New COMPASS results on kaon multiplicities from SIDIS

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Motivation

Fragmentation functions

- **fragmentation functions** $D^h_q$ describe parton fragmentation into hadrons
- can be accessed in $e^+ e^-$ annihilation, mainly sensitive to $q + \bar{q}$ fragm.
- full **flavour separation** in DIS by measuring production of different hadrons
- FFs of light quarks well established, strange quark FF much less well known
- FFs needed for extraction e.g. of flavour separation of polarised PDFs

Recent results in DIS

- results from COMPASS (isoscalar target) and HERMES (p and d target, lower energy) for pions and kaons
- LO and NLO extraction of $u$ and $d$ quark fragmentation into pions agree with previous findings
- **differences** between COMPASS and HERMES, most striking for kaons
- **problem** extracting strange quark FF, especially at high hadron momenta
Kaon multiplicities from proton target

- COMPASS experiment in 2016
- Multiplicity analysis
- Results for kaons

Multiplicity ratios from isoscalar target

- Experimental method
- Results for kaons
- Results for protons
Deep inelastic scattering

\[ Q^2 = -q^2 \]
\[ y = \frac{E - E'}{E} = \frac{\nu}{E} \]
\[ x = \frac{Q^2}{2M\nu}, \quad z = \frac{E_h}{\nu} \]
\[ W^2 = M^2 + 2M\nu - Q^2 \]

- **Hadron multiplicity**

\[
\frac{dM^h(x, z, Q^2)}{dz} = \frac{d\sigma^h(x, z, Q^2)/dx dz dQ^2}{\sigma^{DIS}(x, Q^2)/dx dQ^2}
\]

- **Factorisation Ansatz**

\[
\sigma^h \sim \sum \sigma_{\text{hard}} \otimes \text{PDF} \otimes \text{FF}
\]

with PDFs: \( q(x, Q^2) \) and FFs: \( D^h_q(z, Q^2) \)

- **in LO pQCD:**

\[
\frac{dM^h(x, z, Q^2)}{dz} = \frac{\sum_q e_q^2 q(x, Q^2) D^h_q(z, Q^2)}{\sum_q e_q^2 q(x, Q^2)}
\]
PID with RICH

Target: 2.5 m liq. H₂
       1.2 m ⁶LiD

Spectrometer
- Two magnets (1 Tm, 4.5 Tm)
- Tracking ($p > 0.5$ GeV/c)
- ECAL, HCAL, muon filter

Muons will be detected by the spectrometer and the PID with RICH system.
**COMPASS kinematics**

**data selection**

- $Q^2 > 1 \, (\text{GeV}/c)^2$
- $W > 5 \, \text{GeV}/c^2$
- $0.1 < y < 0.9$
- $0.0025 < x < 0.7$
- $0.20 < z < 0.85$

3-dim. binning in $x$, $y$, $z$ used

$\theta_{\mu} = 70 \, \text{mrad}$
### Multiplicity analysis

**Analysis steps:**

Data from 2016 with liquid $\text{H}_2$ target

**Raw multiplicities** $N^h / N^\text{DIS} \Delta z$

- Pion and kaon identification with RICH
- Radiative corrections
- Unfolding of PID efficiencies
- Diffractive vector meson contamination
- Electron contamination
- Detector acceptance
- Bin migration

**Final Multiplicities**

event-by-event, bin-by-bin, included in acc. correction

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from $\phi \rightarrow K^+K^-$
Results for kaon multiplicities

about 600 data points obtained in 3D binning: \( \frac{dM_K(x, y, z)}{dz} \)

no \( y \) dependence observed \( \rightarrow \) results averaged over \( y \)

**PRELIMINARY**

**COMPASS p DATA 2016**

**Main systematic uncertainties:**
- RICH unfolding: from 0.1\% to 7\%
- acceptance: 10\%
- diffractive vector mesons: up to 6\%

