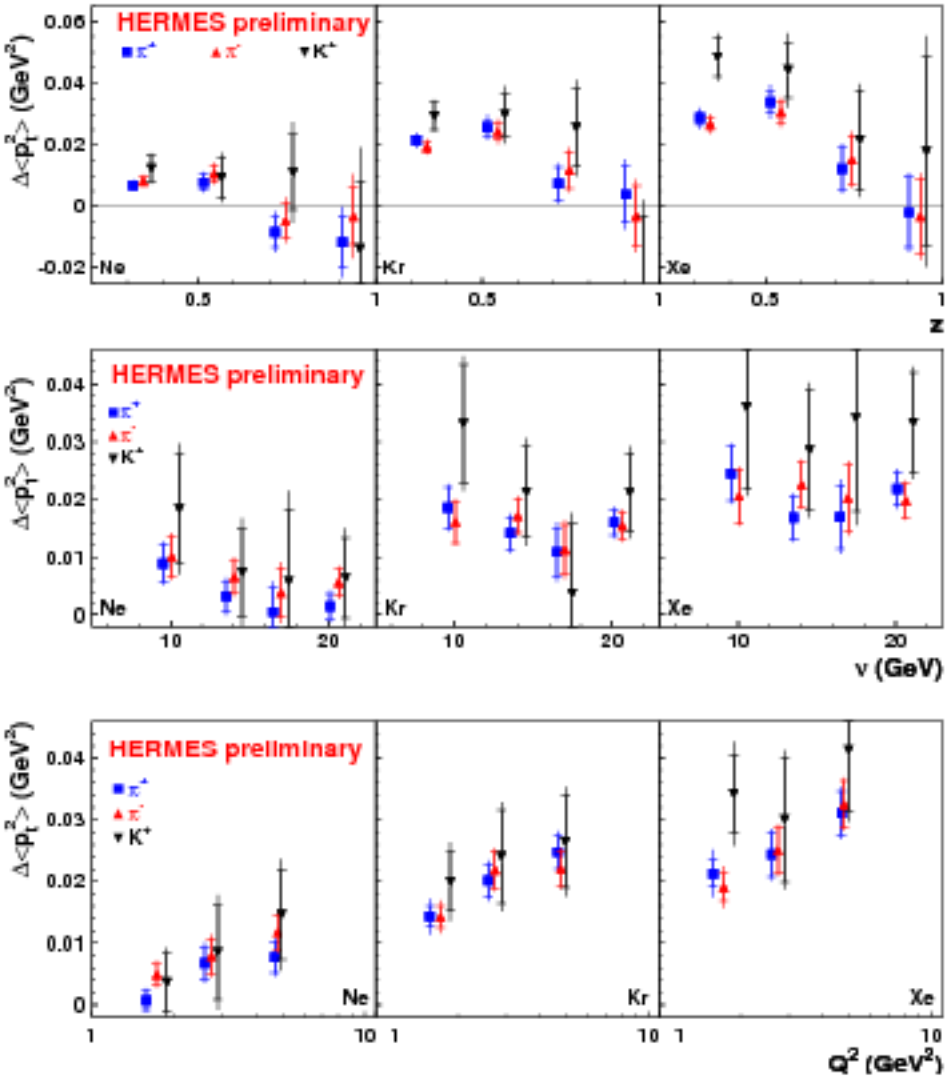
- Nuclear $p_T^2$ broadening (Cronin effect) in lepton DIS due to only FSI

