A TEST OF QUARK FRAGMENTATION IN THE
QUARK-PARTON MODEL FRAMEWORK

MASTER

by

M. Derrick, P. Gregory, F. Lopinto, B. Musgrave,
J. Schlereth, P. Schreiner and R. Singer
S.J. Barish, R. Brock, A. Engler, T. Kikuchi,
R.W. Kraemer, W. Messing, B.J. Stacey and M. Tabak
V.E. Barnes, D.D. Carmony, E. Fernandez,
A.F. Garfinkel and A.T. Laasanen

DISCLAIMER

This document contains information which is proprietary to the United States Government and is loaned to you by the United States Government. It is to be used only for the purposes for which it was loaned and is not to be distributed outside your organization. It is to be destroyed when it is no longer needed for the purposes for which it was loaned. It is not to be used for advertising or promotional purposes, for sale, or for any other purpose without the express written permission of the United States Government.

Prepared for
1979 International Symposium
on
Lepton and Photon Interactions at High Energies
Fermi National Accelerator Laboratory
Batavia, Illinois
August 1979

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

ef

Operated under Contract W-31-109-Eng-38 for the
U. S. DEPARTMENT OF ENERGY

Submitted to the 1979 International Symposium
on Lepton and Photon Interactions at High Energies

A Test of Quark Fragmentation in the
Quark-Parton Model Framework

M. DERRICK, P. GREGORY[†], F. LOPINTO, B. MUSGRAVE,
J. SCHLERETH, P. SCHREINER, and R. SINGER

Argonne National Laboratory, Argonne, IL 60422

S. J. BARISH, R. BROCK, A. ENGLER, T. KIKUCHI,
R. W. KRAEMER, F. MESSING, B. J. STACEY, and M. TABAK
Carnegie-Mellon University, Pittsburgh, PA 15213

V. E. BARNES, D. D. CARMONY, E. FERNANDEZ,
A. F. GARFINKEL, and A. T. LAASANEN

Purdue University, W. Lafayette, IN 47907

Abstract

The hadronic system produced in charged-current antineutrino interactions is used to study fragmentation of the d-quark. Some problems encountered in separating the current quark-fragments are discussed. The fragmentation function for the current quark is in good agreement with the expectations of the naive quark-parton model and, in particular, there is no evidence for either a Q^2 - or x_{BJ} -dependence. *11 references*

[†]Present Address: CERN, EP Division, Geneva 23, Switzerland.

I. Introduction

The fragmentation of a quark into hadrons has been extensively studied in both e^+e^- annihilation and in lepto-hadron production. The energy distribution of the secondary hadrons is usually described by the fragmentation function.⁽¹⁾ Until recently, analyses of the fragmentation function have been in terms of the naive quark-parton model (QPM),⁽¹⁾ which certainly describes the dominant features of the hadronic system. There is currently considerable interest in the possibility of observing departures from the naive QPM picture as predicted by Quantum Chromodynamics (QCD). Due to quark-gluon bremsstrahlung the fragmentation function should exhibit scaling violations. There are, however, arguments suggesting that the magnitude of the scale breaking could be less than is observed in the structure functions themselves.⁽²⁾

In e^+e^- annihilation into hadrons, the scaling violation would appear as a beam energy dependence in the invariant distribution $s \, d\sigma/dx$, where $x = p^h/p_b$. Early results from PETRA at $\sqrt{s} = 13, 17$ and 27.4 GeV show no evidence for scaling violations at high Feynman x although the statistical precision is yet not good.⁽³⁾

In lepto-production of hadrons a quark in the nucleon is struck by the exchanged current and then, as does the spectator di-quark system, fragments into hadrons. The scaling violations would appear as a Q^2 -dependence of the Z distribution or fractional energy distribution of the hadrons from the struck (current) quark.

In this paper we use the hadrons produced in antineutrino-proton interactions to measure the fragmentation function for the d-quark. The criteria necessary to isolate the current quark fragments are presented, and the questions of how one defines the current fragmentation region and the energy sharing variable, z , are addressed.

11. Experimental Details

The data sample was obtained from exposures of the Fermilab 15-foot hydrogen bubble chamber to a broad-band antineutrino beam. Over 90% of the data were obtained using 400 GeV protons with focussing provided by two magnetic horns. Only events with three or more charged particles were processed and topologically-dependent corrections are made for events failing measurement. Neutral particles are in general not detected in this experiment, so one must make some assumptions to calculate the beam energy.⁽⁴⁾ The muon track was selected using kinematic techniques.⁽⁴⁾ Corrections have been made where necessary for muon selection efficiency, neutral current background, and energy resolution. These corrections do not affect the conclusions. To reduce background, we also demand that $y = (E_{\bar{\nu}} - E_{\mu})/E_{\nu} \leq 0.8$, and we use only events with $E_{\bar{\nu}} > 5$ GeV. These selections result in a data sample of 2256 events. In the analysis, all charged particles are assumed to be pions except for those positive particles identified as protons through ionization density in the bubble chamber.

