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PION ELECTROPRODUCTION AT HERMES *

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Measurements of the individual multiplicities of π^+, π^- and π^0 produced in the deep-inelastic scattering of 27.5 GeV positrons on hydrogen have been performed at the HERMES experiment. Moreover, the influence of the nuclear medium on hadron production and quark propagation processes has been studied by semi-inclusive production on deuterium and nitrogen targets.

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1. Introduction

The semi-inclusive production of pseudoscalar mesons in Deep Inelastic Scattering (DIS) is a good tool to test the Quark-Parton Model (QPM). Using the single-photon exchange approximation within this model, the differential cross section $d\sigma^\pi$ for semi-inclusive pion electroproduction on the proton ($e + p \to e' + \pi + X$) can be factored into a product of the parton distribution functions $q_f(x, Q^2)$, the perturbative cross section $d\sigma_f$ of the elementary process ($\gamma^* + f \to f$) on a quark of flavour f, and the fragmentation functions $D_f^\pi(z, Q^2)$:

$$d\sigma^\pi(x, z, Q^2) \propto \sum_f q_f(x, Q^2)\, d\sigma_f\, D_f^\pi(z, Q^2)\,. \tag{1}$$

The energy of the exchanged virtual photon γ^* is $\nu = E - E'$ (E and E' being the energies of the incident and scattered positrons respectively), while its squared four-momentum is $-Q^2$. The quantity $x = Q^2/2M\nu$, where M is the proton mass, is the fraction of the light-cone momentum of the nucleon carried by the struck quark. The fragmentation function $D_f^\pi(z, Q^2)$ is a

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measure of the probability that a quark of flavour f fragments into a pion of energy $E_\pi = z\nu$. The diagram and the relevant variables of the process are shown in Fig. 1.

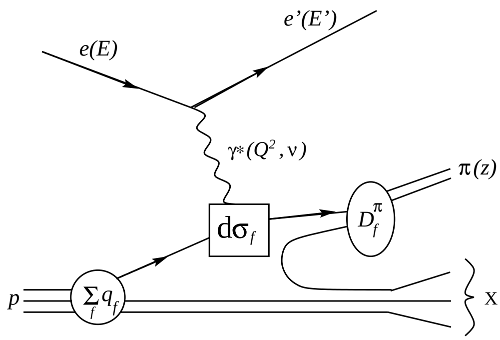

Fig. 1. Semi-inclusive pion electroproduction diagram.

The semi-inclusive production has been studied at the HERMES experiment both on hydrogen and on nuclear unpolarised targets. The HERMES (HERA MEasurement of Spin) experiment [1] is located at DESY and uses the 27.5 GeV HERA electron/positron beam which is longitudinally polarized in the HERMES region with an average polarization of $\sim 55\%$. The HERMES spectrometer covers polar angle acceptance between 40 mrad and 220 mrad. Tracking is performed by several sets of position sensitive detectors before, inside and after the dipole magnet. Particle identification is accomplished using a lead glass calorimeter, a preshower, a six module transition detector and a C_4F_{10}/N_2 (70 : 30) gas threshold Čerenkov counter. The threshold Čerenkov detector has been replaced in 1998 with a dual-radiator ring-imaging Čerenkov to identify pions, kaons and protons over nearly to the entire momentum acceptance of the spectrometer. A synthesis of the HERMES physics results and the details of the experiment can be found in the Steffens report at this workshop.

2. Semi-inclusive pion electroproduction on hydrogen

The quantity of interest is the pion differential multiplicity, or the number of pions produced per z-bin in DIS (N^π) normalised to the total number of inclusive DIS events ($N_{\rm DIS}$). In the quark parton model it is given by the expression:

$$\frac{1}{N_{\rm DIS}}\,\frac{dN^\pi(z,Q^2)}{dz} = \frac{\sum_f e_f^2 \int_0^1 dx\; q_f(x,Q^2) D_f^\pi(z,Q^2)}{\sum_f e_f^2 \int_0^1 dx\; q_f(x,Q^2)}\,, \tag{2}$$

where the sum is over quarks and antiquarks of flavour f, and e_f is the quark charge in units of the elementary charge.

