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K^-/K^+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual photon energy

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For the first time, the K^-/K^+ multiplicity ratio is measured in deep-inelastic scattering for kaons carrying a large fraction z of the virtual-photon energy. The data were obtained by the COMPASS collaboration using a 160 GeV muon beam and an isoscalar ^{6}LiD target. The regime of deep-inelastic scattering is ensured by requiring $Q^2 > 1$ (GeV/c)^2 for the photon virtuality and $W > 5$ GeV/c^2 for the invariant mass of the produced hadronic system. The Bjorken scaling variable range is $0.01 < x < 0.40$. The z-dependence of the multiplicity ratio is studied for $z > 0.75$. For very large values of z, *i.e.* $z > 0.8$, the results contradict expectations obtained using the formalism of (next-to-)leading order perturbative quantum chromodynamics. Our studies suggest that, within this formalism, an additional correction may be required to take into account the phase space available for hadronisation.

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1. Introduction

The strangeness content of nucleons has been a topic of interest since many years, but it has been difficult to measure it experimentally. The difficulty increases for the strange quark polarization (Δs), for which conflicting results have been obtained. When measured in the deep inelastic scattering (DIS) or semi-inclusive DIS (SIDIS) process, the parton distribution functions (PDFs) or their convolution with fragmentation functions (FFs) are needed to describe the cross section and asymmetries. For this reason, the knowledge of FFs is relevant to tackle the abovementioned problem. Quark FFs measure, at leading order, the probability of a given quark to give rise to a given hadron. They are fundamental non-perturbative functions, that are expected to be universal, *i.e.* independent of the physical process involved. In such context, they become ingredients of global perturbative QCD fits, *i.e.* fits that use data taken at different photon virtualities Q^2 and assume the validity of the DGLAP equations to evolve PDFs and FFs to common values of Q^2.

SIDIS experiments, such as the ones studied in the COMPASS experiment, give access to fragmentation functions $D_q^h(z,Q^2)$ by measuring hadron multiplicities M^h,

$$\frac{dM^h(x,Q^2,z)}{dz} \equiv \frac{d^3\sigma^h_{\mathrm{DIS}}(x,Q^2,z)/dx\,dQ^2\,dz}{d^2\sigma^{\mathrm{DIS}}(x,Q^2)/dx\,dQ^2}, \tag{1.1}$$

where x is the Bjorken scaling variable, Q is the photon virtuality and z is the fraction of the photon energy carried by the hadron, using the expression

$$\frac{dM^h(x,z,Q^2)}{dz} \overset{\mathrm{LO}}{=} \frac{\sum_q e_q^2 f_q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 f_q(x,Q^2)}, \tag{1.2}$$

where $f_q(x,Q^2)$ are quark distribution functions and e_q are the relative electric charges of the quarks, and the sum is over quark flavours.

The COMPASS Collaboration has recently published results of multiplicities of charged pions and unidentified charged hadrons [1], multiplicities of charged kaons [2], and also transverse-momentum-dependent multiplicities of charged hadrons, produced in muon-deuteron deep inelastic scattering [3]. While the unidentified charged hadrons and the charged pions are well described by leading order and next to leading order perturbative QCD parametrizations, this is not the case for the kaon multiplicities, in particular at high values of the hadron fractional energy z. In addition, the COMPASS and HERMES results for the ratio of z-integrated kaon multiplicities $\mathscr{M}^{K^+}/\mathscr{M}^{K^-}$ are not compatible within experimental uncertainties.

There was therefore an interest in exploring further the higher values of z, in this case by use of mulplicity ratios, which allow to cancel out many possible sources of systematic uncertainties. In the following sections, the experimental setup is briefly described, after which the method for multiplicity extraction is presented, followed by the obtained results, which are discussed and, finally, a summary is given. This analysis was recently submitted for publication [4].

2. Experimental setup

The COMPASS experiment at CERN is presented in detail in Ref. [5] and some of its recent results and future plans are highlighted in these proceedings [6, 7, 8]. COMPASS is a ground level fixed target experiment at the CERN SPS that uses a terciary muon beam of positive (or negative) charge, or a secondary hadron beam. The two-stage spectrometer provides large angular and momentum acceptances. The trigger is based on hodoscopes that detect the scattered muon and, optionally, an energy deposit in a calorimeter. Particle identification is ensured by use of muon walls, electromagnetic and hadronic calorimeters, and a RICH detector.

The analysis described in this contribution refers to data collected in 2006 with a positive muon beam with 160 GeV/c momentum and with a solid state target of ^{6}LiD. The target was 1.2 meters long, divided in three cells of 30, 60, and 30 cm long.

3. Multiplicity extraction

The process for extraction of multiplicities from data has several steps. First of all, there is a data selection. The spectrometer acceptance and the reconstruction efficiency must be taken into account and corrected for. In addition, the efficiency and the purity of the RICH identification of kaons are corrected for. Also the decays of diffractively produced vector mesons that produce kaons is corrected for. Finally, corrections are applied to account for radiative effects.

