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$\bar{b}bX$ and $W \to \nu\tau$ backgrounds for the UA1 monojet signal

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Backgrounds from $W \to \nu\tau$ and $\bar{b}bX$, via the leptonic decay channel $B_c \to \nu\tau$, may account for three out of the five UA1 monojet events with $\Delta E_M > 40$ GeV.

The UA1 Collaboration has recently reported the observation in antiproton-proton collisions at $\sqrt{s} = 540$ GeV of "monojet" events, in which a very large missing transverse energy ΔE_M is associated with a single narrow jet of hadrons.[1] It has been claimed[1] that no conventional mechanism appears to be capable of producing the five observed events with $\Delta E_M > 40$ GeV.

It is the purpose of this note to present an estimate of the bottom-antibottom ($\bar{b}bX$) and $W \to \nu\tau$ backgrounds affecting the reported monojet signal, based on quantum chromodynamics (QCD) and the electroweak standard model. The $B_c \to \nu\tau$ decay mode, where B_c is the $(b\bar{c})$ pseudoscalar bottom state, is given due attention, and found to yield the dominant contribution within the $\bar{b}bX$ channel. Bottom-flavor excitation is also included, although it is not found to qualitatively alter the results.

A discussion of the UA1 cuts, efficiencies, etc.[1] is in order. Results are based on an integrated luminosity of 0.113 pb^{-1}. Trigger conditions do not sensibly affect rates at $\Delta E_M > 30$ GeV for the background sources we are considering. Monojet events with ΔE_M pointing to within $\pm 20°$ of the vertical are rejected. Monojet events which after subtraction of the jet have a residual ΔE_M pointing within an azimuthal sector $\cos\Delta\phi < -0.8$ with respect to the jet direction are rejected as well. The errors on the measured missing-transverse-energy components $(\Delta E_M)_y$ and $(\Delta E_M)_z$ are quoted to be normally distributed with standard deviations for both of them given by $0.5\sqrt{|E_{\rm tot}|}$, where $|E_{\rm tot}|$ is the observed total scalar transverse energy. This is obtained from a fit to the *bulk* of hadronic events. The cuts and the ΔE_M smearing can be easily taken into account in the present calculation. For the $\cos\Delta\phi < -0.8$ cut, the residual ΔE_M vector is computed from the accompanying (small-E_T) QCD radiation quanta and, for $\bar{b}bX$, from the other debris in the b jet generating the neutrino (or neutrinos). This procedure is based on the assumption that particles from spectator jets approximately balance in transverse momentum among themselves, which is reasonable because of the large multiplicities involved. The $(\Delta E_M)_y$ and $(\Delta E_M)_z$ smearings are computed taking a frozen $|E_{\rm tot}| = 100$ GeV (approximately) complying with the UA1 measurements for the events of interest. We should stress, though, that both the $\cos\Delta\phi < -0.8$ cut and the ΔE_M smearing do not qualitatively alter our results.

$\bar{b}bX$ background. In estimating neutral- or charged-lepton yields from this background source, one must realize that when making a high-p_T selection the relative importance of the various decay modes can dramatically change with respect to what happens for total yields. In particular, purely leptonic decay modes with small branching ratios can become an important or even dominant source of large-p_T leptons. We have already made this point in Ref. 2 when discussing the heavy-quark background to the UA1 $e/\mu + 2$ jets signal. In the present case, a crucial role is played by the $B_c \to \nu\tau$ decay mode, where B_c is the $(b\bar{c})$ pseudoscalar state. The branching ratio for this decay channel is expected to be[3] $B(B_c \to \nu\tau) \simeq 0.06$. A further penalization of this background source comes from the fact that it is a peculiar characteristic of B_c states, and no similar low-multiplicity decay channels are expected for other bottom states. Since experimental evidence appears to indicate that particle yields at large p_T are approximately independent of quantum numbers, one can reasonably expect that $\sigma(B_cX)/\sigma(bX) \simeq \frac{1}{4}$, because the b quark can recombine with u, d, s, and c quarks. Even taking that into account though, it turns out that

$$[d\sigma(B_c \to \nu\tau)/dE_T(\nu)]/[d\sigma(b \to \nu X)/dE_T(\nu)]$$

becomes larger than 1 at large $E_T(\nu)$ (Fig. 1). It is clear that the decay mode $B_c \to \nu\tau$, $\tau \to \nu X$ provides a relatively clean source of monojet events. It is equally clear that, differently from conventional semileptonic decay modes, this

