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Study of $e^+e^- \to H^+H^-$ at a 800 GeV Linear Collider

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Abstract. The production and decay of heavy charged Higgs bosons at a 800 GeV e^+e^- linear collider have been studied. The analysis of the $H^+H^- \to t\bar{b}\bar{t}b$, expected to be dominant in the MSSM, and $H^+H^- \to W^+h^0W^-h^0$ decay modes leading to the same final state consisting of two W bosons and four b quarks, provides with a determination of the boson mass to 1 GeV/c^2 and of the production cross section with 10% accuracy for 500 fb^{-1} of data.

INTRODUCTION

The study of the origin of electro-weak symmetry breaking and the exploration of the Higgs sector is one of the main themes of the e^+e^- linear collider (LC) physics programme. A distinctive feature of several extensions of the Standard Model (SM), such as its minimal supersymmetric extension (MSSM), is the introduction of an extra Higgs doublet resulting in five physical Higgs boson states, two of which are charged $H^\pm$. While the existence of an extended Higgs sector may be indirectly revealed by a detailed study of the production and decay properties of the lightest neutral Higgs boson h^0 [1], its direct manifestation will only come from the detection of pairs of heavier Higgs particles, such as $e^+e^- \to H^+H^-$. We report the results of a study of the sensitivity of a 800 GeV e^+e^- LC, such as TESLA [2], for the detection of pair produced heavy charged Higgs bosons. The $e^+e^- \to H^+H^-$ production cross section depends, at tree level, only on the boson mass, $M_{H^\pm}$, while the dominant $H^\pm$ decay mode depends on the model parameters that may modify the Higgs couplings to gauge bosons and fermions. There have been some earlier studies of H^+H^- reconstruction at the LC for the case of a rather light boson, decaying predominantly into a cs quark pair [3]. This study has considered the two decay processes $H^+H^- \to t\bar{b}\bar{t}b$, expected to be dominant in the MSSM with $0.98 < \mathrm{BR} < 0.82$ for $2 < \tan\beta < 50$, and $H^+H^- \to W^+h^0W^-h^0$, leading to the same final state consisting of two W bosons and four b quarks, for the cases of heavier bosons, with $M_{H^\pm} = 200$ and 300 GeV/c^2 and $M_{h^0} = 115$ GeV/c^2.

By selecting hadronic W decays, the complete reconstruction of the resulting eight jet final states allows to determine the $H^{\pm}$ mass, profiting of the intermediate t (h^0) and W mass constraints, the production cross section and the decay branching fractions. Accurate values for the mass and the decay branching ratios may contribute to fix some of the model parameters. Recent calculations of higher order corrections to the production cross section have shown a significant model dependence [4] that may be useful for discriminating between models, provided an accurate experimental determination of the cross section is possible at the LC.

The results reported here have been obtained from a simulation study for 500 fb^{-1} of integrated luminosity at $\sqrt{s} = 800$ GeV. The signal and backgrounds events have been generated with PYTHIA 6 [5], including initial state radiation and accounting for the beamstrahlung effect computed for the TESLA parameters [6]. The generated events have been passed through the parametric SIMDET detector simulation [7].

EVENT SELECTION

The signal cross section depends strongly on the charged Higgs boson mass, varying from ~ 29 fb for 200 GeV/c^2 to ~ 12 fb for 300 GeV/c^2 corresponding to 1.5×10^4–6×10^3 H^+H^- pairs/500 fb^{-1}. This abundant production at a high luminosity LC, allows to enforce tight requirements on the event preselection and the mass reconstruction. Most two and four fermion background processes can be effectively rejected by requiring eight jets and four b quarks, despite their large production cross sections. The $t\bar{t}$ background which results in multi-jet final state with b quarks can be reduced by the both b tagging and the mass kinematical fits. Genuine $t\bar{b}\bar{t}b$ final states, as those originating from the Higgs radiation off the top quark process $e^+e^- \rightarrow t\bar{t}h^0 \rightarrow t\bar{t}b\bar{b}$, remain the largest source of background with an estimated cross section of 3 fb which has been reduced in this analysis by a kinematical fit.

To select fully hadronic events, the visible energy of the reconstructed tracks and calorimetric clusters has been required to be above 600 GeV, the missing momentum below 100 GeV/c and the energy of the most energetic lepton below 50 GeV. The hadronic system has been clustered into jets, using the CAMJET algorithm [8], varying the y_{cut} value from 2.6×10^{-4} to 5.7×10^{-5}. Only those events giving eight reconstructed jets, for a y_{cut} value in this range, have been further considered. Four out of the eight jets have been required to be b tagged. In this analysis a parametrized b tagging response, corresponding to 90% tagging efficiency with 5% mis-identification probability, has been used.

