High-z proton and kaon multiplicity ratios on deuteron target in SIDIS

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LIP

On behalf of the COMPASS Collaboration

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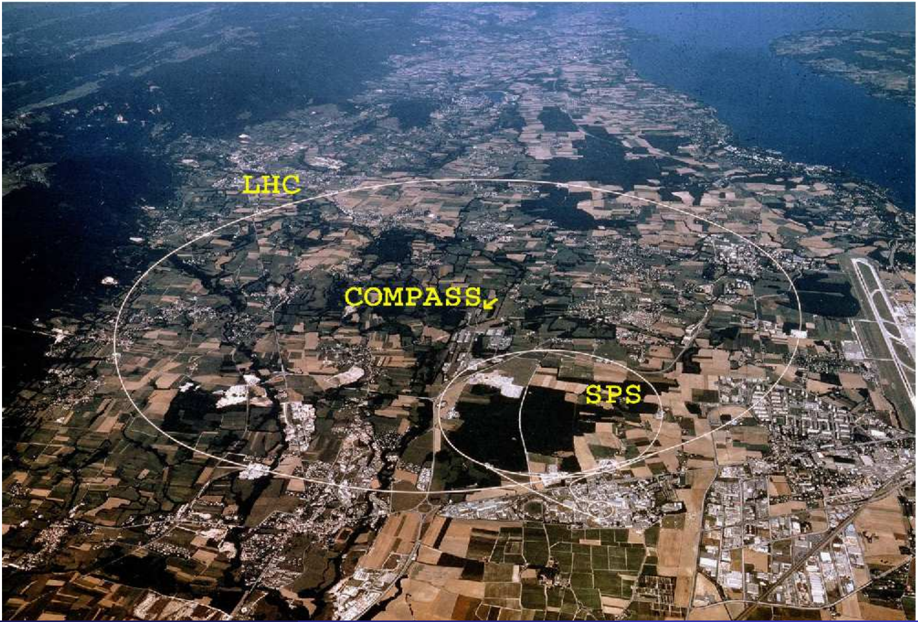
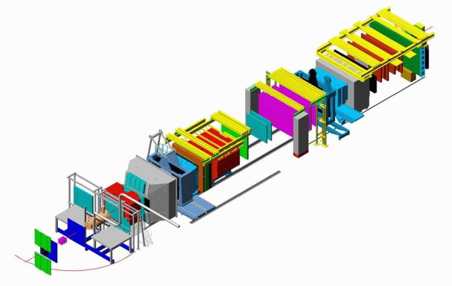
COMPASS at CERN



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: $\pm$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

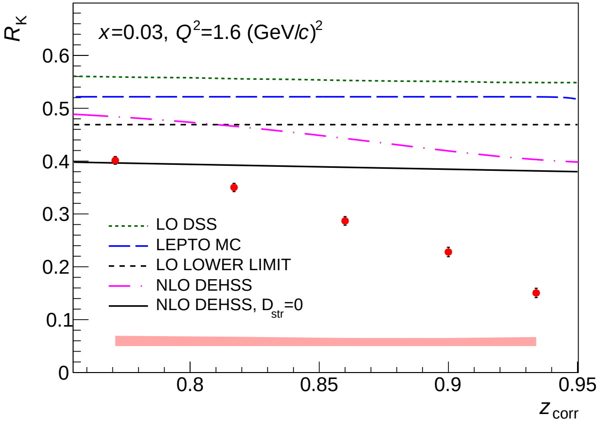
- Fragmentation functions (FF, D_q^h) describe parton fragmentation into hadrons
- FF are needed in analyses which deal with a hadron(s) in the final state
- In Leading Order QCD D_q^h describes probability density for a quark of flavour q to fragment into hadron of type h
- The cleanest way to access 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 high p_T hadrons, access to gluon fragmentation functions
- SIDIS data are crucial to understand quark fragmentation process

