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Search for the MSSM Higgs bosons at the LHC

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Abstract

The search for the neutral and charged MSSM Higgs bosons is discussed. The event selections and the discovery potential of CMS are presented.

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1 Introduction

The minimal supersymmetric extensions of the SM (MSSM) do not exhibit quadratic divergences in the Higgs sector due to the cancellation between the fermionic and bosonic degrees of freedom taking place. Two isospin Higgs doublets are needed to preserve supersymmetry, giving in total eight degrees of freedom. After electroweak symmetry-breaking three of them are absorbed by the Z and W gauge bosons, leaving 5 physical Higgs particles: the light and heavy CP-even higgs bosons, h and H, the CP-odd Higgs boson A, and the charged Higgs bosons, $H^\pm$. In the MSSM Higgs sector all masses and couplings are defined by two independent parameters at tree level, usually chosen to be the mass of the pseudo-scalar M_A and the ratio of the vacuum expectation values of the two doublets $\tan\beta = v_2/v_1$. Higher order corrections, especially from the third generation of quarks and squarks can strongly affect the phenomenology. For high $\tan\beta$ values the Yukawa couplings of the down-type quarks are strongly enhanced giving significant event rates compared to the SM. For large values of M_A the mass of the light scalar Higgs boson h reaches its upper bound ($M_h < 135\text{GeV}$) and becomes SM-like.

2 Neutral MSSM Higgs bosons

For the neutral MSSM Higgs bosons the main production mechanism for low and moderate values of $\tan\beta$ are the gluon fusion processes $gg \rightarrow h, H, A$. For large values of $\tan\beta$ the associated production with bottom quarks $gg \rightarrow b\bar{b}h, H, A$ constitutes the dominant neutral Higgs boson production process. The lightest Higgs boson h, due to its low mass, decays mainly into $b\bar{b}$ and $\tau^+\tau^-$ pairs. For large values of $\tan\beta$ the heavy scalar and the pseudoscalar H, A decay mainly into $b\bar{b}$ and $\tau^+\tau^-$ due to the enhanced Yukawa couplings of the down-type fermions. For small values of $\tan\beta$ other decay modes have sizeable branching ratios: for the heavy scalar $H \rightarrow t\bar{t}, W^+W^-, ZZ, hh, AA$ and for the pseudoscalar $A \rightarrow t\bar{t}, gg, Zh$. The observation of a neutral scalar accompanied by bjets and decaying to taus or muons is an important signature of MSSM Higgs sector. The decay of the Higgs bosons to tau pairs has been analyzed in four decay modes, depending on the tau decays: $H \rightarrow \tau\tau \rightarrow 2\text{jet}, e + \mu, e + \text{jet}, \mu + \text{jet}$.

The main background for the $H \rightarrow \tau\tau \rightarrow 2\text{jet}$ decay mode is the QCD multi-jet production [1]. The $t\bar{t}$, Drell-Yan production of $Z^*/\gamma, W + \text{jet}$ and Wt are also considered. The identification of taus is performed as follows: tracks are searched in a cone of $R_m = 0.1$ ($R_m = (\Delta\eta^2 + \Delta\phi^2)^{1/2}$) around the calorimeter jet and the leading track found defines the signal cone of $R_s = 0.04$. No other tracks must be found in a larger cone of $R_i = 0.5$ around the calorimeter jet, except the ones in the signal cone. The latter must contain one or three tracks with a leading track of high transverse momentum. The two identified taus must have opposite charge calculated from the tracks in the signal cone. The Drell-Yan background can be suppressed by requiring a tagged bjet. The associated bquarks in the signal events have small E_T which makes their bjet tagging a challenging task. The Higgs boson mass can be reconstructed from the visible tau momenta (τ jet) and the missing transverse energy E_T^{miss} , with the collinearity approximation for the neutrinos from highly boosted taus (Figure 1). Additionally, the reconstructed energy for both τ leptons and neutrinos is required to be positive ($E_{\tau 1, \tau 2} > 0, E_{\nu 1, \nu 2} > 0$) and back-to-back topologies are rejected in order to improve the mass resolution. The QCD multijet background can be predicted from data using same sign events.

Figure 1: Reconstructed Higgs boson mass and the background contribution in the decay mode $H \rightarrow \tau\tau \rightarrow 2\text{jet}$ (left) for 60fb^{-1} [1], and in the decay mode $H \rightarrow \tau\tau \rightarrow e + \text{jet}$ (right) for 30fb^{-1} [3].

Figure 2: Reconstructed Higgs boson mass and the background contribution in the decay mode $H \rightarrow \tau\tau \rightarrow \mu + \text{jet}$ (left) for 20 fb^{-1} [2], and in the decay mode $H \rightarrow \mu\mu$ (right) for 30 fb^{-1} [5].

The main backgrounds for the $H \rightarrow \tau\tau \rightarrow \mu + \text{jet}$ are the Drell-Yan $\tau\tau$ and $t\bar{t}$ production processes [2]. A τ jet and a muon of opposite charge is required. The Drell-Yan background is reduced by requiring a tagged bjet. Events containing W bosons ($t\bar{t}$, Wt , $W + \text{jets}$) are suppressed using the transverse mass $m_T(e, E_T^{\text{miss}})$ and top pairs with a central jet veto. The electrons misidentified as taus are reduced by comparing the τ jet energy in the hadronic calorimeter to the leading track momentum. The Higgs mass reconstruction is performed using positive neutrino energies and rejecting back-to-back topologies (Figure 2).

