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Final COMPASS results on hadrons, pions and kaons multiplicities in SIDIS

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COMPASS final results on multiplicities of charged hadrons and of identified pions and kaons produced in the deep inelastic muon scattering off an isoscalar target are presented. Measurements are done in bins of x,y and z in a wide kinematic range. The hadron and pion data show a good agreement with (N)LO QCD expectations. The most interesting is the kaon multiplicity that allows to extract kaon fragmentation functions, a crucial ingredient in solving the strange quark polarisation puzzle. The COMPASS results are quite different from the expectations of the old NLO DSS fit; and they cannot be described by LO QCD either. In this context the importance of K^+/K^- multiplicity ratio at high z is discussed.

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1. Introduction

In the last 15 years there has been a growing interest in analyses of Semi-Inclusive Deep Inelastic scattering data (SIDIS). The measured cross-sections, in the context of perturbative quantum chromodynamics (QCD), depend not only on Parton Distribution Functions (PDF) but also on additional non-perturbative objects the quark Fragmentation Functions (D_q^i). In leading order (LO) QCD D_q^i is interpreted as the probability density for a quark of flavour q to fragment into a hadron of type i. While the cleanest way to access D_q^i is the measurement of hadrons produced in e^+e^- annihilation, this process is sensitive exclusively to $D_q^i + D_{\bar{q}}^i$ and offers only limited possibilities of flavour separation. In the case of SIDIS, FFs are convoluted with PDFs, which makes such measurements more difficult but on the other hand one can separately extract D_q^i and $D_{\bar{q}}^i$ as well as perform a full flavour separation.

COMPASS has recently published a final set of multiplicities for charged hadrons as well as pions [1] and kaons [2]. Measurements were done in bins of the Bjorken variable x, of the beam energy fraction carried by the virtual-photon y, and of the fraction of the virtual photon energy carried by the hadron z. These measurements were performed in a wide kinematic range and are a crucial input for the extraction of fragmentation functions in global fits.

We have further analysed the K^+/K^- multiplicity ratio at high z and found unexpected results in (N)LO QCD. These preliminary results are for the first time presented in this Paper.

2. COMPASS

COMPASS is an experiment located at the CERN SPS accelerator. A detailed description of the COMPASS spectrometer can be found elsewhere [3]. For the results presented in this paper a 160 GeV positive muon beam was impinging on an isoscalar ^{6}LiD target. The angular acceptance of the COMPASS spectrometer is about $\pm$180mrad. With three muon filters along the spectrometer a very good hadron/muon separation is provided. 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 50 GeV/c.

3. Data Selection and Analysis

In this analysis only data from the DIS region is used: events with negative four momentum transfer Q^2 larger than 1 (GeV/c)^2 and with the mass of the hadronic system W larger than 5 GeV/c^2. The Bjorken x, is selected to be in the range $0.004 < x < 0.4$ and y is in the region $0.1 < y < 0.7$. Only hadrons in the momentum range 12–40 GeV/c are analysed, *i.e.* in the range where stable kaon identification and low misidentification probabilities are assured. The reconstructed z is required to be within $0.2 < z < 0.85$. The lower limit ensures that the so called current fragmentation region is analysed, while the upper one removes the region where the contribution from non-DIS processes like diffraction is sizeable. However, in the case of kaon multiplicity the main diffractive channel, $\phi \to K^+K^-$, does not contribute to the kaon cross-section at high z. Therefore, for the new kaon multiplicity charge ratio K^+/K^- studies, this range is extended up to $z = 1$. Moreover, in this analysis more data can be used because in the K^+/K^- multiplicity ratio several systematic uncertainties cancel, thus less strict requirements for trigger type and quality of MC description of data are needed. As a result the statistics for the K^+/K^- multiplicity ratio measurement at high z is increased by a factor of 3 to 4 with respect to the published kaon multiplicities.

The multiplicity of the hadron type i is defined as the number of hadrons produced per DIS event. In LO the observed multiplicity is related in the following way with 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 quark flavour q. Multiplicities are measured as functions of x, y and z. The measured raw multiplicities are corrected by the spectrometer acceptance, the RICH efficiency and the particle misidentification probability, the contribution from decay products of diffractive mesons, and finally by the radiative corrections. Details on this type of analysis can be found in [1, 2].

