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ATTENUATION OF HADRONS IN NUCLEI*

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The influence of the nuclear medium on the production of charged hadrons in semi-inclusive DIS has been studied by the HERMES experiment at DESY with a 27.5 GeV positron beam. The hadron multiplicity has been measured for helium, neon and krypton relative to that of deuterium. The multiplicity ratio is strongly reduced at high values of the atomic number A. The A-dependence of HERMES data on krypton and nitrogen is discussed and is compared to two theoretical models. Assuming a simple A^{α}-dependence of the nuclear attenuation, the HERMES data are found to be closer to the $A^{2/3}$-dependence predicted by some pQCD-based models than to the $A^{1/3}$-dependence that follows from models based on nuclear absorption only.

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Hadronization (or fragmentation) is the process by which final-state hadrons are formed from the struck quark in a hard scattering event. When embedded in a nuclear medium this hadronization process is influenced by energy loss of the quark (or hadron) as it propagates through the medium. The quark looses energy through gluon radiation and multiple scattering. This may cause a reduction of the final hadron yield. If the final hadron is formed inside the nucleus, the hadron can interact via the hadronic interaction cross section, resulting in a possible further reduction of the hadron yield. Though interesting in its own right, the understanding of quark propagation through a nuclear environment is essential for the interpretation of ultra-relativistic heavy ion collisions and high energy proton–nucleus scattering. Semi-inclusive deep inelastic lepton–nucleus scattering provides a clean tool for the study of such quark propagation effects.

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The HERMES experiment has measured the multiplicity ratio $R_{\rm M}^h$ of hadrons of type h produced per DIS event on a nuclear target of mass A relative to that from a deuterium target (D):

$$R_{\rm M}^h(z,\nu) = \frac{\left(\frac{1}{N_e}\frac{d^2N_h}{dzd\nu}\right)_A}{\left(\frac{1}{N_e}\frac{d^2N_h}{dzd\nu}\right)_D} . \tag{1}$$

Here $z \equiv E_h/\nu$ is the fraction of the virtual photon energy ν transfered to the hadron. The quantities $N_e(\nu)$ and $N_h(z,\nu)$ are the number of inclusive DIS leptons and semi-inclusive hadrons of type h recorded in each kinematic bin, respectively The multiplicity ratio has been measured using 12.0 GeV and 27.5 GeV HERA positron beams in conjunction with D, ^{4}He, ^{14}N, ^{20}Ne and ^{84}Kr gas targets. Both the scattered beam positron and one or more final-state hadrons are observed in the HERMES spectrometer [1].

In Fig. 1 the multiplicity ratio $R_{\rm M}^h$ (at $E_{e^+} = 27.5$ GeV) is shown for charged pions as a function of ν and z. A strong dependence of the multiplicity ratio on the atomic number A is observed. Also, a strong reduction of the multiplicity ratio is observed at low ν and high z for ^{20}Ne and ^{84}Kr which confirms the results of previously published HERMES data on nitrogen [3]. For the small ^{4}He nucleus this behavior is less pronounced. A comparison between the left and the right panels of Fig. 1 shows that within the uncertainties no significant charge dependence of the multiplicity ratio is observed for pions.

For the first time the multiplicity ratio for charged hadrons for ^{14}N and ^{84}Kr has been measured using a 12.0 GeV positron beam. In Fig. 2 the results for the multiplicity ratio *versus* ν are compared with the results obtained with a 27.5 GeV positron beam. These new measurements extend the multiplicity ratio data to somewhat lower values of ν and, more importantly, they show that the same qualitative behavior of the multiplicity ratio is observed in two rather different kinematic regimes.

In Fig. 3 a comparison is shown of the data with two theoretical models for the multiplicity ratio *versus* ν (left) and *versus* z (right) on nitrogen and krypton. The model represented by the solid curves attributes the nuclear modification of the hadron multiplicity ratio to a rescaling of the quark fragmentation function combined with nuclear absorption [5], where nuclear absorption gives the largest contribution to the reduction of the multiplicity ratio. The second model, represented by the dash-dotted curve, is a pQCD-based model attributing the attenuation to multiple scattering and induced gluon radiation of the quark propagating through the nucleus [4]. Both models are able to describe the qualitative behavior of the multiplicity ratio *versus* ν and z, although they are based on different physics assumptions.

