heavy quarks and should then scan for a narrow gluon jet of high energy.

Let us conclude with the remark that the concept of invariant masses of jets will not only allow a separate identification of gluon and heavy-quark jets, but will also be a powerful tool in the procedure of detecting the hadrons that carry the new quantum number of the heavy quark.

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[1]For a recent review see B. H. Wiik, DESY Report No. 79/84, 1979 (unpublished), and references contained therein.

[2]S. J. Brodsky and J. F. Gunion, Phys. Rev. Lett. 37, 402 (1976); K. Konishi, A. Ukawa, and G. Veneziano, Nucl. Phys. B157, 45 (1979).

[3]A model with scalar gluons should not be regarded as a serious alternative to QCD, but should rather illustrate that in some cases the results are mainly reflecting phase space restrictions.

[4]K. Koller, H. G. Sander, T. F. Walsh, and P. M. Zerwas, DESY Report No. 79/87, 1979 (unpublished).

[5]L. C. Clavelli and H. P. Nilles, Phys. Rev. D 21, 1242 (1980).

[6]M. Suzuki, University of California Report No. LBL-10094, 1979 (unpublished).

[7]We should mention here that the weak semileptonic decay of c, b, and t quarks can be used to isolate gluon jets for a small percentage of the events (G. Feldman, private communication).

[8]S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967); A. Salam and J. C. Ward, Phys. Lett. 13, 168 (1964); S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970).

[9]This special case $a=0$ has been computed previously by B. L. Ioffee, Phys. Lett. 78B, 277 (1978), and including polarization effects by E. Learmann and P. M. Zerwas, Phys. Lett. 89B, 225 (1980); G. Grunberg, Y. J. Ng, and S.-H. H. Tye, Phys. Rev. D 21, 62 (1980); G. Kramer, G. Schierholz, and J. Willrodt, DESY Report No. 79/69, 1979 (unpublished).

[10]For light quarks one has to demand a cutoff $1-x_3 \geq \epsilon' > 0$ in addition to the one introduced in (7).

[11]G. C. Branco, H. P. Nilles, and K. H. Streng, Phys. Lett. 85B, 269 (1979), and references contained therein.

[12]See, e.g., J. Ellis, in *Proceedings of the Summer Institute on Particle Physics, 1978*, edited by M. C. Zipf (Stanford Univ. Press, Stanford, Cal., 1978), p. 69.

[13]This expectation is based on general estimates of multiplicity and transverse momentum of hadrons inside jets, which are deduced from results in the PETRA experiments (Ref. 1).

[14]One has to be aware of the fact that the weak decay of the heavy quark may lead to a jet structure, but this would only slightly modify our estimates of the thrust value.

Diffractive Dissociation Processes and Quark-Antiquark Jets

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A model for pion diffractive dissociation as a two-stage process is examined, where first the pion breaks up to $q\bar{q}$ system, followed by the hadronization of this quark-antiquark system. This model appears to be consistent with the present experimental data. Implications of this hypothesis for a study of quark-antiquark jets is suggested.

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We note here that hadronization of quark-antiquark pairs is an important theoretical, as well as an experimental, problem. We observe this process, e.g., in e^+e^- annihilation to two jets of hadrons.[1] These jets, however, will be the result of hadronization of many types of quark-antiquark pairs: $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, or $b\bar{b}$. We thus have here very mixed information regarding the hadronization of quarks and antiquarks which cannot be easily deciphered since the signals from heavy-quark-antiquark pairs will differ from that of light ones. E.g., a strong SU(3) nonconservation is derived on phenomenological grounds[2] regarding "fragmentation" of the u and d quarks producing π and K mesons. Further, the decay modes of the D and F mesons are not yet well established.

We would like to propose here, however, that there is most likely an alternative source of hadronization of quark-antiquark pairs which is much more clean, and which has not yet been exploited either theoretically or experimentally in that context. We suggest that the hadrons X produced during diffractive dissociation process $\pi^- p \to Xp$ are the result of hadronization of the quark-antiquark pair $d\bar{u}$ with a center-of-mass energy M_X. We thus imagine the diffractive dissociation process as a two-stage process. First, π^- dissociates to $d\bar{u}$ quark-antiquark pair, and then this $d\bar{u}$ system hadronizes in the same manner as hadronization of neutral quark-antiquark pairs during e^+e^- annihilation to two jets of hadrons.

