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Multijet cross sections in hadronic collisions

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Multijet events have been extensively studied at the CERN $p\bar{p}$ collider. The production rates and the topology of the events can be quantitatively understood in the framework of perturbative QCD. There are many "new physics" processes for which such multijet events are an important background. We examine several such processes, including Higgs boson, heavy-quark pair, and heavy Z production. In each case we calculate the signal and background rates and investigate the efficacy of topological cuts on the final states. Our results have important consequences for future very-high-energy hadron colliders.

I. INTRODUCTION

Many physics processes which one might wish to study at future hadron colliders have multijet final states as a dominant decay mode. Examples include WW, ZZ, Higgs bosons (neutral and charged), $Q\bar{Q}$, and Z' (a new heavy Z-like boson) production. A major difficulty in identifying these processes is that there is a potentially large background from QCD jet production, i.e., from subprocesses of the general form $ab \to c_1 \cdots c_n$ with a,b,c_i quarks and gluons. Although such background cross sections are invariably large, compared with the "weak" processes of interest, they do not have the same invariant-mass combinations in the final state. (We shall use the term "signal" to denote new processes of interest, such as those listed above.) Ultimately, the question is whether the background rate can be substantially reduced by a judicious sequence of mass, angular, . . . cuts appropriately chosen for a particular signal.

The purpose of the present paper is to study a variety of signals and backgrounds which are relevant for present and future hadron colliders. Recent advances in the technology of calculating Feynman diagrams for multiparton processes now allow a fairly reliable estimate of QCD jet production. The exact matrix elements for all $2\to 2$, $2\to 3$, and $2\to 4$ parton subprocesses are known. Furthermore, it is now possible to estimate the matrix elements for $2\to N$ processes with $N\geq 5$ to study, for example, the six-jet background to heavy-quark pair production and decay. The details of the approximations involved are presented below.

In a general survey we are not of course able to explore all possibilities for every process. Our conclusions are, however, rather pessimistic. We are unable to identify any process of interest for which one could confidently state that the jet decay mode is observable. For certain processes, for example, WW production, this result has already been anticipated—we are now able to quantify the situation. We should of course mention that alternative decay modes, in particular those involving leptons, are usually available and are generally less affected by backgrounds. Nevertheless there is inevitably a loss in rate. The inaccessibility of jet decay modes also has important implications for detector design.

The outline of the paper is as follows. In the next section we discuss the paradigm process: $W,Z \to$jets. We illustrate the general problem of QCD jet background by a simple analytic calculation. We choose another simple process, $W\to t\bar{b}\to 4$ jets, which is also relevant for present colliders, to illustrate the effect of multiple mass cuts on the final-state jets. The main results of this work, concerning the physics of future hadron colliders, are presented in Sec. III. We study several processes in detail and also discuss a simple approximation for calculating $N\geq 5$ jet production in QCD. Section IV contains some concluding remarks.

II. $W\to$JETS

All the information on the W and Z bosons at the CERN $p\bar{p}$ collider has been obtained using the leptonic decay modes;[1] the $q\bar{q}$ decay modes have only recently been tentatively identified.[2] The problem is that there is an overwhelming number of jet pairs, produced by $2\to 2$ parton scattering, with an invariant mass of order M_W. We can illustrate this in a simple analytic way. Consider the production of a $u\bar{d}$ pair (i) by the strong-interaction process $u\bar{d}\to u\bar{d}$ and (ii) by W production and decay: $u\bar{d}\to W\to u\bar{d}$. The cross section for producing a jet pair of invariant mass M at center-of-mass scattering angle θ is

$$\begin{aligned}\frac{d^2\sigma_{u\bar{d}}}{dM^2 d\cos\theta} &= \frac{1}{32\pi M^2 s}|\mathcal{M}|^2\frac{d\mathcal{L}}{d\tau}\,,\\ \frac{d\mathcal{L}}{d\tau} &= \int dx_1 dx_2 \delta(x_1x_2-\tau)\\ &\quad\times[G_{u/p}(x_1,Q)G_{\bar{d}/\bar{p}}(x_2,Q)+(p\leftrightarrow\bar{p})]\,,\end{aligned} \tag{1}$$

where $\tau = M^2/s$. Integrating over a narrow mass range of width 2Δ centered on the W mass M_W and over an angular range $\theta_0 \leq \theta \leq 180° - \theta_0$ gives

$$\sigma_{u\bar{d}} = \frac{\Delta g_s^2}{18\pi M_W s} \frac{d\mathcal{L}}{d\tau} f(\cos\theta_0) \,,$$
$$f(c) = 2c + \frac{16c}{1-c^2} - 4\ln\frac{1+c}{1-c} \,. \tag{2}$$