Multiplicity Ratios

- In the multiplicity ratio a lot experimental and theoretical uncertainties cancel
- In LO pQCD one can calculate a lower limit for the ratio
  - $R_K(x,Q^2,z) = \frac{\mathrm{d}M^{\mathrm{K}^-}(x,Q^2,z)/\mathrm{d}z}{\mathrm{d}M^{\mathrm{K}^+}(x,Q^2,z)/\mathrm{d}z} = \frac{4(\bar{\mathrm{u}}+\bar{\mathrm{d}})D_{\mathrm{fav}}+(5\mathrm{u}+5\mathrm{d}+\bar{\mathrm{u}}+\bar{\mathrm{d}}+\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{unf}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}{4(\mathrm{u}+\mathrm{d})D_{\mathrm{fav}}+(5\bar{\mathrm{u}}+5\bar{\mathrm{d}}+\mathrm{u}+\mathrm{d}+\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{unf}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}$
  - $R_p(x,Q^2,z) = \frac{\mathrm{d}M^{\bar{\mathrm{p}}}(x,Q^2,z)/\mathrm{d}z}{\mathrm{d}M^{\mathrm{p}}(x,Q^2,z)/\mathrm{d}z} = \frac{(5\bar{u}+5\bar{d})D_{fav}+(5u+5d+2s+2\bar{s})D_{unf}}{(5u+5d)D_{fav}+(5\bar{u}+5\bar{d}+2s+2\bar{s})D_{unf}}$
- D_{unf} is expected to be small at large z, thus can be neglected
  - $R_K = \frac{4(\bar{\mathrm{u}}+\mathrm{d})D_{\mathrm{fav}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}{4(\mathrm{u}+\mathrm{d})D_{\mathrm{fav}}+(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}}$
  - $R_p = \frac{\bar{u}+\bar{d}}{u+d}$
- since $(\mathrm{s}+\bar{\mathrm{s}})D_{\mathrm{str}}$ is positive, it can also be neglected for the lower limit calculation
  - $R_K > \frac{\bar{\mathrm{u}}+\bar{\mathrm{d}}}{\mathrm{u}+\mathrm{d}}$
  - $R_p > \frac{\bar{\mathrm{u}}+\bar{\mathrm{d}}}{\mathrm{u}+\mathrm{d}}$
- The lower limits predicted by LO pQCD for R_K and R_p are the same
- R_K expected to be 10-15% higher than R_p because of D_{str}
- R_π suffers from large contamination of decay products of diffractive ρ^0

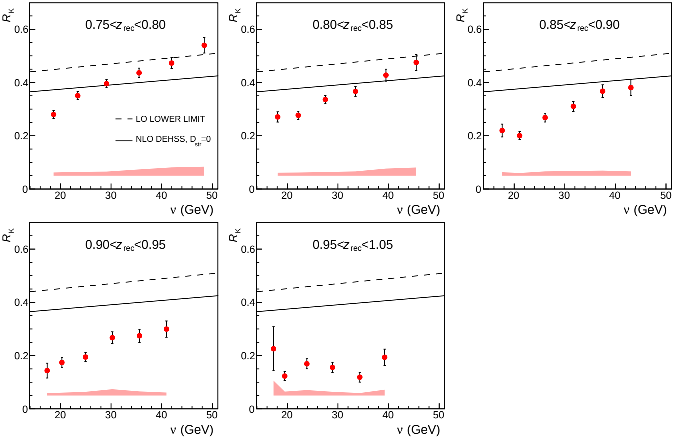
Results K^-/K^+ ratio, PLB 786 (2018) 390

- Shown already twice on DIS conferences
- Clear disagreement with models and (N)LO lower limit is observed!
- z is the fraction of the virtual photon energy carried by hadron



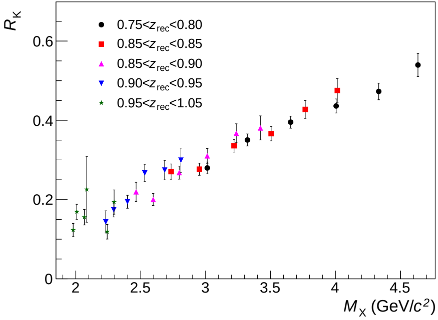
R_K and ν Dependence, PLB 786 (2018) 390

- Non expected in pQCD ν dependence of R_K was observed
- With higher energy of the virtual photon, ν, R_K is closer to pQCD expectation



Missing Mass and R_K (PLB 786 (2018) 390)

- high-z kaon $\rightarrow$ reduced phase space for other particles
- At the same time conservation laws need to be fulfilled *e.g.* charge, baryon number and strangeness.
- Natural variable to study such events is the missing Mass, M_X
- $M_X = \sqrt{M_{\mathrm{p}}^2 + 2M_{\mathrm{p}}\nu(1-z) - Q^2(1-z)^2}$
- Indeed R_K vs M_X shows a smooth trend!
- This suggests that a correction within the pQCD formalism is needed, to take into account the phase space available for the hadronisation of the target remnant.



