Single-Jet Events at the Proton-Antiproton Collider—A Possible Interpretation via Top Flavor

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Pair production of a very heavy flavor like top leads to large-p_T isolated electrons back to back with jets as observed by Arnison *et al.* With a top-quark mass ~ 35 GeV, one can account for all the experimental features of these single-jet events available so far. Further tests for this interpretation are suggested.

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Experimenters at the proton-antiproton collider have recently observed[1] forty high-p_T (> 15 GeV) electron (or positron) events—six isolated $e\nu$ events, eleven single-jet events with an isolated electron coming back to back with a jet, and 23 two-jet events where the electron is itself part of a jet. Whereas W-boson production naturally accounts for the six jetless events, it cannot evidently account for the other two categories. We suggest that the single-jet events are due to top-particle production. Firstly, the same experiment has also observed eleven high-p_T (> 15 GeV) isolated neutrino events coming back to back with a jet. This suggests that the single-jet electron events also come from weak processes like semileptonic decay of heavy flavors rather than electromagnetic ones like the Drell-Yan process. Secondly, unlike the six jetless events, these single-jet events are strongly clustered near the p_T cut (15 GeV). This suggests that they are the tail end of processes peaked at lower p_T, like the heavy-flavor contributions. It has been realized for several years, in fact, that the dominant source of electrons in this p_T range should be the heavy flavors —charm, bottom, and top—each significantly larger than the W and the electromagnetic contributions.[2,3] The three have comparable magnitudes, but the bottom contribution turns out to be the largest and therefore a very serious background to a top-production signal. We shall see, however, that a clean separation between the top and the lighter flavor contributions is provided by the correlation between the electron and the accompanying hadron momenta in the semileptonic decay

$$Y \to e\nu X. \qquad (1)$$

For a $p_T \simeq$ 15-GeV electron, the e and X momentum directions are well separated for top decay but lie extremely close for bottom and charm decays, the former simulating an isolated electron and the latter an electron as part of a jet. Thus the single-jet and the two-jet events are expected to come from $T\bar{T}$ and $B\bar{B}+C\bar{C}$ productions, respectively.

We first illustrate the point with a simple calculation for electrons produced at 90°. For a three-body decay with $m_Y \gg m_X$, the electron momentum is peaked at $q_e \simeq m_Y/3$ in the Y rest frame. And since the production cross section is strongly damped in Y transverse momentum, the large-p_T electrons would correspond to q_e being aligned along the Y momentum p_Y—i.e., both in the transverse direction. Then a simple linear boost along this direction gives

$$p_e = (m_Y/3)\{p_Y/m_Y + [1+(p_Y/m_Y)^2]^{1/2}\}. \qquad (2)$$

This leads to entirely different configurations for typical T and B decays into 16-GeV transverse electrons:

Y	m_Y	p_e	p_Y	$p_{X\parallel} \simeq p_{\nu\parallel}$	$p_{X\perp} \simeq p_{\nu\perp}$
T	30	16	15	−1/2	10
B	5	16	24	4	5/3

Whereas the decay hadron comes essentially perpendicular to the electron for T decay, it closely follows the electron direction to within a 20° cone for B decay. Similarly the neutrino momentum component along the electron direction is essentially zero for T decay but significantly positive for B decay, and the neutrino momentum component in the perpendicular direction is small for B compared to T. The charm-decay configuration is similar to that for B except that the cone angle and the $p_{\nu\perp}$ are even smaller.

We have computed the $C\bar{C}$, $B\bar{B}$, and $T\bar{T}$ production cross sections using the perturbative QCD mechanism of quark-antiquark and gluon-gluon fusion (flavor creation). The relevant formulas are all very elegantly described by Combridge.[4] We have used the quark distributions from de Groot *et al.*,[5] the standard power-law gluon distribution, and a fixed $\alpha_s = 0.4$, for all the heavy flavors. The choices are favored by the $C\bar{C}$ production phenomenology.[6] The possible effects of Q^2 evolution can suppress the $T\bar{T}$ cross section by as much as a factor of 3–4, whereas inclusion of possible nonfusion mechanisms (flavor excitation)[4] can enhance it by a similar factor, in the kinematic range of our interest. Thus the magnitudes of the three heavy-flavor cross sections, and even their relative magnitudes, are only very crude estimates. On the other hand, the predicted kinematic configurations should be quantitatively reliable. The semileptonic decay formulas can be found in Ref. 6. For charm decay we take $e\nu K$ and $e\nu K^*$ final states with equal probability. For $B \to e\nu C$ and $T \to e\nu B$ also we take equal mixtures of pseudoscalar and vector mesons in the final state with a common mass of 2 GeV for C,[7] and 5 GeV for B. The electronic branching fraction is assumed to be 10% for each flavor.

Table I shows the predicted cross-sections for the pseudorapidity interval $|\eta_e| = 0-3$ and $p_{Te} = 15-25$ GeV, appropriate for the experiment of Ref. 1. The upper p_T cut retains ten of the eleven single-jet events. To facilitate comparison with experiment, we have shown the expected number of events in each case for the integrated experimental luminosity of 18 nb. The average p_T of the decay hadron is also shown. Figure 1 shows the relative azimuthal distribution between the electron and the accompanying hadron. Figure 2 shows the neutrino p_T distributions parallel and perpendicular to the electron p_T, along with the corresponding distributions of the ten single-jet events.

