Final COMPASS SIDIS results on charged hadron, pion and kaon multiplicities

Elena Zemlyanichkina

on behalf of the COMPASS Collaboration

Joint Institute for Nuclear Research
Dubna, Russia
COMPASS at CERN

Hadron multiplicities at COMPASS
COmmon Muon and Proton Apparatus for Structure and Spectroscopy

- **TARGET:** \(^6\)LiD, 3 cells (120 cm total length)
- **BEAM:** \(\mu^+\) at 160 GeV/c
- **FEATURES**
  - angular acceptance: \(\pm 180\) mrad
  - track reconstruction: \(p > 0.5\) GeV/c
  - \(h, e, \mu\) identification: calorimeters and muon filters
  - \(\pi, K, p\) identification (RICH); \(p > 2, 9, 18\) GeV/c, respectively

- **DETECTOR**
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes

NA58 at the CERN SPS

\(~ 220\) physicists

24 institutes

E. Zemlyanichkina (JINR, Dubna)

Hadron multiplicities at COMPASS

QCD’17, 3-7 July 2017
Motivation

- Fragmentation functions (FFs, $D^h_q$) describe parton fragmentation into hadrons.
- FFs are needed in analysis which deals with a hadron(s) in the final state.
- In Leading Order QCD, $D^h_q$ describes probability density for a quark of flavour $q$ to fragment into hadron of type $h$.
- The cleanest way to access FFs is in $e^+e^-$ annihilation. However, only sensitive to the sum of $q + \bar{q}$ fragmentation.
- In SIDIS data, FFs are convoluted with PDFs. However, possibility to separate fragmentation from $q$ and $\bar{q}$.
- By studying $pp$ collisions with a high $p_T$ hadrons, access to gluon fragmentation functions.
- SIDIS data are crucial to understand quark fragmentation process.
Multiplicity measurement

- Hadron multiplicities are defined as number of observed hadrons in a number of DIS events

\[
\frac{dM^h(x, z, Q^2)}{dz} = \frac{d^3\sigma^h(x, z, Q^2)/dx dQ^2 dz}{d^2\sigma^{DIS}(x, Q^2)/dx dQ^2}
\]

- Experimentally measured hadron multiplicities need to be corrected for various effects, e.g.
  - spectrometer acceptance and reconstruction program efficiency
  - RICH efficiency and purity (for $\pi$ and $K$)
  - radiative corrections
  - diffractive vector meson production
  - ...
Multiplicities of $\pi^\pm$ on iso-scalar target

- COMPASS extracted $\pi^\pm$ multiplicities
- Results published in PLB 764 (2017) 001
- Some preliminary data were used in DSS+ fit
- COMPASS performed LO fit, using HKNS FF program
- Results agree with world FFs. As expected $D_{fav} > D_{unf}$
The $\pi$ multiplicity sum

For iso-scalar target:

$$\frac{dM_{\pi^+}}{dz} + \frac{dM_{\pi^-}}{dz} = D_{fav} + D_{unf} - \frac{2S}{5Q+2S} (D_{fav} - D_{unf}) \approx D_{fav} + D_{unf}$$

- $Q = u + \bar{u} + d + \bar{d}; S = s + \bar{s}$
- $D_{fav} = D^h_q$ where $q$ is a valence quark of $h$
- $D_{unf} = D^h_q$ where $q$ is NOT a valence quark of $h$
- $D(Q^2, z) \rightarrow$ obtained multiplicity sum is effectively independent of $x$
- in fixed target experiment $x$ and $Q^2$ are correlated, but $Q^2$ dependence of $z$ integrated FF is weak

$$\mathcal{M}_{\pi^+} + \mathcal{M}_{\pi^-} = \int_{0.2}^{0.85} \left( \frac{dM_{\pi^+}}{dz} + \frac{dM_{\pi^-}}{dz} \right) dz \text{ vs. } x \text{ should be almost flat}$$

---

**Graphs:**

- Left graph: $\mathcal{M}_{\pi^+}$ vs. $x$ for COMPASS and HERMES.
- Right graph: $\mathcal{M}_{h^+}$ vs. $x$ for COMPASS and EMC.
Significant cancellation of experimental systematic errors

A good agreement between HERMES and COMPASS

Difference between HERMES and JLab likely explained by different $W$

A good agreement between COMPASS and EMC data for unidentified hadrons
Multiplicities of $K^\pm$ on iso-scalar target

- COMPASS extracted $K^\pm$ multiplicities
- More than 620 data points
- Results published in PLB 767 (2017) 133
Kaon multiplicity sum and ratio

For iso-scalar target:

\[ 5 \left( \frac{dM^{K^+}}{dz} + \frac{dM^{K^-}}{dz} \right) \approx D_Q^K + S/Q D_S^K \approx 4D^K_{fav} + 6D^K_{unf} + S/Q D_S^K \]

