HADRON FORMATION IN NUCLEI IN DIS*

E. Garutti

For the HERMES Collaboration

Nationaal Instituut voor Kernfysica en Hoge-Energiefysica (NIKHEF)
P.O. Box 41882, 1009 DB Amsterdam, The Netherlands

e-mail: garutti@hermes.desy.de

(Received June 10, 2002)

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. A large reduction of the differential multiplicity of charged hadrons from krypton relative to that from deuterium is observed. The reduction is larger than that seen in previously published HERMES data on nitrogen. The data are compared to two theoretical models. Both well describe the reduction of the multiplicity ratio at low values of the virtual photon energy ν and at high values of the fractional energy transfer z to the hadron. In order to obtain a better understanding of the hadronization process and possibly be able to distinguish between the two theoretical models the multiplicity ratio on the krypton data has been evaluated separately for pions, kaons and protons.

PACS numbers: 13.60.Le, 13.60.Wb

1. Introduction

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, the hadronization process is influenced by quark energy loss through gluon radiation as the quark propagates through the medium and multiple scattering of the produced hadron. Though interesting in their own right, these processes need to be understood for the accurate interpretation of ultra-relativistic heavy ion collisions: a modification of hadronic spectra is one of the expected signatures of the transition from

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

cold nuclear matter to the deconfined quark-gluon plasma. Semi-inclusive deep inelastic lepton-nucleus scattering provides a clean tool for the study of such quark propagation effects.

2. Experimental results

The HERMES experiment has measured the multiplicity ratio R_{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)

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

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 of semi-inclusive hadrons of type h recorded in each kinematic bin. The 27.5 GeV HERA positron beam was used in conjunction with D, ^{14}N and ^{84}Kr gas targets with densities of up to 10^{16}nucl/cm^2. Both the scattered beam positron and one or more final-state hadrons were observed in the HERMES spectrometer [1].

The HERMES data for the charged-hadron multiplicity ratio R_{M}^{h} are shown in Fig. 1 as a function of ν and z, for $\nu > 7$ GeV. The data are compared to the model of Ref. [2], where modified fragmentation functions and their Q^2 evolution were calculated in the framework of multiple parton scattering and induced gluon radiation. The kinematic behavior of the data

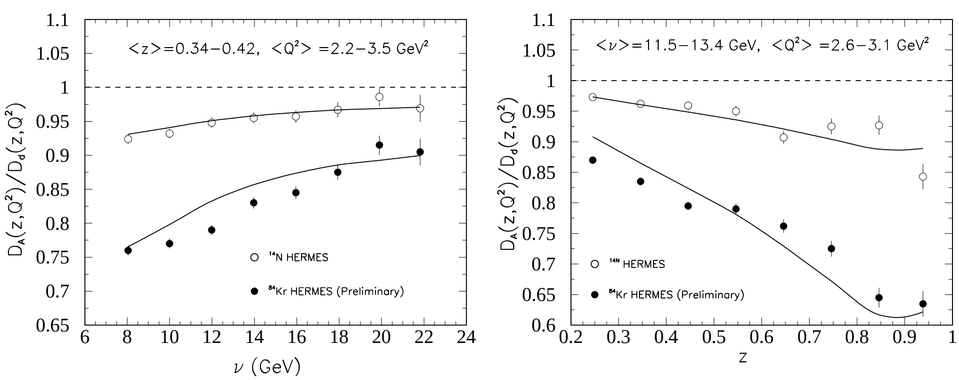

Fig. 1. Multiplicity ratio for charged hadrons *versus* ν and z for ^{14}N and ^{84}Kr targets. The curves are predictions of the fragmentation function modification model of Ref. [2].

