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Role of gluon-jet fragmentation in heavy-quark production by hadrons

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The role of perturbative gluon-jet fragmentation $g\to Q\bar{Q}$ in heavy-quark production by hadrons is quantitatively assessed with respect to the more conventional mechanisms of fusion and flavor excitation. At the energy of the CERN $p\bar{p}$ collider this contribution is found to give $\sim 20\%$ of the inclusive large-p_T muon yield, and $\sim\frac{1}{3}$ of the opposite-sign dimuons. The bulk of the associated event structure is not very different from that of the other heavy-quark contributions combined, as far as decay leptons are concerned.

Halzen and Hoyer[1] have recently called attention to perturbative gluon conversion into a pair of heavy quarks, $g\to Q\bar{Q}$, as a possibly relevant source of large-p_T heavy quarks, and hence of large-p_T leptons, in hadron collisions. We have run the computer program COJETS,[2] which simulates QCD in hadron collisions and already includes this process, in order to make a more complete assessment of the importance of this source of heavy quarks with respect to the more conventional ones, fusion and flavor excitation. The program includes initial and final radiation of QCD quanta treated in the leading-pole approximation (LPA). Therefore, effects such as the initial-parton transverse momentum generated by the radiation which leads to scaling violations of initial parton densities, and the QCD degradation of the hard-scattered partons, which is especially important for the $g\to Q\bar{Q}$ mechanism because of the more intense radiation off gluons, are duly accounted for.

$g\to Q\bar{Q}$, where g is a hard-scattered gluon, is actually not a process strictly distinct from fusion. Like flavor excitation, it corresponds to diagrams which, at least in the case of a gg initial state, are already part of radiative fusion (Fig. 1). Rather than in the diagrams, the distinction lies in the different kinematical regions dominated by the intervening poles. Within the approximation schemes conventionally used, double counting is avoided when for each kinematical region the approximation scheme, or "mechanism," most appropriate to it is applied, with exclusion of others having a common diagrammatic structure. Thus, for $gg\to gQ\bar{Q}$, the kinematic region with a moderate-p_T gluon is appropriately treated with hard fusion binary diagrams and initial-gluon emission calculated in the LPA, whereas the region with a large-p_T gluon should be treated according to the $O(\alpha_s{}^2)+\text{LPA}$ approximation schemes corresponding to flavor excitation or gluon fragmentation, depending on the p_T configuration for the heavy quarks.

Once a large-p_T lepton is required, the calculation does not offer particular problems of stability for the kinematic regimes associated with all three types of contributions. Specifically, flavor excitation does not incur the cutoff-dependence problems met when calculating its contribution to the total heavy-quark cross sections,[3] as discussed in detail in Ref. 4. When calculating lepton yields, the largest source of uncertainty is represented by the heavy-quark fragmentation functions. For charmed quarks, the experimental data from e^+e^- colliders are sufficiently constraining and well described by a heavy-quark fragmentation function[5,6]

$$D_Q(z)\propto\left[z\left(1-\frac{1}{z}-\frac{\epsilon_Q}{1-z}\right)^2\right]^{-1}, \tag{1}$$

with $\epsilon_Q=\epsilon_c\simeq 0.25$. The resulting $\langle z\rangle\simeq 0.5$ is in good agreement with the early indications from neutrino data.[7] At large p_T, however, the lepton yield from charm represents only a relatively unimportant fraction. The main contribution comes from bottom-quark decays, whose fragmentation is more poorly known, quantitatively. Fitting the relevant experimental data with the functional form of Eq. (1), the limits on $\epsilon_Q=\epsilon_b$ are rather broad. In Ref. 4 we have used the muon inclusive yield as measured[8] by UA1 to constrain ϵ_b. The decay of the heavy-flavor hadron into the lepton plus other particles also requires some care. For bottom-particle semileptonic decays, the somewhat popular simplification of neglecting the mass of the secondary charmed particle leads to a substantial overestimate of the

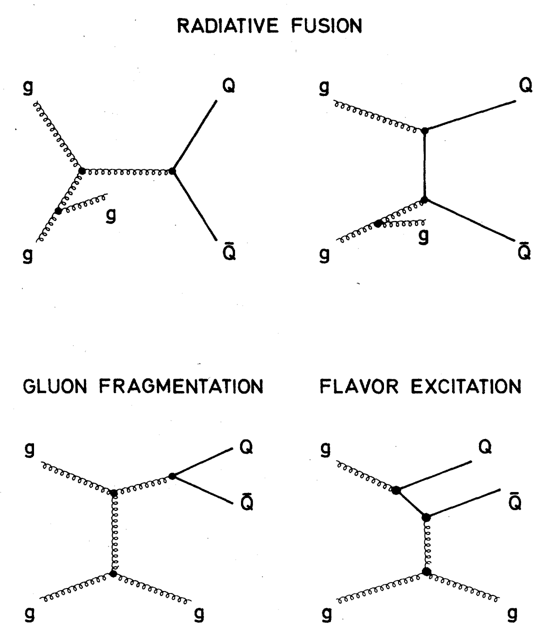

FIG. 1. Examples of Feynman diagrams contributing to radiative fusion, flavor excitation, and gluon fragmentation.

