Pion and kaon multiplicities in Semi Inclusive Deep Inelastic Scattering at COMPASS

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On behalf of the COMPASS collaboration
Deep Inelastic Scattering (DIS)

- **Relevant kinematics for cross section**
  
  - $Q^2$ photon virtuality $\leftrightarrow$ resolution at which the nucleon is probed
  - $x_B$ long. momentum fraction of the struck quark in the nucleon
  - $y$ momentum fraction transferred by lepton to the virtual photon

**Inclusive DIS**: $\ell N \rightarrow \ell' \chi$

**Semi-inclusive DIS**: $\ell N \rightarrow \ell' h \chi$

**DIS Cross section**:

- **Unpolarized** $\sigma^h$:
  $$\sim f_q(x, Q^2) \cdot D^h_q(z, Q^2)$$

- **Polarized** $\Delta\sigma^h$:
  $$\sim \Delta f_q(x, Q^2) \cdot D^h_q(z, Q^2)$$

- **Information on PDFs & FFs can be found in other processes**:
  - hadron-hadron collisions, $e^+e^-$ annihilations, ...

- **Current knowledge of**:
  - PDFs: well known
  - FFs: poorly known

- **Parton Distribution functions (PDFs)**

- **Fragmentation functions (FFs)**

What about polarized PDFs $\Delta f_q$?
Polarized parton distributions $\Delta f_q$

The extraction of polarized parton distributions from spin asymmetries at LO depend on FFs and PDFs.

PDFs + FFs + Asym.

$\Delta f_q$

Different FFs $\rightarrow$ different results for polarized parton distributions especially for strange quark $\Delta s$

$\Delta s$ always thought to be negative from DIS data but ... using SIDIS data $\Delta s \geq 0$

puzzling result but relies on:
- kaon fragmentation functions
- unpolarized PDFs ($s(x)$ ?)
- ...

How well do we know FFs & $s(x)$ ?
need more experimental data and further theoretical studies.

hadron multiplicities in Semi-inclusive Deep Inelastic Scattering
Why hadron multiplicities?

Assuming Quark Parton Model, Leading Order

\[
\frac{dM_h(x, Q^2, z)}{dz} = \sum_q e_q^2 f_q(x, Q^2) D^h_q(z, Q^2) \frac{1}{\sum_q e_q^2 f_q(x, Q^2)}
\]

- Gives access to non-perturbative but universal objects that enter cross sections of different processes (pp collisions, SIDIS, ...):
  - Fragmentation functions: \( D^h_q(z, Q^2) \)
  - Parton distribution functions: \( f_q(x, Q^2) \)
  - Disentangle quarks & antiquarks
  - Allows flavor/charge separation
  - Provides inputs to global analysis
  - Improves the current FF parametrizations
The COMPASS Experiment
Common Muon and Proton Apparatus for Structure and Spectroscopy

- Fixed target experiment at CERN
- Secondary $\mu$ beam from SPS
- Tracking, PID

$\pi$-$K$ separation in the range $3 < P < 50$ [GeV/c]

2004 Data presented:
160 GeV/c $\mu^+$ beam
Deuteron ($^6$LiD) target
Experimental definition of hadron multiplicities & experimental cuts

Multiplicity: Averaged number of hadrons per deep inelastic scattering event:

\[
\frac{dM^h(x, Q^2, z)}{dz} = \frac{dx dQ^2}{d^2 N^{DIS}(x, Q^2)} \cdot \frac{d^3 N^h(x, Q^2, z)}{dx dQ^2 dz} = \text{Hadron yields} \cdot \text{DIS events yields}
\]

- **DIS events cuts:**
  - \( Q^2 > 1 \text{ [GeV/c]}^2 \)
  - \( y: [0.1, 0.9] \)
  - \( W > 7 \text{ GeV} \)
  - \( x: [0.004, 0.7] \)

- **Hadron candidate cuts:**
  - \( z: [0.2, 0.85] \) to avoid target fragmentation region and exclusive processes
  - \( P < 50 \text{ GeV/c} \) to ensure \( \pi \)-K separation
Kinematical distributions of DIS events

COMPASS 2004, $\mu^+d\rightarrow\mu^+X$

$Q^2>1\,\text{GeV}^2$, $0.1<y<0.9$, $4\times10^{-3}<x<0.7$

Events

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Events
From hadron yields to final hadron multiplicities

