Single W- and Z-boson production as a probe for rapidity gaps at the Superconducting Super Collider

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The cross sections for the production of single W's and Z's via electroweak boson fusion are calculated for pp collisions at the Superconducting Super Collider (SSC). We present general event characteristics of the $qq \to qqW$ and $qq \to qqZ$ signals and the dominant backgrounds for leptonic decays of the W or Z. Special emphasis is given to the study of rapidity gap signatures, i.e., the existence of virtually hadron-free regions between the quark jets in the signal events. By measuring the rate at which rapidity gaps appear in W, Z production, the gap survival probability for electroweak signals can be determined. Thus, the feasibility of a rapidity gap trigger for the Higgs-boson search or for weak-boson scattering events can be verified directly at the SSC.

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I. INTRODUCTION

One of the main tasks of experiments at the Superconducting Super Collider (SSC) is the study of rare electroweak processes, in particular, elastic weak-boson scattering and the production of the Higgs boson via WW or ZZ fusion. Correspondingly, a large amount of work has gone into devising techniques for isolating these events, usually by considering the signal and background processes at the parton level. In addition, it was suggested several years ago that the color flow in these events can be used as a distinguishing feature [1] and that the "W-fusion" process $qq \to qqH$, $H \to WW$ with subsequent hadronic decay of one of the W's leads to substantially lower charged-particle multiplicities than the dominant QCD backgrounds [2].

Recently, Bjorken has extended these ideas by considering the multiplicity distributions of signal and background events in the pseudorapidity-azimuthal angle plane, the lego plot [3, 4]. In a W-W scattering event no color is being transferred between the two beam protons. For each of the struck protons the event looks like a deep-inelastic-scattering event. Since the momentum transfer (of order m_W) is much smaller than the typical energy of the struck quarks, the spectator quarks which emitted the virtual W's will be produced at small forward angles. Color separation only occurs between these forward spectator quarks and the beam remnants. During the hadronization process the color-singlet restoration will therefore mainly produce hadrons in the forward regions. This leads to the formation of a rapidity gap, i.e., a region between the left- and right-moving spectator jets, which contains few or no hadrons. The resulting particle distribution of a rapidity gap event is schematically shown in Fig. 1. Clearly, such gaps may provide an alternative and/or complementary trigger for processes which arise from t-channel electroweak-boson exchange and this includes the production of Higgs particles.

This simple picture of the particle flow in weak-boson scattering events will need to be modified in a more realistic description: (i) The gap may be filled by gluon radiation and the hadronization products from the beam fragments and the spectator quarks, or (ii) the underlying event, e.g., in the form of multiple parton scattering resulting in several additional "minijets," may fill the gap region with their hadronization products. The feasibility of a rapidity gap trigger crucially depends on the probability that the gap survives in spite of these additional effects. This "survival probability" of the gap may be defined operationally for any jjX production process as the probability to observe less than some fixed number of hadrons inside the gap region:

$$P_n(y_{\text{gap}}) = \frac{\sigma_{jjX}(\leq n \text{ particles in gap; } |\eta_{j_1} - \eta_{j_2}| > y_{\text{gap}} + 2 \times 0.7)}{\sigma_{jjX}(|\eta_{j_1} - \eta_{j_2}| > y_{\text{gap}} + 2 \times 0.7)} . \quad (1)$$

Here the gap region is defined as the pseudorapidity range bounded by the tangents to the jet definition cones, which here are assumed to have radius 0.7; see Fig. 1. Alternatively, one may define the gap survival probability as the probability of no additional inelastic interaction between the two beam protons beyond the exchange of the electroweak boson. Estimates of the survival probability in $qq \to qqH$ events at the SSC range around 5%, with a large uncertainty [3, 5].

While the basic idea of a hadron-poor region between the two spectator jets in WW scattering events is confirmed by existing Monte Carlo programs [4, 5], their ability for predicting details of multiplicity distributions in individual events may legitimately be questioned. In addition, the fact that we need to extrapolate by more than a factor 20 in energy in going from the Tevatron to the

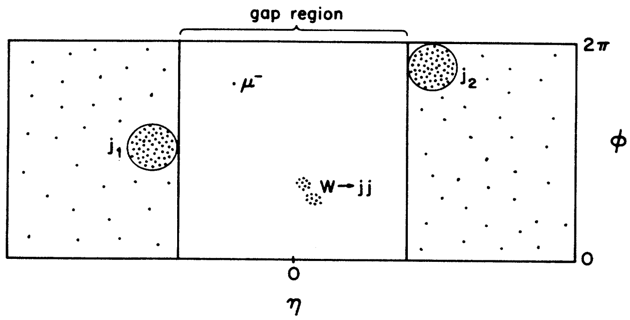

FIG. 1. Schematic particle distribution in the lego plot for a $qq \to qqH$, $H \to W^+W^- \to jj\ \mu^-\bar{\nu}$ event at the SSC. Allowing for a cone radius of 0.7 for each of the spectator jets j_1 and j_2, the gap region is defined as the space between the tangents to these cones. Ideally only the Higgs decay products would be contained inside the gap region.

