Study of Diquark Fragmentation at the CERN Intersecting Storage Rings

D. Hanna[a] and D. DiBitonto[a]
Harvard University, Cambridge, Massachusetts 02138

and

J. Eickmeyer,[b] A. Kernan, J. O'Connor, G. VanDalen, and R. Wojslaw[c]
University of California, Riverside, California 92521

and

A. Böhm and K. L. Giboni
III. Physikalisches Institut der Technischen Hochschule, D-5100 Aachen, Germany

and

M. Barone, F. Ceradini,[d] F. Muller, B. Naroska,[e] M. Nussbaum,[f] and C. Rubbia[g]
CERN, CH-1211 Geneva 23, Switzerland

and

J. Irion, F. Navach,[h] D. Schinzel,[a] H. Seebrunner, A. Staude, R. Tirler, and R. Voss
Sektion Physik der Universität München, D-8000 München 22, Germany

and

M. Block and R. Campanini[i]
Northwestern University, Evanston, Illinois 60201
(Received 7 October 1980)

Forward particle production in pp interactions triggered by a 30° pion of momentum exceeding 5 GeV/c has been studied at c.m. energy of 63 GeV. Quantum-chromodynamic model calculations show that in a majority of such interactions the incident proton loses a valence quark. Results indicate that hadronization of diquarks is primarily a recombination process leading to the formation of a high-x baryon.

PACS numbers: 13.80.Kf, 12.40.Cc

The fragmentation of quarks has been extensively studied in e^+e^- annihilation as well as in hadron collisions and deep-elastic lepton production experiments. Data on the "diquark" system which remains when a valence quark is ejected from a nucleon is, however, considerably more limited.[1] In order to investigate the mechanism of diquark hadronization we have undertaken a study of small-angle hadron production in 63-GeV (c.m. energy) pp collisions triggered by a high-momentum pion at 30° in the same hemisphere. In this experiment the forward fragments were identified by Čerenkov counters. Previous studies along this line[2,3] have been handicapped by the absence of forward-particle identification.

In the naive quark-parton model,[4] the trigger pion is a fragment of a quark ejected in a hard-scattering process, as shown in Fig. 1(a). For a pion of $p_T \gtrsim 2.5$ GeV/c, the parent is likely to be a valence quark with $x_{\rm Bj} \gtrsim 0.2$, implying the production of a forward diquark. Moreover, the charge of the trigger pion should reflect the flavor of the quark (u for π^+ and d for π^-), and thereby give a clue to the flavor content of the diquark (ud or uu). A calculation based on the more realistic quantum-chromodynamics- (QCD-) inspired model of Feynman, Field, and Fox[5] indicates that hard gluons are a sizable source of triggers. Table I shows the fractional parton composition for a $p_T = 3$ GeV/c $\pi^\pm$ trigger given by this calculation.[6]

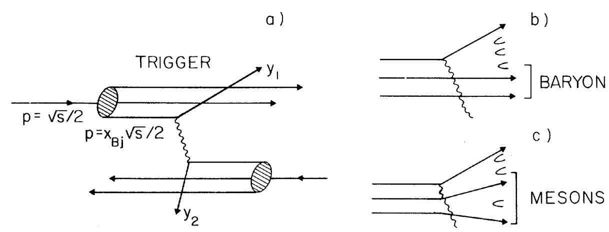

FIG. 1. Parton diagrams for (a) quark-quark elastic scattering, (b) diquark hadronization by fast baryon formation, and (c) diquark hadronization by fast meson formation.

TABLE I. Fractional composition of parent parton for $\pi^{\pm}$ particles produced at 30° with p_T of 3 GeV/c in pp collisions at c.m. energy of 63 GeV (Ref. 8). The average x_{Bj} of the parton is 0.26.