Under the assumption of isospin symmetry, the quark-parton model predicts that the multiplicity for neutral pions is equal to the average of those for positive and negative pions. The multiplicities $\frac{1}{N_{\rm DIS}}\frac{dN^{\pi^0}}{dz}$ and $\frac{1}{N_{\rm DIS}}\left[\frac{dN^{\pi^+}}{dz}+\frac{dN^{\pi^-}}{dz}\right]\Big/2$ are plotted as a function of z in Fig. 2. The solid curve shown in Fig. 2 is the Field Feynman Q^2-independent parameterization using the independent fragmentation model [2]. This parameterization reproduces the experimental behavior fairly well, apart from the high z region. Isospin symmetry predicts that the data for neutral and charged pions should agree. The agreement is excellent up to $z \sim 0.75$, at higher z, the multiplicity is larger for charged pions than for neutral pions. This difference suggests a possible contribution from exclusive charged diffractive channels.

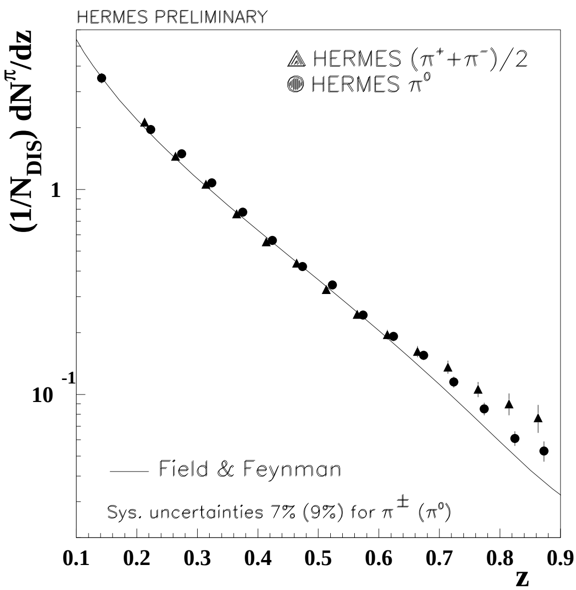

Fig. 2. Neutral (circles) and average charged (triangles) pion multiplicities. The error bars are statistical. The solid line is a parameterization using the independent fragmentation model [2].

In Fig. 3 (left) the HERMES results for the multiplicity of neutral pions are compared with previous results from EMC [3] and from SLAC [4]. Fig. 3 (right) compares the HERMES results for the average charged pion multiplicity with previous fragmentation function data from EMC [5]. The