The corresponding result for $u\bar{d}$ produced via W decay is

$$\sigma_W = \frac{\pi^2 \alpha}{48 s \sin^2\theta_W} c(3+c^2)\frac{d\mathcal{L}}{d\tau}, \quad c = \cos\theta_0 \tag{3}$$

assuming that $\Delta > \Gamma_W$. The signal-to-background ratio is therefore

$$\frac{\sigma_W}{\sigma_{u\bar{d}}} = \frac{M_W}{\Delta} \frac{\alpha}{\alpha_s^2} \frac{9\pi}{1280 \sin^2\theta_W} F(c) \,, \tag{4}$$

where F is an angular function, normalized to $F=1$ at $c=0$, i.e., $\theta_0 = 90°$. Notice that this ratio is independent of the parton luminosities and, as expected, is proportional to the ratio of the weak coupling and the strong coupling squared. Perhaps surprisingly we find, on substituting standard values for the parameters, that numerically the ratio is of order 1:

$$\frac{\sigma_W}{\sigma_{u\bar{d}}} = \frac{6.1 \text{ GeV}}{\Delta} \tag{5}$$

for $\theta_0 \approx 90°$. In other words, the rates for producing a $u\bar{d}$ pair from W decay and a "fake" $u\bar{d}$ pair from QCD $2 \to 2$ scattering are similar. (Note that R decreases as θ_0 decreases because of the forward singularity in the QCD matrix element—the signal-to-background ratio is largest for centrally produced jets.)

The reason why looking for W and Z in the two-jet final state is so difficult is not because the strong cross sections are intrinsically large—rather it is because the $u\bar{d}$ final state is such a small fraction of total two-jet production, i.e., summed over all quark and gluon pairs. With a standard choice of structure functions we find that at the W mass at $\sqrt{s} = 630$ GeV

$$\frac{\sigma_{u\bar{d}}}{\sigma_{jj}} \approx 3\% \,. \tag{6}$$

So in fact most of the large background comes from two-jet final states which do not have the "correct" flavor quantum numbers for W decay. Since it appears to be impossible to tag jets according to their parent parton on an event-by-event basis, the situation is very difficult. Recently, however, the UA2 Collaboration have identified an excess of two-jet events in the vicinity of the W and Z mass, approximately consistent with expectations from hadronic W and Z decay.[2]

We have studied the single-W case in some detail to illustrate a general problem which will arise again in the examples studied below—the large backgrounds to new physics processes with quarks in the final state generally involve gluon jets. The situation in fact gets worse at higher collision energy as scattering processes involving gluons become more important.

A second case of interest which may again be relevant for the present generation of $p\bar{p}$ colliders is the process $p\bar{p} \to W \to t\bar{b} \to 4$ jets. The rate for this is potentially an order of magnitude larger than the usual semileptonic top-quark decay modes which have been studied in some detail.[3] Here the background comes from QCD $2 \to 4$ scattering processes. All the relevant matrix elements are now known and so this background can be calculated numerically.[4] We have studied this situation at present collider energies and preliminary results have been presented elsewhere.[5]

We first of all specify a set of jet cuts which should lead to a clean set of four-jet events. Guided by the $W \to 2$ jets analysis we require the jets to be central in rapidity (thus avoiding the forward/backward region where the background cross section is very large). In order to retain a sizable fraction of the signal, however, these cuts cannot be too stringent. A suitable choice is

$$p_T^{\min} = 5 \text{ GeV}/c, \quad |\eta_j| < 1.0, \quad \theta_{jj} > 45° \,. \tag{7}$$

