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

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Recently COMPASS has reported unexpected results concerning K^- over K^+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy, PLB **786** (2018) 390. The obtained ratio is significantly below the lower limit given by NLO pQCD.
In order to provide more information about the observed phenomenon we show for the first time results concerning $\bar{p}$ over p multiplicity ratio for protons produced in DIS with a large fraction of the virtual-photon energy. In addition the kaon multiplicity ratio is presented in an extended kinematic phase-space with respect to the one used in the aforementioned paper.

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1. Introduction

Last year COMPASS reported unexpected results concerning the K^- over K^+ multiplicity ratio, R_K, for kaons produced in DIS with a large fraction, z, of the virtual-photon energy, ν, [1]. The obtained ratio R_K is significantly below the lower limit given by NLO pQCD. In addition the observed ratio shows dependencies on z and ν which are unexpected in NLO pQCD. In order to better understand the observed phenomenon COMPASS recently analysed the $\bar{\mathrm{p}}$ over p multiplicity ratio, R_p. In LO pQCD the expected lower limit for R_K and R_p are the same. Since in the case of R_K a large discrepancy is observed with respect to the pQCD prediction this naturally motivated an analysis of the proton multiplicity ratio. In addition kaon multiplicity ratio is re-analysed in an increased ν range.

2. COMPASS Experiment

COMPASS is a CERN experiment using the M2 beam line of the SPS accelerator. A detailed description of the COMPASS spectrometer can be found elsewhere [2]. The data collected in the year 2006, from which the presented results are extracted, were obtained with a 160 GeV positive muon beam impinging on an isoscalar ^{6}LiD target. With three muon filters along the spectrometer a very good hadron/muon separation is achieved. Hadrons are identified in the Ring Imaging CHerenkov counter (RICH) from thresholds of 3 GeV/c, 9 GeV/c and 18 GeV/c, for pions, kaons and protons respectively and up to about 40 GeV/c. However, this upper limit was extended for the present analysis up to 55-60 GeV/c for kaons and protons, respectively. While the angular acceptance of the COMPASS spectrometer is about $\pm$180mrad, only the central part of the RICH could be sufficiently well calibrated, and the effective acceptance was about 120 mrad.

3. Data Selection and Analysis

The analysis was restricted to the kinematic region where perturbative pQCD is expected to work. Namely, only events with negative four momentum transfer Q^2 above 1 (GeV/c)^2 and with the mass of the hadronic system W larger than 5 GeV/c^2 are used. In addition the Bjorken x is selected to be in the range $0.004 < x < 0.4$ and the fraction of muon energy carried by the virtual photon, y, is between $0.1 < y < 0.7$. Protons with momenta between 20 GeV/c and 60 GeV/c are analysed, while for kaons results from the range 12 GeV/c to 40 GeV/c were presented in [1]. Here, the momentum range between 40 GeV/c and 55 GeV/c is analysed. The proton multiplicities were not measured so far in COMPASS, thus a wider range of the $z > 0.5$ was used, while for kaons following Ref. [1], $z > 0.75$ cut was applied.

For a given hadron type i the multiplicity is defined as the number of hadrons produced per DIS event. In LO pQCD the observed multiplicity is given by the parton distribution function $q(x)$ and the fragmentation functions D_q^i

$$\frac{dM^i(x,Q^2,z)}{d(x,Q^2,z)} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^i(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}. \tag{3.1}$$

Here e_q is the electric charge of a quark flavour q. Multiplicities are measured as function of x, ν and z variables.

The measured raw multiplicities are corrected by several factors, like: the spectrometer acceptance, the contribution from decay products of diffractive mesons, and the radiative events corrections. In addition the RICH efficiency and possibility of particle misidentification in the RICH are accounted for. Details on this type of analysis can be found in *e.g*. Ref. [3].

It should be stressed that when measuring multiplicity ratios many systematic effects cancel, of both experimental and theoretical origin. Therefore, the multiplicity ratios are typically known with better relative precision than the hadron multiplicities themselves.