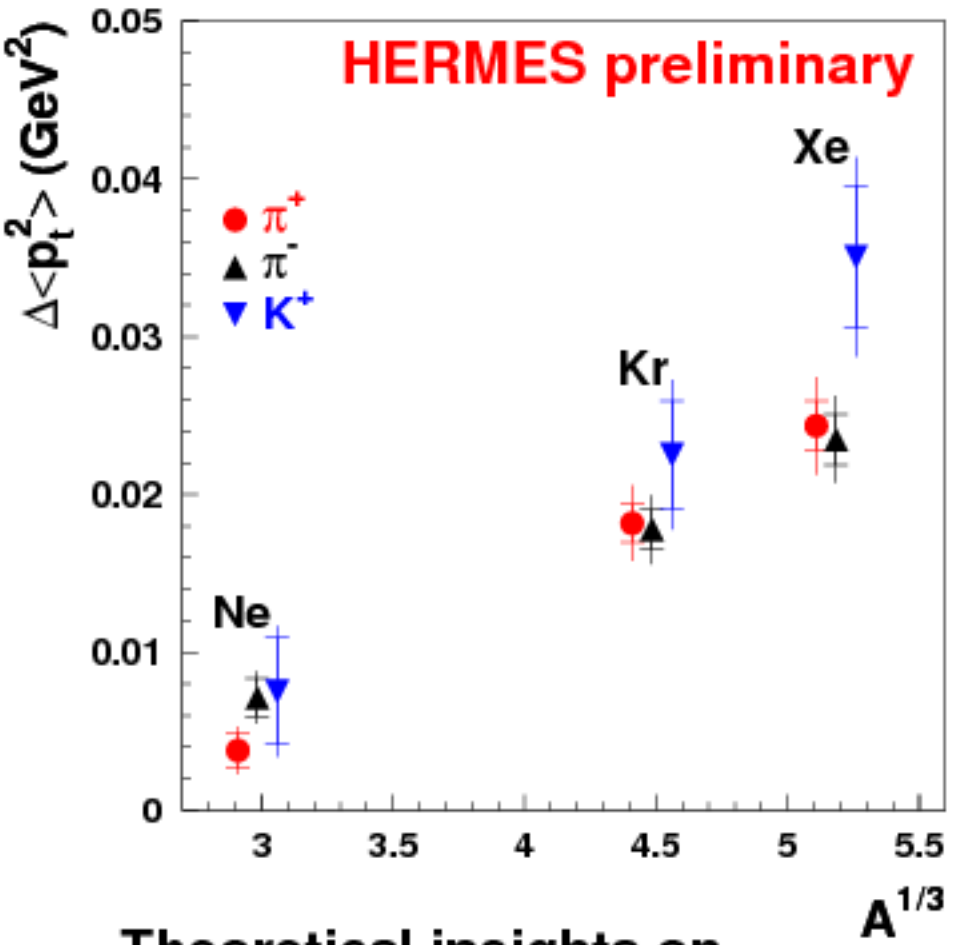
# Two-dimensional multiplicity ratios for pions




- Dependence of Cronin effect with $z$ range

# Transverse momentum broadening




**Theoretical insights on parton propagation and energy loss in cold nuclear matter**

- $\Delta < p_t^2 >_A^h = < p_t^2 >_A^h - < p_t^2 >_D^h$

# Double-hadron attenuation

## Additional way to study hadronization

$$R_{2h}(z_2) = \frac{\left(\frac{dN^{z_1>0.5}(z_2)/dz_2}{N^{z_1}}\right)_A}{\left(\frac{dN^{z_1>0.5}(z_2)/dz_2}{N^{z_1}}\right)_D}$$

