E 395

Submitted to Physics Letters

FERMILAB-PUB-78-181-E

UPR - 55E
Univ. of Pennsylvania
October 1978

Evidence That Quark-Quark Scattering Can be Studied with Jet Experiments

M. Dris, L. Cormell, W. Kononenko,
B. Robinson, W. Selove, and B. Yost
University of Pennsylvania, Philadelphia, Pa. 19104
and
P. J. Gollon
Fermilab, Batavia, Ill. 60510
and
A. Kanofsky
Lehigh University, Bethlehem, Pa. 18015
and
M. D. Corcoran, A. R. Erwin, E. H. Harvey, and M. Thompson
University of Wisconsin, Madison, Wi. 53706

Abstract: Previous measurements by us of high-p_T jet pairs have given the first direct determination of the quark (plus antiquark) structure function of the pion. We discuss evidence which supports the conclusion that the jet pair events used for this determination correspond to quark-quark scattering. This evidence strengthens our expectation that hadron jets produced in hadron collisions will provide a practical tool for the study of the strong interaction in parton-parton scattering.

Introduction and summary

We have previously reported evidence that high-p_T jet pairs in hadron collisions are produced by parton-parton collisions[1]. We have also reported the first direct determination of the $(q+\bar{q})$ structure function of the pion, $f_{(q+\bar{q}),\pi}(x)$, for x between 0.26 and 0.56 [2], which we found to be in rather close quantitative agreement with the predictions of theoretical models [3,4]. In this paper we discuss new related information which leads to the following conclusions:

(1) The jet pair events we have studied correspond to quark-quark scattering as distinguished from collisions involving gluons.

(2) The shape of the $f_{(q+\bar{q}),\pi}(x)$ results we have obtained from a jet experiment agrees very closely with that obtained from the study of an entirely different process, di-muon production [5]. This agreement gives substantial support to the conclusion that in both experiments the analysis gives accurate information on the shape of the quark (plus antiquark) structure function of the pion [6].

One thus now has even stronger evidence than our own experiment gave by itself that hadron jets provide a tool which can actually be used to obtain information on strong-interaction forces observed in the scattering of constituents of hadrons. In particular, one can expect to study the angular and energy dependence of quark-quark scattering, and prospectively of quark-gluon and gluon-gluon scattering.

Evidence of quark-quark scattering

The new evidence that the jet-pair events we have studied correspond to quark-quark scattering consists of the following:

(1) For single-arm jet triggers in the kinematic range we have used we find that the away-side jet is quite similar to the trigger-side jet [7,8]. Thus these jets most likely originate from the scattering of similar constituents of hadrons, rather than from the scattering of dissimilar constituents such as quarks scattering on gluons.

(2) An analysis of our measurements of the angular dependence of the ratio $\sigma(pp \to 2 \text{ jets} + X)/\sigma(\pi p \to 2 \text{ jets} + X)$ has been made by Owens [9]. His results when combined with our data indicate that gluon scattering is relatively unimportant in producing the two-jet events that we observe. A plausible reason for a relative suppression of events with gluon jets lies in the theoretical prediction that gluon jets are "softer" than quark jets [7,8,10,11].

Comparison with the new results of Anderson et al.

Anderson et al. [5] have measured di-muon production in π^--nucleus collisions over the kinematic range $x_1 = 0.2$ to 1.0 and $x_2 = 0.05$ to 0.27, where x_1 and x_2 are the momentum fractions for the incident and target partons respectively. If they assume that the dominant mechanism in their kinematic range is $\bar{q}q$ annihilation, and that the magnitude of the cross section is given by the Drell-Yan formalism, they can then obtain information on both the pion quark structure function and a certain effective nucleon quark structure function. The data give the magnitude of the product of these structure functions. Their result for the shape of the effective nucleon structure function, in first approximation, is not in good agreement with results expected from deep inelastic scattering. They find that if they try to estimate the effects of parton transverse momentum, the exact effects of which are difficult to determine, the shape of the effective nucleon structure function they obtain can be changed considerably, though the shape of the pion structure function they obtain is apparently less sensitive to these transverse momentum effects. They state that in view of these uncertainties the normalization of their pion structure function should therefore be used with caution.

For the x_1 range 0.25 to 0.56, for which results are shown below, the bulk of the data used by Anderson et al. has x_2 in the range $0.15 \le x_2 \le 0.25$ for $x_1 = 0.25$, and in the range $0.07 \le x_2 \le 0.13$ for $x_1 = 0.56$. For such low x_2 values we note that target gluons as well as target quarks (and antiquarks) may contribute appreciably to di-muon production [12,13]. It is important to realize that if such a contribution were present it could be expected to perhaps distort the shape of the effective nucleon structure function [14],

and to increase the experimental cross section over that which would result if no quark-gluon collisions contributed. Theoretical studies indicate that such gluon constributions for the target parton could be present without disturbing either the factorization of the di-muon production in x_1 and x_2 [15] or the di-muon helicity angle distribution [16].

