Transverse-momentum signatures for heavy Higgs bosons

Robert N. Cahn
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

Stephen D. Ellis
Physics Department, University of Washington, Seattle, Washington 98195

Ronald Kleiss
CERN, CH 1211 Geneva 23, Switzerland

W. J. Stirling
Physics Department, Univeristy of Durham, Durham City, England DH1 3LE
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Heavy Higgs bosons produced by WW fusion at the Superconducting Super Collider will have transverse momentum of order M_W. The background due to $q\bar{q}\to ZZ$ will produce pairs with characteristically less transverse momentum, so the transverse momentum of the Z pair provides a useful signature. The transverse momentum of the Higgs boson is balanced by that of the quarks that emitted the virtual W's. These quark jets can be used to tag WW fusion events.

I. INTRODUCTION

The investigation of electroweak symmetry breaking is a primary goal of the proposed Superconducting Super Collider (SSC). A particularly severe challenge is the detection of the Higgs boson of the minimal standard model. For Higgs bosons with masses greater than twice the mass of the W or Z, the dominant decays of the Higgs boson are $H\to W^+W^-$ and $H\to ZZ$. There are two significant production mechanisms for such very massive Higgs bosons in the SSC energy range ($\sqrt{s}\approx 40$ TeV). The first is the gluon-fusion mechanism[1] in which two gluons couple to a heavy-fermion loop. The Higgs boson is emitted from this loop. The second is the WW fusion mechanism in which incident quarks emit virtual W's or Z's which collide to form the Higgs boson.[2] For $M_H > 300$ GeV, it is the latter mechanism that dominates.[2,3] The cross sections are in the picobarn range, giving some tens of thousands of Higgs bosons produced in a nominal SSC year (defined to have an integrated luminosity of 10^{40} cm^{-2}).

While the total number of Higgs bosons produced is thus expected to be large, kinematic cuts forced by detector considerations take their toll. More importantly, studies show[4,5] that the detection of two W's or Z's when only one decays leptonically is extremely difficult. These events are overwhelmed by the background from events containing a single real W or Z together with a pair of hadronic jets that together simulate a second W or Z. The conservative alternative is to require that both intermediate vector bosons decay leptonically. Clearly, the ZZ signature is far superior to that of the W's. We concentrate henceforth on the sequence $H\to ZZ\to(l^+l^-)(l^+l^-)$, but return briefly to $H\to WW$ at the end of the paper.

If it is assumed that both μ's and e's can be identified reliably and their momenta measured, this sequence has a branching ratio of nearly $\frac{1}{3}\times(0.06)^2\approx 1.2\times 10^{-3}$. Thus each picobarn of cross section, will produce 12 such events in a standard SSC year. While this is a small number, the signature is extremely clean. It is reasonable to assume that the primary background comes entirely from continuum pairs of Z's that are not associated with the Higgs boson. The simplest process contributing is $q\bar{q}\to ZZ$.

This continuum ZZ background can be separated from the signal in a variety of ways. The most obvious is that the background falls uniformly as a function of the invariant mass of the ZZ pair. If the Z's are required to have rapidities less than 1.5, the cross section is roughly $d\sigma/dM_{ZZ}=0.3\exp(-M_{ZZ}/125\text{ GeV})$ pb/GeV. A narrow signal could be isolated over this smooth background. In fact, the width of the Higgs boson increases rapidly with its mass: $\Gamma_H\approx 55\times(M_H/500\text{ GeV})^3$ GeV. Thus a Higgs boson with a mass of 200 GeV is quite narrow (about 2 GeV) while a 600-GeV Higgs boson would be very broad (about 100 GeV). Of course, the resolution of the detector would broaden a narrow resonance into one with a width of perhaps 10 GeV or so. A realistic assessment of the signal requires comparing the signal and background integrated over some appropriate interval. In this regard, it should be noted that the canonical reference, Eichten, Hinchliffe, Lane, and Quigg[3] (EHLQ) compared the full signal to the background integrated only over a single width of the Higgs boson (or 10 GeV for a narrower Higgs boson). This produced an overly optimistic comparison. We have chosen always to integrate the signal and the background over two widths, or 20 GeV, whichever is greater. Compared to EHLQ, this means roughly that the background is twice as big, while the signal is only 70% as big. Unfortunately, this is a more real-