MASS RECONSTRUCTION

In order to efficiently distinguish the signal charged Higgs production from the underlying backgrounds and to measure the boson mass, it is important to obtain a clean Higgs signal in the mass distribution of the multi-jet final states. The two decay hypotheses $H^+H^- \to t\bar{b}\bar{t}b$ and $H^+H^- \to W^+h^0W^-h^0$ have been considered. Events fulfilling the above selection criteria have been tested for the presence of two W decaying into non-b tagged jets. Each t quark has then been reconstructed from a W candidate paired with a b tagged jet, in the case of the $H^+H^- \to t\bar{b}\bar{t}b$ while for the case of $H^+H^- \to W^+h^0W^-h^0$, each $h^0 \to b\bar{b}$ decay has been reconstructed from tagged $b\bar{b}$ pairs. To further reject backgrounds as well as poorly reconstructed signal events, leading to an inaccurate measurement of $M_{H^\pm}$, the compatibility of the mass of the jet combination to that of $W^\pm$ and h^0 bosons and the top quark within the measurement accuracy has been required. After completing the jet assignment, a kinematical fit, imposing energy and momentum conservation, the mass of intermediate states and equal Higgs boson masses, has been applied. This fit improves the signal mass reconstruction from by a factor of two for $M_{H^\pm} = 300$ GeV/c^2.

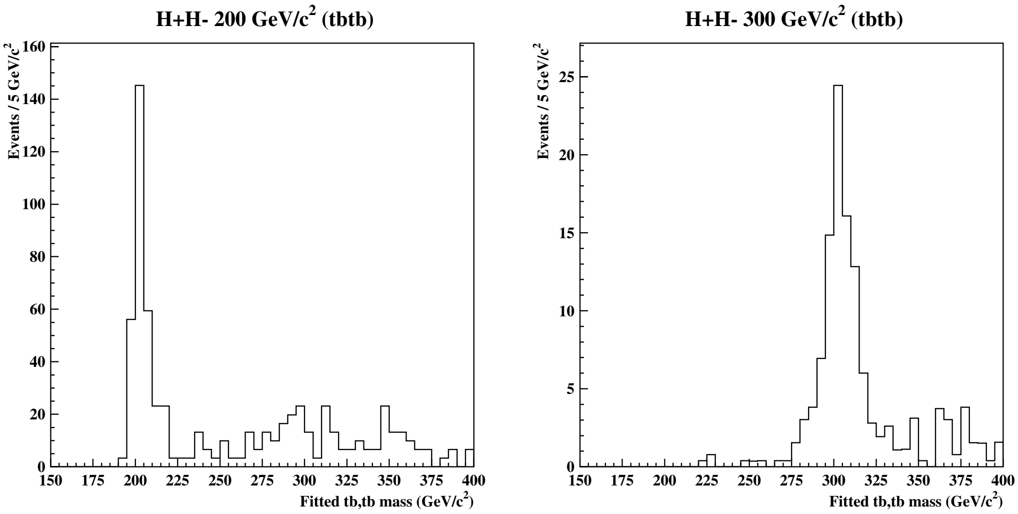

FIGURE 1. Fitted charged Higgs boson mass for $H^+H^- \to t\bar{b}\bar{t}b$ with $M_{H^\pm} = 200$ GeV/c^2 (left plot) and $M_{H^\pm} = 300$ GeV/c^2 (right plot). The histograms are normalized to 500 fb^{-1} integrated luminosity and 100% branching ratio into the analyzed decay mode.

The resulting fit χ^2 has also been used to further reject background events and to distinguish between the two signal decay channels under study, based on the hypothesis giving the best χ^2 value.

RESULTS

After applying these reconstruction and selection criteria, signal efficiencies in the range 2%-4%, according to the charged Higgs boson mass and adopted χ^2 cut value, has been obtained with a high signal purity. With a data set of 500 fb^{-1} at $\sqrt{s} = 800$ GeV, these correspond to signal samples of 150 - 600 events, with

$s/\sqrt{b} > 100$. The corresponding statistical accuracies on the measurements of the boson mass and the production cross section are summarized in Table 1.

TABLE 1. Statistical accuracy on the determination of the mass and production cross section for a charged Higgs boson at $\sqrt{s} = 800$ GeV with 500 fb^{-1}

$M_{H^\pm}$ (GeV/c^2)	$\delta\ M_{H^\pm}$ (GeV/c^2)	$\delta\sigma_{H^+H^-}/\sigma_{H^+H^-}$
200	0.4	0.06
300	1.1	0.10

Due to the low level of background achieved, the sensitivity to a charged Higgs pair production is guaranteed up to $M_{H^\pm} \simeq 350$ GeV/c^2, where the cross section falls below 5 fb, due to the β suppression, reducing the number of signal events below the detection threshold at a $\sqrt{s} = 800$ GeV collider.

CONCLUSIONS

The full reconstruction of the charged Higgs boson $H^+H^- \to t\bar{b}\bar{t}b$ and $W^+h^0W^-h^0$ multi-jet final states has been studied for a sample of e^+e^- LC data at $\sqrt{s} = 800$ GeV with $M_{H^\pm} = 200$ and 300 GeV/c^2. Statistical accuracies of 1 GeV/c^2 on the boson mass and of 10% on its production cross sections have been obtained. These results can provide significant information about the parameters of an extended Higgs sector in the MSSM or in other SM extensions.

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