Can we distinguish energy loss from hadron absorption?

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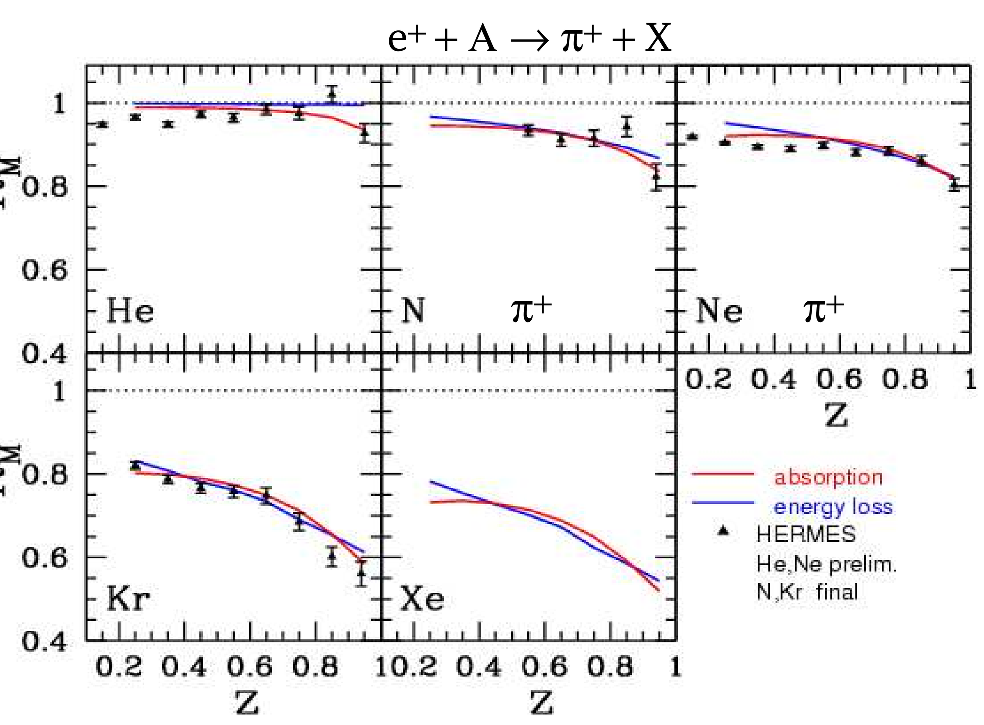
Introduction. Knowing wether a hadron is formed inside or outside the nuclear medium is very important for correctly interpreting jet-quenching data. The cleanest experimental environment to study the space-time evolution of hadronization is semi-inclusive DIS on nuclear targets.

Two frameworks are presently competing to explain the observed attenuation of hadron production: quark energy loss (with hadron formation outside the nucleus) and nuclear absorption (with hadrons formed inside the nucleus).
I explore the possibility to distinguish them using the A-dependence of the hadron attenuation ratio in nuclear DIS.

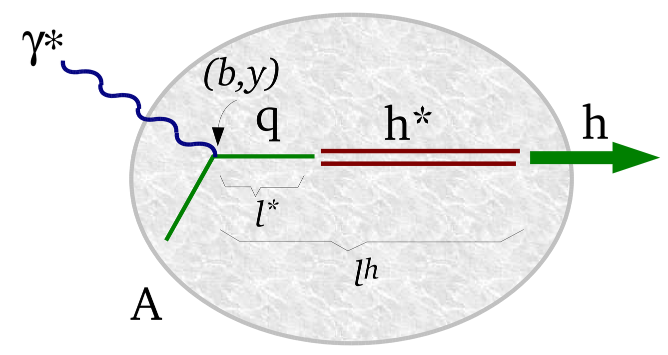
Hadron attenuation in nuclear DIS

$$R_M^h(z) = \frac{1}{N_A^{DIS}}\frac{dN_A^h(z)}{dz} \Big/ \frac{1}{N_D^{DIS}}\frac{dN_D^h(z)}{dz}$$



- **Both energy loss and hadron absorption models account well for HERMES R_M data**
- Without correcting for finite medium length the energy loss model cannot describe data

Hadron absorption model [1]