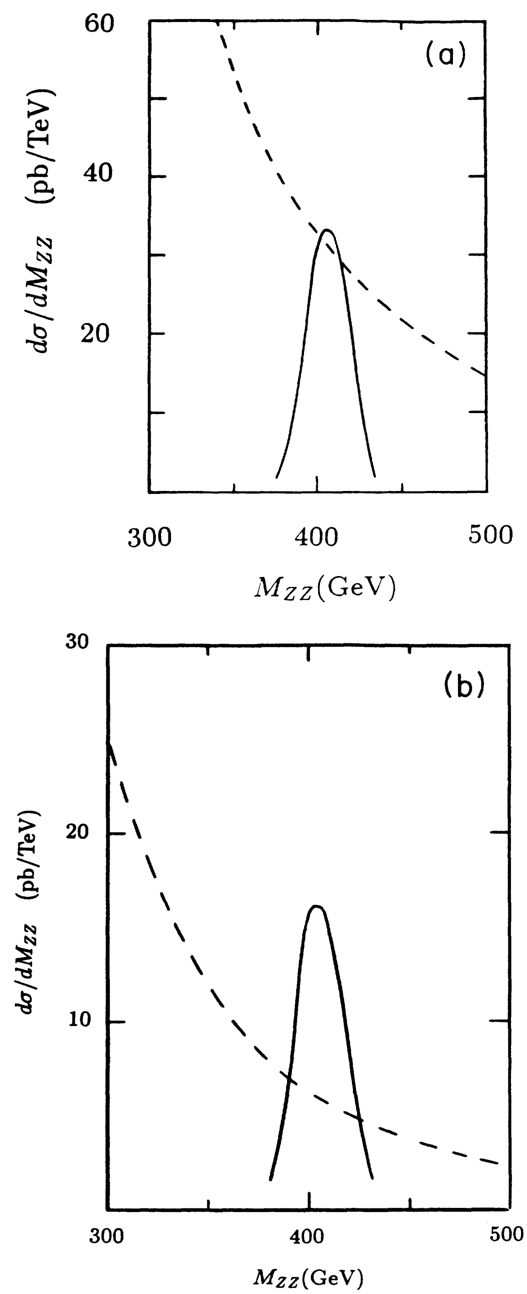

FIG. 1. (a) The invariant-mass distribution of Z pairs from Higgs-boson decay (solid line) and the continuum background, $q\bar{q} \to ZZ$. The Higgs-boson mass is set at 400 GeV. No cuts are made. (b) The invariant-mass distribution of Z pairs from Higgs-boson decay (solid line) and the continuum background, $q\bar{q} \to ZZ$. The Higgs-boson mass is set at 400 GeV. The outgoing Z's are required to have rapidity $\eta < 1.5$.

