Quenching of hadron spectra in DIS on nuclear targets

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Outline

- ✗ Motivations
  - → Quark energy loss in cold nuclear matter
- ✗ Hadron production in semi-inclusive DIS on nuclei
  - → Model for nuclear fragmentation functions
  - → Quenching weight
  - → Transport coefficient
- ✗ Results on hadron attenuation
  - → Comparison to EMC and HERMES data
  - → Discussion
- ✗ Summary

References

F. Arleo, JHEP 11 (2002) 044

F. Arleo, Phys Lett B532 (2002) 231

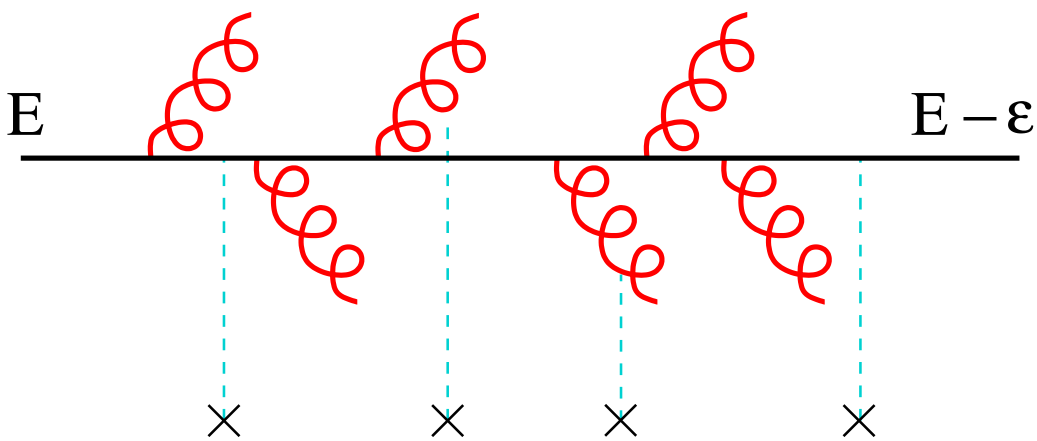
F. Arleo, to appear

Parton energy loss in QCD media

Baier, Dokshitzer, Mueller, Peigné, Schiff
Gyulassy, Lévai, Vitev, Wang
Zakharov
Wiedemann

Multiple soft collisions incurred by hard partons

→ Gluon radiation $dI/d\omega$ proportional to the medium density



Energy loss expected to be huge in dense media such as quark-gluon plasma

What happens in a cold QCD medium ?

Aim

To explore quark energy loss in nuclei

How ?

Hadron production in DIS on nuclear targets

→ Sensitive to quark energy loss

→ A lot of new data

Here

Analysis of hadron production compared to EMC and HERMES measurements

Caveat

Many other nuclear effects may compete

LO hadron production in DIS on nuclei

$$
\begin{aligned}
\frac{1}{N_A^e}\frac{dN_A^h(\nu,z)}{d\nu\,dz} &\simeq \int dx \sum_{q,\,\bar{q}} e_q^2\, x\, f_q^{N/A}(x,Q^2)\, D_q^h(z,Q^2,A) \\
&\Big/ \int dx \sum_{q,\,\bar{q}} e_q^2\, x\, f_q^{N/A}(x,Q^2) \\
&\simeq D_u^h(z,Q^2,A) \qquad\qquad (\, x \simeq 0.1 \,)
\end{aligned}
$$

