Final COMPASS Results on Hadrons, Pions and Kaons Multiplicities

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LIP

On behalf of the COMPASS Collaboration

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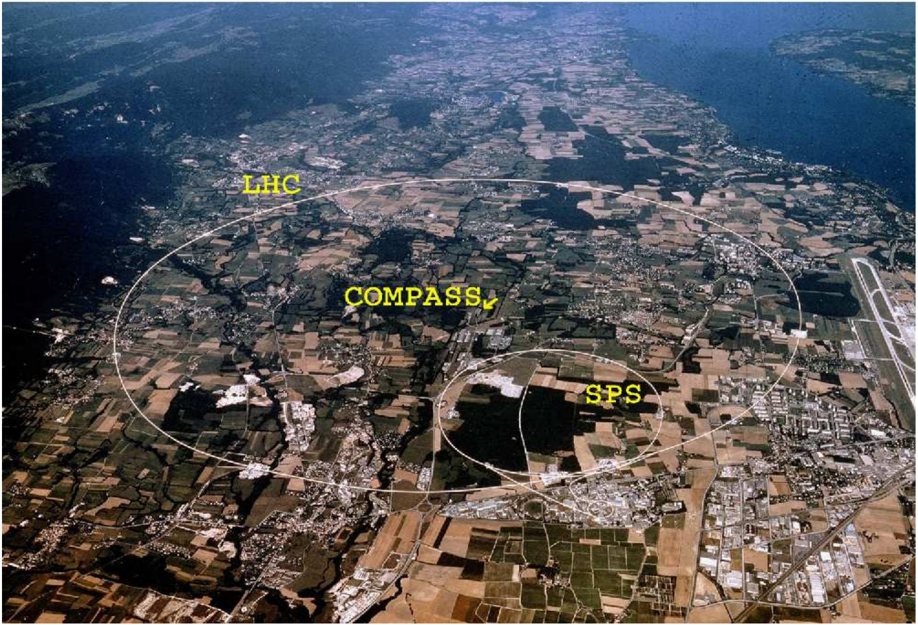
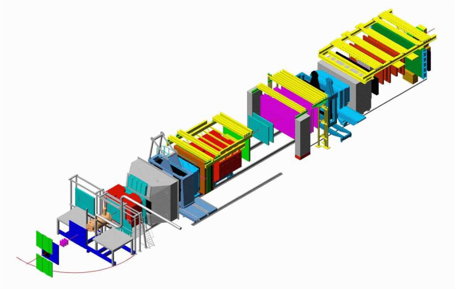
Outline

COMPASS at CERN



COMPASS Spectrometer 2006



- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes
- TARGET
  - ^{6}LiD target
  - 3 cells (120 cm total length)
- BEAM
  - μ^+ at 160 GeV/c
- FEATURES
  - angular acceptance: ± 180 mrad
  - track reconstruction: $p > 0.5$ GeV/c
  - identification h, e, μ: calorimeters and muon filters
  - identification: π, K, p (RICH) $p > 2$, 9, 18 GeV/c respectively

Motivation

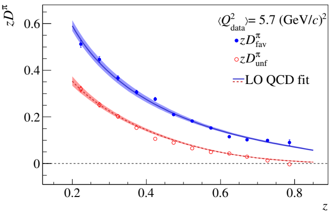
- Fragmentation functions (FF, D_q^h) describe parton fragmentation into hadrons
- FF are needed in analyses which deal with a hadron(s) in the final state
- In Leading Order QCD D_q^h describes probability density for a quark of flavour q to fragment into hadron of type h
- The cleanest way to access FFs is in e^+e^- annihilation. However,
  - only sensitive to the sum of $q + \bar{q}$ fragmentation
  - flavour separation possibilities are limited
- In the SIDIS data, FF 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

