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Hadronization in the Nuclear Media

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Abstract The influence of the nuclear environment on the production of charged pions, kaons and (anti)protons in semi-inclusive deep inelastic scattering has been studied by the HERMES experiment at DESY using a 27.6 GeV positron beam. Identified hadron multiplicities have been measured for helium, neon, krypton and xenon relative to that of deuterium as a function of ν , z and p_t^2 . Dependences have been extracted in a one and two-dimensional representation, i.e. in the form of detailed binning over one variable and integrating over all other variable or three slices over the other variable. The most prominent features compared to a one-dimensional analysis are changes of the ν -, p_t^2 two-dimensional dependences of ratios, in particular in case of protons. In general pions and negative kaons show similar dependences, however, positive kaons, protons and antiprotons behave quite differently.

1 Introduction

Production of hadrons in deep-inelastic scattering (DIS) offers the possibility to investigate quark propagation and hadronization. The relatively clean nuclear environment of lepton-induced reactions allows the investigation of the space-time evolution of the hadronization process already in the early stage of hadron production. The most convenient experimentally measurable observable for this process is the multiplicity ratio:

$$R_A^h(\nu, z, Q^2, p_t^2) = \left(\frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)} \right)_A \bigg/ \left(\frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)} \right)_D, \quad (1)$$

which is the ratio of the number of hadrons produced per DIS event for a nuclear target with atomic mass number A to that from a deuterium (D) target. The z , Q^2 and p_t^2 represent the fraction of the virtual photon energy ν transferred to the hadron, the virtuality of the photon, and the square of the hadron momentum component transverse to the virtual photon direction, respectively.

The data within the experimental acceptance are presented: (a) as a function of one kinematic variable, integrating over other variables (one-dimensional dependences); (b) using a detailed binning in one variable and three slices is another one and integrating over the other (two-dimensional dependences). This allows to study these dependences in more detail.

From the theoretical side there is significant interest in hadron-multiplicity ratios, as exemplified by the diversity of model calculations [1–6]. It is beyond the scope of this report to compare the results of the various models with the data. Instead, some of the most prominent features of the data are presented and discussed.

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2 Experiment and Results

The multiplicity ratio R_A^h has been measured at HERMES using D, He, Ne, Kr and Xe gas targets internal to the 27.6 GeV HERA positron storage ring, identifying both the scattered positron and the produced hadrons in the HERMES spectrometer [7]. The identification of charged hadrons was accomplished using information from the dual-radiator ring-imaging Čerenkov detector (RICH), which provides separation of pions, kaons and (anti)protons in the momentum range between 2 and 15 GeV/c.

The left panel of Fig. 1 shows the one-dimensional dependence of R_A^h on ν , z and Q^2 . The basic feature of all charged hadrons is the decrease of R_A^h with increasing value of the atomic mass number A of the nucleus, as well as a decrease of R_A^h with decreasing ν and increasing z . This clear influence of the nuclear environment on hadronisation process is qualitatively understood as being due to increased partonic (quark energy loss) or hadronic (absorption) effects. Furthermore, there is a large similarity between the data for π^+ and π^- , and a clear difference between those for K^+ and K^- , and those for p and $\bar{p}$. The difference for the kaons may be partially due to differences in the hadron-nucleon interaction cross section (σ_{hN}) for K^+ and K^- . The results for protons cannot really be related to those for any of the other particles. Because protons are already present in a nucleus, an appreciable fraction of them may originate, especially at low z , from the target remnant. Furthermore, in final-state interactions they generally are not absorbed, but give rise to more nucleons (both protons and neutrons), thus possibly even increasing R_A^h at lower z . Antiprotons feature a rather strong attenuation, which might be attributed to the relatively large $\bar{p}N$ cross section.

The right panel of Fig. 1 shows the two-dimensional dependence of R_A^h on ν for three slices in z . The global trend that R_A^h steadily increases with ν seems to be broken at low values of ν for the higher z -ranges for $\pi^\pm$ and, in particular, for K^+ and protons. The results for protons are very different from those for the other hadrons. For the heavier nuclei R_A^h is becoming larger than unity at higher ν for the lowest z slice. In contrast, for $z > 0.7$ R_A^h is smaller than unity, and remains constant or drops with ν . In case of protons at the lowest values of ν the differences between the z ranges seem to disappear.

The left panel of Fig. 2 shows the one-dimensional dependence of R_A^h on p_t^2 . An enhancement of the number of hadrons at high p_t^2 with atomic mass number A is observed. Thus, the observed enhancements in the pion and kaon spectra are more suppressed than in the proton spectra. Such an effect was first observed by EMC [9] for all charged hadrons taken together, while it was measured for identified hadrons by HERMES [8]. This so-called Cronin-effect was also observed in heavy-ion collisions. Lepton probes,

Fig. 1 The one-dimensional dependence of R_A^h on ν , z , and Q^2 [8] (left panel). The two-dimensional dependence of R_A^h on ν for three slices in z (right panel). The inner error bars represent the statistical uncertainty, while the full ones show the total uncertainty

Fig. 2 The one-dimensional dependence of R_A^h on p_t^2 [8] (left panel). The two-dimensional dependence of R_A^h on p_t^2 for three slices in z (right panel). Statistical and total errors are shown as in Fig. 1

however, provide a cleaner measurement as initial state interactions do not contribute except for shadowing effects, which are small in the x_{Bj} range of the present experiment.

The right panel of Fig. 1 shows the two-dimensional dependence of R_A^h on ν for three slices in z for positively charged hadrons. For all hadrons, except for the proton, we see the same behaviour in different slices in z : the rise at high p_t^2 for values $0.2 < z < 0.7$ and its constant behaviour for higher range in z . Protons show a much stronger rise in the p_t^2 distribution which, in contrast to the other hadrons, does hardly diminish when going to higher ranges in z .

We expect these data to be a useful ingredient to constrain and improve models on hadronization and, hence, improve our understanding of the hadron formation mechanism.

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References

1. Kopeliovich, B., et al.: Nuclear hadronization: Within or without? Nucl. Phys. A **740**, 211–245 (2004)
2. Accardi, A., et al.: Atomic mass dependence of hadron production in deep inelastic scattering on nuclei. Nucl. Phys. A **761**, 67–91 (2005)
3. Wang, E., Wang, X.-N.: Jet tomography of dense and nuclear matter. Phys. Rev. Lett. **89**, 162301 (2002)
4. Falter, T., et al.: Hadron attenuation in deep inelastic lepton-nucleus scattering. Phys. Rev C **70**, 054609 (2004)
5. Akopov, N., et al.: Application of the two-scale model to the HERMES data on nuclear attenuation. Eur. Phys. J. **C44**, 219–226 (2005)
6. Sassot, R., et al.: Fragmentations Functions in Nuclear Media. Phys. Rev D **81**, 054001 (2010)
7. Ackerstaff, K., et al. [HERMES]: The HERMES spectrometer. Nucl. Inst. Meth. A **417**, 230–265 (1998)
8. Airapetian, A., et al. [HERMES]: Hadronization in semi-inclusive deep-inelastic scattering on nuclei. Nucl. Phys. B **780**, 1–27 (2007)
9. Ashman, J., et al.: Comparison of forward hadrons produced in muon interactions on nuclear targets and deuterium. [EMC] Z. Phys. C **52**, 1–12 (1991)