SSC does not aid matters. Hence, one would like to gauge the rapidity gap tool with a separate class of events [6]. In this report we analyze the electroweak production of Wjj and Zjj events, i.e., events where a single W or Z is radiated off a t-channel electroweak boson exchanged between two spectator quarks. These processes are the direct analogues of Higgs production via W fusion, the Higgs boson being replaced by a W or a Z, and thus the hadronization properties and gap survival probabilities of the three classes of events should be very similar.

Here we are interested in the general event characteristics of these signal events and the QCD backgrounds at the parton level, identifying colored partons with hadronic jets. If signal and background can be separated at the level of jets and leptons, their hadronization properties can be studied independently. Hence, one could directly test to what extent rapidity gaps occur in the signal events and whether they are indeed rare in the QCD background. In Sec. II we start with a brief summary of the calculational tools used in our analysis (we have simulated the signal and background signatures by parton-level Monte Carlo programs which incorporate the full production and decay processes at the tree level). We then proceed in Sec. III with an analysis of the event characteristics of Vjj events ($V = W^\pm, Z$) arising from either the electroweak signal or the QCD backgrounds. Here we discuss to what extent a direct measurement of gap survival probabilities is possible at the SSC. Final conclusions are drawn in Sec. IV.

In our analysis we have in mind the capabilities of a full acceptance detector (FAD) at the SSC [3], which would allow one to observe hadronic jets down to arbitrarily small scattering angles. However, for the signal events the intrinsic transverse momentum scale for hadronic jets is the W mass. Combined with the necessity to impose minimal transverse momentum requirements on jets for background reduction, this results in an effective pseudorapidity range of $|\eta_j| < 6$, which contains the hard scattering part of the events. As a result the physics described in this report does not demand the full capabilities of a FAD and can also be investigated at general purpose SSC detectors such as the Solenoidal Detector Collaboration (SDC) [7] or the Gamma-E-Mu Detector (GEM) [8].

II. CALCULATIONAL METHODS

A. Signal processes

The processes to be investigated in this paper—we shall term them "signal" processes in the following—can summarily be described as the production of weak bosons $V = W, Z$ by electroweak-gauge-boson annihilation. The outgoing gauge bosons in turn are radiated off (anti)quarks inside the incident protons. Since we are interested in the detailed distributions of these "spectator" quarks, which will manifest themselves as very energetic forward jets, we need to go beyond the equivalent boson approximation and model the complete subprocesses

$$q_1 q_3 \to q_2 q_4\, V, \quad V \to \bar{f}_5 f_6\,, \tag{2a}$$

$$\bar{q}_2 q_3 \to \bar{q}_1 q_4\, V, \quad V \to \bar{f}_5 f_6\,, \tag{2b}$$

$$q_1 \bar{q}_4 \to q_2 \bar{q}_3\, V, \quad V \to \bar{f}_5 f_6\,, \tag{2c}$$

$$\bar{q}_2 \bar{q}_4 \to \bar{q}_1 \bar{q}_3\, V, \quad V \to \bar{f}_5 f_6\,. \tag{2d}$$

The Feynman graphs which contribute to these processes at the tree level are shown in Fig. 2. Feynman graphs (e) and (f) need to be considered when going beyond the

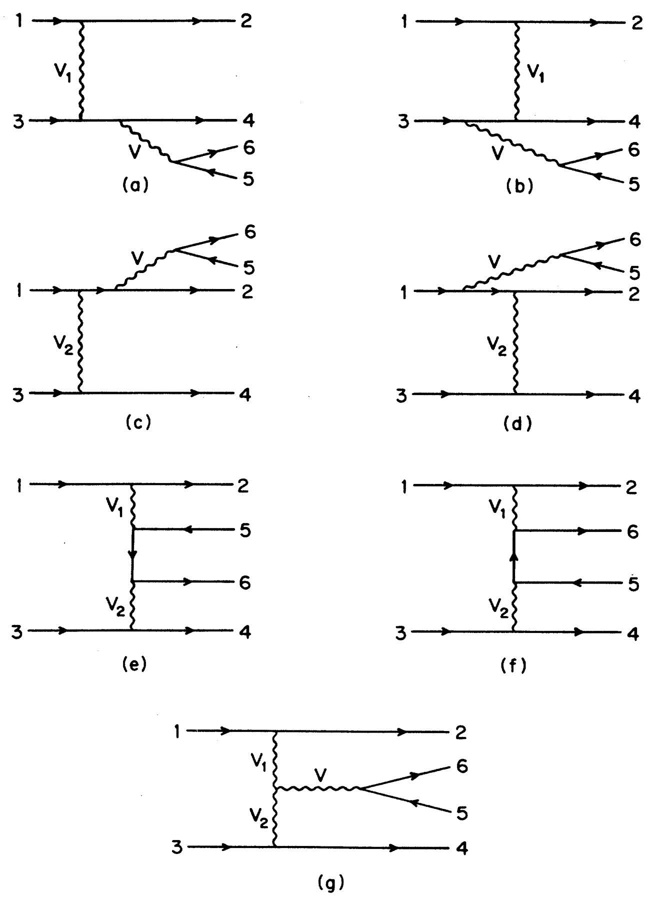

FIG. 2. Feynman graphs for the generic weak-boson production process $q_1 q_3 \to q_2 q_4 V$, $V \to \bar{f}_5 f_6$ ($V = W, Z$). The flavors of the external quarks determine the charge of the exchanged gauge bosons V_1 and V_2.

narrow width approximation for W production: In order to maintain subtle gauge theory cancellations between the various graphs, a t-channel photon (V_1 or V_2) must be coupled to all intermediate particles which are connected by the flow of electric charge. This includes the decay products of the $W^{\pm}$.

