Hadronization from DIS at CLAS

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Introduction

- Goal: measure observables of quark propagation through cold QCD matter.
- Pions: PhD work of H. Hakobyan (Yerevan)
- Kaons: work of postdoc A. Daniel (Ohio)
  - Do kaons hadronize differently than pions?
  - Heavy s-quarks could affect the hadronization.
  - No difference between $\pi^+$, $\pi^-$ or $\pi^0$.
  - New: $K^0$ attenuation ratios (not done by HERMES).
Relevance to RHIC

Relativistic Heavy-Ion Collisions

Deep Inelastic Scattering

These experiments try to recreate conditions of the early universe.

Initial quark energy is known
Properties of medium are known

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Graphics by Will Brooks
Observables

Hadronic multiplicity ratio:

\[ R^h_M(z, \nu) = \frac{\left\{ \frac{N_h(z, \nu)}{N^DIS_e(\nu)} \right\}_A}{\left\{ \frac{N_h(z, \nu)}{N^DIS_e(\nu)} \right\}_D} \]

Transverse momentum:

\[ \Delta p_T^2 = \left\langle p_T^2 \right\rangle^DIS_A - \left\langle p_T^2 \right\rangle^DIS_D \]

Binning:

- \( Q^2 \) (range 1.0-2.5 GeV\(^2\))
- \( \nu \) (range 2.6-4.3 GeV)
- \( z \) (range 0.1-1.0)
Theoretical Models

- No (dynamical) lattice calculations yet.
- Accardi et al. (nucl-th/0211011):
  - gluon radiation and absorption included.
  - good agreement with HERMES data.
  - increased *deconfinement* in nuclei.
- Many other phenomenological models.
Inside the Models

HERMES: K⁺ and K⁻ different.

Figure 6: Nuclear attenuation of a hadron $h$: the virtual photon $\gamma^*$ interacts with a quark $q$ at a longitudinal coordinate $y$; the quark turns into a “prehadronic” state $h_*$ at position $y'$ and the hadron $h$ is formed at $y''$. Each state interacts with the surrounding nucleons with a cross-section $\sigma_q$, $\sigma_*$, and $\sigma_h$, respectively.
CLAS – the CEBAF Large Acceptance Spectrometer

Drift Chambers
35,000 wires
$\sigma_R = 350 \mu m$

Superconducting Toroidal Magnet
$\int Bdl \equiv 1.7 T\cdot m$

Cerenkov Counters
216 channels
99.5% efficient over 50 m$^2$ area

Time of Flight Counters
500+ channels, 145 ps resolution

Electromagnetic Shower Calorimeters
1700+ channels
$\sigma/E = 10%/E^{0.5}$

electron beam direction
eg2: pion attenuation

\[ 2.20 < \sqrt{s} < 3.00 \quad 1.25 < Q^2 < 1.50 \mid \pi^+ \]

H. Hakobyan analysis: one of \( \sim 50 \) bins
Examples of multi-variable (preliminary) CLAS data

- $0.60 < Z_\pi < 0.80$ $1.85 < Q^2 < 2.40$ $|\pi^+|
- 2.20 < v < 3.00$ $0.60 < Z_\pi < 0.80$ $|\pi^+|
- 3.50 < v < 4.00$ $1.25 < Q^2 < 1.50$ $|\pi^+|
- Cronin effect for Lead ($Z_\pi > 0.2$)

- $v$ dependence
- $Q^2$ dependence
- $p_T^2$ dependence
- $Z_\pi$ dependence
Quarks lose energy by *gluon emission* as they propagate within a medium.

- This energy loss is manifested by $\Delta p_T^2$.
- $\Delta p_T^2$ gives the *production time* $\tau_p$.

- $\Delta E \sim L$ dominates in QED.
- $\Delta E \sim L^2$ dominates in QCD?

\[ \frac{dE}{dx} \approx \frac{\alpha_s}{\pi} N_c \langle p_T^2 \rangle_L \]

Medium-stimulated loss calculation by BDMPS.
eg2: pion $p_T$ broadening

H. Hakobyan analysis

$\Delta p_T^2$ vs $\nu$ (GeV)

1 $< Q^2 < 2$  0.5 $< Z_{\pi^+} < 0.6$  $\pi^+$

$\nu$ (GeV)

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A-dependence of $\Delta p_T^2$

Only statistical errors shown

Only one of many bins of CLAS data

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$K^0$ from $M(\pi^+\pi^-)$ at $z=0.55$

**LD$_2$ target**

**Fe target**
z-dependence of $K^0$ peak

(CLAS PRELIMINARY)

Multiplicity
K0 counts normalized by dis e-

(C, Fe, Pb, D2)
$K^0$ Multiplicity Ratio

$K^0$ hadronization

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Multiplicty ratios

$z = \frac{E_h}{\nu}$

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$K^0$ broadening of $<p_t^2>$

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K⁰ Cronin Effect

Cronin effect

(CLAS PRELIMINARY)
Examples of Experimental Data and Theoretical Predictions

Bins in yellow accessible at 5 GeV at CLAS
Summary

- There is good statistical precision of the pion data at 5 GeV.
  - Hadronization ratios, $\Delta p_T^2$, and Cronin effect.
  - Results are still preliminary but nearly final.
- There is modest statistical precision for the $K^0$ data at 5 GeV.
  - From these data, we hope to learn about the quark mass dependence of hadronization.
- The JLab 12 GeV upgrade creates new possibilities to study quark-matter propagation.
Backup Slides

Multiplicity
K0 counts normalized by dis e-

Multiplicity vs. \( P_t^2 \)

- C
- Fe
- Pb
- D2

C, Fe, Pb, D2
• Two targets in the beam simultaneously
• 2 cm LD2, upstream
• Solid target downstream
• Six solid targets:
  - Carbon
  - Aluminum (2 thicknesses)
  - Iron
  - Tin
  - Lead
  - Al + empty target
Cronin Effect

Theoretical prediction:

Probes reaction mechanism

CLAS preliminary data
z=0.5 and 0.7

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