New COMPASS results on kaon multiplicities from SIDIS

Eva-Maria Kabuß
for the COMPASS collaboration

Institut für Kernphysik, Universität Mainz

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COMPASS
Großgeräte der physikalischen Grundlagenforschung

COMPASS

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Motivation

Fragmentation functions

- fragmentation functions $D_{\mathrm{q}}^{\mathrm{h}}$ describe parton fragmentation into hadrons
- can be accessed in $\mathrm{e}^{+}\mathrm{e}^{-}$ 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

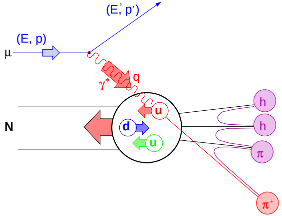
Recent results in DIS

- 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

Outline

- **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



$$Q^2 = -q^2$$
$$y = \frac{E - E'}{E} = \frac{\nu}{E}$$
$$x = \frac{Q^2}{2M\nu}, \quad z = \frac{E_\mathrm{h}}{\nu}$$
$$W^2 = M^2 + 2M\nu - Q^2$$

- **Hadron multiplicity**

$$\frac{\mathrm{d}M^\mathrm{h}(x,z,Q^2)}{\mathrm{d}z} = \frac{\mathrm{d}\sigma^\mathrm{h}(x,z,Q^2)/\mathrm{d}x\mathrm{d}z\mathrm{d}Q^2}{\sigma^\mathrm{DIS}(x,Q^2)/\mathrm{d}x\mathrm{d}Q^2}$$

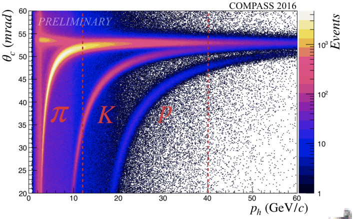
- **Factorsation Ansatz**

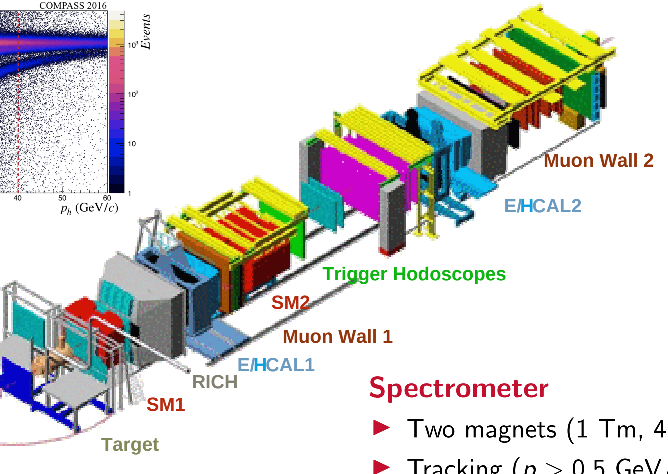
$$\sigma^\mathrm{h} \sim \sum \sigma_\mathrm{hard} \otimes \mathrm{PDF} \otimes \mathrm{FF}$$

with PDFs: $q(x, Q^2)$ and FFs: $D_q^\mathrm{h}(z, Q^2)$

- **in LO pQCD:** $$\frac{\mathrm{d}M^\mathrm{h}(x,z,Q^2)}{\mathrm{d}z} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^\mathrm{h}(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

PID with RICH

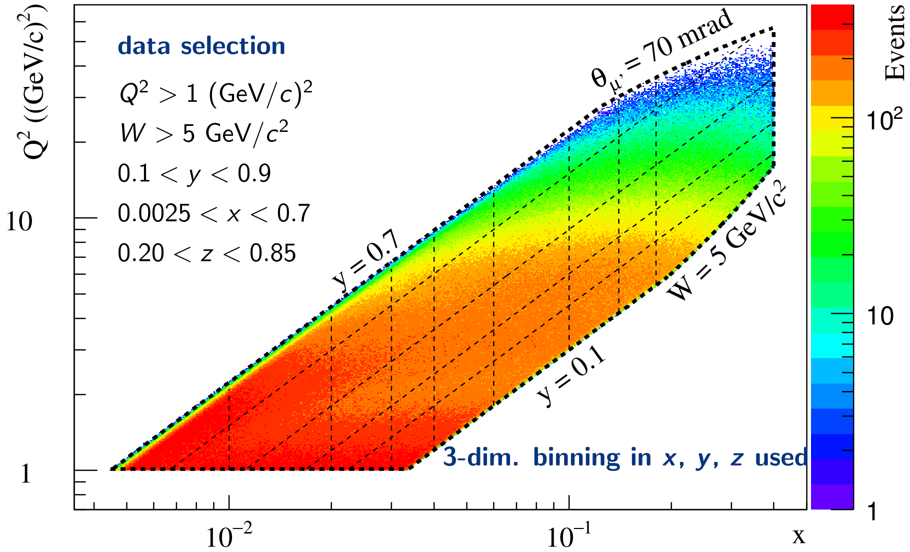




Target: 2.5 m liq. H_2
1.2 m ^{6}LiD

Spectrometer

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


data selection
$Q^2 > 1$ (GeV/c)^2
$W > 5$ GeV/c^2
$0.1 < y < 0.9$
$0.0025 < x < 0.7$
$0.20 < z < 0.85$
$\theta_{\mu'} = 70$ mrad
y = 0.7
y = 0.1
W = 5 GeV/c^2
3-dim. binning in x, y, z used
Q^2 ((GeV/c)^2)
x
Events
1
10
10^2
10^{-2}
10^{-1}