In the case of identical quark flavors ($q_1 = q_3$ or $q_2 = q_4$) initial- or final-state identical quarks need to be antisymmetrized in processes (2a) and (2d), or s-channel weak boson exchange and its interference with the t-channel exchange graphs give an additional contribution to the cross section [processes (2b) and (2c)]. Interference terms are suppressed, however, in the large-$N_{\rm color}$ limit because the quarks must have identical colors. The s-channel contributions correspond to the production of two electroweak bosons. In the phase-space region in which we are interested (two very forward jets and hence a very large dijet invariant mass) one of the two produced bosons is highly virtual and hence the s-channel contribution is expected to be small. In addition, its characteristics, both regarding the event topology and the color flow (and hence the formation of rapidity gaps), are quite similar to the QCD backgrounds which will be discussed shortly and therefore the s-channel graphs constitute a minor correction to these backgrounds. In our analysis we consistently neglect the electroweak s-channel contributions as well as any interference terms with the QCD amplitudes in the presence of identical quarks.

Close analogues of the processes of Eqs. (2) have been considered in the past in the context of single W or Z production at ep colliders [9]. Following the work of Refs. [9, 10] we have used the amplitude method of Refs. [11, 12] for a direct numerical evaluation of the helicity amplitudes which correspond to the various Feynman graphs of Fig. 2. For all signal processes we have chosen the momentum transfer to the struck quarks as the scale for the parton structure functions. We use Harriman-Martin-Roberts-Stirling set B [HMRS(B)] [13] for both signal and background processes. The final computer program, which performs the phase-space integration, the summation over all contributing subprocesses, and the fermion helicities uses the Monte Carlo integration package VEGAS [14].

Because of the presence of t-channel photon-exchange graphs in all W and Z production processes (except for charged current Z production), the total cross sections for the W and Z signals are formally divergent in the approximation of massless quarks. A proper treatment of low Q^2 photon exchange is possible (see Ref. [9] for the analogous case of single W, Z production in ep collisions). For the suppression of large QCD backgrounds we are, however, only interested in events with two clearly visible forward jets with substantial transverse momentum ($p_T > 40$ GeV), a requirement which leaves us with finite signal cross sections.

B. QCD Wjj and Zjj backgrounds

The $\mathcal{O}(\alpha_s^2)$ corrections to Drell-Yan production of a W or Z with two additional partons in the final state constitute an irreducible physics background to the single-weak-boson production signals of Eq. (2), as long as final-state quarks and gluons have to be treated as experimentally indistinguishable jets, and while not considering the possibility of rapidity gap signatures. These background processes include

$$q\bar{q} \to ggV \,, \tag{3a}$$

$$qg \to qgV \,, \tag{3b}$$

or

$$qq \to qqV \tag{3c}$$

via t-channel gluon exchange and all crossing-related processes [15]. As before V stands for either W or Z. We shall call these processes the "QCD Wjj" or "QCD Zjj" background. Similar to the treatment of the signal processes we use a parton-level Monte Carlo program based on the work of Ref. [12] to model the QCD backgrounds. The scales of the parton distribution functions and of the strong-coupling constant $\alpha_s(Q^2)$ are chosen to be the transverse energy of the produced W or Z.

C. Backgrounds due to double parton scattering

A second class of background processes which needs to be considered is double parton scattering (DPS), i.e., the simultaneous hard scattering of two pairs (p_{a_1}, p_{a_2}) and (p_{b_1}, p_{b_2}) of partons in the two initial-state protons:

$$p_{a_1} + p_{a_2} \to A \,, \tag{4a}$$

$$p_{b_1} + p_{b_2} \to B \,. \tag{4b}$$

We use the prescription of Halzen, Hoyer, and Stirling [16] to calculate the DPS cross sections:

$$d\sigma_{\rm DPS} = \frac{d\sigma(p_{a_1} + p_{a_2} \to A)\, d\sigma(p_{b_1} + p_{b_2} \to B)}{\pi R^2} \times q(x_{a_1}, x_{b_1}, Q^2)\, q(x_{a_2}, x_{b_2}, Q^2) \,, \tag{5}$$

where a simple factorized form of the two-parton distributions inside the proton is assumed:

$$q(x_1, x_2, Q^2) = q(x_1, Q^2) q(x_2, Q^2)(1 - x_1 - x_2). \tag{6}$$

The "parton-beam cross section" πR^2 is not very well determined. Even though the study of four-jet events at UA2 suggests a somewhat larger value [17], we use $\pi R^2 = 16$ mb [16], which leads to a conservative estimate of the DPS background.

