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HIGGS → FOUR LEPTONS AT THE SSC

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Abstract

Detection of an intermediate mass or heavy Higgs boson through its decay into four charged leptons is studied with emphasis on background considerations and detector requirements. The intermediate mass Higgs decay via ZZ^* is expected to be a difficult mode to observe due to low event rates. In addition, cuts which are needed to reduce the backgrounds reduce the signal even further. The rapidity coverage and energy resolution requirements for this mode are more severe than for the heavy Higgs. The heavy Higgs boson decay $H \to Z^0Z^0 \to 4\ell^\pm$ continues to be observable for a Higgs mass between twice the Z mass and about 600 GeV/c^2 when detector characteristics of generic large SSC detectors are included. A careful study is made of backgrounds from $q\bar{q}, gq \to Z + Jets$ and detector-related issues. It is shown that an isolation cut on the lepton candidates can be expected to reduce the background from this source to low levels.

1. Introduction

One of the primary motivations for the SSC is the understanding of the mechanism for electroweak symmetry breaking. In the minimal standard model this occurs through a single Higgs boson. Although there are more complicated scenarios such as supersymmetric models, we concentrate here on the "standard Higgs boson." Assuming a Higgs boson exists, the experimental limits on and theoretical prediction of its mass are not yet sufficiently constraining and a search over a range of Higgs masses must be performed.

For a Higgs boson in the intermediate mass range, that is, for a Higgs mass (M_H) between half the mass of the Z^0 (M_Z) and $2\,M_Z$, it has been suggested[1],[2] that the decay mode $H \to ZZ^* \to 4\,\ell^\pm$ where one Z is off mass shell may be a viable channel for discovery, at least in the mass range 125 GeV/c^2 $< M_H < 2\,M_Z$. This possibility will be reexamined with attention paid to backgrounds. If the mass of the Higgs boson is greater than twice the mass of the Z^0, it will decay predominantly through the modes Z^0Z^0 and W^+W^-. This Higgs mode will subsequently be referred to as the heavy Higgs mode. The most easily detected mode occurs when both Z^0's decay to e^+e^- or $\mu^+\mu^-$. These are the so-called "gold-plated" events. This decay has been studied extensively in previous workshops and papers[3],[4],[5],[6]. However, the probability for the Higgs boson to decay by this mode is only 1.4×10^{-3}, which limits the discovery range to $\sim$ 600 GeV/c^2 in Higgs mass, depending on the mass of the top quark, for a year's running at the SSC at design luminosity (taken to be 10^4 pb^{-1}). The branching ratio for $H \to Z^0Z^0 \to \ell^+\ell^-\nu\bar{\nu}$ is six times larger, so the discovery range can be extended to higher Higgs mass, provided that this decay can be detected in a convincing manner. The $H \to \ell^+\ell^-\nu\bar{\nu}$ decay has also been studied

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in numerous workshops and papers[3], [7], [8], [9]. Another decay mode worth investigating is $H \to Z^0 Z^0 \to \ell^+\ell^- q\bar{q}$.

This group has tried to add to previous work mostly in the areas of background considerations and detector requirements for the detection of Higgs decays into four leptons. We will focus primarily on backgrounds to both the intermediate and heavy Higgs decay to four leptons from the processes generically known as $Z + Jets$, that is, from $q\bar{q} \to Zg$, $gq \to Zq$ and $gg \to ZQ\bar{Q}$, where Q represents a heavy quark such as bottom or top.

2. Rates and Backgrounds

2.1 Intermediate Mass Higgs

In the intermediate mass region, the Higgs boson is produced mainly by the gluon-gluon fusion process, shown in Fig. 1. For a top quark mass (M_t) of 55 GeV/c^2, the production cross section is $\sim$ 200 pb and is slowly falling in the Higgs mass range from 100–200 GeV/c^2. Branching ratios for Higgs decay into ZZ^* for various Higgs masses, taken from Ref. 2 , are shown in Table 1. If, in addition, the branching ratios for $Z^0 \to e^+e^-$ or $\mu^+\mu^-$ of 3.4% for each of the Z's are included, the event rate is found to be quite small ($\sim$16 events in one SSC design year for M_H = 140 GeV/c^2), as shown in Table 1.

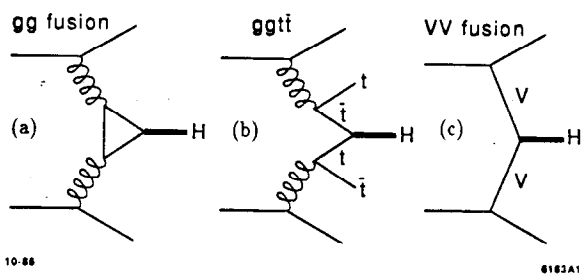

FIG. 1. Higgs production via (a) gluon-gluon fusion, (b) quark-antiquark annihilation, and (c) WW or ZZ fusion.

M_{Higgs} (GeV)	Br. Ratio ($H \to ZZ^*$)	M_{cut} (GeV)	Signal Ev./yr.	$q\bar{q} \to ZZ^*$ Ev./yr.	$gg \to Zb\bar{b}$ Ev./yr.
120	4×10^{-4}	10	3	2	1000 ± 500
140	1×10^{-3}	20	16	3	550 ± 200
160	3×10^{-3}	25	44	2	300 ± 150
180	8×10^{-3}	40	84	8	300 ± 150

Table 1. $H \to ZZ^*$ Branching Ratios and Rates for One SSC Design Year (10^{40} cm^{-2}) for M_t = 55 GeV/c^2.

