New COMPASS results on kaon multiplicities from SIDIS

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Abstract. Preliminary COMPASS results on kaon multiplicities produced in semi-inclusive deep inelastic scattering of 160 GeV muons off a pure proton target are presented. The results constitute a data set of more than 600 data points, covering a large $x$, $Q^2$ and $z$ domain in a fine binning with $W > 5$ GeV/$c^2$. The results from the sum of the $z$-integrated multiplicities $M(K^+)+M(K^-)$ are presented versus $x$ and compared to earlier COMPASS results on a deuteron target and to other experiments. In addition, we show the $K^-/K^+$ as well as $\bar{p}/p$ multiplicity ratios measured for hadrons carrying a large fraction $z$ of the virtual-photon energy, $0.5 < z < 1$. The data were obtained using a 160 GeV muon beam and an isoscalar $^6$LiD target. For values of $z$ larger than 0.8, the results contradict expectations obtained using the formalism of (next-to-) leading order perturbative quantum chromodynamics. In particular the data show a strong dependence upon the missing mass $M_x$, not expected from the calculations. The results suggest that additional corrections to the formalism may be required to take into account the phase space available for hadronization.

1. Introduction

The structure and formation of hadrons can be investigated using hadron production in semi-inclusive measurements of deep inelastic lepton-nucleon scattering (SIDIS). Using the factorisation Ansatz the cross section can be written in perturbative quantum chromodynamics (pQCD) as a convolution of hard scattering cross sections with nucleon parton distributions (PDFs) and quark-to-hadron fragmentation functions (FFs). FFs can be studied as well in electron-positron annihilation, which is mainly sensitive to the sum of quark and antiquark FFs. Using proton and neutron targets and measuring positive and negative hadrons SIDIS allows access to flavour separated FFs. While the FFs of light quarks into pions are well known, much less information is currently available for the production of kaons.

In SIDIS FFs are extracted from kaon and pion multiplicities. Recent results from COMPASS using in 2006 a solid-state isoscalar target ($^6$LiD) [1, 2] and from HERMES using hydrogen and deuterium targets [3] show some discrepancies, which cannot be explained easily by the different kinematic regions covered by the two experiments due to the much lower beam energy for HERMES. The differences are most striking for the kaon results. We present here new results from COMPASS using a 160 GeV muon beam and a liquid hydrogen target obtained in 2016 with a set-up modified compared to the one used in 2006.

1 supported by the BMBF
2. Kaon multiplicities

In leading order QED deep inelastic scattering (DIS) can be described by the exchange of a virtual photon $\gamma^*$ between lepton and proton with a 4-momentum transfer squared $-Q^2$ and an energy $\nu$ in the target rest frame. Differential hadron multiplicities are defined as the ratio of the cross section for hadron production and inclusive DIS

$$\frac{dM^h(x,z,Q^2)}{dz} = \frac{d\sigma^h(x,z,Q^2)/dzdQ^2}{\sigma^{\text{DIS}}(x,Q^2)/dzdQ^2},$$

where $x = Q^2/2M\nu$ is the Bjorken variable and $z$ the hadron energy relative to the virtual photon energy.

In leading order pQCD one obtains for the multiplicities

$$\frac{dM^h(x,z,Q^2)}{dz} = \frac{\sum_q e_q^2 q(x,Q^2)D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}.$$

Here, $q(x,Q^2)$ are the PDFs for (anti)quarks of type $q$ and $D_q^h(z,Q^2)$ the FFs for (anti)quarks $q$ to hadrons of type $h$.

Differential hadron multiplicities are experimentally accessed using the ratio of the number of produced hadrons in a certain kinematic bin divided by the number of inclusive DIS events:

$$M_{\text{raw}}(x,y,z) = N^h(x,y,z)/N^{\text{DIS}}(x,y)\Delta z$$

In fixed target kinematics there exists a strong correlation between $x$ and $Q^2$, thus the experimental analysis is performed in bins of $x$ and $y$, where $y = \nu/E$ is the relative energy transfer by the virtual photon with $E$ the incoming muon energy. The kinematic selections applied to the reconstructed events are $Q^2 > 1 \text{ GeV}/c^2$, $W > 5 \text{ GeV}/c^2$, where $W$ is the invariant mass of the final state hadronic system, $0.1 < y < 0.7$, $0.0025 < x < 0.7$ and $0.2 < z < 0.85$. Pions and kaons are identified using a ring-imaging Cerenkov detector. The following corrections have to be applied to the raw multiplicities: corrections for higher-order QED processes, for PID efficiencies and misidentifications, subtraction of diffractive vector meson contribution and acceptance. Hence, Fig. 1 shows the $y$ averaged results for $K^+$ and $K^-$ multiplicities [4]. The main systematic uncertainties are due to the PID efficiency, acceptance and the diffractive vector meson contribution. To be able to compare our data to the ones obtained by HERMES the results for positive and negative kaons are summed and additionally integrated over the measured $z$ range, $\mathcal{M}(x) = \int_{0.2}^{0.85} M(x,z)dz$. In leading order the multiplicity sum can be expressed as