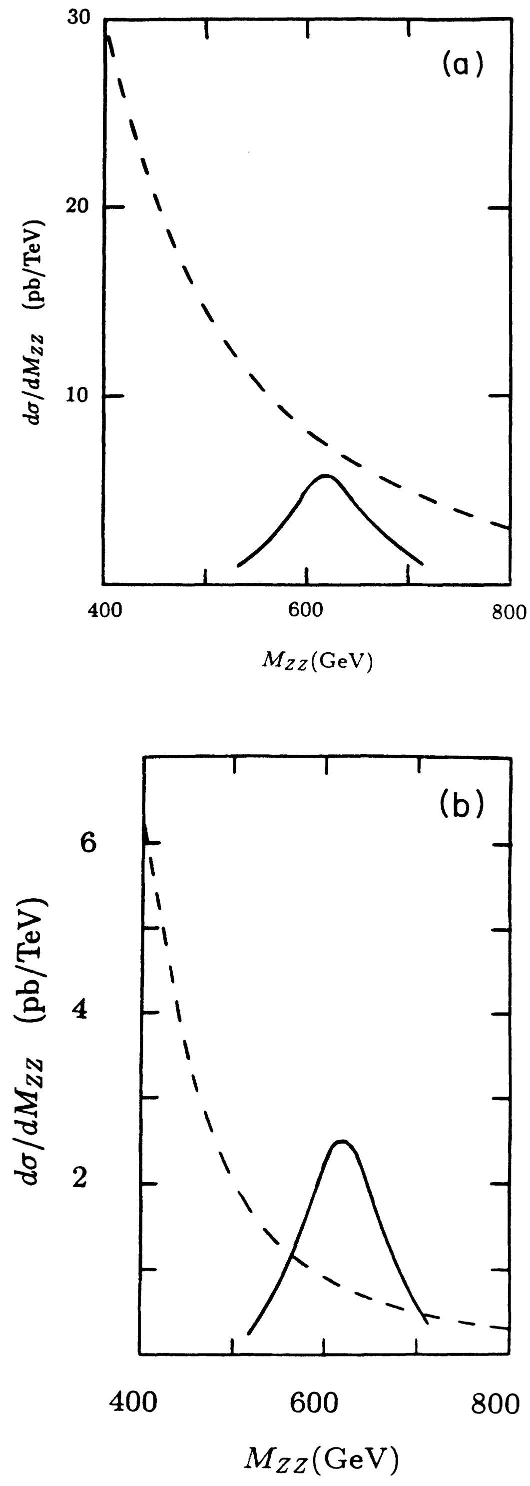

FIG. 2. (a) The invariant-mass distribution of Z pairs from Higgs-boson decay (solid line) and the continuum background, $q\bar{q} \to ZZ$. The Higgs-boson mass is set at 600 GeV. No cuts are made. (b) The invariant-mass distribution of Z pairs from Higgs-boson decay (solid line) and the continuum background, $q\bar{q} \to ZZ$. The Higgs-boson mass is set at 600 GeV. The outgoing Z's are required to have rapidity $\eta < 1.5$.

istic approach.

At very low Higgs-boson mass, but still above the ZZ threshold, there is no problem in isolating the Higgs boson, assuming, as always, the integrated luminosity and energy postulated for the SSC. At a mass of 200 GeV, the Higgs boson is narrow and copiously produced. In addition to about 10 pb of Higgs-boson production via the WW mechanism, there are about 20 pb produced through gluon fusion, both figures representing totals without kinematic cuts. For masses in this range the decay into $t\bar{t}$ can be significant. For $m_t = 40$ GeV, the branching ratio for $H \rightarrow ZZ$ is reduced to about 18%, giving some 54 000 events in this channel for a standard year. Requiring charged leptonic decays of both Z's reduces the number to about 200 [i.e., by a factor $(0.06)^2$]. Since a 200-GeV Higgs boson is quite narrow, we use the ± 10 GeV interval rather than two full widths convention described above. All of the signal would fall inside this 20-GeV bin, assuming adequate resolution. In the same ZZ mass bin the continuum production rate will be roughly 5 pb, if no additional kinematic cuts are made. Thus in the purely charged leptonic decay channel there would be about 180 background events yielding signal to background of about 1 to 1. If very good resolution were possible, this ratio could be increased by cutting to events within plus or minus one Higgs-boson width of the nominal mass. The signal would be reduced to about 140 events but the background would be reduced by a factor of about 5. In any case such a narrow and statistically significant signal would be readily observed.

Assuming that the mass of the t quark is not much greater than 50 GeV and that there are no other heavy quarks yet to be discovered, the gluon-fusion mechanism quickly becomes ineffective for producing the Higgs boson as its mass increases. For a mass of 300 GeV, the WW fusion mechanism is already slightly more productive. Of course, this latter mechanism also produces a cross section that falls with increasing Higgs-boson mass. By 500 GeV, the cross section has fallen to about 3.3 pb, and by 1000 GeV it has fallen by another factor of three to 1.1 pb (Ref. 6).

Despite this falling cross section, the background does not overwhelm the signal. This is so for two reasons. First, the background $d\sigma/dM$ falls roughly exponentially as noted above, so that even though this background must be integrated over an interval increasing as M^3, the total background falls rapidly. Second, the background, while composed of the same final-state particles, ZZ, differs from the signal in important ways.

The Higgs boson particle has spin zero, so the decay angular distribution of the Z's from it is necessarily isotropic. The Z's produced by $q\bar{q}$ annihilation tend to be forward and backward, once the invariant mass is large compared to $2M_Z$ (Ref. 7). This can be exploited by requiring that the Z's observed have not too large center-of-mass rapidity. Indeed, this may be unavoidable unless the detector is specially designed to accept leptons in the very forward and backward directions. The effect of such a cut is displayed in Figs. 1(a) and 1(b) and 2(a) and 2(b). These show ZZ-pair invariant masses for Higgs bosons with mass 400 and 600 GeV. The backgrounds are also shown. A cut of $\eta < 1.5$, where η is the Z rapidity, reduces the background by about five and the signal by about two.

While the signal to background ratio seen in Figs. 1 and 2 is encouraging, the total number of events expected is small. For the 600-GeV case, after the rapidity cut, $\eta < 1.5$, there remains only 0.3 pb in the ZZ channel, corresponding to 10 or 11 events in the all-charged-lepton mode. For this reason, it is important to seek additional signatures, characteristics of the events arising from Higgs-boson decay that can distinguish them from the background of continuum ZZ production.

