Search for a light charged Higgs boson decaying to a W boson and a CP-odd Higgs boson in trilepton final states in pp collisions at 13 TeV with CMS

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A search for a light charged Higgs boson (H\(^{+}\)) decaying to a W boson and a CP-odd Higgs boson (A) using trilepton final states (electron-dimuon or trimuon) is presented. The result is based on data from pp collisions at a center of mass energy of 13 TeV, recorded by the CMS detector, corresponding to an integrated luminosity of 35.9 fb\(^{-1}\). In this search, it is assumed that the H\(^{+}\) boson is produced in decays of top quarks, and the A boson decays to two oppositely charged muons. The first upper limits are set on the combined branching fraction for the decay chain.
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The Higgs boson with a mass around 125 GeV was discovered in 2012 by the ATLAS and CMS Collaborations [1–3], and its observed properties have been consistent with the expectation in the standard model (SM) [4, 5]. However, there are models beyond the SM which have a different Higgs sector compared to the SM, yet are consistent with the experimental results. Two-Higgs-doublet models (2HDM) are an example of such models [6].

In 2HDM, a charged Higgs boson ($H^+$) and a CP-odd Higgs boson ($A$) are predicted. The $H^+$ boson can be mainly produced in top quark decays ($pp \rightarrow t\bar{t} \rightarrow b\bar{b}W^+H^+$) and decay to $W$ and $A$ bosons ($H^+ \rightarrow W^+A$) [7, 8]. The $A$ boson can decay to an oppositely charged muon pair ($A \rightarrow \mu^+\mu^-$). A search is performed to investigate this production and decay mode of $H^+$ and $A$ bosons. The $A$ boson mass ($m_A$) hypotheses between 15 and 75 GeV and the $H^+$ boson mass ($m_{H^+}$) hypotheses between ($m_A + 85$ GeV) and 160 GeV are considered. The motivation behind the choice of the range of $m_{H^+}$ values is based on the mass thresholds of ($m_A + m_W$) and ($m_t - m_b$) for the decay. For the two $W$ bosons in the decay chain, semileptonic decay channels ($WW \rightarrow \ell\nu qq'$, $\ell = e$ or $\mu$) are targeted.

The search utilizes a data set of $pp$ collisions at a center of mass energy of 13 TeV, corresponding to an integrated luminosity of 35.9 fb$^{-1}$, recorded using the CMS detector [9]. Selected events are required to contain two muons, and one electron or an additional muon. The three leptons should include at least one $\mu^+\mu^-$ pair, and the invariant mass of $\mu^+\mu^-$ pair is required to satisfy $m_{\mu\mu} > 12$ GeV and $|m_{\mu\mu} - 91.2| > 10$ GeV for all the $\mu^+\mu^-$ pairs in an event. In addition, the events are required to contain two or more jets, at least one of which is identified as originating from a $b$ quark. The $m_{\mu\mu}$ distribution is analyzed to look for the $A$ boson resonance. The background of the search originates mainly from $t\bar{t}$ processes that include a nonprompt lepton from B hadron decays.

No statistically significant evidence of the signal is found, and 95% confidence level (CL) upper limits are set on the product of branching fractions, $B_{\text{sig}} = B(t \rightarrow bH^+)B(H^+ \rightarrow W^+A)B(A \rightarrow \mu^+\mu^-)$. The upper limits on $B_{\text{sig}}$ vary between $1.9 \times 10^{-6}$ and $8.6 \times 10^{-6}$ depending on the assumed $m_{H^+}$ and $m_A$ values, as shown in the Fig. 1.

![Figure 1](image_url): The upper limits at 95% CL on $B_{\text{sig}} = B(t \rightarrow bH^+)B(H^+ \rightarrow W^+A)B(A \rightarrow \mu^+\mu^-)$ [10]. In the upper (lower) panel, the $m_{H^+}$ values are assumed to be $m_A + 85$ GeV (160 GeV).
This result can be used to derive upper limits on the product of branching fractions, \( \mathcal{B}(t \rightarrow bH^+)\mathcal{B}(H^+ \rightarrow W^+\phi) \), at the order of \( 10^{-2} \) \( (10^{-3}) \) in the type-I and 2 (X) 2HDM. This is more stringent than the previous results from the CDF experiment, using different decay modes of the A boson [11, 12]. This is the first search for the decay mode of the H^+ boson \( (H^+ \rightarrow W^+\phi \rightarrow W^+\mu^+\mu^-) \), and it constrains the class of models which predict a significant rate of the production and decay mode of the H^+ boson.

References


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