New Developments

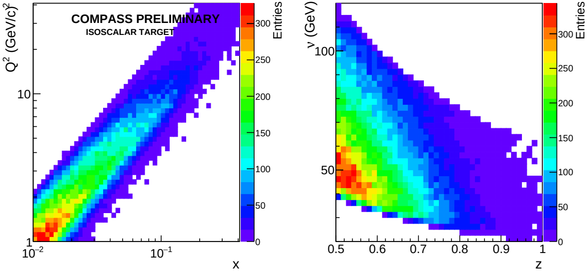
- Based on those (published) kaon results we were curious about behaviour of R_p
  - Does R_p is below lower limit of LO pQCD?
  - Does R_p show unexpected in LO pQCD dependence on ν?
  - Does R_p vs. M_X shows a smooth trend?
- Similarly we were curious about K behaviour at high ν
  - Can we observe at high ν some kind of saturation so that R_K matches pQCD expectations?
  - So far could identify kaons with momentum up to 40 GeV/c
  - With additional work we moved upper limit to 55 GeV/c, allowing accessing larger ν values
- The results of these studies, R_p, R_K at higher ν, are presented for the first time.

Multiplicity Measurement

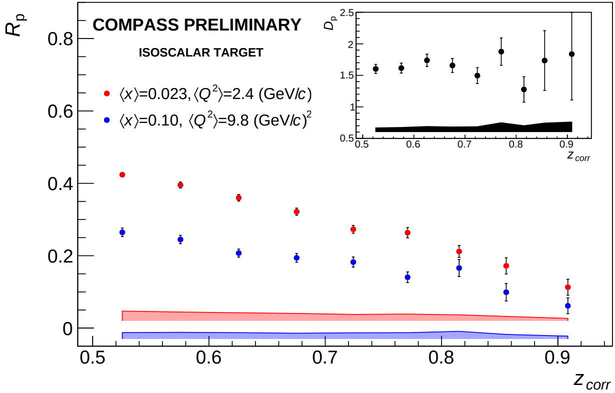
- Hadron multiplicities are defined as number of observed hadrons per DIS event
- $$\frac{dM^h(x,z,Q^2)}{dz} = \frac{d^3\sigma^h(x,z,Q^2)/dxdQ^2dz}{d^2\sigma^{DIS}(x,Q^2)/dxdQ^2}$$
- Experimentally measured hadron multiplicities need to be corrected for various effects e.g.
  - spectrometer acceptance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

Data Selection

- Reconstructed μ and μ', $Q^2 > 1$ $(\text{GeV}/c)^2$ and $W > 5$ GeV/c^2, $y > 0.1$
- Proton with momentum between 20 GeV/c and 60 GeV/c
- Kaon with momentum 40 GeV/c and 55 GeV/c
- The analysis is performed in two x bins, *i.e.* $x < 0.05$ and $x > 0.05$
- Binning in z is performed, usually with a step of 0.05
- In addition a binning in hadron momentum is done

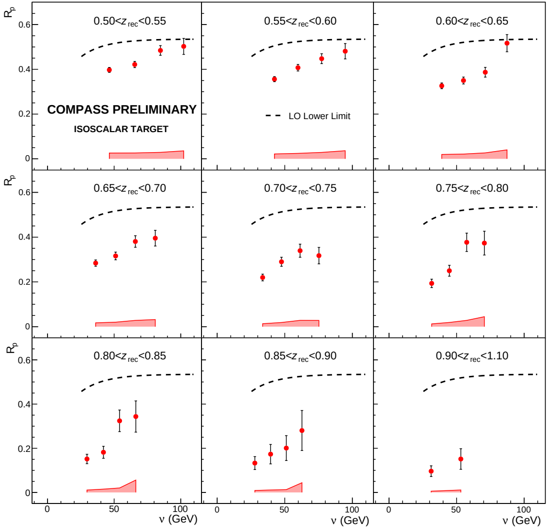


R_p vs z



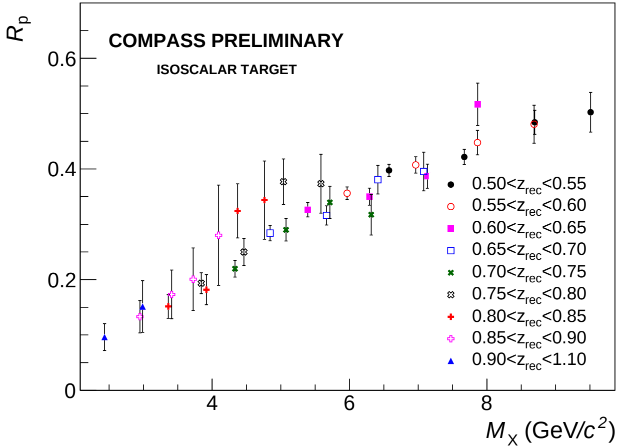
- The expected lower limits from LO pQCD are
  - 0.51 for low $x-$bin
  - 0.28 for high x-bin
- The data are below the lower limit in the whole studied z-range
- Including $Q^2 \approx 10$ (GeV/c)^2 data!