with $f_q^{N/A}(x,Q^2)$: MRST 2001 LO parton densities

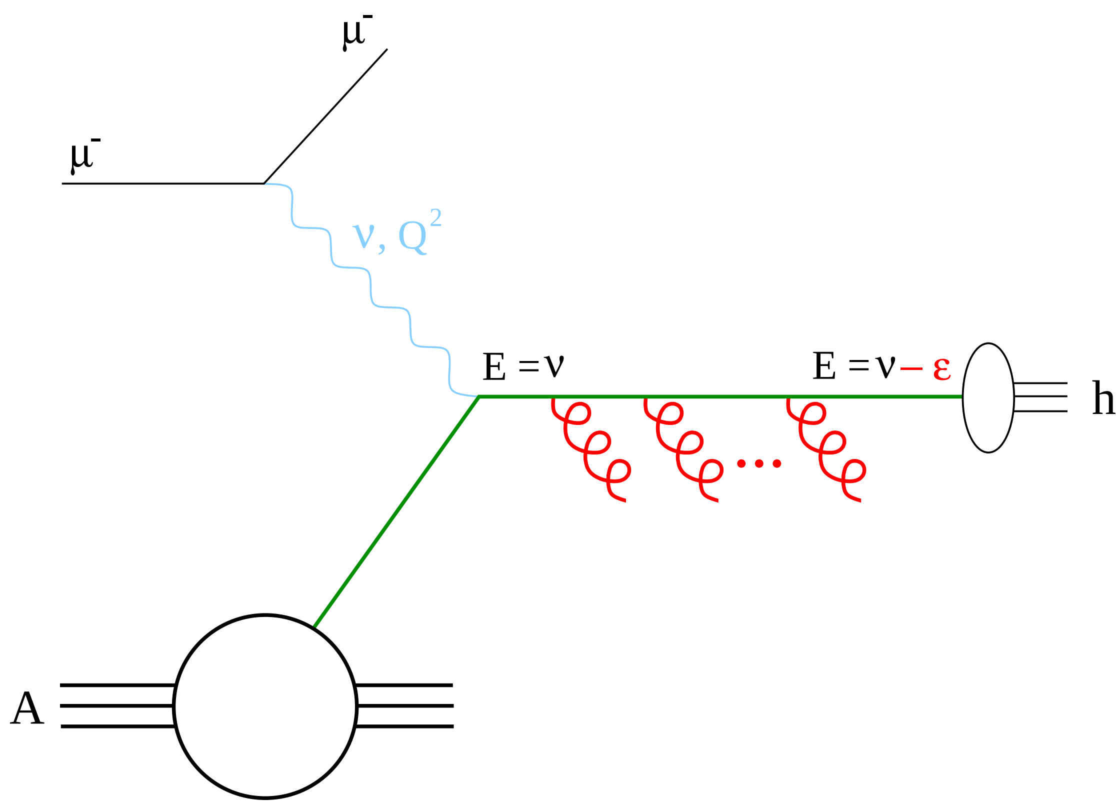
Nuclear production ratio

$$
\begin{aligned}
R_A^h(z,\nu) &= \frac{1}{N_A^e}\frac{dN_A^h(\nu,z)}{d\nu\,dz} \Big/ \frac{1}{N_D^e}\frac{dN_D^h(\nu,z)}{d\nu\,dz} \\
&\simeq D_u^h(z,Q^2,A) \Big/ D_u^h(z,Q^2,D)
\end{aligned}
$$

How does the nuclear medium affect fragmentation functions ?

Energy loss in DIS

Multiple scatterings shift quark energy from ν to $\nu - \epsilon$



Simple model for modified fragmentation functions

[Wang, Huang, Sarcevic, PRL **77**, 231 (1996)]

$$z\, D_f^h(z, Q^2, A) = \int_0^\nu d\epsilon\ D(\epsilon, \nu)\ \ z^*\, D_f^h(z^*, Q^2)$$

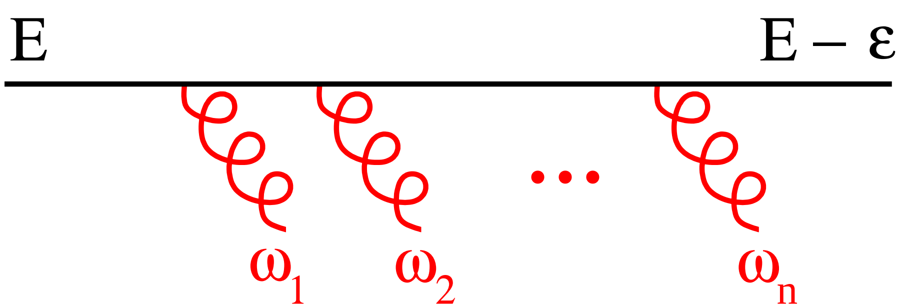
with

$$z^* = \frac{E_h}{\nu - \epsilon} = \frac{z}{1 - \epsilon/\nu}$$

Quenching weight $D(\epsilon)$

[Baier, Dokshitzer, Mueller, Schiff, JHEP 09 (2001) 033]