The intrinsic backgrounds considered in Ref. 2 are $q\bar{q} \to ZZ^*$ (or γ^*) and $gg \to ZZ^*$ (or γ^*). The mode $q\bar{q} \to Z\gamma^*$ was considered to be the largest background but could be eliminated by requiring that the invariant mass of the two leptons which do not come from the decay of the real Z be larger than some cut (M_{cut}) since this background peaks at zero invariant mass. Shown in Table 1 are the numbers of signal and background events that pass such an invariant mass cut and fall within a 2% wide mass bin around the nominal Higgs mass. The Higgs width is typically between 10 MeV to 1 GeV for the Higgs mass range considered. Since the signal is a sharp peak and the background gives a broad distribution, the signal is readily observable above the background. An M_{ZZ^*} spectrum was not presented in Ref. 2 with cuts on the invariant mass of the leptons from the off-shell particle. It was concluded that this mode provides sensitivity in the range 125 GeV/c^2 $< M_H <$ $2M_Z$. What is not known for this mode are the effects of the background from $Z + Jets$ and in particular the $gg \to ZQ\bar{Q} \to Z\ell^+\ell^- X$ rate. This will be discussed below.

2.2 Heavy Higgs

The heavy Higgs boson can be produced at the SSC through gluon-gluon fusion, quark-antiquark annihilation, and gauge boson fusion, as shown in the diagrams in Fig. 1 . The first two processes depend strongly on the top quark mass. The relevant production cross sections are shown in Fig. 2, taken from Ref. 10. The calculation of the cross section is less reliable for $M_H \gtrsim 600$ GeV/c^2 (see the discussion in Ref. 3). The branching ratio for $H \to Z^0 Z^0$ is $\sim$ 30%.

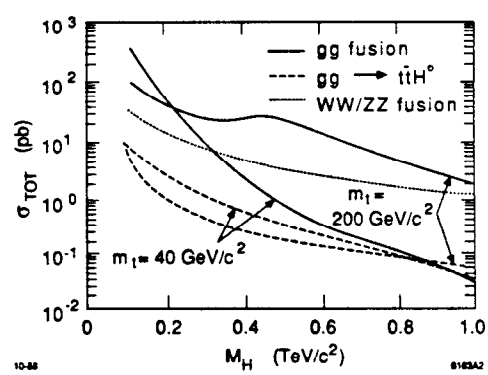

FIG. 2. Heavy Higgs production cross sections from the various processes shown in Fig. 1 as a function of Higgs mass for two different t quark masses (from Ref. 10).

The processes $q\bar{q} \to ZZ$ and $gg \to ZZ$ are serious intrinsic backgrounds to $H \to ZZ$. Calculations of the cross sections for these processes are uncertain because of uncertainties in the structure functions and higher order QCD corrections. The calculations of the ZZ continuum rate are probably reliable to at least a factor of two. Gluon-gluon production of continuum ZZ is approximately 50% of $q\bar{q}$ annihilation for $|y_Z| < 1.5$, where y_Z is the rapidity of the Z. In practice, the measurements of such processes as di-lepton production at the SSC will contribute to the

knowledge of the structure functions by the time the Higgs search takes place[3] . Comparisons between the theoretical calculations and the Monte Carlo programs ISAJET[11] and PYTHIA[12] were made in Ref. 3.

2.3 Z + Jets Backgrounds

As stated earlier, the QCD processes $q\bar{q} \to Zg$, $gq \to Zq$, and $gg \to ZQ\bar{Q}$ also contribute background to Higgs production. The effects of these backgrounds, however, are sensitive to detector characteristics. For the heavy Higgs case, we are interested in the final state in which two lepton candidates not from the real Z have an invariant mass near M_Z. Most of the $Z + Jets$ background can probably be removed[5] by cuts on lepton isolation and requiring that the invariant mass of pairs of leptons be consistent with the Z mass. For instance, recently it has been found[13] that $gg \to Zt\bar{t}$, shown in Fig. 3 , is the dominant contribution to the $Z + Jets$ background to the heavy Higgs signal.

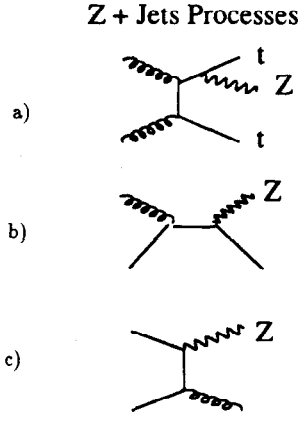

FIG. 3. Z + Jets processes a) $gg \to Zt\bar{t}$,b) $gq \to Zq$, c) $q\bar{q} \to Zg$

A potential background to the four lepton channel from this process arises if the two leptons from the semileptonic decay of the t quarks have the invariant mass of a Z. An explicit parton level calculation shows, however, that if sufficiently high transverse momentum (P_T) is required for the two Z's (i.e., the real Z and the fake Z from leptons from the top decays), the rate is low. Other detector-related backgrounds such as conversion electrons, particle misidentification and particle decays have not been included in that calculation. In this case, even the other $Z + Jets$ subprocesses, $q\bar{q}$ and gq, can be significant. Reliably estimating such backgrounds presents a challenge since fluctuations of one part in 10^4 can become important. Rates for production of a heavy Higgs decaying to four charged leptons and relevant background processes are shown in Table 2. An estimate of the background after cuts due to $q\bar{q}, gq \to Z + Jets$ is given in Section 4.2.