At $\sqrt{s} = 630$ GeV this gives a total $W \to 4$ jet cross section of 44 pb with $M_t = 40$ GeV$/c^2$. The acceptance cuts on the jets have reduced the signal by a factor of 15, arising mainly from the rapidity cuts. At this stage one might argue that the standard semileptonic top-quark decay becomes more attractive. It must be remembered however that this also suffers a reduction in signal from transverse momentum, rapidity, and isolation cuts on the charged lepton. The four-jet background with the jet cuts of Eq. (7) is 0.6 μb, more than 4 orders of magnitude larger. Again we stress that most of the background jets do not have the same flavor combination (e.g., $u\bar{d}b\bar{b}$) as the signal. However one might argue that the comparison is unfair since the $t\bar{b}$ jets have a distinctive topology: the four-jet invariant mass is M_W and three of the jets have an invariant mass M_t. Accordingly, we impose on the background the requirement that M_{4j} should lie in the range $M_W \pm 10$ GeV$/c^2$. This reduces the background from 0.6 μb to 39 nb. The next step is to look for a clustering of the three-jet mass. Since for the $t\bar{b}$ signal the $\bar{b}$ jet is almost always the fastest, we identify the slowest three jets with the top quark and consider the ratio $\xi = M_{3j}/M_{4j}$. For the signal this should in principle be almost a δ function: in practice the experimental jet resolution will determine the width of the peak. The distribution in ξ for the four-jet background is shown in Fig. 1. It is interesting and at first sight surprising that this also shows a peak at around $\xi = 0.5$, which would also correspond to a top-quark mass of 40 GeV$/c^2$. The reason for this is that the jet cuts have led to a situation where a large fraction of the background events have a similar topology to the $t\bar{b}$ signal. The conclusion from this analysis is therefore that the background is uncontrollably large. Note that varying the cuts in Eq. (7) has little impact on this result. For example, Fig. 2 shows the effect of changing the jet-transverse-momentum threshold on both the signal and background—evidently the ratio is quite insensitive to this cut.

To summarize, we have illustrated the two main difficulties in trying to extract signals from multijet backgrounds. The first is that most of the background does

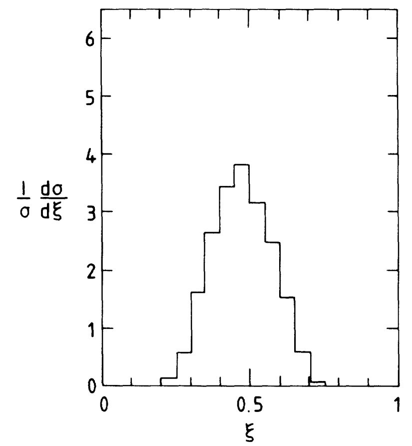

FIG. 1. Distribution in the variable $\xi = M_{3j}/M_{4j}$ for the QCD four-jet background for $W \to t\bar{b}$ production in $p\bar{p}$ collisions at $\sqrt{s} = 630$ GeV.

not have the same flavor structure as the signal but there is no way at present to select events of the correct type. The second is that requiring the jets to be energetic, central, well separated, etc., inevitably means that a significant fraction of the background events are able to mimic the mass combinations of the signal. This is especially relevant if the jet mass resolution of a particular experiment does not allow for narrow mass cuts.

III. JET BACKGROUNDS AT VERY-HIGH-ENERGY HADRON COLLIDERS

The next generation of hadron colliders will search for new physics in the mass range up to several TeV. Already, a substantial amount of work has been done to study the various ways in which this new physics might be manifest.[6] Inevitably such studies have concentrated on the *signals* rather than on the *backgrounds.* It has however been realized that jet decay modes are potentially susceptible to large backgrounds. We can illustrate the problem quite simply by calculating the cross sections for n-jet final states as a function of the total jet invariant mass. For definiteness, we choose pp collisions at 17 TeV [the energy of the proposed CERN Large Hadron Collider (LHC)] and a typical set of jet cuts:

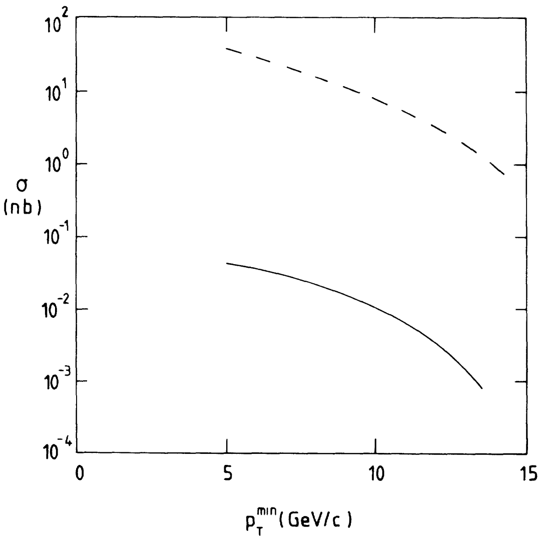

FIG. 2. Dependence on the jet transverse-momentum threshold for the four-jet signal and background for $W \to t\bar{b}$ production in $p\bar{p}$ collisions at $\sqrt{s} = 630$ GeV.

