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

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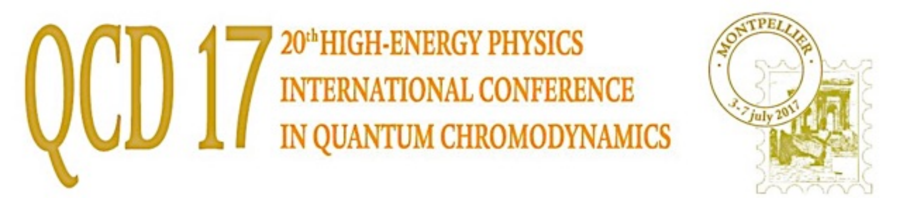
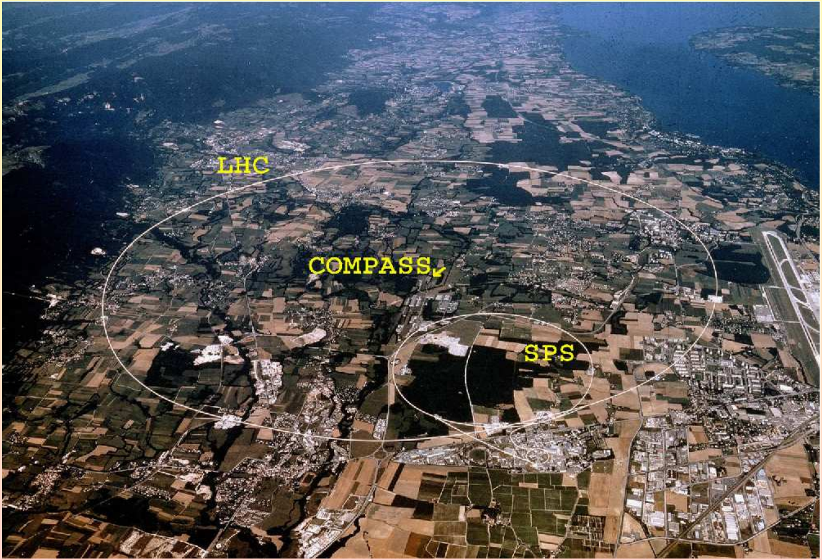
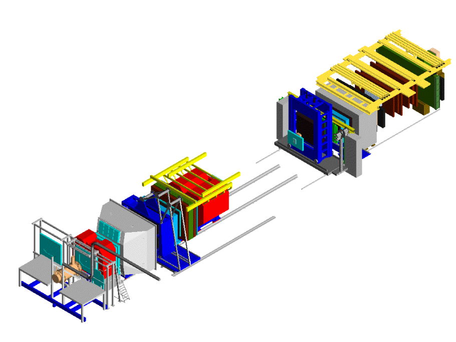


COMPASS at CERN



COmmon Muon and Proton Apparatus for Structure and Spectroscopy

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



- DETECTOR
  - two stage spectrometer
  - 60 m lenght
  - about 350 detector planes

NA58 at the CERN SPS ~ 220 physicists 24 institutes

Motivation

- Fragmentation functions (FFs, D_q^h) 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_q^h 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^- annihilaton. However,
  - only sensitive to the sum of $q + \bar{q}$ fragmentation
  - flavour separation possibilities are limited
- In SIDIS data, FFs are convoluted with PDFs. However,
  - possibility to separate fragmentation from q and $\bar{q}$
  - full flavour separation possible
- 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

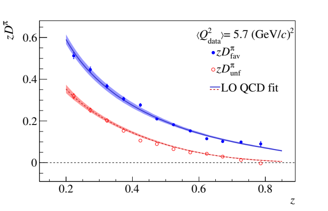
- Hadron multiplicities are defined as number of observed hadrons in a number of DIS events

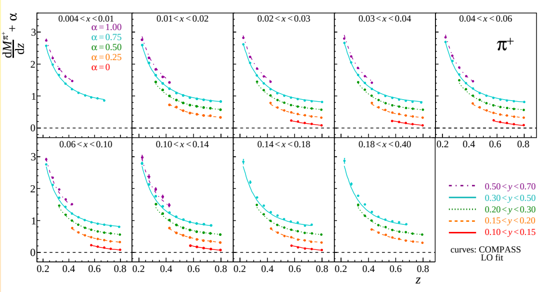
$$\frac{dM^h(x,z,Q^2)}{dz} = \frac{d^3\sigma^h(x,z,Q^2)/dxdQ^2dz}{d^2\sigma^{DIS}(x,Q^2)/dxdQ^2}$$

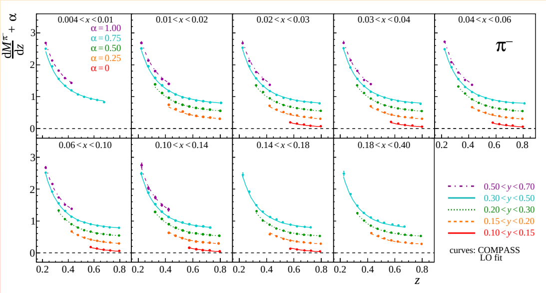
- Experimentally measured hadron multiplicities need to be corrected for various effects, e.g.
    - spectrometer acceptance and reconstruction program efficiency
    - RICH efficiency and purity (for π and K)
    - radiative corrections
    - diffractive vector meson production
    - ...