For the intermediate mass Higgs decay to ZZ^*, the power of an M_Z consistency cut is lost for one of the pairs. If one a) generates $gg \to ZQ\bar{Q}$ where the heavy quarks are top or bottom; b) demands that the invariant mass of the decay leptons from the heavy quarks be larger than a value, M_{cut}, as in Ref. 2 ; and c) asks for the number of these events that fall within a 2% mass bin around the nominal Higgs mass, then one finds the rates shown in the last column of Table 1. Fig. 4 shows the invariant mass spectra, M_{ZZ^*}, for signal and $q\bar{q}$ background, adapting numbers from Ref. 2 , and superimposing the $ZQ\bar{Q}$ contribution. Indeed, the $Z + Jets$ background is already becoming significant.

Process	Raw Rate No Cuts	Rate with Cuts*
$H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$		
$M_H = 200$ GeV/c^2, $M_t = 40$ GeV/c^2	575	70
$M_H = 200$ GeV/c^2, $M_t = 200$ GeV/c^2	687	93
$M_H = 400$ GeV/c^2, $M_t = 40$ GeV/c^2	144	89
$M_H = 400$ GeV/c^2, $M_t = 200$ GeV/c^2	560	345
$M_H = 600$ GeV/c^2, $M_t = 40$ GeV/c^2	60	40
$M_H = 600$ GeV/c^2, $M_t = 200$ GeV/c^2	225	146
$q\bar{q} \to ZZ \to \ell^+\ell^-\ell^+\ell^-$	1500	280
$gg \to Zt\bar{t} \to \ell^+\ell^-\ell^+\ell^-$		
$M_t = 40$ GeV/c^2	Large	14
$M_t = 100$ GeV/c^2	Large	~ few
$q\bar{q}, gq \to Z(\to \ell^+\ell^-) + g, q$ ($M_{Zjet} > 200$ GeV/c^2)	10^7	-

Table 2. Rates for Higgs Production and Decay to $\ell^+\ell^-\ell^+\ell^-$ and Background Processes for One SSC Design Year (10^{40} cm^{-2}). * Cuts are $y_\ell < 2.5, P_{T,\ell} > 10$ GeV, $P_{T,Z} > 50$ GeV and $\Delta M_Z < \pm 10$ GeV.

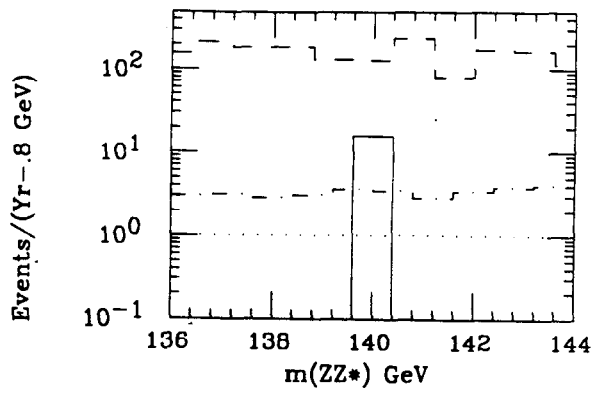

FIG. 4. Invariant mass spectra of ZZ^* for $M_{Z^*} > 20$ GeV/c^2 adapting rates from Ref. 12 and using parton level calculation from program PAPAGENO written by Ian Hinchliffe. Higgs signal shown as solid curve, $q\bar{q}$ as dotted, $gg \to Zt\bar{t}$ as dot-dashes and $gg \to Zb\bar{b}$ as dashes.

3. Analysis Procedures

We now explore some detector requirements for the intermediate mass Higgs decay $H \rightarrow ZZ^*$ and for the heavy Higgs decay $H \rightarrow Z^0Z^0$. In both cases the Z's decay to $\ell^+\ell^-$. Part of the analysis procedure is common to the two cases, although the kinematic ranges may be different.

1. The event must have at least four identified electrons or muons. The detector must then be able to identify electrons and muons over the kinematic ranges required by the physics, as described below.
2. The four leptons must be isolated. This cut is needed to reduce the background from $Z + Jets$.
3. A cut on the P_T of the decay leptons is needed to remove leptons which do not come from Higgs decays, for example, leptons from b quark decays from $gg \rightarrow Zb\bar{b}$, Dalitz decays of π^0's, and $\pi^\pm$ and $K^\pm$ decays.
4. At least one pair of leptons must have invariant mass consistent with M_Z (one pair for the intermediate mass Higgs, both pairs for the heavy Higgs). This cut is needed to reduce background from QCD processes and from $Z + Jets$ in the case of the heavy Higgs. There should be at least four e's, or four μ's, or two e's and two μ's. If there are more than four leptons which pass all the cuts, combinatorics must be handled. The possibility of no charge determination is discussed below. The degree to which background can be reduced depends on the width of the Z peak, which in turn depends on the energy or momentum resolution and the angular resolution.
5. The final step in the analysis in both cases is examining the plot of the invariant mass of the Z and Z^* candidates or the two Z candidates. There should, of course, be a bump at the mass of the Higgs. The measured width of the bump should not be much larger than the intrinsic width of the Higgs or observability will be degraded. This requirement again places constraints on the energy or momentum resolution and the angular resolution for the four leptons. The rates for background processes can then be evaluated.