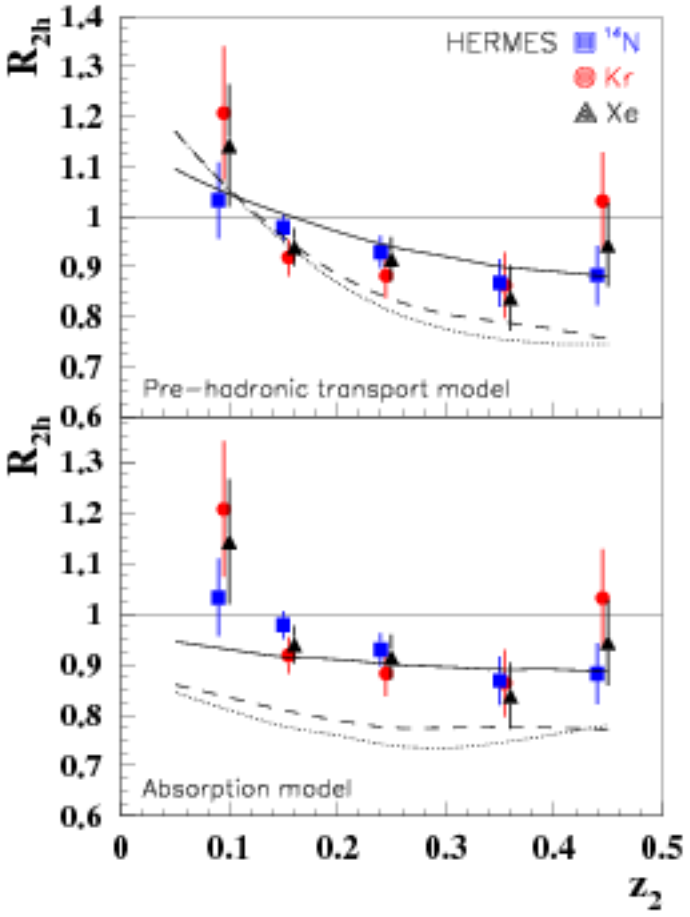
**Partonic energy loss mechanism:**

Ratio slightly dependent on the $A$

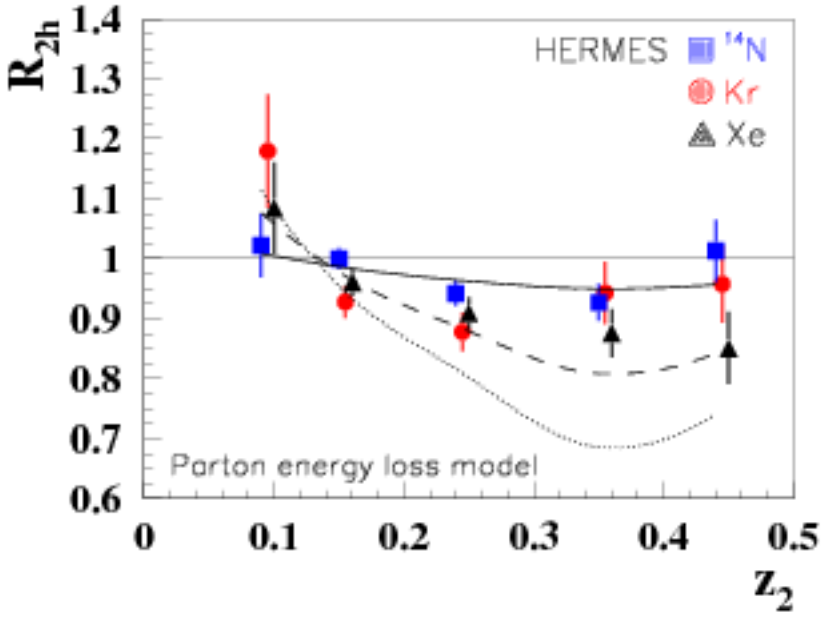
**The final hadron absorption:**

Ratio should decrease with $A$

# Double-hadron attenuation




Phys.Rev.Lett. 96(2006) 162301




**The curves from:**

X.N. Wang: Phys.Lett. B579 299(2004); A. Majumder Eur.Phys.J. C43 259(2005)

T.Falter et al.: Phys.Lett. B594 61(2004); Phys.Rev. C70 054609(2004)

K.Gallmeister and W. Cassing: Nucl.Phys. A748 241(2005)

**Double-hadron observables provide new information for differentiating between models**

# Overview of models

- **Rescaling model:**

  Gluon radiation and absorption of the produced hadron (A. Accardi et al.)

- **FF modification model:**

  Modification of parton FF to account for energy loss: multiple scattering and gluon bremsstrahlung (X.-N. Wang et al.)

- **Gluon Bremsstrahlung model:**

  Vacuum and induced energy loss, attenuation of colorless pre-hadrons in nuclear medium (B. Kopeliovich et al.)

