HADRON MULTIPLICITIES AND QUARK FRAGMENTATION FUNCTIONS AT COMPASS

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Abstract

Quark fragmentation functions (FF) $D_q^h(z, Q^2)$ describe final-state hadronisation of quarks q into hadrons h. The FFs can be extracted from hadron multiplicities in semi-inclusive deep inelastic scattering. The COMPASS collaboration has measured charged hadron multiplicities for identified pions and kaons using 160 GeV/c muons impinging on an isoscalar target. The data cover a large kinematical range and provide an important input for global QCD analyses at NLO, aiming at the determination of FFs, in particular in the strange quark sector. The latest results from COMPASS on pion and kaon multiplicities are presented.

Within the QCD parton model, semi-inclusive deep inelastic scattering can be factorised [1] into three components, the hard scattering cross section, the parton distribution functions (PDF), and the fragmentation functions (FF). The PDFs describe the structure of the initial-state hadrons, while the latter describe the hadronisation process as a collinear conversion of a single parton into final-state hadrons. While e^+e^- collider experiments provide precise measurements, only the sum of quark and anti-quark fragmentation functions can be extracted. In semi-inclusive deep inelastic scattering, flavour separated fragmentation functions can be determined in leading order from measured hadron multiplicities $M^h(Q^2, x, z)$, *i. e.* from the numbers of final-state hadrons normalised by the number of detected DIS events, using:

$$M^h(x, Q^2, z) = \frac{1}{\sigma^{DIS}} \frac{d\sigma^h}{dx\, dz\, dQ^2} \overset{\text{LO}}{=} \frac{\sum_q e_q^2\, q(x, Q^2)\, D_q^h(z, Q^2)}{\sum_q e_q^2\, q(x, Q^2)} \tag{1}$$

Here, $q(Q^2, x)$ are the parton distribution functions of the struck quarks, e_q the charge of the quark with the flavour q and $D_q^h(z, Q^2)$ the fragmentation function of quark q into hadron h. The kinematic variables are the virtual photon four-momentum squared Q^2, the Bjorken variable x and the hadron energy fraction z. The current interest in FFs is motivated, *i. g.* by contradicting results of the strange quark helicity density. the contribution of the strange quarks to the nucleon spin,$\Delta s + \Delta\bar{s}$, can be extracted from an inclusive measurement [3] of the polarised structure function $g_1(x, Q^2)$ for proton and deuteron using pQCD. The result in NLO is negative. On the other hand, $\Delta s(x)$ can be extracted using semi-inclusive hadron asymmetries [4] in combination with a parametrisation of parton distribution functions and fragmentation functions. The integral over the measured x range tends to be zero, but strongly depends on the used parametrisation (*i. g.* EMC [5] and DSS [6]). The COMPASS experiment is an excellent facility to study fragmentation functions from semi-inclusive muon nucleon scattering in a large kinematic range.

The COMPASS experiment [2] is located at the M2 beam line of the Super Proton Synchrotron at CERN. It uses a tertiary muon beam impinging on a isoscalar fixed-target. The set-up comprises a beam spectrometer, a target and two magnetic spectrometer stages. Both magnetic spectrometer stages have high resolution trackers and hadron as well as electromagnetic calorimetry. The first stage includes a Ring Imaging CHerenkov (RICH) detector for pion and kaon separation.

The analysis used data recorded in 2006 with a 160 GeV muon beam scattering off a polarised lithium-deuterid (^{6}LiD) target. The polarisation cancels out as the direction was regularly reversed during data taking. After quality checks and geometric cuts on the interaction vertex of the beam muon and the target nucleon, DIS events are selected using $Q^2 > 1\,\mathrm{GeV}^2$, $5 < W < 17\,\mathrm{GeV}$ for the invariant mass of the final hadronic state, $0.004 < x < 0.7$ and $0.1 < y < 0.9$ for the relative virtual photon energy. In addition, hadrons are constrained to $0.2 < z < 0.85$. The lower limit is introduced to suppress contributions from target fragmentation and the upper limit to reduce contributions from production of exclusive vector mesons. To assure a good separation between pions and kaon, a hadron momentum cut of $10\,\mathrm{GeV} < P_h < 40\,\mathrm{GeV}$ has been applied for pions and kaons. The data are analysed in a three-dimensional binning of x, y and z. The obtained raw multiplicities are corrected for radiative QED effects, for the acceptance of the spectrometer and for the particle identification efficiency.

