FINDING THE STANDARD HIGGS IN DECAYS OF Z°'s PRODUCED IN e^+e^- COLLISIONS

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Summary

Characteristics of Higgs meson production from e^+e^- collision with center of mass energies at the Z° peak are discussed along with techniques for isolating the Higgs signal. Experiments to find the standard Higgs should be feasible with anticipated luminosities.

Experiments searching for Higgs mesons H° via Z° decay have been discussed in the SLC workshop[1], Cornell workshop[2], the EFCA/LEP Working Group[3], and also by Barger et al.[4].

For orientation purposes we first consider a Higgs of

$$M_{H^{\circ}} \cong 10 \text{ GeV}/c^2,$$

where the rate

$$\Gamma(Z^{\circ}\rightarrow H^{\circ}+X)/\ \Gamma(Z^{\circ}\rightarrow \mu^+\mu^-) \cong .03. \qquad (1)$$

The primary process contributing to such decays is the bremsstrahlung mechanism shown in Figure 1, where $f,\bar{f}$ are quarks or leptons.

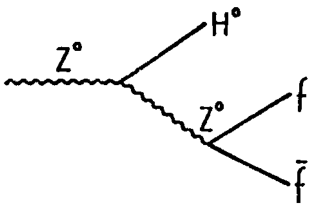


Fig. 1. Z° decay diagram; $f,\bar{f}$ bremsstrahlung are quarks or leptons.

Since

$$\Gamma\,(Z^{\circ}\rightarrow \mu^+\mu^-)/\Gamma\,(Z^{\circ}\rightarrow \text{all})\ \ .03, \qquad (2)$$

H° must be found by searching in an environment with signal/noise $\cong 10^{-3}$. With average yearly luminosities at the Z° anticipated to be in the vicinity of 10^{37} cm^{-2}, and peak cross sections on the Z° are $\cong 40 \times 10^{-33}$ cm^{-2}, we can expect several hundred Higgs/year. This situation deteriorates rapidly for heavier Higgs masses.

Searches for Higgs based on its decay modes must be designed to examine a $\cong 60\%$ branching ratio into $c\bar{c}$ and/or $\cong 30\%$ into $\tau\bar{\tau}$ if $M_{H^{\circ}}<10\text{GeV}/c^2$, or the 90% branching into $b\bar{b}$ for $M_{H^{\circ}} > 10$ GeV/c^2. The predicted branching ratios as functions of mass are shown in Figure 2[4]. Unless the identity of the $f\bar{f}$ of Figure 1 are e^+e^- or $\mu^+\mu^-$, backgrounds and combinatorics would be high even if some decay paths are measured. Since e^+e^- plus $\mu^+\mu^-$ costs only a factor $\cong 6$ in rate, an analysis of the decays

$$Z^{\circ}\rightarrow H^{\circ} + \begin{cases} e^+e^- & \text{(a)} \\ \mu^+\mu^- & \text{(b)} \end{cases} \qquad (3)$$

seems most feasible. We will focus on these modes for most of the remainder of this note. Further, if we assume a shower calorimeter with

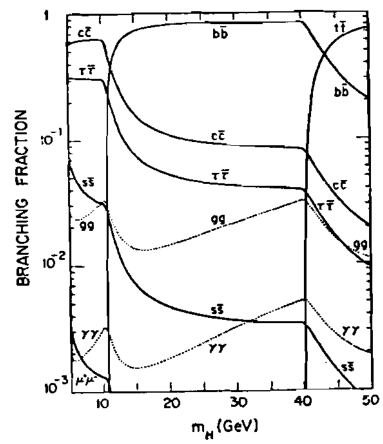


Fig. 2. Branching ratios of a Higgs boson as a function of its mass, based on the following quark masses in GeV: $m_s = 0.3$, $m_c = 1.5$, $m_b = 5$, $m_t = 20$.

$\sigma/E_c = 0.1/\sqrt{E_{GeV}}$, since $E_\ell > 20$ GeV for the leptons from the decay (3), $\sigma/E < 0.025$ for electrons. Since muon resolution will be several times worse, we will concentrate on the electron position pair in the decay (3a).

The rate for this decay relative to $Z^{\circ}\rightarrow\mu^+\mu^-$ is illustrated[3] in Figure 3. If the background were negligible, $\cong 10$ events could establish the existence of the H°, and the necessary luminosities for this are shown, setting upper limits to the observable Higgs mass. We explore the situation $M_{H^{\circ}} = 10$ GeV/c^2, 40 events, Lt = $.10^{37}$ cm^{-2} in more detail. Typically these events contain two high momentum electrons well separated from the hadronic fragmentation. Separation from background may be based on cuts in three variables: i) the mass recoiling (M_{recoil}) from the e^+e^- system, low in this case, ii) the effective mass of the leptons $M_{e^+e^-}$, iii) the angles α of the leptons with the sphericity (or similar) axis of the remaining particles. The latter two cuts are explored[1] in Figure 4, where the effective mass plot is presented for Lt = 10^{37} cm^{-2} with two possible Higgs masses. Here the primary background is assumed to be

$$Z \rightarrow t+\bar{t} \rightarrow e^+e^- + X \qquad (4)$$

with the branching ratio = $0.08 \times (0.1)^2$.