In this paper we explore the utility of measuring the transverse momentum of the Higgs boson, that is, the vector sum of the transverse momenta of the Z's into which it decays. The background production of Z pairs from $q\bar{q}$ annihilation is expected to produce little transverse momentum for the pair. We shall estimate the transverse-momentum distribution using perturbative methods. For example, we calculate the process $q\bar{q} \rightarrow ZZg$. The Z pair recoils against the gluon and thus receives transverse momentum. In contrast, the WW fusion mechanism produces Higgs bosons with sizable transverse momentum. This follows from the behavior of the propagator for the virtual W's (or Z's) producing the Higgs boson. The propagator is roughly $1/(p_\perp{}^2 + M_W{}^2)$ where $p_\perp$ is the transverse momentum of the W relative to the incident direction. Thus the transverse momenta of the virtual W's are of order M_W, and, consequently, so is the transverse momentum of the Higgs boson they form.

The transverse momentum of the Higgs boson is balanced by that of the jets formed by the quarks that emitted the virtual W's or Z's. These quarks are analogous to the e^+ and e^- that emit virtual photons in two-photon processes. This raises the possibility of using quark jets to tag WW or ZZ fusion events. Such triggering necessarily reduces the event rate and could be justified only if it permitted looser constraints on the final-state identification. In particular, tagging might be a way to isolate events in which a Higgs boson was produced, decayed into ZZ, and subsequently one of the Z's decayed hadronically. Our analysis indicates that double tagging would be effective in identifying Higgs bosons of mass 400 GeV and above.

II. ANALYTICAL ESTIMATE OF THE TRANSVERSE-MOMENTUM DISTRIBUTION OF THE HIGGS BOSON

An approximate form for the cross section for $q_1 q_2 \rightarrow q_1' q_2' H$ via the WW mechanism is

$$d\sigma = \frac{1}{16\pi^2}\left[\frac{\alpha}{x_W}\right]^3 sM_W{}^2 \frac{dx_1 dx_2 d^2p_{\perp 1} d^2p_{\perp 2}}{(p_{\perp 1}{}^2/x_1 + M_W{}^2)^2 (p_{\perp 2}{}^2/x_2 + M_W{}^2)^2}\delta(s(1-x_1)(1-x_2) - M_H{}^2)\ , \tag{1}$$

where $x_W=\sin^2\theta_W$. This gives a total cross section of

$$\sigma=\frac{1}{16M_W{}^2}\left[\frac{\alpha}{x_W}\right]^3[(1+M_H{}^2/s)\ln(s/M_H{}^2)-2+2M_H{}^2/s] \quad (2)$$

the standard result.[8-10]

The Higgs boson receives a transverse momentum $\mathbf{P}_\perp=-\mathbf{p}_{\perp 1}-\mathbf{p}_{\perp 2}$. The distribution in this variable may be calculated approximately by writing

$$d\sigma\propto\frac{d^2p_{\perp 1}d^2p_{\perp 2}d^2P_\perp\delta^2(\mathbf{P}+\mathbf{p}_{\perp 1}+\mathbf{p}_{\perp 2})}{(p_{\perp 1}{}^2/\langle x\rangle+M_W{}^2)^2(p_{\perp 2}{}^2/\langle x\rangle+M_W{}^2)^2}, \quad (3)$$

where, in view of the δ function in Eq. (2.1), we take $1-\langle x\rangle=M_H/\sqrt{s}$. The integration can be done in closed form to yield the normalized distribution

$$\frac{dN}{dP_\perp{}^2}=\frac{1}{\langle x\rangle M_W{}^2}F\left[\frac{P_\perp{}^2}{\langle x\rangle M_W{}^2}\right], \quad (4)$$

where F is defined by

$$F(z)=\int_0^1 dy\frac{2y(1-y)}{[(y-y^2)z+1]^3}=\frac{2z^2-4z}{(z^2+4z)^2}+\frac{16z(1+z)}{(z^2+4z)^{5/2}}\text{arctanh}\frac{1}{\sqrt{1+4/z}}. \quad (5)$$