We show in Figure 1 our own results [2] (circles) for $f_{(q+\bar{q}),\pi}(x)$, which cover the x range between 0.25 and 0.56. We also show for that x range results (crosses) for the same quantity which we have derived from the di-muon experiment of Anderson et al. [5] by taking $f_{(q+\bar{q}),\pi}(x)$, in this "valence" region, to be equal to twice the value of $x\bar{u}(x)$ shown in reference [3]. In view of the uncertainty in absolute normalization of the di-muon results, the agreement in the shapes of the distributions obtained from the two experiments must be regarded as more significant than the agreement in absolute magnitude [17]. We also show in Figure 1 a dashed line corresponding to the results of reference [3] multiplied by a factor of 1.4 [18].

Conclusion

The agreement in the shape of $f_{(q+\bar{q}),\pi}(x)$ obtained in these two experiments, especially taken together with the quantitative agreement noted earlier between the jet results for $f_{(q+\bar{q}),\pi}(x)$ and the theoretical predictions, supports the interpretation that in both experiments the incident parton is dominantly a quark, or an antiquark--but not a gluon. This conclusion, along with the other evidence described above relating to the jet experiment, leads to the further conclusion that in the jet experiment the jet pair events studied correspond to quark-quark scattering. These results support the expectation that one can study the fundamental strong-interaction force between quarks, and hopefully between quarks and gluons [19], using hadron jets as a practical means of obtaining information on parton-parton scattering.

We thank F. Halzen for very helpful discussions. This work was supported in part by the U. S. Department of Energy.

Figure Caption

Figure 1. The quark-plus-antiquark structure function of the pion, in the x range 0.25 to 0.56. In standard notation $f_{(q+\bar{q}),\pi}(x)$ is equal, for the π^+, to $x\left[u_{valence}(x) + \bar{d}_{valence}(x) + q_{sea}(x) + \bar{q}_{sea}(x)\right]$. The solid points are from jet-pair data, reference [2]. The crosses and the dashed line are derived from di-muon data, reference [5], with two different normalizations, as discussed in the text. (The latter work also gives results at larger x than the range shown here.) We estimate the systematic uncertainty of the jet experiment data to be of the order of 15% [2]. The systematic uncertainties of the di-muon results are discussed in the text.

Footnotes and References

1. M. D. Corcoran et al., Phys. Rev. Letters 41 (1978) 9.

2. M. Dris et al., π^+ Structure Information from a Jet Experiment, Univ. of Pennsylvania Report UPR-39E, May, 1978, submitted to the 19th International Conference on High Energy Physics (Tokyo, 1978). An expanded version is to be published elsewhere.

3. Glenys R. Farrar, Nucl. Phys. B77 (1974) 429.

4. R. D. Field and R. P. Feynman, Phys. Rev. D15 (1977) 2590.

5. K. J. Anderson et al., Hadronic Production of High-Mass Muon Pairs and the Measurement of the Pion Structure Function, Univ. of Chicago Report EFI 78-38, submitted to the 19th International Conference on High Energy Physics, Tokyo (August, 1978).

6. F. T. Dao et al., Phys. Rev. Lett. 39 (1977) 1388, have given the first published results on the quark structure function of the pion. See their work, and reference 2, for further discussion of their results.

7. Reports presented by A. R. Erwin and W. Selove at the Symposium on Jets in High Energy Collisions, Niels Bohr Institute, Copenhagen, July 1978.

8. M. D. Corcoran et al., Results from a 2-arm Calorimeter Array Jet Experiment, Univ. of Pennsylvania Report UPR-50E, August 1978, to be published in the proceedings of the 19th International Conference on High Energy Physics (Tokyo, 1978).

9. J. F. Owens, High-P_T Two-Jet Cross Sections and Tests of Parton Distributions, Florida State University Preprint, June 1978.

10. We thank D. Duke and H. Miettinen for an early discussion on this point.

11. K. Shizuya and S.-H. H. Tye, Phys. Rev. Lett. 41 (1978) 787.

12. See e.g. H. Fritzsch and P. Minkowski, Phys. Lett. 73B (1978) 80.

13. L. Lederman, rapporteur talk at the 19th International Conference on High Energy Physics (Tokyo, 1978).

14. E. g., the gluon structure function may rise more rapidly at small x than the effective nucleon quark structure function which enters in the analysis of Anderson et al.

15. F. Halzen (private communication).

16. This helicity angle distribution would be changed for much higher di-muon transverse momentum, but would not be changed appreciably in the kinematic range of the bulk of the data of Anderson et al. (F. Halzen, private communication.)

17. The structure functions used in the analysis in references [2] and [5] must be expected to be functions of Q^2 as well as of x. No Q^2 dependence is used in reference [2]. Q^2 in the di-muon experiment is taken to be the effective mass squared, M^2. We take Q^2 in the di-jet experiment to be the square of the three-momentum-transfer in the jet-jet rest system. Since the di-jet events typically correspond to parton scattering angles near 90°, since the jet P_T is about 2.5 to 3.5 GeV for the data of reference [2], and since the bulk of the data of reference [5] have $M \approx 4$ to 5 GeV, the Q^2 values for the bulk of the data in the two experiments are quite similar, about 20 GeV^2.