is reproduced quite well by the model. Also, the observed attenuation of fast hadrons is considerably stronger for ^{84}Kr than for ^{14}N, and roughly agrees with the $A^{2/3}$ dependence predicted by the model. In the context of this same model, the average parton energy loss in the nuclear medium was evaluated from the ^{84}Kr data [3]. The obtained value of $dE/dx \approx 0.3\,\mathrm{GeV/fm}$ for the krypton target is in surprising agreement with $dE/dx \approx 0.25\,\mathrm{GeV/fm}$ extracted from recent PHENIX data [6] on Au–Au collisions. However, when corrections are made for the rapid expansion of the dense medium in the heavy ion case, a result of $dE/dx \approx 12\,\mathrm{GeV/fm}$ is obtained. This value is 40 times larger than that from the DIS data, and suggests that the gluon density in the PHENIX Au–Au collisions is 40 times higher than in cold nuclear matter.

Fig. 2 shows the multiplicity ratio for pions alone. The pions were identified in the momentum range from 4 to 15 GeV using the new HERMES RICH detector for the ^{84}Kr data and a threshold Čerenkov detector for the older ^{14}N data. The data are compared to the gluon bremsstrahlung model of Ref. [4], which includes effects of hadronic rescattering after the pion is formed. Calculations in this model are only available for leading pions, and so the comparison is restricted to $z > 0.5$. Both the model calculation and the data agree well with a simple parameterization involving a single time scale $\tau_h = c_h \nu(1-z)$ for pion formation in the laboratory frame. The values of the proportionality constant c_h as obtained from the model calculation ($c_h = 1.35$ fm/GeV [5]) well agrees with the value of $c_h = 1.37 \pm 0.14\,\mathrm{fm/GeV}$ derived from a fit to the HERMES data.

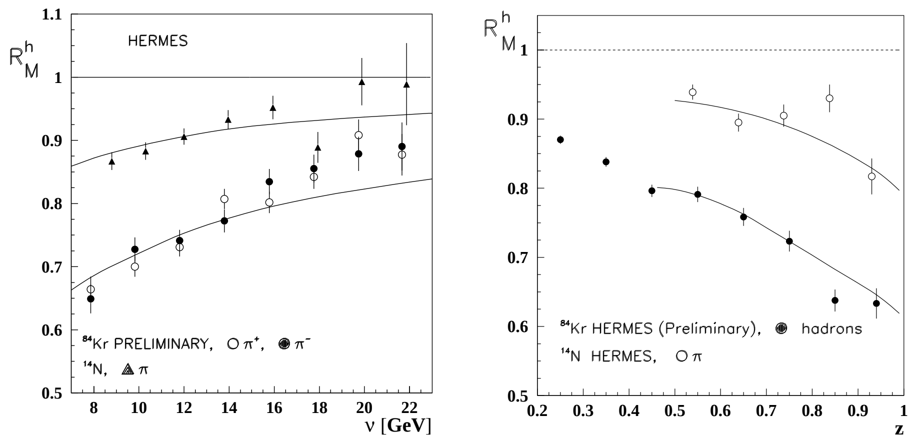

Fig. 2. Multiplicity ratio for identified pions (hadrons) *versus* ν and z for ^{14}N and ^{84}Kr targets. The curve is the prediction of the gluon bremsstrahlung model of Ref. [4].

The HERMES data on ^{84}Kr are presented in Fig. 3 as a function of ν separately for positive and negative pions and kaons and for protons and anti-protons. The separation between different particle types is achieved by unfolding the RICH information in the momentum range between 2.5 and 15 GeV for mesons, and 4 to 15 GeV for baryons. Within the errors the multiplicity ratios for positive and negative mesons is found to be consistent suggesting no charge dependence of the formation times of these particles. Also, it can be observed that the attenuation for pions and kaons is similar, pointing to similar formation times for the two particle types. The observed attenuation of protons is much smaller than the one of anti-protons. These can be partially explained by the difference between the interaction cross sections $\sigma(\bar{p}d)$ and $\sigma(pd)$, which at the energy of interest differ by about a factor 3. If the hadron is formed well inside the nucleus the interaction probability for a proton is substantially smaller than that of an anti-proton. Alternatively, the data may indicate different modifications of the quark and anti-quark fragmentation functions in nuclei [7]. The bottom panel of Fig. 3 shows the average kinematic values for Q^2 and for z showing no strong variation of other kinematics variables in the ν range covered by the data. Note the two different values given for z are motivated by the different energy ranges for mesons and baryons.