$$p_T^{\min} = 50 \text{ GeV}/c, \quad |\eta_j| < 3.0, \quad \theta_{jj} > 30^\circ . \tag{8}$$

The p_T threshold is now set much higher than at 630 GeV, in order to remain in the perturbative domain. Notice that we are concentrating on hard, well-separated jets characteristic of the final states expected from new physics signals. For such configurations it is appropriate to use exact lowest-order matrix elements rather than QCD-inspired jet fragmentation Monte Carlo simulations. The latter are of course important for analyzing the expected shape and content of the parton jets, but are not appropriate for multijet final states where, because of hardness and separation requirements, the leading-pole approximation is not valid.

The matrix elements for the $2 \to N$ parton subprocesses are known exactly for $N \leq 4$ (Ref. 7). We estimate those for $N = 5, 6, \ldots$ using an approximation based on a result of Parke and Taylor,[8] who have shown that a particular helicity amplitude for $gg \to ng$ has a simple analytic form in the large-N_c limit. We assume that all helicity amplitudes are of comparable size numerically and simply multiply the analytic form by a combinatoric factor. This is of course an approximation, but it can be shown to be reasonable for $N = 4$ where the exact result is known. It also agrees quite well with another recent attempt to estimate the exact amplitudes.[9] Although the corresponding quark matrix elements are unknown, we can use the effective structure function approximation; i.e., we use only the gluon scattering amplitude multiplied by the structure function $G + 4/9(Q + \bar{Q})$ for each hadron. This is known to be a good approximation for 2,3-jet production, and is expected to improve with increasing collider energy as gluon scattering becomes more important. Another source of uncertainty is the choice of scale for the argument of α_s and the structure functions: the more powers of α_s the greater the uncertainty. We have chosen to use $Q = \langle p_T \rangle$, the average transverse momentum of the jets in a given event. The UA1 Collaboration have preliminary results for the multiplicity of large p_T jets at $\sqrt{s} = 630$ GeV up to and including six-jet final states.[10] We have checked that our predictions are in broad agreement with the data. If anything, we tend to slightly underestimate the 5,6-jet rates. To summarize, there is some uncertainty in all our jet rates from the choice of scale (equivalently, the lack of knowledge of the K factors) and in our $5, 6, \ldots$-jet rates from approximating the matrix elements. However, our cross sections *are* expected to have essentially the correct kinematical structure, in terms of the jet energy and angular distributions.

The cross sections for the multijet final states with the above cuts are shown in Fig. 3. (Note that all our cross sections are evaluated using the Set 1 distributions of Ref. 11 with the QCD scale set equal to the average jet transverse momentum in an event.) At small jet mass we see the expected hierarchy of cross sections. (We use the term "jet mass" to denote the invariant mass of the multijet final state.) Notice however that the more "jetty" final states become more important at large jet mass. We have chosen to terminate our distributions at $M = 2$ TeV/c^2 for reasons of statistics, and also because our perturbative approach breaks down when the jet rates become comparable. Fortunately, most detectable new physics processes occur at lower masses. The jet multiplicity fractions are shown in Fig. 4, integrated over all jet masses (solid circles) and for large mass ($M > 1$ TeV/c^2) final states (open circles).