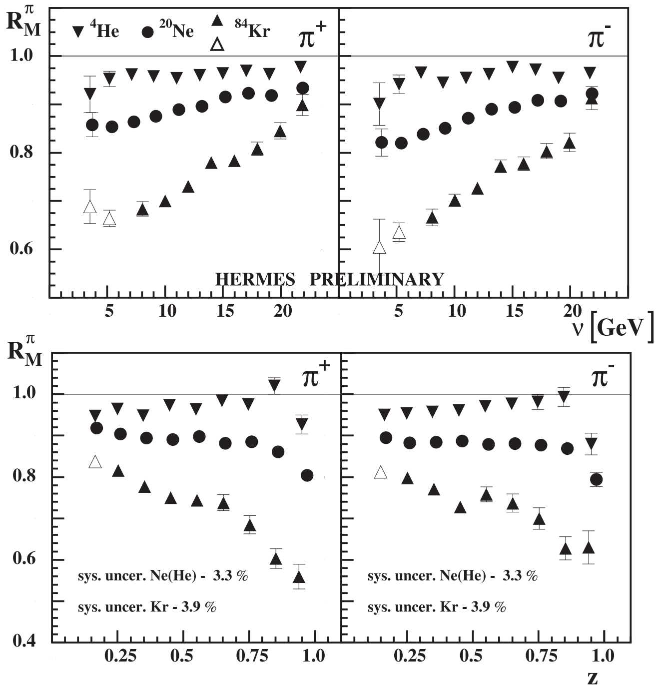

Fig. 1. Multiplicity ratio for charged pions *versus* ν (top panel) and *versus* z (bottom panel) for ^{4}He, ^{20}Ne and ^{84}Kr targets as obtained with the 27.5 GeV positron beam. The filled triangles for the krypton target represent recently published HERMES data [2].

By studying the A-dependence of the multiplicity ratio additional information can be obtained on the origin of the observed attenuation effects. The model of Ref. [4] contains the so-far untested QCD prediction that the induced radiative energy loss of a quark traversing a length L of hot or cold nuclear matter is proportional to L^2. This results in an $A^{2/3}$-dependence of the nuclear attenuation $1-R_{\mathrm{M}}^h$. In contrast to this, models based on nuclear absorption only exhibit an $A^{1/3}$-dependence[1].

Information on the A-dependence of the data is obtained by assuming that the attenuation depends on an arbitrary power of A, *i.e.* $1-R_{\mathrm{M}}^h \propto A^{\alpha}$. In this way it is found that the data are closer to the $A^{2/3}$-dependence [8] predicted in Ref. [4] than to the $A^{1/3}$-dependence expected for the nuclear absorption models. However, this result has been obtained from the analysis of two targets only, and more targets have to be analyzed to enable systematic studies of the A-dependence of the nuclear attenuation effects.

[1] It should be noted though that due to additional ingredients in the model of Ref. [5], the predicted A-dependence results in a power larger than 1/3.

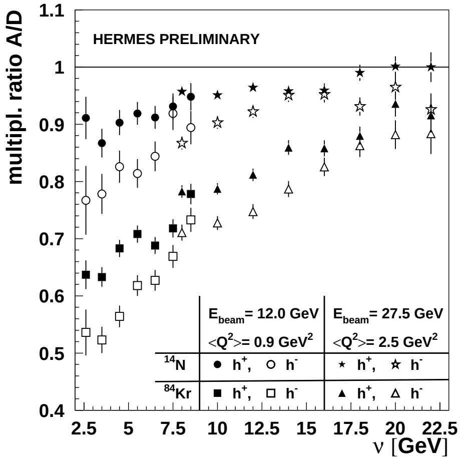

Fig. 2. Multiplicity ratio for charged hadrons *versus* ν for ^{14}N and ^{84}Kr targets. In the figure combining the data taken with a 12.0 GeV and a 27.5 GeV beam energy are combined. The open (closed) symbols represent the negative (positive) hadrons.