Multiplicity analysis

Analysis steps:

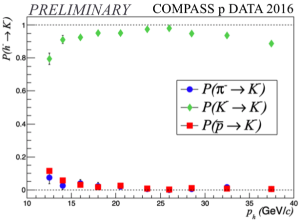
Data from 2016 with liquid H_2 target

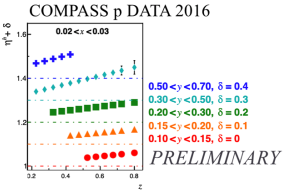
Raw multiplicities $N^{\mathrm{h}}/N^{\mathrm{DIS}}\Delta z$

Pion and kaon identification with RICH

Radiative corrections

Unfolding of PID efficiencies





Diffractive vector meson contamination

Electron contamination

Detector acceptance

Bin migration

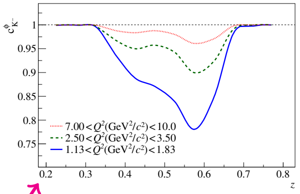
Final Multiplicities

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

Multiplicity analysis

Analysis steps:

from $\phi \to K^+K^-$



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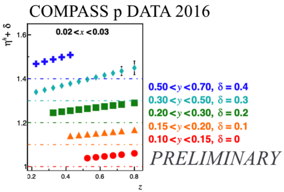
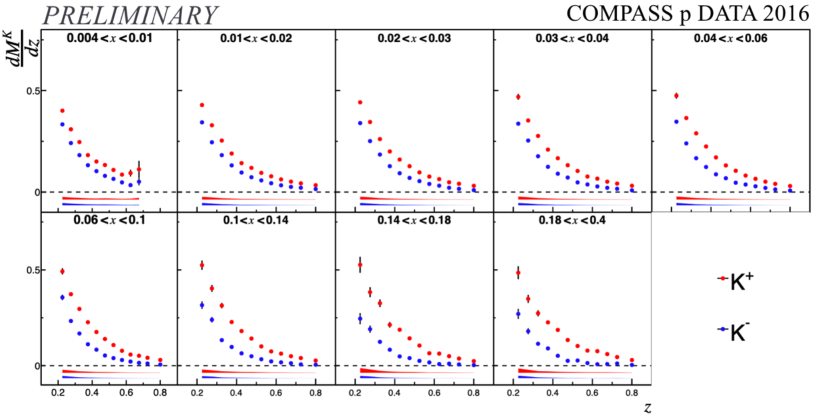


Final Multiplicities

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

Results for kaon multiplicities

about 600 data points obtained in 3D binning: $\mathrm{d}M_\mathrm{K}(x,y,z)/\mathrm{d}z$
no y dependence observed $\longrightarrow$ results averaged over y



Main systematic uncertainties:

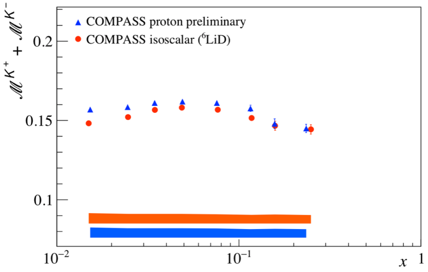
RICH unfolding: from 0.1% to 7%
acceptance: 10%
diffractive vector mesons: up to 6%

Kaon multiplicity sum

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

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

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



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

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

Kaon multiplicity sum

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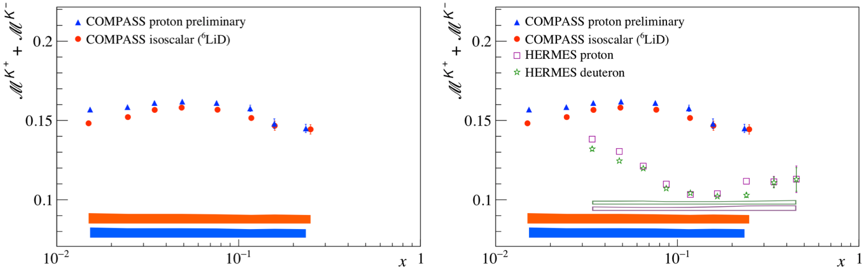


- expectation: sum for proton about 5% higher then for isoscalar target
- results agree with expectation
- similar discrepance COMPASS-HERMES for results from proton and isoscalar target

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. $\mathrm{d}M^{\mathrm{K}^-}/\mathrm{d}M^{\mathrm{K}^+}$
- isoscalar target data: radiative and VM correction cancel
- acceptance mostly cancels except for secondary interactions in target
- all 2006 data used (all phyiscs triggers)
- PID with RICH improved