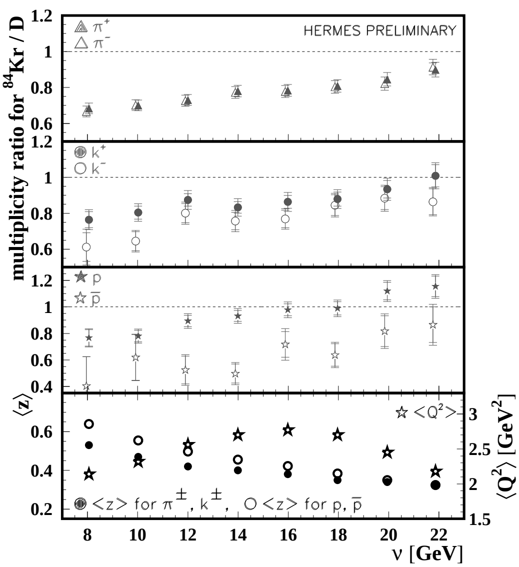

Fig. 3. Multiplicity ratio for identified positive and negative pions and kaons and for protons and anti-protons *versus* ν for ^{84}Kr compared to D. The bottom panel shows the average kinematic values for the other independent variables describing the process.

Fig. 4 shows the z dependence of the same data samples. It is shown that pions and kaons have the same z dependence which agrees with a parameterization of the formation time of the type $\tau_f \propto \nu(1-z)$, as proposed by the gluon bremsstrahlung model. For protons and anti-protons the z dependence is quite different. At low z the proton attenuation ratio overshoots unity, which might be explained by rescattering, while the anti-proton attenuation ratio is almost constant in z. It is noted that at high z the anti-proton attenuation ratio gives direct information on the fragmentation function of anti-quarks forming anti-protons, $D_{\bar{q}}^{\bar{p}}$ [2].

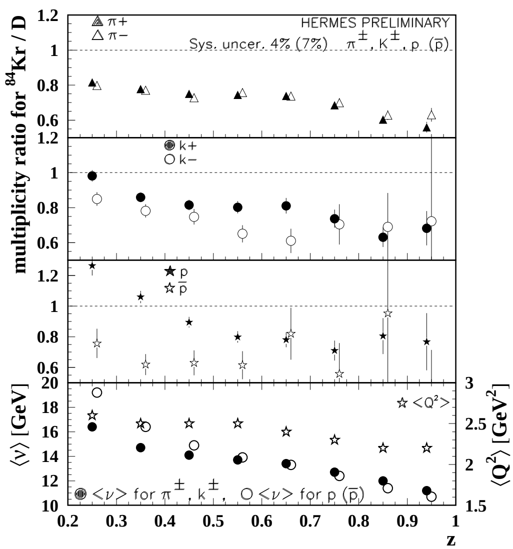

Fig. 4. Multiplicity ratio for identified positive and negative pions and kaons and for protons and anti-protons *versus* z for ^{84}Kr compared to D. The bottom panel shows the average kinematic values for the other independent variables describing the process.

REFERENCES

[1] K. Ackerstaff *et al.*, HERMES Collaboration *Nucl. Instrum. Methods Phys. Res.* **A417**, 230 (1998).
[2] X.F. Guo, X.N. Wang, *Phys. Rev. Lett.* **85**, 3592 (2000).
[3] X.N. Wang, `hep-ph/01111404`.
[4] B. Kopeliovich *et al.*, `hep-ph/9511214`.
[5] B. Kopeliovich, private comunications.
[6] K. Adocox *et al.*, PHENIX Collaboration, `nucl-ex/0109003`.
[7] X.F. Guo, X.N. Wang, `hep-ph/0102230`.