Independent gluon radiation → Poisson approximation



$$D(\epsilon) \propto \sum_{n=0}^{\infty} \frac{1}{n!} \left[\prod_{i=1}^{n} \int d\omega_i \, \frac{dI(\omega_i)}{d\omega} \right] \delta\left(\epsilon - \sum_{i=1}^{n} \omega_i \right)$$

Relevant scale for the medium-induced gluon spectrum

$$\omega_c = \frac{1}{2} \, \hat{q} \, L^2$$

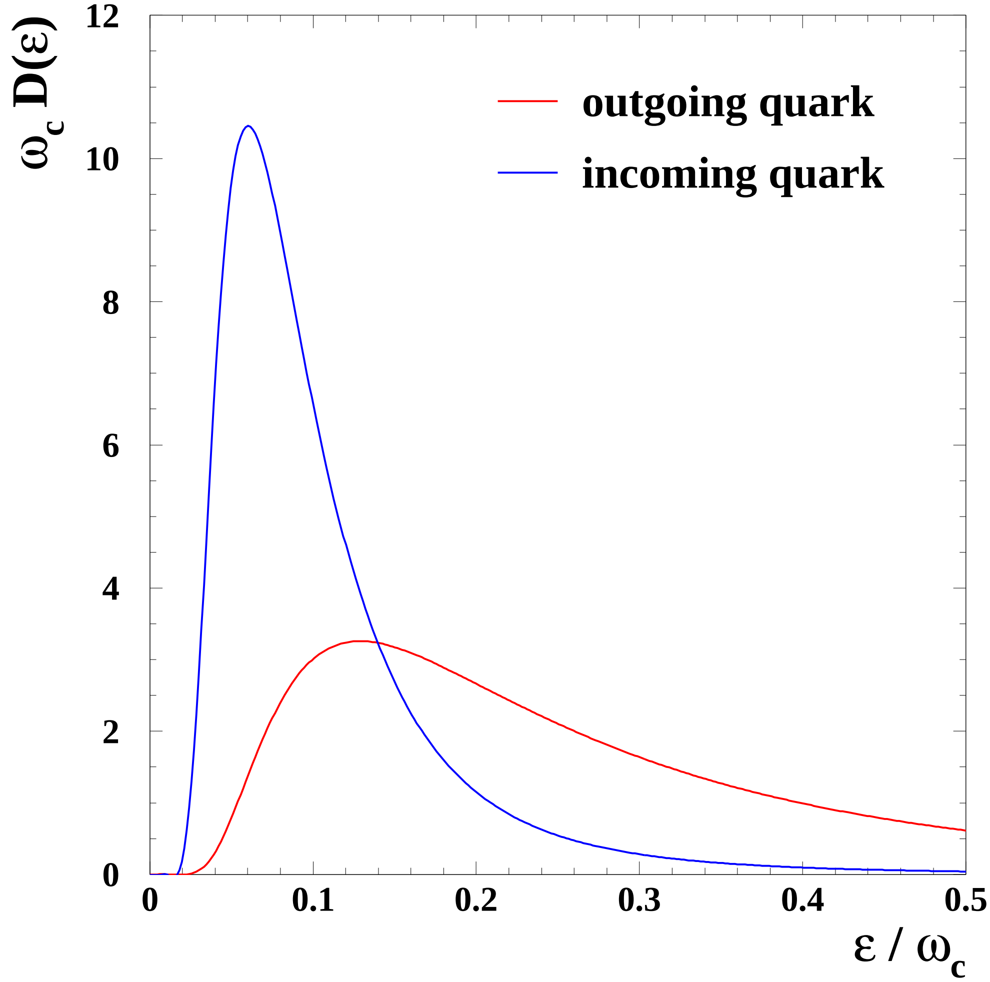
✗ $\hat{q}$: transport coefficient

→ “scattering property” of the medium ($\sim$ density)

✗ L : length covered by the parton in the medium

Computation of the quenching weight

[F.A., JHEP 11 (2002) 044]



✗ Log-normal behavior

✗ Smaller energy loss for incoming quarks

✗ Long energy tail

→ cannot be approximated by $D(\epsilon) \simeq \delta(\epsilon - \langle\epsilon\rangle)$!