The limiting behavior of F is

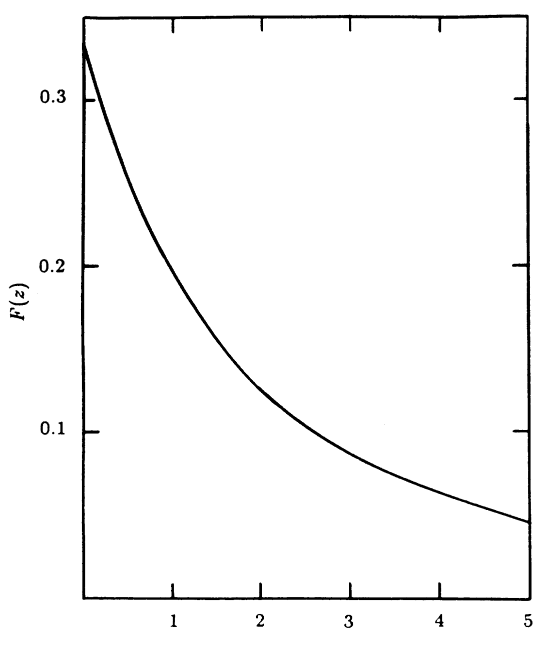

FIG. 3. The function $F(z)$ that describes the approximate distribution of Higgs bosons as a function of their transverse momentum squared: $dN/dP_\perp{}^2\propto F(P_\perp{}^2/\langle x\rangle M_W{}^2)$. See Eqs. (2.4)–(2.9).

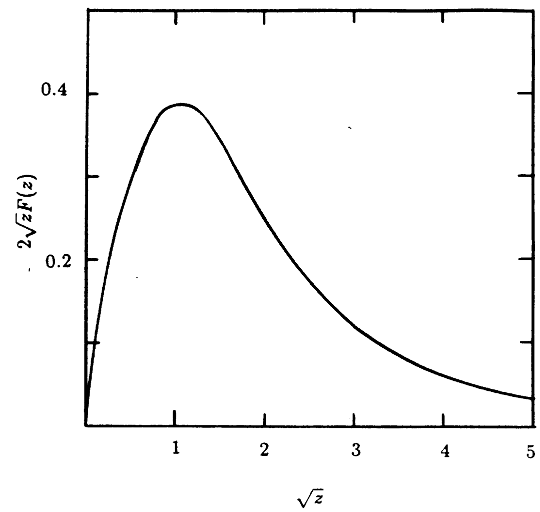

FIG. 4. The function $2\sqrt{z}F(z)$ as a function of $\sqrt{z}$. This describes the transverse-momentum distribution of the Higgs boson as a function of $P_\perp$: $dN/dP_\perp\propto P_\perp F(P_\perp{}^2/\langle x\rangle M_W{}^2)$.

$$\lim_{z\to 0}F(z)=\tfrac{1}{3}, \quad (6)$$

$$\lim_{z\to\infty}F(z)=2/z^2, \quad (7)$$

and it is normalized:

$$\int_0^\infty dz\,F(z)=1. \quad (8)$$

As anticipated, the $P_\perp{}^2$ distribution has characteristic width $M_W{}^2$. Of course for very large $P_\perp{}^2$ the approximation is not reliable. The energy-conserving δ function has terms involving the transverse momenta that have been ignored. Nevertheless, the result is a good guide to the transverse-momentum behavior. In Figs. 3 and 4 we show $dN/dP_\perp{}^2\propto F(P_\perp{}^2/\langle x\rangle M_W{}^2)$ and $dN/dP_\perp\propto P_\perp F(P_\perp{}^2/\langle x\rangle M_W{}^2)$. The latter distribution peaks for $P_\perp\approx M_W$.

III. ON-SHELL APPROXIMATION FOR JET EMISSION

To the extent to which the partons inside the proton have no transverse momentum, the continuum ZZ pairs produced by $q\bar{q}\to ZZ$ in lowest order have no transverse momentum. If gluons are emitted by the annihilating quarks, the produced ZZ pair will generally have transverse momentum. For small values of this transverse momentum, multiple-gluon emission is important. For sufficiently large transverse momentum, it is the first-order emission of a single hard gluon or quark that dominates. The important processes are then $q\bar{q}\to ZZg$, $qg\to ZZq$, and $\bar{q}g\to ZZ\bar{q}$.