The initial sample is the data collected by COMPASS in 2006 with a 160 GeV/c positive muon beam impinging in an isoscalar target of ^{6}LiD. It is required that the tracks of a beam particle and of a scattered muon are reconstructed. Furthermore, the deep inelastic scattering regime is ensured by requirements of $Q^2 > 1$ GeV/c^2 and of the mass of the hadronic final state $W > 5$ GeV/c^2. To avoid events with badly reconstructed kinematic variables, it is further required that the fraction of beam muon energy carried by the virtual photon satisfies $y > 0.1$. The reconstructed fraction of the energy of the virtual photon carried by the kaon is, for the present analysis, restricted to the region of high values, $z_{\rm rec} > 0.75$. The momentum of the hadron is restricted to the region where kaons are well identified by the RICH, *i.e.* $12 < p_h/(\mathrm{GeV}/c) < 40$. The hadron is required to be identified as a kaon, in a way that ensures a very pure sample of kaons.The kinematic coverage of the final sample with kaon events is depicted in Fig. 1.

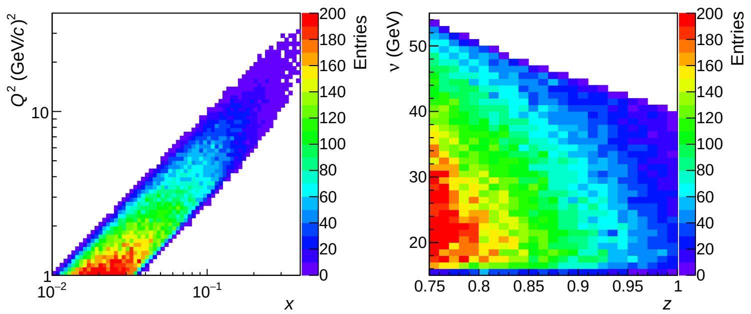

Figure 1: Kinematic coverage of the final sample of kaon events used in the present analysis: Q^2 vs. x (left) and ν vs. z (right) [4].

The final sample comprises 64000 charged kaons. For the analysis, we use two bins of the Bjorken scaling variable: $x < 0.05$ and $x > 0.05$, with $\langle Q^2\rangle = 1.6$ (GeV/c^2) and $\langle Q^2\rangle = 4.8$ (GeV/c^2), respectively. The following bins limits for the z variable are used: 0.75, 0.80, 0.85, 0.90, 0.95 and 1.05.

The way the final sample was obtained and the fact that a ratio of multiplicities is used allows to simplify many of the corrections applied. The ratio of acceptances of K^- and K^+ was found to be constant over z, and the constant obtained from a fit was used as correcting factor for all z_{rec} bins. Moreover, the great purity of the sample allowed a simplified unfolding. As for the vector meson corrections, they were simulated with the program HEPGEN [9], and it was verified that the ϕ decay is not important in the high-z region of this analysis. Finally, the electromagnetic radiative efects cancel out in the multiplicity ratio, because they don't depend on the charge of the hadron.

4. Results and discussion

In Fig. 2, the results for the ratio of multiplicities $R_K = (dM^{K^-}/dz)/(dM^{K+}/dz)$ are show for the first bin in x, together with several predictions. Except for the first z bin, all the remaining four data points are below the predictions. It should be noted that possible corrections to account for the vector meson decays or for pion misidentification as kaon further decreses the values of R_K obtained from the data, thereby increasing the tension between data and predictions.

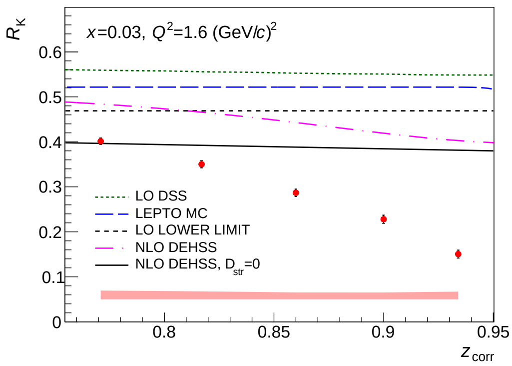

Figure 2: (Left) Final results obtained for the ratio of multiplicities of K^- over K^+, R_K, for the bin with $x < 0.05$. The ratio is shown as a function of the variable $z_{\mathrm{corr}} = z_{\mathrm{rec}}^{\mathrm{data}}$-$(z_{\mathrm{rec}}^{\mathrm{MC}} - z_{\mathrm{gen}}^{\mathrm{MC}})$, that is, a correction is applied to the values of z obtained from the data that is equal to the difference obtained in Monte Carlo simulations between the generated and the reconstructed values of that variable. The curves represent the predictions for the ratio R_K obtained from the leading order DSS parametrization, from a simulation using the LEPTO generator, together with the leading order lower limit, and from the next to leading order parametrization DEHSS, both without and with the constraint of $D_{\mathrm{str}} = 0$ [4].