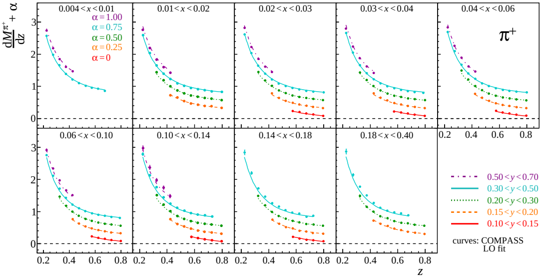
Multiplicity Measurement

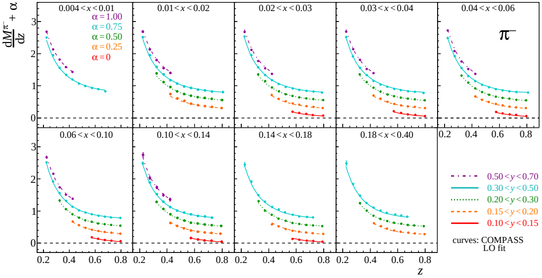
- Hadron multiplicities are defined as number of observed hadrons in a number of DIS events
- $\frac{dM^h(x,z,Q^2)}{dz} = \frac{d^3\sigma^h(x,z,Q^2)/dxdQ^2dz}{d^2\sigma^{DIS}(x,Q^2)/dxdQ^2}$
- Experimentally measured hadron multiplicities need to be corrected for various effects e.g.
  - spectrometer acceptance & reconstruction program efficiency
  - RICH efficiency & purity (for π and K)
  - radiative corrections
  - diffractive vector meson production
  - ...

Multiplicities of π 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 programme
- Results agrees with world FFs. As expected $D_{fav} > D_{unf}$

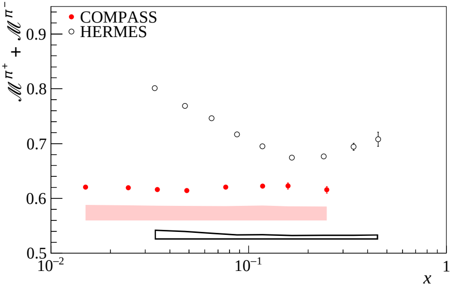


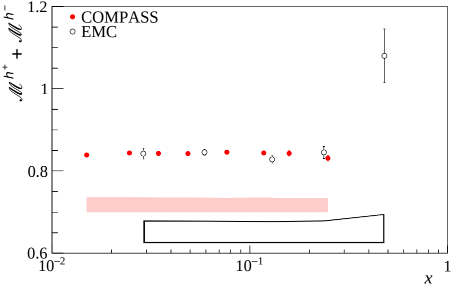




The π Multiplicity Sum

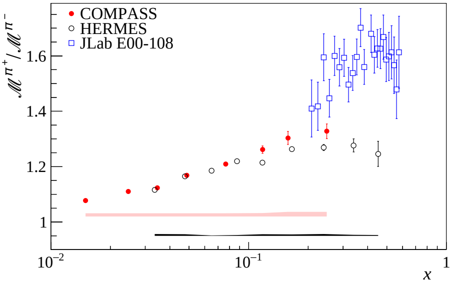
- For iso-scalar target:
- $\frac{dM^{\pi^+}}{dz} + \frac{M^{\pi^-}}{dz} = D_{fav} + D_{unf} - \frac{2S}{5Q+2S}(D_{fav} - D_{unf}) \approx D_{fav} + D_{unf}$
  - $Q = u + \bar{u} + d + \bar{d}$; S$= s + \bar{s}$
  - $D_{fav} = D_q^h$ where q is valence quark of h
  - $D_{unf} = D_q^h$ where q is NOT 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
- $\mathcal{M}^{\pi^+} + \mathcal{M}^{\pi^-} = \int_{0.2}^{0.85} \frac{dM^{\pi^+}}{dz} + \frac{dM^{\pi^-}}{dz} dz$ vs. x should be almost flat