Figure 3 can be used directly to read off any background of interest. For example, consider the production of a new heavy Z-like boson: $pp \to Z' + \cdots$. We may assume that the Z' is produced by the usual $q\bar{q}$ annihilation mechanism, but with a coupling which is suppressed relative to that of the standard Z—the degree of suppression depending on the model. If we take as an upper limit the *same* coupling to quarks for Z and Z' and the *same* branching ratio (70%) for the two light-quark jets then the signal and background can be calculated and compared. Figure 5 shows the $pp \to Z' \to 2$ jet cross section as a function of $M_{Z'}$ with the same jet cuts as above. Note that for ease of comparison, this signal has been multiplied by a factor of 1000. The background is calculated as the cross section for a pair of QCD jets in a 10-GeV/c^2 invariant-mass bin centered on $M_{Z'}$. It is of course straightforward to rescale both of these cross sections for different Z' couplings and different bin sizes. Evidently the signal-to-background ratio increases from 0.001 to 0.01 as $M_{Z'}$ increases from 300 to 3000 GeV/c^2. The slight difference in shape is due to the different effect of a fixed rapidity cut for different masses on the two cross sections. The background is therefore overwhelming, for the same reasons described above for W and Z production at $\sqrt{s} = 630$ GeV. Detection will once again be via the leptonic decay channels.[6]

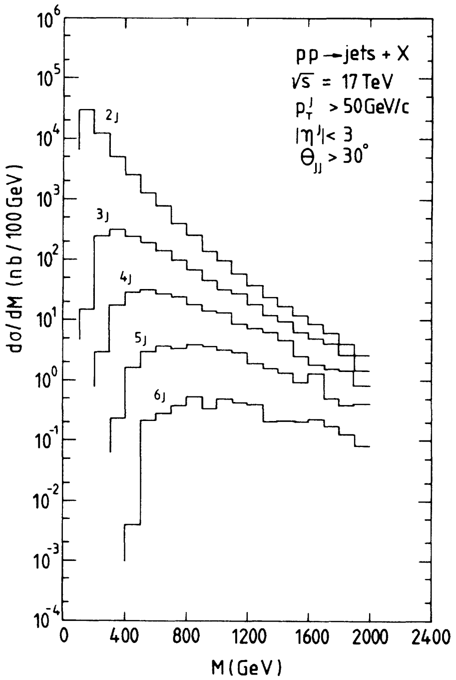

FIG. 3. Multijet cross sections in pp collisions at $\sqrt{s} = 17$ TeV with the jet cuts of Eq. (8), as a function of the total jet invariant mass.

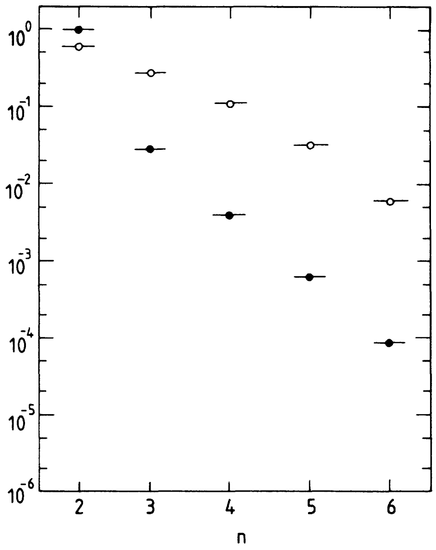

FIG. 4. Jet multiplicity fractions for the cross sections of Fig. 3, integrated over all jet masses (solid circles) and over multijet final states with $M > 1$ TeV/c^2 (open circles).

We next investigate processes with four jets in the final state. The most important example is the production and decay of the standard heavy Higgs boson. For $M_H > 200$

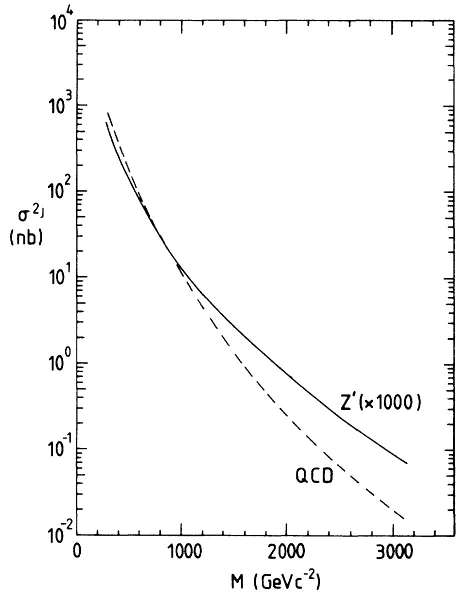

FIG. 5. Cross section for the production of a new Z' boson with mass M in pp collisions at $\sqrt{s} = 17$ TeV (multiplied by a factor of 1000), assuming the same couplings to light quarks as the standard Z and including a branching ratio of 0.7 for the two-jet decay mode (solid line). Also shown (dashed line) is the QCD two-jet background, defined as the cross section for two jets with an invariant mass in the range $M \pm 5$ GeV/c^2. Other jet cuts as listed in Eq. (8).

