π and K SIDIS multiplicities, \( \bar{p}/p \) and \( K^-/K^+ \) ratios at large \( z \) measured at COMPASS

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On behalf of COMPASS Collaboration
COnmon Muon Proton Apparatus for Structure and Spectroscopy

~240 physicists, 13 countries, 25 institutions

Fixed target experiment, multi-purpose set-up.
Secondary ~200 GeV muon and hadron beams from CERN SPS
Various targets
Motivation
Longitudinal spin- Impact of FF on $\Delta s$ extraction

$\Delta s$ extraction from SIDIS depends on value of $D^K_S$ fragmentation function.

$\Delta s$ vs $R_{SF}$

$R_{SF} = D^K_S / D^K_u$

Most $\Delta s$ extractions from SIDIS used the old DSS value for $R_{SF}$. Could be revisited.
Quark Fragmentation Functions (FF)

**FFs**: - Non perturbative object; needed to describe various reactions
- Strange quark FF= **largest uncertainty in Δs extraction** from polarized SIDIS.

Data exist from $e^+e^-$ and pp reactions, but insufficient and at too high $Q^2$

→ Measure hadron multiplicities in **SIDIS**: $\mu^+d \rightarrow \mu^+h^\pm X$

$$dM^h(x, Q^2, z) \over dz \text{ at LO} = \sum_q e_q^2 f_q(x, Q^2) D_q^h(z, Q^2)$$

PDFs depend on $x$, while FFs depend on $z$

→ With kaons, access typically: $s(x, Q^2).D^h_S(z, Q^2)$

Corrections for: acceptance, RICH purity & efficiency, radiative effects and vector meson contamination

Data obtained in a fine binning in $x$, $z$, $Q^2$

→ $\pi$ and $K$ multiplicities constitute an input to global NLO QCD analyses to extract quark FFs,
→ Especially, $K$ will constrain strangeness
COMPASS $\pi$ and K multiplicities vs $z$ in $(x,y)$ bins

- Isoscalar target ($^6$LiD)
- More than 1200 points in total, various $Q^2$ staggered vertically for clarity
- Strong $z$ dependence
- $M(\pi^+)$ $\sim$ $M(\pi^-)$ and $M(K^+)$ $>$ $M(K^-)$
From multiplicities to quark Fragmentation Functions

**Pions**
Results from COMPASS LO fits assuming 2 independent FFs: $D_{\text{fav}}^{\pi}$ $D_{\text{unf}}^{\pi}$

- As expected, $D_{\text{fav}}^{\pi} > D_{\text{unf}}^{\pi}$
- COMPASS LO fit results \(\sim\) agree with DSEHS and LSS NLO.

**Kaons**
Assuming 3 independent FFs: $D_{\text{fav}}^{K}$ $D_{\text{str}}^{K}$ $D_{\text{unf}}^{K}$

- LO fit not conclusive. Some difficulty in fitting high $z$ data, even at NLO.
- Still, get constraints on FFs from sum of $K^+$ and $K^-$ multiplicities (see later)

(\text{e.g. in } DSS17\text{ where half of data come from COMPASS, and also in combined fit of PDF and FF via iterative study})

\textbf{Borsa, Sassot, Stratmann, arXiv:1708.01630}
Longitudinal spin- Impact of FF on $\Delta s$ extraction
Sum of z-integrated multiplicities \( \pi^+ + \pi^- \) & \( K^+ + K^- \)

For isoscalar target, simple dependence on FFs:

\[
M^{\pi^+ + \pi^-} = (1 - 2S/(5Q + 2S)) \left( D_{\text{fav}} + D_{\text{unf}} \right)
\]

where:

\[
\begin{align*}
Q &= u + \bar{u} + d + \bar{d}, \\
S &= s + \bar{s}, \\
D_Q^K &= 4D_{\text{fav}}^K + 6D_{\text{unf}}^K
\end{align*}
\]

At high \( x \), \( \sim \) no \( x \) dependence expected

COMPASS pion data:
- significantly below HERMES ones
- no \( x \) dependence as expected (as in EMC h, but not shown here)

COMPASS kaon data:
- significantly above HERMES ones
- Indicate larger \( D_Q^K \) than old NLO fits

\[ 5M^{K^+ + K^-} = D_Q^K + S/Q D_S^K \]

\( \text{high } x \) data \hspace{1cm} \( \text{low } x \) data

PLB 764 (2017) 001

PLB 767 (2017) 133
K Multiplicities on \( p \) target

- Preliminary result from 2016 run (2017 to come)
- Radiative corrections using DJANGOH event generator (Spiesberger) → reduces systematics

\[
M(K^-) + M(K^+) = \frac{d_N}{d_T} + \frac{d_N}{d_T} K^+ + \frac{d_N}{d_T} K^+
\]

- Results on \( p \) confirm discrepancy COMPASS vs HERMES (\( x,z \)) data set, observed on \( d \) target
- \( p \) results 5% above \( d \) ones, as expected
Kaons:

- Target hadron mass corrections could explain part of discrepancies.

