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MODEL-INDEPENDENT ANALYSIS OF QUARK AND GLUON FRAGMENTATION*

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ABSTRACT

Multiple jets produced in hard collisions fragment independently. Correlations between their fragments arise through dependence on the jet type (quark flavor, gluon). We propose a simple method for exploring the differences in quark and gluon fragmentation using data on correlations in e^+e^- and large p_T hadron collisions.

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Experimental tests of perturbative QCD rely on the factorization between hard scattering vertices and soft, non-perturbative processes. This factorization, which is expected[a] to hold in QCD [1], implies the universality of structure and fragmentation functions in all hard collisions. The present experimental evidence,[2] based on comparisons between deep inelastic, Drell-Yan, e^+e^- and large p_T hadron processes, supports such a universality (within the rather large uncertainties).

Here I would like to point out some simple consequences of factorization applied to a single process with several partons (jets) in the final state. Because the jets fragment independently, correlations between hadrons in different jets[b] can arise only through correlations in the jet types. Thus in $e^+e^- \rightarrow q\bar{q}$ the quark and antiquark have the same flavor, while in $e^+e^- \rightarrow q\bar{q}G$ there is precisely one gluon jet. We shall see how the hadron correlations can be used to obtain a quantitative measure of the flavor-dependence of quark fragmentation. A study of $e^+e^- \rightarrow$ 3 jets allows in principle a complete determination of the gluon fragmentation, without the need to identify individual jets. The method can also be applied to large p_T jets in hadron collisions. For earlier work along the same lines see ref. 3.

We begin by considering $e^+e^- \rightarrow q\bar{q} \rightarrow$ 2 jets, assuming that the hadrons associated with each jet have been identified by a cluster

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a) Complete proofs beyond two loops have not been given. See ref. 1.

b) In what follows we can neglect the usual short-range correlation by not considering soft hadrons.

algorithm. For the purposes of the following analysis <u>any</u> feature of the hadron distributions may be considered (except those that involve soft hadrons, to avoid short-range correlations between jets). Thus we could discuss the amount of energy carried by neutral particles, leptons coming from weak decays, etc. For definiteness we shall consider the charged hadron inclusive distribution D(z), with $z = E_h/E_{jet}$ being the fraction of the jet momentum carried by the hadron.

The inclusive hadron distribution measured in $e^+e^- \to 2$ jets is

$$D(z) = \sum_f \sigma_f \, D_f(z) \tag{1}$$

where $D_f(z)$ is the distribution for flavor f and

$$\sigma_f = e_f^2 \Big/ \sum_f e_f^2 \tag{2}$$

is the relative production rate of that flavor. The two-particle distribution, with one particle belonging to each jet and carrying the same fractional momentum, is

$$D(z,z) = \sum_f \sigma_f \, D_f^2(z) \tag{3}$$

since both jets have the same flavor. The correlation can be expressed as

$$D(z,z) - D^2(z) = \sum_f \sigma_f \, [D_f(z) - D(z)]^2 \quad . \tag{4}$$

Hence the correlation is always positive, and can vanish only if $D_f(z) = D(z)$ for all f, i.e., if all flavors have identical fragmentation functions. Since the σ_f are known[c)], an observed correlation can be

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[c)] Eq. (2) holds even after higher order corrections to the process $e^+e^- \to q\bar{q}$, provided only that quark mass effects can be neglected.

used to estimate the differences between fragmentation functions for different quarks. A negative correlation would imply a breakdown of factorization between the hard and soft physics.