III. Separation of Target and Current Fragments

The kinematical region available to the hadronic system can be defined in terms of the distributions in total hadronic energy, W , and the lepton four momentum transfer squared, Q^2 .⁽⁵⁾ These variables are related to the scaling variable x_{BJ} through

$$W^2 = M_p^2 + Q^2 \left(\frac{1}{x_{BJ}} - 1 \right), \quad (1)$$

where $x = Q^2/2M_p \nu$ and $\nu = E_\nu - E_\mu$. The median values of W and Q^2 in our experiment are 3.4 GeV and 2.7 (GeV/c)^2 , respectively. The rapidity range available to the hadrons, $\sim \ln W^2$, is then quite small and, if one accepts that the cluster correlation length of ~ 2 units of rapidity measured in hadron physics is typical of the hadron mobility⁽⁶⁾, a strong cut in W may be anticipated as necessary to separate the current quark and the target fragments. For $W \geq 4$ GeV, a plateau is discernible in the single particle rapidity distributions of Fig. 1. This is not the case for $W < 4$ GeV and so we use this selection as an initial cut.

While the observation of a plateau is a minimal requirement for separation of current and target fragments, it is still necessary to define both the current fragmentation region and the energy sharing variable, z , to be employed. Definitions in use are:

- (a) All hadrons in the forward hemisphere of the current Breit frame.⁽¹⁾ Here the struck quark has momentum $Q/2$ and one may use $z_B = 2P_L/Q$ where P_L is the longitudinal momentum of the hadron.

- (b) All hadrons in the forward hemisphere of the hadronic CM system, i.e. all particles with $x_F (=2P_L^*/\sqrt{s}) \geq 0.0$.⁽⁷⁾ Here one generally takes $z_L = E^h/\nu$ defined in terms of laboratory quantities.
- (c) All hadrons (tracks) with $z_L (=E^h/\nu) \geq 0.2$ constitute current fragments.⁽⁸⁾

Because of the low energy of present $\nu, \bar{\nu}$ experiments, it is possible to arrive at somewhat different conclusions according to which representation is adopted.

We then find that the requirement $W \geq 4$ GeV also results in:

- (a) A reasonable leading hadron behavior as expected for fragmentation of the d-quark, i.e. dominance of negative over positive hadrons at high z_L .
- (b) Strong rejection of particles typical of the target fragments from the current region, e.g., protons and Λ^0 hyperons. The W cut is clearly essential if such particles indeed typify the mobility of target fragments.

We conclude that minimal cuts to achieve a reasonably pure sample of current quark fragments are:

- 1) $W \geq 4 \text{ GeV}^2$
- 2) $Q^2 \geq 1.0(\text{GeV}/c)^2$,

the latter to ensure a reasonable rapidity interval for the current quark fragments and to help in rejecting the resonance component.⁽⁹⁾ These selections result in a sample of 650 events.

IV. Comparison with Quark-Parton Model

In Feynman's quark-parton model,⁽¹⁾ the hadron production rate is the product of the probability to hit a given type of quark in the nucleon times the probability that this struck quark will decay into a given hadron plus anything:

$$\frac{d^3\sigma}{dx dy dz} = \left(\frac{d^2\sigma}{dx dy} \right) D_q^h(z) . \quad (2)$$

The fragmentation functions, $D(z)$, are then independent of the scaling variables x , y and are generally asserted to be independent of W , Q^2 , etc.⁽⁸⁾ In particular, this leads to:

a) Factorization, i.e. $D(x, z, Q^2) \rightarrow D(Q^2, z)$

b) Scaling, i.e. $D(Q^2, z) \rightarrow D(z)$,

where the latter would be violated if QCD effects gave rise to detectable Q^2 -dependence of $D(z)$.

Operationally, the fragmentation functions are defined by:

$$D^{h\pm}(z) = \frac{1}{N_{ev}} \frac{dN_{h\pm}}{dz} , \quad (3)$$

so that the first moment of the fragmentation function, the hadron charge multiplicity, is

$$\langle n_{ch} \rangle_{h\pm} = \int D^{h\pm}(z) dz . \quad (4)$$

As previously stressed, it is instructive to look for possible differences arising from the various definitions of current fragments discussed above. For example, the behavior of $\langle n_{ch} \rangle$ depends markedly on which picture is employed. It is well known that in the hadron CM, $\langle n_{ch} \rangle$ grows logarithmically with W^2 .⁽²⁾ This behavior is clearly seen in Fig. 2 for the current fragments

using the hadron CM definition. The $\langle n_{ch} \rangle$ in this definition, however, depends little on Q^2 . In contrast, using the Breit frame representation these roles are essentially reversed. Since Q^2 now defines the rapidity interval available to the hadrons, there is a strong variation of $\langle n_{ch} \rangle$ with Q^2 , as seen in Fig 2(d). The $\langle n_{ch} \rangle$ depends little on W .