A DPS background to Vjj production ($V = W, Z$) can arise in two ways: The two pairs of partons may create the final state ($A = V$, $B = jj$) or the final state ($A = Vj$, $B = jj$). In the second case any pair of the three jets may define the boundary of the gap region. The main difference between the two final states lies in the transverse momentum of the produced vector boson V: It is strictly zero in the first case. The truncated shower approximation (TSA) [18] provides for an interpolation between the two cases and both processes can be simulated simultaneously. The tree-level $V + 1$ jet differential cross section $d\sigma(Vj)_{\rm TL}$ is replaced by

$$d\sigma(Vj)_{\rm TSA} = d\sigma(Vj)_{\rm TL} \left(1 - e^{-c_V p_{Tj}^2}\right) \,, \tag{7}$$

with the constant c_V properly chosen to correctly reproduce the full two-loop V production cross sections $\sigma(Z) = 98$ nb and $\sigma(W) = 305$ nb [19]. As $p_{Tj} \to 0$ the final factor in Eq. (7) acts as a regulator. We use $c_V = \left(\frac{1}{5.6\,\mathrm{GeV}}\right)^2$ for our DPS simulation. The TSA also estimates how often a soft jet will be generated inside the gap region.

III. SINGLE W AND Z PRODUCTION: SIGNAL AND BACKGROUNDS

The signal processes of single Z and W production occur copiously compared to other electroweak processes but are relatively rare when compared to typical QCD backgrounds. With a p_T requirement of 40 GeV for the two final-state spectator quarks one obtains signal cross sections, at the SSC, of

$$\sigma_{\rm sig}(pp \to Zjj) = 59 \text{ pb} , \tag{8a}$$

$$\sigma_{\rm sig}(pp \to W^{\pm}jj) = 203 \text{ pb} . \tag{8b}$$

The dominant hadronic decays of the W and the Z will be hidden in a large background of QCD-induced four-jet events. Using a rapidity gap trigger the signal might conceivably be isolated from the background [3]; however, we prefer to concentrate on the leptonic decay modes and thus restrict ourselves to the cleanest

$$B(Z \to e^+e^-, \mu^+\mu^-) = 6.7\% , \tag{9a}$$

$$B(W \to e\nu, \mu\nu) = 21.6\% , \tag{9b}$$

of the event sample.

For the case of the W signal a potential background source is the production of top-quark pairs with the subsequent decay $t \to Wb$. For a top-quark mass of $m_t = 140$ GeV the production cross section is $\sigma(pp \to t\bar{t}X) \approx 15$ nb [20] and hence about 2 orders of magnitude larger than the Wjj signal. Compared to the inclusive W production cross section, the top background is already small. A characteristic feature of the W signal is the presence of two energetic forward jets. In Ref. [21] it was shown in connection with single forward-jet tagging that the dominant source of forward jets in $t\bar{t}$ events arises from QCD radiation, i.e., the additional parton in $t\bar{t}j$ events, and not from the top decay products. A 3-TeV-energy cut on the forward jet and central jet vetoing was sufficient to reduce the $t\bar{t}$ background well below the cross section for a heavy Higgs-boson signal [21], which with $\sigma(pp \to HjjX) \sim 1$ pb, has a total production cross section 2 orders of magnitude below the one for the W signal. Hence, we expect that $t\bar{t}$ production with subsequent top decay to real W's will be a negligible background in the present study. When considering events with a rapidity gap, the ultimate isolation cut for the W decay lepton, this assumption is certainly warranted and we shall not consider the top-quark background any further.

This leaves Drell-Yan production of Z and W bosons, with expected cross sections of 100 and 300 nb [19], as the dominant source of background processes. Being more than 3 orders of magnitude larger than the signal cross sections, all characteristics of the Zjj and Wjj signals have to be exploited in order to improve the signal-to-background ratio. Thus, we concentrate on events where both spectator quarks produce visible jets and impose generic acceptance cuts on the transverse momenta and the separation of jets and charged leptons throughout the rest of the discussion:

$$p_{Tj} > 40 \text{ GeV} , \quad R_{jj} = (\Delta\eta_{jj}^2 + \Delta\phi_{jj}^2)^{\frac{1}{2}} > 0.7 , \tag{10}$$
$$p_{T\ell} > 20 \text{ GeV} , \quad R_{\ell j} = (\Delta\eta_{\ell j}^2 + \Delta\phi_{\ell j}^2)^{\frac{1}{2}} > 0.7 .$$

In the case of Z production the dilepton invariant mass is required to be consistent with the Z mass:

$$|m_{\ell^+\ell^-} - m_Z| < 10 \text{ GeV} . \tag{11}$$

No constraints are imposed on the missing transverse momentum or the transverse mass of the W decay products because the precision of the $\not{p}_T$ measurement strongly depends on detector properties such as the jet energy resolution and calorimetric coverage in the forward region.