Transport coefficient $\hat{q}$ for nuclear matter

→ Perturbative estimate

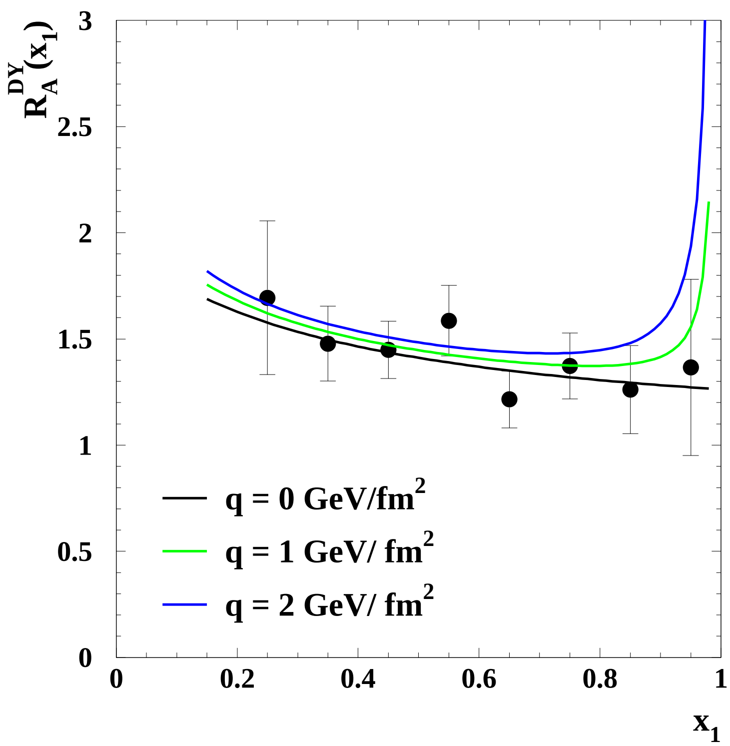
[BDMPS, Nucl Phys B484 (1997) 265]

$\hat{q}$ related to gluon density

$$\hat{q} = \frac{4\,\pi^2 \alpha_s\, N_c}{N_c^2 - 1}\,\rho\, x\, G(x, Q^2) \simeq 0.25\ \mathrm{GeV/fm^2}$$

→ Constraints from Drell-Yan data

[F.A., Phys Lett B532 (2002) 231]



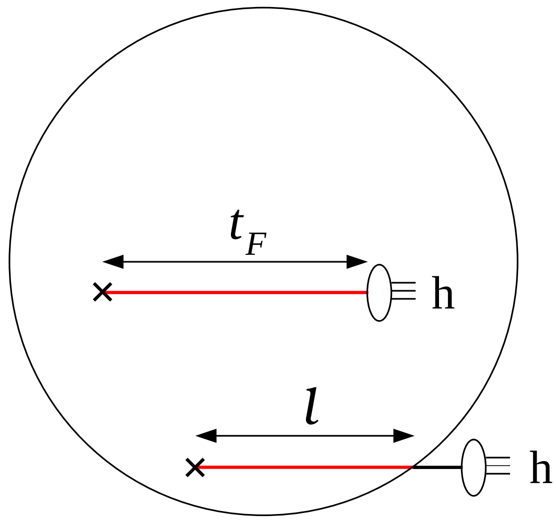
large energy loss

RULED OUT

$$\hat{q} = 0.72 \pm 0.54\ \mathrm{GeV/fm^2}$$

Length of matter

Averaging L from a hard sphere nucleus



$$L = t_f \times \left[1 - \frac{3}{8}\frac{t_f}{R} + \frac{1}{64}\left(\frac{t_f}{R}\right)^3\right] \qquad t_f \leq 2\,R$$