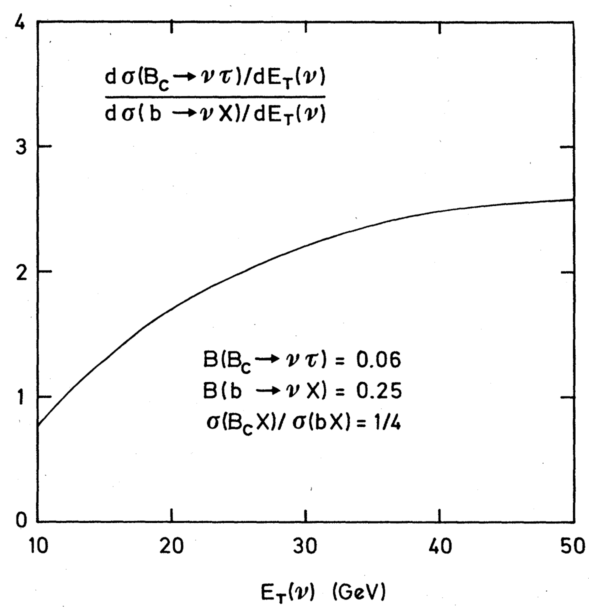

FIG. 1. Ratio of $d\sigma(B_c \to \nu\tau)/dE_T(\nu)$ to $d\sigma(b \to \nu X)/dE_T(\nu)$ at large $E_T(\nu)$.

type of background does not give corresponding events with an electron or a muon replacing the leading neutrino, and that therefore it cannot be monitored via the charged-lepton yield at large p_T.

The calculation of rates for this background source critically depends on the shape of the fragmentation function for bottom quarks. We assume for this sake the functional form of Ref. 4:

$$D_b(z) \propto \{z[1-1/z-\epsilon_b/(1-z)]^2\}^{-1} .$$

The determination of the ϵ_b parameter from electron-positron data is subject to strong uncertainties. Only the approximate bounds $0.001 \lesssim \epsilon_b \lesssim 0.08$ can be derived.[5] We fix ϵ_b so as to reproduce the large-p_T muon yield as measured[6] by UA1. We find that in order to achieve that a rather small value for this parameter is required,[2] $\epsilon_b \simeq 0.001$.

Calculations for $\bar{b}bX$ have been carried out using the program[7] COJETS, which includes QCD radiation off the initial and final partons in the hard binary parton process. Besides fusion ($gg, \bar{q}q \rightarrow \bar{b}b$) flavor excitation ($gb \rightarrow gb$, $qb \rightarrow qb$) is also computed. In the kinematic region of interest results for the latter are stable, as discussed in Ref. 2. Event rates reported in Fig. 2 are comprehensive of the semileptonic decay modes (which, however, give a small contribution) and of $B_c \rightarrow \nu\tau$, $\tau \rightarrow \nu X$. $\Lambda = 0.1$ GeV and a (Gaussian-distributed) transverse momentum for initial partons with $\langle K_T^2 \rangle = 0.4$ (GeV/c)^2 have been assumed. UA1 experimental cuts and ΔE_M smearing are applied, as discussed above. However, we have not imposed any cut on the maximum allowed transverse energy of the other jet debris accompanying the neutrino(s), since in Ref. 1 the minimal threshold for detection of the residual particle jet is not specified. Figure 3 gives the distribution in this quantity for $B_c \rightarrow \nu\tau$ events surviving the cut $\Delta E_M > 30$ GeV. Of course, what is presented here for the $\bar{b}bX$ monojet background is a theoretical estimate subject to all the uncertainties of this type of QCD calculation. The contribution from flavor excitation is comparable to that from fusion, and therefore its presence does not qualitatively alter the results.