In LO pQCD the lower limit for R_K and R_p on isoscalar target is given by:

$$R_p, R_K > \frac{\bar{u}+\bar{d}}{u+d} \tag{3.2}$$

While the lower limit is the same for R_p and R_K it is actually expected that $R_K > R_p$, because of the favoured strange quark fragmentation into kaons. Still, the expected difference is of the order of 10% for $x \approx 0.05$.

4. Results

The preliminary results of p̄ over p multiplicity ratio on isoscalar target as function of z, for data below and above x=0.05, are shown on Fig. 1. The expected lower limit from LO pQCD calculations is about 0.51 and 0.28 for data below and above $x = 0.05$, respectively. Therefore, in the whole measured range of z, the R_p ratio is below the lower limit predicted by pQCD. It is worth mentioning that in the kaon case a discrepancy with pQCD predictions was observed at much higher z, *i.e*. $z > 0.8$, [1]. In the insert of Fig. 1 the double ratio of R_p from two studied x-bins is shown. Within the uncertainties it agrees with LO pQCD expectations. The same behaviour was earlier observed for kaons [1]. Fig. 2 confirms another observation done earlier for kaons. Namely, for higher values of ν the results of R_p are closer to the expectation from LO pQCD. Still in case of protons, the discrepancy between results and predictions is larger even at the highest value of ν available in the study. It should be noted that R_p in different bins is measured at slightly different values of x and Q^2 and as a result LO pQCD limit (which just depends upon PDFs) effectively changes for different ν values, as shown in the Fig. 2.

In both proton and kaon ratios two behaviours non-expected in pQCD were observed: as a function of z and of ν. In [1] it was noticed that the values of R_K were showing a smooth trend as a function of the missing mass variable $M_X = |\mathbf{p}+\mathbf{q}-\mathbf{p_h}|$, where $\mathbf{p}$, $\mathbf{q}$ and $\mathbf{p_h}$ are four vectors of target, virtual photon and produced high-z hadron, respectively. In our calculation M_X was approximated as $\sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z)^2}$. In the left panel of Fig. 3 the results of R_p as function of M_X are presented. A smooth trend is visible as in the case of kaons, albeit the uncertainties are large. This observation gives another hint that perhaps M_X is of primary importance, while observed z and ν dependencies of R_K or R_p are only coming from kinematic correlations of z and ν with M_X. Note that due to baryon number conservation R_p is required to be 0 at two proton masses *i.e*. 1.88 GeV/c^2. Assuming that independent fragmentation is working in COMPASS kinematics, R_p should grow very fast (a few π mass above the threshold) above/to the lower limit predicted by pQCD. However, the rise of R_p observed in data is very gentle and the

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lower limit predicted by pQCD (0.51 in Fig. 2) , seems to be reached at or beyond the kinematic limit accessible in COMPASS.

In the right panel of Fig. 3 a comparison between the preliminary R_p results and the published R_K ones, [1], [4] is shown. As mentioned in section 3, the expected difference between R_K and R_p is about 10%. However, taking into account the slightly different x and Q^2, for the proton and kaon samples, this difference is actually reduced to about 0-5%. A much larger difference is observed in the data. This suggests that the level at which the pQCD lower limit is broken strongly depends upon the mass of the particle under study.

In [4] the analysis was performed for kaons with momenta between 12 GeV/c and 40 GeV/c. This limit was imposed by the RICH detector, since pure and efficient separation of π from K was possible only in the selected kinematic region. Recently some work using artificial neural networks was done in order to improve the separation between π and K at higher momenta. As a result for the first time COMPASS can show preliminary results for R_K in the momentum range between 40 GeV/c and 55 GeV/c. The obtained results are presented in Fig. 4 as blue points. Comparing these to the previous results the growth of R_K with ν seems to be smaller and a possible saturation of R_K is seen. Moreover the value of R_K at saturation seems to be above the NLO pQCD lower limit.