GeV/c^2 the dominant decay modes are $H \to WW$ and $H \to ZZ$ in a ratio of about 2:1. The total branching ratio for $H \to 4$ jets is then approximately 0.5. The corresponding decay branching ratio for a four- (observable) lepton final state, $H \to l^+l^-l^+l^-$ with $l = e,\mu$, is only 0.0012 by comparison. There is an enormous volume of literature on Higgs-boson production at high-energy hadron colliders, mostly concentrating on the leptonic channels.[12]

In attempting to control the four-jet background, we encounter a similar problem to the $W \to t\bar{b}$ search described above: if we impose *tight* jet cuts to reduce the QCD background then the signal is decreased. Since heavy-Higgs-boson total cross sections are not large to begin with, we risk losing the signal altogether. In addition, if more than 2 orders of magnitude of signal are lost through the jet cuts, then the purely leptonic channels become potentially more efficient. For illustration we choose $M_H = 500$ GeV/c^2. Before jet cuts, the total $H \to 4$ jets cross section is 0.48 pb. With the standard jet cuts listed above, this is reduced to 0.06 pb. Figure 6 shows the four-jet mass distribution for the signal and background, using a bin width of 40 GeV/c^2. For display purposes, the signal has been multiplied by a factor of 1000. The background-to-signal ratio is enormous. Decreasing the jet p_T threshold and reducing the minimum jet separation causes the background to increase at an even faster rate than the signal, as in Fig. 2. The next step is to try to reduce the background by requiring that there are two pairs of jets in the final state with a mass near M_W or M_Z. One possible algorithm is to accept only those jet events in which there are two pairs of jets whose masses differ by less than, say, 20 GeV/c^2, i.e., $|m_{12} - m_{34}| < 20$ GeV/c^2. Figure 7 then shows the distribution in the jet-pair mass $M = m_{ij}$ (two entries per event). There is clearly a sizable number of background events in the 70–100 GeV/c^2 range. The effect of selecting only those four-jet events falling within the above ranges is shown by the dashed histogram in Fig. 6. The actual cross sections are 224 (total 4 jets), 52 (total 4 jets with two pairs of similar mass), and 1.5 nb (total 4 jets with two pairs each in the M_W, M_Z mass range). The suppression is largest for large-mass final states, but is still many orders of magnitude short of approaching the signal. Although for illustration we have chosen a very specific set of parameters and cuts, we have checked that our conclusions are valid in general. We therefore arrive at the conclusion that one weak boson must decay leptonically to have any possibility of an observable signal. It is interesting to note that for a high-energy e^+e^- collider, the heavy Higgs boson *can* be detected via the four-jet decay mode, as there is no correspondingly large QCD background.[13] It is known that the cross sections for double weak boson pair production $q\bar{q} \to WW, ZZ$ are of comparable size to Higgs-boson cross sections.[11] We can therefore also state that this class of four-jet processes is also completely obscured by the QCD jet background.

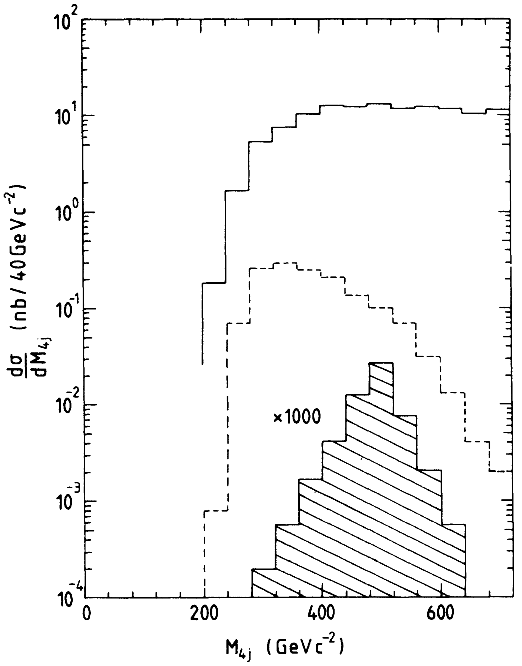

FIG. 6. Four-jet invariant-mass distribution for Higgs production (shaded histogram, multiplied by a factor of 1000) and QCD background (solid histogram) in *pp* collisions at $\sqrt{s} = 17$ TeV. The Higgs-boson mass is 500 GeV/c^2 and the jet cuts are as listed in Eq. (8). Also shown (dashed histogram) is the background with the additional jet mass cuts as described in the text.