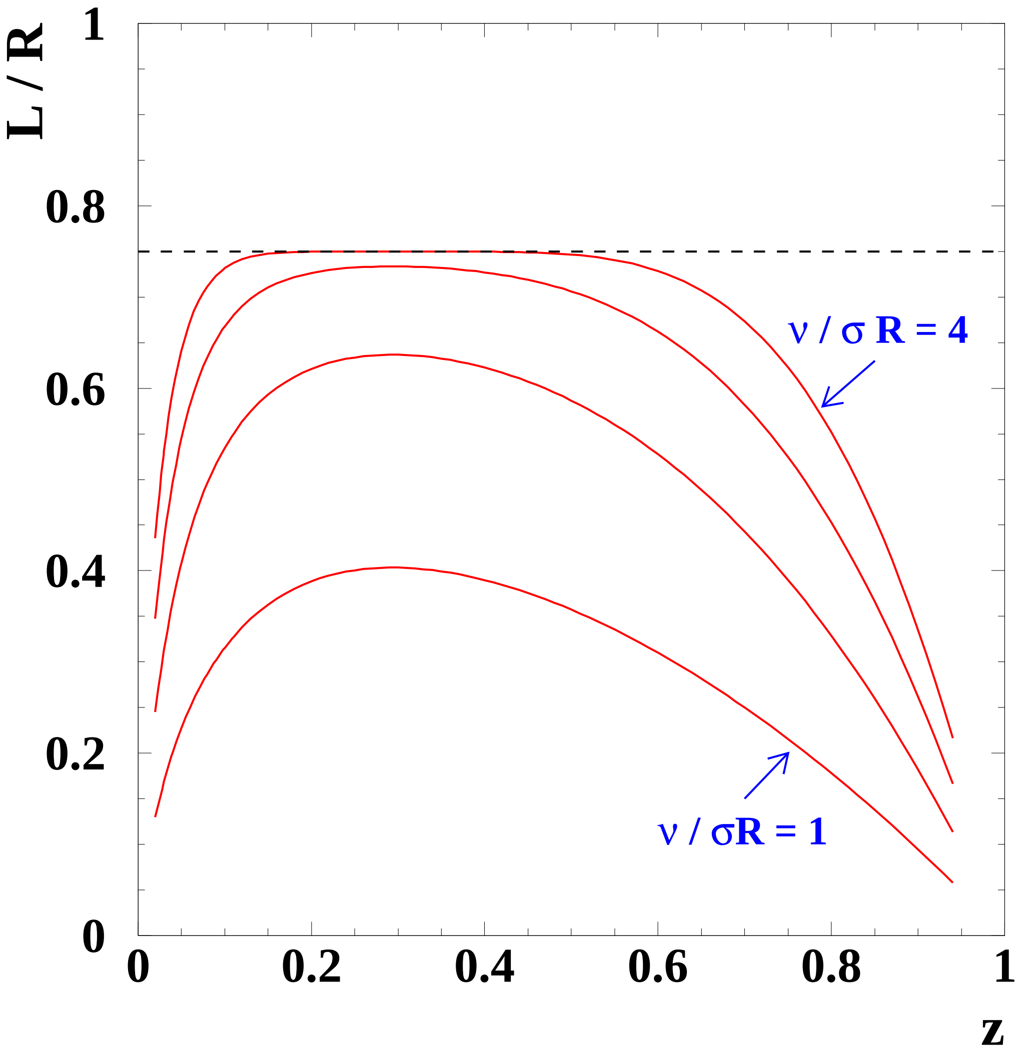
$$L = \frac{3}{4}R \qquad t_f \geq 2\,R$$

Take Lund model hadron formation time t_f

$$t_f = \left(\frac{\ln(1/z^2) - 1 + z^2}{1 - z^2}\right) \times \frac{z\,\nu}{\sigma}$$

σ: string tension

$L(\nu, z)$



Large formation time effects

at large z and/or small ν

ν dependence $R_A^h(\nu)$

Taking Kretzer parameterization $z\,D(z,Q^2) \sim (1-z)^\eta$

$$R_A^h(\nu) \simeq \frac{D(z^*,Q^2)}{D(z,Q^2)} \simeq 1 - \frac{z}{1-z}\,\frac{\epsilon}{\nu}\,\eta^h$$