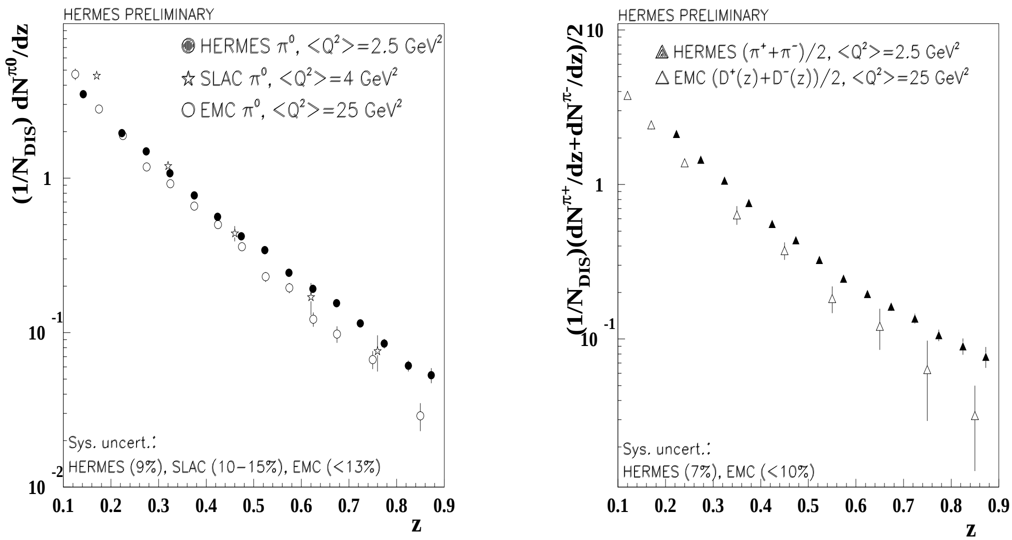

Fig. 3. π^0 multiplicity from HERMES, EMC [3] and SLAC [4] (left). Average charged pion multiplicity from HERMES compared to EMC fragmentation functions [5] (right). Only the statistical uncertainties are shown.

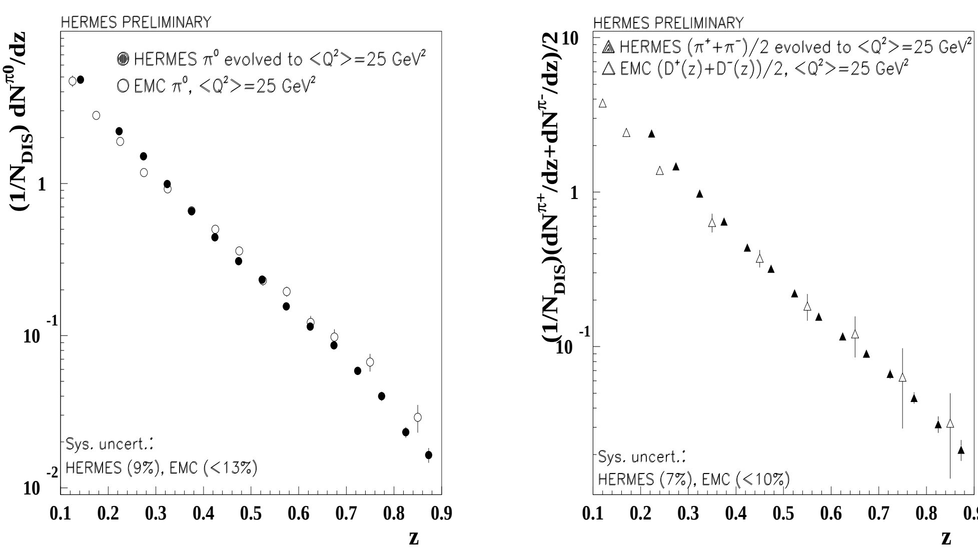

Fig. 4. Multiplicities for neutral pions (left), and the average of charged pions (right). The HERMES results have been evolved to Q^2 =25 GeV^2 using a NLO QCD model [6]. Only statistical uncertainties are shown.

HERMES results for both neutral and charged pions are systematically higher than those from EMC. This difference can be explained by the different Q^2 range covered by the two experiments: $\langle Q^2 \rangle = 2.5$ GeV^2 for HERMES and $\langle Q^2 \rangle = 25$ GeV^2 for EMC. In Fig. 4 the HERMES data have been evolved to the mean Q^2 of the EMC data using a NLO model for the evolution of the fragmentation functions [6]. The agreement between the evolved HERMES data and the EMC data is much improved, demostrating the need of QCD corrections. In order to better investigate scaling violations in the fragmentation process, the Q^2 dependence of the data at fixed z was studied. The total (neutral plus charged) pion multiplicity is plotted for 4 different z bins in Fig. 5. The data show a clear Q^2 dependence, especially in the high-z bins. The Q^2-behavior of the data is in agreement with the Q^2-evolution predicted by the NLO QCD models [6, 7].