The acceptance has been determined with a Monte Carlo simulation of the COMPASS experiment. It includes the LEPTO [7] generator which contains the parton distribution functions MSTW08 and the JETSET [8] package for the hadronisation model according to the Lund string model. The produced events are reconstructed in a GEANT3 model

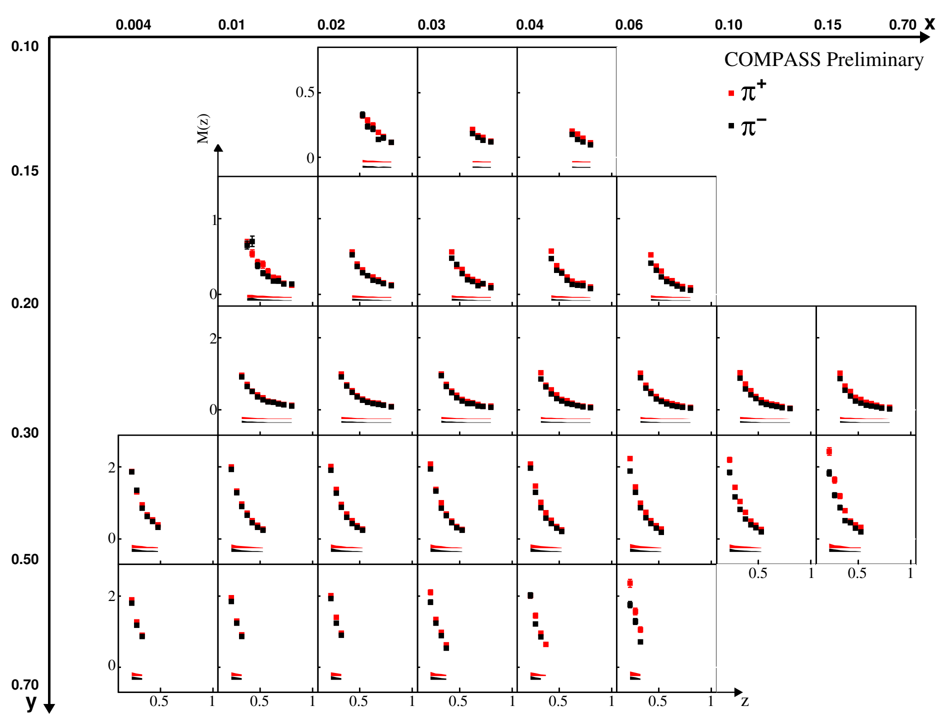

Figure 1: The preliminary, corrected pion hadron multiplicities in bins of x, y and z for positive pions (red) and negative pions (black). The systematic uncertainties are shown as error bands.

of the COMPASS experiment using the COMPASS tuning [9]. The three dimensional acceptance correction is flat in z and reaches values from 0.4 to 0.6. Due to the hadron momentum cut some LEPTO extrapolation into the non-measured range is necessary. To avoid model dependence, all kinematic bins where the extrapolation contribution is higher than 10 % are excluded. The RICH efficiency is determined by analysing the final-states of known decays (K^0_S, ϕ and Λ). The identification efficiency for pions is 98% with a systematic uncertainty of 1% to 3%, depending on the hadron momentum and the entrance angle in the detector. The misidentification of kaons to pions is less than 3 %.
Figure 1 and Figure 2 show the preliminary results for pion and kaon multiplicities for both charges: red (gray) for positive and black for negative hadrons. The systematic uncertainties are shown as bands in the corresponding x, y and z bins. It dominates the overall uncertainties, even in the kaon multiplicities, where the statistics is limited. The unidentified hadron multiplicities, which are not shown here, and the pion multiplicity are very similar, since 70% of the produced hadrons are in fact pions. The multiplicities show a strong dependence on the hadron energy fraction z and a small dependence on y. The dependence on x is rather small and is due to the parton distribution functions. In the pion case, a small difference between positive and negative hadrons is observed. With higher x the positive pion multiplicities are larger than the negative ones. For the kaon multiplicities, the charge difference and its x and y dependence is much more pronounced. This difference is explained by the quark content of the kaons. K^+ mesons can be produced off valence quarks and sea quarks, while K^- mesons can only be produced off sea quarks.