4. Results

COMPASS published multiplicity data contains about 620 points simultaneously extracted in bins of x, y and z in a wide kinematic range both for π and K. For the π case a very reasonable description of data by (N)LO QCD fits was found. In addition extracted fragmentation functions are in agreement with world data fits, see [1]. However, significant differences between COMPASS and HERMES multiplicity sum of π^+ and π^- as a function of x and integrated over z denoted as $\mathcal{M}^{\pi^+} + \mathcal{M}^{\pi^-}$ were noticed. In LO QCD this quantity is expected to be rather flat cf. Eq. (6) in [1]. Such behaviour is indeed observed in case of COMPASS π, while HERMES results [4] show a very different trend, as presented in the left panel of Fig. 1. The unexpected behaviour of HERMES data was also discussed in the recent literature, see [5, 6, 7, 8]. However, it is interesting to notice that in the case of π multiplicity ratio COMPASS and HERMES data agree within uncertainties, as presented in the right panel of Fig. 1.

The situation is more complex in the kaon case. As presented in the left panel of Fig. 2, the kaon multiplicity sum $\mathcal{M}^{K^+} + \mathcal{M}^{K^-}$ of COMPASS and HERMES have different shapes but additionally differs a lot in the high x region where such a difference cannot be explained by DGLAP evolution. In the right panel of Fig. 2 the kaon multiplicity ratio is compared for COMPASS and HERMES. Contrary to the π case, for kaons, a clear difference is visible between the two results.

While QCD cannot predict values of fragmentation functions, predictions can be made concerning the K^+ to K^- multiplicity ratio, especially at high z. Namely, in LO QCD, assuming 3 fragmentation functions, D_{fav}, D_{str} and D_{unf}, the kaon multiplicity ratio, for simplicity written for the proton target, is the following:

$$\frac{M^{K^+}}{M^{K^-}} = \frac{4uD_{fav} + (4\bar{u} + d + \bar{d} + s)D_{unf} + \bar{s}D_{str}}{4\bar{u}D_{fav} + (4u + d + \bar{d} + \bar{s})D_{unf} + sD_{str}} \tag{4.1}$$

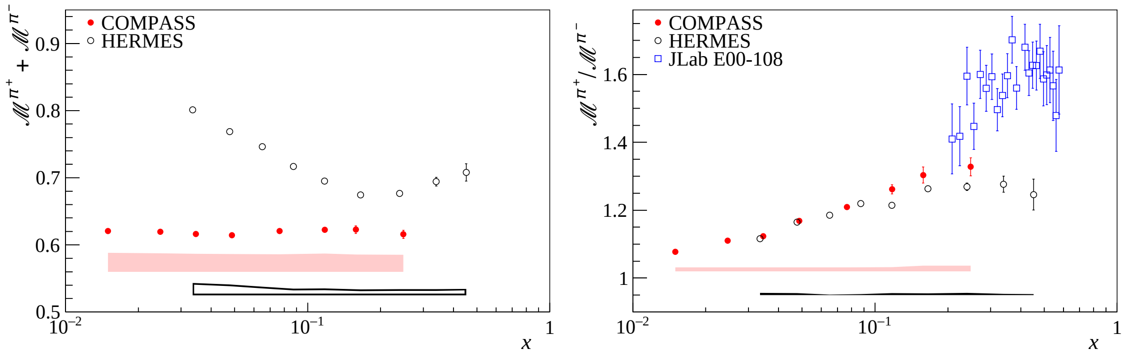

Figure 1: Left: Sum of $\mathscr{M}^{\pi^+} + \mathscr{M}^{\pi^-}$ for COMPASS [1] and HERMES [4], clear differences between the two experiments are seen. Note that in LO QCD this distribution is expected to be almost flat. Right: Comparison of $\mathscr{M}^{\pi^+}/\mathscr{M}^{\pi^-}$ for COMPASS and HERMES, where a good agreement is seen. JLab results [9] are also shown for completeness.