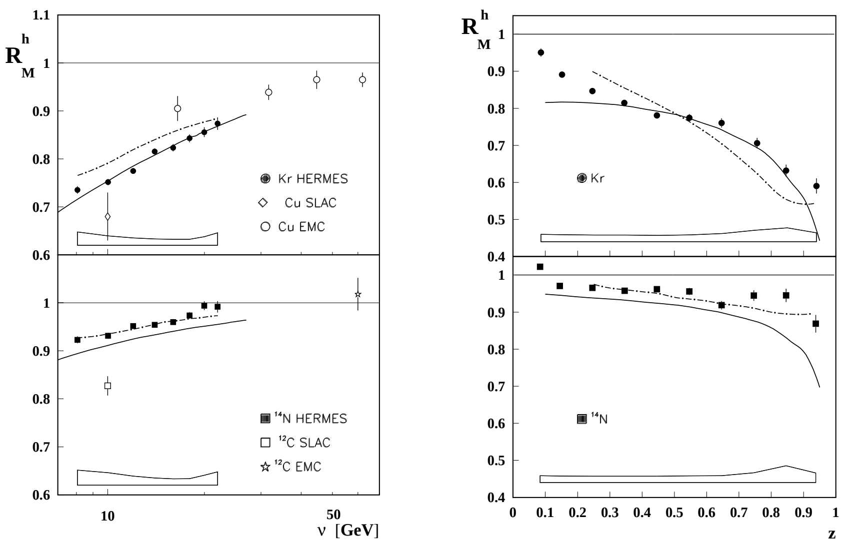

Fig. 3. Charged-hadron multiplicity ratio R^h_{M} *versus* ν for $z > 0.2$ (left) and *versus* z for $\nu > 7$ GeV (right). In the upper left panel HERMES data on ^{84}Kr are compared with SLAC [6] and CERN [7] data on Cu. In the lower left panel the HERMES data on ^{14}N are compared with CERN and SLAC data on ^{12}C. The error bars represent the statistical uncertainties, and the systematic uncertainty is shown as the band. The solid curves are calculations from Ref. [5] and the dot-dashed curves are calculations from Ref. [4]

In Ref. [8] the one-time-scale model, which is based on nuclear absorption only, was fitted to the HERMES data on krypton. Here, it is assumed that a pre-hadronic state (or string) is formed immediately after the quark is struck. The string interacts with a cross section σ_s, and after a time τ_f the final hadron is formed which interacts with a cross section σ_h within the nucleus. For the expression of the formation time τ_f the following form is taken [3]: $\tau_\mathrm{f} = \frac{\nu}{k}(1-z)$, where k is the string constant. Using this expression a two-parameter fit has been performed with k and σ_s as the only free parameters. In Ref. [3] the same fit has been performed for the nitrogen pion data. The values of the corresponding fit parameters are listed in Table I. The results for ^{84}Kr and ^{14}N are expected to be the

TABLE I

Values for the string tension k and the string cross section σ_s as extracted from a fit using the one-time-scale model. On the left the results for pions on ^{84}Kr are listed [8], and on the right the results for pions on ^{14}N [3].

	^{84}Kr	^{14}N
σ_s [mb]	4.1 ± 0.7	2.7 ± 0.6
k [GeV/c fm^{-1}]	0.28 ± 0.06	0.12 ± 0.04

same if the effect of the nuclear medium is properly accounted for, and k and σ_s characterize the hadronization process sufficiently well. Instead, a significant difference for both the string constant and the string cross section is observed between the two targets. This result provides first evidence that phenomenological models based on nuclear absorption only do not reproduce the A-dependence of the HERMES attenuation data.

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