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FINDING AN INTERMEDIATE MASS HIGGS BOSON*

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Summary

We demonstrate that the production mode

$$pp \to W^+ + H^\circ + X, \quad H^\circ \to t\bar{t}$$

provides a favorable signal/background ratio for intermediate Higgs masses ($2m_t < m_H < 2m_W$) provided that b/t jet discrimination can be made at the 1% level while maintaining about a 10% resolution in the mass squared of the $t\bar{t}$ jet pairs and top detection efficiencies above 20% .

The difficulty of seeing a directly produced Higgs boson with mass $2m_t < m_H < 2m_W$ in the process

$$pp \to H^\circ + X, \quad H^\circ \to t\bar{t}$$

is well known. The continuum QCD background of $t\bar{t}$ pairs is too large by several orders of magnitude to allow identification of the $H^\circ \to t\bar{t}$ signal with, for instance, a 10% mass resolution in M^2, the $t\bar{t}$ pair mass squared. When $m_H > 2m_W$ the decay $H^\circ \to W^+W^+$ dominates and the smaller background of W^+W^- continuum pairs should make identification of such a Higgs possible.[1] Planned e^+e^- machines will be able to produce and identify a Higgs with mass < 100 GeV through toponium decays or production in association with a Z°.[2]

We have investigated in detail the backgrounds to the process

$$(a) \quad pp \to W^+ + H^\circ + X, \quad H^\circ \to t\bar{t}$$

a possible probe of the intermediate mass region. In this production mechanism the intermediate virtual W^+ implies the presence of the relatively large (order gM_W) $W^+ \to W^+H^\circ$ coupling while the final state W^+ trigger provides an appreciable suppression of the backgrounds. The worst backgrounds come from two sources:

$$(b) \quad pp \to W^+ + g + X, \quad g \to t\bar{t}$$

and

$$(c) \quad pp \to W^+ + b + \bar{t} + X ,$$

where the b is misidentified as a t.

Sample Feynman diagrams for (a), (b) and (c) are illustrated in Fig. 1. (b) is initiated by $u\bar{d}$ annihilation, as is the production mechanism (a), and in particular cannot make use of the large gg luminosity function that makes the $t\bar{t}$ continuum without the W^+ trigger so large. (c) is primarily a gg initiated process (in fact we compute only these terms), but can be suppressed by adequate b/t jet discrimination.

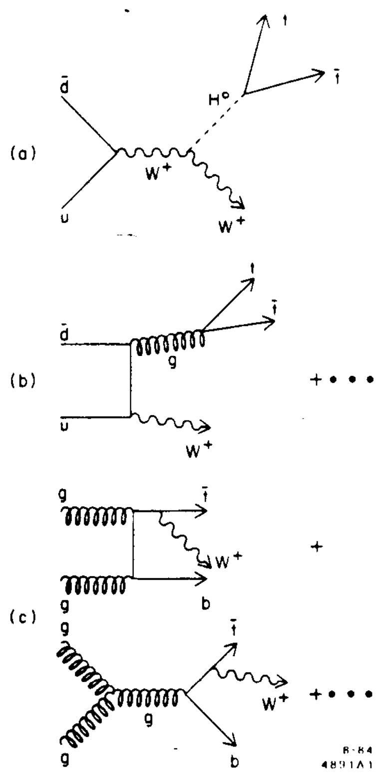

Figure 1

The matrix element for (a), without the $H^\circ \to t\bar{t}$ decay, appears in EHLQ.[1] We have added the decay matrix element, and also, in computing cross sections, have required cuts on the $t\bar{t}$ pairs and W^+ which enhance their observability in the apparatus. The matrix elements for (b) and (c) were computed in several independent ways using algebraic manipulation programs and manual checks, and will appear elsewhere.[3] The same cuts as for (a) are imposed for the (b) and (c) cross sections. The cuts can be specified in terms of:

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(*i*) y_W — the W rapidity,

(*ii*) y_H — the $t\bar{t}$ or $b\bar{t}$ pair, or Higgs rapidity,

(*iii*) p_T^W — the W transverse momentum.