3.1 Intermediate Mass Higgs

We now examine in more detail the requirements for the $H \rightarrow ZZ^*$ mode. Two questions come to mind. First, is there a cut that can reduce the large $ZQ\bar{Q}$ background while retaining the signal? Second, what happens to the signal if lepton rapidity or P_T cuts are imposed or energy resolution is included? We cannot properly address the first question since we presently cannot fragment the $ZQ\bar{Q}$ system to generate a real experimental environment, but some type of isolation cut involving the decay lepton P_T will probably be necessary to reduce this background. We ignore this for now and study the second question in a simple way. The procedure is as follows:

1. Generate a 140 GeV/c^2 Higgs with PYTHIA (v4.9) selecting the gluon-gluon fusion process.
2. Force the Higgs to decay into a real Z and Z^* where the decay leptons from the Z^* reconstruct to a uniform distribution in invariant mass between 20 and 50 GeV/c^2. (Higgs decays to virtual Z's are not included in PYTHIA.) This is roughly what is expected as described in Ref. 2 .
3. Examine the rapidity and P_T distributions of the leptons.
4. Observe the degradation of the mass spike due to lepton momentum resolution.

3.2 Heavy Higgs

Heavy Higgs production and decay $H \rightarrow Z^0Z^0 \rightarrow 4\ell^\pm$ is generated using PYTHIA. Distributions for this process assuming a perfect detector are given in Ref. 3. The analysis procedure includes the points listed above with the following additions specific to the heavy Higgs:

1. The four e's or μ's must have $|\eta| \leq 2.5$, where η is the pseudorapidity. This cut is essentially equivalent (see Ref. 3) to the cut $|y_Z| < 1.5$, which is needed to reduce the background from $Z + Jets$ and from continuum ZZ production, both of which tend to be produced in the forward direction. For a detector with a solenoidal magnet, the leptons are in the region of the best tracking measurement. (Of course, if they weren't, we would have to design a different type of detector.)
2. The leptons are generally required to have $P_T > 10$ GeV/c. Leptons from heavy Higgs decays typically have $P_T > 20$ GeV/c.
3. An additional cut is needed to reduce the background from $gg \rightarrow Zt\bar{t}$. We require that the transverse momenta of the Z candidates (P_{TZ}) be greater than 50 GeV/c. Another possibility is a scalar E_T cut.

4. Results

4.1 Intermediate Mass Higgs

Lepton Acceptance We first check basic lepton rapidity and P_T distributions. Figure 5 (a) shows the rapidity distribution of the largest rapidity lepton from either the Z or Z^* decay. If most of the signal events are to be kept, acceptance of leptons must extend to five units of rapidity. Figure 5 (b) shows the P_T distribution of the smallest P_T lepton from either the Z or Z^* decay. Clearly, a small P_T cut on the lepton of $\sim$ 10 GeV/c will significantly reduce the signal. Such a cut will probably be necessary to remove the $gg \rightarrow Zb\bar{b}$ background. With the already low rates before cuts, statistics will be severely limited for the 140 GeV/c^2 Higgs.

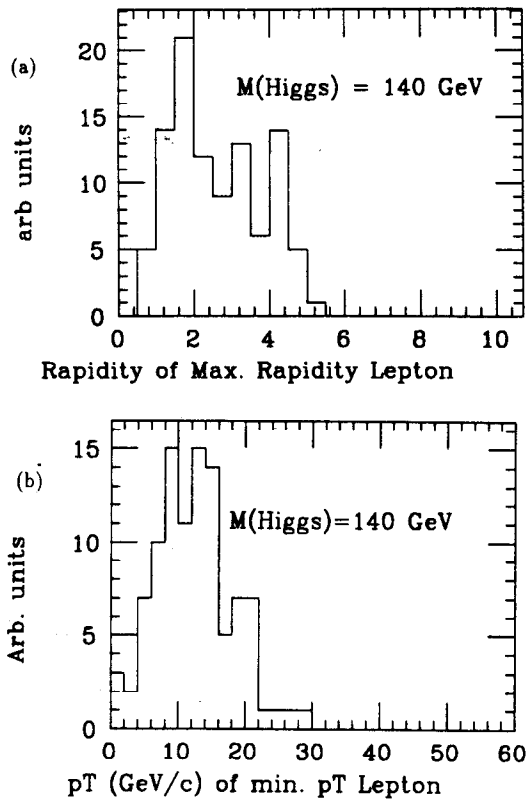

FIG. 5. (a) The rapidity distribution of the largest rapidity lepton from 140 GeV Higgs decay to 4 leptons via the ZZ^* mode with $M_{Z*} > 20$ GeV. (b) The transverse momentum distribution of the lepton with the smallest P_T for the same events just described.