It may seem that the observed phenomena are related to just a corner of the phase-space. In the COMPASS case it is mostly true. However, with experiments at lower center of mass energy the problem with the pQCD description of the data should be already clearly noticeable at lower values of z. In addition protons and kaons add up together to about 25% of all produced hadrons. Thus, when performing phenomenology studies of non-identified hadrons one should be quite careful, as the presence of kaons and protons may introduce bias in the obtained results.

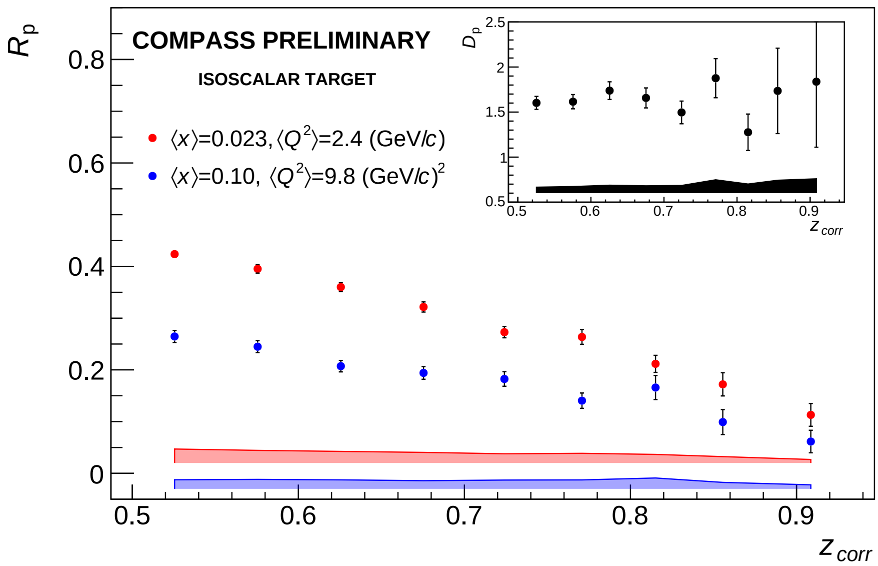

Figure 1: The $\bar{\mathrm{p}}$ over p multiplicity ratio as a function of z in two x-bins. The corresponding lower limit expected from LO pQCD is about 0.51 for the red data points, and about 0.28 for the blue data points. The obtained R_p ratio is below the lower limit expected from LO pQCD in the whole studied z range.

