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A DETERMINATION OF THE FRAGMENTATION FUNCTIONS
OF u-QUARKS INTO CHARGED PIONS

The European Muon Collaboration (EMC)

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Abstract

The fragmentation functions of u-quarks into positive and negative pions are determined from an analysis of identified pions produced in deep inelastic muon deuterium scattering. The method adopted is not sensitive to the knowledge of the primary quark distribution functions. The fragmentation of u quarks to positive pions is found to fall less steeply in z than that to negative pions as expected in the Quark Parton Model.

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For footnotes see next page.

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The production of hadrons in deep inelastic muon scattering is described in the Quark parton Model (QPM) by

$$\frac{1}{\sigma_{\text{tot}}} \frac{d\sigma^h}{dz} = \frac{1}{N_\mu} \frac{dN^h}{dz} = \frac{\sum_i e_i^2 q_i(x) D_i^h(z)}{\sum_i e_i^2 q_i(x)}, \quad (1)$$

where e_i are the charges of the different quarks and $q_i(x)$ are their distribution functions which in the simple QPM depend on x alone. Here $x = Q^2/2M\nu$ is the Bjorken variable, where Q^2 is the square of the 4 momentum transfer to the nucleon in the deep inelastic process and ν is the energy of the virtual photon. The fragmentation of the quark of type i into a hadron of type h is described by the fragmentation function $D_i^h(z)$ which depends on the hadron momentum fraction $z = E_h/\nu$, where E_h is the energy of the hadron.

A deuterium target as an isoscalar allows a simplification of the above formula from which solutions for the fragmentation functions into pions can be deduced which are independent of the quark distribution functions, $q_i(x)$. This is otherwise only possible in neutrino experiments but has not yet been done due to lack of particle identification. If the contribution of sea quarks is neglected and pions are measured, the following relations hold

$$\frac{1}{N_\mu} \left[\frac{dN^{\pi^+}}{dz} + \frac{dN^{\pi^-}}{dz} \right] = D^+ + D^- \text{ and } \frac{1}{N_\mu} \left[\frac{dN^{\pi^+}}{dz} - \frac{dN^{\pi^-}}{dz} \right] = \frac{3}{5} (D^+ - D^-). \quad (2)$$

In the derivation of equations (2) isospin conservation is assumed such that $D_u^{\pi^+} = D_d^{\pi^-} = D^+$ and $D_u^{\pi^-} = D_d^{\pi^+} = D^-$. D^+ (D^-) is understood to be the effective fragmentation function of a quark of flavour u into positive (negative) pions which includes contribution from resonance decays. Solving equations (2) for D^+ and D^- gives

$$D^\pm = \frac{1}{N_\mu} \cdot \frac{1}{3} \left[4 \cdot \frac{dN^{\pi^\pm}}{dz} - \frac{dN^{\pi^\mp}}{dz} \right]. \quad (3)$$

Equations (3) show that the fragmentation functions $D^\pm$ can be determined without knowing the quark distributions, $q_i(x)$. However, sea and gluon

distributions distort this simple picture. With a suitable Bjorken x cut the kinematic regions where these contributions become important can be avoided. The effect of various x cuts was studied with the Lund model for deep inelastic muon scattering [2] with standard parameter settings and standard parameterisations of the quark distribution functions [3].

The Lund generator, which uses the break up of colour flux tubes to describe the fragmentation process does not explicitly contain D functions. These functions were extracted from the generated pion spectra which included resonance decays, with the parton fragmentation restricted to u-quarks only. The D functions were also compared with those extracted using equations (3) from pion spectra obtained from a simulation of hadron production on deuterium which included the effects of the sea quarks and first order QCD processes as treated in the Lund generator. Figure 1 shows the ratio, ξ , of the D-functions extracted in this manner to those in which u quark fragmentation alone was simulated. Two different cuts on x were used. For $x > 0.02$ the Lund model indicates that any D functions extracted from the data using equations (3) will be distorted by the influence of the sea and QCD effects. However, a cut at $x = 0.15$ will reduce these effects to less than 10%. The size of the distortion changes little if the quark and gluon distribution functions of [4] are used rather than those of [3].

The experiment was performed in the M2 muon beam at the CERN SPS using the European Muon Collaboration forward spectrometer (experiment NA2) further details of which are published elsewhere [1]. The data were taken with muons of 280 GeV impinging on a 6m target filled with liquid deuterium. The integrated luminosity was $2.3 \times 10^{37} \text{ cm}^{-2}$. Pions were identified in a momentum range between the pion threshold, at 12.4 GeV and the kaon threshold at 44.0 GeV using a threshold Cerenkov counter filled with neon [5]. The data were corrected for acceptance losses, smearing, reinteractions of primary produced hadrons, and effects due to hard bremsstrahlung from the muons. The electron contamination of the pion sample was measured to be 5-10% using the calorimeter H2 [1]. Events were selected in the kinematic range $x > 0.15$, $Q^2 > 5 \text{ GeV}^2$ with cuts on the scattered muon energy of $40 < E' < 255 \text{ GeV}$ to avoid regions of poor resolution and the effects of hard photon radiation. The total number of events after cuts was 34798.