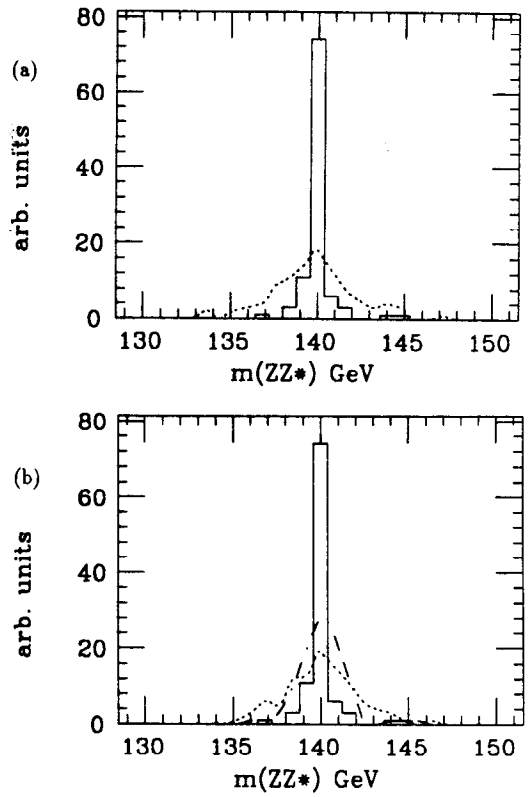

FIG. 6. (a) The Higgs mass peak reconstructed from leptons for a perfect detector (solid histogram) and an EM calorimeter with a resolution of $\sigma_E/E = .01 + .15/\sqrt{E}$ (GeV , dotted curve). (b) The Higgs mass peak reconstructed from leptons for a perfect detector (solid histogram) and a tracker with momentum resolutions of $\sigma_{PT}/P_T = .54\ P_T$ (TeV/c, dot-dashed curve) and $\sigma_{PT}/P_T = .26\ P_T$ (TeV/c, dotted curve). The intrinsic width of the Higgs is included.

Effects of Energy and Momentum Resolution The Higgs peak for various lepton energy resolutions is shown in Fig. 6 . For a perfect detector the peak is very sharp, but with such a small number of events we are particularly sensitive to energy resolution. Figure 6 (a) shows ZZ^* invariant mass distributions for $\sigma_E/E = 0.15/\sqrt{E}$ (E in GeV/c), characteristic of the energy resolution expected for an SSC electromagnetic calorimeter. Figure 6 (b) shows the ZZ^* mass distribution for a momentum resolution of $\sigma_{P_T}/P_T = 0.54P_T$ (P_T in TeV/c), characteristic of a large magnetic detector[14] , and also for a momentum resolution of $0.26P_T$, which could be obtained by such a magnetic detector if particles are constrained to come from the interaction region. The ZZ^* mass resolution obtained for a typical SSC electromagnetic calorimeter and for a typical tracking system without beam constraint will probably not suffice for observation of a 140 GeV/c^2 Higgs boson. The mass resolution obtained with momentum measurement with a beam constraint is somewhat better, but the ratio of signal to background is still problematic.

4.2 Heavy Higgs

Effects of Energy and Momentum Resolution We have also investigated the effects of energy or momentum resolution on the measured width of the di-lepton invariant mass and on the invariant mass of the two Z candidates for heavy Higgs decays. The width of the di-lepton invariant mass determines how well background from fake Z's can be reduced by requiring that two leptons have invariant mass consistent with the mass of the Z. The width of the invariant mass of the two Z candidates determines how well a Higgs peak can be discriminated from background. Figure 7 shows the di-lepton invariant mass for several energy or momentum resolution functions for a 400 GeV/c^2 Higgs decaying into $ZZ \rightarrow \ell^+\ell^-\ell^+\ell^-$: (a) $\sigma_E/E = 0.15/\sqrt{E}$ (E in GeV), (b) $\sigma_{P_T}/P_T = 0.54P_T$ (P_T in TeV/c), (c) $\sigma_E/E = 10\%$, and (d) $\sigma_E/E = 20\%$, characteristic of the momentum resolution in a muon system toroidal detector. The mass resolution in Fig. 7 (a) is quite good – a cut of $\pm$ 5 GeV/c^2 on the mass around M_Z could be used. For

Figs. 7(b) and (c) one could still use $\Delta M_Z < 10$ GeV/c^2. However, some signal would be lost with this cut for the case of 20% energy or momentum resolution. Assuming we could retain the true Z signal without allowing too much background from fake Z's, we next examined the effects of energy or momentum resolution on the Z-pair mass. Figure 8 (a)–(e) shows the Z-pair mass distribution along with the background from ZZ continuum production for a 400 GeV/c^2 Higgs boson for perfect detection and for the four energy or momentum resolutions shown in Fig. 7. We see that an energy resolution of $0.15/\sqrt{E}$ gives a Higgs peak which is indistinguishable from perfect detection because of the intrinsic width of the Higgs. The cases $0.54P_T$ and 10% energy resolution give somewhat broader but still observable peaks at the Higgs mass. However, 20% energy resolution broadens the Higgs peak so much that it is not distinguishable from background.

Our conclusion was that the resolutions under discussion for electromagnetic calorimeters and momentum measurement in a solenoidal detector are acceptable for finding a heavy Higgs signal. A cut of $\pm$ 10 GeV/c^2 around M_Z can be used with such detectors. However, an energy or momentum resolution of 20%, such as in a toroidal muon detector, produces an unacceptable degradation of the signal for a 400 GeV/c^2 Higgs.

