LBL-21695

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics Division

Presented at the Workshop on Physics Simulations at High Energy, Madison, WI, May 7-16, 1986

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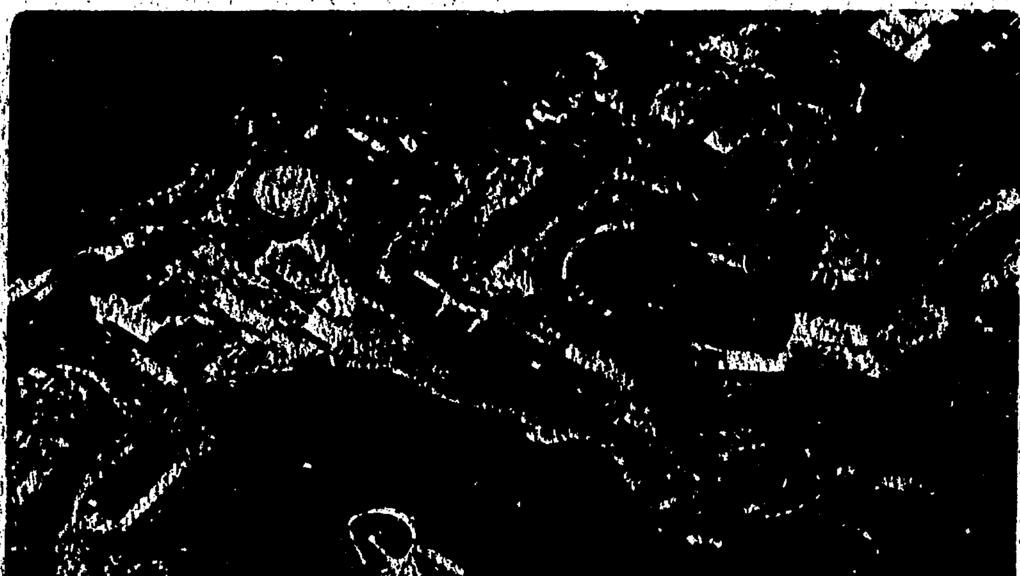
June 1986



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL--21695

DE86 013487

June 1986

IDENTIFYING HEAVY HIGGS BOSONS [1]

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ABSTRACT

Two techniques for identifying heavy Higgs bosons produced at SSC energies are discussed. In the first, the Higgs boson decays into ZZ, with one Z decaying into an e-pair or μ-pair and the other into a neutrino pair. In the second, the production of the Higgs boson by WW fusion is tagged by detecting the quarks that produced the bremsstrahlung virtual W's. The associated Higgs decay is identified by one leptonic and one hadronic decay. Both methods appear capable of finding a heavy Higgs boson provided the SSC design parameters are achieved.

INTRODUCTION

Electroweak symmetry breaking is a primary concern of contemporary particle physics and a primary motivation for the proposed SSC. The three most commonly discussed alternatives for the symmetry breaking mechanism are the simple, single Higgs doublet of the standard model, a two doublet variant as required in supersymmetry, and technicolor. It is the simplest model we address here. Despite its simplicity, the single Higgs doublet model provides the most severe experimental challenge for there is but one new particle to find - the Higgs boson - and it couples feebly to ordinary matter.

As is well-known, there are two primary production mechanisms that will be effective for producing the Higgs boson at the SSC, provided its mass is in the range 200 - 1000 GeV to which we restrict ourselves henceforth. In the first, two gluons collide to produce a heavy quark - anti- quark pair which subsequently annihilates into a Higgs boson.[1] In the second, incident quarks or anti-quarks emit virtual W's or Z's which collide to form the Higgs boson.[2] The cross sections for these processes have been computed by several authors, [2,3,4,5,6,7,8], with results in the picobarn range. Since a picobarn corresponds to 10,000 events for the nominal SSC design parameters ($\int \mathcal{L}\, dt = 10^{40}$ cm^{-2}), it is not rate that is the problem

[1]This work was supported in part by the Director, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under contract DE-AC03-76SF00098.

but rather identification. The most conservative approach is to require that the Higgs boson decay into ZZ (which it does about one third of the time if the Higgs boson is very heavy) and that both Z's decay into e-pairs or μ-pairs. This costs a factor of about $(1/3)\cdot(0.06)^2 \approx 1.2\cdot 10^{-3}$, leaving only 12 of these gold-plated events per picobarn of production cross section. This may itself be enough. It took fewer than twelve events to discover the Z. It is clear, however, that alternative signatures are very much to be desired.