It should also be noted that the behaviour of R_K is similar for both the x bins considered, being well fitted by a functional form of type $\propto (1-z)^{\beta}$, $\beta = 0.71 \pm 0.03$. Furthermore, the ratio of the results obtained from the two x bins is constant over z, as can be seen in Fig. 3.

In Fig. 4, the results for the ratio of multiplicities R_K is shown as a function of the energy of the virtual photon ν, in five bins of z_{rec}. Also the leading order lower limit and the next to leading order parametrization of DEHSS, assuming $D_{\mathrm{str}} = 0$, are shown. The ratio is seen to be below the predictions, most noticeably for low ν and for higher z. This is in agreement with the observation from the LSS group ("the largest discrepancy between pQCD expectations and experimental results is observed in the region of large z and small y, *i.e.* small ν" [10].)

It should be noted that high values of z of a given kaon correspond to a reduction of the phase space available for the formation of other particles. Therefore, the missing mass, $M_X \approx$

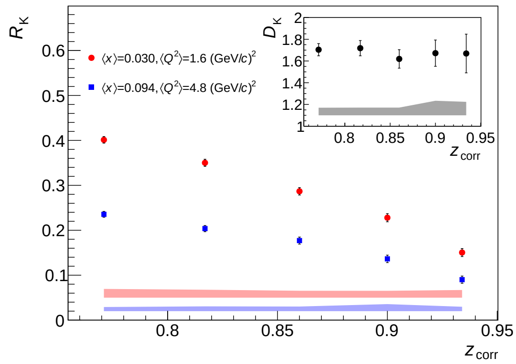

Figure 3: Final results obtained for the ratio of multiplicities of K^- over K^+, R_K, for the two two bins of x. In the inset, the ratio D_K of the results of the two x bins is also shown [4].

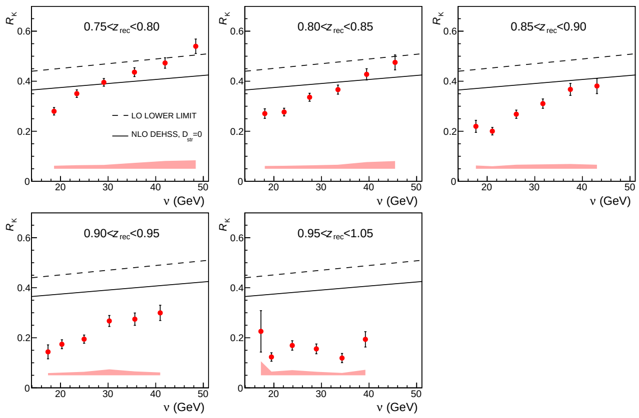

Figure 4: $R_K(\nu)$ in 5 bins of z, together with the lower limit prediction at leading order and the next to leading order DEHSS parametrization for D_{str} [4].

$\sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z^2)}$, seems a natural variable to study the observed effect and, indeed, there is a smooth increasing trend of R_K as a function of M_X, as can be seen in Fig. 5.

5. Summary

For the first time, the ratio of multiplicities of charged kaons produced in deep inelastic scattering was measured in the region of high z. This ratio is particularly useful because it doesn't depend on most of the possible sources of systematic uncertainties. The results are at contrast to the expectations from QCD leading order and next to leading order parametrizations as well as from limits at the leading order approximation. The disagreement is larger at larger values of z and lower values of ν, the energy of the virtual photon. The beforementioned ratio of multiplicities exhibits a smooth trend as a function of the missing mass $M_X \approx \sqrt{M_p^2 + 2M_P\nu(1-z) - Q^2(1-z^2)}$, which may be an indication that, within the perturbative QCD framework, a correction might be included in order to take into account the phase space available for the hadronisation of the target remnants.

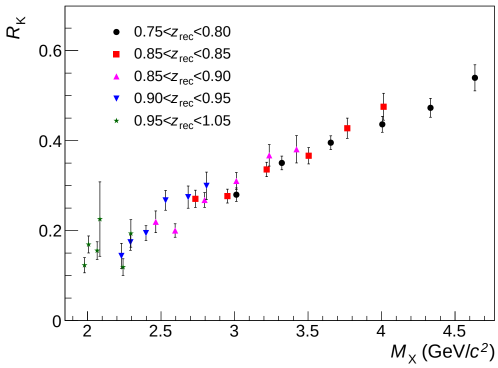

Figure 5: Ratio R_K as a function of the missing mass, defined as $M_X \approx \sqrt{M_p^2 + 2M_p\nu(1-z) - Q^2(1-z^2)}$ [4].

Acknowledgements

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