A SEARCH FOR HIGHER TWIST EFFECTS IN THE HADRONIC DISTRIBUTIONS
IN DEEP INELASTIC MUON PROTON SCATTERING

The European Muon Collaboration (EMC)

CERN¹, DESY (Hamburg)², Freiburg³, Kiel⁴, Lancaster⁵, LAPP (Annecy)⁶, Liverpool⁷,
Marseille⁸, Oxford⁹, Rutherford¹⁰, Sheffield¹¹, Turin¹², Wuppertal¹³.

J.J. Aubert⁸, G. Bassompierre⁶, K.H. Becks¹³, C. Benchouk⁸, C. Best^{10a}), E. Böhm⁴,
X. de Bouard⁶, F.W. Brasse², C. Broll⁶⁺), S. Brown⁷, J. Carr^{10b}), R. Clifft¹⁰,
J.H. Cobb^{5c}), G. Coignet⁶, F. Combley¹¹, G.R. Court⁷, G. D'Agostini⁸, W.D. Dau⁴,
J.K. Davies^{9d}), Y. Déclais^{6e}), U. Dosselli^{1f}), J. Drees¹³, A. Edwards^{13a},
M. Edwards¹⁰, J. Favier⁶, M.I. Ferrero¹², W. Flauger², H. Forsbach¹³,
E. Gabathuler⁷, R. Gamet⁷, J. Gayler², V. Gerhardt^{2g}), C. Gössling^{2h}), J. Haas³,
K. Hamacher¹³, P. Hayman⁷, M. Henckes¹³ⁱ), V. Korbel², B. Korzen¹³, U. Landgraf³,
M. Leenen^{1j}), M. Maire⁶, W. Mohr³, H.E. Montgomery^{1k}), K. Moser³, R.P. Mount^{9l}),
E. Nagy^{6m}), J. Nassalski²ⁿ), P.R. Norton¹⁰, J. McNicholas^{9o}), A.M. Osborne¹,
P. Payre⁸, C. Peroni¹², H. Peschel¹³, H. Pessard⁶, U. Pietrzyk¹³, K. Rith³,
M. Schneegans⁶, A. Schneider¹³, T. Sloan⁵, H.E. Stier³, W. Stockhausen¹³,
J.M. Thénard⁶, J.C. Thompson¹⁰, L. Urban^{6m}), M. Villers⁹, H. Wahlen¹³,
M. Whalley^{11p}), D. Williams^{7q}), W.S.C. Williams⁹, J. Williamson^{11r}),
S.J. Wimpenny^{7h}).

Abstract

The hadronic distributions in Q^2 , y , z , p_T , and ϕ in deep inelastic muon proton scattering have been studied to search for higher twist effects in the hadronic final state. The expected effects are not observed.

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For footnotes see next page.

- a) Now at JET, Joint Undertaking, Abingdon, England.
- b) Now at University of Colorado, Boulder, Colorado, USA.
- c) Now at University of Oxford, England
- d) Now at Plessey Defence Systems, Fareham, England.
- e) Now at Université d'Aix-Marseille II, Luminy, France.
- f) Now at INFN. Sez. Padova, Italy.
- g) Now at Beiersdorf AG, Hamburg, Germany.
- h) Now at CERN, Geneva, Switzerland.
- i) Now at ICR-PV, Köln, Germany.
- j) Now at Physikalisches Institut der Universität, Bonn, Germany.
- k) Now at FNAL, Batavia, Illinois, U.S.A.
- l) Now at California Institute of Technology, Pasadena, California, USA.
- m) Now at Central Research Institute for Physics of the Hungarian Academy of Science, Budapest, Hungary.
- n) Now at Institute for Nuclear Studies, Warsaw, Poland.
- o) Now at GEC Computers, Coventry, England.
- p) Now at Durham University, Durham, England.
- q) Now at U.K.A.E.A., Winfrith, Dorchester, England.
- r) Now at RAL, Chilton, Didcot, Oxon, England.
- +) Deceased.