Hadron tracks were selected, using the same criteria as an earlier hydrogen analysis [6,7], in the momentum range from 22 to 43 GeV. The corrections for electron contamination and losses in the track selection almost cancel and are therefore not applied. A signal in the Cerenkov counter was required leaving 3714 identified charged pions.

Figure 2 shows the normalised energy scaled multiplicities i.e. $z \cdot \frac{1}{N_\mu} \cdot \frac{dN^\pi}{dz}$ for positive and negative pions separately as a function of z . The mean value of v of the different data points in fig. 2 varies with z as well as the mean Q^2 leaving the Bjorken x approximately constant at 0.23. This is due to the correlation of the hadron and the muon variables and the need to restrict the momentum range for pion identification in the Cerenkov counter. Table 1 summarises these variations and lists the data shown in fig. 2. The quoted errors are statistical only. The systematic error is the same for π^+ and π^- . This error arises from uncertainties in track selection, muon momentum determination and corrections due to secondary interactions. It is slightly dependent on z and is indicated by the shaded band in fig. 2 which shows the systematic error relative to the full line.

Figure 3 shows the D functions extracted from the data in table 1 using equations (3). As the small corrections due to the gluon and sea contributions are different for D^+ and D^- the corrections obtained using the Lund generator (fig. 1) were applied. The results are also listed in table 1. A simple parameterisation of $z \cdot D^+$ is found to be $0.7 \cdot (1-z)^{1.75}$. The full line in fig. 3 follows this function. The dashed line was calculated from the full line using a suppression factor $(1-z)/(1+z)$ to give a description of the unfavoured D^- . Both parameterisations give a reasonable representation of the data. They show a steeper behaviour than a fit to data at lower Q^2 ($Q^2 \sim 1 \text{ GeV}^2$) as given in [8] and also shown in fig. 3.

In conclusion, from deep inelastic muon deuterium scattering data the favoured fragmentation function $D_u^{\pi^+}$ and the unfavoured $D_u^{\pi^-}$ were extracted using simple QPM formulae. The function $D_u^{\pi^+}$ is well described by a simple parameterisation and $D_u^{\pi^-}$ by the same parameterisation with an extra suppression factor $(1-z)/(1+z)$. The behaviour with z is steeper than that observed in earlier experiments at lower energies.

We wish to thank all the people in our home institutions who have contributed to the construction, operation and analysis of this experiment. The support of the CERN staff in operating the SPS, the muon beam and computer facilities is gratefully acknowledged.

Figure Captions

1. Ratio of the extracted $D^{\pm}$ functions using equations 3 from a full Monte Carlo simulation of deep inelastic scattering on deuterium to that containing u quarks alone.
2. Energy scaled differential multiplicities for positive and negative pions.
3. Fragmentation functions $D_u^{\pi^+}$ and $D_u^{\pi^-}$ obtained from the data with parameterisations (see text).

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Table 1

z	0.16	0.25	0.35	0.45	0.59	0.79
$\langle \nu \rangle$ /GeV	170	118	89	72	57	42
$\langle Q^2 \rangle$ /GeV ²	71	53	39	32	26	20
$\frac{1}{N_\mu} \frac{z \cdot dN_\mu^{\pi^+}}{dz}$	0.477 $\pm$ 0.024	0.388 $\pm$ 0.015	0.282 $\pm$ 0.013	0.192 $\pm$ 0.012	0.116 $\pm$ 0.009	0.034 $\pm$ 0.007
$\frac{1}{N_\mu} \frac{z \cdot dN_\mu^{\pi^-}}{dz}$	0.371 $\pm$ 0.020	0.304 $\pm$ 0.013	0.186 $\pm$ 0.011	0.095 $\pm$ 0.009	0.063 $\pm$ 0.007	0.024 $\pm$ 0.006
$z \cdot D_u^{\pi^+}$	0.517 $\pm$ 0.033	0.433 $\pm$ 0.020	0.336 $\pm$ 0.018	0.247 $\pm$ 0.016	0.150 $\pm$ 0.12	0.042 $\pm$ 0.010
$z \cdot D_u^{\pi^-}$	0.319 $\pm$ 0.028	0.262 $\pm$ 0.018	0.146 $\pm$ 0.015	0.060 $\pm$ 0.013	0.043 $\pm$ 0.010	0.020 $\pm$ 0.008

Figure 1

Figure 2

Figure 3