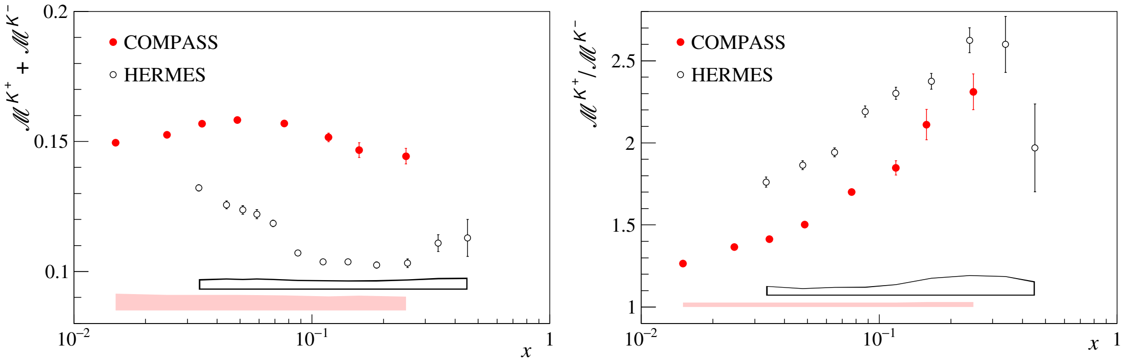

Figure 2: Left: Sum of $\mathscr{M}^{K^+} + \mathscr{M}^{K^-}$ for COMPASS [2] and HERMES [4], clear differences between the two experiments are seen. Right: Comparison of $\mathscr{M}^{\pi^+}/\mathscr{M}^{\pi^-}$ for COMPASS and HERMES, where contrary to the π case, clear differences are also observed between the two experiments.

In most of the QCD fits, for the kaon case D_{unf} is already small for $z = 0.4$, thus can be safely neglected in the high z region. This simplifies the ratio to:

$$\frac{M^{K^+}}{M^{K^-}} = \frac{4uD_{fav} + \bar{s}D_{str}}{4\bar{u}D_{fav} + sD_{str}} < \frac{u}{\bar{u}}. \tag{4.2}$$

For the inequality of Eq. (4.2) $s = \bar{s}$ was assumed in the right hand side. Using isospin symmetry the obtained limit can be rewritten for the isoscalar target as:

$$\frac{M^{K^+}}{M^{K^-}} < \frac{u+d}{\bar{u}+\bar{d}}. \tag{4.3}$$

In MSTW08L [10] the above limit in case of an isoscalar target for $x = 0.03$ and $Q^2 = 1.6$ (GeV/c)^2 is about 2.15. In the more recent NNPDF3.0LO the discussed limit is 1.9 ± 0.10 [11]. The actual predicted ratio of M^{K^+}/M^{K^-} from DSS [12] is about 1.8, while LEPTO Monte Carlo with Lund string fragmentation model gives M^{K^+}/M^{K^-} of about 1.9, if using MSTW08L as PDF input. The predicted ratios are lower than the limit because $s(\bar{s})D_{str}$ are not zero. In NLO the inequality (4.3) can be broken with corrections of the order of $\alpha_S/2\pi$ and the limit for the multiplicity ratio tends to be higher by 5%–10% in NLO with respect to LO.

The analysis of the kaon multiplicity ratio at high z is kept similar as possible to the analysis published in [2], with a few exceptions, namely that the z range is extended, a larger data sample is used and a different unfolding procedure is employed.

The preliminary results for $x < 0.05$ are presented in Fig. 3 as red dots, the systematic uncertainty is marked by the red band. The measured M^{K^+}/M^{K^-} ratio is much larger than the expected limit derived in LO QCD, which for MSTW08L is presented as the black line in Fig. 3. In addition, a prediction from the LO DSS QCD fit is presented as a green line while the expectation from LEPTO Monte Carlo is shown in blue. Note that in Fig. 3 the results are presented before unfolding in z. As shown in the conference talk, the impact of the unfolding procedure is small for the first four points, and in addition it can only increase the obtained ratio. The results clearly contradict the expectation of LO QCD, which may mean that the universality of FF does not hold and/or factorisation of the cross-section is broken in this region.