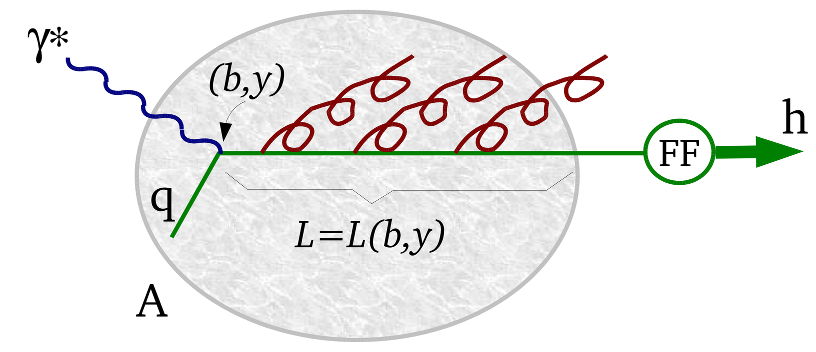


- Two-step hadronization inside the nucleus:
  1) quark q neutralizes color ⇒ **prehadron** h^*
  2) **hadron** h's wavefunction fully develops
- Average formation lengths $\langle l^*\rangle(z,\nu)$, $\langle l^h\rangle(z,\nu)$ from Lund model
- (Pre)hadron-nucleon cross sections:
  - $\sigma_* = 2/3\ \sigma_h$ - fitted to $e^+ + \mathrm{Kr} \to \pi^+ + X$
  - σ_h - from Particle Data Group
- Survival probability S_A by transport diff. eqns.
- Full integration over $\gamma^* q$ interaction point (b,y)

$$\frac{1}{N_A^{DIS}}\frac{dN_A^h(z)}{dz} = \frac{1}{\sigma^{lA}} \int_{\text{exp. cuts}} dx\, d\nu \sum_f e_f^2 q_f(x,Q^2) \frac{d\sigma^{lq}}{dx\,d\nu} S_{f,h}^A(z,\nu) D_f^h(z,Q^2)$$

$$S_{f,h}^A = \int d^2b\, dy\, \rho_A(b,y) \int_y^\infty dx' \int_y^{x'} dx \frac{e^{-\frac{x-y}{\langle l^*\rangle}}}{\langle l^*\rangle} e^{-\sigma_* \int_x^{x'} ds A \rho_A(b,s)} \frac{e^{-\frac{x'-x}{\langle \Delta l\rangle}}}{\langle \Delta l\rangle} e^{-\sigma_h \int_{x'}^{\infty} ds A \rho_A(b,s)}$$

Energy loss model



- The quark hadronizes outside the nucleus
- Quark energy loss ⇒ modified fragment. funct.

$$D_q^h(z,Q^2) \longrightarrow D_q^h\Big(\frac{z}{1-\Delta z}, Q^2\Big) \quad ; \quad \Delta z = \varepsilon/\nu$$

- Quenching weights $P(\Delta z, L)$ [2] with corrections for finite in-medium path $L = L(b,y)$
- Transport coefficient $\hat{q} = 0.5$ GeV^2/fm - fitted to $e^+ + \mathrm{Kr} \to \pi^+ + X$
- Full integration over $\gamma^* q$ interaction point (b,y)

$$\frac{1}{N_A^{DIS}}\frac{dN_A^h(z)}{dz} = \frac{1}{\sigma^{lA}} \int d^2b\, dy\, \rho_A(b,y) \int_{\text{exp. cuts}} dx\, d\nu \sum_f e_f^2 q_f(x,Q^2) \frac{d\sigma^{lq}}{dx\,d\nu} \tilde{D}_f^h(z,Q^2; L(b,y))$$

$$\tilde{D}_f^h(z,Q^2;L) = \int_0^{(1-z)} d\Delta z\, \mathcal{P}(\epsilon;\hat{q},L) \frac{1}{1-\Delta z} D_f^h\Big(\frac{z}{1-\Delta z}, Q^2\Big) + p_0(\hat{q},L)\, D_f^h(z,Q^2)$$

A-DEPENDENCE
naïve argument

a) Energy loss (LPM effect):

$1-R_M \sim \langle \Delta z\rangle \sim L^2 \sim A^{2/3}$

b) Hadron absorption:

$1-R_M \sim \langle \text{no. of rescatterings} \rangle \sim L \sim A^{1/3}$

⇒ a simple fit to A^α should discriminate the 2 models

HOWEVER... let's really expand in powers of $A^{1/3}$

[approximations: hard-sphere nuclei ($R_A = r_0 A^{1/3}$), neglect effects on ^{2}H]

a) Energy loss [approx: no finite size corrections, large ν ⇒ neglect boundary in $\int d\Delta z$]

$$1 - R_M^{\text{en.loss}} = \frac{C_F \alpha_s r_0^2}{5} \frac{\hat{q}}{\nu} \left[-1 - z\frac{\partial_z D(z)}{D(z)}\right] A^{2/3} + \text{h.o.t.}$$

b) Hadron absorption [approx: prehadron formed inside A, hadron outside)]

$$1 - R_M^{\text{abs.}} = \frac{2\rho_0 r_0^2}{5} \frac{\sigma_*}{\langle l^*\rangle(z)} A^{2/3} + \text{h.o.t.}$$

Hadron absorption follows $A^{2/3}$ law, as well!
need to look for higher order terms to distinguish from energy loss

Note: $A^{2/3}$ law valid for a large class of absorption models, not an artifact of this one [1]. Numerical results below computed without these approximations.