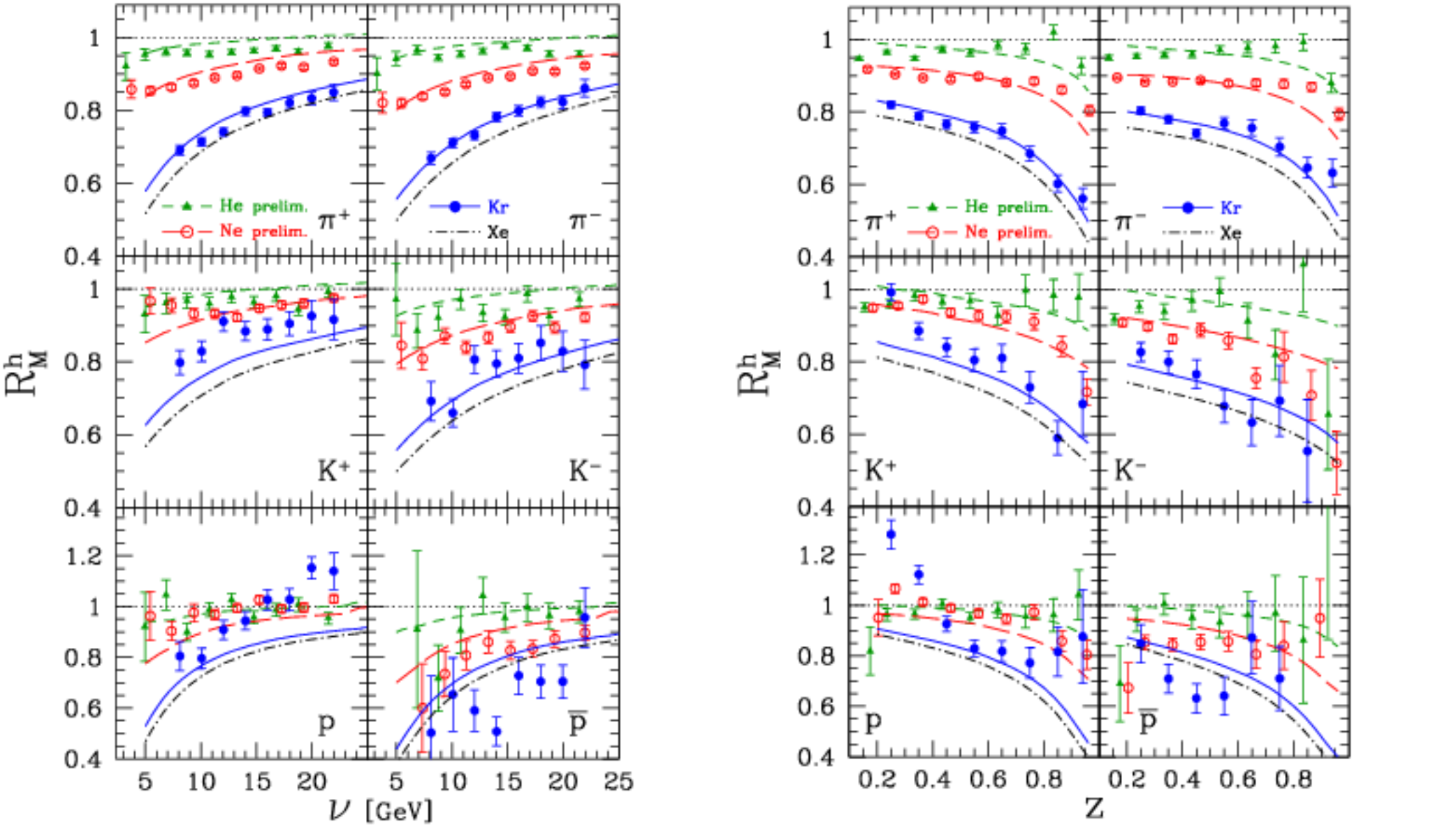
- **BUU transport model:**

  Full coupled-channel treatment of FSI by means of BUU transport model, where while interacting with the nucleon, hadron may not only be absorbed but can also be decelerated in an elastic or inelastic collission (T. Falter et al.)