Parent parton	Fraction of the trigger π^+	Fraction of the trigger π^-
u quark	0.57 ± 0.03	0.17 ± 0.03
d quark	0.06 ± 0.03	0.38 ± 0.03
Gluon	0.32 ± 0.03	0.40 ± 0.03
Antiquark	0.05 ± 0.03	0.05 ± 0.03

Most of the apparatus has been described previously.[7] Briefly, it consisted of two coaxial spectrometers surrounding beam 1 just downstream of intersection region I6 at the Centre Européen de Recherches Nucléaires (CERN) intersecting storage rings (ISR) (Fig. 2). The outer spectrometer was used to define and detect the trigger particle while the inner one measured forward fragments from 1° to 6° with respect to the beam axis.

The trigger spectrometer was based on an air-core toroid known as the lamp-shade magnet (LSM). A total of twelve coils divided the azimuth into 30° sectors, ten of which were instrumented with a Čerenkov (C) and shower (S) counter combination as well as trigger scintillators (TF, TB). The Čerenkov counters contained CO_2 at atmospheric pressure with a pion threshold of 5 GeV/c. The six sectors used in the trigger covered 50% in azimuth. A small scintillator (B) behind the shower counters restricted the polar angle of the trigger particle to 30° ± 1°. The forward spectrometer comprised two identical septum magnets ($\int \vec{B} \cdot d\vec{l} = 12.9$ kG m) which sandwiched the beam pipe. Hodoscopic Čerenkov counters built into the front half of each magnet provided particle identification; each counter had four cells and was filled with Freon-114 at atmospheric pressure.

The trigger was designed to select events in which a fast $\pi^{\pm}$ was emitted at 30° with respect to beam 1. The standard requirements in any one of the six trigger sectors were (i) a coincidence of TF, TB, S, and B, (ii) a pulse from the Čerenkov counter, and (iii) pulse heights consistent with minimum ionization in (a) TB and (b) S. Condition (iiia) suppressed pairs from photon conversion in the beam pipe and the front trigger counter while condition (iiib) rejected events where a hard δ ray or electron from an asymmetric pair had fired the Čerenkov counter. This trigger rejected, on line, 99% of hadrons below pion threshold ($p_T = 2.5$ GeV/c).

The integrated luminosity was 1.4 pb^{-1}. Track reconstruction and fiducial cuts in the LSM left a total of 40 000 positive and 32 000 negative trigger tracks with $p_T > 2.5$ GeV/c. About half of the selected events were found to have one or more charged particles in the forward spectrometer and these particles were identified with use of information from the Čerenkov counter. The π, K, and p thresholds in Freon-114 are 2.6, 9.3, and 17.7 GeV/c, respectively. While π/K separation is difficult above kaon threshold it is easy to distinguish between mesons and baryons over the range of momenta of interest here. So we label

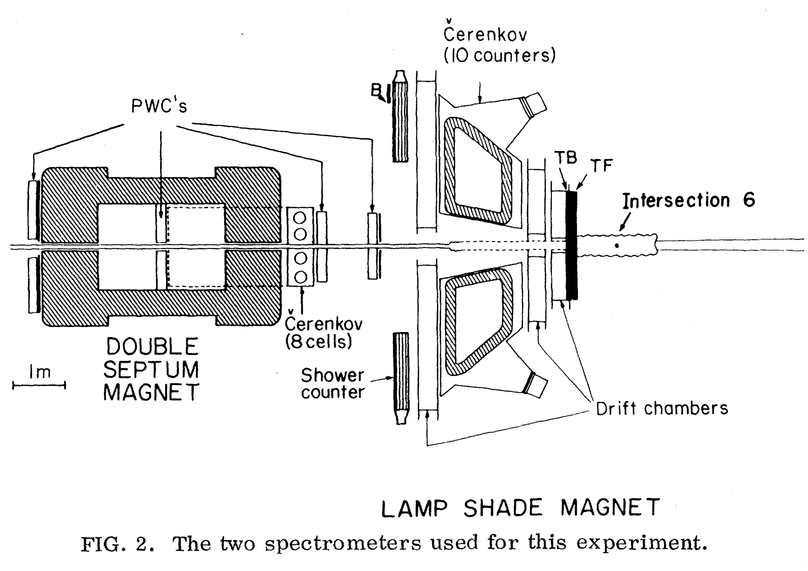

FIG. 2. The two spectrometers used for this experiment.

forward hadrons as either mesons or protons, using the notation π for mesons since pions are the dominant component.