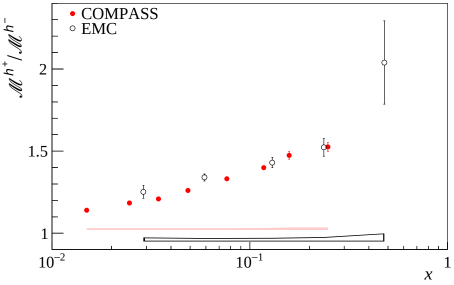




The π^+/π^- Multiplicity Ratio

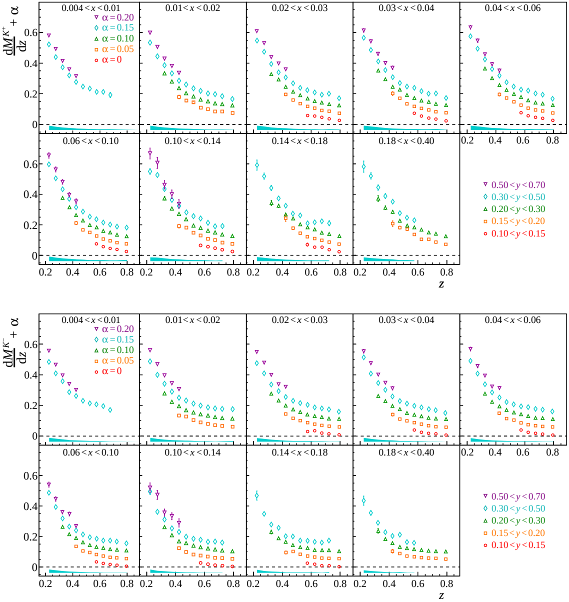
- The ratio of π^+/π^- or (h^+/h^-) is interesting to study due to significant cancellation of experimental systematic errors
- Here, a good agreement between HERMES and COMPASS is seen
- Difference between HERMES and JLab likely explained by different W
- As previously there is a good agreement between COMPASS and EMC data for unidentified hadrons





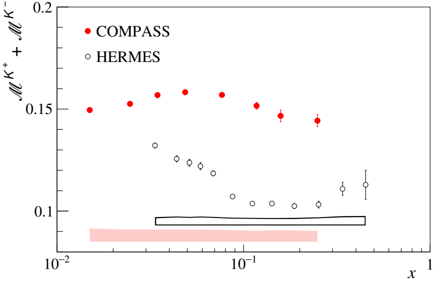
Multiplicities of Kaons on Iso-Scalar Target

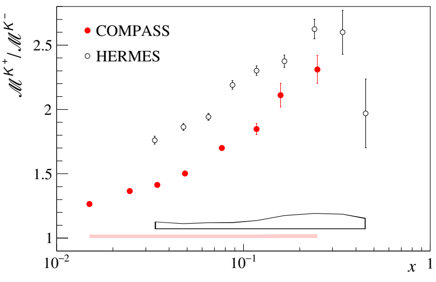
- COMPASS extracted Kaon multiplicities
- More than 620 data points
- Recently published in PLB 767 (2017) 133



Kaon Multiplicity Sum and Ratio

- For the 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 differences observed between COMPASS and HERMES
  - shape of the distribution a low x
  - the value of $\mathcal{M}^{K^+} + \mathcal{M}^{K^-}$ at high $x \to \int D_Q$!
  - $\mathcal{M}^{K^+}/\mathcal{M}^{K^-}$ multiplicity ratio (which agrees for π case)





Kaon Multiplicity Ratio at High z

NEW!