- Radiative corrections (< 15%)
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Acceptance correction:
  - Production of large MC sample (~10^7 events)
    - using full Monte Carlo simulation of DIS process
      (LEPTO, GEANT3, COMPASS event reconstruction)
    - using fragmentation parameters in MC optimized for COMPASS data
  - detection efficiency
  - Kinematical smearing
Monte Carlo description of data for DIS variables

Good description of data by Monte Carlo for inclusive variables

COMPASS 2004, $\mu^+d\rightarrow \mu^+X$

$Q^2 > 1$ GeV/c$^2$, $0.1 < y < 0.9$, $4.10^{-3} < x < 0.7$, $W > 7$ GeV

Data / MC

Nour Makke

Hadron 2011, Munich, June 2011 - 10
Monte Carlo description of data for SIDIS variables

Fractional energy \( z \)

Momentum

Transverse momentum

Good description of data by Monte Carlo for semi-inclusive variables
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- Analysis performed in bins of (x,z) and (Q2,z)
  - Acceptance in bin i:
    \[
    \epsilon_i = \frac{M_{MC,i}^{rec}}{M_{MC,i}^{gen}}
    \]
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Analysis performed in bins of (x,z) and (Q2,z)

- acceptance in bin i:
  $$\epsilon_i = \frac{M_{MC, i}^{rec}}{M_{MC, i}^{gen}}$$

- Corrected data multiplicity in bin i:
  $$M_{corrected, i} = \frac{M_{data, i}}{\epsilon_i}$$
Results: 2D (x,z) Multiplicities for $\pi^\pm$ & $K^\pm$

Disentanglement of x and z

- For $0.2 < z < 0.3$:
  - $\pi^+$ and $\pi^-$
  - $K^+$
  - $K^-$

- For $0.3 < z < 0.45$:
  - $\pi^+$ and $\pi^-$
  - $K^+$
  - $K^-$

- For $0.45 < z < 0.65$:
  - $\pi^+$ and $\pi^-$
  - $K^+$
  - $K^-$

- For $0.65 < z < 0.85$:
  - $\pi^+$ and $\pi^-$
  - $K^+$
  - $K^-$
Comparison with predictions: 2D (x,z) multiplicities

- Good agreement with DSS+MRST04 for $\pi^\pm$ (except at high z)
- Large deviations from prediction for $K^\pm$ at high x

-Model uncertainty?
- Unpolarized strange quark distribution $s(x)$?
- Higher orders contributions?
Results: 2D \((Q^2, z)\) Multiplicities for \(\pi^\pm\) & \(K^\pm\)

- High statistics
- Fine z binning
- Strong \(Q^2\) dependence for negative hadrons \((\pi^- & K^-)\)
Results: 2D ($z, Q^2$) Multiplicities for $\pi^\pm$ & $K^\pm$

$Q^2$ dependence more pronounced for negative hadrons ($\pi^-$ & $K^-$)

COMPASS Preliminary
Results: 1D z Multiplicities for $\pi^\pm$ & $K^\pm$

- $\pi^+ \text{ and } \pi^-$ multiplicities in agreement with predictions (DSS+MRST) & (KRE+MRTS)
- deviations at high z for $\pi^\pm$
- poor agreement with DSS for $K^+$
- Large deviations for $K^-$

Model uncertainty? Higher orders?
Some systematic effects cancel in the ratio $M^{\pi^+}/M^{\pi^-}$

gives access to ratio of fragmentation functions
Summary

- $\pi^\pm$ and $K^\pm$ multiplicities as a function of $(x,z)$ and $(Q^2,z)$ from muon-deuteron(LiD) deep inelastic scattering measured at COMPASS

- Data will be used:
  - for direct LO extraction of quark fragmentation functions
  - for direct LO extraction of unpolarized Parton distribution functions
    → the strange distribution $s(x)$ from kaon’s multiplicities
  - To test the LO assumption of factorization

- Data can significantly contribute to knowledge of the hadronization process
Backup
Backup
Comparison HERMES/COMPASS

\[ \pi^+, \pi^-, K^+, K^- \]

- 0.25 < z < 0.35
- 0.35 < z < 0.45
- 0.45 < z < 0.65
- 0.65 < z < 0.75

\[ Q^2 > 1 \text{ GeV}^2 \]

COMPASS
HERMES