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COMPASS Hadron Multiplicity Measurements and Fragmentation Functions

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Abstract. COMPASS preliminary results on hadron, pion and kaon multiplicities are presented. The hadron and pion data show a good agreement with (N)LO QCD expectations and some of these preliminary data have been already successfully incorporated in the global NLO QCD fits to world data. However, the results for kaon multiplicities, are different from the expectations of the DSS fit. There is also a tension between COMPASS and HERMES results, the only other experiment which measured kaon multiplicities in SIDIS.

1 Introduction

In recent years there is a growing interest in analysis of the Semi-Inclusive Deep Inelastic scattering data (SIDIS). In order to interpret these measurements in the context of perturbative quantum chromodynamics (QCD), a new non-perturbative object has to be extracted from data, namely the fragmentation functions (D_q^i). In leading order (LO) the QCD D_q^i describe the probability density for a quark of flavour q to fragment into a hadron of type i. The cleanest way to access D_q^i is the measurement of hadrons produced in e^+e^- annihilation. However, in such a measurement only the quark anti-quark sum of fragmentation functions, $D_q^i + D_{\bar{q}}^i$, can be accessed. In addition, in e^+e^- measurements full flavour separation is not possible. The extraction of D_q^i from SIDIS data is more complex, as the fragmentation functions are convoluted with the parton distribution functions. On the other hand one can separately extract D_q^i and $D_{\bar{q}}^i$ as well as perform a full flavour separation. In this proceeding the preliminary results of COMPASS multiplicity measurements for $h^\pm$, $\pi^\pm$ and $K^\pm$ and the extraction of π and K fragmentation functions are presented.

2 COMPASS experiment

COMPASS is an experiment located at CERN SPS accelerator. A detailed description of the COMPASS spectrometer can be found elsewhere [1]. For the results presented in this paper a 160 GeV positive muon beam was impinging on ^{6}LiD target. The COMPASS spectrometer was designed to reconstruct scattered muons and charged hadrons in a wide kinematic range. The angular acceptance of the COMPASS spectrometer is about ±180mrad. Three muon filters along the spectrometer provide

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very good hadron/muon separation. Hadrons are identified in the Ring Imaging CHerenkov counter (RICH) from 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 the analysis only data from DIS region are used: it is required that the negative four momentum transfer Q^2 is larger than 1 (GeV/c)^2 and the mass, W, of the hadronic system is larger than 5 GeV/c^2. The Bjorken scaling variable, x, is selected to be between $0.004 < x < 0.4$. The beam energy fraction carried by the virtual photon, y, is kept between $0.1 < y < 0.7$. The lower limit of the latter is related with the precision and stability of the μ' reconstruction, while the higher y cut excludes the region where radiative corrections are large. The total number of selected DIS events is about 13 millions.

For the analysis a hadron candidate must have a measured momentum and must not to be identified as a muon. The fraction of the virtual-photon energy carried by the hadron candidate, z, should be $0.2 < z < 0.85$. 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 sizable. Stability of the RICH performance limited the hadron momenta to the interval 12-40 GeV/c.

The multiplicity is defined as the number of hadrons per DIS event. In LO the observed multiplicity is related in the following way with the parton distribution function $q(x)$, and fragmentation functions D^i_q

$$\frac{dM^i(x,Q^2,z)}{d(x,Q^2,z)} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^i(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}. \tag{1}$$

Here e_q is the electric charge of quark flavour q. In this analysis the multiplicities are measured as functions of x, y and z; Q^2 is not used due to a strong correlation between x and Q^2. Measured raw multiplicities are corrected by spectrometer acceptance, the RICH efficiency and particle misidentification probability, the contribution from decay products of diffractive mesons, and finally radiative corrections. The COMPASS acceptance is high, between 40% and 70%. It was evaluated using the LEPTO generator and a COMPASS spectrometer simulation program based on GEANT3. The RICH efficiency and purity were evaluated on real data using using decay products of K^0, ϕ and Λ. The efficiency for π is high, above 90% for $p < 30$ GeV/c, while the misidentification probability is low. For kaon the efficiency is above 90% in the whole momentum range used. Since there are much more produced pions than kaons the misidentification probability that a π is identified as a K is very important. In COMPASS it is below 2%. The contribution from decay products of diffractively produced mesons is estimated using HEPGEN Monte Carlo program [2]. This correction is most important for π, where a sizable contribution from $\rho^0 \to \pi^+\pi^-$ exists. The correction is largest for low Q^2 data and can reach 0.55 at high z. The (x, y) dependent radiative corrections are calculated using the programme TERAD [3].