Introduction

It has been suggested by Berger [1] that the variables Q^2 , y , z , p_T , and ϕ in the production of hadrons in deep inelastic scattering will be correlated due to higher twist effects. Here $y=v/E$, where $v=E-E'$ is the energy of the virtual photon in the laboratory frame, E is the energy of the incident muon and E' is that of the scattered muon; $-Q^2$ is the four momentum transfer squared from the incident to scattered muon; $z=E_h/v$ is the fraction of the energy of the virtual photon carried by the observed hadron of energy E_h , p_T is the transverse momentum of the hadron relative to the virtual photon direction and ϕ is the azimuthal angle of the hadron relative to the plane containing the incident and scattered muon. Berger predicts [1] that at fixed Q^2 the correlation will take the form

$$z \frac{d^4\sigma}{dzdyd\phi dp_T^2} \propto \int dx G_{qN}(x) \frac{1}{y p_T^4 Q^2} \cdot$$

$$\left\{ (1-z)^2 \left(\frac{1+(1-y)^2}{2} \right) + \frac{2}{3} (1-z)(1+(1-y))(1-y)^{\frac{1}{2}} \cos \phi \left(\frac{p_T^2}{Q^2} \right)^{\frac{1}{2}} + \frac{4}{9} (1-y) \frac{p_T^2}{Q^2} \right\} \quad (1)$$

where $G_{qN}(x)$ are the quark distributions in the nucleons. This prediction comes from arguments concerning the constituent binding in the hadronic wave functions and shows the $1/Q^2$ dependence typical of higher twist contributions.

The term in equation (1) proportional to $(1+(1-y)^2)/2$ is a standard deep inelastic scattering term. The other terms inside the bracket are two new contributions from higher twist [1]. These terms lead to correlations between the muon variables y , Q^2 and the hadron variables z , p_T and ϕ . The term in $\cos \phi$ leads to asymmetries in the azimuthal angle and both higher twist terms should produce a rise of $\langle p_T^2 \rangle$ at large z .

Searches for such correlations in the final state hadrons produced in deep inelastic neutrino scattering [2] gave contradictory results. Contradictory results have also been presented from studies of the Drell-Yan process [3]. In this paper a search for these effects in deep inelastic muon proton scattering experiments is reported. The Q^2 , y , z , p_T^2 and ϕ distributions were studied and the correlations predicted by equation (1) investigated. The y dependence was studied by comparing data taken at three different incident muon energies.

Data Analysis

The data were taken in the M2 muon beam at the CERN SPS. The scattered muon and the fast forward hadrons ($E_h \gtrsim 3$ GeV) from deep inelastic scattering were detected and measured in the EMC forward spectrometer further details of which are published elsewhere [4]. Data were taken in different experimental runs with muons of energy 120, 200 and 280 GeV incident on a 6 meter long liquid hydrogen target. Events were required to satisfy the trigger, have a vertex inside the target and to lie within the cuts shown in table 1. A total of 143000 events remained after selection. These cuts were chosen to avoid regions where smearing due to resolution and radiative effects were large and also where the acceptance was small or varied rapidly. The track selection criteria for hadrons were identical to those described previously [5]. All hadrons were treated as pions which are dominant in the forward region. In this region misassignment of the particle mass introduces little error in z .

Table 1

E_{Beam} [GeV]	Kinematic Range				E_h min [GeV]
	Q^2 min [GeV ²]	ν min [GeV]	ν max [GeV]		
120	2	30	100		3
200	3	50	170		4.5
280	5	70	240		6

The acceptance of the apparatus was calculated from a complete Monte Carlo simulation. Deep inelastic scattering events were generated using the Lund String Model for the fragmentation process [7]. Radiative effects due to QED processes and also secondary interactions of the produced hadrons in the target material were fully simulated. The scattered muon and produced hadrons were tracked through the spectrometer taking into account the effects of multiple Coulomb scattering. The effects of chamber and hodoscope inefficiencies and their resolutions were simulated and the computed coordinates of each chamber measurement passed through the reconstruction program chain which is described elsewhere [6]. In this manner the losses due to imperfections in the off line analysis procedures were corrected.