The top mass m_t is taken to be 25 GeV, while higher m_t will produce electron with larger transverse momentum, the decrease in the branching ratio $Z^{\circ}\rightarrow t+\bar{t}$ partly cancels this potential problem. Since a selected pair of hadrons in each event could fake a high effective mass e^+e^- pair if misidentified, the hadron rejection of the electron identifier must be of the order of $\sqrt{10^5}$ for these high energy electrons.

Figure 5 illustrates[1] a Monte Carlo scatter plot of M_{recoil} vs $M_{e^+e^-}$ for the 40 Higgs events and the postulated background. As the Higgs mass increases, the number of events falls rapidly, but the resolution in recoil mass improves[3]. Some potential background at high Higgs mass can also be rejected by additional cut, in visible energy, multiplicity and

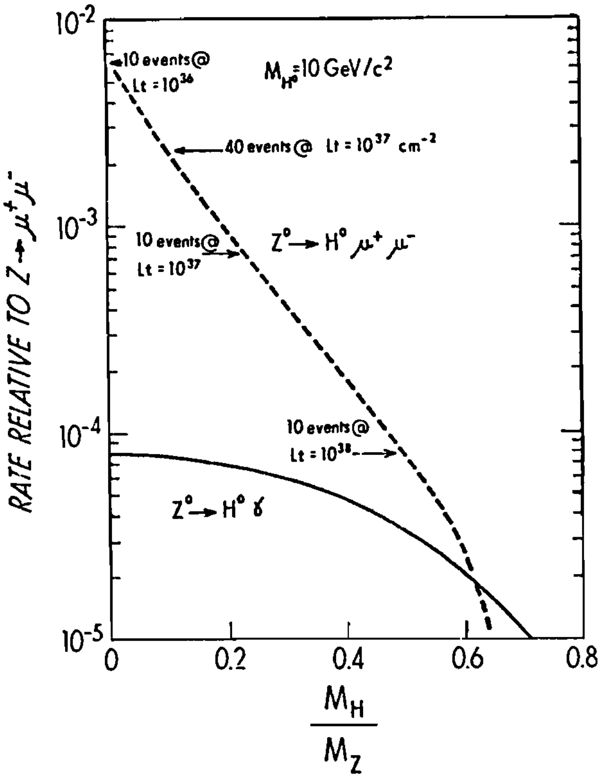


Figure 3. The ratios $\Gamma(Z^0 \rightarrow H^0\mu^+\mu^-)/\Gamma(Z^0\rightarrow\mu^+\mu^-)$ and $\Gamma(Z^0\rightarrow H^0\gamma)/\Gamma(Z\rightarrow\mu^+\mu^-)$ as functions of m_H/m_Z. The 10 event limit is shown for several luminosity scenarios.

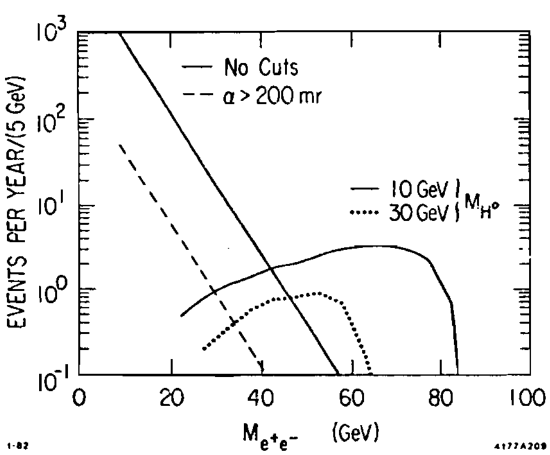


Fig. 4. Electron-positron pairs mass spectra for:
(i) e^+e^- pairs from jets without cuts (solid line),
(ii) e^+e^- pairs from jets with 200 mr cut described in text (dashed line),
(iii) e^+e^- pairs from $Z^0 \rightarrow H^0e^+e^-$, M_H = 10 GeV (solid curve),
(iv) e^+e^- pairs from $Z^0 \rightarrow H^0e^+e^-$, M_H = 30 GeV (dashed curve).

sphericity. Thus the 10 event/year limits of Figure 3 could be close to the real limits with optimization of selection criteria.

