Brief Reports

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Comparison of jets in diffractive dissociation and e^+e^- annihilation

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I point out the conditions under which the final states of photon or meson diffractive dissociation should most resemble those of e^+e^- annihilation into hadrons. Possible differences are considered and predictions are made for strange- and charmed-particle multiplicities.

Recently there has been some work on the production of quark-antiquark ($q\bar{q}$) jets in diffractive dissociation.[1-3] Comparison of some crude features of final states in hadronic reactions and e^+e^- annihilations is also receiving renewed attention.[4,5] In this paper we will examine the similarities—and differences—expected for jets produced in diffractive dissociation and in e^+e^-, having first pointed out the conditions under which these similarities can be safely expected. The beams whose fragmentation we consider are photons and mesons. The dissociation of the proton, which remains an interesting and open question, receives no significant illumination from the present investigation.

The framework used will be based upon consideration of the flow of color charges[6] and their configuration in the "semifinal" state, i.e., after the hard scattering but before the nonperturbative processes responsible for the neutralization of color and formation of physical hadrons. We are thus assuming a two-step process, wherein the beam first dissociates or is diffractively excited by some mechanism and then the quarks and gluons (hereinafter collectively called chromons) interact softly to form the physical final state. This dichotomy between scattering process and final-state hadronization is a consequence of hard scattering and is a necessary condition for the applicability of perturbation theory. We suspect that the color-configuration arguments have a somewhat broader range of applicability than just to hard processes, and so our arguments may be more general than the perturbative language in which they are presented. In fact, some of the concepts we use have been used in dual models for soft processes. For example, color-singlet exchange ($q\bar{q}$) across large rapidity gaps has been suggested,[7] and the fragmentation of separating color charges has been treated.[8]

In order to compare the jets of diffractive dissociation with those of e^+e^-, we need a way of separating the $q\bar{q}$ jets resulting from the photon or meson fragmentation from the other debris present in these reactions, e.g., fragments of the target proton. This is conveniently accomplished by following the suggestion of Refs. 1 and 2 and requiring a large rapidity gap separating beam and target fragments—or even requiring an elastic recoil proton, i.e., the final proton being the only fast particle in one c.m. hemisphere. That this requirement does accomplish the desired separation can be seen by considering two different color configurations in the semifinal state in photoproduction, for example.

Consider first photon-gluon fusion[9] or one-gluon exchange (1GE).[10] After the initial hard subprocess the color configuration is as depicted in Fig. 1(a), a $q\bar{q}$ in a color-octet state receding in one direction while the fragments of the target, also a color octet, rush off in the opposite direction in the overall c.m. The soft hadronization process then creates $q\bar{q}$ pairs between the separating octets with small relative momentum, as indicated pictorially in Fig. 1(b). This leads to a final state in which large rapidity gaps are rare. (This picture does not necessarily conflict with the "primarily elastic" claim for ψ photoproduction[11] since there $M_{c\bar{c}}^2 < 4m_D^2$, whereas for us $M_{q\bar{q}}^2 \gg m_q^2$.) This final state is to be contrasted with that arising from (the color-singlet part of) two-gluon exchange[1,2] (2GE), or any other color-singlet exchange. The semifinal color configuration is shown in Fig. 2(a). The fragments of beam and target are now each separately in color-singlet states and do not exert the long-range

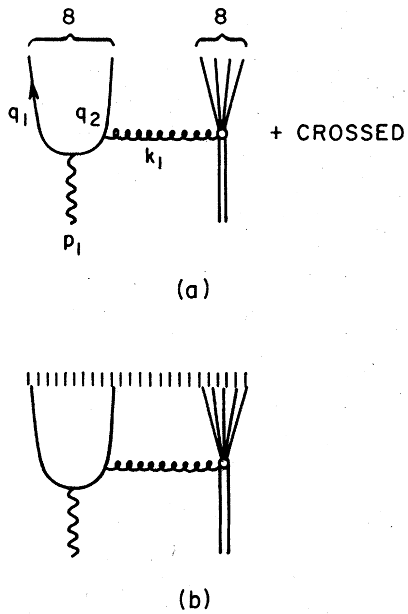

FIG. 1 (a) Semifinal color configuration resulting from one-gluon exchange. (b) Representation of the hadronization of the color configuration of one-gluon exchange.