A new observable: cA^α fits [1]

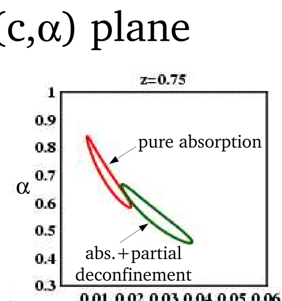
Definition:

i) fit $1-R_M(z) = c(z)\, A^{\alpha(z)}$
- at fixed z (or ν or Q^2)
- with c and α as free parameters

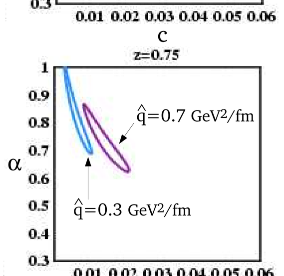
ii) draw 1σ confidence contour in (c,α) plane

The power of this observable:

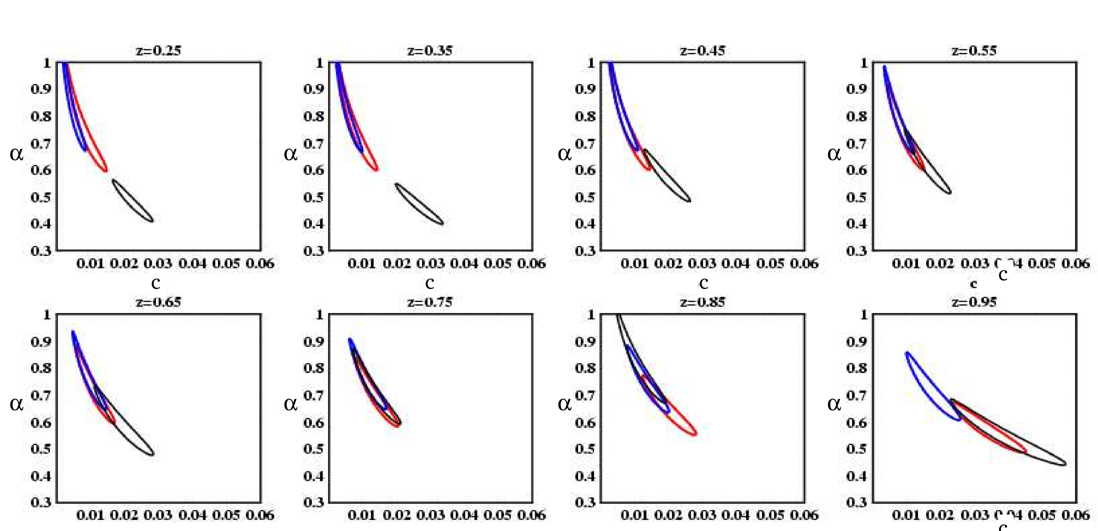
- sensitive to model assumptions
  E.g., pure absorption vs. absorption plus partial quark deconfinement



- sensitive to model parameters
  E.g., energy loss with $\hat{q}$=0.3 GeV^2/fm vs. $\hat{q}$=0.7 GeV^2/fm



HERMES vs. THEORY



Nuclei included in the fit: He, N, Ne, Kr

- absorption model - $\sigma_* = 2/3\ \sigma_h$
- energy loss model - $\hat{q} = 0.5$ GeV^2/fm
- HERMES data

BAD LUCK!
the 2 models mimick each other!

- small differences mainly due to inclusion of He in the fit
- increasing number of targets (possible in the near future at JLAB) shrinks contours but doesn't separate models
- Restricting to either heavy or light target doesn't help, either
- Other author's models may be different

cA^α fits will help reducing the no. of theory models, but will not distinguish energy loss from hadron absorption

Conclusions

- Contrary to common expectations, the A-dependence of hadron attenuation doesn't distinguish energy loss from hadron absorption.
- We need more exclusive observables (e.g., the z-dependence of the Cronin effect [3]).

For future experiments (JLAB, a few runs at HERMES)

- Use a few more targets, but not too many, to complete the light-heavy scan (and to keep our eyes open to surprises).
- Concentrate resources on collecting high-statistics, in order to access more exclusive observables

References: [1] Accardi et al., hep-ph/0502072, NPA + erraturm in press [2] Salgado, Wiedemann, PRD68(2003)014008 [3] Kopeliovich et al., NPA740(2004)211-245