R_p vs ν



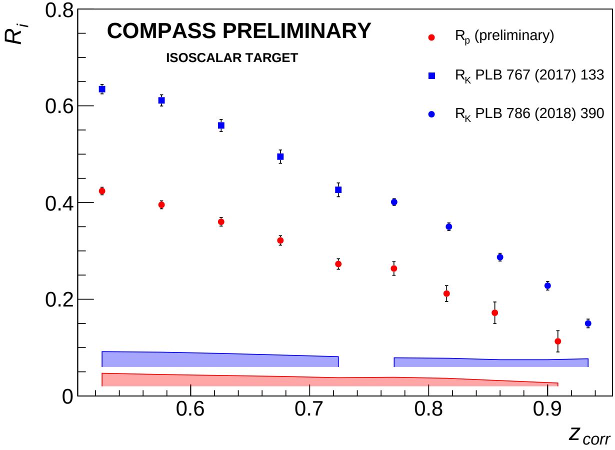
- As for kaons we do observe a ν dependence of R_p
- With larger ν the results are closer to pQCD expectations.

R_p vs M_X



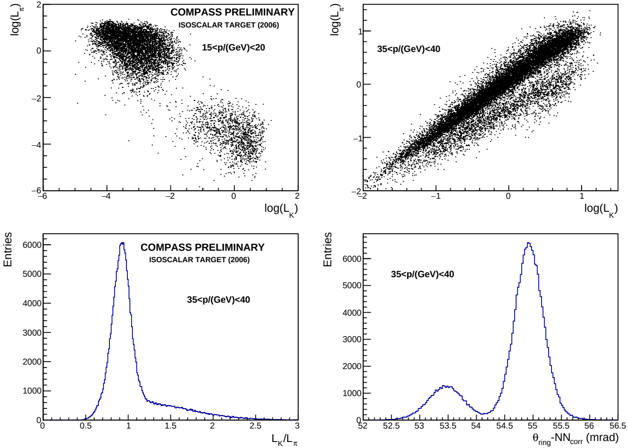
- Unexpected in LO pQCD, both dependencies on z and ν can be simultaneously described by the missing mass variable, M_X
- $M_X = \sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z)^2}$

R_p and R_K vs z



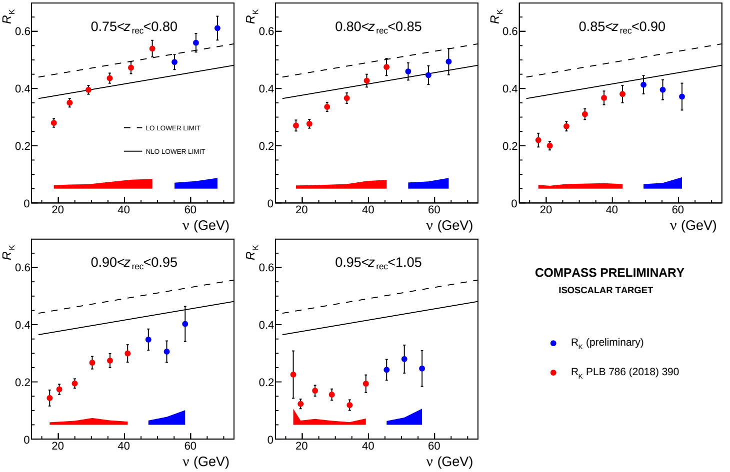
- in LO pQCD difference between R_p and R_K should be small 10-15%
- The ratio R_p/R_K is much lower with respect to the LO pQCD expectation
- Hints that the discrepancy between experiment and theory is growing with the mass of the studied hadron

Kaon Identification at Higher Momenta



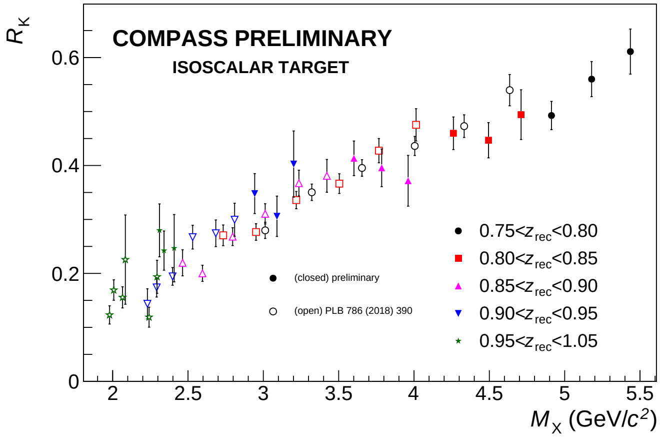
- COMPASS has very good separation between π and K using RICH
- However, for high momenta the two distributions start to overlap
- Some work was dedicated to improve RICH performance at higher momenta
- We can now show preliminary results of R_K for $40 < p_K/(\mathrm{GeV/c}) < 55$