confining force on each other.[12] The $q\bar{q}$ into which the photon dissociated then hadronize between themselves, as occurs in e^+e^-. The proton chromons also hadronize among themselves, leaving an unpopulated rapidity gap between the two sets of fragments, Fig. 2(b). Thus the large rapidity gap accomplishes two things for us. It effects the separation of beam fragments from other final particles, and it also marks events in which the $q\bar{q}$ from the diffractively excited beam fragment in the same color environment as they do in e^+e^- two-jet events.

A possible alternative to the large-gap suggestion would be to declare anything in the appropriate overall c.m. hemisphere to be a beam fragment and then to analyze the beam fragments in their own collective c.m. This would yield a better counting rate, and it could do a reasonable job of separating the beam and target fragment systems. If most or all events are used, however, the most likely dynamical mechanism would be of the 1GE type, in which case the beam $q\bar{q}$ would hadronize in a different environment than in e^+e^-. This could lead to differences between the diffractive dissociation $q\bar{q}$ and the $q\bar{q}$ in e^+e^-, in much the same way as the altered color configuration of $e^+e^- \to q\bar{q}g$ affects the (small-x) quark fragmentation.[13] These differences in $e^+e^- \to q\bar{q}$ or large-gap diffractive dissociation when compared to all diffractive dissociation could be interesting in their own right, but they lie outside the scope of this paper. We shall confine ourselves to the large-gap events.

The similarities that can safely be expected then occur when comparing the photon- or meson-fragment system in large-gap events to e^+e^- events at the same W $(=M=\sqrt{s})$. Multiplicity, $\langle p_\perp \rangle$, x distribution of jet fragments, sphericity, thrust, and invariant-mass distribution of the jets should all be the same. This is only true, however, to leading order in α_s. Because initial states of the subprocesses are different, the abundance and angular distribution of three-jet events need not be the same, leading to $O(\alpha_s)$ discrepancies in $\langle p_\perp \rangle$, thrust, etc.

In addition to the similarities between the jets in (large-gap) diffractive dissociation and e^+e^-, there are at least two important differences: the angular distribution of the jets, which is predicted in Refs. 1 and 2, and the fraction of the jets initiated by any given flavor quark or antiquark. In e^+e^- away from flavor thresholds $q\bar{q}$ pairs of different flavors are produced in proportion to their charges squared. In photon fragmentation this is true only at large angle θ^*, and in meson fragmentation, of course, the jets are initiated by the valence $q\bar{q}$ of the meson. As emphasized by Misra, Panda, and Parida,[5] this provides the unique opportunity to investigate jets of a known type.

As an example, consider the relative multiplicities of different flavors in e^+e^- and diffractive

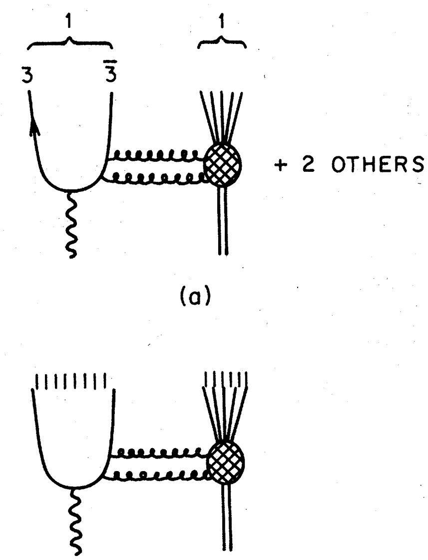

FIG. 2 (a) Semifinal color configuration resulting from two-gluon exchange. (b) Representation of the hadronization of the color configuration of two-gluon exchange.