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 $D_{fav} > D_{unf}$



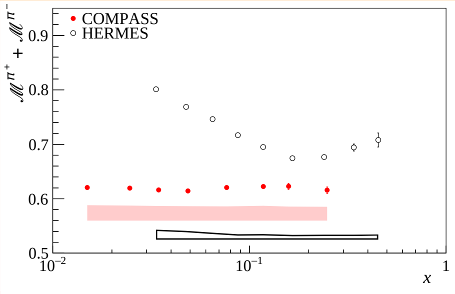


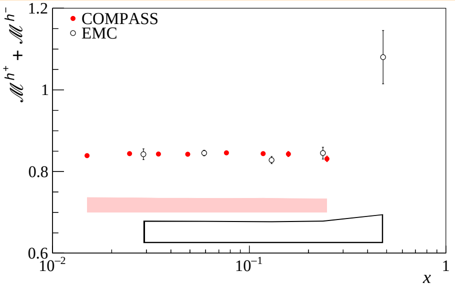


The π multiplicity sum PLB 764 (2017) 001

For iso-scalar target:

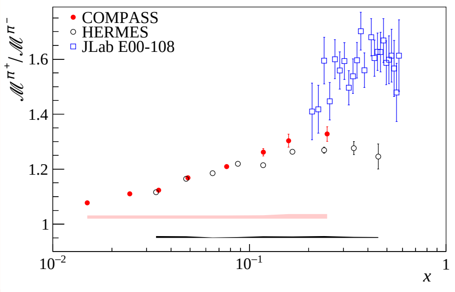
- $\frac{dM^{\pi^+}}{dz} + \frac{dM^{\pi^-}}{dz} = D_{fav} + D_{unf} - \frac{2S}{5Q+2S}(D_{fav} - D_{unf}) \approx D_{fav} + D_{unf}$
  - $Q = u + \bar{u} + d + \bar{d}$; $S = s + \bar{s}$
  - $D_{fav} = D_q^h$ where q is a valence quark of h
  - $D_{unf} = D_q^h$ where q is NOT a valence quark of h
  - $D(Q^2, z) \rightarrow$ 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
- $\mathscr{M}^{\pi^+} + \mathscr{M}^{\pi^-} = \int_{0.2}^{0.85} (\frac{dM^{\pi^+}}{dz} + \frac{dM^{\pi^-}}{dz}) dz$ vs. x should be almost flat

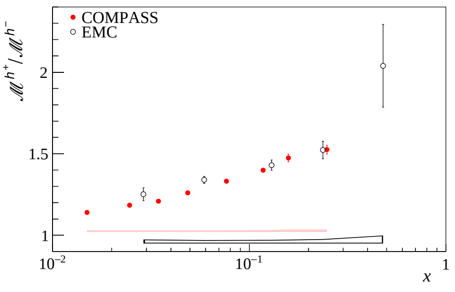




The π^+/π^- multiplicity ratio PLB 764 (2017) 001

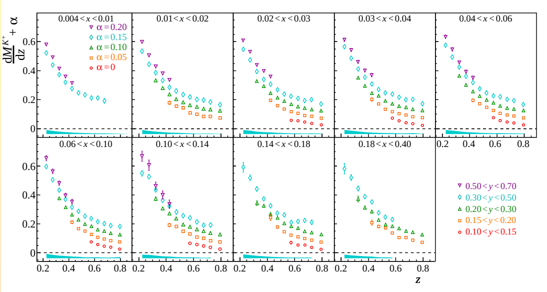
- Significant cancellation of experimental systematic errors
- A good agreement between HERMES and COMPASS
- Difference between HERMES and JLab likely explained by different W
- A good agreement between COMPASS and EMC data for unidentified hadrons