This model has verifiable consequences. In Fig. 1 we examine the charged multiplicity for the system X in[3] $\pi^- p \to Xp$ against the same in e^+e^- annihilation[4] and plot the respective experimentally observed multiplicities. We may notice that with $\sqrt{s} = M_X$ from 2 to 10 GeV the points are very close to each other. With a quark fragmentation model[5] we have verified that the charged multiplicity for the charged quark-antiquark system $d\bar{u}$ is the same as the charged multiplicity for the neutral $u\bar{u}$ or $d\bar{d}$ system at such energies. We regard the agreements of these data points for the two systems in Fig. 1 as evidence that the π^- dissociation charged multiplicity is also the result of the hadronization of the $d\bar{u}$ system. The agreement of these multiplicities from 7 to 10 GeV is rather accidental, since here there will be substantial charm production in e^+e^- annihilation.[6] The disagreement between the two around and below 2 GeV is, however, expected, as may be clear from a careful analysis of exclusive channels for e^+e^- annhilation below charm threshold[7] and is apparently due to the tail of ρ' production.

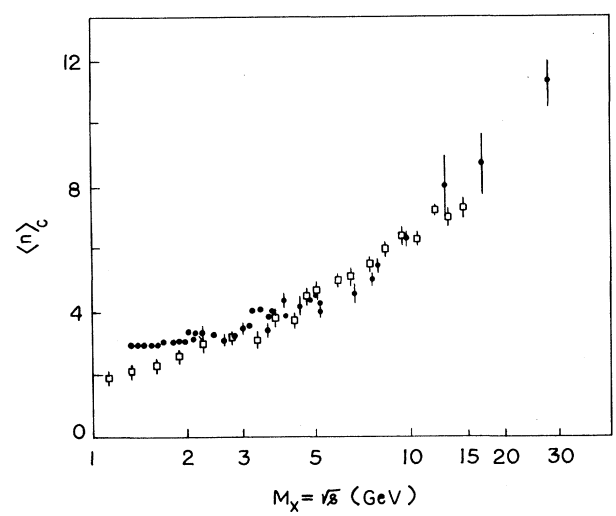

FIG. 1. The experimental average charged multiplicities for e^+e^- annihilation and π^- dissociation are plotted against M_x or $\sqrt{s}$. The data for e^+e^- annihilation from ADONE, SPEAR–MARK I, DASP, PLUTO, and TASSO Collaborations have not been distinguished and are all represented by solid circles (Ref. 4). The open squares represent the π^--dissociation data (Ref. 3).

We also consider the signals for two-, four-, six-, and eight-prong events for the above process[3] $\pi^- p \to Xp$. In the present model this involves calculating the probabilities for charged multiplicities 1, 3, 5, and 7 for the quark-antiquark system $d\bar{u}$ as a function of $M_X = \sqrt{s}$. We do these calculations in the quark fragmentation model[5] including isotopic spin dependence by taking the primordial fragmentation function as

$$f_{ij}(x) = (\tfrac{1}{3} + \tfrac{2}{3}\tau_1)_{ij} f_\pi(x). \tag{1}$$

Here i, j refer to the pair of quarks (u, d), τ_1 is the familiar Pauli spin matrix and we have included isotopic spin symmetry for the pionization of the u, d quarks. We illustrate the results of the calculations with two primordial fragmentation functions

$$f_\pi(x) = \alpha + \beta(1-x)^2, \tag{2}$$

as given by Field and Feynman[5] with $\alpha = 0.12$ and $\beta = 2.64$, and

$$f_\pi(x) = \frac{d\sigma(d + \tilde{Q} \to \pi^- + u + \tilde{Q})/dx}{\sigma_t(d + \tilde{Q} \to \pi^- + u + \tilde{Q})}, \tag{3}$$

as was suggested earlier[8] as the ratio of two cross sections for the calculation of such primordial fragmentation functions. Except pion production, we neglect the other channels of hadroniza-

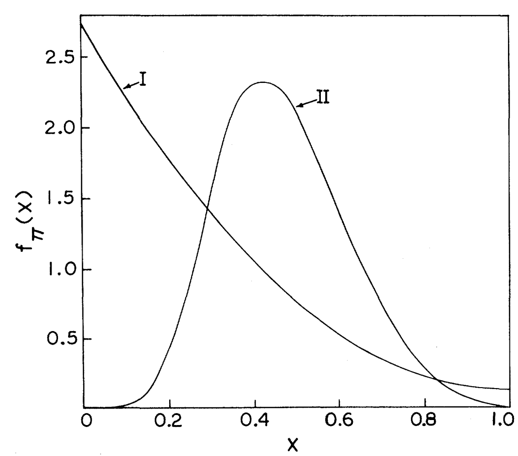

FIG. 2. The primordial fragmentation functions $f_\pi(x)$ given by Eqs. (2) and (3) as phenomenological inputs are plotted against x as curves I and II, respectively.