These features are important in understanding the x_{BJ} dependence of $\langle n_{ch} \rangle$. This is shown in Fig. 3 for both the hadron CM and the Breit frame representation. The strong variation seen in both distributions is just a reflection of the effects already discussed for Fig. 2. More informative is the dependence of the second moment, $\langle z \rangle$, on x_{BJ} . As seen in Fig. 3, there is no x_{BJ} dependence of $\langle z \rangle$, in either representation, for positive or negative hadrons.

To exhibit any Q^2 -dependence in the fragmentation function, we show data for positive and for negative hadrons separately in Figs. 4 and 5, respectively. Both the hadron CM representation and the Breit-frame representation are shown. There is no indication of Q^2 dependence at high z , although the data are limited in this region. For comparison the data with no W cut are also shown.

V. Conclusions

To summarize, we conclude that strong cuts in W and Q^2 are necessary in order to cleanly isolate the current quark fragments. When these selections are made, we find no evidence for either x_{BJ} or Q^2 -dependence of the fragmentation function describing the

current fragments.

These conclusions are to be compared to those from a neutrino-proton experiment where Q^2 -dependence of the fragmentation function is observed and where the non-singlet moments of the fragmentation function exhibit the Q^2 -dependence predicted by QCD. Furthermore, a dependence of the fragmentation function on x_{BJ} is remarked.⁽¹⁰⁾ In that experiment, no W cut was applied and, indeed, no attempt was made to demonstrate that separation of the current quark fragments was achieved. Any conclusions based on observation of current quark fragments must then be questionable. In fact, in our experiment with no restriction on W , the non-singlet moments become negative in some regions of Q^2 because of contamination from target fragments. Their Q^2 -dependence is completely inconsistent with QCD predictions.

This experiment was made possible by the support of the Neutrino Department at Fermilab and by the operating crew of the 15-foot bubble chamber. We wish to acknowledge informative discussions with T. Gottschalk. This reserach was supported by the U.S. Department of Energy.

References

1. R. P. Feynman, Photon-Hadron Interactions (Benjamin, New York, 1972).
2. R. D. Field, "Applications of Quantum Chromodynamics", CALT-68-696 (1978).
3. B. Wiik, "Results from PETRA", "Neutrino '79" Proceedings, Bergen, June 1979.
4. S. J. Barish et al., Phys. Rev. D18, 2205 (1978), and E. Fernandez, A. Garfinkel, and A. T. Laasanen, Purdue University Report PU79-480 (unpublished).
5. M. Derrick et al., Phys. Rev. D17, 1 (1978).
6. J. Erwin et al., Phys. Rev. Letters 33, 1443 (1974).
7. S. J. Brodsky and N. Weiss, Phys. Rev. D16, 2325 (1977).
8. P. C. Bosetti et al., Nucl. Phys. B149, 13 (1979).
9. A more complete discussion may be found in B. Musgrave, "Properties of the Hadronic System Produced by Antineutrino Proton Interactions, "Neutrino '79" Proceedings, Bergen, June 1979 and ANL-HEP-CP-79-11 (unpublished).
10. W. Wittek, "Observation of Scaling Deviations in the Energy Distribution of Secondary Hadrons in Inelastic Neutrino-Proton Interactions, "Neutrino '79" Proceedings, Bergen, June 1979.

Figure Captions

- Fig. 1 The single particle rapidity distributions in the hadronic CM for (a) negative hadrons, (b) positive hadrons, and (c) the difference.
- Fig. 2 The dependence of the integrated charged hadron multiplicity $\langle n_{ch} \rangle$ for the forward Breit frame hemisphere as a function of (c) W and (d) Q^2 ; (a) and (b) are for the hadron CM with $X_F \geq 0.0$.
- Fig. 3 The dependence on x_{BJ} of (a) the integrated charge multiplicity $\langle n_{ch} \rangle$, (b) the $\langle z \rangle$ for h^- , and (c) the $\langle z \rangle$ for h^+ ; (1) for the Breit selection and (2) for the hadron CM selection.
- Fig. 4 The fragmentation function for h^+ in terms of z_B and z_L for the Q^2 selections shown.
- Fig. 5 The fragmentation function for h^- in terms of z_B and z_L for the Q^2 selections shown.

Fig. 1 The single particle rapidity distributions in the hadronic CM for (a) negative hadrons, (b) positive hadrons, and (c) the difference.

Fig. 2 The dependence of $\langle n_{ch} \rangle$ on (a) W and (b) Q^2 for $X_F \geq 0.0$.

Fig. 2 The dependence of the integrated charged hadron multiplicity $\langle n_{ch} \rangle$ for the forward Breit frame hemisphere as a function of (c) W and (d) Q^2 .

Fig. 3 The dependence on X_{BJ} of (a) the integrated charge multiplicity $\langle n_{ch} \rangle$, (b) the $\langle z \rangle$ for h^- , and (c) the $\langle z \rangle$ for h^+ ; (1) for the Breit selection and (2) for the hadron CM selection.

Fig. 4 The fragmentation function for h^+ in terms of z_B and z_L with Q^2 selection.

Fig. 5 The fragmentation function for h^- in terms of z_B and z_L with Q^2 selection.