Comparison of the results from the different data sets indicated that the relative normalisation uncertainty was 5%. This represents the systematic error in the data.

Results

Fig. 1(a) shows the energy scaled differential multiplicities for the sum of the positive and negative hadrons $\frac{1}{N} z \left(\frac{dN^+}{dz} + \frac{dN^-}{dz} \right)$ from data taken at each incident muon energy in the range $5 < Q^2 < 20 \text{ GeV}^2$ and $70 < \nu < 100 \text{ GeV}$. In this small range of ν and Q^2 , y is the only variable which changes significantly. Fig. 1(b) shows the ratio of the differential multiplicity at $E=280 \text{ GeV}$ to that at 120 GeV . The dashed line at unity is the prediction if QCD and the effects of primordial quark transverse momentum, k_T , are included, whilst the smooth curve is the prediction when the additional higher twist terms from equation (1) contribute. The experimental errors are too large to allow a definite conclusion to be drawn.

The last two terms in equation (1) predict a correlation between p_T^2 and Q^2 . Previous measurements of the mean transverse momentum squared, $\langle p_T^2 \rangle$, using the 280 GeV data alone, showed no significant variation with Q^2 [8]. In the analysis presented here these measurements have been extended to lower Q^2 using the data at lower incident muon energies. The differential multiplicities were measured in two separate Q^2 ranges. Fig. 2 shows the ratios of $\langle p_T^2 \rangle$, in the two Q^2 ranges indicated, as a function of z for each of the three incident muon energies. The dashed line at unity shows the prediction of QCD and k_T alone and the smooth curve includes again the additional higher twist terms. The ratios are consistent with 1 over the whole range of z and the data are inconsistent with the sharp rise at large z expected from the higher twist effects.

Equation (1) predicts a positive value for $\langle \cos \phi \rangle$. Previous measurements of the moments of the azimuthal distributions, $\langle \cos \phi \rangle$ showed that these tend to be negative [9], as expected from QCD arguments or from the primordial k_T of the struck quark [10]. The positive contribution to $\langle \cos \phi \rangle$ should occur at high z . Therefore the data have been analysed to search for this effect at high z . Fig. 3 shows $\langle \cos \phi \rangle / f_1(y)$ as a function of z , where $f_1(y)$ is a kinematic factor [9] given by:

$$f_1(y) = \frac{(2-y)(1-y)^{\frac{1}{2}}}{1+(1-y)^2}.$$

The smooth curve again shows the prediction of equation (1), added to the effects of k_T and QCD [10]. There is no indication of the sharp rise at high z expected from higher twist effects.

Conclusions

The hadronic distributions in deep inelastic muon proton scattering have been investigated to search for higher twist effects in the final state. The expected correlation between the variables y and z cannot be excluded. The predicted correlation between the variables p_T^2 and Q^2 is excluded by the data, the values of $\langle p_T \rangle^2$ as a function of z being independent of Q^2 within the errors. The term $\langle \cos \phi \rangle$ is found to be negative over the whole range of z and the sharp rise at high z , expected from higher twist, is not observed. In summary, the specific predictions for higher twist effects [1] are excluded by the data.

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Figure Captions

1. a) Energy scaled differential multiplicities
 b) Ratio of the 280 GeV and 120 GeV multiplicities shown in Fig. 1a. The solid curve is the prediction of [1].
2. Ratio of the mean transverse momentum as a function of z in the two different Q^2 ranges indicated. The solid curves are the predictions of [1].
3. The $\langle \cos \phi \rangle$ as a function of z . The solid curves are the predictions of [1] including the effects of the primordial k_T and QCD [10].

Fig.1

Fig. 2

Fig.3