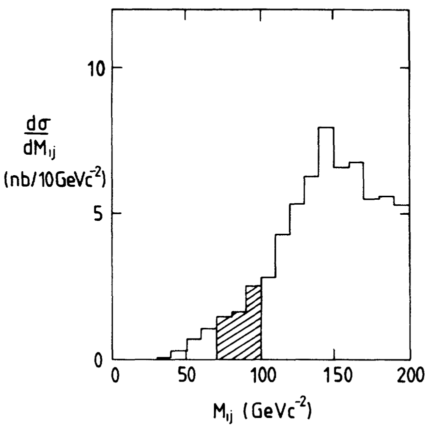

FIG. 7. Distribution in the jet pair mass for the background of Fig. 6, after requiring two jet pairs of approximately equal mass as defined in the text.

The final class of processes which we wish to consider are those involving six jets in the final state. The most important process of this type is the production of new heavy-quark pairs: $gg \to Q\bar{Q}$, $q\bar{q} \to Q\bar{Q}$. For definiteness we shall assume that Q is the top quark and therefore that the dominant decay mode is $Q \to 3$ jets.

The net branching ratio into a six-jet final state will be approximately 4/9, and the question is whether this can survive the QCD six-jet background.

We can distinguish two different final-state topologies, depending on whether the top-quark mass is greater than or less than the W mass. For the former, the decay will proceed via an intermediate on-shell W, giving a distinctive structure to the final-state jets. We will consider for definiteness three different top-quark masses: 50, 150, and 250 GeV/c^2. Figure 8 shows the total six-jet cross sections for these three masses together with the QCD background, as a function of the jet p_T threshold. The rapidity and separation cuts are as before. The situation for light top quarks would appear to be hopeless. The signal-to-background ratio is improved for heavier top quarks, and so we investigate the 250-GeV/c^2 case in more detail.

With a 50-GeV/c p_T threshold, we start with a total QCD six-jet background which is about a factor of 3000 larger than the signal. Figure 9 shows the six-jet mass distribution for the signal and the background with a 50-GeV/c p_T threshold and our standard rapidity and separation cuts. An improvement can clearly be achieved by using the characteristic mass combinations of the jets in the signal. We first require that there are two three-jet combinations with the same invariant mass, say $|M_{123}-M_{456}|<20$ GeV/c^2. Within each three-jet group we then require a pair of jets with an invariant mass in the range $M_W \pm 20$ GeV/c^2. We may optimistically assume that these cuts have essentially no effect on the top-quark signal. The effect of these cuts is to reduce the background by about a factor of 600, the dominant effect coming from the second of the mass cuts described above. (In fact it is interesting to note that almost half of the background events contain two-jet triplets of approximately equal mass.) The background with these cuts is shown by the dashed histogram in Fig. 9. There is still a factor of 50 separating the signal and background. We see no obvious way of rescuing this situation. Tightening the rapidity cuts, for example, gives only a marginal improvement.

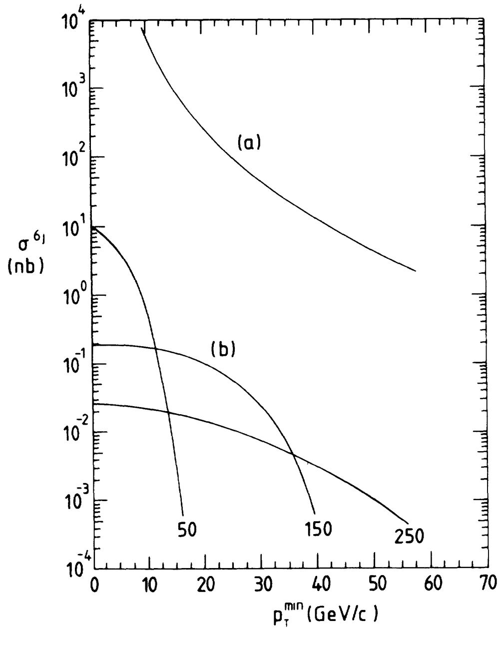

FIG. 8. Six-jet cross sections for (a) the QCD background and (b) the $t\bar{t}$ signal in pp collisions at $\sqrt{s}=17$ TeV as a function of the jet transverse-momentum threshold $p_T^{\min}$, for three values of m_{top}: 50, 150, and 250 GeV/c^2. Jet rapidity and separation cuts as listed in Eq. (8).