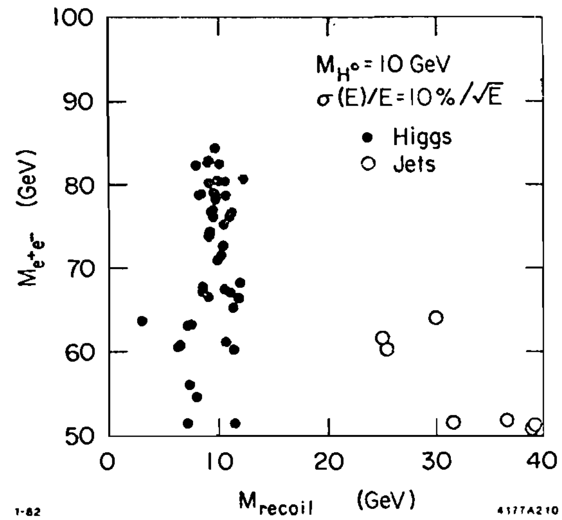


Fig. 5. Scatter plot of $M(e^+e^-)$ versus recoil mass with calorimeter resolution $\Delta E/E = 0.1/\sqrt{E}$.

For the Z° decay under consideration, Figure 6 illustrates[1] a low mass limit due to background from

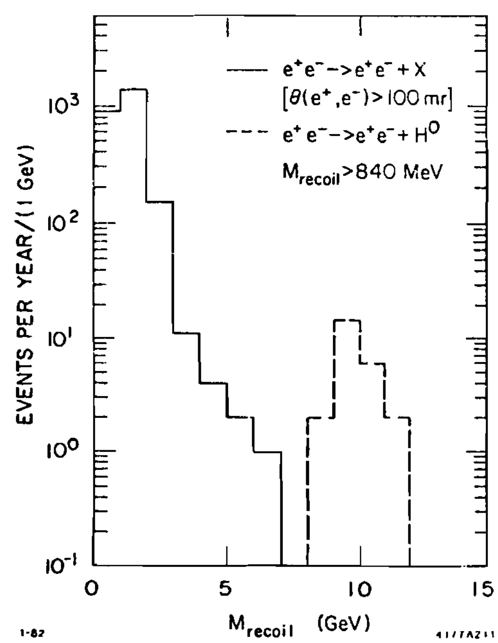


Fig. 6. Mass spectrum recoiling against high mass (>50 GeV) e^+e^- pairs from $Z^0 \rightarrow H^0e^+e^-$ and $e^+e^- \rightarrow e^+e^- + X$.

two photon interactions. This restricts $M_{H^\bullet}$ to be greater than ~ 8 GeV/c^2. Since low $M_{H^\bullet}$ implies larger event samples, this restriction may be overcome by studying the decay sequence.

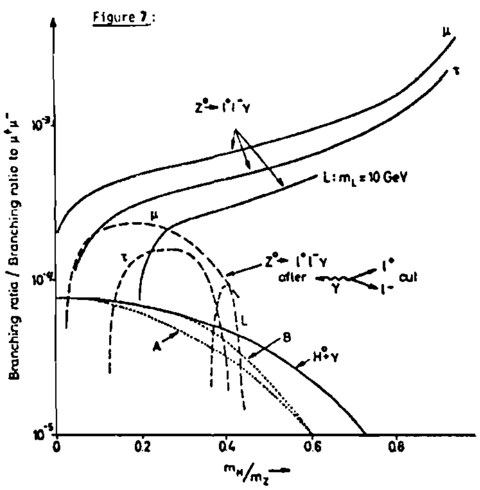
$$Z^\bullet \rightarrow H^\bullet + \mu^+ \mu^- \qquad (5)$$
$$\quad \hookrightarrow \tau^+ \tau^-$$

with two very high energy muons.

Finally, we consider the decay

$$Z^\bullet \rightarrow H^\bullet + \gamma \qquad (6)$$

In Figure 3 we see that the branching ratio provides barely useful samples at the highest luminosity considered. Further, Figure 7 indicates[3] that



The $Z^0 \rightarrow L^+L^-\gamma$ background to the search for $Z^0 \rightarrow H^0 + \gamma \rightarrow L^+L^- + \gamma$.

background problems from $Z^\bullet \rightarrow \ell^+ \ell^- \gamma$ are severe, except for certain leptonic channels at certain Higgs masses. Nevertheless, this reaction provides important gauge theoretical information, and should be measured if possible.

References

1. Proceeds of the SLC Workshop, SLAC 247, Stanford Linear Accelerator Center, March 1982.
2. Proceeds of the Cornell Theory Workshop, CLNS-81-485, Cornell University, February 1981; Detectors and Experiments for e^+e^- at 100 GeV, CLNS 81-490, Cornell University, April 1981.
3. The Production and Detection of Higgs Particles at LEP, DESY 79-27.
4. V. Barger, F. Hulzen and W.Y. Keung, PRL 110B, 323, 1982.