- **String models:**

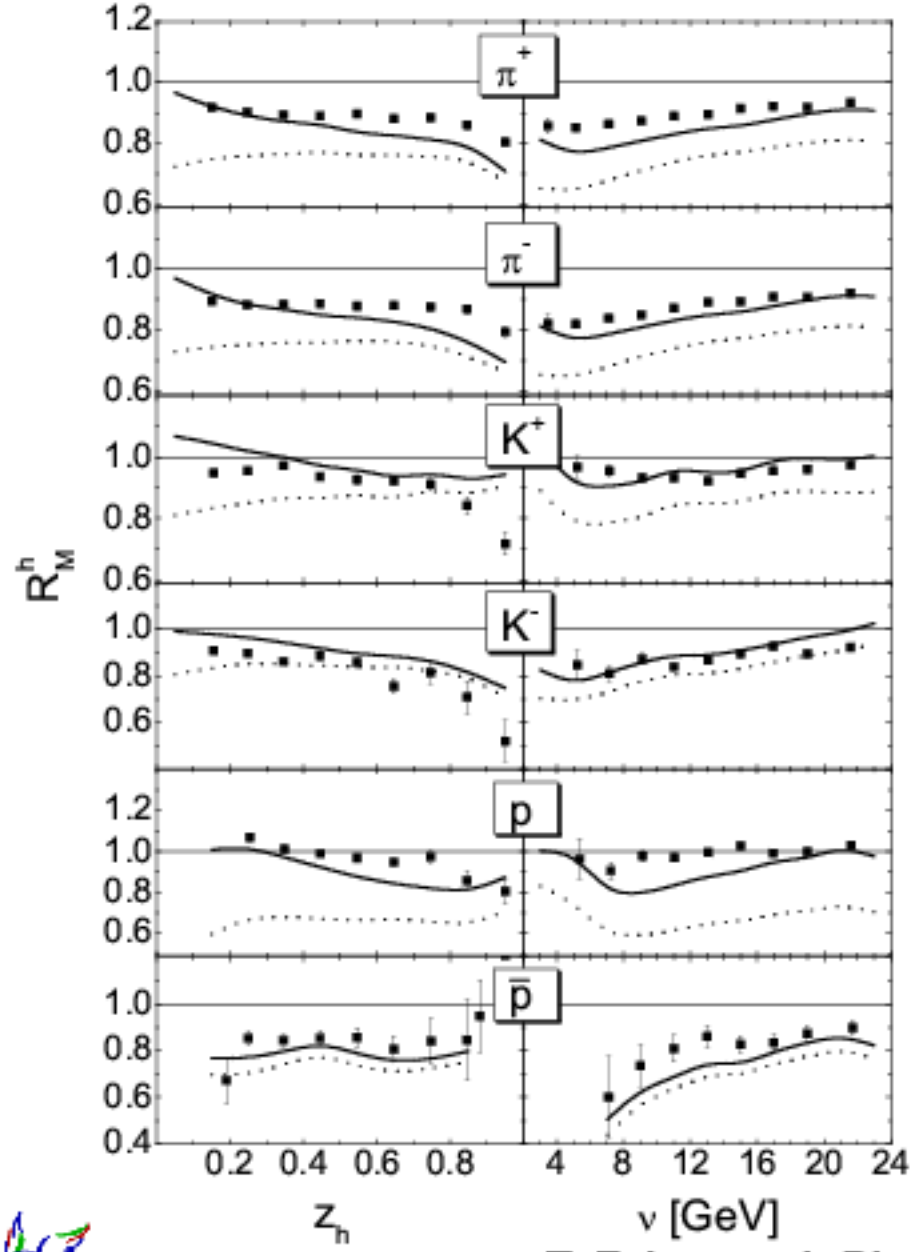
  Colorless pre-hadrons system-string-propagates in nuclear medium, multiple interactions and gluon radiation (e.g. B. Andersson et al., A. Bialas et al., N. Akopov et al.)