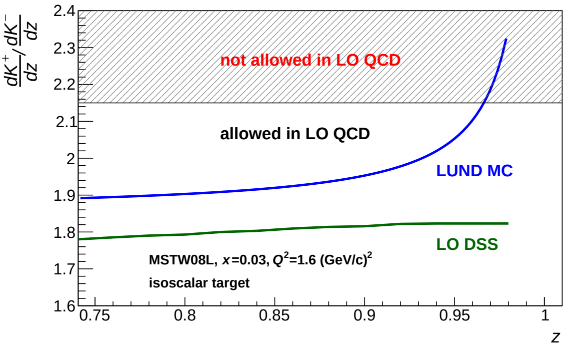
- COMPASS measured kaon multiplicity ratio at high z
- High z region is free from kaons coming from decays of diffractive production of ϕ
- Why ratio?
  - radiative corrections largely cancel
  - a lot of experimental systematic uncertainties also cancels
  - DIS sample is not needed
- It was possible to extend studies for all 2006 data and also semi-inclusive triggers
  $\rightarrow$ Statistics was increased four fold w.r.t. published data

Motivation - Physics

- 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 $z \approx 0.5$, Thus for data with $z > 0.75$, one can neglect it.
- $\frac{dM^{K^+}}{dz} / \frac{dM^{K^-}}{dz} = \frac{4uD_{fav}+\bar{s}D_{str}}{4\bar{u}D_{fav}+sD_{str}}$
- $\frac{dM^{K^+}}{dz} / \frac{dM^{K^-}}{dz} < \frac{u}{\bar{u}}$
- $\frac{dM^{K^+}}{dz} / \frac{dM^{K^-}}{dz} < \frac{u+d}{\bar{u}+\bar{d}}$, for deuteron target

Motivation - Physics cont.

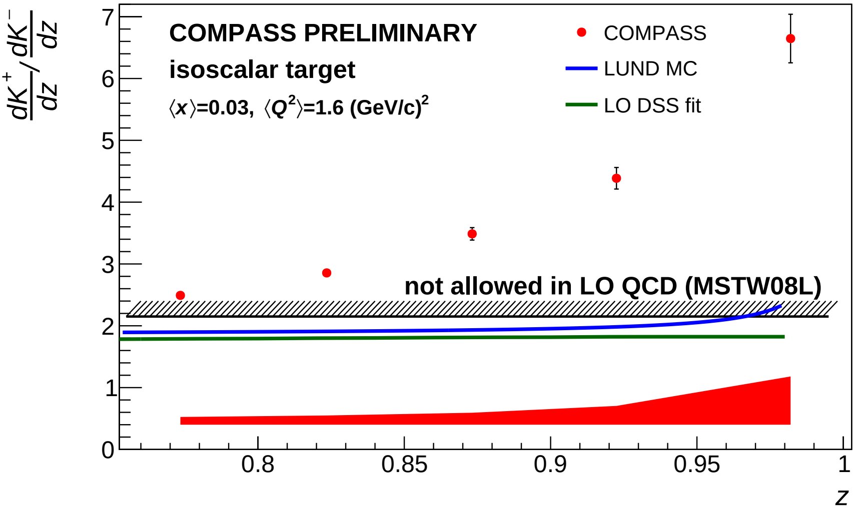
- Typical ratio $\frac{u+d}{\bar{u}+\bar{d}}$ at $Q^2 = 1.6\ (\mathrm{GeV}/c)^2$ and $x = 0.03$
  - 2.15 MSTW08 LO , 2.05 MRST04L
  - 1.90 ± 0.10 NNPDF3.0L , 2.35 ± 0.20 NNPDF2.3
  - $2.12 - 2.38$ NLO
- Note that in NLO, the limit can be broken ($\sim \alpha_S/2\pi$) as cross section formula is more complex
- In Lund string model the kaon multiplicity ratio (almost) fulfils the limit



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 764 (2017) 133
- Here we concentrate in region of $x < 0.05$
  - $\langle x \rangle = 0.03$
  - $\langle Q^2 \rangle = 1.6(\mathrm{GeV}/c)^2$
  - 40000 K^+ and K^- analysed for $z > 0.75$

