COMPASS Results on Pion and Kaon Multiplicities from SIDIS on Proton Target

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Abstract. New COMPASS preliminary results on pion and kaon multiplicities from SIDIS on a proton target are presented. These proton results provide a complementary data set to the deuteron results published in 2016. In the current analysis, we use an improved treatment of Radiative Corrections using DJANGOH MC. Compared to the previously used method relative differences up to 12% are observed at the level of multiplicities. Despite these changes the preliminary COMPASS kaon results are still incompatible with HERMES ones. The presented results will provide an important input for global fragmentation function fits.

1 Introduction

Quark fragmentation into hadrons is a process of fundamental nature and importance. It can be studied in various processes *e.g.* e^+e^- annihilation, semi-inclusive deep inelastic scattering (SIDIS), and hadron–hadron collisions. In the framework of perturbative Quantum Chromodynamics (pQCD), quark fragmentation is described by non-perturbative objects called fragmentation functions (FFs). These functions are believed to be universal, *i.e.* they are the same in various processes mentioned above, but at present cannot be predicted by the theory and must be determined through experimental measurements.

In the case of SIDIS cross-section for hadron production fragmentation functions are convoluted with parton distribution functions (PDF), but it is possible to access and separate quark and anti-quark contributions as well as perform full flavour separation. These features are impossible to achieve in e^+e^- semi-inclusive annihilation data, which otherwise give direct access to FFs without complications related to PDFs. COMPASS has already published several papers on the subject, *e.g.* [1],[2]. However, so far, all the measurements have been performed on the isoscalar target. Here, COMPASS preliminary results based on 2016 data are presented, where beam muon interacts with liquid hydrogen target. In what follows multiplicities of charged pions, kaons and unidentified hadrons are presented. For their direct connection to FFs, see *e.g.* Ref. [1].

2 Experimental Setup and Data Selection

The data were collected in 2016 using $\mu^\pm$ from the M2 beamline at the CERN SPS. The beam had a momentum of 160 GeV/c it was delivered in cycles of 36 s, consisting of two spills,

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each lasting 4.8 s. The intensity of the beam was 1.6 10^7 s^{-1} - threefold lower than in the case of previous COMPASS isoscalar studies. The liquid hydrogen target had a total length of 250cm and a diameter of 4cm. Scattered muons and produced hadrons were reconstructed in a two-stage COMPASS spectrometer. More than 300 detector planes of various types are used in the tracking process. The pion, kaon and proton separation is performed by a Ring Imaging Cherenkov counter (RICH) [3]. In this analysis, the selected trigger system was based on three pairs of hodoscopes and used only information about scattered muons.

The multiplicities, M, are defined as the number of hadrons of a given type i = $\{\pi^{\pm}, K^{\pm}, \mathrm{h}^{\pm}\}$ observed per number of DIS events. The measurement is performed in bins of the Bjorken scaling variable x, the relative virtual-photon energy y, and the relative hadron energy z.

$$\frac{dM^i(x,y,z)}{dz} = \frac{1}{N^{\mathrm{DIS}}(x,y)} \frac{dN^i(x,y,z)}{dz}. \tag{1}$$

The obtained values have to be corrected for acceptance of the spectrometer, efficiency and purity of RICH identification, a contribution from the decay product of diffractively produced Vector-Mesons, and QED radiative effects.

The selected events have reconstructed incoming and outgoing muons, which are attached to the common interaction vertex. Events are accepted if negative fourmomentum transfer $Q^2 > 1$ (GeV/c)^2, $0.004 < x < 0.4$ and invariant mass of the hadron system $W > 5$ GeV/c^2. These requirements select the deep-inelastic scattering regime and avoid contributions from the nucleon resonances decays region. For a selected DIS event, all reconstructed tracks that may originate from the interaction vertex are considered. In the final analysis, hadrons satisfying the following criteria are used: $0.2 < z < 0.85$, momentum in range 12 GeV/c to 40 GeV/c, and polar angle in horizontal (vertical) direction is limited to 0.01 rad $< \theta <$ 0.12(0.08) rad, respectively.

The acceptance of the COMPASS spectrometer is obtained using the LETPO [4] generator and a GEANT4-based [5] programme to simulate re-interactions in the COMPASS spectrometer. The typical acceptance is found to be between 70-80%, only at the high value of x and low values of y it drops to about 25%.

The RICH purity and efficiency are obtained by studying two-body charged decays of the following particles: K^0, ϕ, and Λ. Typical pion efficiency (median) is about 98%, with a 0.3% chance that the pion will be identified as a kaon. The kaon reconstruction efficiency is about 95%, with 2-3% misidentification probability of true kaon as pion.