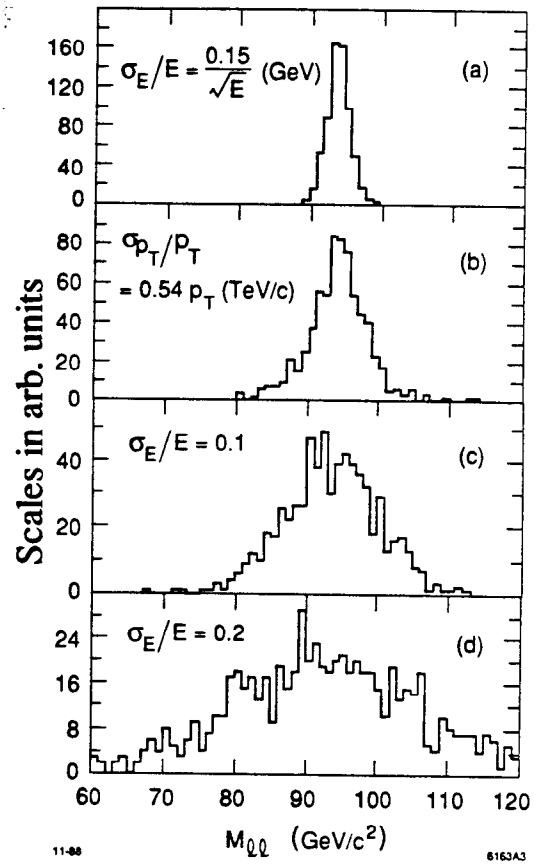

FIG. 7. Di-lepton invariant mass distributions for various energy or momentum resolutions for leptons from Higgs bosons of 400 GeV/c^2 mass decaying into $ZZ \rightarrow 4\ell^{\pm}$.

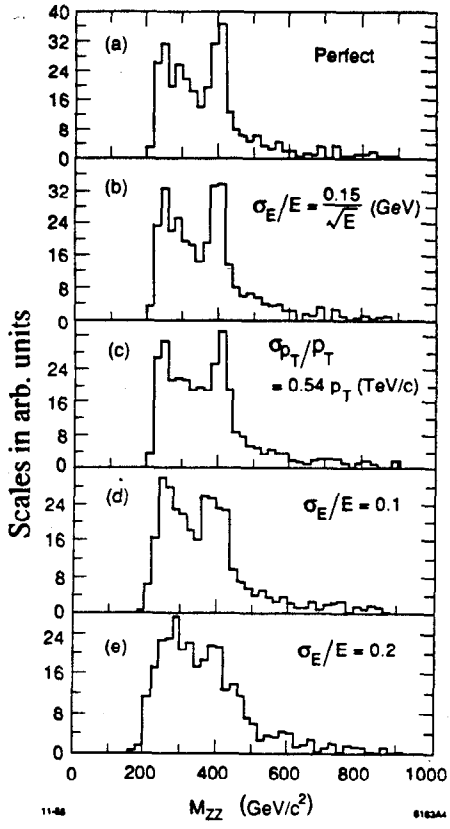

FIG. 8. Z-pair mass distributions for various energy or momentum resolutions for $H \to ZZ \to 4\ell^{\pm}$ for $M_H = 400$ GeV/c^2, along with the background from continuum ZZ production.

Electron Identification and Lepton Isolation A more detailed study was performed of backgrounds from $Z + Jets$ and detector-related issues. The signal consists of two Z's each of which subsequently decays into two charged leptons. For simplicity, we considered the case of four electrons. The main purpose of this study was to find out how many background events pass the Higgs selection cuts without particle identification and then to determine the requirements on electron purity and track separation.

Background from $Z + Jets$ events arises from combinations of *a*) one real Z and one fake Z or *b*) two fake Z's. Fake Z's can be reconstructed from *a*) two real electrons, *b*) one real electron and another charged or neutral particle which is not an electron, or *c*) two particles which are not electrons. Cases *b*) and *c*) represent complete misidentification for the particles which are not electrons.

We proceeded by generating 100K $q\bar{q}, gq \to Z + Jets$ events using PYTHIA with a minimum $P_T > 50$ GeV/c in the hard scattering frame and imposed the cuts described in Sec. 3.2 on all particles. Roughly speaking, this left particles traversing the central rapidity region of a detector. We addressed the problem of two or more particles that are close together or essentially overlapping appearing as one particle in a detector. To simulate this overlapping, all particles which hit one cell (a cell is defined to be a cone with opening angle equal to the angular resolution and its size heareafter will be labeled by this angle) were treated as a single particle, hereafter referred to as a cluster. If adjacent cells were fired, those clusters were grouped to form a single cluster. Only those clusters which consist of one cell were used to construct Z candidates. In this simulation, the cell size for π^0's and γ's was taken to be 30 mr, and that for charged particles was assumed to be either 0.5 mr or 50 mr.

Tracks in jets tend to have other tracks going along the same direction. To reject those tracks, clusters were required to be isolated. As a measure of isolation, the minimum opening angle between a cluster and all other clusters (θ_{min}) was used. Figure 9 shows θ_{min} distributions for clusters which are electrons from Z decays (referred to as e) and for clusters which are not electrons from Z decays (referred to as h) for two cell sizes. Isolated clusters were taken to be those with $\theta_{min} > 0.5$ radian.