In analogy with quark fragmentation studies, the kinematics of the forward particles are summarized in the invariant quantity $F(z)\equiv(z/N)dn^h/dz$, where n^h is the number of hadrons of type h observed with fraction z of the diquark's momentum, and N is the corresponding number of triggers. The diquark momentum p_{qq} depends on $x_{\rm Bj}$, the fraction of the incident proton's momentum carried by the ejected quark: $p_{qq}=\frac{1}{2}(1-x_{\rm Bj})\sqrt{s}$. By assuming that both outgoing quarks have the same transverse momentum p_{qT} leads to $x_{\rm Bj}\simeq p_{qT}\times|\exp(y_1)+\exp(y_2)|/\sqrt{s}$ where y_1 and y_2 are the rapidities of the outgoing quarks. y_2 is unmeasured but QCD calculations[6] and the results of Della Negra *et al.*[8] indicate that the quark which scatters off the valence quark is usually a low-x sea quark which recoils at large c.m. angle with $y\simeq 0$. Hence we take $y_2=0$ and obtain $x_{\rm Bj}=0.075\times p_{qT}(\text{GeV}/c)$. Then, assuming that the trigger particle takes $\approx 90\%$ of the jet momentum[9] leads to $x_{\rm Bj}=0.08p_T(\text{GeV}/c)$, where p_T now refers to the triggering hadron. Note that for $p_T=3$ GeV/c, $x_{\rm Bj}=0.24$, close to the value of 0.26 from the Feynman, Field, and Fox model (Table I).

Figure 3 shows $F(z)$ versus 1-z for p, π^+, and π^- for positive and negative triggers in the trigger p_T range 2.5–4.0 GeV/c. Arguments based on counting rules[10] suggest that $F(z)$ should behave as a power of $1-z$. A fit of the data in Fig. 3 with the form $A(1-z)^n$ gives for positive (negative) triggers the following values for the exponent n: 0.97 ± 0.09 (0.68 ± 0.08) for protons, 3.49 ± 0.24 (2.93 ± 0.22) for π^+, and 4.46 ± 0.32 (4.06 ± 0.37) for π^-. Thus forward meson production is consistent with a single n value for π^- (4) and π^+ (3), independent of trigger charge; the proton data are consistent with $n=1$ for positive triggers, but n is significantly below unity for negative triggers.

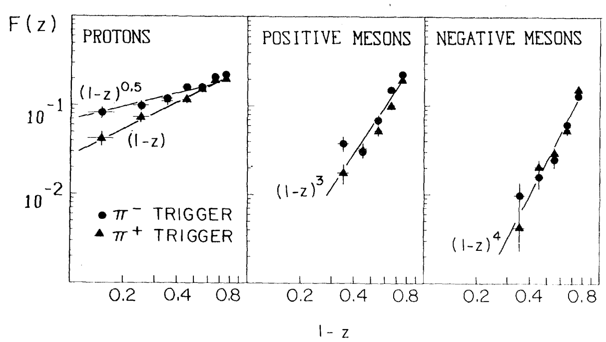

FIG. 3. The z dependence of forward-particle production for a triggering pion with $2.5<p_T<4.0$ GeV/c.

The general features of these distributions are the following: (1) Protons are produced more frequently and with a harder z spectrum than mesons. (2) There is a positive correlation between proton production and a negative-pion trigger. (3) The meson distributions are consistent with independence of trigger sign (although some positive correlation between π^+ production and a negative trigger is not ruled out).

In order to explore the implications of these results we outline two classes of models for diquark fragmentation[11]:

(a) The diquark behaves as a coherent color charge which creates a color field with the ejected quark [Fig. 1(b)]. It eventually recombines with a quark to form a leading baryon. Mesons are produced mainly from the newly created quark pairs and hence are not correlated to the sign of the trigger charge.