When is the transverse momentum large enough so that the single-emission picture can be trusted? The relevant scale for comparison is the Q^2 at which the incoming part structure functions are evaluated. A crude measure of the contributions from multiple-emission processes is offered

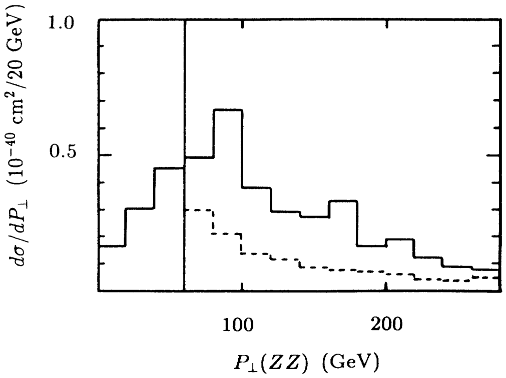

FIG. 5. Monte Carlo results for the transverse-momentum distribution of Z pairs that decay into $(e^+e^-)(e^+e^-)$. The solid line represents the signal due to Higgs bosons of mass 400 GeV, while the dotted line indicates the background arising from the perturbative QCD processes $q\bar{q}\to ZZg$, $gq\to ZZq$, and $g\bar{q}\to ZZ\bar{q}$. The background calculation continues to rise for $P_\perp < 60$ GeV, but cannot be trusted for very small values of $P_\perp$. The vertical scale is such that 1.0 in a single bin corresponds to one event of $(e^+e^-)(e^+e^-)$, or four events if both electrons and muons are observed.

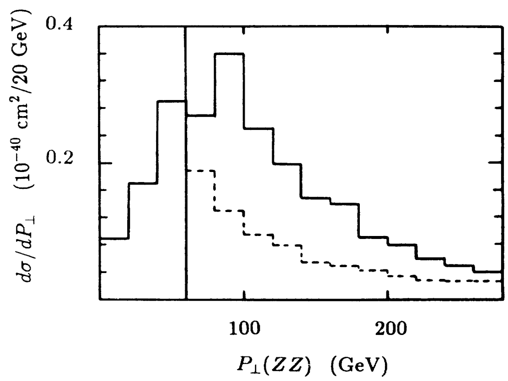

FIG. 6. The same distribution as in Fig. 5 except that the Higgs-boson mass is 600 GeV.

by the double logarithmic terms characteristic of the Sudakov form factor. Such contributions are not important as long as $(\alpha_s/2\pi)\ln^2(Q^2/P_\perp^2) \ll 1$. For the scales of interest here, this relation suggests that the single-emission processes will provide an adequate estimate of the full cross section for $P_\perp > Q/10$. This certainly covers the domain we are concerned with where $Q \simeq M_W$ and $P_\perp \simeq M_W$. A second constraint on the range of applicability of the single-emission picture arises from insisting that the contribution to the total cross section from the production of a ZZ pair plus an extra gluon or quark integrated over $P_\perp$ in the range of applicability be only a small correction to the lowest-order process $q\bar{q}\to ZZ$.

The calculation of the processes producing a ZZ pair and an additional quark or gluon is facilitated by the use of "spinor techniques."[11]

Alternatively, approximate calculations can be made by treating the QCD part of the process as nearly on shell. Thus for $q\bar{q}\to ZZg$, we write

$$d\sigma_{q\bar{q}\to ZZg} = \frac{d^2P_\perp}{(2\pi)^3 P_\perp^2}\frac{dy}{y}[1+(1-y)^2]4\pi\alpha_s \tfrac{4}{3} d\sigma_{q\bar{q}\to ZZ} \,. \tag{9}$$

We recognize the familiar Altarelli-Parisi splitting function for $q\to qg$. The factor $\frac{4}{3}$ comes from color considerations. The gluon carries a fraction y of the incident quark or antiquark momentum. The result must be multiplied by 2 to account for emission of the gluon from both the quark and antiquark. The analogous formula for $gq\to ZZq$ is

$$d\sigma_{gq\to ZZq} = \frac{d^2P_\perp}{(2\pi)^3 P_\perp^2}\frac{dy}{y}\frac{y}{2}[y^2+(1-y)^2]4\pi\alpha_s d\sigma_{q\bar{q}\to ZZ} \,. \tag{10}$$

The quantity of interest is $d\sigma/dM_{ZZ}^2$ for transverse momentum of the ZZ pair restricted to some interval, say, $P_{\perp\min} < P_\perp < P_{\perp\max}$. Thus, for example, we have

$$\frac{d\sigma_{q\bar{q}\to ZZg}}{dM_{ZZ}^2} = \int \frac{d^2P_\perp}{(2\pi)^3 P_\perp^2}\frac{dy}{y}[1+(1-y)^2]4\pi\alpha_s \tfrac{4}{3} d\sigma_{q\bar{q}\to ZZ}\,\delta(\hat{s}(1-y)-M_{ZZ}^2) \,, \tag{11}$$

where $\hat{s}$ is the c.m. energy squared for the $q\bar{q}$ system and y is the fraction of the initial quark momentum given to the gluon. This and the analogous formulas for $qg\to ZZq$ were compared to the full Monte Carlo simulation done with the complete matrix elements. There was agreement to within 10% in the kinematic range of interest here, more than adequate for our purpose of estimating the background.