There were early hopes that the decay chain $H \to ZZ$ could be identified if one Z decayed leptonically and the other hadronically. Such hopes turned out to be too optimistic.[9,10] However, extensive analysis has renewed the hope of using hadronic decays by judicious cuts on the energies in the jets.[11]

I discuss here two techniques that may be used to identify very heavy Higgs bosons at the SSC. The first relies on the ZZ decay of the Higgs and requires that one Z decay into the clean signature e-pair or μ-pair. The other Z decays into a neutrino pair. This signature was originally proposed by Chanowitz and Gaillard [12] and has recently been investigated by Cahn and Chanowitz.[13] The second technique is an analogue of tagging in two-photon physics.[14,15] Here the idea is to detect the quarks that give the bremsstrahlung virtual W's or Z's that produce the Higgs boson. These quarks recoil against the bremsstrahlung with a transverse momentum scale set by M_W. These quark jets can then be detected in conjunction with the Z's or W's into which the Higgs boson decays. There is adequate rate only if one Z or W is allowed to decay hadronically.

In both instances the critical question is that of the background. Analysis of the backgrounds indicates that the two techniques would indeed be effective in finding a heavy Higgs boson at the SSC.

DETECTING $H \to Z(\to l^+l^-) + Z(\to \nu\nu)$[13]

A clearly identified Z recoiling against large missing momentum would be a striking signature. We believe that the dominant background to such Higgs decays would come from pairs of Z's produced by the mundane process $q\overline{q} \to ZZ$. For each event we compute the quantity

$$M_T = 2\sqrt{p_\perp^2 + M_Z^2} \qquad (1)$$

where $p_\perp$ is the transverse momentum of the observed Z. The Higgs is produced with non-zero transverse momentum, typically of order M_W.[14,15] Thus the missing transverse momentum will not precisely balance the observed $p_\perp$. It is important, therefore, to compute the process using the full matrix element, rather than the effective-W approximation. Figure 1 shows the spectrum in M_T expected for Higgs bosons of mass 600, 800, and 1000 GeV. The dashed curve shows the background from $q\bar{q} \rightarrow ZZ$. The observed Z is required to have a rapidity less than 1.5.

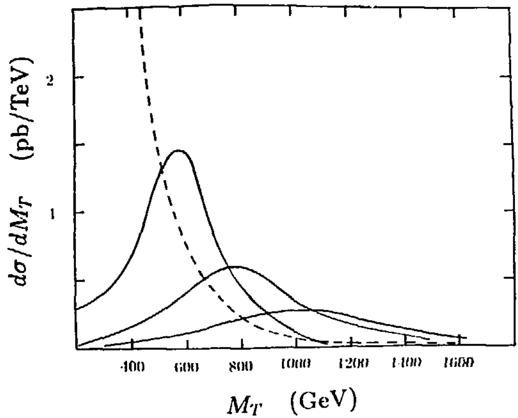

Figure 1: The transverse mass distribution of the background and signal for $pp \rightarrow ZZX$ for center of mass energy 40 TeV. The transverse mass is defined in terms of the transverse momentum of the observed Z. The signals shown correspond to $M_H = 600$, 800, 1000 GeV. The dashed curve corresponds to the background. The observed Z has a rapidity with magnitude less than 1.5.

Another presentation of the results is given in Table 1.[13] The table indicates that it should be possible to demonstrate the presence of a heavy Higgs boson and determine its mass reasonably well should the Higgs lie in the range 400 - 1000 GeV. Of course the estimates of the background must be considered provisional. Much more reliable estimates will be possible using data from the SSC itself. The uncertainty in the background will be dominated by uncertainties in the structure functions. These, however, can be measured independently by measuring well-understood processes like Drell-Yan production of lepton pairs.

	$M_T > 400$	$M_T > 500$	$M_T > 700$	$M_T > 900$
$M_H = 400$	71/112	26/53	4/17	1/7
$M_H = 600$	107/112	86/53	26/17	8/7
$M_H = 800$	76/112	72/53	54/17	30/7
$M_H = 1000$	61/112	59/53	53/17	43/7

Table 1: Signal from Higgs bosons over background from $q\overline{q}$ annihilation. The observed channel is ZZ with one Z decaying to e or μ pair and the other to neutrinos. The visible Z has rapidity less than 1.5. The masses are in GeV and the events are for a standard SSC year.