(b) The diquark behaves incoherently [Fig. 1(c)] and the two valence quarks transform into mesons either by fragmentation or by recombination. Fast mesons will contain the valence quarks and therefore be correlated to the trigger sign.

Note that if the triggering particle comes from a gluon jet as expected in (30–40)% of the interactions, no charge correlation with the forward particle is expected.

The results of this experiment are all suggestive of model (a), namely, (i) protons dominate the forward hadron signal at large z values, and (ii) there is no trigger charge dependence for negative-meson production. From counting-rule arguments as well as specific models such as recombination,[10,11] one expects $F_{uu}^{\pi^-}(z)/F_{ud}^{\pi^-}=(1-z)^4$. We thus conclude that the valence quarks do not fragment independently.

In the previous ISR studies[2,3] the feature of proton dominance could not be seen because of the absence of particle identification. In Ref. 2, the triggering particle was at 90° in the c.m. system and correlation effects were consequently diluted. A trigger charge effect was reported in Ref. 3 for trigger particles at 20°. In that experiment, however, the rapidity gap between forward and triggering particles was $\simeq 1.7$ units, sufficiently low for the occurrence of short-range charge correlations.

In summary, we conclude that hadronization of diquarks occurs predominantly via recombination of the diquark with another quark to form a baryon.

We are most grateful for the assistance of the ISR experimental support group as well as the operations group and user support group of the CERN computer center. We thank R. Field for his continued interest and help, and T. DeGrand and S. Brodsky for illuminating discussions. This work was supported in part by the U. S. Department of Energy and by the Bundesministerium für Forschung and Technologie.

[a]Present address: CERN, CH-1211 Geneva 23, Switzerland.

[b]Present address: Bell Labs, Whippany, N.J. 07981.

[c]Present address: Hughes Aircraft Co., Los Angeles, Cal. 90009.

[d]Present address: Università degli Studi di Roma, I-00185 Roma, Italy.

[e]Present address: Deutsches Elektronen-Synchrotron, Hamburg 52, Germany.

[f]Permanent address: University of Cincinnati, Ohio 45221.

[g]Also Harvard University, Cambridge, Mass. 02138.

[h]Present address: Università degli Studi di Bari, I-70126 Bari, Italy.

[i]Present address: Università degli Studi di Bologna, I-40126 Bologna, Italy.

[1]For a summary of the experimental information, see M. Fontannaz, B. Pire, and D. Schiff, Phys. Lett. 77B, 315 (1978).

[2]M. G. Albrow *et al.*, Nucl. Phys. B135, 461 (1978).

[3]D. Drijard *et al.*, Nucl. Phys. B156, 309 (1979).

[4]R. P. Feynman, *Photon Hadron Interactions* (Benjamin, New York, 1972).

[5]R. P. Feynman, R. D. Field, and G. C. Fox, Phys. Rev. D 18, 3320 (1978).

[6]R. D. Field, private communication. The errors in Table I reflect uncertainty in the gluon parametrizations.

[7]F. Ceradini *et al.*, Nucl. Instrum. Methods 156, 171 (1978); K. L. Giboni *et al.*, Phys. Lett. 85B, 437 (1979); L. Baksay *et al.*, Nucl. Instrum. Methods 133, 219 (1976).

[8]M. Della Negra *et al.*, Nucl. Phys. B127, 1 (1977).

[9]R. P. Feynman and R. D. Field, Phys. Rev. D 15, 2590 (1977).

[10]R. Blankenbecler and S. J. Brodsky, Phys. Rev. D 10, 2973 (1974); S. J. Brodsky and J. D. Gunion, Phys. Rev. D 17, 848 (1978).

[11]For theoretical approaches to forward fragmentation in pointlike interactions, see Ref. 1; B. Anderson, G. Gustafson, and C. Peterson, Phys. Lett. 69B, 221 (1977); J. Ranft, Phys. Rev. D 18, 1491 (1978); T. DeGrand, Phys. Rev. D. 19, 1398 (1979).