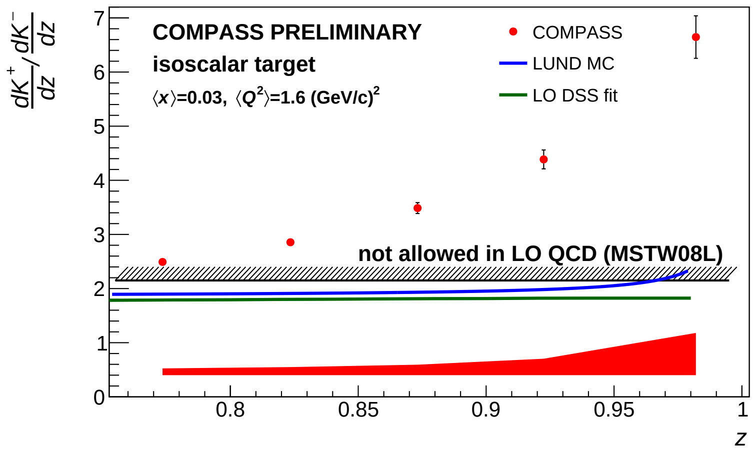

Figure 3: Kaon multiplicity ratio for $x < 0.05$ as a function of reconstructed z. The ratio obtained is much larger than expected from the limit of LO QCD, which is denoted by a black line. For comparison, the expectation from DSS LO fit and LEPTO MC with Lund string fragmentation model are also presented.

In Fig 4 the kaon multiplicity ratio is presented as a function of ν. In the left panel, data corresponding to z reconstructed between 0.80–0.85 are shown. A clear ν dependent trend is observed. With higher ν values the kaon multiplicity ratio is closer to the limit expected in LO QCD. These results may suggest that for this analysis COMPASS is in a transition region between perturbative and non-perturbative regimes, *e.g.*, events with high z kaons become “too exclusive”, and there might be not enough energy left for an independent fragmentation as assumed in the QCD cross-section formula. The observed behaviour of the kaon multiplicity ratio suggests that experiments with lower available ν, like HERMES or experiments in JLAB may be dominated by non-perturbative effects in case of kaon SIDIS analyses. Possibly these effects may become relevant even at lower z values than in COMPASS case. Finally it should be added that at the higher z presented in the right panel of Fig 4, the uncertainties are too large to draw any conclusions.

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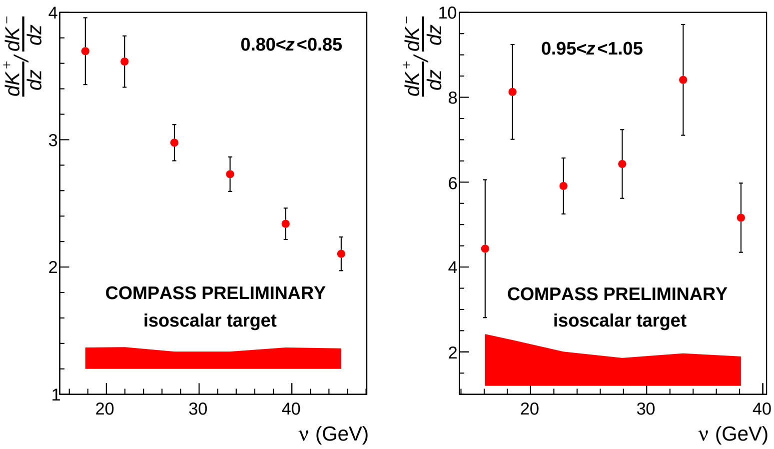

Figure 4: Kaon multiplicity ratio M^{K^+}/M^{K^-} for $x < 0.05$ in two z bins as a function of ν. A clear trend is visible in the left panel, see text for details.

5. Summary

COMPASS recently published a large and precise data set of multiplicities of charged hadrons and identified pions and kaons from SIDIS. These data, measured in a wide kinematic range, are crucial to any global fit of fragmentation functions. In addition, here for the first time, we present the preliminary results concerning the kaon multiplicity ratio K^+/K^- at high z. The obtained ratio is much higher than the limit expected from LO QCD, which may mean that the universality of FF does not hold and/or factorisation of the cross-section is broken in this region. All these COMPASS results are crucial in order to better understand the fundamental problem of the quark fragmentation into hadrons.

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