They are typically $-2 < y_W < 2$, $-2 < y_H < 2$ and $p_T^W >$ 40 GeV/c. For (*b*) and (*c*) we present $(d\sigma/dM^2)\,\Delta M^2$, where M is $t\bar{t}$ or $b\bar{t}$ pair mass (and is set equal to the m_H value under consideration), and $\Delta M^2 = .1\ m_H^2$ is the assumed mass squared resolution. For (*a*) we simply have integrated over the Breit–Wigner pole for the H° decay. All calculations employ NSET = 2 EHLQ distribution functions;[1] m_t = 40 GeV/c^2 throughout.

We exhibit our results in a series of figures. In Figs. 2–7 process (*a*) is represented by the solid curve, (*b*) by a dashed curve, and the contributions of (*c*) have been divided by a factor of one hundred (100)—equivalent to the assumption of 1% b/t jet discrimination—and shown as a dotted curve.

Figure 2 shows the cross sections as a function of m_H for $\sqrt{s}$ = 40 TeV, $-2 < y_W, y_H < 2$, $p_T^W >$ 40 GeV/c. Clearly background (*b*) is nicely below the signal process (*a*), while 1% b/t jet discrimination reduces (*c*) to a manageable problem. The signal cross section is of order 1 pb yielding ten thousand events in a standard $L = 10^{40}/\text{cm}^2$ year. A leptonic W^+ trigger leaves more than a thousand events, assuming leptonic detection efficiencies above 50%. Efficiencies for top jet detection as low as 20% would leave a measureable signal.

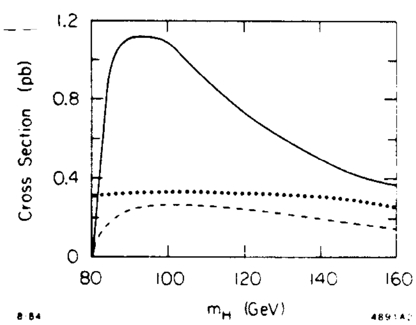

Figure 2

Figure 3 shows the cross sections as a function of $\sqrt{s}$ for m_H = 130 GeV/c^2, $-2 < y_W, y_H < 2$, $p_T^W >$ 40 GeV/c. Lower machine energies make the event rate marginal, but do not significantly alter the signal to background ratio.

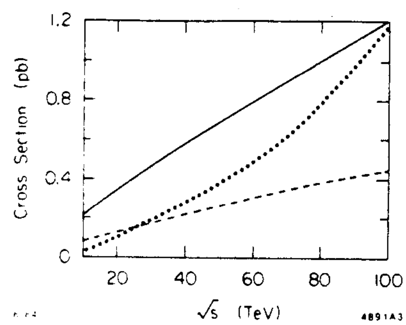

Figure 3

Figure 4 gives the differential distributions for the top quark energy for m_H = 130 GeV/c^2, $-2 < y_W, y_H < 2$, $p_T^W >$ 40 GeV/c, and $\sqrt{s}$ = 40 TeV. Apparently, cuts in this variable can be used to enhance signal to background, somewhat.

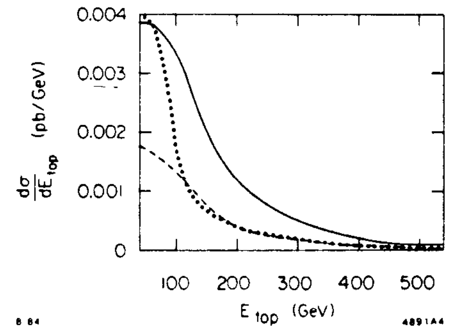

Figure 4

Figure 5 gives the differential distributions in p_T^W for m_H = 130 GeV/c^2, $-2 < y_W, y_H < 2$, and $\sqrt{s}$ = 40 TeV. From Fig. 5 we see that increasing the minimum allowed value of p_T^W does yield some signal to background enhancement, but only at the sacrifice of event rate.