Signal and background cross sections after the generic event selection are given in the first column of Table I. The background is still overwhelming at this stage. However, we have not yet exploited the strikingly different event topologies of the signal versus the background. The signal is characterized by one forward and one backward spectator jet, both with large jet energy, while the typical jet activity in the background is due to the emission of soft gluons in the central region. These features are

TABLE I. Wjj and Zjj signal and background cross sections (in pb) at various stages of the event selection. Leptonic decay modes $Z \to e^+e^-$, $\mu^+\mu^-$ and $W \to e\nu$, $\mu\nu$ only are considered. The generic cuts $p_{Tj} > 40$ GeV, $p_{T\ell} > 20$ GeV, $R_{jj} > 0.7$, $R_{\ell j} > 0.7$ are imposed throughout.

Process	Generic cuts	$M_{jj} > 800$ GeV	Leptons between jet pair	$\lvert\eta_{j_1} - \eta_{j_2}\rvert > 4.4$
Zjj signal	2.6	1.43	0.92	0.72
QCD background	300	33	5.6	4.0
DPS background	40	3.0	0.95	0.94
Wjj signal	35	18.1	13.4	10.4
QCD background	3400	390	103	74
DPS background	470	35	13.7	13.2

visible in Fig. 3(a), where the separation of the two spectator quark candidates is shown for the Zjj signal and its background. In addition, the dijet invariant-mass spectrum of the signal is much harder than the one for the backgrounds; see Fig. 4. Hence, we consider events only if they have a jet pair of large dijet invariant mass and impose $m_{jj} > 800$ GeV. This cut reduces the background by one order of magnitude, with a much smaller effect on the signal; see column 2 in Table I.

In the signal events the W and Z decay products are expected to be located between the two spectator jets, inside the gap region as indicated in Fig. 1. Calling the two jets closest to the charged leptons j_1 and j_2, we thus require

$$\eta_{j_1} + 0.7 < \eta_\ell < \eta_{j_2} - 0.7 \,, \tag{12}$$

and these two jets must satisfy the $m_{jj} > 800$ GeV cut. In the case of $Z \to \ell^+\ell^-$ decays both leptons must fall into the gap region defined by Eq. (12). This requirement reduces the signal and background cross sections to the values in the third column of Table I. Figure 3(b) shows the resulting distance in pseudorapidity between the two spectator jet candidates, and the dijet invariant-mass spectra are shown by the dashed lines in Fig. 4.

Our goal is to use the hadron multiplicity in the gap region as a trigger for the signal. At SSC energy the typical multiplicity in minimum bias events is expected to be [3]

$$\left\langle \frac{dN}{d\eta} \right\rangle \approx 8 - 10 \tag{13}$$

(for charged + neutral hadrons), whereas one expects $n_{\rm gap}$ =1–2 hadrons inside the gap region for events with a rapidity gap [3, 22]. Requiring a gap width $y_{\rm gap}$ of three units appears sufficient to eliminate Poissonian multiplicity fluctuations of the background. On the other hand, Fig. 3 suggests that jet separations

$$\Delta\eta = |\eta_{j_1} - \eta_{j_2}| \; > \; y_{\rm gap} \; + \; 2 \times 0.7, \tag{14}$$

with $y_{\rm gap} = 3$, are quite common for the signal. Hence, we require, somewhat arbitrarily, the gap region to be at least three units wide in the following.

The final cross sections, including the gap-width requirement, are shown in the last column of Table I and the resulting dijet invariant-mass distributions are given by the dot-dashed lines in Fig. 4. Table I shows an improvement of the signal-to-background ratio from less than 1:100 to about 1:7, while retaining approximately 30% of the signal. The jet- and lepton-level selection reduces the DPS background to the size of the signal cross section, and at all stages of the analysis the DPS background constitutes a small correction to the QCD background. For an integrated luminosity of 1 fb^{-1} the combined signal and background event samples after the final parton-level cuts contain 5700 leptonic Z decays and 98 000 leptonic W decays and hence provide a large statistics sample for detailed analyses of the underlying event structure.

If the fundamental assumption underlying the rapidity gap trigger is correct, then the signal events will exhibit a multiplicity distribution of hadrons inside the gap region which is strikingly different from the background distribution: For a fraction $P_{\rm survival}$ of all signal events the gap region will contain no or at least very few hadrons while background events with such low values of $n_{\rm gap}$ are suppressed by an extra factor f. Estimates for this suppression factor range from [3] $f = 0.1$ to (most likely unrealistic) values around [23] $f = 4 \times 10^{-5}$ as obtained with the PYTHIA Monte Carlo [24].

In either case one expects a multiplicity distribution qualitatively similar to the one shown in Fig. 5. For large values of $n_{\rm gap}$ the contribution is largely from background events, while the low $n_{\rm gap}$ sample, below some "cut," mostly will contain signal events. Even for a conservative estimate of the background suppression factor, $f = 0.1$, and using $P_{\rm survival} = 0.05$, the low-$n_{\rm gap}$ sample will contain 520 (36) signal and only 440 (25) background events for W (Z) production. These numbers are for an integrated luminosity of 1 fb^{-1}, which corresponds to one year of running at a luminosity of $\mathcal{L} = 10^{32}\,{\rm cm}^{-2}\,{\rm sec}^{-1}$. Larger luminosities would soon lead to multiple interactions per beam crossing and hence to overlapping minimum bias events filling the gap.