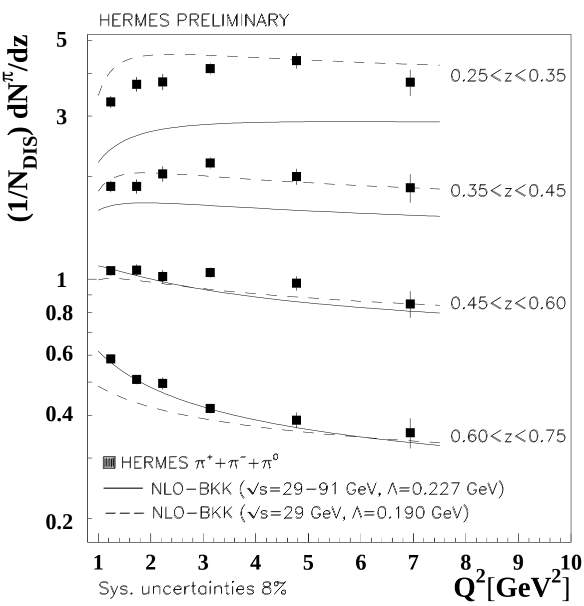

Fig. 5. Total (neutral plus charged) pion multiplicity as a function of Q^2 for different z bins. Two NLO QCD calculations of fragmentation functions found in Refs. [6] (solid line) and [7] (dashed line) are shown.

3. Semi-inclusive electroproduction on nuclei

Deep inelastic lepton nucleus scattering offers a direct way to study the space-time development of the hadronization process, because one can use the secondary reactions of the final state particles for measuring the so-called hadron formation time ($\tau_{\rm f}$) or the corresponding hadron formation length ($l_{\rm f} = c\tau_{\rm f}$). At the HERMES energies ($4 < \nu < 24\,{\rm GeV}$) nuclear effects may be significant since $l_{\rm f}$ is of the same order of magnitude as the diameter of the target nucleus. In addition previous experiments performed at SLAC with deep-inelastic electron scattering [9], at CERN with high-energy muons by SMC [10] and with neutrinos by WA21/WA59 [11] indicate that the optimal energy range of the lepton to study hadronization dynamics with nuclei ranges from a few GeV to a few tens of GeV. Moreover, in order to discriminate among the different models for the formation time, it is important to study the hadronization process as function of hadron species.

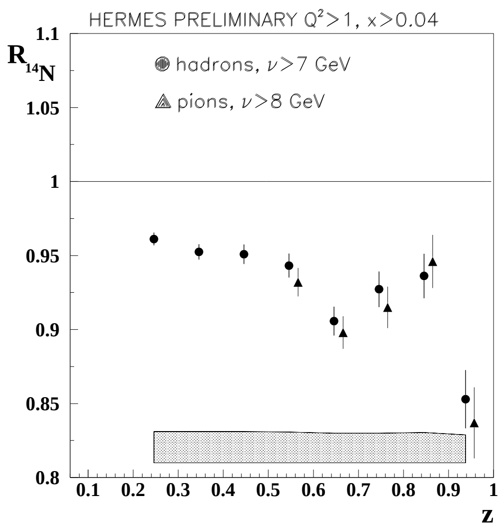

Fig. 6. The attenuation ratio as function of z for charged hadrons and pions. The band represents the systematic uncertainties.

The quantity measured in the experiment is the attenuation ratio for the nitrogen $R_{^{14}{\rm N}}$, defined as the ratio between the differential charged hadron multiplicity N_h normalized by the number of scattered electrons $N_{\rm DIS}$, for nitrogen (N) and deuterium (D) targets:

$$R_{^{14}{\rm N}} = \frac{\left(\frac{1}{N_{\rm DIS}}\frac{dN_h}{dz d\nu}\right)_{\rm N}}{\left(\frac{1}{N_{\rm DIS}}\frac{dN_h}{dz d\nu}\right)_{\rm D}} .$$

The attenuation ratio as function of z for charged hadrons and pions is shown in Fig. 6. A significant depletion of the charged hadrons and pions in the interactions with the nitrogen nucleus is seen in the whole region $0.2 < z < 1$. Pion attenuation can be studied by using the Čerenkov detector in a restricted energy region. The z behavior of the pion attenuation is similar to that of the unidentified hadron ones. It is worth noticing that the data cover the unexplored region $0.85 < z < 1$ showing a decrease of the attenuation ratio. This finding is in qualitative agreement with the predictions from the gluon bremsstrahlung model [12].