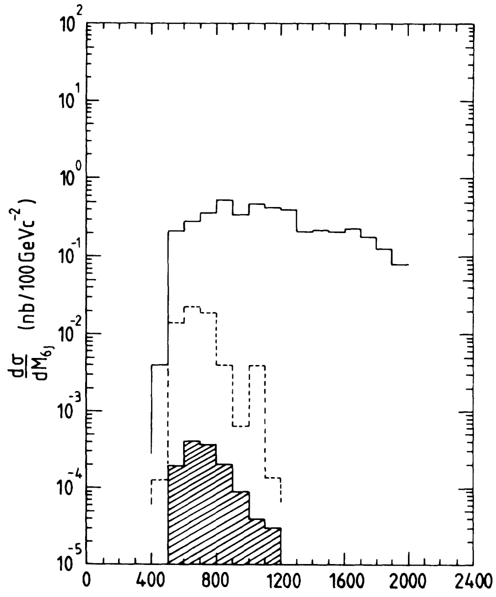

FIG. 9. Six-jet invariant-mass distribution for the $m_{\text{top}}=250$ GeV/c^2 signal (shaded histogram) and the QCD jet background (solid histogram) of Fig. 8 with a 50-GeV/c jet p_T threshold. Also shown (dashed histogram) is the background with the additional jet mass cuts as described in the text.

It is possible that requiring one of the heavy quarks to decay semileptonically, giving a $l\nu jjjj$ final state, will give a significant improvement. This has been discussed recently in Ref. 14. Unfortunately no reliable background estimate exists for this case as the relevant matrix elements $ab \rightarrow Wc_1c_2c_3c_4$ have not yet been calculated. Nevertheless it seems reasonable to assume that replacing two jets by a W in the QCD matrix element will reduce the cross section by about 2 orders of magnitude. Even allowing for the reduction in signal due to the smaller leptonic branching ratio, this would probably be sufficient to leave a detectable signal. This important question deserves further study.

IV. CONCLUSIONS

The central question addressed by this study is whether any of the standard "new physics" processes can be observed in their purely hadronic (i.e., jet) decay channels. Using a new approach based on analytic approximations to multiparton scattering matrix elements, we have compared a variety of signals and backgrounds. We have been unable to identify any process which could be easily detected this way. In general, our signals fall several orders of magnitude short of the backgrounds, even when the characteristic mass configurations (e.g., two jets of invariant mass M_W) are used to reject background events. To avoid a proliferation of figures, we have performed all our calculations for a proton-proton collider at $\sqrt{s}=17$ TeV. We do not, however, expect any of our conclusions to change dramatically at higher [e.g., Superconducting Super Collider (SSC)] energies.

The reason why the backgrounds are so large is that they are dominated by configurations, particularly those involving gluons, which do not have the same flavor structure as the signals. We have confirmed this explicitly for the simple case of single-W production and two-jet decay. There seems little possibility of resolving this problem by tagging jets according to the parent parton, at least in the near future.

The way out of the whole dilemma is of course very simple: decay channels should be exploited which involve leptons and/or missing energy in the final state. This already forms the basis for the standard methods of Higgs-boson detection in hadronic collisions.[12] For supersymmetric-particle production, there are invariably photinos at the end of the decay chains which give the possibility of large missing energy in the final state. The natural standard-model background processes are then those with one or more W or Z in the final state. For example, a background to the supersymmetric process $gg \to \tilde{g}\tilde{g} \to q\bar{q}q\bar{q}\tilde{\gamma}\tilde{\gamma}$ is provided by $ab \to c_1 c_2 c_3 c_4 Z$ with $Z \to \nu\bar{\nu}$. Unfortunately, many of these important background matrix elements have not yet been calculated. There is therefore still much work to be done.

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