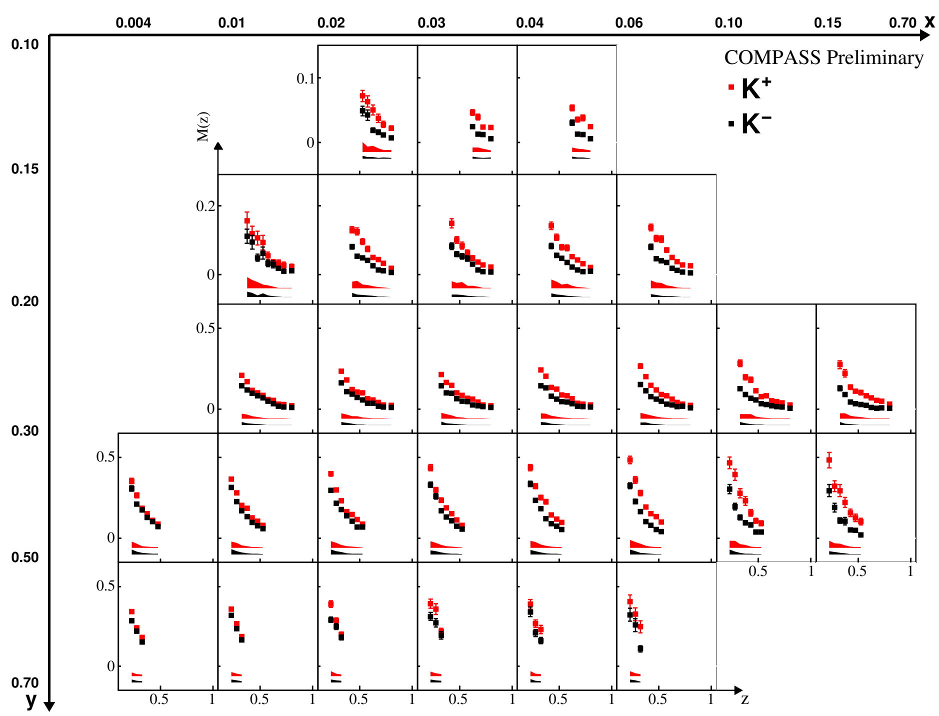

Figure 2: The preliminary, corrected pion hadron multiplicities in bins of x, y and z for positive kaons (red) and negative kaons (black). The systematic uncertainties are shown as error bands.

In Figure 3, the sum of the charged kaon multiplicities is shown as a function of x, averaged over y and integrated over the measured range of the fractional hadron energy z. The charge sum is related to the strange quark distribution $S(x) = s(x)+\overline{s}(x)$ and the strange fragmentation function D_S^K, shown in Equation (2). With decreasing x, one expects an increase of the strange parton distribution, hence an increase of the sum of the kaon multiplicities. The data presented in Figure 3 do not exhibit the expected dependence, thus the strange fragmentation function to kaons seems to be small.

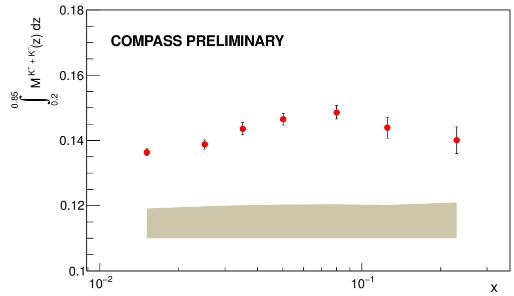

Figure 3: The charge sum of the corrected kaon multiplicities integrated over the measured z range.

$$\int M^{K^+ + K^-}(z)dz = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x)+2S(x)} \propto \frac{S(x)}{Q(x)}\left(\frac{\int D_S^K(z)dz}{\int D_Q^K(z)dz} - \frac{2}{5}\right) \tag{2}$$

In conclusion, COMPASS has measured the hadron multiplicities for pions and kaon from deep inelastic scattering off an isoscalar target with a systematic uncertainty up to 3 (10)% for pions (kaons), depending on the kinematic range.Also under studies are the determination of the K_S^0 multiplicities, where soon results are expected. In 2012, COMPASS took data with an unpolarised liquid hydrogen target. More data will be taken in the future, most likely after 2015. The large data sample will allow the measurement of hadron multiplicities $M^h(x, y, z, p_t, \theta_h)$ with the hadron transverse momentum p_t and the hadron azimuthal angle θ.

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