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Kaon multiplicity sum

**Isoscalar target**: data averaged over $y$ and integrated over $z$:

$$\mathcal{M}^{K^+} + \mathcal{M}^{K^-} = \frac{UD_U^K + SD_S^K}{5U + 2S}$$

with $U = u + \bar{u} + d + \bar{d}$, $S = s + \bar{s}$

- at high $x$ $\mathcal{M}^{K^+} + \mathcal{M}^{K^-} = D^K_U / 5$
- **COMPASS**: $D^K_U \approx 0.7$
  **DSS**: $D^K_U \approx 0.34 \pm 0.04$
- points to larger non-strange FFs than by DSS

- expectation: sum for proton about 5% higher than for isoscalar target
- results agree with expectation
- still to come: more data statistics, reduced systematics for acceptance
**Kaon multiplicity sum**

**Isoscalar target:** data averaged over $y$ and integrated over $z$:

$$\mathcal{M}^{K^+} + \mathcal{M}^{K^-} = \frac{U \mathcal{D}_U^K + S \mathcal{D}_S^K}{5U + 2S}$$

with $U = u + \bar{u} + d + \bar{d}$, $S = s + \bar{s}$

- expectation: sum for proton about 5% higher than for isoscalar target
- results agree with expectation
- similar discrepancy COMPASS-HERMES for results from proton and isoscalar target
Can we shed some light on this discrepancy?

possible explanations:

- different kinematic range of COMPASS-HERMES (160 GeV vs. 27 GeV incident lepton energy), especially in $W$
- $Q^2$ dependence as given by NLO QCD fit of FFs
- hadron mass correction
- all still under discussion, yield some improvement
- but problems with NLO QCD fit at high $z$

Why multiplicity ratios?

- multiplicities at very high $z$ very challenging: low statistics, large smearing effects
- easier: multiplicity ratios e.g. $dM^{K^-}/dM^{K^+}$
- isoscalar target data: radiative and VM correction cancel
- acceptance mostly cancels except for secondary interactions in target
- all 2006 data used (all physics triggers)
- PID with RICH improved
Multiplicity ratios at high $z$

- results from 2006 data taken with isoscalar target in two bins of $x$
- analysis extended to $z_{\text{rec}} = 1.05$
- smearing correction from MC $\rightarrow z_{\text{corr}}$
- in LO a lower limit obtained at large $z$

$$R_K(x, Q^2, z) = \frac{dM_K^-(x, Q^2, z)/dz}{dM_K^+(x, Q^2, z)/dz}$$

$R_K > \frac{\bar{u} + \bar{d}}{u + d}$, $R_p > \frac{\bar{u} + \bar{d}}{u + d}$

clear disagreement with expectations in (N)LO at large $z$ for both $x$ bins

(LO limit for second $x$ bin is 0.31)

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Comparison of $R_K$ and $R_p$

- new analysis for protons in larger $z$ range than for kaons, kaon analysis extended up to momenta of 55 GeV/c
- expectations in LO: 0.51 for low $x$ bin, 0.28 for high $x$ bin
- proton result also below prediction in whole studied $z$ range, also for $Q^2 \approx 10 \text{ (GeV/c)}^2$
- effect growing with mass of studied hadron
dependence of multiplicity ratios

- unexpected dependence on $\gamma^*$ energy $\nu$ observed
- saturation at high $\nu$ for kaon ratio?
- values at high $\nu$ close to expectation

- similar $\nu$ dependence observed for proton ratio
Missing mass dependence

- at high $z$ reduced phase space for other particles plus conservation law to be fulfilled

- dependence on missing mass
  
  $M_X = \sqrt{M_i^2 + 2M_i\nu(1-z) - Q^2(1-z)^2}$ with $M_i = M_K$ or $M_p$

- very smooth dependence

- seems that a correction within the pQCD formalism is needed taking into account the phase space available for hadronisation
new **COMPASS** results for kaon multiplicities from proton target
consistent with results from isoscalar target
discrepances with HERMES lower energy results

- multiplicity ratios from isoscalar target at high $z$
- ratios considerably larger than LO QCD expectation for kaons and protons
- $z$ and unexpected $\nu$ dependence combined in missing mass dependence
- phase space effect should be accounted for in pQCD analyses

- effect will also be studied using 2016/2017 data taken with a proton target