4 Results

The preliminary results of pion multiplicities are presented in figure 1, together with the LO QCD fit performed by COMPASS and described in section 5. The data are well described by the fit. The closer inspection reveals that in the whole kinematic range the multiplicity of π^+ is higher than that of π^-. Remembering that absolute charges of u, $\bar{u}$ quarks are higher than those of d, $\bar{d}$, the above mentioned fact confirms that $D_{fav} > D_{unf}$, *i.e.* the fragmentation into quarks which are valence quarks of a hadron X, (D^X_{fav}) is higher than into quarks which belong to the sea of a hadron X (D^X_{unf}).

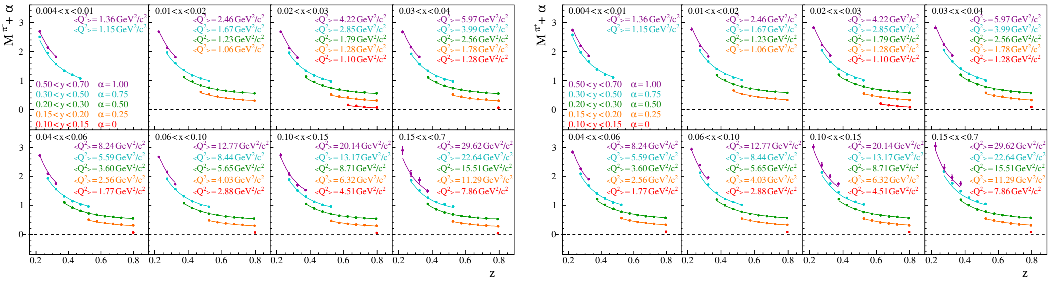

Figure 1. The pion multiplicity as a function of (x, y, z) for π^+ (left) and π^- (right). The results of COMPASS LO QCD fit (cf. section 5) are also shown.

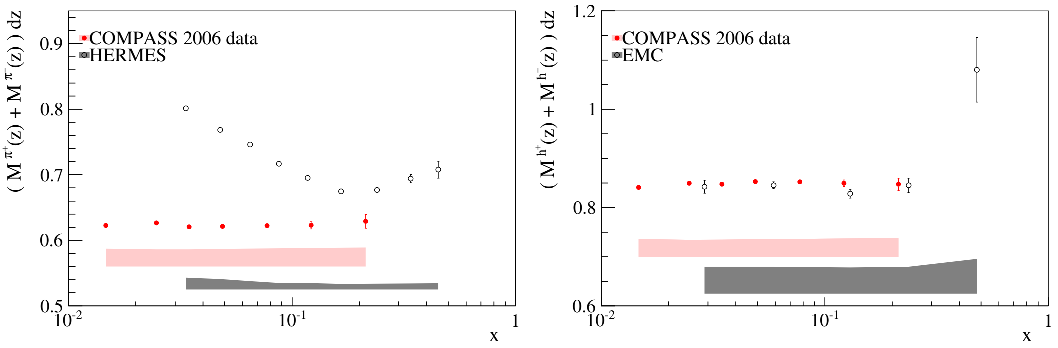

Figure 2. The z integrated pion multiplicity sums from COMPASS and HERMES [6] (left) The z integrated hadron multiplicity sums from COMPASS and EMC [5] (right). The data points are shown with statistical errors only, the systematic is presented as a shaded band below.

A very interesting observation can be made while studying the z-integrated sum of π^+ and π^- multiplicities, $\mathcal{M}^{\pi}$, as a function of x. In LO QDC the relation between $\mathcal{M}^{\pi}$ and the fragmentation functions for an isoscalar target is the following:

$$\mathcal{M}^{\pi} = \int D^{\pi}_{fav} + \int D^{\pi}_{unf} - \frac{2S}{5Q+2S}\left(\int D^{\pi}_{fav} - \int D^{\pi}_{unf}\right) \approx \int D^{\pi}_{fav} + \int D^{\pi}_{unf} \approx const, \qquad (2)$$

where $Q = u + \bar{u} + d + \bar{d}$ and $S = s + \bar{s}$. The $\int D^{\pi}_{fav}$ and $\int D^{\pi}_{unf}$ are the z-integrated favoured and unfavoured pion fragmentation functions. In equation (2) a possible x and y dependencies were neglected for simplicity. In fixed target experiments x is correlated with Q^2, but the Q^2 dependence of the z-integrated $D^{\pi}_{fav} + D^{\pi}_{unf}$ is rather weak (3% according to Ref. [4] in the COMPASS Q^2 range). Thus, the $\mathcal{M}^{\pi}$ distribution is expected to be approximately flat. A similar expectation holds for unidentified hadrons. The COMPASS data are presented in figure 2. Indeed the distribution of $\mathcal{M}^{\pi}$ and $\mathcal{M}^{h}$ are flat as expected in LO QCD. The same conclusion can be reached for the EMC results of unidentified hadron multiplicities [5], presented on the right panel of figure 2. However, it is interesting to notice that the shape of HERMES data, [6], is very different from the COMPASS (and EMC) results.