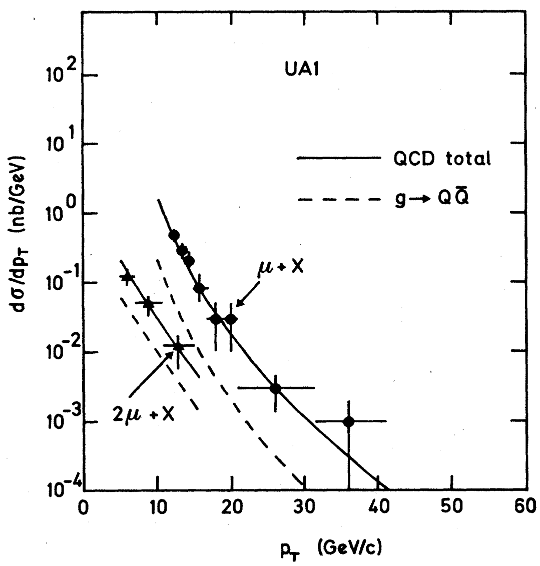

FIG. 2 Comparison with UA1 data (Ref. 8) of the muon and (opposite-sign) dimuon p_T distributions, calculated including fusion, flavor excitation, and gluon fragmentation (solid curves). The dashed curves refer to gluon fragmentation alone. Dimuons are defined by a cut $p_T > 5$ GeV/c on the muons (there are two entries for each event).

lepton yield and should be avoided.[9] Also, at large p_T the contribution from purely leptonic decay modes may become substantial, especially if additional selection criteria (e.g., lepton isolation) are imposed.[4] About the QCD perturbative part, it should be realized that some of the so-called higher-order contributions do not give negligible effects, especially when they involve semihard kinematic configurations. Everybody is prepared to appreciate the importance of scaling-violation effects for initial-parton densities, but the same QCD radiation source responsible for them is often neglected when dealing with the transverse momentum it generates for the initial partons and the momentum degradation it entails for the final hard-scattered quanta. That leads to an undue alteration of the results, which is especially sizable when gluons are involved. Moreover, one should take into account that when all radiation effects are included the final results are considerably stable towards the value of the QCD Λ parameter, because of compensation with the semihard momentum degradation, whereas neglecting them gives rise to a marked dependence of Λ due to the direct (and uncompensated) proportionality of the two-body matrix element to α_s^2.

Figure 2 reports the results we have obtained for the inclusive lepton yield, to be compared with the UA1 measurement.[8] The dominant source of large-p_T leptons is represented by semileptonic decays of bottom particles. We have taken 0.1 as the semileptonic branching ratio, and $\epsilon_Q = \epsilon_b = 0.001$ for bottom quarks in Eq. (1). We have also assumed $\Lambda = 0.1$ GeV, although the results depend little on its value. What we find is consistent with the calculation of

TABLE I. Main topological characteristics of dileptons, as generated according to the fusion, flavor-excitation, and gluon-fragmentation mechanisms. Numerical results refer to $p\bar{p}$ collisions at $\sqrt{s} = 540$ GeV, and a cut $p_T > 4$ GeV/c on the leptons. σ is the dilepton cross section, m and m_T the invariant and transverse dilepton masses, respectively, p_T the dilepton transverse momentum, f_{SS} the fraction of dileptons having an azimuthal aperture less than 90° (same-side dileptons).

	σ (nb)	$\langle m \rangle$ (GeV)	$\langle m_T \rangle$ (GeV)	$\langle p_T \rangle$ (GeV/c)	f_{SS}
Fusion	0.50	15.4	12.2	2.9	0.02
Flavor excitation	0.04	11.7	8.0	6.3	0.30
Gluon fragmentation	0.28	11.3	10.0	3.4	0.14

Ref. 1, once it is taken into account that (i) flavor excitation, not considered in Ref. 1, gives a contribution about 1.5 times larger than fusion, (ii) the charm-particle mass is neglected in Ref. 1 when handling bottom semileptonic decays, which leads to an overestimate of at least a factor of 2 in the lepton yield, (iii) the lepton yield from gluon fragmentation, which is found about equal to that of fusion in Ref. 1, goes appreciably down once radiation off the gluon (much stronger than radiation off heavy quarks) is taken into account, as we do. In sum, we find that gluon fragmentation gives a contribution of $\sim 20\%$ at $p_T(\mu) \simeq 10$ GeV/c, which becomes $\sim 10\%$ at $p_T(\mu) \simeq 40$ GeV/c.

For opposite-sign dimuon events the relevance of gluon fragmentation becomes somewhat more substantial, largely because of the poor large-p_T dilepton yield supplied by flavor excitation. This is a simple consequence of the fact that in the latter, one of the heavy quarks comes from initial semihard radiation, and therefore has a small mean p_T. Anyway, under the kinematic conditions of the UA1 dimuon measurement,[8] gluon fragmentation contributes only $\sim \frac{1}{3}$ of the dilepton yield (Fig. 2). Table I reports the mean values of several dilepton quantities illustrating the characteristics of dilepton topologies for the bulk of events generated according to the three mechanisms under consideration. As to dileptons with small invariant mass and large overall p_T, and therefore with the two leptons mostly lying in the same azimuthal half-plane, one can see, as noted in Ref. 1, that gluon fragmentation contributes some of them, whereas fusion gives a negligible contribution to such configurations. However, a comparable amount of this type of dilepton is supplied by flavor excitation, and moreover such dilepton topologies hardly appear to be a characteristic feature of gluon fragmentation, since they represent only a rather small fraction of the global dilepton yield from this mechanism.

About the $b\bar{b}$ background to the UA1 $\mu + 2$ jets signal, which has been calculated in Ref. 4, we have included in its computation the gluon-fragmentation mechanism and found that the latter increases it by $\sim 20\%$, which is of course immaterial in view of the other existing theoretical uncertainties. The same increase approximately applies to the $b\bar{b}$ background before the muon-isolation cuts.

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