The results of the Monte Carlo simulations for $M_H = 400$ GeV and $M_H = 600$ GeV are shown in Figs. 5 and 6, and in Tables I and II. The backgrounds calculated for $q\bar{q}\to ZZ$, $q\bar{q}\to ZZg$, $qg\to ZZq$, and $\bar{q}g\to ZZ\bar{q}$ are

TABLE I. Production by WW and ZZ fusion of Higgs bosons that decay into ZZ in pp collisions at center-of-mass energy 40 TeV. All cross sections are in pb. A pb corresponds to 10 000 events for an integrated luminosity of 10^{40} cm^{-2}, or to approximately 36 events if it is required that the Z's decay into e's or μ's.

	$M_H = 400$ GeV	$M_H = 600$ GeV
$\sigma(H\to ZZ)$	1.5	0.9
and within $\pm\Gamma$	1.0	0.6
and $\eta_Z < 1.5$	0.5	0.3
and $P_\perp(\text{Higgs}) > 60$ GeV	0.4	0.24

TABLE II. Continuum production of ZZ, the background for the detection of the Higgs boson. The cross sections are in pb. A pb corresponds to 10 000 events for an integrated luminosity of 10^{40} cm^{-2}, or to approximately 36 events if it is required that the Z's decay into e's or μ's.

	$M_H = 400$ GeV	$M_H = 600$ GeV
$\sigma(q\bar{q}\to ZZ)$ within $\pm\Gamma$	1.5	1.5
and $\eta_Z < 1.5$	0.3	0.2
$\sigma(q\bar{q}\to ZZg)$	0.05	0.07
$\eta_Z < 1.5$, $P_\perp(ZZ) > 60$ GeV		
$\sigma(gq,\bar{q}\to ZZq,\bar{q})$	0.08	0.06
$\eta_Z < 1.5$, $P_\perp(ZZ) > 60$ GeV		

shown in Table II and Figs. 5 and 6. The efficacy of the $P_\perp$ cut is apparent.

IV. DOUBLE TAGGING

Just as tagging in the two-photon e^+e^- process produces a clean signal, tagging the quarks that emit virtual W's or Z's offers the prospect of isolating the $WW\to H$ and $ZZ\to H$ events. The transverse momenta of the scattered quarks are of order M_W, as explained above. It is thus possible to retain a reasonable fraction of the $WW\to H$ events while requiring the transverse momenta of the observed quarks to be large. The rapidities of the scattering quarks peak around $|\eta|=3$ (see Fig. 7), a value within the reach of a likely detector. Throughout the discussion of the double tag, we fix $M_H=400$ GeV and require that each of the quark jets have a longitudinal momentum of at least 500 GeV and a transverse momentum of at least 60 GeV. As before, the W's and Z's from the decaying Higgs bosons are required to have rapidities less than 1.5. These cuts on the quark jets reduce the 0.5-pb cross section given in Table I to 0.07 pb, corresponding to just 3 events if it required that both Z's decay into e^+e^- or $\mu^+\mu^-$. If instead one Z is allowed to decay hadronically, the rate goes up by a factor $2B(Z\to\text{had})/B(Z\to e^+e^-,\mu^+\mu^-)\approx 20$.

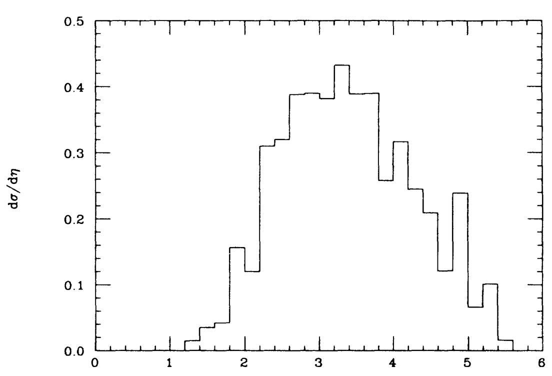

FIG. 7. The rapidity distribution for a quark jet used to tag a Higgs-boson production event. The jet is required to have longitudinal momentum greater than 500 GeV and transverse momentum greater than 60 GeV. The center-of-mass energy is 40 TeV and the Higgs-boson mass is 400 GeV.