$$\mathcal{M}^{K^+} + \mathcal{M}^{K^-} = \frac{U\mathcal{D}_U + S\mathcal{D}_S}{5U + 2S}$$

with $U = u + \bar{u} + d + \bar{d}$, $S = s + \bar{s}$ depending on $x$ and $Q^2$ and $\mathcal{D}(Q^2) = \int_{0.2}^{0.85} D(z,Q^2)dz$. The results for the kaon multiplicity sum are compared in Fig. 2 a) to the ones from the isocalar target as well as to results from HERMES. As expected the results for protons are about 5% higher than the ones for isoscalar target or deuterons, while a similar discrepancy between COMPASS and HERMES results is observed for both targets. Several explanations are under discussion, e.g. the different kinematic range especially in $W$, the $Q^2$ dependence as given by next-to-leading order QCD fits or a possible hadron mass correction.

3. Multiplicity ratios

More light can be shed on the discussed discrepancy extending the multiplicity measurements to high $z$. A determination of multiplicities at high $z$ is very challenging due to low statistics and large bin migration effects. Much easier is the extraction of multiplicity ratios as e.g.

$$R_K(x,Q^2,z) = dM^{K^-}(x,Q^2,z)/dM^{K^+}(x,Q^2,z).$$
Figure 1. $z$ dependence of charged kaon multiplicities in bins of $x$. The bands correspond to the total systematic uncertainties.

Figure 2. a) Kaon multiplicity sum versus $x$. The COMPASS results for an isoscalar target and the new preliminary results for protons are compared to the HERMES results for protons and deuterons. b) Results for $R_K$ and $R_p$ as a function of $z_{\text{corr}}$ for the low $x$ bin with $\langle x \rangle \approx 0.030$. The systematic uncertainties are shown as bands at bottom.

First results of kaon ratios for $z > 0.75$ were recently published by COMPASS [5] using the same data obtained with the isoscalar target as for the pion and kaon multiplicities. In the current analysis the published ratios are extended to higher kaon momenta and complemented by antiproton-proton multiplicity ratios [6]. The analysis is performed in two $x$ bins with $\langle x \rangle$ of 0.030 and 0.094. At high $z$ a lower limit for $R_K$ and $R_p$ can be obtained using

$$R_K > \frac{\bar{u} + \bar{d}}{u + d}, \quad R_p > \frac{\bar{u} + \bar{d}}{u + d}.$$

The lower limit is 0.47 for the low $x$ bin using the MSTW08 LO PDFs [7], while the limit is about 10-20% lower using NLO PDFs. The results for the $z$ dependence in the lower $x$ bin are shown...
in Fig. 2 b) for the kaon and proton ratio ($R_K$ and $R_p$). In contrast to the multiplicity analysis discussed above, in the ratio analysis the migration of hadrons between $z$ bins is not included in the acceptance correction. To properly treat the considerable migration at high $z$ due to the strong $z$ dependence of the FFs, the average measured $z$ is corrected using a MC simulation resulting in corrected values $z_{corr}$ given in Fig. 2 b). A strong $z$ dependence of multiplicity ratios is observed. The kaon ratio lies below the pQCD limit at high $z$, while the proton ratio lies below in the whole measured $z$ range. An analysis of the data in bins of $\nu$ and $z$ reveals in addition an unexpected nearly linear $\nu$ dependence reaching the pQCD limit at large $\nu$ values for the lower $z$ values. The observed violation of the QCD expectation may indicate that the phase space available for hadronisation has to be accounted for at high $z$. A natural variable to study such an effect is the missing mass

$$M_X = \sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z^2)},$$

which depends simultaneously on $z$ and $\nu$. Figure 3 shows the resulting $M_X$ dependence for the kaon and proton ratio. A smooth behaviour of the data points in both cases is observed. This finding suggests that for experiments with smaller $\nu$ larger discrepancies to pQCD are expected, which may occur already at lower $z$ values than observed at COMPASS kinematics.

References

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