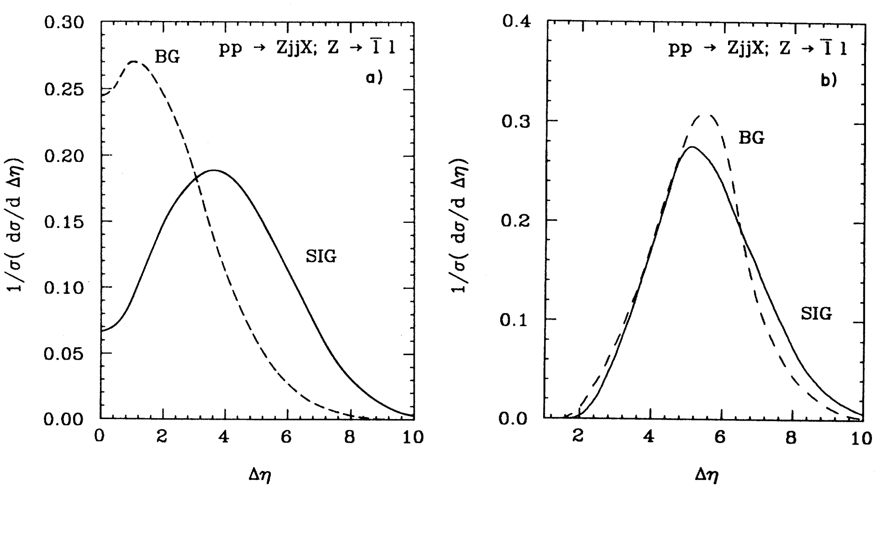

FIG. 3. Normalized pseudorapidity distribution $\frac{1}{\sigma}\frac{d\sigma}{d\Delta\eta}$, where $\Delta\eta = |\eta_{j_1} - \eta_{j_2}|$ is the distance between the two spectator jet candidates. Results are shown for the Zjj signal (solid lines) and the combined QCD and DPS Zjj backgrounds (dashed lines) at two stages of the event selection: (a) generic cuts of Eqs. (10) and (11) only, (b) imposing the $m_{jj} > 800$ GeV requirement and requiring the two Z decay leptons to fall into the region between the two jets.

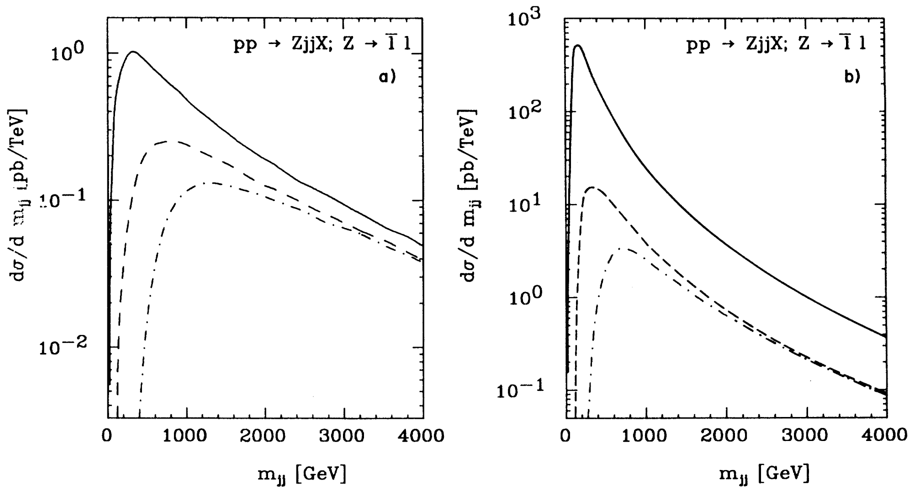

FIG. 4. Dijet invariant-mass distributions of the two spectator jet candidates for (a) the Zjj signal and (b) the combined QCD and DPS Zjj backgrounds at different stages of the event selection: generic cuts of Eqs. (10) and (11) only (solid lines), requiring the two Z decay leptons to fall into the region between the two jets (dashed lines) and considering events with $y_{\text{gap}} > 3$ only (dot-dashed lines).

By considering events with $n_{\text{gap}} < n_{\text{cut}}$ only, the different shapes of the lepton and jet distributions of the signal as compared to the ones of the backgrounds allow the separate determination of P_{survival} for the signal and $f \times P_{\text{survival}}$ for the background. Several examples are shown in Figs. 6–9. The shape of the $d\sigma/d\eta_{j\ell}$ distributions, where $\eta_{j\ell}$ is the smallest distance of one of the charged decay leptons to the spectator jet candidates, is shown in Fig. 6 for Zjj events. In the background sample the leptons tend to be close to the spectator jets, while the signal events prefer minimal separations of 2 or larger. A similar effect is present for the Wjj cross sections. Closely related is the shape of the charged-lepton pseudorapidity distribution for Wjj events, which is shown in Fig. 7. The background distribution is much wider than $d\sigma/d\eta_\ell$ for the signal. The effect is particularly big for the W^+ sample because of the large valence u-quark distribution: the background process $gu_V \to W^+dg$ produces W's with a relatively strong boost of the center-of-mass system along the beam axis. Hence, large values of $|\eta_\ell|$ are preferred.