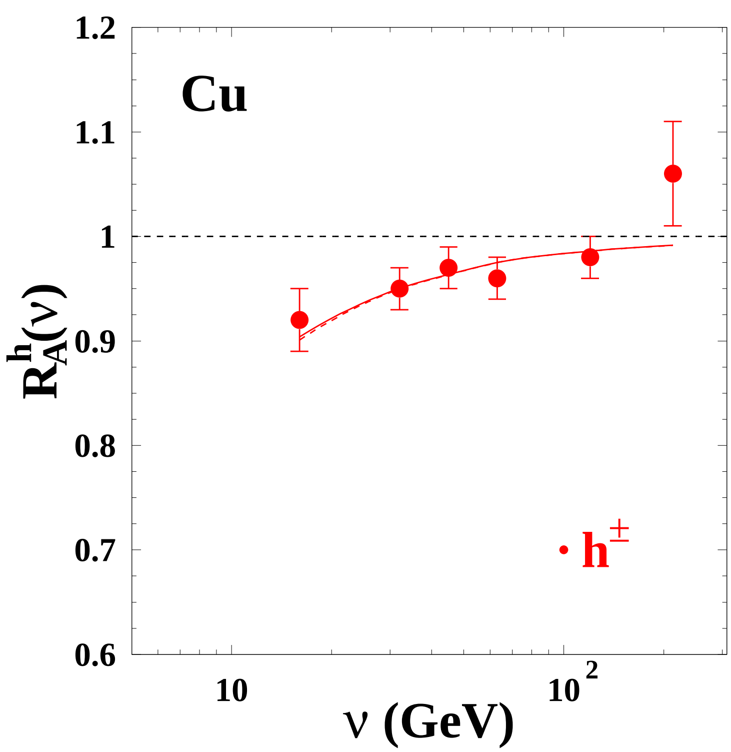
Expected trend

→ Strong attenuation at small ν

→ Depletion depends on FF slopes η^h

→ $R(\nu \gg \epsilon) \simeq 1$: OK with factorization theorems

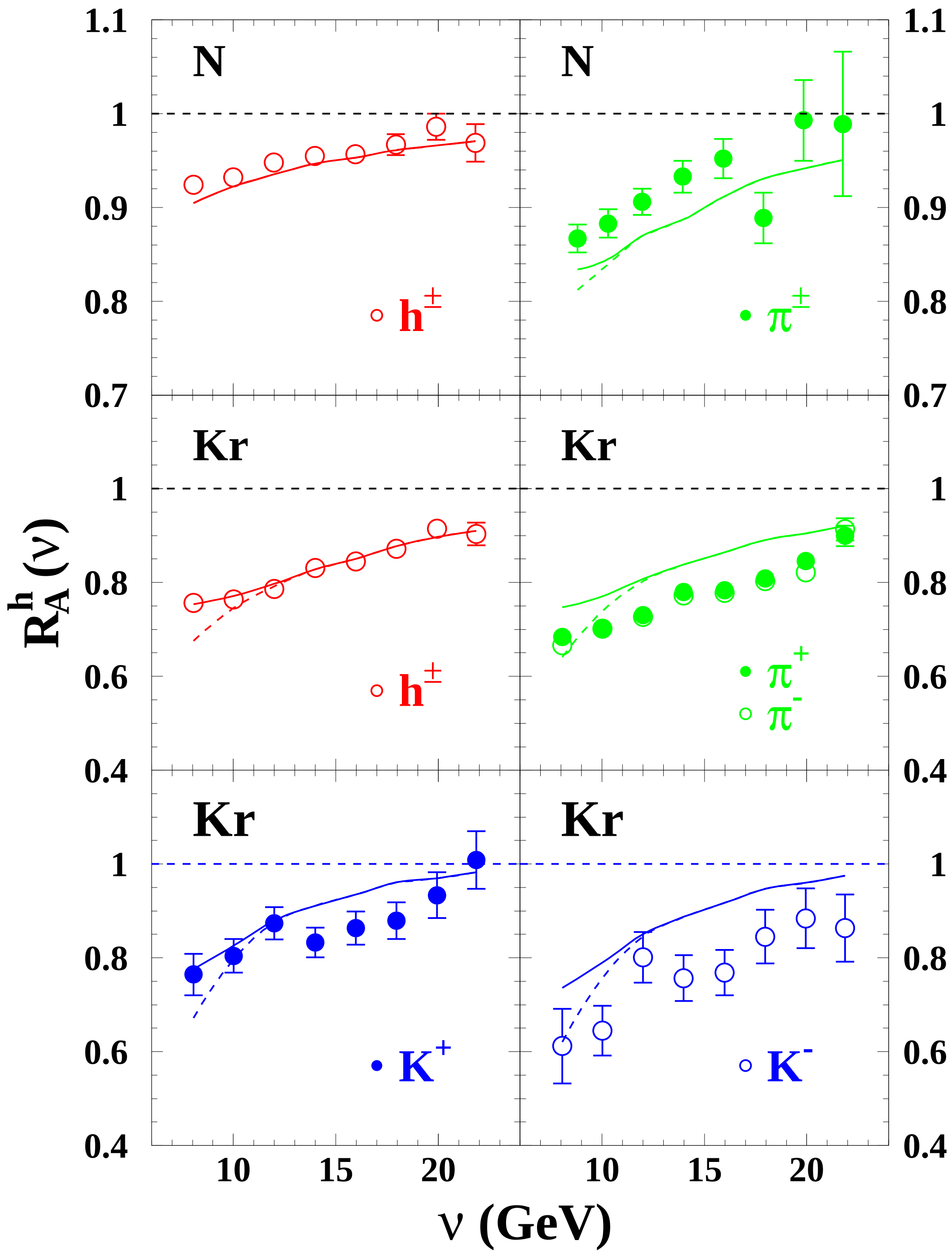
Comparing with EMC ...