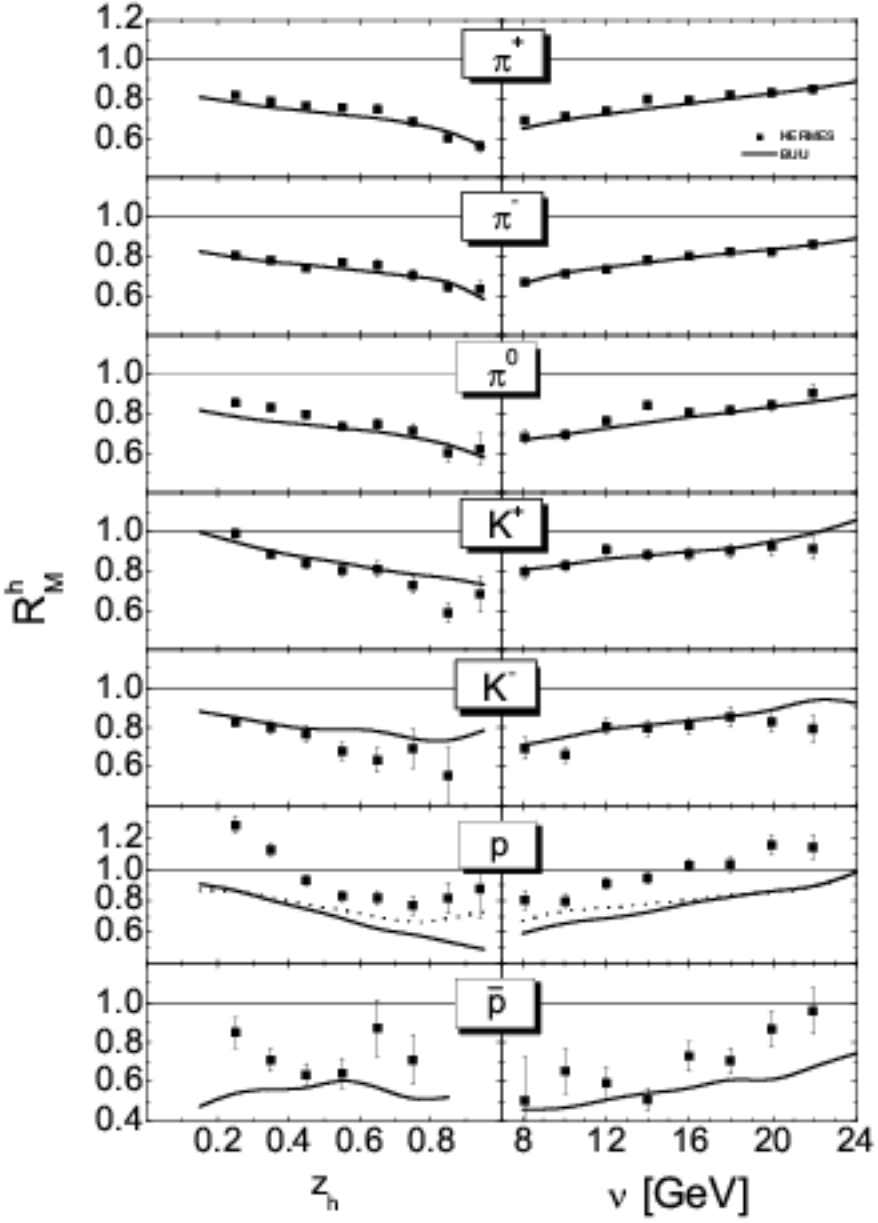
# Rescaling model




A. Accardi et al. NP A 761 (2005) 67

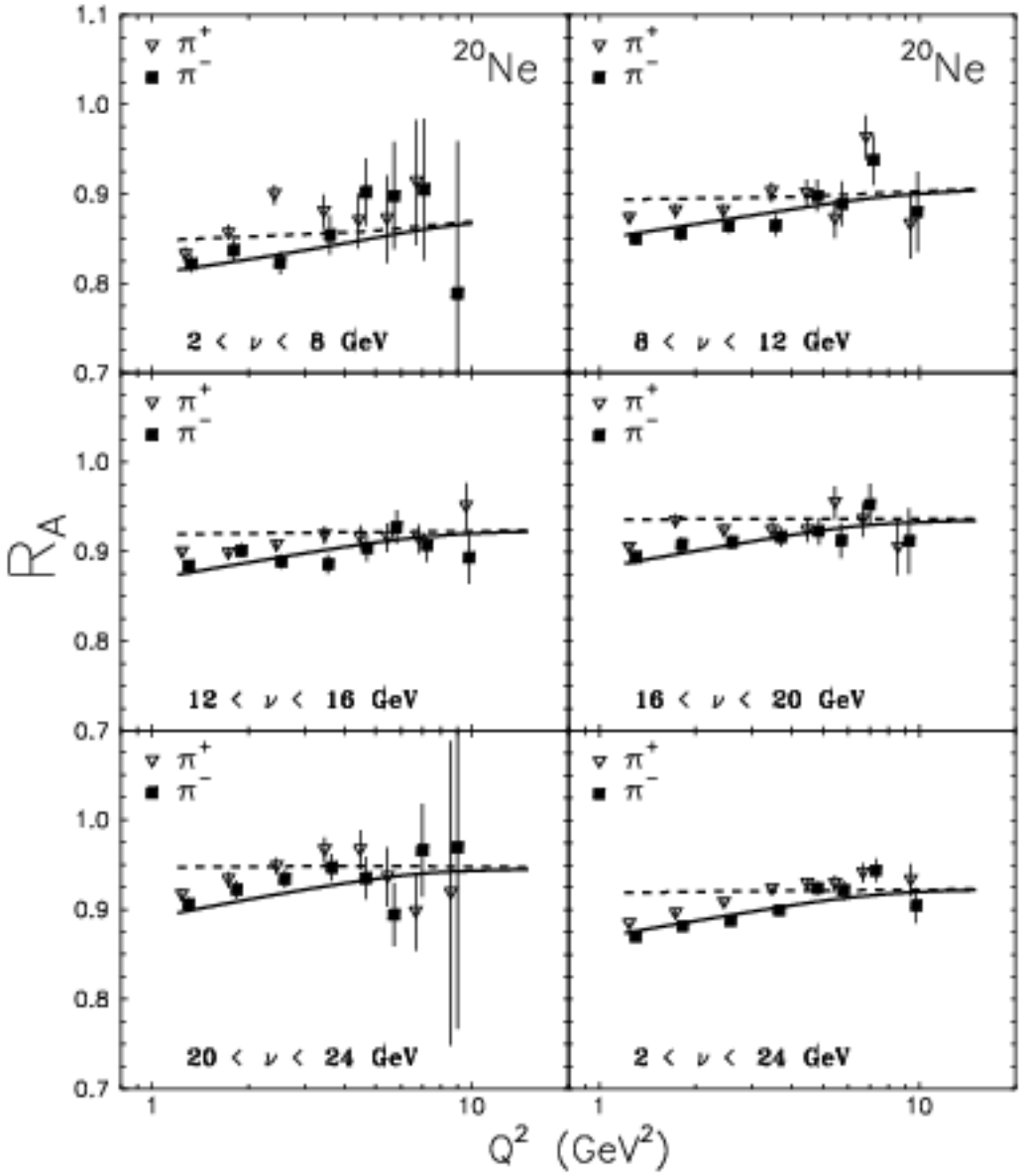
# BUU model

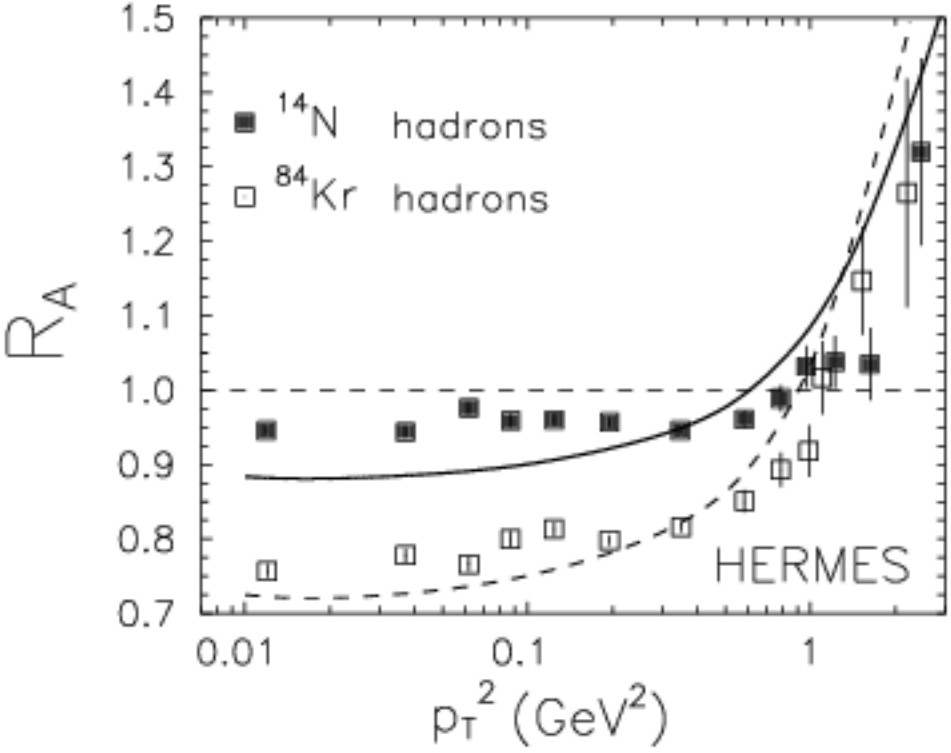



T. Falter et al. Phys. Rev C 70 (2004) 054609

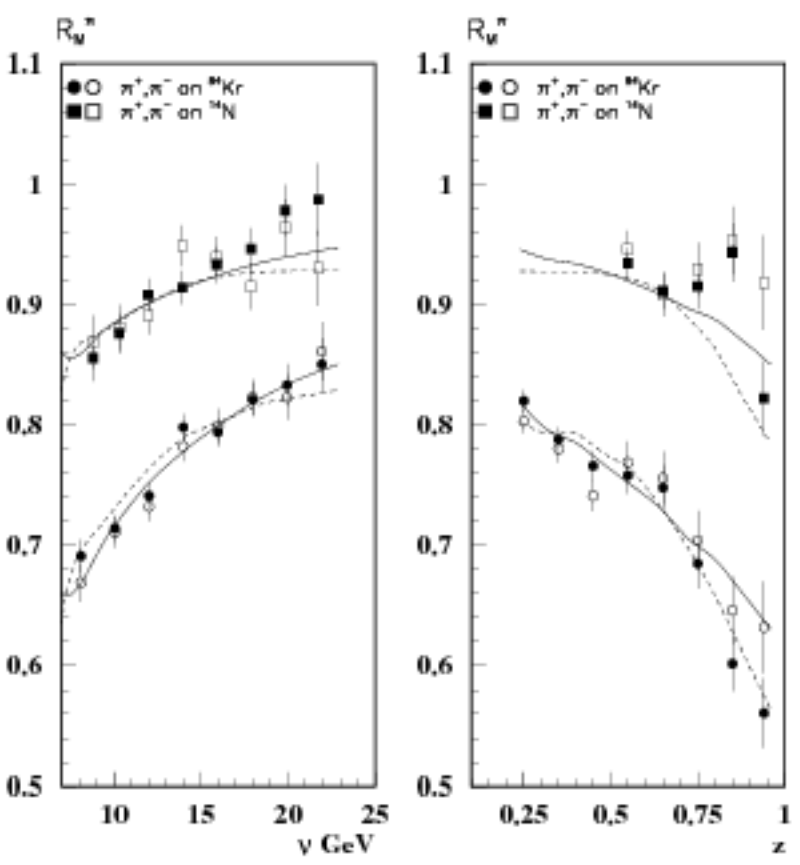
# Gluon bremsstrahlung model

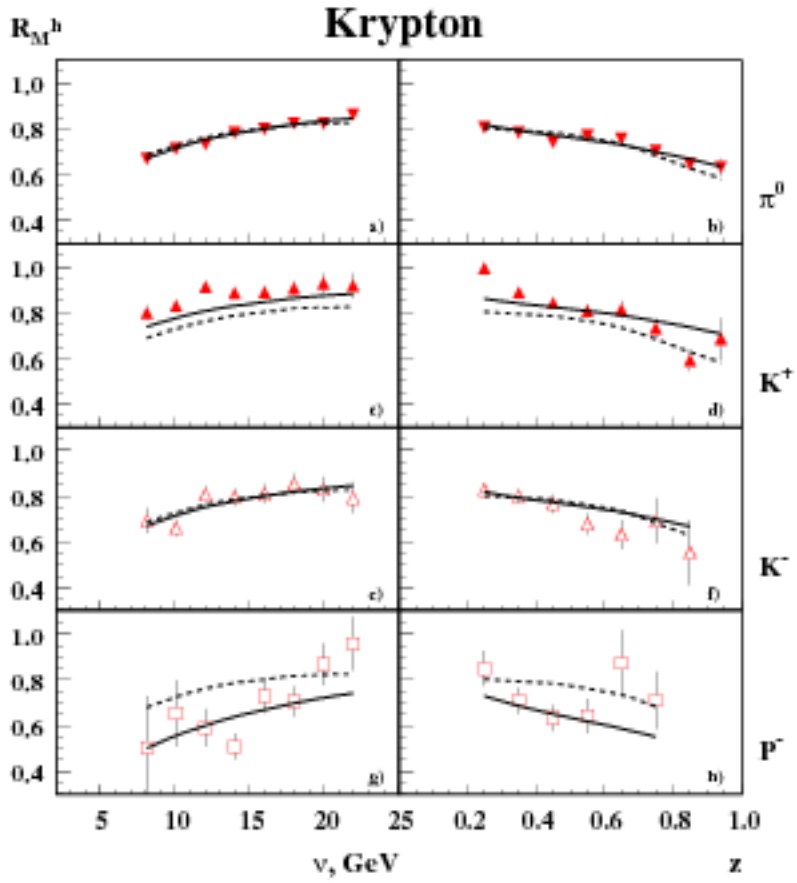



**B. Kopeliovich et al. NP A 740 (2004) 211**

# String model




N. Akopov et al. Eur.Phys. J. 44(2005) 219

**The hadronization in the nuclear medium is sensitive to the combination of both energy loss and nuclear absorption mechanism**

# Summary

* Hadron multiplicity ratios for $\pi^{\pm}$,$K^{\pm}$, $p$ and $\overline{p}$ on $^4He$, $Ne$, $Kr$ and $Xe$ targets have been measured at HERMES
* Substantial nuclear attenuation observed as a function of kinematic variables such as $\nu$, $z$, $p_T^2$ and $Q^2$
* Clear indication of influence of the nuclear environment on hadron formation process
* Broadening: provide theoretical insights on parton propagation and energy loss in cold nuclear matter
* Double-hadron attenuation: new tool to study modification of hadronization in nuclear matter