Can such a signature be used? It is known[4,5] that the process $q\bar{q}\to ZZ$ or WW, with one W or Z decaying hadronically, cannot be observed directly because of the background from processes such as $gq\to gqZ$, where the gq in the final state has an invariant mass near that of the Z. (There is some indication that very well-designed cuts on the transverse momentum of the hadronic jets may allow some observation of the signal[12].) Thus while the $q\bar{q}\to WW$ or ZZ continuum is a small background for $H\to ZZ, WW$, this is relevant only if the W's and Z's decay leptonically. Otherwise, it is not the "real" background, $q\bar{q}\to WW,ZZ$, but the "fake" background, $qg\to qgZ$, etc., that dominates. Studies[4,5] have shown that the fake background is about 70 times as large as the real background for observing two gauge bosons, one of which decays leptonically.

An analogous situation prevails for the double tagged $q_1q_2\to q_1'q_2'H$ process, if the Higgs-boson decay leads to one hadronically decaying W or Z. There is a real background, e.g., $qg\to qZZg$, and a fake background, e.g., $qg\to qggZg$. Complete Monte Carlo simulation of these processes is daunting. We have confined ourselves here to the real background (i.e., four-particle final state) and we have used the approximation discussed and justified in the previous section. Recall that in this approximation the QCD emission from each incident particle is treated as an on-shell process and the produced hadronic jet is tagged. We tentatively assume that the dominant, fake background is about 70 times the computed real background.

The results of our calculations are shown in Table III. In this instance we have considered the WW final state as well as ZZ. The branching ratios for $ZZ\to l^+l^-+\text{hadrons}$ and $WW\to l\nu+\text{hadrons}$ have been taken to be $2\times 0.06\times 0.7=0.084$ and $2\times 0.16\times 0.76=0.24$, respectively. The final row of the table shows our estimate of the dominant background, based on our calculation of the background from real pairs of gauge bosons. The signals in both channels are significant. Of course, the reconstruction of the WW channel is more difficult since there is a missing neutrino. Since the outgoing quark jets will have been measured, some additional information will be available from transverse-momentum balance.

TABLE III. Cross sections in 10^{-40} cm^2 to produce ZZ or WW via the Higgs boson (signal) or the continuum ($q\bar{q},qg,gg$), with one leptonic and one hadronic decay. The mass of the Higgs boson is 400 GeV. The final line gives an estimate of the background from events in which a pair of hadronic jets simulates a W or Z.

	ZZ	WW
Signal	60	400
$q\bar{q}\to gZZg$, $gWWg$	0.06	1.0
$gq\to qZZg$	0.22	3.3
$gg\to qZZ\bar{q}$	0.14	2.2
Total "real" background	0.42	6.5
$70\times$total "real" background	29	455

This preliminary analysis suggests that the tagging of outgoing quark jets may provide an effective means of identifying the production of heavy Higgs bosons that subsequently decay into W or Z pairs, with only one of the gauge bosons decaying leptonically. The signal is not so clean as that provided by events in which two Z's decay leptonically, but it does provide higher statistics. The double tag is thus an important complement to the schemes already proposed for the search for the heavy Higgs boson at the SSC.

V. SUMMARY

There are at present three primary techniques proposed for identifying a Higgs boson produced at SSC energies decaying into WW or ZZ. The primary one requires that the Higgs-boson decay into ZZ and that the Z's both decay into e^+e^- or $\mu^+\mu^-$. The dominant background is expected to be Z pairs that are produced via $q\bar{q}\rightarrow ZZ$. We have shown that the charged leptonic signal can be enhanced by measuring the transverse momentum of the Z pair. A second technique relies on the ZZ decay of the Higgs boson, but allows one Z to decay to a neutrino pair, while the other Z decays to e^+e^- or $\mu^+\mu^-$ (Refs. 8 and 13). The third technique allows one Z or W to decay hadronically, while the other decays leptonically.

While the third technique addresses a much larger signal than the first two, it also encounters a much larger background since the hadronically decaying Z or W can be mimicked by a pair of ordinary hadronic jets. We propose to reduce this background by requiring that two additional jets be observed, each having substantial longitudinal and transverse momentum. Such jets naturally accompany the Higgs boson when it is produced via WW fusion. Our study indicates that a favorable signal/background rate could be achieved. Observation of the tagging jets would require a detector capable of measuring jets with rapidities in the range 2—4.

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