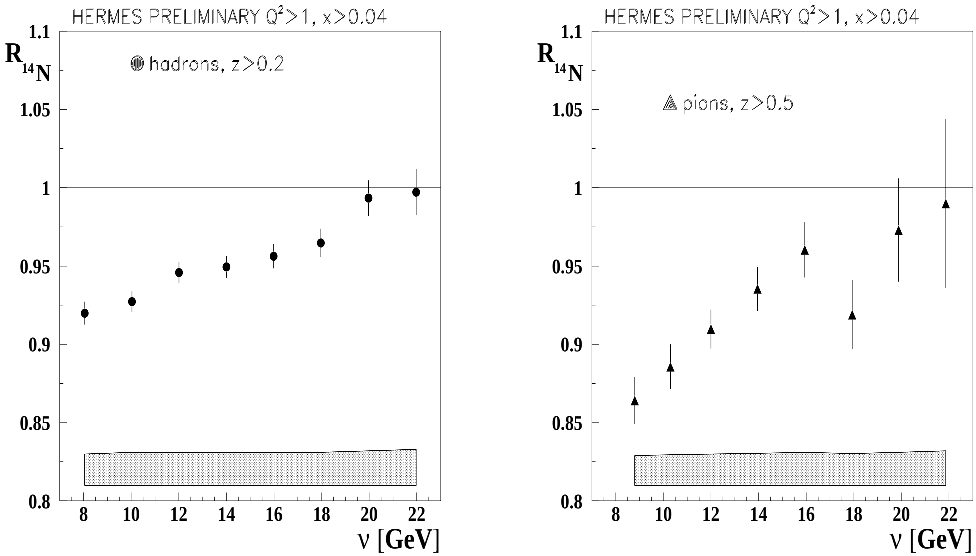

Fig. 7. The attenuation ratio as function of ν for charged hadrons and pions. The band represents the systematic uncertainties.

The attenuation ratio as a function of ν is shown in Fig. 7 for charged hadrons and pions. The ratio is observed to increase with increasing ν. This increase can be understood if at high ν the hadron formation takes place largely outside the nucleus.

Because the hadronic mass distribution of the detected particles is very different for the positive and the negative charge samples, the hadron attenuation for the two charge states is shown in Fig. 8 for hadrons and pions respectively. Since the attenuation of positive and negative pions is the same within the experimental uncertainties, the difference between positive and negative hadrons must be related to the difference in attenuation of the other hadrons, mostly protons and kaons. This finding suggests that the proton attenuation is smaller with respect to the pion attenuation and therefore that the proton formation time in the hadronization process is larger than for lighter hadrons.