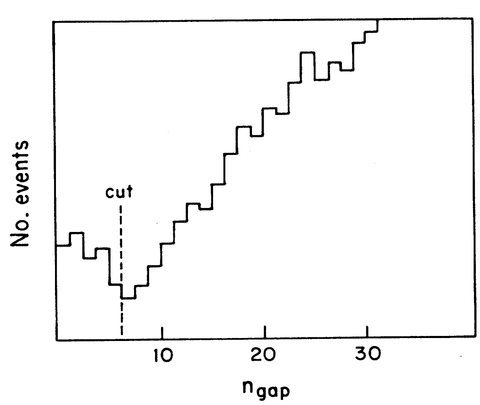

FIG. 5. Schematic plot of the particle multiplicity distribution inside the gap region for signal and background combined after final event selection as described in the text. The high-multiplicity region will be dominated by background events while the low-n_{gap} events (below the "cut") will mainly be signal events.

Relatively soft gluon radiation dominates for the QCD processes. As a result, the energy spectrum of the least energetic spectator jet candidate is considerably softer for the backgrounds than for the signal events. This is shown in Fig. 8 for the Zjj case. Above $E_{j,\,\text{min}} = 2$ TeV the signal actually exceeds the background. However, such a stringent cut reduces the Zjj signal to 0.03 pb and hence comes at too large a price for the signal rate. The same basic effect results in a much harder dijet invariant-mass distribution for the signal events as compared to both the QCD and the DPS backgrounds. The dijet invariant-mass distributions for Wjj events are shown in Fig 9.

Because of the different properties of the signal as compared to the background, a fit to the various distributions with the cross sections, within cuts, of the Vjj signal, and the background processes as the two free parameters, allows one to separately determine the respective event

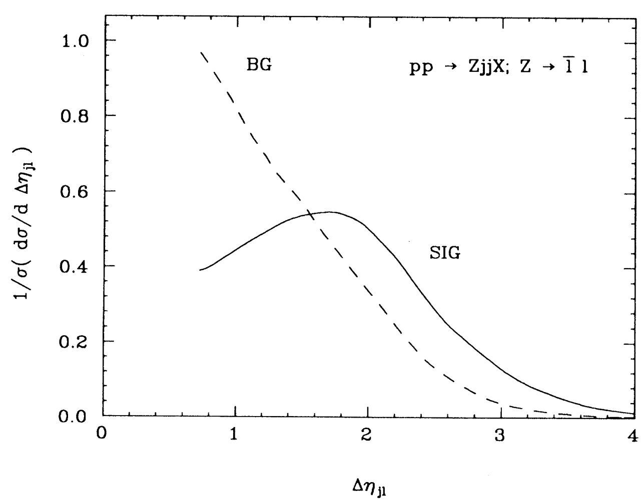

FIG. 6. Normalized pseudorapidity distribution $\frac{1}{\sigma}\, d\sigma/d\Delta\eta_{j\ell}$ for the Zjj signal (solid line) and background (dashed line) after the final event selection. $\Delta\eta_{j\ell}$ is the smallest distance in pseudorapidity between any of the Z decay leptons and the spectator jet candidates in the event. The QCD and DPS backgrounds have been combined.

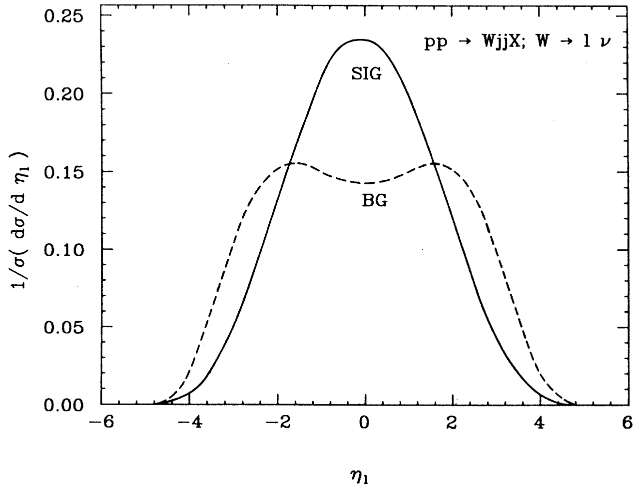

FIG. 7. Normalized pseudorapidity distribution $\frac{1}{\sigma}\, d\sigma/d\eta_\ell$ of the charged lepton in Wjj signal (solid line) and background (dashed line) events after the final event selection. The QCD and DPS backgrounds have been combined.

rates with a rapidity gap signature. Hence, Vjj events at the SSC allow one to directly determine the gap survival probability for processes involving t-channel electroweak-boson exchange. At the same time, one can measure the rate of exceptionally low hadronic multiplicities in the region between jets in QCD events. For any value of the background suppression factor $f < 0.2$ the signal events will constitute more than $\approx 40\%$ of the events with a rapidity gap and hence the extraction of the gap survival probability for the signal poses no problem unless its value is too small to allow for a significant event rate. In this case the gap signature would not be interesting any more for the Higgs-boson search. The extraction of $f \times P_{\text{survival}}$ for the QCD background is already possible