18. The 1.4 corresponds to a correction factor which should be applied to the results of reference [5]. (C. Newman, private communication.)

19. There is already some evidence in high-p_T experiments that gluon jets may be visible as well as quark jets. See the reports particularly concerning the CERN-College de France-Heidelberg-Karlsruhe (CCHK) results on trigger-side and away-side charge correlations, E. E. Kluge at the Symposium on Jets in High Energy Collisions, Niels Bohr Institute, Copenhagen, July 1978, and by K. Hansen and by R. Sosnowski (rapporteur talk) at the 19th International Conference on High Energy Physics, Tokyo, August 1978.

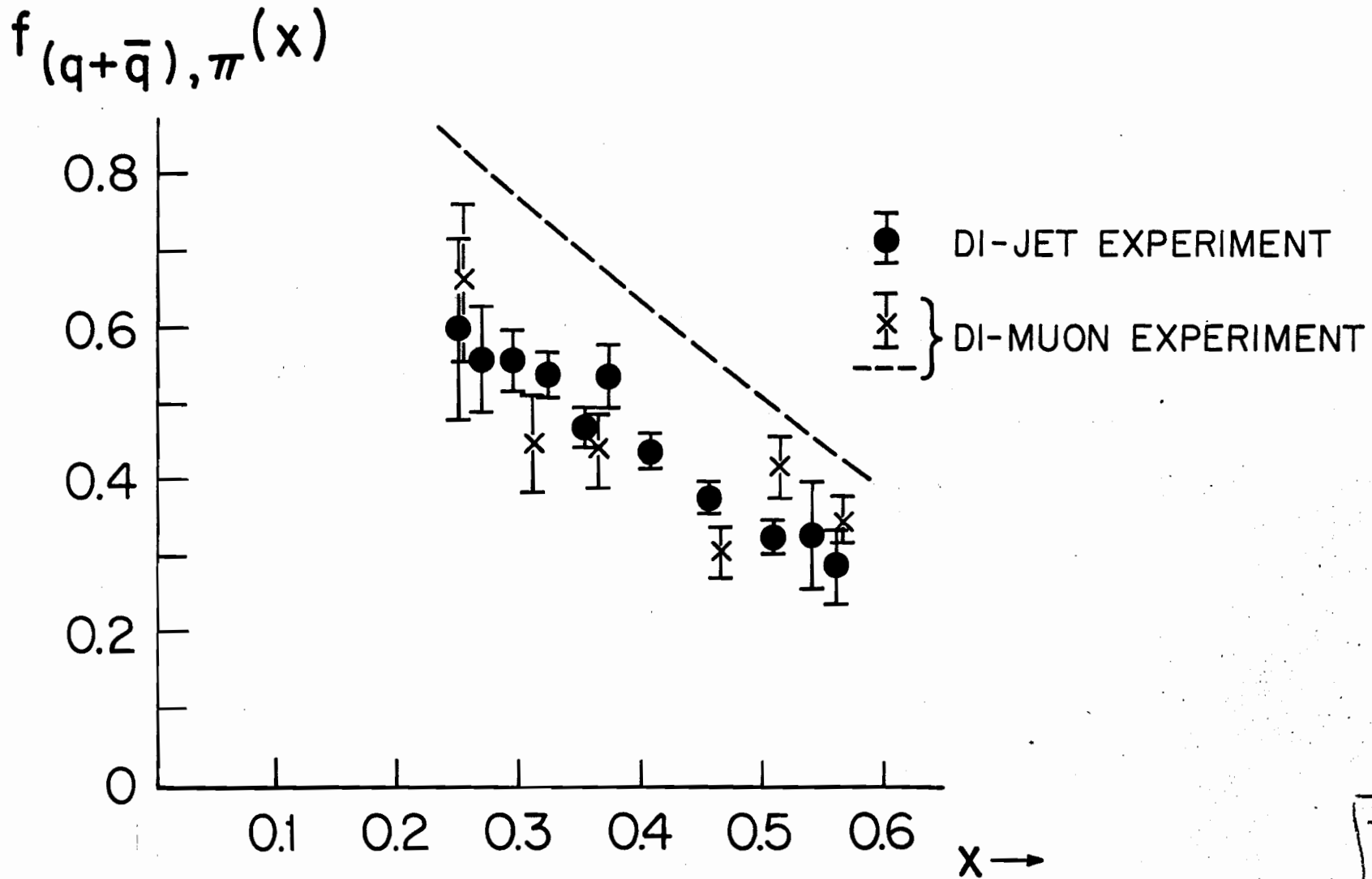
$f_{(q+\bar{q}),\pi}(x)$
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
x →
DI-JET EXPERIMENT
DI-MUON EXPERIMENT

FIG. 1