R_K vs ν



- Perhaps, a sign of R_K saturation is observed at lower z

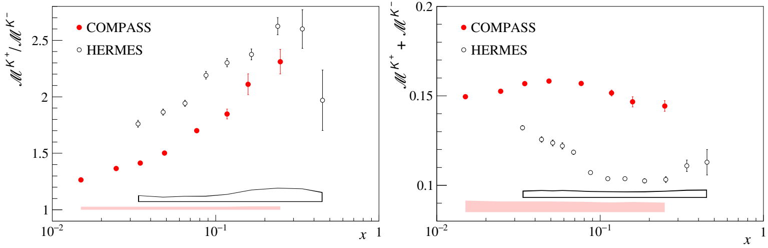
R_K vs M_X



- Slightly extended range in M_X
- Larger overlap between various z-bins
- At the same M_X, data from different z and ν bins agree with each other

Instead of Summary

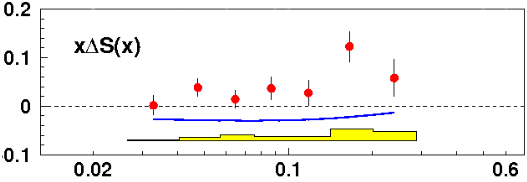
- In COMPASS the pQCD prediction fails in the corner of the phase space
- However, taking into account the observed ν and/or M_X dependence
  in experiments at lower energy much larger region of phase-space is affected
  - Note that selection of large Q^2 is not enough!
- This gives interesting insights:
  - It can be a reason for discrepancy between COMPASS and HERMES kaon multiplicity ratio and sum

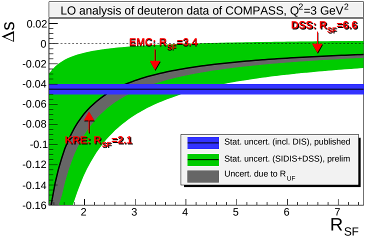


  - See also:
    - J. V. Guerrero *et al.*, JHEP **1509** (2015) 169
    - E. Christova and E. Leader, Phys. Rev. D **94** (2016) 096001
    - J. V. Guerrero and A. Accardi, Phys. Rev. D **97** (2018) 114012

Instead of Summary cont.

- The present results may be interpreted as follows in the affected region of the phase-space we get more hadrons from u quarks than expected in pQCD
- May explain positive ΔS of HERMES (left plot). If the contribution from positively polarised Δu is wrongly taken as coming from strange quarks, the extracted polarisation of ΔS will be biased towards positive value.





- *K* and *p* accounts for 20-25% of all hadrons. Results of any analysis which uses unidentified hadrons at low ν may be affected by the problem, Including e.g. TMD studies.

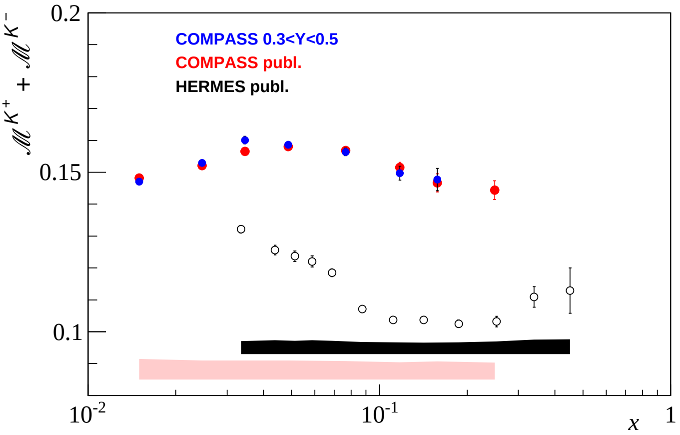
THE BOTTOM LINE:

The region of applicability of factorised pQCD in SIDIS should be revisited

BACKUPS

Kaon multiplicity sum in COMPASS and HERMES

- Some Colleagues were questioning the way we treat our results are averaged over y
- Below we show results from certain y bin without any averaging procedure
- The way COMPASS averages data does not have an impact on the observed COMPASS HERMES discrepancy



COMPASS Δs extraction