dissociation. Following Field and Feynman,[14] let γ_a be the probability that in the fragmentation of a jet a newly created $q\bar{q}$ pair is of type $a\bar{a}$. For four flavors and isospin symmetry ($\gamma_u=\gamma_d$) there are two independent γ's, which we take to be γ_s and γ_c. They will determine the relative multiplicity of each flavor quark, which in turn determines the relative multiplicity of that flavor in the final state *provided* we have two additional pieces of information. We need to know the fraction of the final-state strangeness (charm) which is hidden in $s\bar{s}$ ($c\bar{c}$) bound states, and we need to know the probability that the jet was initiated by an s (c) quark. If we call the hidden fraction η, $\eta_s=2\langle n_{s\bar{s}}\rangle/\langle n_s+n_{\bar{s}}\rangle$, and let ρ_s be the probability that a strange quark or antiquark initiated the jet, then the number of strange hadrons in the final state of a $q\bar{q}$ two-jet process is given by

$$\frac{\langle n_S\rangle}{\langle n\rangle}=2(1-\eta_s)[\gamma_s(1-1/\langle n\rangle)+\rho_s/\langle n\rangle]\,, \tag{1}$$

where $\langle n\rangle$ is the average total multiplicity and we have assumed that

$$\langle n\rangle=\tfrac{1}{2}\sum_q\langle n_q+n_{\bar{q}}\rangle=1+\sum_q\langle n_q+n_{\bar{q}}\rangle_{\text{vac}}\,, \tag{2}$$

i.e., a two-jet event in which all final particles are quark-antiquark states. We adopt the convention that lower-case subscripts refer to quark quantities whereas capitals refer to hadrons carrying that quantum number, e.g., $\langle n_s\rangle$ vs $\langle n_S\rangle$. Equation (1) also applies to charm or other heavy flavors, of course, with s, S replaced by c, C.

Different approximations to Eq. (1) can be made for strangeness and charm. In the case of strangeness, only the 0^- $s\bar{s}$ state lies below the $K\bar{K}$ threshold so that it is reasonable to assume/hope that few of the strange quarks produced will be hidden in the final state (a hope which can be tested by measuring the η and η' cross sections). Therefore we let $\eta_s\simeq 0$. For charm we would expect that γ_c would be very small due to the large charm mass, so that $\gamma_c\simeq 0$ would be a good approximation provided $\rho_c\neq 0$. Also, if the charmed quarks occur only as the initial quark in the jet, one would expect $\eta_c\simeq 0$ for $W^2\gg 4m_c^2$. The other information available is $\rho_{s,c}$ for the four processes under consideration. In e^+e^- away from new-flavor thresholds, $\rho_s=0.10$, $\rho_c=0.40$ for four flavors. In large-gap π (K) fragmentation, of course, $\rho_s=0.0$ (0.5) and $\rho_c=0.0$ (0.0). For photon diffractive dissociation the situation is not quite so clean. As mentioned above, mass effects become important at small θ^*, where the cross section is largest. In addition, the predictions become less reliable as $\cos\theta^*$ gets very near 1. Nevertheless, we can obtain approximate values for ρ_s and ρ_c when the cross sections are integrated over all $\cos\theta^*$. The result is that ρ_s is about 0.10 to 0.15 for M^2 between 20 and 60 GeV^2 and ρ_c is about 0.22 at $M^2=60$ GeV^2.[1,2]