tion which are known to be small.[2,8] The two primordial fragmentation functions, which are quite different, are plotted in Fig. 2. With these primordial fragmentation functions as illustrations, we next calculate the probabilities for the charged multiplicities to be 1, 3, 5, and 7 in a straightforward manner[9] with quark-jet production model[5,8] for the $d\bar{u}$ system as a function of M_X and multiply these probabilities by the experimental value of $d\sigma/dM^2$ of Ref. 3. The corresponding curves are plotted in Figs. 3(a)–3(d) against the observations.[3] We may see the crude nature of the experimental results, but again, the conclusion appears to be that the charged multiplicity of X in $\pi^- p \rightarrow Xp$ could as well be the result of the hadronization of the quark-antiquark system $d\bar{u}$ after a hard scattering.

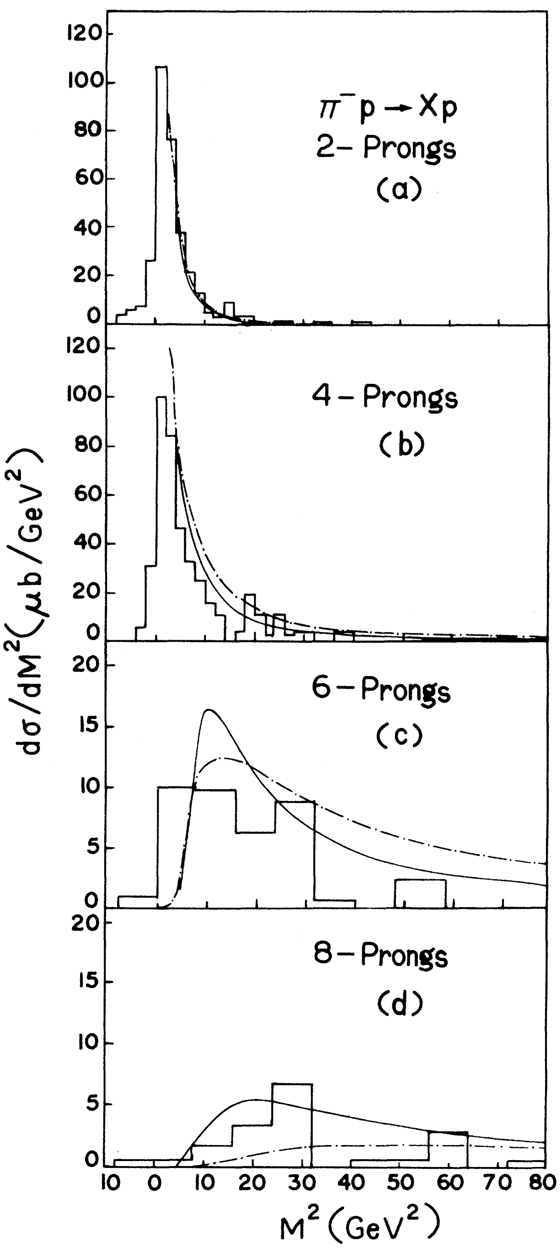

FIG. 3. (a) $d\sigma/dM^2$ (two prongs) vs M^2 is plotted. The continuous and the dot-dashed curves correspond to the primordial fragmentation functions I and II of Fig. 1, respectively. The experimental data are taken from Ref. 3 after background subtraction. $d\sigma/dM^2$ for four-, six-, and eight-prong events, respectively, are plotted in (b), (c), and (d) against experimental data (Ref. 3).

We may thus conclude with the following observarions:

(1) It may be worthwhile to do more carefully the individual charged multiplicity analysis as in Ref. 3.

(2) In $\pi^- p \rightarrow Xp$, it will be desirable to examine the hadronic system in the rest frame of X, and see whether we have the two-jet structure. With limited transverse momentum for the system X, it is clear that such a two-jet structure may be there from kinematics. Also, in such a case, comparison of $d\sigma/dy$ with y as rapidity for the system X in the above case and for $e^+e^- \rightarrow X$ may be desirable. We note that here we need M_X and not the momentum transfer. There is also likely to be some two-jet events where the transverse momentum of the system X is not too small.

(3) It is clear that the same mechanism may also be at work for $pp \rightarrow pX$ diffractive dissociation,[10] where the *target* proton may be examined as a possible example of the hadronization of diquark-quark jets parallel to lepton-proton collisions. In such a case the system X in their c.m. frame above will exhibit a two-jet structure corresponding to the diquark and the quark jets.