The contribution from the decay product of diffractively produced exclusive vector mesons is subtracted based on HEPGEN [6] and LEPTO MC and their comparison to real data. Only ρ and ϕ mesons are accounted for in HEPGEN. In pion and unidentified hadrons at high z and low x, this vector meson contribution may exceed the SIDIS cross-section itself. In the case of kaons, the maximum value is about 24% at low x and $z = 0.6$.

For the first time in COMPASS, we use the DJANGOH-MC programme [7] to estimate values of correction related to QED radiative effects. It turned out that the values were found significantly different than the ones used in the past, especially for [1]. In figure 1, we show a comparison of present and past values of RC obtained for a selected bin $0.02 < x < 0.03$ and $0.2 < y < 0.3$ as a function of z. Clear differences are seen. Note that this correction is a multiplicative factor of multiplicities itself. The trust of the present RC comes from the fact of reasonable agreement of data and DJANGOH-MC of which selected examples are shown below. In the left panel of figure 2 a ratio is presented for events where only μ and μ' are detected in the primary vertex to all DIS events. Here, radiative effects are predominantly visible as a large increase of these “empty events” at high values of y. The data and DJANGOH-MC agree within about 20%. In the right panel of figure 2, a distribution of the squared transverse momentum of the particle is presented with respect to the virtual photon direction axis. A peak close to zero, related to the conversion of real $\gamma \rightarrow e^+e^-$ followed by electron(s) miss-identification as hadrons, is seen both in data and MC. Observe that in electron-induced DIS, due to the electron's very low mass, the dominant directions of the emission of the real photons are along the incoming and scattered electron. A non-negligible mass of μ is the reason why in the muon-induced DIS, the third preferred direction is also seen in data and MC.

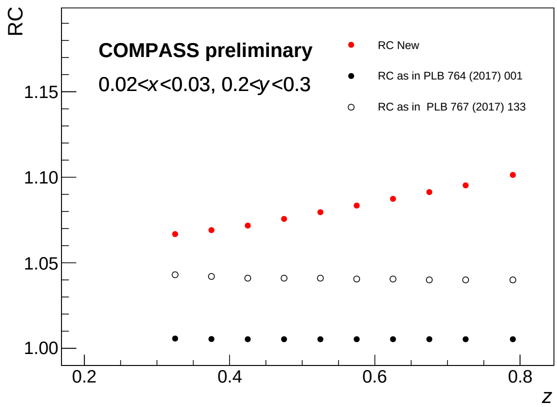

Figure 1. Comparison of present RC in a selected (x, y) bin as function of z with respect to previously used RC in COMPASS.

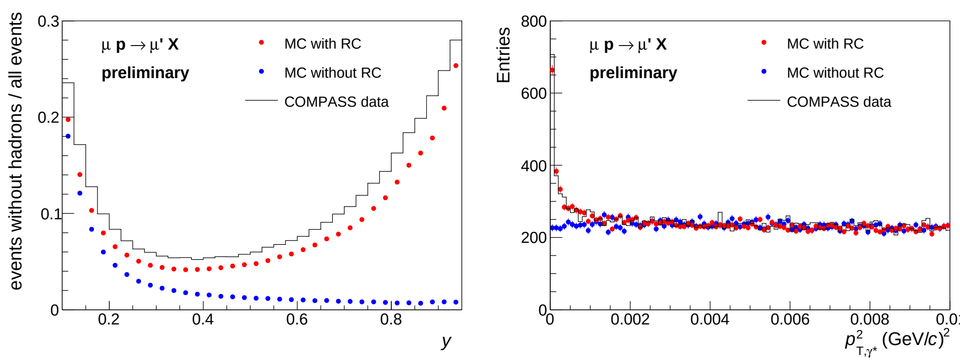

Figure 2. Left panel: fraction of events without hadrons in the interaction vertex, right panel: squared transverse momentum with respect to the virtual photon direction. See text for details.

3 Results

Selected examples of COMPASS preliminary results are presented below. In total about 1800 data points of various multiplicities were obtained. In figure 3 multiplicity results for pion for positive (top) and negative (bottom) are shown. For several bins in x multiplicity are shown as a function of z, while results for different y are presented in a staggered way. The sum of $\pi^+ + \pi^-$, multiplicities averaged over y and integrated over z and shown as a function of x is an interesting value. First of all, it is proportional to FFs and thus should be rather flat in x as FFs depend upon Q^2 and z but not x. Secondly, it is expected that the multiplicity results between isoscalar and proton targets differ by less than 1% in LO pQCD. In the left panel of figure 4, a comparison of the present results using old RC with the ones from [1] is shown. For both of these data sets the uncertainty of the data point corresponds to the total uncertainty. There is a systematic shift between the two results. However, since most of the systematic uncertainties are correlated, the observed discrepancy is on the level of 1σ. Applying new RC to present data does lead to significantly different results, and also the shape shows some x dependence. Note that here only statistical errors are shown for data points, while systematic uncertainties are presented as a band below. In the right panel comparison of multiplicity sum between COMPASS and HERMES [8] is shown. While the absolute difference between the two results is not that large, the shape in x is different. Note that HERMES data are taken at a lower centre of mass energy as the electron beam had only 27.5 GeV. Still, this fact should not matter within (N)LO formalism of pQCD.