The kaon multiplicities are presented in figure 3 as functions of $(x,\ y,\ z)$. Again the results are compared to the COMPASS LO QCD fit described in section 5. For kaons the $\mathcal{M}^{K}$ is even more

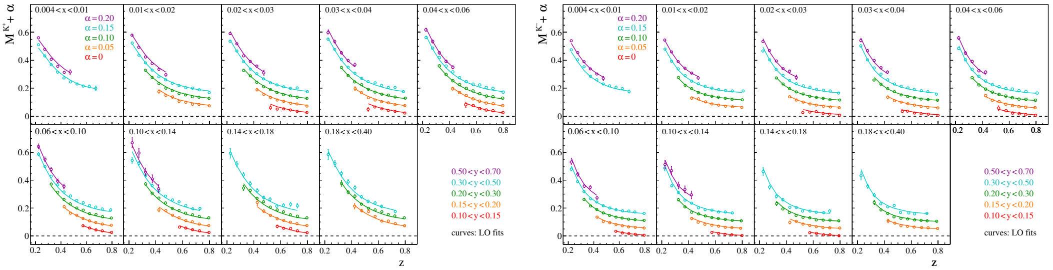

Figure 3. The kaon multiplicity as a function of (x, y, z) for K^+ (left) and K^- (right). The results of COMPASS LO QCD fit (cf. section 5) are also shown.

interesting than for the pion case. As pointed out in [7] in LO QCD the following relation holds

$$5\mathcal{M}^K \approx \int D_Q^K + S/Q \int D_{str}^K. \tag{3}$$

Here, $\int D_Q^K$ is the z-integrated value of $4D_u^K + 4D_{\bar{u}}^K + D_d^K + D_{\bar{d}}^K \approx 4D_{fav} + 6D_{unf}$ and $\int D_{str} = D_{s+\bar{s}}^K$. In the high x region the value of S/Q is small. Therefore, in this region the $\int D_Q^K$ can be extracted. The COMPASS result, presented in figure 4, points towards $\int_{0.2}^{0.85} D_Q^K \approx 0.70$, while the expectation of the DSS fit is only 0.43 . The COMPASS results on $\mathcal{M}^K$ suggest that D_{fav} and/or D_{unf} are larger than those from the DSS fit. On the other hand, for low x values the last therm in Eq. (3) cannot be neglected. Again assuming $S(x)$ as in MSTW08L, [8], and D_{str} from DSS parametrisation, [4], an increase of the $\mathcal{M}^K$ by about 50% should be seen comparing the low and high x regions. Such an increase is not observed in the COMPASS data, which points towards smaller value of D_{str}/D_{fav} ratio than in the DSS fit (or $S(x)$ is smaller than expected from MSTW08L). Such a result strongly influences the extracted polarisation of the strange sea in SIDIS analyses. The lower values of D_{str}/D_{fav} with respect to DSS parametrisation can explain the so called strange quark polarisation puzzle [9, 10]. It should be noted that even the shapes of $\mathcal{M}^K(x)$ of COMPASS and HERMES do not agree, as was already seen in the pion case. In addition in the COMPASS case much more kaons are produced at high x with respect to HERMES. Due to the beam energy difference and to RICH restrictions the HERMES and COMPASS kinematics for charged kaons are not overlapping. However, for the neutral K^0, the RICH momentum cut $12 < p < 40$ GeV/c is not needed. This allows COMPASS to study K^0 production in the lower energy region, closer to the HERMES kinematics. The analysis of K^0 multiplicities is ongoing.

Another interesting observation can be done when inspecting figure 5, where the multiplicity ratios of π^+, π^- and K^+, K^- are shown for COMPASS, HERMES and JLab. Despite the different shape of $\mathcal{M}^\pi$ in COMPASS and HERMES, ratios of π^+/π^- multiplicities agree very well. This is not the case for the ratios of K^+/K^- multiplicities. It should be also noted that from the experimental point of view the ratio of X^+/X^- is known with much better precision than the individual values, as a considerable fraction of experimental systematic uncertainties cancel in the X^+/X^- ratio.