The $H \rightarrow \tau\tau \rightarrow e + \text{jet}$ has similar backgrounds and selection [3]. The electron identification is based on the ratio of the tracker momentum and electromagnetic to the hadronic energy. The fake taus from electrons are suppressed using a threshold for the most energetic hadronic cell, as well as the ratio of the hadronic energy to the leading track momentum. Events with W bosons are reduced using the reconstructed transverse mass $m_T(e, E_T^{\text{miss}})$. Similar requirements as in the previous analysis are used for the Higgs mass reconstruction.

The mode where both taus decay leptonically has smaller branching ratio but clean experimental signature [4]. The $H \rightarrow \tau\tau \rightarrow e + \mu$ has backgrounds that are easier to suppress compared to a final state with same flavour leptons. The selection requires two opposite charge, isolated leptons (one e and one μ), a tagged bjet, a central jet veto and a high combined transverse impact parameter significance of the two leptons ($\sigma_{\text{ip}}(e) \oplus \sigma_{\text{ip}}(\mu)$). The mass reconstruction has similar requirements as the previous channels. After selection, the main backgrounds are top pairs and Drell-Yan.

The decay $H \rightarrow \mu\mu$ has very small branching ratio ($O(10^{-4})$) but takes advantage of the very good muon momentum measurement in CMS [5]. There is no E_T^{miss} in the final state which allows precise reconstruction of the Higgs mass (Figure 2). Two isolated, high P_T muons are required, as well as a tagged bjet. The top pairs are suppressed by requiring low E_T^{miss} and applying a jet veto. The background shape is obtained by fitting the dimuon mass in the off-peak regions. The measured Higgs width is strongly correlated with $\tan\beta_{\text{eff}}$ and can be used to put constraints on this parameter.

The results for the SM Higgs searches in the vector boson fusion and higgs to diphotons channel can also be interpreted in terms of MSSM with $q\bar{q} \rightarrow q\bar{q}h(H)$, $h(H) \rightarrow \tau\tau \rightarrow l + \text{jet}$ and $pp \rightarrow h + X$, $h \rightarrow \gamma\gamma$, covering almost the entire $M_A, \tan\beta$ plane with 60fb^{-1} (m_h^{max} scenario).

3 Charged MSSM Higgs bosons

No charged scalar Higgs boson is predicted within the SM. The light charged Higgs boson ($m_{H^\pm} < m_t - m_b$) can be produced via top quark decays, $t \rightarrow H^\pm b$. The light charged Higgs bosons decay to $\tau\nu$ almost independent of $\tan\beta$ (for $\tan\beta > 10$) and has a branching ratio close to 1 for $m_{H^\pm} < m_t$. The leptonic decay of $W^\pm$ and hadronic tau decay leads to a final state with two bjets, a τ jet, a lepton and missing energy [6]. The main backgrounds are $t\bar{t}$, $W+3\text{jet}$ and single top production. The selection requires ≥ 3 jets, one tagged bjet, a τ jet with isolation criteria in both the tracker and the electromagnetic calorimeter, large E_T^{miss} and tau visible energy.

For $m_{H^\pm} > m_t$, the charged Higgs boson is produced in $g\bar{g} \rightarrow t\bar{b}H^\pm$ [7]. The channel with hadronic W decay and charged Higgs decay to $\tau\nu$ allows reconstruction of the transverse mass of the latter from the τ jet and E_T^{miss} . Isolated leptons are vetoed to remove signal events with E_T^{miss} from leptonic W decays. A τ jet must be found

Figure 3: The 5σ discovery regions for the MSSM neutral (left), and charged Higgs bosons with the $\tau\nu$ decay mode (right) [5].

satisfying tracker and electromagnetic calorimeter isolation criteria and must have a large fraction of its energy carried by the leading track. The top mass is reconstructed by minimising the $\chi^2 = ((m_{jj} - m_W)/\sigma_W)^2 + ((m_{jjj} - m_{top})/\sigma_{top})^2$, where m_{jj} and m_{jjj} are the invariant masses of all two and three-jet combinations in the event. Any of the three jets assigned to the top is required to be tagged as a bjet and no other central jet with significant energy must be found. Further cuts requiring large reconstructed Higgs transverse mass and opening angle between the τ jet and E_T^{miss} lead to a very small number of background events after selection.

4 Conclusions

Significant neutral Higgs boson rates can be observed in the associated production with bottom quarks due to the enhanced couplings of the latter in the high $\tan\beta$ region. The most promising decays are the $H \rightarrow \tau\tau \rightarrow 2\text{jet}, e + \text{jet}, \mu + \text{jet}, e + \mu$. The decay to two jets has as a dominant background the QCD multijet production while the rest of the decays have large contributions from Drell-Yan and top pairs. The $H \rightarrow \mu\mu$ has small event rate but clean experimental signature. The most promising search for the charged Higgs is via its decay to $\tau\nu$ with hadronic tau decays. The light charged higgs boson can be observed in top quark decays with W decaying leptonically, while for $m_{H^\pm} > m_t$ the fully hadronic channel in $gg \rightarrow tbH^\pm$ has very small background contribution after selection. A large fraction of the $M_A, \tan\beta$ plane can be covered (m_h^{max} scenario), for both neutral and charged Higgs bosons with up to 60 fb^{-1} (Figure 3).

References

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