DOUBLE TAGGING[15]

Most Z's and W's decay hadronically. Unfortunately, there appears to be no way to identify these decays using just the measured invariant mass of the pair of hadronic jets. This is so because of the enormous background from hadronic jets arising from ordinary QCD processes.[9,10]. There remains the possibility of isolating the signal by looking in more detail at events with a leptonically decaying Z or W and a pair of hadronic jets whose invariant mass corresponds to that of the W or Z. For the particular case of Higgs boson production, the event structure is quite distinctive. If the Higgs boson is very heavy, the dominant production mechanism is WW fusion[2]. The exiting quarks, having given off bremsstrahlung W's or Z's, have typically large longitudinal and transverse momentum. The background process $q\overline{q} \to ZZ, WW$ has no such additional hadronic jets. Thus identification of these jets discriminates against the background. Of course there are higher order background processes like $q\overline{q} \to ggZZ$ that do simulate the real WW fusion process. We have calculated the cross sections for such processes.[15]

The cross sections for these higher order processes are indeed very small, on the order of 10^{-40} cm^2. Unfortunately, if the ZZ or WW final state is observed with one hadronic decay we must consider in addition to 'real' backgrounds like $q\overline{q} \to ggZZ$, 'fake' backgrounds like $q\overline{q} \to ggggZ$ where two gluons simulate a Z.

Processes like $q\overline{q} \to ggZZ$ are already complicated enough so that it is sensible to work with some strong approximations rather than calculating the full matrix elements. For the simpler process $q\overline{q} \to gZZ$ we compared a full calculation using 'spinor techniques'[16] to an approximation in which the process q → qg (or $\overline{q}$ → $\overline{q}$g) was treated as being entirely on-shell. We found that the approximation was good to about 10% in the region of interest. On this basis, we used this on-shell approximation for both legs of $q\overline{q} \to ggZZ$ and the analogous processes.

The more arduous task of calculating $q\overline{q} \to ggggZ$ and its variants has not been attempted. Instead we have used as a rule of thumb the results of calculations comparing $q\overline{q} \to ZZ$ and $q\overline{q} \to ggZ$ (again, with its variants) which suggest that the 'fake' background is 70 times as big as the 'real' background.

Cuts have been made on the signal and background in an effort to represent plausible detector capabilities. We have required the Z's and W's to have rapidities less than 1.5. The QCD jets which are tagged are required to have longitudinal momentum at least 500 GeV and transverse momentum at least 60 GeV. It turns out that the rapidities of the tagged jets are typically 3 to 4, not too large to be seen by a likely SSC detector. See Fig.2.

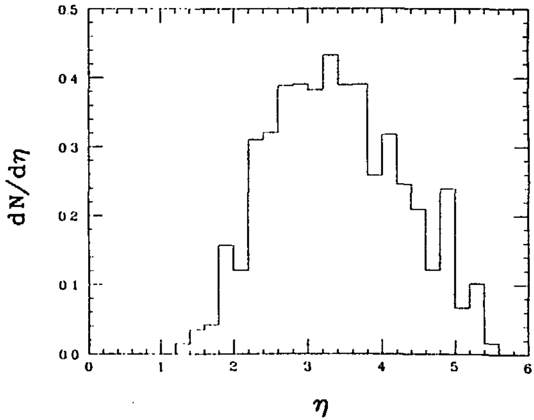

Figure 2: The rapidity distribution for a quark jet used to tag a WW fusion Higgs production event. The jet is required to have longitudinal momentum greater than 500 GeV and transverse momentum greater than 60 GeV.

In Table 2 we show our results for the signal and background when we insist on one leptonic and one hadronic decay of the Z's or W's and the detection of two additional QCD jets. The signals in both the ZZ and WW channels are significant. While there is more statistical significance to WW channel, it is not clear it is really useable since there is a missing neutrino.

	ZZ	WW
signal	60	400
$q\bar{q} \rightarrow gZZg,\ gWWg$	0.06	1.0
$gq \rightarrow qZZg$	0.22	3.3
$gg \rightarrow qZZ\bar{q}$	0.14	2.2
total 'real' background	0.42	6.5
70 x total 'real' background	29	455

Table 2: Cross sections in 10^{-40} cm^2 to produce ZZ or WW via the Higgs (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.

ACKNOWLEDGMENTS

I would like to thank my collaborators, M. S. Chanowitz, S. D. Ellis, R. Kleiss, and W. J. Stirling, whose work is reported here.This work was supported in part by the Director, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under contract DE-AC03-76SF00098.

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