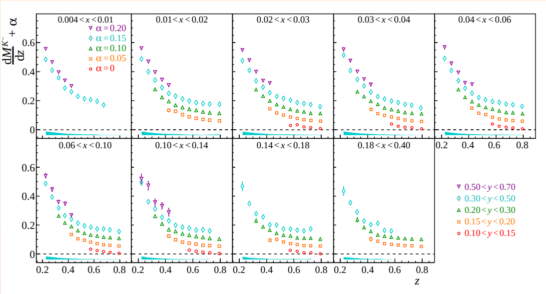




Multiplicities of $K^{\pm}$ on iso-scalar target

- COMPASS extracted $K^{\pm}$ multiplicities
- More than 620 data points
- Results published in PLB 767 (2017) 133



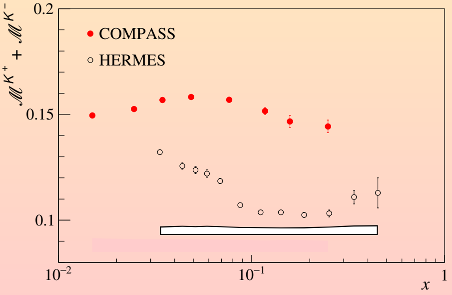


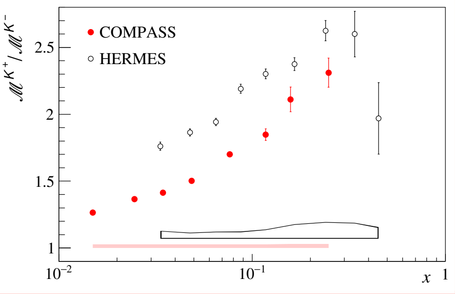
Kaon multiplicity sum and ratio PLB 767 (2017) 133

For iso-scalar target:

- $5(\frac{dM^{K^+}}{dz} + \frac{dM^{K^-}}{dz}) = \approx D_Q^K + S/QD_S^K \approx 4D_{fav}^K + 6D_{unf}^K + S/QD_S^K$

- There are large difference observed between COMPASS and HERMES
  - shape of the distribution at low x
  - the value of $\mathscr{M}^{K^+} + \mathscr{M}^{K^-}$ at high $x \to \int D_Q$
  - $\mathscr{M}^{K^+}/\mathscr{M}^{K^-}$ multiplicity ratio (while agrees for π case)





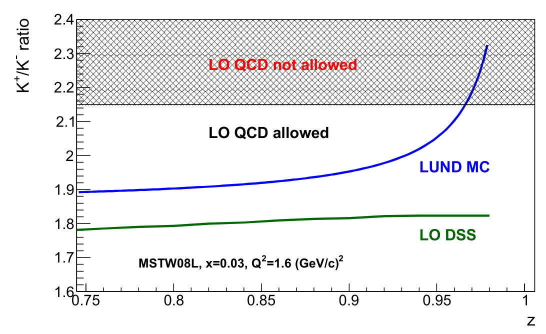
Kaon multiplicity ratio at high z: physics motivation

- 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
  - $\frac{dM^{K^+}}{dz} / \frac{dM^{K^-}}{dz} = \frac{4uD_{fav} + \bar{s}D_{str}}{4\bar{u}D_{fav} + sD_{str}}$, 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

COMPASS

- 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 ± 0.10 (NNPDF3.0L), or 2.35 ± 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 ϕ

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

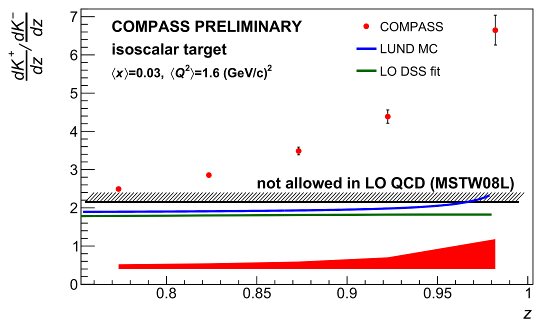
- COMPASS can and DID measure kaon multiplicity ratio at high z

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/π 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

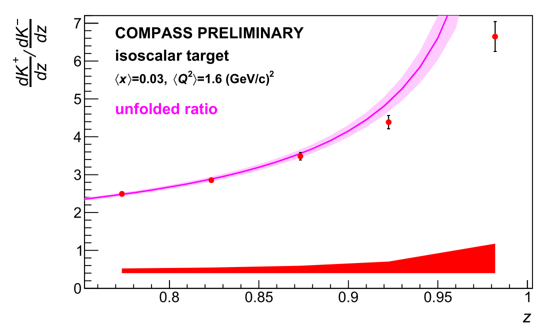
- Observe clear discrepancy between LO QCD expectation and data
- This discrepancy is even larger than presented in figure because of the z smearing
- Obtained result may indicate that factorisation and/or universality of FF does not hold in the studied region
- Further calculations are welcome, also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



No z unfolding, which would futher 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 $z_{generated}$ vs. $z_{reconstructed}$ 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



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