The results for kaons are presented in figure 5 in the same manner as for pions. Here, a larger difference is observed between positive and negative particles than in the case of pions, also observed multiplicities are on average about 4-5 times lower than for pions. In the left panel of figure 6, the sum of kaon multiplicities is shown for present COMPASS and past isoscalar measurements. Very good agreement between the two results is observed, in contrast to the pion results. The reason is twofold. Firstly kaon results have larger statistical error, and secondly, for [2] the "educated guess" of RC was indeed closer to present DJANGOH-MC than RC values used in [1]. Note that here, the x is not expected to be flat as x dependent contribution strange quark is expected to be seen, $cf.$ [9]. In the right panel of figure 6 COMPASS and HERMES results are compared. Very different shapes as well as values for both experiments are observed. Note that in LO pQCD it would be expected that COMPASS results should be at or below HERMES ones as seen for pions.

4 Summary

New preliminary results for multiplicities of pions, kaons and, unidentified hadrons were presented in bins of x, y, z obtained from scattering off muons on a liquid hydrogen target. In total about 1800 data points were measured, which provide complementary information to the past COMPASS multiplicities results on isoscalar data. A DJANGOH generator was used to estimate the impact of QED radiative effects, which was found up to 12% larger than previously estimated. Aside from QED radiative effect estimation, the present and past COMPASS results do agree well with each other. Thus, the tension observed between COMPASS and HERMES data in the isoscalar target, is still present for the hydrogen one.

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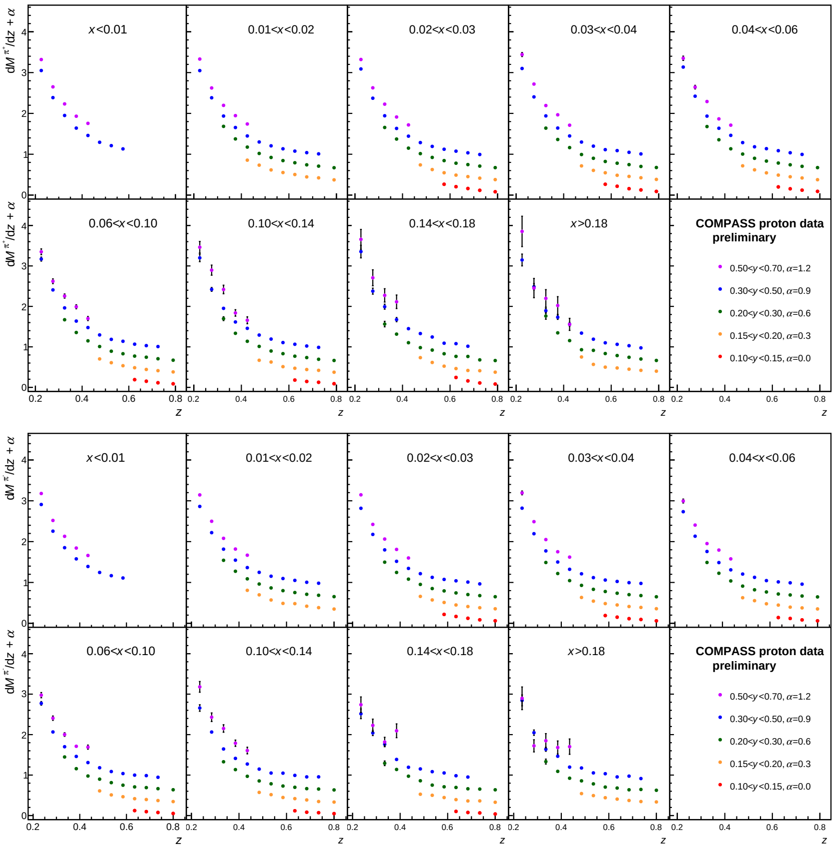

Figure 3. Multiplicities of positive (top) negative (bottom) pions in bins of x, y as a function of z.