- There are large differences observed between COMPASS and HERMES

  ▶ shape of the distribution at low \( x \)
  ▶ the value of \( M^{K^+} + M^{K^-} \) at high \( x \) \( \rightarrow \) \( \int D_Q \)
  ▶ \( M^{K^+}/M^{K^-} \) multiplicity ratio (while agrees for \( \pi \) case)
Kaon multiplicity ratio at high $z$: physics motivation

- There are $e^+e^-$ measurements of multiplicities up to $z = 0.98$

- So far, region $z > 0.85$ was not investigated in SIDIS

- In LO pQCD + independent fragmentation and proton target

\[
\frac{dM_{K^+}}{dz} / \frac{dM_{K^-}}{dz} = \frac{4uD_{fav} + (4\bar{u} + d + \bar{d} + s)D_{unf} + \bar{s}D_{str}}{4\bar{u}D_{fav} + (4u + d + \bar{d} + \bar{s})D_{unf} + sD_{str}}
\]

- So far, all the studies show that $D_{unf} \approx 0$ for $z \approx 0.5 \Rightarrow$ for data with $z > 0.75$, one can neglect it

\[
\frac{dM_{K^+}}{dz} / \frac{dM_{K^-}}{dz} = \frac{4uD_{fav} + \bar{s}D_{str}}{4\bar{u}D_{fav} + sD_{str}}, \text{ or } \frac{dM_{K^+}}{dz} / \frac{dM_{K^-}}{dz} < \frac{u}{\bar{u}}
\]

- For iso-scalar target: $\frac{dM_{K^+}}{dz} / \frac{dM_{K^-}}{dz} < \frac{u+d}{\bar{u}+\bar{d}}$

Kaon multiplicity ratio at high $z$: physics motivation

- Typical ratio $\frac{u+d}{\bar{u}+\bar{d}}$ at $Q^2 = 1.6(\text{GeV}/c)^2$ and $x = 0.03$:
  - $2.15$ (MSTW08 LO), or $2.05$ (MRST04L)
  - $1.90 \pm 0.10$ (NNPDF3.0L), or $2.35 \pm 0.20$ (NNPDF2.3)
  - $2.12 - 2.38$ (NLO)

- Note, that in NLO a bound can be broken ($\sim \alpha_s/2\pi$) as cross section formula is more complex.

- In Lund string model the kaon multiplicity ratio (almost) fulfils the limit.
Kaon multiplicity ratio at high $z$ with COMPASS

- High $z$ region is free from kaons coming from decays of diffractive production of $\phi$

- Why ratio?
  - radiative corrections largely cancel
  - experimental systematic uncertainties are also mostly canceled out
  - DIS sample is not needed

- COMPASS can and DID measure kaon multiplicity ratio at high $z$
Kaon multiplicity ratio at high $z$ with COMPASS Analysis

- We try to keep all the cuts as in the published kaon paper, but
  - $z$ range was extended above 0.85
  - stricter cuts on $K/\pi$ separation were applied
  - improved method of acceptance corrections was used
  - 4 times more data was used than in PLB 767 (2017) 133

- Here we concentrate in region of $x < 0.05$
  - $\langle x \rangle = 0.03$
  - $\langle Q^2 \rangle = 1.6(\text{GeV}/c)^2$
  - 40000 $K^+$ and $K^-$ analysed for $z > 0.75$
Kaon multiplicity ratio at high $z$ with COMPASS

Results

- Observe clear discrepancy between LO QCD expectation and data
- This discrepancy is even larger than presented in figure because of the $z$ smearing
- Obtained result may indicate that factorisation and/or universality of FF does not hold in the studied region
- Further calculations are welcome, also at higher orders

![Graph showing kaon multiplicity ratio at high $z$](graph.png)

No $z$ unfolding, which would further increase the ratio
Kaon multiplicity ratio at high $z$ with COMPASS

$z$ unfolded kaon multiplicity ratio

- An “hybrid method” was used consisting of
  - smearing matrix $z_{\text{generated}}$ vs. $z_{\text{reconstructed}}$ from MC
  - functional form assumed for the $K^+, K^-$ yields: $\alpha e^{-\beta z} (1 - z)^\gamma$

- As expected, unfolding procedure further increases the ratio $K^+/K^-$
- However, for $z < 0.95$ the unfolding impact is not that dramatic

![Graph showing the ratio $dK^+/dK^-$ as a function of $z$. The graph includes data points and a fitted curve.](image-url)
Summary

- COMPASS recently published final multiplicities for $h^\pm$, $\pi^\pm$, and $K^\pm$ from DIS on an iso-scalar target
  - Large sample of precise data vs. $(x, y, z)$ covering a wide kinematical range, constitute an important input for future FF global analysis
  - PLB 764 (2017) 001, and PLB 767 (2017) 133

- Preliminary results for the kaon multiplicity ratio $K^+/K^-$ at high $z$ were shown
  - Results are inconsistent with prediction of (N)LO pQCD
  - They may indicate that factorisation and/or universality of FF does not hold in the studied region
  - Hints of the problem can already be noticed in the published data
  - More calculations are needed, possibly also at higher orders