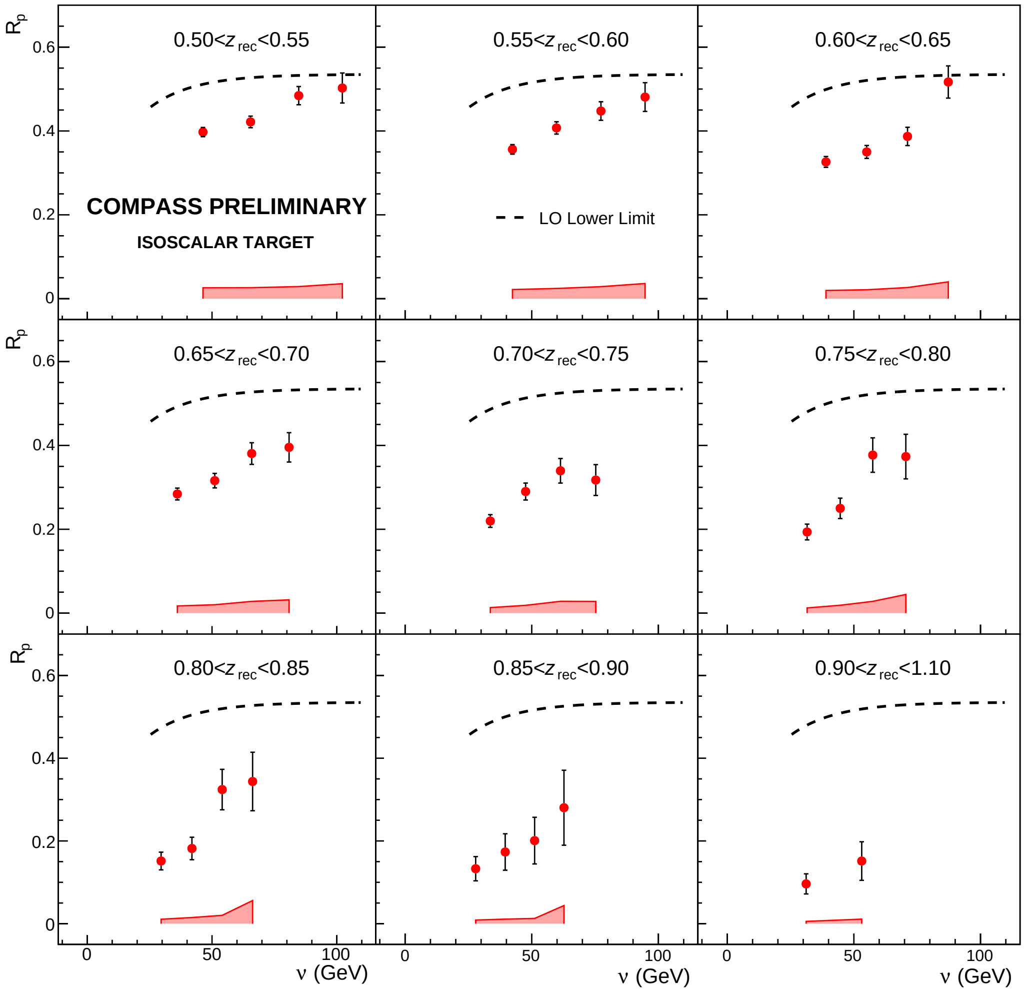

Figure 2: The R_p as a function of ν in nine z-bins. For the higher values of ν the obtained results are closer to the prediction of pQCD, shown as a line in the plots.

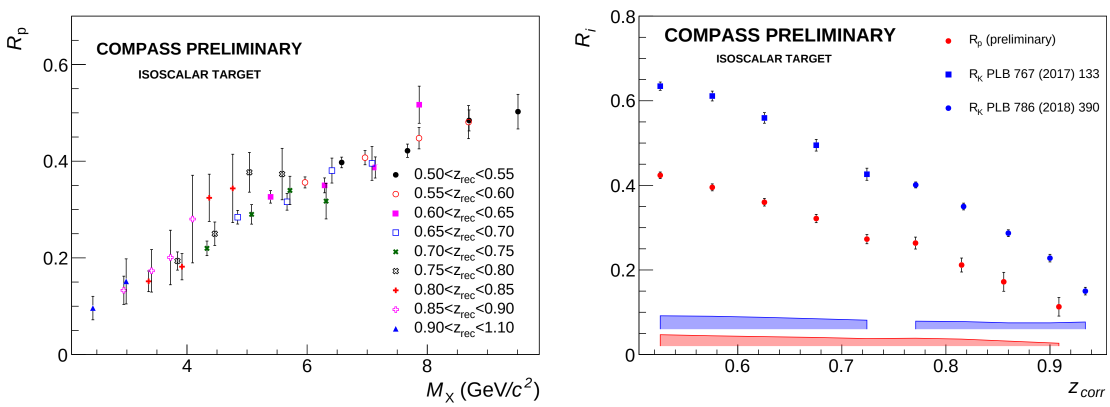

Figure 3: Left Panel: The R_p ratio as a function of the missing mass. A rather smooth trend is observed. Right Panel: Comparison of R_p and published R_K [1], [4]. In the whole studied phase-space the R_p is below R_K. In LO pQCD and taking into account small differences in x and Q^2, a difference of the order of 0-5% is expected.