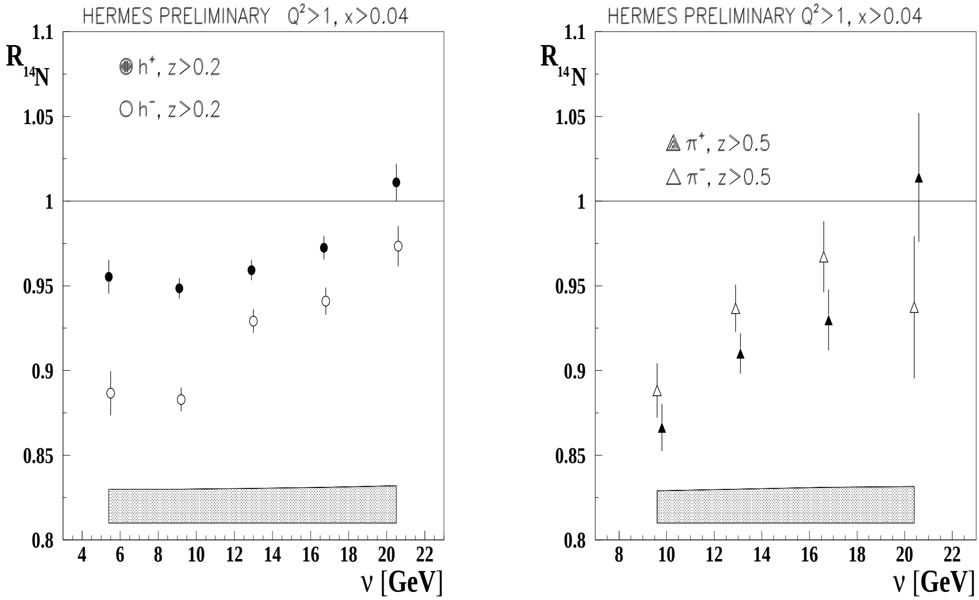

Fig. 8. The attenuation ratio as function of ν for positive and negative hadrons and pions. The band represents the systematic uncertainties.

Additional measurements of the attenuation ratio in various heavy nuclei with pions, kaons and protons identification provided by the RICH detector are needed to clarify the issues raised by the present data. Such measurements are actually underway at HERMES.

4. Conclusions

Charged and neutral pion multiplicities in semi-inclusive deep-inelastic scattering on hydrogen at 27.5 GeV have been measured at the HERMES experiment. The preliminary results show that the multiplicities are consistent with isospin symmetry below $z \sim 0.75$. These measurements provide data with improved statistical and systematic accuracies compared to earlier measurements. The Q^2-behavior of the present data is in general agreement with NLO QCD calculations.

The nuclear attenuation of fast charged hadrons and pions, which provides informations on the time development of the hadronization process, has been measured on nitrogen. Preliminary results have shown a significant attenuation of fast charged hadrons and pions on nitrogen relative to deuteron providing information in the unexplored region $0.85 < z < 1$. Moreover, a possible dependence of the nuclear attenuation on the hadron mass has been for the first time evidentiated.

REFERENCES

[1] HERMES Collaboration, K. Akerstaff *et al., Nucl. Instrum. Methods Phys. Res.* **A417**, 230 (1998).

[2] R.D. Field, R.P. Feynman, *Phys. Rev.* **D15**, 2590 (1977).

[3] EMC Collaboration, J.J. Aubert *et al.*, *Z. Phys.* **C18**, 189 (1983).

[4] T.P. McPharlin *et al., Phys. Lett.* **B90**, 479 (1980).

[5] EMC Collaboration, M. Arneodo *et al.*, *Nucl. Phys.* **B321**, 541 (1989).

[6] J. Binnewies, B.A. Kniehl, G. Kramer, *Z. Phys.* **C65**, 471 (1995).

[7] J. Binnewies, B.A. Kniehl, G. Kramer, *Phys. Rev.* **D52**, 4947 (1995).

[8] A.Bialas, E.Bialas, *Phys. Rev.* **D21**, 675 (1980).

[9] L.S. Osborne *et al., Phys. Rev. Lett.* **40**, 25 (1978).

[10] J.Ashman *et al., Z. Phys.* **C52**, 1 (1991).

[11] W. Burkort *et al., Z. Phys.* **C70**, 47 (1996).

[12] B.Z. Kopeliovich, J.Nemchik, E. Predazzi, 1st ELFE Summer School on Confinement Physics Cambridge, UK; 22-28 Jul. 1995. Publ. in: S.D. Bass and P.A.M. Guichon Ed., Frontieres, Gif-sur-Yvette, 1996 p. 391-395 and `hep-ph/9511214`.