One readily sees from Fig. 1 that the decay electron from $B\bar{B}$ and $C\bar{C}$ is always accompanied by hadrons within a $\Delta\varphi$ of 15° and carrying a p_T of roughly 10 GeV. Thus it simulates a two-jet event according to the experimental criterion used. One indeed sees from Table I that the predicted rate is roughly consistent with the 23 events of this nature observed. Figure 2 shows that the corresponding $p_{T\nu}^{\perp}$ is much too small and $p_{T\nu}^{\parallel}$ much too positive compared to the single-jet events. They should, of course, be compared with the corresponding distributions of the double-jet events.

In contrast, the decay electron from a 35-GeV T particle emerges as an isolated electron with the associated hadron (B) coming out at large relative azimuthal angle (Fig. 1). Thus the $T\bar{T}$ contribution simulates single-jet events. The predicted rate agrees with the ten observed events (Table I), and the $p_{T\nu}^{\parallel}$ and $p_{T\nu}^{\perp}$ distribu-

TABLE I. Charm, bottom, and top contributions to large-p_T electrons of the experiment of Ref. 1 are shown for three top particle masses.

Flavor	σ (nb)	No. of events	$\langle p_{TX}\rangle$ (GeV)
C	0.28	5.0	9.5
B	1.19	21.4	11.9
T			
25 GeV	1.12	20.2	9.3
35 GeV	0.57	10.3	12.1
45 GeV	0.25	4.5	15.8

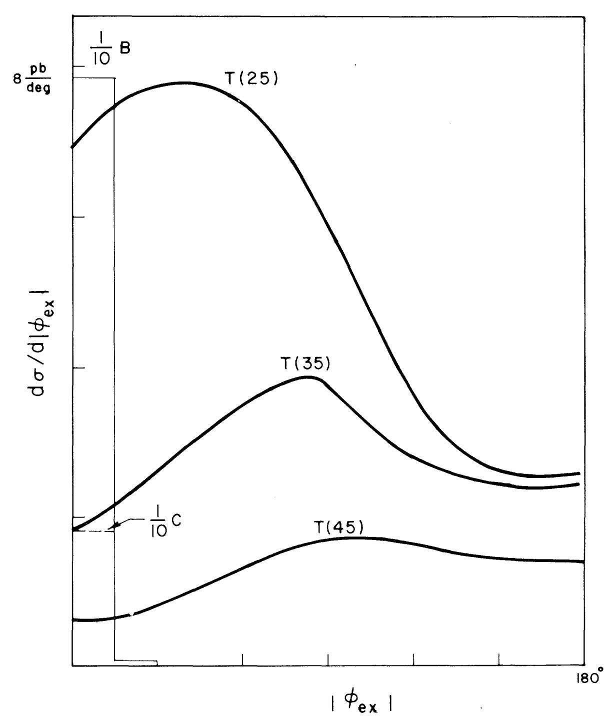

FIG. 1. Charm, bottom, and top contributions, shown as functions of the relative azimuthal angle between the electron and the accompanying hadron.

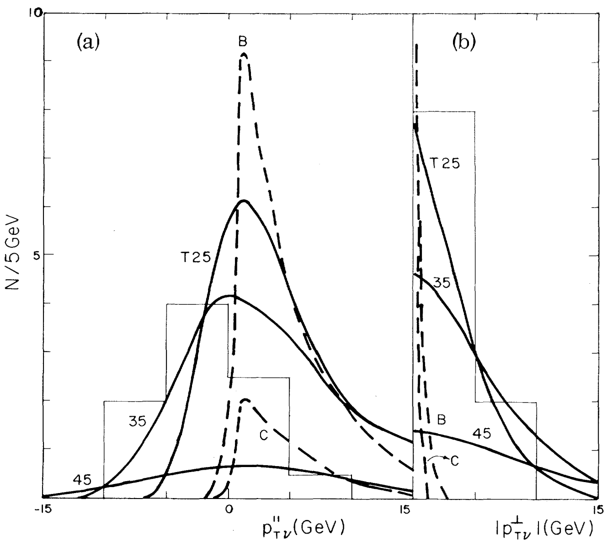

FIG. 2. Distribution of the single-jet events from Ref. 1 in the neutrino transverse momentum (a) along and (b) perpendicular to the electron transverse momentum. The charm, bottom, and top contributions are shown with free normalization.

tions are also consistent with these events (Fig. 2). The available data can tolerate a top-particle mass in the range 25–45 GeV. At larger mass values the production rate becomes too low and the $p_{T\nu}$ distributions too broad, while at smaller mass the isolated electron configuration becomes increasingly rare and the $p_{T\nu}^{\parallel}$ much too positive.

Finally, we should emphasize a couple of rather obvious predictions which can be checked with the available data. (1) The jet coming back to back with the electron should be a fat jet containing a top particle for flavor creation, and an ordinary narrow jet for flavor excitation.[4] For the latter case, the associated heavy flavor particle ($\bar{T}$) is expected to emerge along the beam line and hence escape detection. (2) In most of the single-jet events, one should in fact be able to see a second and smaller jet, corresponding to the decay product X (which is expected to be B most of the time). It should show up at $\varphi \sim 90°$ and $|\eta| < 1.5$ relative to the electron, and carry $p_T \simeq 12$ GeV and a charged multiplicity of 6–7 (typical of nonleptonic B decay).[7] Whereas (1) provides a distinguishing test for the top production mechanism, (2) provides an important confirmatory test for the top signal irrespective of the production mechanism.

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Note added.—After the completion of this work we have received a preprint by V. Barger, A. D. Martin, and R. J. N. Phillips (Univeristy of Wisconsin, Madison, Report No. MAD/PH/94-DTP/83/4), with a similar conclusion. They have not considered, however, what seems to us the most significant evidence for top so far—i.e., the event topology.

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