$W \rightarrow \nu\tau$ background. The calculation of the contribution to monojet events from $W \rightarrow \nu\tau$, $\tau \rightarrow \nu +$jet is a relatively simple one. The only notable feature in the present calculation is the inclusion of initial QCD radiation, which, together with the intrinsic transverse momentum of initial partons, is responsible for the W transverse momentum. The calculations have been performed using the program[8] WIZJET. Corresponding results for the p_T distribution of the W and for the characteristics of the hadronic transverse energy produced in its association have been presented and compared with available UA1 data elsewhere.[9]

The total number of $W \rightarrow \nu\tau$ events should be the same as that of $W \rightarrow \nu e$ events. Normalizing to the number of $W \rightarrow \nu e$ events observed[1] by UA1, correcting for the branching ratio[10] $B(\tau \rightarrow \nu + \text{hadrons}) \simeq 0.65$, and for the azimuthal sectors of the UA1 apparatus counted out (80° in total), and finally applying a $E_T(\text{jet}) > 25$ GeV cut, inspired by the UA1 trigger conditions, we find that about 10 $W \rightarrow \nu\tau$ monojet events are left to contribute. This is in reasonable agreement with the 9 events obtained in Ref. 1 with a "full detector simulation." The ΔE_M distribution we

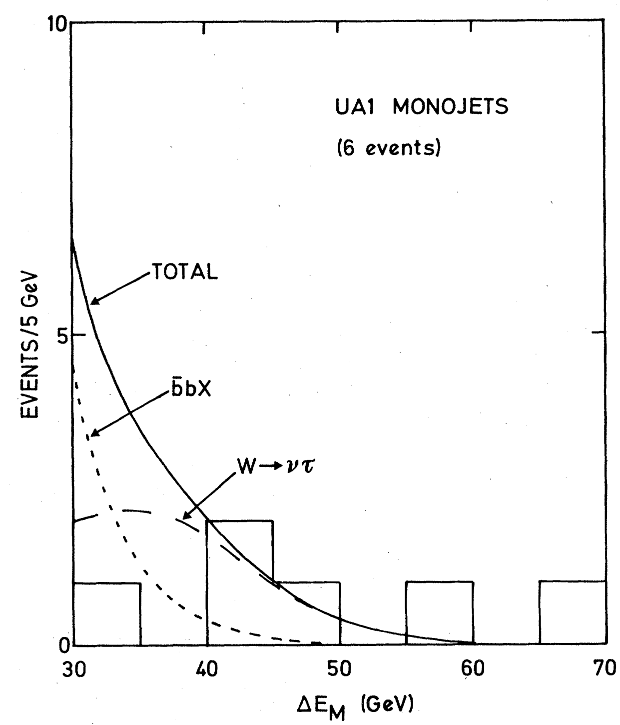

FIG. 2. Comparison of calculated $\bar{b}bX$ and $W \rightarrow \nu\tau$ backgrounds to monojet events with UA1 data (Ref. 1) at large missing transverse energy ΔE_M.