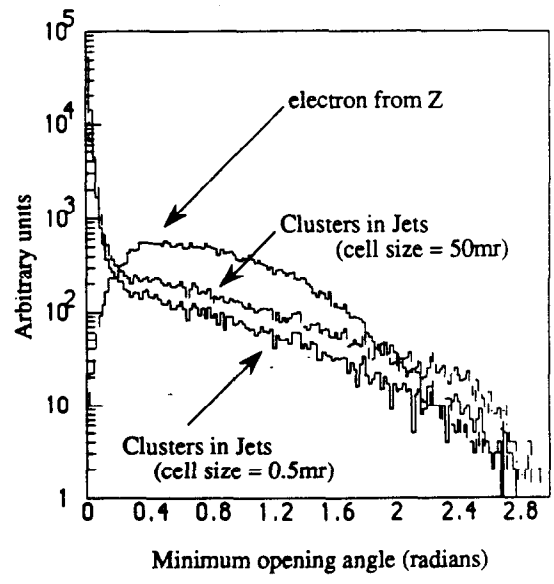

FIG. 9. Minimum opening angle distribution between two clusters for cases described in text.

Two isolated clusters were combined to form a Z candidate if 1) P_T of the pair was larger than 50 GeV/c and 2) the invariant mass of the pair was within 10 GeV/c^2 of M_Z. Table 3 shows the number of Z candidates which passed this selection, where *ee* (*eh*, *hh*) represents a Z candidate which is composed of two type *e* (*e* and *h*, two *h*) clusters (See Figure 10). We then subjected these clusters to the θ_{min} isolation cut and the Z candidates surviving this were deemed *Good Z's*. As is seen from this Table, many more fake Z candidates passed the isolation cut for the largest cell size. Two Z candidates were combined to form Higgs candidates. Table 4 shows the number of ZZ pairs with invariant mass above 200 GeV/c^2, where, e.g., *hh–ee* means one Z is *hh* type and the other is *ee* type (i.e., a real Z) for all Z candidates and *Good Z* candidates. Figure 11 (a)–(d) shows the invariant mass distributions for ZZ pairs for a cell size of 0.5 mr.

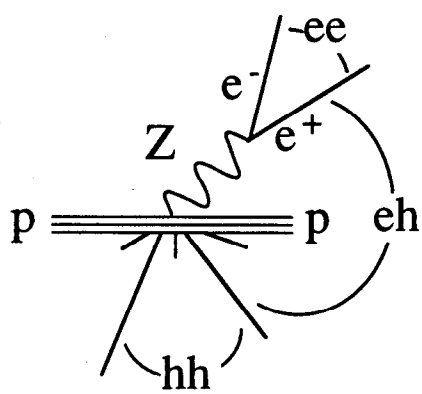

FIG. 10. Cluster pairing types used in constructing Z candidates. Type *ee* involves two electrons from the Z, type *eh* involves one electron from Z and another particle and type *hh* involve particles other than electrons.

Cell Size (mr)	Z Consistency	*hh*	*eh*	*ee*
0.5	none	3400	16300	14900
0.5	Good Z	20	700	9700
50	none	2200	7700	14900
50	Good Z	140	1100	9700

Table 3. Isolation Effects on the Number of Z^0 Candidates from 100K $Z + Jets$ Events Generated: A Z^0 candidate requires two slim clusters with total invariant mass = $M_Z \pm 10$ GeV/c^2 and $P_T > 50$ GeV/c. Good Z consistency requires that each cluster is isolated(as described in the text). For an SSC year run (10^4 pb^{-1}), multiply these numbers by 30 to get proper number of events.

Cell Size (mr)	Higgs Consistency	*hh–hh*	*hh–eh*	*eh–eh*	*hh–ee*
0.5	none	2000	6100	4300	3000
0.5	Good Higgs	0	1	8	16
50	none	200	1400	1000	2100
50	Good Higgs	0	3	18	104

Table 4. Isolation Effects on the Number of Higgs Candidates from 100K $Z + Jets$ Events Generated: A Higgs candidate requires two Z candidates. Good Higgs consistency means that the two Z's are Good as described in the text and Table 3. For an SSC year run (10^4 pb^{-1}), multiply these numbers by 30 to get proper number of events.

It should be noted that in Fig. 11 statistics are low, but it is clear that most background appears at low mass. The effective rate when scaled to cross section, however, is high. But all of this assumes no lepton/hadron separation. Fairly modest rejection factors of 0.1 to 0.01 will eliminate this form of $Z + Jets$ background. More precise estimates of this background will require experimental verification and more detailed simulation of electron identification.

We note again that other backgrounds arising from pure QCD and $gg \rightarrow ZQ\bar{Q}$ have not yet been put through this analysis.