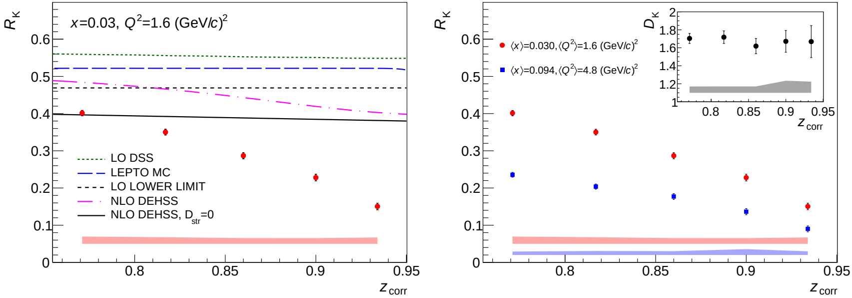
Multiplicity ratios at high z

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

$$R_{\rm K}(x, Q^2, z) = \frac{\mathrm{d}M^{\rm K^-}(x, Q^2, z)/\mathrm{d}z}{\mathrm{d}M^{\rm K^+}(x, Q^2, z)/\mathrm{d}z}$$

$$R_{\rm K} > \frac{\bar{u} + \bar{d}}{u + d} \;, \quad R_{\rm p} > \frac{\bar{u} + \bar{d}}{u + d}$$

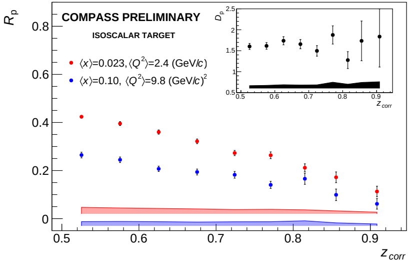
PLB 786 (2018) 390

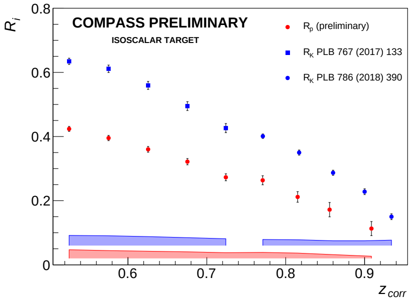


- clear disagreement with expectations in (N)LO at large z for both x bins
  (LO limit for second x bin is 0.31)

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



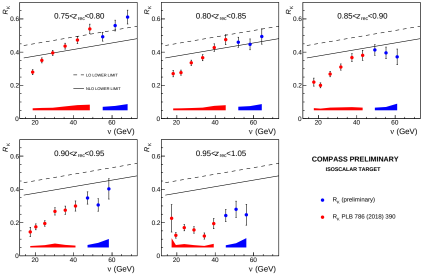


- proton result also below prediction in whole studied z range, also for $Q^2 \approx 10\,(\mathrm{GeV}/c)^2$
- effect growing with mass of studied hadron

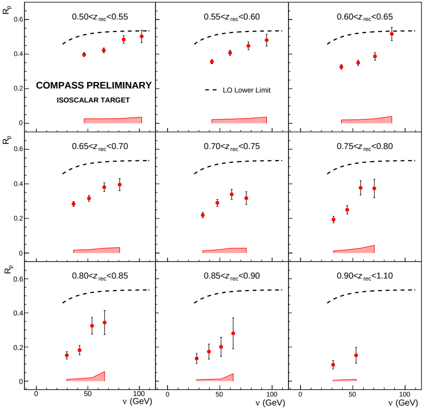
ν dependence of multiplicity ratios

- unexpected dependence on γ^* energy ν observed
- saturation at high ν for kaon ratio?
- values at high ν close to expection

R_K



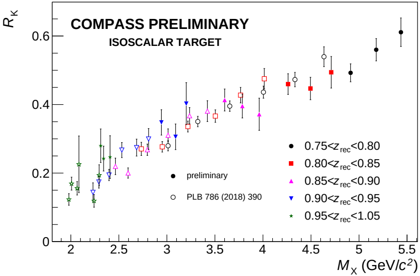
R_p

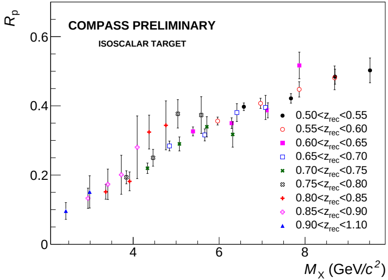


- similar ν dependence observed for proton ratio

Missing mass dependence

- at high z reduced phase space for other particles plus conservation law to be fulfilled
- dependence on missing mass
  $M_{\mathrm{X}} = \sqrt{M_i^2 + 2M_i\nu(1-z) - Q^2(1-z)^2}$ with $M_i = M_{\mathrm{K}}$ or M_{p}





- very smooth dependence
- seems that a correction within the pQCD formalism is needed taking into account the phase space available for hadronisantion

Summary and outlook

- 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 that LO QCD expectation for kaons and protons
- z and unexpected ν 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