✗ data well reproduced

✗ No formation time effect

... and HERMES measurements



✗ Pretty good agreement (except pions)

✗ isospin effects in the kaon channel reproduced

→ "Easier" to fragment $u \to K^+$ than $u \to K^-$

z dependence $R_A^h(z)$

$$R_A^h(z) \simeq 1 - \frac{z}{1-z}\,\frac{\epsilon}{\nu}\,\eta^h$$

Main features

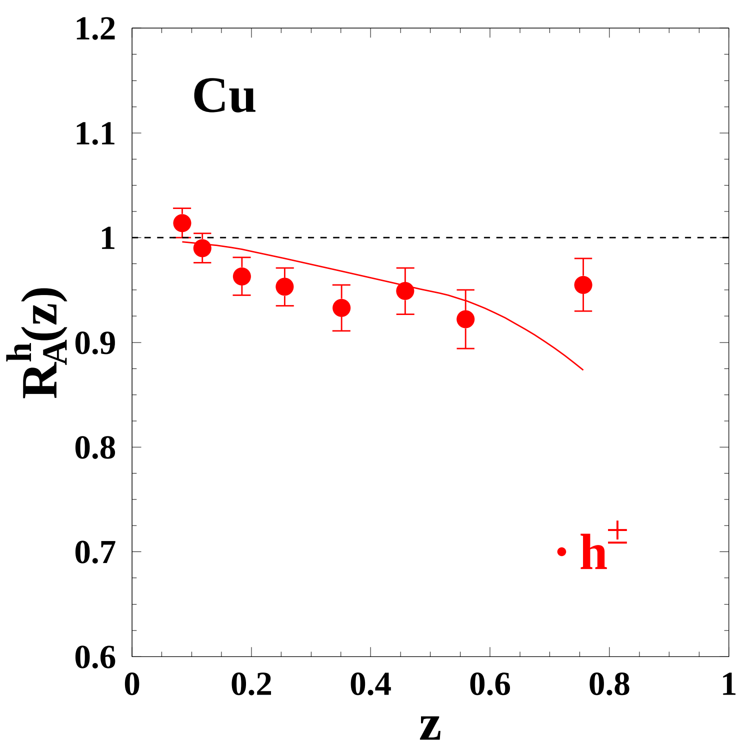
→ Steeper at larger z

→ Phase space restricted $\epsilon < \nu - E_h$

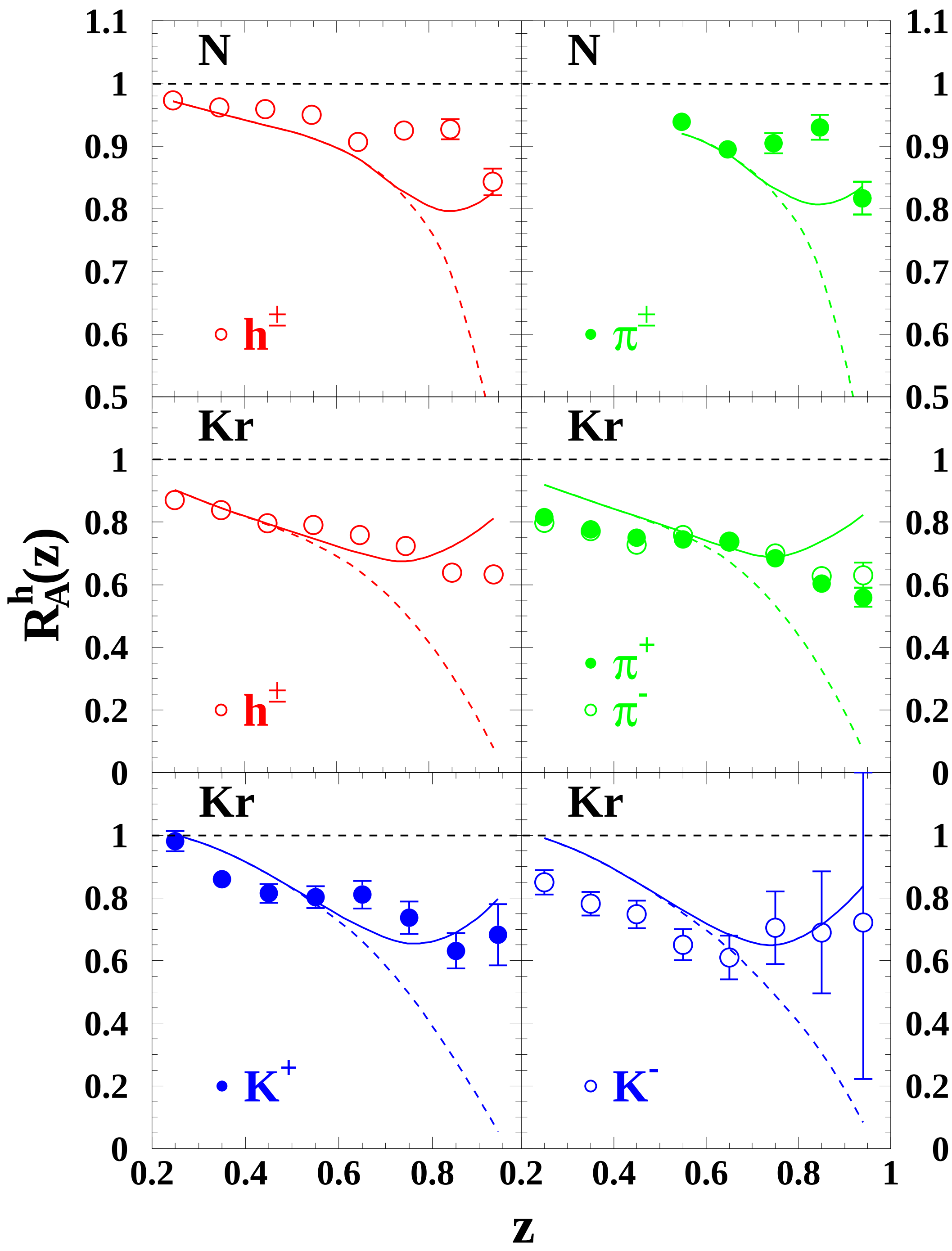
$$R(z) \sim \int_0^{(1-z)\nu} D(\epsilon)$$

→ Hadronization inside the nucleus at large z

EMC measurements



HERMES measurements



- ✗ Pretty good agreement for all hadron species
- ✗ Important formation time effects at large z

What about possible hadron absorption in the nucleus ?

Tricky to disentangle various nuclear effects

Two predictions to (hopefully) clarify the picture

1. Energy loss saturates in large nuclei ($L \simeq t_F$)

$$\rightarrow \text{Xe / Kr} \simeq 1$$

2. At smaller x, u and $\bar{u}$ sea quarks contribute equally

$$\rightarrow K^+/K^- \simeq 1$$

$\rightarrow$ Need for heavy nuclei

$\rightarrow$ Need for Q^2 dependence

Summary

✗ Energy loss useful to probe QCD media

→ proportional to gluon density

✗ Nuclear fragmentation functions

→ Simple model for quark energy loss in nuclei

✗ Hadron production in DIS on nuclei

→ Nice agreement with present measurements

→ DIS data consistent with Drell-Yan estimates

→ Probes dynamics of hadronization