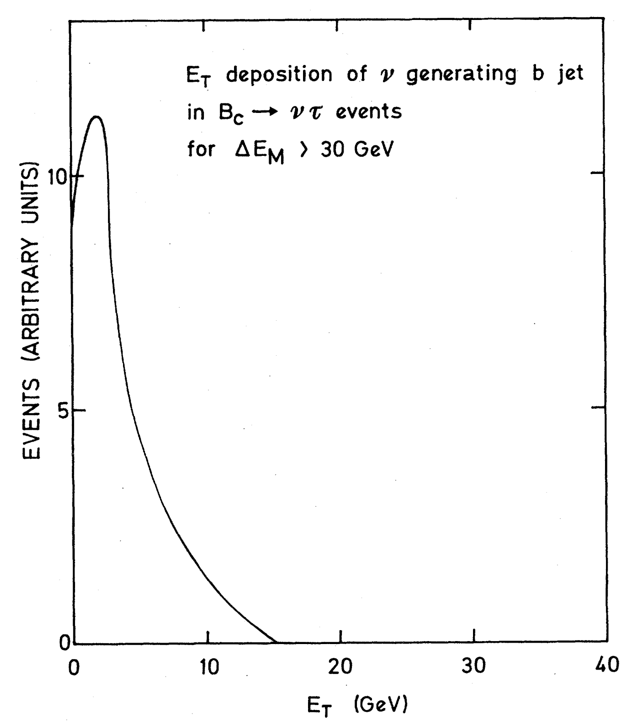

FIG. 3. Distribution in the calorimetric transverse energy deposited by the debris of the neutrino-generating b-quark jet in $B_c \rightarrow \nu\tau$ events for $\Delta E_M > 30$ GeV.

find for these events, however, has a more substantial tail at large ΔE_M than that reported in Ref. 1. We are able to recover the distribution quoted there only by forcing neglect of the transverse momentum of the W. In Ref. 1 not enough details are given to better understand the origin of the discrepancy. The result reported in Fig. 2 includes experimental ΔE_M smearing, as quoted in Ref. 1.

The combined $\bar{b}bX$ and $W \rightarrow \nu\tau$ monojet background for $30 < \Delta E_M < 40$ GeV appears to be even larger than the event rate observed by UA1 in this region (Fig. 2). Of course, the present poor experimental statistics makes a strict quantitative comparison immaterial. The very same QCD and $W \rightarrow \nu\tau$ backgrounds calculated[1] by UA1 appear to exceed the observed event rate for $25 < \Delta E_M < 35$ GeV.

In conclusion, three out of the five monojet events observed by UA1 for $\Delta E_M > 40$ GeV appear to be attributable to conventional background sources. Experimental data with higher statistics will allow clarification of the significance of the residual monojet signal at $\Delta E_M > 50$ GeV.

Note added. The assumption that at large p_T (≥ 30 GeV) yields of bottom particles are approximately independent of other quantum numbers implies the existence of a nonperturbative source of charm quarks. It should be clear that the assumption only demands that such a source is active when the phase space available for fragmentation is large with respect to the charm-quark mass, so that phase-space constraints act approximately in the same way for u, d, s, and c quarks.

Monojet events are defined according to Ref. 1 (footnotes 5 and 6), i.e., as containing no more than one jet with $\Delta R = 1$ and $E_T > 12$ GeV. For $W \rightarrow \nu\tau$ events, jets are reconstructed by clustering with $\Delta R = 1$ resolution the τ-decay (hadronic) debris and QCD bremsstrahlung quanta (the reconstructed jet may therefore turn out to have an invariant mass larger than the τ mass).

The $\tau \rightarrow \nu +$hadrons decay model used (see Refs. 7 and 8 and references therein for details) is a phase-space model yielding a hadron multiplicity distribution of approximately Gaussian form with $\langle n \rangle = 2.8$ and $< n^2 - \langle n \rangle^2 >^{1/2} = 1.5$ (the $\tau \rightarrow \nu\pi$ channel has a branching ratio $\simeq 0.10$). Polarization effects are neglected, since they are important only for the $\tau \rightarrow \nu\pi$ decay mode whose contribution at large ΔE_M is small anyway. The contribution at $\Delta E_M \gtrsim 30$ GeV is dominated by the higher-multiplicity decay modes, for which detailed modeling is irrelevant in the present application, and left somewhat arbitrary by present data, anyway.

Still, for the $W \rightarrow \tau\nu$ background, at $\Delta E_M > 40$ GeV the p_T distribution of the W is not appreciably different from that observed (and calculated[9]) for the bulk of $W \rightarrow e\nu$ events. In the same ΔE_M region, multiple QCD bremsstrahlung yields a mean multiplicity of 1.9 for quanta with $E_T > 1$ GeV.

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