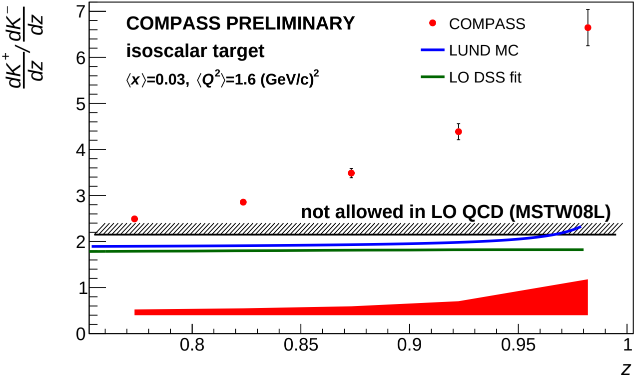
Results



NO z unfolding, which would further increase the ratio

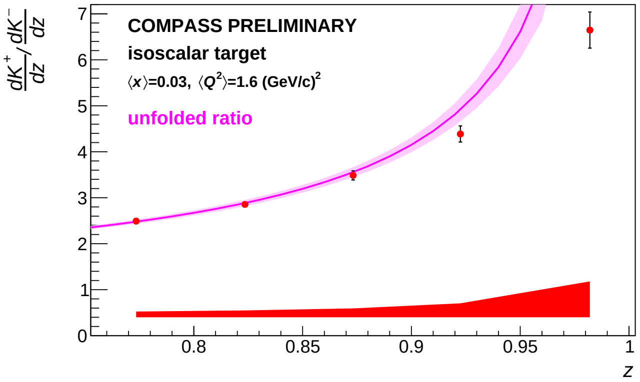
Comments

- 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 mean that universality of FFs does not hold and/or factorisation is broken
- Further calculations are welcome, also at higher orders



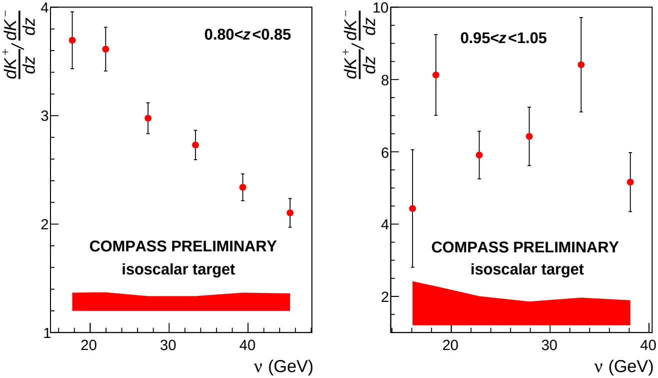
z Unfolded Kaon Multiplicity Ratio

- An "hybrid method" was used consisting of
  - smearing matrix $z_{generated}$ vs $z_{reconstructed}$ from MC
  - functional form assumed for the K^+, K^- yields: $\alpha exp(-\beta z)(1-z)^\gamma$
- As expected unfolding procedure further increases the ratio K^+/K^-
- However, for $z < 0.95$ the unfolding impact is not that dramatic



ν Dependence of Kaon Multiplicity Ratio

- Strong dependence of the kaon multiplicity ratio on $\nu = E - E'$ is observed in certain z bins
- In NLO QCD fits it should be difficult to describe COMPASS high z and low y data points of the published paper, PLB 767 (2017) 133
- Note that HERMES has lower ν than COMPASS.



Summary

- COMPASS recently published final multiplicities for $h^{\pm}$, $\pi^{\pm}$ and $K^{\pm}$ from DIS on an iso-scalar target
  - PLB 764 (2017) 001, PLB 767 (2017) 133
  - Large sample of precise data vs (x, y, z) covering a wide kinematical range, constitute an important input for future FF global analyses
- 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 is broken
  - hints of the problem can already be noticed in the published data
  - more calculations needed, possibly also at higher orders