Attenuation of hadrons in nuclei

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On behalf of the HERMES collaboration

Layout:

- Introduction
- NEW Results:
  - more targets ($^4\text{He}, ^{14}\text{N}, ^{20}\text{Ne}, ^{84}\text{Kr}$)
  - various hadrons ($\pi^+, \pi^-, K^+, K^-, p, \bar{p}$)
  - different beam energies (27/12 GeV)
- Comparison with models
- A dependence
- Conclusions
Nuclear Attenuation
reduction of multiplicity of the fast forward hadrons due to:
- gluon radiation
- parton rescattering
- hadron absorption

\[
R_M(z, \nu) = \frac{\left[ \frac{1}{N_e} \frac{d^2 N_h}{dz d\nu} \right]_A}{\left[ \frac{1}{N_e} \frac{d^2 N_h}{dz d\nu} \right]_D}
\]

\[
\frac{1}{N_e} \frac{d^2 N_h(x, z)}{dxdz} = \sum_i e_i^2 q_i(x) D_i^h(z) / \sum_i e_i^2 q_i(x)
\]

Formation time:

\[
\tau_f = \frac{l_f}{c}
\]
Why study hadronization?

- Check QCD prediction of parton energy loss in nuclei
  \[ \Delta E \propto r_A^2 \implies (1 - R_M) \propto A^{2/3} \]

- \( \tau_f \) for different hadron types

- Link to heavy-ion physics: parton energy loss related to gluon density of quark-gluon plasma.
Existing HERMES data \(^{14}\text{N}\)

- decrease of attenuation versus \(\nu\)
- no charge dependence for pions
- charge dependence hadrons:
  \[(1 - R^p_M) < (1 - R^\pi_M) \Rightarrow \tau_f^p > \tau_f^\pi\]
- suppression of high-z hadrons

Possible interpretation suppression at high z:
- high z: quarks emit few gluons
- small formation time
- long time for hadron-nucleus interaction
New results for pions on $^4$He, $^{20}$Ne and $^{84}$Kr

- Strong A dependence
- $R_M^{\pi^+}(\nu, z) = R_M^{\pi^-}(\nu, z)$

confirmed by new targets
New results for $p$, $K$ on $^4$He, $^{20}$Ne and $^{84}$Kr

$R^p_M > R^\bar{p}_M, R^{K^+}_M > R^{K^-}_M$
New results at 12 GeV beam energy

New data extends existing data to lower $\nu$: Large Attenuation!

qualitative behavior of 27 GeV data confirmed
Model calculations for $^{84}\text{Kr}, ^{14}\text{N}$ vs. $\nu$

**I** fragmentation function modification:

$$D_f^{h|A}(z, Q^2) = D_f^h(z, Q^2) + \Delta D_f^h(z, Q^2)$$

pQCD based model, with:

- multiple scattering
- induced gluon radiation

Wang et al. [PRL 89(2002) 162301]

**II** Rescaling model:

$$q_f^{A}(x, Q^2) = q_f(x, \xi_A(Q)Q^2)$$

$$D_f^{h|A}(z, Q^2) = D_f^h(z, \xi_A(Q)Q^2)$$

comb. with (pre-)hadron absorption

A. Accardi et al. (2003)[nucl-th/0211011]
Model calculations for $^{84}$Kr, $^{14}$N vs. $z$

- models reproduce qualitative behavior of $R_M(\nu, z)$
- both models tune 1 parameter to the data

Important difference models:

1. FF. modification $\implies \alpha = 2/3$
2. Rescaling model: nucl. absorption part $\implies \alpha = 1/3$

using $1 - R_M \propto A^\alpha$
Simple absorption model

Fits to HERMES data, by E. Garutti et al, PhD Thesis UvA - 2003, to be published

HERMES preliminary

1-t + string interaction

Fit results:

<table>
<thead>
<tr>
<th></th>
<th>$^{84}$Kr (mesons)</th>
<th>$^{14}$N (pions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_s$ [mb]</td>
<td>$4.2 \pm 0.7$</td>
<td>$2.7 \pm 0.6$</td>
</tr>
<tr>
<td>$k$ [GeV c fm$^{-1}$]</td>
<td>$0.28 \pm 0.06$</td>
<td>$0.12 \pm 0.04$</td>
</tr>
</tbody>
</table>

fit results target dependent

nuclear abs. models don’t reproduce A dependence
A dependence of the data, \( R_{\text{att}}(A) \)

A dependence provides a way to distinguish between models:

- nuclear absorption models \( \Rightarrow \alpha = 1/3 \)
- pQCD based models \( \Rightarrow \alpha = 2/3 \)

\( (\text{Wang et al.}) \)

Extracted A dependence using:

\[
1 - R_M \propto A^\alpha
\]

Combining \(^{14}\text{N}\) and \(^{84}\text{Kr}\):

\[
\alpha = \ln \left( \frac{1 - R^N_M}{1 - R^Kr_M} \right) / \ln \left( \frac{14}{84} \right)
\]

\( \Rightarrow \) data indicate \( \alpha \simeq 2/3 \), but further study is needed using all targets
Conclusions:

- Strong A dependence of $R_M(\nu, z)$
- New targets confirm behavior of $R_M$ vs. $\nu$ and $z$
- No charge dependence of attenuation for pions
- $R_{K^+}^M(\nu, z) > R_{K^-}^M(\nu, z)$ and $R_{p}^M(\nu, z) > R_{\bar{p}}^M(\nu, z)$
- 12 GeV beam energy extends existing data to low $\nu$
- First prelim. study of A dependence of data indicate $\alpha \simeq 2/3$
New results at 12 GeV beam energy

Large increase of attenuation vs. $z$
Proton attenuation

HERMES PRELIMINARY

\[ R_A^{p} \]

\[ \Delta^4\text{He} \quad \bullet^{20}\text{Ne} \quad \bigtriangleup^{84}\text{Kr} \quad \bigtriangledown p \quad \bigtriangledown p^- \]

sys. uncer. Ne(He) - 4.5 \%
sys. uncer. Kr - 7.2 \%

\[ v, \text{GeV} \]

\[ z \]

sys. uncer. Ne(He) - 4.4 \%
sys. uncer. Kr - 3.9 \%
Kaon attenuation

\[ R_A^K \]

HERMES PRELIMINARY

\[ v, \text{GeV} \]

\[ Z \]

sys. uncer. Ne(He) - 3.0 %

sys. uncer. Kr - 4.2 %