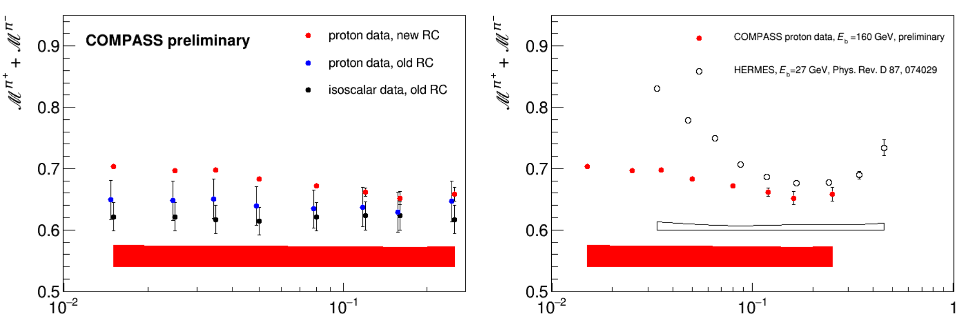

Figure 4. The sum of multiplicities of charged pions averaged over y and integrated over z as a function of x. Left panel - comparison of present preliminary results with isoscalar ones, and with ones obtained using old RC factors. Right panel: comparison between COMPASS and HERMES experiments.

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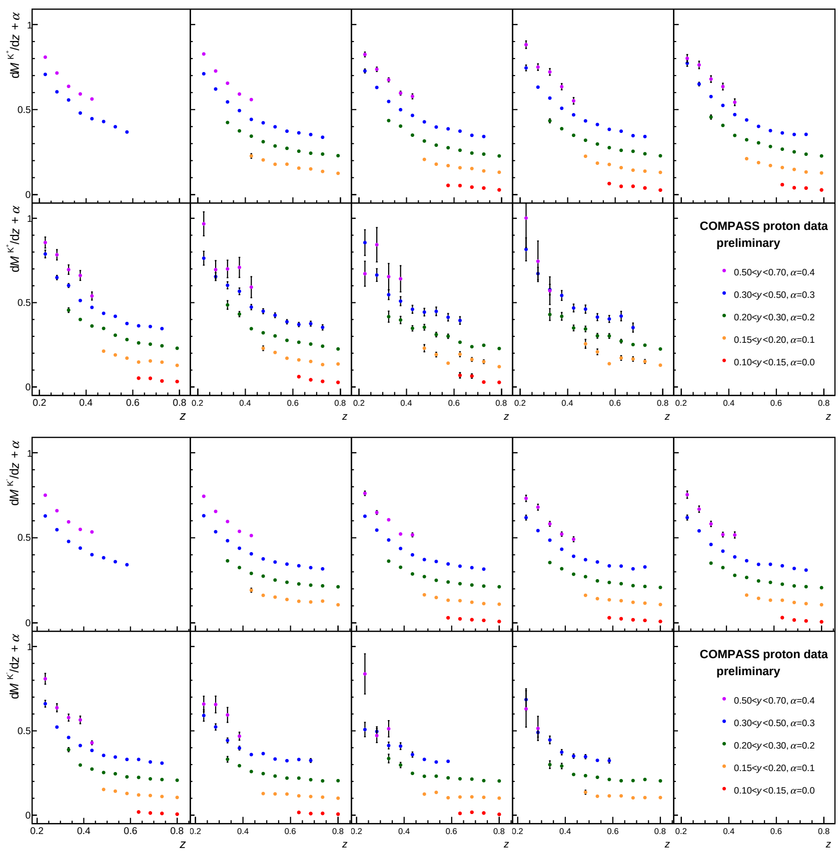

Figure 5. Multiplicities of positive (top) negative (bottom) kaons in bins of x, y as a function of z.

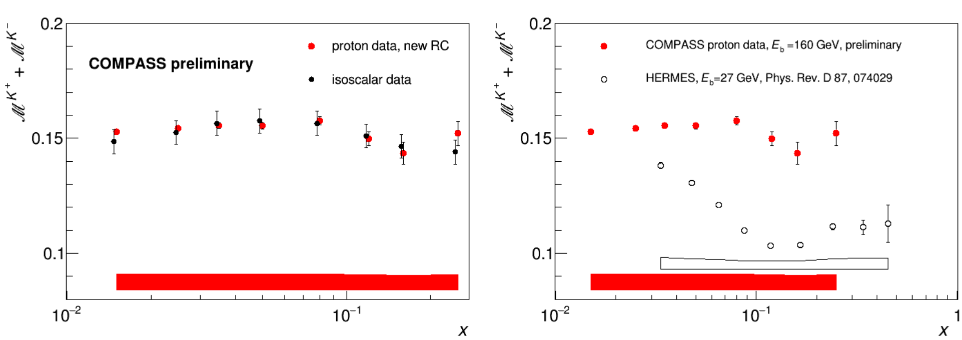

Figure 6. The sum of multiplicities of charged kaons averaged over y and integrated over z as a function of x. Left panel - comparison of present preliminary results with isoscalar ones. Right panel: comparison between COMPASS and HERMES experiments.