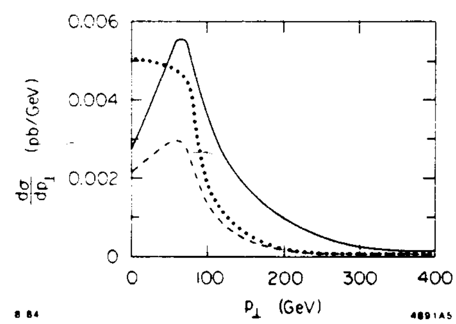

Figure 5

Figure 6 gives the differential distribution in $\cos\theta_{aco}$, where $\cos\theta_{aco} = (\hat{p}_{beam} \times \hat{p}_W) \cdot (\hat{p}_{t\,\text{or}\,b} \times \hat{p}_{\bar{t}})$, for m_H = 130 GeV/c^2, $-2 < y_W, y_H < 2$, $p_T^W >$ 40 GeV/c, and $\sqrt{s}$ = 40 TeV. A cut to keep θ_{aco} away from 0° or 180° is desirable.

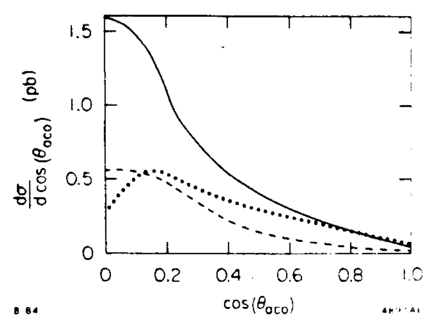

Figure 6

Figure 7 shows the y_H rapidity distribution for m_H = 130 GeV/c^2, $-2 < y_W < 2$, $p_T^W > 40$ GeV/c. Tightening the rapidity cut enhances signal to background, again at the sacrifice of rate.

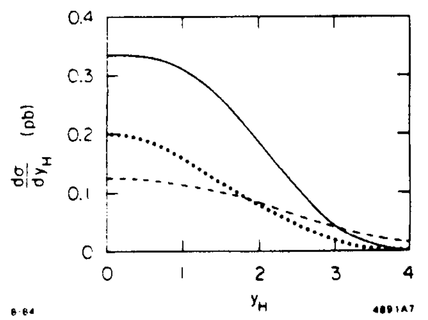

Figure 7

The results for the cross sections including cuts are encouraging. The background process, (b), of $W + t\bar{t}$ continuum pair produced through an intermediate gluon definitely can be made smaller than the Higgs signal for moderately good resolution in M. If it proves to be desirable to trigger on the associated W through its leptonic decay, it would be necessary to identify the top jets through their purely hadronic decays without the loss of any energetic neutrinos in the flavor decay chain. Otherwise the W and $t\bar{t}$ masses could not be reconstructed. Furthermore, top-bottom jet discrimination must be made at the level of 1%, with at least moderate top detection efficiency; in this way the $Wb\bar{t}$ (or $Wt\bar{b}$) misidentification background would be adequately suppressed without too great a loss of event rate. While these are nontrivial requirements, preliminary studies[4] at Snowmass '84 indicate that highly segmented detectors and cleverly designed discrimination algorithms (based on a set of optimally chosen variables) may be able to achieve the required mass resolution and discrimination power.

Acknowledgments

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We learned while our calculations were in progress that similar work has been carried out by Z. Kunszt, BUTP-84/10-BERN, May 1984. P.K. would like to thank Prof. S. D. Drell for hospitality at SLAC, and acknowledges the support of a Postdoctoral Fellowship from the Natural Sciences and Engineering Research Council of Canada.

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4. See the reports from the "Standard Model" and "Heavy Flavor Identification" working groups in *Proceedings, 1984 DPF Summer Study, Snowmass, USA, June 23 - July 13, 1984.*