The approximations of the previous paragraph enable us to write Eq. (1) in the following approximate forms for the different reactions,

$$\begin{aligned}\langle n_S\rangle\nu &\simeq 2\left[\gamma_s(1-\nu)+\begin{Bmatrix}0.1\\0.09\end{Bmatrix}\nu\right],\quad e^+e^-,\quad W=\begin{Bmatrix}5\text{ GeV}-9\text{ GeV}\\11\text{ GeV}-?\end{Bmatrix},\\ &\simeq 2[\gamma_s(1-\nu)+0.12\nu],\quad \gamma\text{ fragmentation},\quad W=\sqrt{20}\text{ GeV}-\sqrt{60}\text{ GeV},\\ &\simeq 2\gamma_s(1-\nu),\quad \pi\text{ fragmentation},\\ &\simeq 2[\gamma_s(1-\nu)+\nu],\quad K\text{ fragmentation},\end{aligned} \tag{3}$$

for strange-particle production, and

$$\begin{aligned}\langle n_C\rangle\nu &\simeq \begin{Bmatrix}0.8\\0.73\end{Bmatrix}\nu,\quad e^+e^-,\quad W=\begin{Bmatrix}5\text{ GeV}-9\text{ GeV}\\11\text{ GeV}-?\end{Bmatrix},\\ &\simeq 0.44\nu,\quad \gamma\text{ fragmentation},\quad W\simeq\sqrt{60}\text{ GeV},\\ &\simeq 2\gamma_c(1-\eta_c)(1-\nu),\quad \pi, K\text{ fragmentation},\end{aligned} \tag{4}$$

for charm production, where for convenience we have written $\nu=1/\langle n\rangle$. The multiplicities of strange particles for the four different processes are described by the one parameter γ_s, and charmed-particle multiplicity predictions contain no parameters for two processes and the one combination $(1-\eta_c)\gamma_c$ for π or K fragmentation.

The fact that in meson diffractive dissociation the jets are of a known type has been of limited practical use in the above analysis. Because ρ_s is known in e^+e^-, it is unnecessary to go to other reactions to measure γ_s. For γ_c or $(1-\eta_c)\gamma_c$, meson fragmentation is probably the optimum reaction since such small effects would be lost in the leading charm production in e^+e^-. But because of the expected smallness of γ_c, it may be difficult to measure even in diffractive dissociation. If we investigate γ_s in more detail, however, the advantage of meson fragmentation can be used to good effect. In general, γ_s is not really a constant, but rather a function of x.[15] This functional dependence would be impossible to measure directly in e^+e^- (or γ fragmentation) where the final-state strangeness could have come from the short-distance process rather than from the soft hadronization. In large-gap pion diffractive dissociation, on the other hand, all the final strangeness comes from $s\bar{s}$ pairs produced in the fragmentation of the quark jets, and the x dependence of γ_s (and γ_c in principle) is accessible.

Before concluding it is appropriate to contrast this approach to the recent work of Ref. 5 (MPP). They suggest that in $\pi p \to Xp$ the entire system X be considered as having come from the hadronization of the $q\bar{q}$ into which the π dissociated. There seem to be some obvious difficulties with that approach: Why cannot the proton fragment? How would one treat $\pi\pi$ or pp scattering? (MPP actually consider $pp \to Xp$ and suggest that X consists of the fragments of the quark-diquark jets of the one proton which does dissociate.) The two-jet structure for X predicted by MPP will be present, but not for their reasons. Indeed, people have been observing two-jet structure in hadronic reactions for the past ten years. Excluding the final-state proton from the one jet will still leave a group of proton fragments with limited $p_\perp$ relative to the jet axis. Feynman's original description,[16] with or without suitable QCD language and embellishments,[6] makes more sense than assuming that all those particles recoiling with the proton in the overall c.m. are actually fragments of one of the valence quarks of the pion, this quark having been turned around in the initial collision.

To summarize then, we have given conditions under which the jets produced in diffractive dissociation of photons or mesons should be compared to the jets of e^+e^-. The jets in the diffractive reactions should be the same as those in e^+e^- in most respects, but they will have a different (previously predicted) angular distribution relative to the beam axis. Heavy-flavor multiplicities will also vary, and we have obtained predictions for the multiplicities of strange and charmed particles.

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