We may thus have clean and attractive sources for experimental and theoretical analysis of hadronization of quark-antiquark or quark-diquark jets from purely hadronic reactions with appropriate selection of data, which will supplement other reactions.

We are grateful to Professor J. C. Pati for discussions, and to Professor D. L. Scharre for a communication regarding observation of exclusive channels.

[1]G. Hanson, Phys. Rev. Lett. 35, 1609 (1975).

[2]I. Cohen *et al.*, Phys. Rev. Lett. 40, 1614 (1978).

[3]F. C. Winkelman *et al.*, Phys. Rev. Lett. 32, 121 (1974).

[4]G. Wolf (TASSO Collaboration), in *Proceedings of the 1979 International Symposium on Lepton and Photon Interactions at High Energies, Batavia, Illinois, 1979*, edited by T. B. W. Kirk and H. D. I. Abarbanel (Fermilab, Batavia, 1979), p. 34.

[5]R. D. Field and R. P. Feynman, Nucl. Phys. B136, 1 (1978).

[6]In this context, one may note that the multiplicity of hadrons could be independent of flavor; see, e.g., S. J. Brodsky and J. F. Gunion, Phys. Rev. Lett. 37, 402 (1976).

[7]J.-E. Augustin, in invited talk at the European Physical Society International Conference on High Energy Physics, Geneva, 1979 (to be published), and Laboratoire de l'Accélérateur Linéaire, Orsay, Report No. LAL-79/15, 1979 (unpublished).

[8]S. P. Misra and A. R. Panda, Phys. Rev. D 21, 3094 (1980).

[9]We consider the energy dependence here by assuming that the quarks stop fragmenting when they reach a characteristic momentum μ, and we have fixed the parameter μ such that there is reasonable agreement with the respective number of charged pions and an arbitrary number of neutral pions, and include recombination with an appropriate isospin weightage as in Eq. (1). For a possible mechanism of a "hard" scattering of a quark in the context of the diffractive dissociation processes with a quark-antiquark dissociated structure, see S. P. Misra, A. R. Panda, and B. K. Parida, Phys. Rev. D (to be published).

[10]Y. Akimov *et al.*, Phys. Rev. D 14, 3148 (1976); R. D. Schamberger, Jr., *et al.*, Phys. Rev. D 17, 1268 (1978); E. Jenkins *et al.*, Fermilab Report No. FERMILAB-Pub-79/56-EXP, 1979 (unpublished).

Space-Time Structure of Jet Hadronization

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The space-time development of jet hadronization is investigated in two-dimensional quantum electrodynamics. It is found that the characteristic space-time scale of jet hadronization is considerably shorter than the one given by approximately free propagation of quarks.

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Recently a great deal of progress has been made in understanding inclusive jet phenomena.[1] However, there is still lacking an understanding of the final stage of jet evolution, i.e., jet hadronization. Aside from an interesting attempt by Amati and Veneziano,[2] we know very little about the hadronization.

In this note, I wish to address the question of jet hadronization in solvable two-dimensional (one space and one time dimension) gauge theories. These theories seem to provide a unique place to investigate the interplay between hard and soft processes.

One of the most important aspects of jet hadronization may be its time scale. Therefore I first develop, in a systematic way, a formalism which enables me to describe the space-time structure of jet hadronization. Secondly, I will discuss two-dimensional gauge theories.

Following Carruthers and Zachariasen[3] I introduce a field theoretic version of Wigner's phase-space distribution[4] in quantum mechanics,

$$\tilde{F}(p,R) = \int d^2r e^{ipr}(\Box + m^2)_{R-r/2}\langle\Phi|\varphi(R-\tfrac{1}{2}r)\varphi(R+\tfrac{1}{2}r)|\Phi\rangle \times (\Box + m^2)_{R+r/2}. \tag{1}$$

Here $|\Phi\rangle$ is a normalized Heisenberg "in" state, and φ is the Heisenberg operator for a hadron with mass m. We deal with the amputated quantity since it is directly related to an observable quantity:

$$\frac{2\pi}{\sigma}2\omega_p\frac{d\sigma}{dp} \equiv \langle\Phi|a_{\rm out}^\dagger(p)a_{\rm out}(p)|\Phi\rangle = \int d^2R\tilde{F}(p,R)|_{p^2=m^2}. \tag{2}$$

If we impose the mass-shell condition, it is clear from the above equation that $\tilde{F}(p,R)$ contains the information about which space-time region dominantly contributes in producing the hadron of momentum p. Although I restrict myself to the production of spinless hadrons in two-dimensional space-time, the generalization of the present formalism to more realistic cases is straightforward.

Let us examine how the formalism works in