Differential Study of Nuclear Effects in Hadronization by DIS

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(Parton propagation through strongly interacting matter)

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Overview:
Study hadronization in \( A(e, e'[\pi, K])X \), on \(^2\text{H}, ^{12}\text{C}, ^{64}\text{Cu}, \) and \(^{184}\text{W}, \) by the attenuation of hadron yield

\[
R(\nu, z, P_T, Q^2) = \frac{dN^h(A)}{N_e(A)dz} \frac{dN^h(D)}{N_e(D)dz}
\]

* Main objective-
  Provide precise data for understanding hadronization mechanism, study propagation of quarks and hadrons \textit{under specific kinematic conditions}.
  → \text{small acceptance detectors};
  → \text{essential to QCD}.

* Additional objective-
  Input to RHIC data interpretation, jet quenching
  → Is QGP recreated at RHIC?
Hadronization by DIS

\[ e' \gamma^v e \rightarrow \text{nucleon} \rightarrow \pi \]

- Quark propagation
- Hard scattering
- Hadronisation
Multi-variable process

dependence on:
A
$Q^2, \nu, (x)$
z, $P_T$

$z = \frac{E_h}{\nu}$
Multi-mechanism and multi-effect process

Induced gluon radiation
LPM--Landau-Pomeranchuk-Migdal effect
Pt broadening (Cronin effect)

C

Cu

W

target nucleon

spectators

hadron
Space-time evolution of hot matter

\[ P_T (\text{RHIC}) \leftrightarrow v (\text{DIS}) \]
High $P_T$ suppression in Au-Au collision, in comparison with dA data. Bathe (PHENIX).
Previous data:

<table>
<thead>
<tr>
<th>data</th>
<th>beam</th>
<th>$E_0$ (GeV)</th>
<th>$\nu$ (GeV)</th>
<th>$Q^2$ (GeV/c$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FNL</td>
<td>$\mu$</td>
<td>490</td>
<td>&gt;100</td>
<td>0.1-150</td>
</tr>
<tr>
<td>EMC</td>
<td>$\mu$</td>
<td>175</td>
<td>&gt;10</td>
<td>&gt;2</td>
</tr>
<tr>
<td>SLAC</td>
<td>$e^-$</td>
<td>20.5</td>
<td>&gt;4</td>
<td>0.35-5</td>
</tr>
<tr>
<td>HERMES</td>
<td>$e^+$</td>
<td>27</td>
<td>7-23</td>
<td>&lt;2.5</td>
</tr>
<tr>
<td>HERMES</td>
<td>$e^+$</td>
<td>12</td>
<td>2.5-9</td>
<td>&lt;0.9</td>
</tr>
<tr>
<td>CLAS</td>
<td>$e^-$</td>
<td>5.7</td>
<td>3-5</td>
<td>1.5-5</td>
</tr>
<tr>
<td>HRS*</td>
<td>$e^-$</td>
<td>6</td>
<td>4</td>
<td>2.8, 4.2</td>
</tr>
</tbody>
</table>

Data required at lower $\nu$ AND higher $Q^2$'s:
DIS is dominating and factorization is valid.
Data required on larger A nuclei ($^{184}$W):
stronger attenuation and test of models.
Data required at various $P_T$'s and high $z$:
sensitive to different dynamics.
Sources of the attenuation?

HERMES hadronization inside nucleus;
Wang quark-medium interaction;
Kopeliovich colorless pre-hadronic state.
Flavor dependence is required.
Higher precision at large $z$ is required.
The first major goal:

Determine
Whether the hadron is produced inside the nucleus.

Lower $\nu$— shorter formation length;
larger difference in $\sigma_\pi$ and $\sigma_K$.
Larger $A$— longer traversing path.
PID— Different attenuation for $\pi^+$ and $K^+$ if they are formed inside the medium.
The second major goal:

Kopeliovich: Data required on variation with $z$, direct measure of formation length. Large $A$ - stronger effect.
Dynamic features

Multi-variable ($Q^2$, $\nu$, $z$, $P_T$, $A$);
Multi-mechanism (quark, color-dipole, and hadron propagation);
Multi-effects (gluon radiation, LPM, $P_T$ broadening).

Requirements:
Higher $Q^2$ and larger $Q^2$ range;
Large $z = E_h/\nu$;
Data at smaller bins;
Particle ID.
Kinematic selectivity

In order to -

disentangle the dependence on each variable,
distinguish one effect from the other,
identify one mechanism from the other,

Specific data sets are required concentrated at a fixed selective kinematic region with small bins. These data will be complementary to that from large acceptance detector.
Dilema

On one hand, we like to selectively take data at higher $Q^2$, this will require to measure electrons at larger angle;

On the other hand, at high $Q^2$, the leading hadron will favor smaller forward angles.

Solution:
Using separate detectors for electrons and hadrons. While setting the electron arm at larger angle, leaving the hadron arm more toward forward direction.
Detector setup

- Target
- Beam
- Electron
- Hadron

Focus at high $Q^2$
Focus at large $z$
$P_T$ selection
$\pi, K, p$ separation
High luminosity
## Detector Description

<table>
<thead>
<tr>
<th></th>
<th>Hall A</th>
<th>Hall C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HRS</td>
<td>MAD</td>
</tr>
<tr>
<td>$P_c$ (GeV/c)</td>
<td>4.3</td>
<td>7.5</td>
</tr>
<tr>
<td>$\Delta P$ (%)</td>
<td>±5</td>
<td>±15</td>
</tr>
<tr>
<td>$\delta P$ (%)</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>$\Delta \Omega$ (msr)</td>
<td>12</td>
<td>28</td>
</tr>
</tbody>
</table>
$Q^2 - \nu$ Phase at 12 GeV
Projected attenuation ratio $R(\nu)$ with 12 GeV beam, at different $Q^2$, $z$ and PID;
HERMES data: $z > 0.5$, all $Q^2$ and $P_T$ (blue).
Summary:
Hadronization can be studied with small acceptance detectors by SIDIS from light to heavy nuclei at high $Q^2$, large $z$.

Select data at isolated high $Q^2$;
Select data at large $z$;
Select data at large $P_T$;

More sensitive to different effects;
More sensitive to the response of variable change.