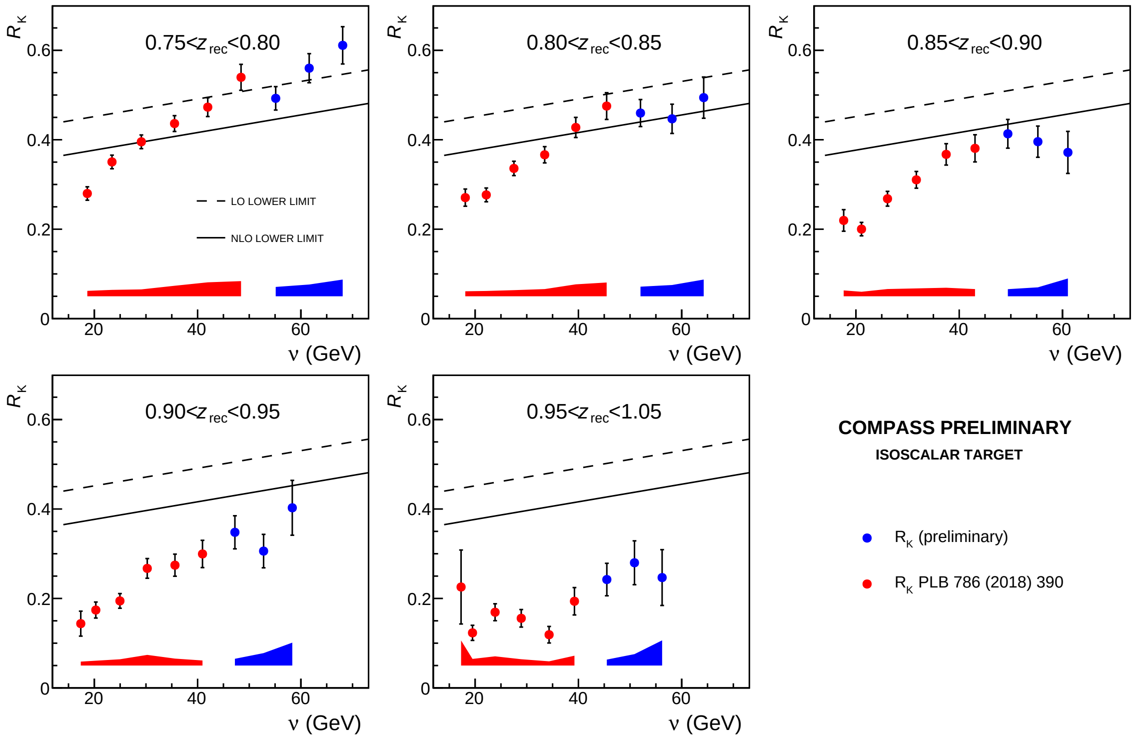

Figure 4: New preliminary results on R_K measured in an extended ν range compared to the published ones. For some z-bins possibly a sign of expected R_K saturation at higher values of ν is seen in data.

5. Summary

Preliminary results concerning on the $\bar{\mathrm{p}}$ over p multiplicity ratio were presented. In the whole studied region of z, *i.e.* $(z > 0.5)$, the value of R_p is observed to be below the lower limit predicted by LO pQCD. The R_p ratio shows also a ν dependence: for higher ν values the results are closer to the LO pQCD expectations. Both z and ν dependencies may have their origin in the missing mass dependence of R_p. In experiments at lower center-of-mass energy than COMPASS those effects may affect results in almost all kinematics phase-space available. Finally the results of R_K as a function of ν in several z bins were presented, for an identification range extended up to 55 GeV/c. Possibly a sign of (expected) R_K saturation at higher values of ν is seen in data.

References

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[4] COMPASS Collaboration, C. Adolph *et. al*, *Phys. Lett. B* **767** (2017) 133.