Hadron Electro-production in Cold Nuclear Matter at HERMES

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Abstract. The influence of the nuclear medium on lepto-production of hadrons was studied in the HERMES experiment at DESY using semi-inclusive deep-inelastic scattering of 27.6 GeV positrons off deuterium, helium, nitrogen, neon, krypton, and xenon targets. The differential multiplicity of krypton relative to that of deuterium has been measured for the first time for various identified hadrons (π^+ , π^- , π^0 , K^+ , K^- , p and $\bar{p}$) as a function of the virtual photon energy ν , the fraction z of this energy transferred to the hadron, and the hadron transverse momentum squared p_t^2 . By studying the attenuation of leading and sub-leading hadrons in various nuclei, it is investigated how the hadron absorption and energy loss mechanisms contribute to the formation of hadrons.

Keywords: Hadronization, nuclear attenuation, double hadron correlation

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INTRODUCTION

If hadronization occurs in a nuclear environment rather than in vacuum, additional processes may occur before the final-state hadron is formed. This can result in a modification of the quark fragmentation functions. Acquiring a good understanding of quark propagation in the nuclear medium is crucial for the interpretation of ultra-relativistic heavy ion collisions, and high energy proton-nucleus and lepton-nucleus interactions. Quark propagation in the nuclear environment involves processes like multiple interactions with the surrounding medium and induced gluon radiation, resulting in energy loss of the quark. If the (pre-)hadron is formed inside the nucleus, it can interact via the relevant cross section, causing a further reduction of the hadron yield. Therefore, quark and (pre-)hadron propagation in nuclei are expected to result in a modification of the leading-hadron spectra [1]. By studying the properties of the leading hadrons emerging from nuclei, information on the time-space picture of hadronization can be obtained.

The process of double hadron production in nuclei can provide information about how the energy loss and the absorption mechanism contribute to hadronization, e.g. if the two produced hadrons are correlated, the energy loss mechanism is expected to dominate over the absorption mechanism, because energy loss occurs before the prehadrons are formed.

Semi-inclusive deep-inelastic lepton-nucleus collisions are most suitable to obtain quantitative information on the hadronization process because no deconvolution of the parton distributions of the projectile and target particles is needed.

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DATA ANALYSIS

The experimental results for semi-inclusive deep-inelastic scattering on nuclei are presented in terms of the hadron multiplicity ratio R_M^h . This is the ratio of the number of hadrons of type h produced per deep-inelastic scattering event on a nuclear target with mass number A to that from a deuterium (D) target. It depends on the leptonic variables ν and Q^2 , which are the energy in the target rest frame and the squared four-momentum of the virtual photon, respectively, and on the hadronic variables $z = E_h/\nu$ and p_t^2 , where p_t is the hadron momentum component transverse to the virtual photon direction. The multiplicity ratio is defined as

$$R_M^h(z, \nu, p_t^2, Q^2) = \frac{N_h(z, \nu, p_t^2, Q^2)}{N_e(\nu, Q^2)} \Big|_A \Big/ \frac{N_h(z, \nu, p_t^2, Q^2)}{N_e(\nu, Q^2)} \Big|_D, \quad (1)$$

where N_h is the yield of semi-inclusive hadrons in a given (z, ν, p_t^2, Q^2) -bin, and N_e the yield of inclusive deep-inelastic scattering leptons in the same (ν, Q^2) -bin.

The measurements described were performed with the HERMES spectrometer [2, 3, 4] using the 27.6 GeV positron beam stored in the HERA ring at DESY. Contributions from target fragmentation were suppressed by requiring $z > 0.2$. The data have been corrected for radiative processes.

To study how the energy loss and absorption mechanisms contribute to hadronization, the double ratio for leading and sub-leading hadrons

$$R_{2h}(z_2) = \left(\frac{d^2N(z_1, z_2)}{dN(z_1)} \right)_A \Big/ \left(\frac{d^2N(z_1, z_2)}{dN(z_1)} \right)_D \quad (2)$$

has been considered. The term $d^2N(z_1, z_2)$ is the number of events with at least two hadrons ($z_{\text{leading}} = z_1 > 0.5$). The term $dN(z_1)$ is the number of events with at least one hadron, with $z_1 > 0.5$ [5].

RESULTS

For the first time the ν -dependence of the multiplicity ratios were studied for identified neutral and charged pions, kaons, protons and antiprotons, as shown in Fig. 1-right. The corresponding z -dependence of R_M^h with $\nu > 7$ GeV is shown in Fig. 1-left. In the bottom panels the average values for Q^2 and z or ν are displayed for all data.

The results presented in Fig. 1 show that the multiplicity ratios for positive and negative pions are similar and consistent with the multiplicity ratio for neutral pions. However, R_M^h for positive kaons is significantly larger. An even larger difference is observed between protons and antiprotons. Also, a stronger attenuation was observed for targets with increasing atomic mass number A [8] (not shown).

A nuclear enhancement at high p_t^2 is observed in the HERMES data shown in Fig. 2-left both for ^{14}N and Kr nuclei. The data for $p_t^2 < 0.7 \text{ GeV}^2$ show the attenuation previously discussed, while the data for $p_t^2 \geq 0.7 \text{ GeV}^2$ reflect the p_t -broadening attributed to multiple scattering effects. This broadening is also called the Cronin effect and has previously been observed in heavy-ion and hadron-nucleus induced reactions. In contrast

FIGURE 1. Multiplicity ratios for identified pions, kaons, protons and antiprotons from a Kr target as a function of ν for $z > 0.2$ (right), and as a function of z for $\nu > 7$ GeV (left). In the upper panels the ratios for pions, kaons and protons are shown. In the bottom panels the average z and ν values are displayed for pions, kaons, and protons. The inner (outer) error bars represent the statistical (total) uncertainties. The thick (thin) solid curves represent the calculations of Ref. [6] for positive (negative) charge states.

to the previous reactions the Cronin effect at HERMES can only be due to final state interactions.

The results on $R_{2h}(z_2)$, displayed in Fig. 2-right, show a reduction of R_{2h} compared to unity and essentially no A dependence [5].

SUMMARY

The multiplicities of identified hadrons on krypton relative to deuterium were measured for the first time. Different multiplicity ratios were observed for various hadrons.

The hadron multiplicity is observed to be enhanced at high p_t^2 in the nuclear medium, showing evidence for the Cronin effect in deep-inelastic scattering process, which can

FIGURE 2. Left: Multiplicity ratio for charged hadrons versus p_t^2 for $\nu > 7$ GeV and $z > 0.2$. The HERMES data on Kr and ^{14}N are compared to the EMC data on Cu. The error bars represent the statistical uncertainties. The systematic uncertainty for Kr (^{14}N) is shown as the lower (upper) band. Right: R_{2h} as a function of z_2 for ^{14}N , Kr, and Xe. The curves (solid for ^{14}N , dashed for Kr, dotted for Xe) are calculated within a BUU transport model [9] (upper panel), assuming only absorption [9] (lower panel).

only be due to final state interactions.

The ratio of leading and sub-leading hadron R_{2h} has been proposed, for the first time, as a tool to disentangling different mechanisms. The data show a reduction of R_{2h} compared to unity and essentially no A dependence. These results, according to Ref. [10], suggest that a contribution from rescattering of the (pre-)hadron is present in the nuclei considered here.

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