For the very few points that have exactly the same kinematics in $x,y,z$ variables, HERMES and COMPASS agree.

Guerrero, Accardi, PRD 97 (2018) 114012
M(K⁻)/ M(K⁺) kaon multiplicity ratio at high z

**Motivation:** High z region not studied so far
Most experimental and theoretical uncertainties cancel in ratio

Some simple estimation at LO, proton target with assumptions ($D_{\text{unf}}$ neglected…):

$$\Delta K/\Delta K = \frac{4\bar{u}D_{\text{fav}} + sD_{\text{str}}}{4uD_{\text{fav}} + \bar{s}D_{\text{str}}}.$$

and assuming $s = \bar{s}$, gives limits:  

$$R_K > \frac{\bar{u}}{u}$$  
for a proton target

$$R_K > \frac{\bar{u} + \bar{d}}{u + d}$$  
for a deuteron target
M(K⁻)/ M(K⁺) at high z – Results vs z

Ratio measured vs z in two x bins

M(K⁻) / M(K⁺) ratio well below expectations at high z

Compare to theory, bin x=0.03

PLB 786 (2018) 390
M(K⁻)/ M(K⁺) – Results vs $\nu = \frac{E_{h}}{z}$ in 5 $z$ bins

Isoscalar target for bin $x=0.03$

Larger discrepancy with theory for smaller $\nu$
High $z$ kaon $\rightarrow$ reduced phase space for other particles

Study missing mass behaviour

- $\frac{M(K^-)}{M(K^+)}$ shows unexpected strong rise with $M_X$
- Suggests to take into account the available phase space for hadronization, in the formalism
Recent developments

$K^-/K^+$ Does $R_K$ reaches pQCD expectations at higher $\nu$?  

$\rightarrow$ Extend $\nu$ range up to 70 GeV  
done by improving kaon selection at high momenta $40 \rightarrow 55 \text{ GeV/c}$

$\bar{p}/p$ Does $R_p$ show similar unexpected behaviour as $R_K$?  

$\rightarrow$ Study antiproton/ proton case :  
$R_p$ vs lower LO limit, dependence on $\nu$, dependence on $M_X$
Kaons (I): $R_K$ vs $\nu$ in 5 $z$ bins

New data with high $K$ momenta cover higher $\nu$ range, up to 70 GeV

- Better compatibility with pQCD expectations at higher $\nu$
- ... and at lower $z \sim 0.75$ - 0.85
- For lower energy experiments, could lower $z$ regions be affected?
Kaons (II): $R_K$ vs $M_X$

- New data slightly extend $M_X$ range (closed points)
- At fixed $M_X$, no dependence on $v$ nor $z$
  $\Rightarrow$ confirms that $M_X$ encompasses all dependences
Kaons and protons: $R_K$ and $R_p$ vs $z$

- $R_p$ decreases vs $z$, as $R_K$
- Observe large difference between $R_K$ and $R_p$, while only 15% expected from LO pQCD

→ Is discrepancy wrt theory larger for higher mass hadrons?

PoS (DIS2019) 207
Protons (II): $R_p$ vs $\nu$ in 9 $z$ bins

- Observe $\nu$ dependence for $R_p$ (as seen for $R_K$) (beyond expected from $x(\nu)$)
- $R_p$ closer to pQCD expectations at higher $\nu$ values
Protons (III): $R_p$ vs $M_X$

For protons also, $M_X$ encompasses all dependences ($\nu$ and $z$)
Protons (I): $R_p$ vs $z$ in two $x$ bins

Lower LO limits for:
\begin{itemize}
  \item $<x>=0.02$
  \item $<x>=0.10$
\end{itemize}

$R_p$ ratio below lower limit in whole $z$ range
Summary – SIDIS $\pi$, K and p multiplicities

$\bar{p}/p$ and $K^-/K^+$ multiplicity ratios at high $z$:
- Data **disagree** with current NLO QCD calculations at high $z$ and low $\nu$ (At lower energy, larger region in $z$ may be affected)
- Unexpected rise of ratios with missing mass, suggesting to take into account the available phase space for hadronization, in the formalism.

… Paper in preparation

**Reminder**: $\pi$ and K SIDIS multiplicities

- **isoscalar target**: PLB 2017
- **hydrogen target**: prelim data DIS-2019
  - Largest kaon sample measured, to constrain kaon FFs ($D^K_S$)
  - Some hints on reasons for **large discrepancy** COMPASS vs HERMES

- Smaller $D^K_S$ and larger $D^K_U$ than previously leads to **slightly larger** $\Delta S$ from SIDIS, i.e. no longer strong incompatibility with $\Delta S$ from inclusive data.