Charged Hadron Production at HERMES

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### Experimental Method

- **Semi-Inclusive Deep Inelastic Scattering (SIDIS)**
  - Access parton fragmentation functions

\[
d\sigma^h = \sum q \otimes d\sigma_f \otimes D^h_f
\]
Experimental Method

- Semi-Inclusive Deep Inelastic Scattering (SIDIS)
  - Access parton fragmentation functions

\[
d\sigma^h = \sum q \otimes d\sigma_f \otimes D^h_f
\]

\[
\nu = E_e - E_{e'}
\]

\[
Q^2 = -q^2
\]

\[
x_B = \frac{Q^2}{2P \cdot q} = \frac{Q^2}{2M \cdot \nu}
\]

\[
p_t = P_{h\perp}
\]

\[
z = \frac{E_h}{\nu}
\]
Measurements on Nucleons

- Compare yields of positively and negatively charged pions and kaons on
  - the proton
  - the deuteron (accessing neutron contrib.)
- Probe flavour dependence of fragmentation
- Probe fragmentation functions at low energy scales
  - in contrast to lepton annihilation
- Differentiate between quark and antiquark contributions
- Improve QCD fits to extract fragmentation functions
- Observable: hadron multiplicity

\[
M^n_h(x_B, Q^2, z, P_{h\perp}) = \frac{1}{d^2 N_{DIS}(x_B, Q^2)} \cdot \int_0^{2\pi} \frac{d^5 N^h(x_B, Q^2, z, P_{h\perp}, \phi_h)}{dx_B dQ^2 d\phi} d\phi_h
\]

\[
= \frac{1}{d^2 \sigma_{DIS}(x_B, Q^2)} \cdot \int_0^{2\pi} \frac{d^5 \sigma^h(x_B, Q^2, z, P_{h\perp}, \phi_h)}{dx_B dQ^2 d\phi} d\phi_h.
\]
Measurements on Nuclei

• Initial reaction identical to nucleon SIDIS
• Final state influenced by nuclear matter

• Compare several nuclei
• Information on final state interaction
Hadronisation in Matter

• Schematic evolution in space and time
• Parton propagation
  ▪ Gluon radiation
  ▪ Partonic rescattering
  ▪ length $< l_c$
• Pre-hadron propagation
  ▪ Quantum numbers of $h$
  ▪ Colourless but off shell
• Hadron formation
  ▪ Formation length $l_f$ up to 10fm (outside N)
Experimental Observable

- Hadron multiplicity ratio on nuclei
  - comparing nucleus A with deuterium D
  
  \[ R^h_A(\nu, Q^2, z, p_t^2) = \left( \frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)} \right) \frac{A}{D} \left( \frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)} \right) \]

  - Exp. systematics cancel largely
  - Partonic and hadronic effects contribute

Inti Lehmann

HERMES Hadr, Baryons 2013, Glasgow
• Long. polarized electron/positron beams 27.6 GeV
HERMES Spectrometer

Magnetic spectrometer with transv. and long. polarized targets

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HERMES Hadr, Baryons2013, Glasgow

27.6 GeV
Multiplicities on Nucleons

- HERMES publication
  - $\pi^+, \pi^-$
  - $K^+, K^-$
  - On proton, deuteron
  - With, without vector meson contribution
    - $\rho^0 \to \pi^+\pi^-$
    - $\phi \to K^+K^-$
  - Function of
    - $x_B$, $Q^2$, $z$, $P_{h\perp}$

- Phys. Rev. D87 (2013) 074029
- http://www-hermes.desy.de/multiplicities

134 distributions online
• In the following
  ▪ vector-meson corrected
• Differences
  ▪ proton, deuteron
  ▪ explained by favoured or unfavoured fragmentation due to quark content
Multiplicity on Nucleons


$x_B$ and $Q^2$ dependencies more flat, as expected
• Comparison with LO calculations
  ▪ collinear factorisation, ie integration over $P_{h\perp}$
  ▪ discrepancies apparent


Multiplicity on Nucleons
First Ratios on Nuclei

- Multiplicity ratio
  \[ R_A^h(\nu, Q^2, z, p_t^2) \]
  - 1 dim. dependence
- A dependence
  - compatible with \( A^{2/3} \)

2D Ratios on Nuclei

- Recent HERMES publication
- 2D dependences extracted
  - variables:
    \[ \nu \ z \ p_t \ Q^2 \]

Over 100 distributions online
Durham: http://durpdg.dur.ac.uk or
http://inspirehep.net/record/918944/files/

- avoids integration
- disentangles dependence
- \( \nu \) dependence in \( z \) slices
  - substructures observed
  - \( \pi^+ \) and \( K^+ \) similar
  - protons pronounced differences for different \( z \)

2D Ratios on Nuclei

- $p_t^2$ dep. in $z$ slices
  - Nuclear broadening – Cronin effect
    - Disappears for high $z$
  - Compatible for negative hadrons

2D Ratios on Nuclei

- **z dep. in $p_t^2$ slices**
  - z-dependence increases with $p_t$
  - $p_t$ dependence disappears at high $z$

Summary

• Semi-Inclusive Deep Inelastic Scattering (SIDIS)
  ▪ Nucleon: fragmentation functions
  ▪ Nucleus: parton propagation + hadronisation

• HERMES Results
  ▪ Fragmentation functions at low energies
  ▪ Probe flavour dependence
  ▪ Discriminate quark and antiquark contribution
  ▪ Improve QCD fits
  ▪ Strong nuclear effects on multiplicity ratio
  ▪ Two-dim. correlations (some unexpected)
  ▪ All dependencies published in databases
Multiplicity on Nucleons

\[ \frac{1}{N_{DIS}(Q^2)} \frac{dN^h(z,Q^2)}{dz} = \sum_f e_f^2 \int_0^1 q_f(x_B,Q^2) dx_B D_f^\pi(z,Q^2) \]

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\[ \sum_f e_f^2 \int_0^1 q_f(x_B,Q^2) dx_B D_f^\pi(z,Q^2) \]
2D Ratios on Nuclei

\[ R_A^h \]

<table>
<thead>
<tr>
<th>Ne</th>
<th>Kr</th>
<th>Xe</th>
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\[ \pi^+ \]

\[ \pi^- \]

\[ K^+ \]

\[ K^- \]

\[ p \]

\[ v \ [GeV] \]

\[ z = 0.2-0.4 \]
\[ z = 0.4-0.7 \]
\[ z > 0.7 \]

\[ \pi^+ \text{ and } \pi^- \text{ similar while } K^- \text{ differ} \]