In the above example the fragmentation functions of a quark and its antiquark were the same, $D_f(z) = D_{\bar{f}}(z)$. If they are different (e.g., the π^+ inclusive distribution), the above argument holds provided the particles measured in the two jets are charge conjugate (π^+ and π^-). Eq.(3) then reads

$$D(z,z) = \tfrac{1}{2} \sum_f \sigma_f \, [D_f^2(z) + D_{\bar{f}}^2(z)] \tag{5}$$

and eq. (4) is valid provided f and $\bar{f}$ are treated effectively as two different flavors. A measurement of the <u>same</u> particle in each jet (π^+ and π^+) would give

$$\bar{D}(z,z) = \sum_f \sigma_f \, D_f(z) \, D_{\bar{f}}(z) \tag{6}$$

which one can combine with (5) to obtain an expression for the differences between quark and antiquark fragmentation:

$$D(z,z) - \bar{D}(z,z) = \tfrac{1}{2} \sum_f \sigma_f \, [D_f(z) - D_{\bar{f}}(z)]^2 \quad . \tag{7}$$

Consider next $e^+e^- \to q\bar{q}G \to 3$ jets. Clearly the practical problems associated with defining these jets and determining their energies are more severe than in the 2-jet case. Note, however, that there is no need to accept "all" 3-jet events in the following analysis, nor to decide on which jets soft particles belong to. We can use our freedom in the fragmentation feature being considered by including only "clean" jets, e.g., those in which the transverse spread of the fast particles is below a given limit. Such a selection may reduce the "signal", i.e., the differences in the fragmentation distributions of the various jet types, but the method itself is not affected.

Consider then the inclusive distribution of particles in 3-jet events (possibly selected by applying a "cleanliness" criterion to each of the three jets). The one-particle distribution averaged over all jets and events is

$$D(z) = \frac{2}{3} D_q(z) + \frac{1}{3} D_G(z) \tag{8}$$

where $D_q(z)$ is the flavor averaged quark distribution given by (1). The fractional momentum $z = E_h/E_{jet}$ is calculated w.r.t. the energy of the jet in which the particle is found (or, more properly, w.r.t. the total energy of the fast particles in that jet). Similarly,

$$D(z,z) = \frac{1}{3} \sum_f \sigma_f \, D_f^2(z) + \frac{2}{3} D_q(z) \, D_G(z) \tag{9}$$

$$D(z,z,z) = \sum_f \sigma_f \, D_f^2(z) \, D_G(z) \tag{10}$$

are the two- and three-particle distributions, all particles being in separate jets and carrying the same fraction of the jet momentum.

The correlations can now be expressed as

$$D(z,z) - D^2(z) = \frac{1}{3}\left[\sum_f \sigma_f \, D_f^2(z) - D_q^2(z)\right] - \frac{1}{9}\left[D_q(z) - D_G(z)\right]^2 \tag{11}$$

$$D(z,z,z) - D^3(z) = \left[\sum_f \sigma_f \, D_f^2(z) - D_q^2(z)\right] D_G(z) - \frac{1}{27}\left[8D_q(z) + D_G(z)\right]\left[D_q(z) - D_G(z)\right]^2. \tag{12}$$

The first terms on the r.h.s. of (11) and (12) are proportional to the correlation (4), which can be measured in 2-jet events. Hence (11) and (12) can be directly used for determining the gluon fragmentation function $D_G(z)$.

The correlations (11) and (12) should be independent of the production angular configuration of the jets. Naturally one expects jet-jet correlations to arise as the angle between the jets becomes small and the jets begin to coalesce. There will also be energy-dependent (threshold) effects when one jet energy is low. A study of such limits on factorization could prove most interesting.

We shall conclude by briefly discussing the situation in hadron collisions ($\bar{p}p$ and pp) with two large p_T jets. Depending on the subprocess, the jets can be GG, qG or $\overset{(-)}{q}q$. Neglecting the production of heavy flavors and the differences between u and d quark fragmentation we are in effect dealing with just one (light) quark flavor. If σ_{GG}, σ_{qG} and σ_{qq} are the relative production rates for the final states ($\sigma_{GG} + \sigma_{qG} + \sigma_{qq} = 1$), the correlation analogous to (4) is

$$D(z,z) - D^2(z) = [\sigma_{qq}\sigma_{GG} - \tfrac{1}{4}\sigma_{qG}^2][D_q(z) - D_G(z)]^2 \qquad (13)$$

where $D_q(z)$ is now the light (u,d) quark fragmentation function. The correlation (13) is a product of a term depending on the hard vertex (the σ's) and a term describing the fragmentation (the D's). By changing the parameters in either one non-trivial consistency tests can be made.

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