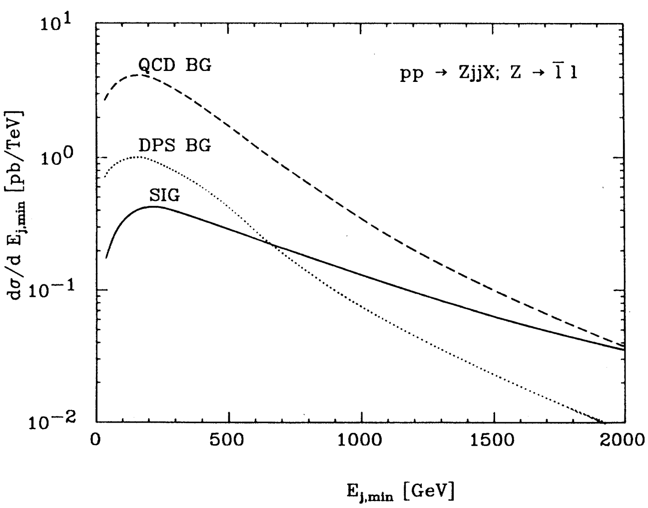

FIG. 8. Energy distribution of the least energetic spectator jet candidate in Zjj events for the signal (solid line), QCD background (dashed line), and DPS background (dotted line) after the final event selection.

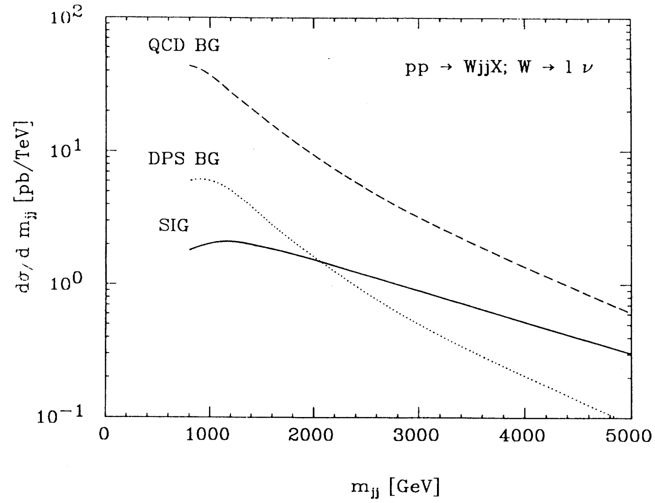

FIG. 9. Dijet invariant-mass distribution of the two spectator jet candidates for Wjj events after final event selection. The signal (solid line), the QCD background (dashed line), and the DPS background (dotted line) are shown separately.

in dijet events at the Fermilab Tevatron [23]. For small values of f its extraction in Vjj events at the SSC will have large errors. However, only an upper bound on f is needed to show the feasibility of a rapidity gap trigger for the Higgs boson search at the SSC.

IV. CONCLUSIONS

Rapidity gap triggers are a promising tool for the study of weak-boson elastic scattering or for the Higgs-boson search at the SSC. In order to prove the feasibility of such a trigger, an improved understanding of the multiplicity distributions in hard scattering events at hadron colliders is essential. For an estimate of the background levels one must know how often a rapidity gap appears between high p_T jets in typical QCD processes. Two-gluon exchange in the t channel, where the two gluons are in a color-singlet state, leads to a color flow similar to the one in t-channel electroweak-boson exchange and hence possibly to a rapidity gap signature [3]. The analysis of high-p_T dijet events at the Tevatron will tell us how often rapidity gaps occur in the background processes [23].

For the signal the major question is the survival probability of the rapidity gap. QCD radiation or parton showers from the spectator quarks may fill the gap region even if there is no double parton scattering [5]. Whether this does indeed happen can be probed directly in deep-inelastic-scattering events at the DESY ep collider HERA (with $Q^2 > 1000$ GeV^2 in order to test the same kinematics as at the SSC). We should know the answer in the very near future.

If QCD radiation does not fill the gap region, then multiple parton interactions due to the transverse overlap of the two initial protons in electroweak signal events will lead to hadrons inside the gap region. The probability for this to happen and hence the gap survival probability can be measured directly at the SSC in Wjj and Zjj production from t-channel electroweak-boson exchange.

We have shown that with proper event selection at the jet and lepton level, this Vjj signal can be enhanced to 1/7 of the QCD background. Even though the backgrounds still dominate, jet and lepton distributions are sufficiently different for the signal and the background to allow the measurement of the gap survival probability in t-channel electroweak-boson exchange on a statistical basis.

This measurement of the gap survival probability is needed in order to obtain quantitative results on heavy Higgs boson production rates or elastic weak-boson scattering cross sections. If no signals are found, a direct confirmation for the existence of rapidity gaps and their frequency is even more crucial in order to establish bounds on the Higgs-boson mass, which is then expected to lie in the intermediate-mass region. Observation of the $H \rightarrow b\bar{b}$ decay mode of such an intermediate-mass Higgs boson is an even more challenging task for a rapidity gap trigger. Its prospects crucially depend on the rate of rapidity gaps in QCD background events [3, 23]. A serious analysis will have to await experimental results on the multiplicity distributions in dijet events at the Tevatron.

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