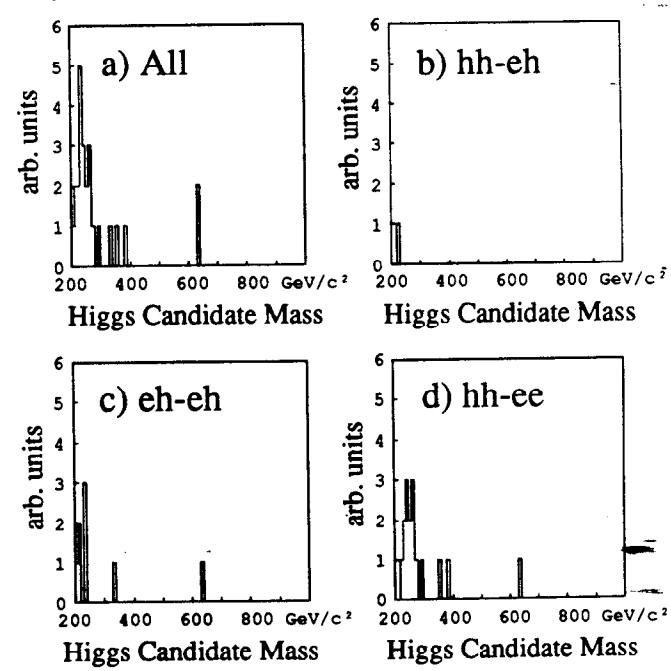

FIG. 11. The invariant mass distributions for Good Higgs candidates for cases (a) All combinations of clusters, (b) *hh–eh*, (c) *eh–eh* and (d) *hh–ee*. The cases are described in the text.

Charge Discrimination We now address the question of charge discrimination. Using the same 100K $q\bar{q}, gq \rightarrow Z + Jets$ events from PYTHIA as described in the previous section, we consider only the charges of the two particles which reconstruct to a Z mass. Again, the particles were required to have $P_T > 10$ GeV/c and $|\eta| < 2.5$. A pair of particles was considered a Z candidate if its $P_T >$ 50 GeV/c and its invariant mass was within 10 GeV/c 2 of the Z mass. No isolation cuts were made. Figure 12 (a)-(c) shows the ZZ invariant mass for Z candidates under various charge requirements. Curve (a) shows M_{ZZ} for all ZZ combinations, regardless of charge. Curve (b) shows it for combinations with no neutral particles contributing to either Z candidate, and (c) shows M_{ZZ} only for combinations in which both Z candidates are made of one positive and one negative particle. Of 4953 original combinations, 1713 (35%) have no neutrals and 514 (10%) have the correct charge combination. This simple cut assumes no lepton/hadron discrimination, yet reduces the background by a factor of 4 above 400 GeV/c^2, and by a factor of 40 at 200 GeV/c^2. It is a powerful but simple cut for background reduction. Again, other backgrounds have not been put through this analysis.

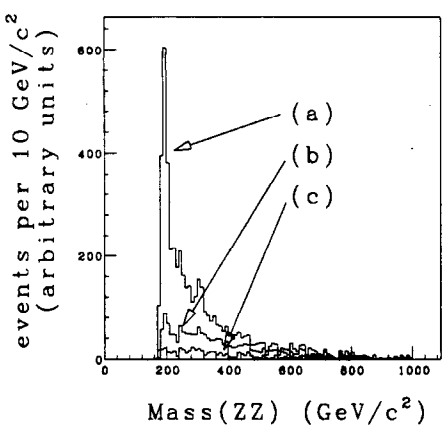

FIG. 12. Diboson mass with varying degrees of charge discrimination. (a) ZZ combinations for all Z candidates, regardless of charge, (b) with discrimination against neutral particles, and (c) with full charge discrimination.

5. Future Work

The $gg \rightarrow ZQ\bar{Q}$ system must be hadronized before its contribution due to particle identification problems can be estimated.

This group looked at some of the backgrounds due to $Z + Jets$ in an idealized way using four-vectors. While this is satisfactory for gaining intuition on relative sizes of various backgrounds, the effects of detector deficiencies have not been studied adequately.

Of course, the spectre of the pure QCD two-jet background remains unstudied but not forgotten. The raw QCD cross section is another factor of 10^4 larger than the $Z + Jets$ background.

Another area which was discussed in this group was the decay $H \rightarrow \ell^+\ell^-\nu\bar{\nu}$. It is clear that more work is needed to establish that this decay of the Higgs can give a believable signal. However, within the short time period of the Workshop we were not able to advance beyond the previous work on this mode. Another higher-rate decay of the Higgs which may prove promising is $H \rightarrow Z^0Z^0 \rightarrow \ell^+\ell^-q\bar{q}$. To our knowledge no detailed study has been made for this mode.

6. Conclusions

The intermediate mass Higgs boson decay into four charged leptons via the ZZ^* mode is expected to be difficult to observe due to low event rates. The case of a 140 GeV/c^2 Higgs was examined in some detail. The detector requirements are stringent in terms of rapidity and minimum P_T acceptance and energy and momentum resolution for the leptons. Cuts needed to reduce backgrounds, for example, from $gg \rightarrow Zb\bar{b}$, also significantly reduce the already very small signal.

The heavy Higgs boson decay $H \rightarrow Z^0Z^0 \rightarrow \ell^+\ell^-\ell^+\ell^-$ still seems to be observable for a Higgs mass of from $2M_Z$ to ~ 600 GeV/c^2 when detector effects are included. Momentum and energy resolution requirements for the leptons are within the range proposed for SSC detectors, for example, of the large solenoid type. A careful study of backgrounds from $q\bar{q}, gq \rightarrow Z + Jets$ shows that an isolation cut on lepton candidates can be expected to reduce this contribution to the 400 GeV/c^2 Higgs signal to low levels.

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