5 COMPASS LO QCD fit to fragmentation functions

COMPASS performed a LO QCD fit of the fragmentation functions using the presented multiplicities. A simple functional form was used, $N_i z^{\alpha_i}(1-z)^{\beta_i}$, for parametrisation of fragmentation functions at

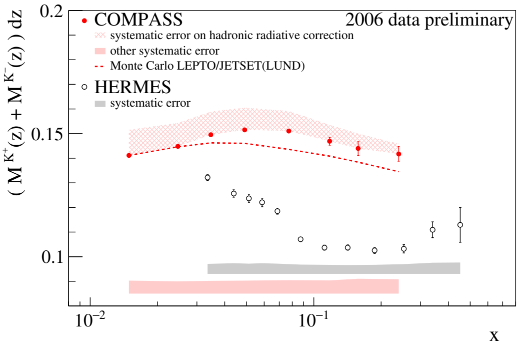

Figure 4. The z integrated kaon multiplicity sums for COMPASS and HERMES [6] experiments. The data points are shown with statistical errors only, the systematic uncertainty is presented as a shaded band below. The shaded area above COMPASS points corresponds to 100% uncertainty of SIDIS radiative corrections. The dashed line is a LEPTO MC prediction with fragmentation tuning from Ref. [11].

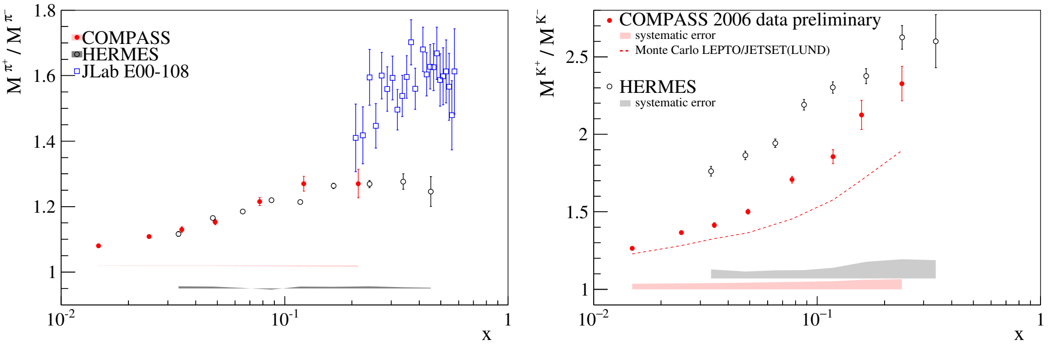

Figure 5. The $\pi^/\pi^-$ (left) and K^+/K^- (right) multiplicity ratio for COMPASS, HERMES [6] and in π case also JLab [12]. The data points are shown with statistical errors only, the systematic uncertainty is presented as a shaded band below.

the reference scale. The values of N_i, α_i, β_i are the fit parameters. In the case of pions a favoured and unfavoured fragmentation functions were considered in the fit ($i = \{fav, unf\}$), while in the kaon case in addition a strange fragmentation function was also included ($i = \{fav, unf, str\}$). In both cases the gluon fragmentation functions were also extracted. For the evolution of MSTW08L the LHAPDF library was employed [13], while for the evolution of the fragmentation function the code [14] was used. Results for the pion fragmentation functions (not shown here) agree well with the most recent NLO fits [15, 16]. For the kaon case the results for the D_{fav} and D_{unf} are presented in figure 6. The COMPASS fit suggests higher values of D^K_{fav} and D^K_{unf} than the DSS results [4]. This is not a surprise as the analysis of $\mathcal{M}^K$ points towards very different values of D_Q obtained from the COMPASS and DSS fits. The result for the strange quark fragmentation into kaons need further study.

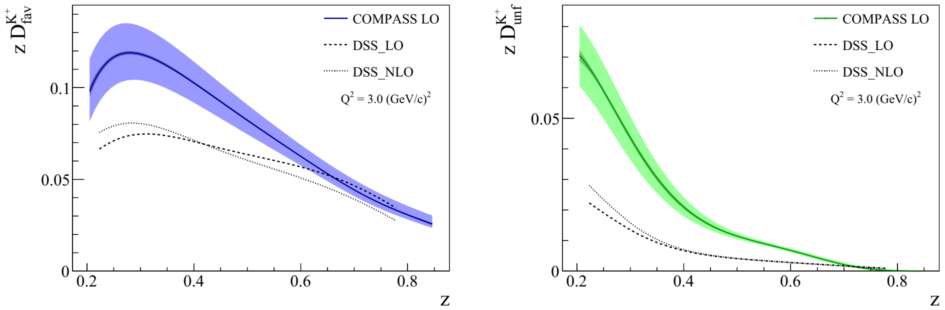

Figure 6. The results of COMPASS LO QCD fit to the kaon multiplicities: D^K_{fav} (left) and D^K_{unf} (right).

6 Summary

Preliminary results for charged hadrons, pion and kaon multiplicities from the COMPASS experiment were presented. They were compared to results of HERMES; observed differences were discussed and are subject of further studies. They also motivate importance of multiplicity measurements at the future electron-proton collider. The presented measurements give an important input to the global analyses of fragmentation functions.

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