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Search for the Standard Model Higgs Boson Decaying to $\mu^+\mu^-$ in pp
Collisions at $\sqrt{s} = 7$ and 8 TeV with the CMS Detector

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ABSTRACT

A search for the standard model Higgs boson in the rare $\mu^+\mu^-$ decay channel is presented. The data samples, recorded by the CMS experiment at the LHC, correspond to integrated luminosities of $5.0 \pm 0.1 \text{ fb}^{-1}$ at 7 TeV center-of-mass energy and of $19.7 \pm 0.5 \text{ fb}^{-1}$ at 8 TeV. To enhance the Higgs signal over the dominant Drell-Yan background, the events are categorized by topologies corresponding to different production processes. Upper limits on the production rate, with respect to the Standard Model prediction, are reported at the 95% confidence level for Higgs boson masses in the range from 120 to 150 GeV.

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1 Introduction

The recent discovery of a particle with properties consistent with a standard model (SM) Higgs boson [1, 2] has provided new insight into the nature of the SM and possible new physics extensions. More may be learned by further study of the production and decay modes of the new particle, especially highly suppressed ones. The SM Higgs boson decay to a pair of opposite sign muons is a perfect candidate, due to the small SM branching ratio (2.2×10^{-4} [3]), combined with the clean final state.

This document reports on a search for a SM-like Higgs boson in the $\mu^+\mu^-$ decay channel with the CMS experiment at the CERN LHC. This search has previously been reported in more detail in Ref. [4]. Data samples corresponding to integrated luminosities of $5.0 \pm 0.1 \text{ fb}^{-1}$ at a center-of-mass energy (\sqrt{s}) of 7 TeV and $19.7 \pm 0.5 \text{ fb}^{-1}$ at 8 TeV are analyzed. The Higgs boson signal is sought as a narrow signal peak in the dimuon invariant mass ($m_{\mu\mu}$) spectrum, over a smoothly falling background dominated by the Drell–Yan and $t\bar{t}$ production processes. An event categorization is used to increase search sensitivity. The signal efficiency is estimated using a Monte-Carlo simulation which has been extensively validated on data. The rates of signal and background production are estimated by fitting parameterized shapes to the $m_{\mu\mu}$ spectra in each category.

2 Search Methodology

Events are collected with a trigger that requires at least one isolated muon candidate with transverse-momentum (p_T) greater than 24 GeV, and $|\eta| < 2.1$, where η is the pseudorapidity. In the offline data analysis, events are required to contain two opposite-sign muon candidates, each with $|\eta| < 2.1$. The muon candidate that passed the trigger selection must have $p_T > 25$ GeV, while the other must have $p_T > 15$ GeV. Both muon candidates must also pass isolation and quality criteria.

Events passing the above selection are then assigned to categories. Events where the leading jet p_T is greater than 50 GeV, the sub-leading jet p_T is greater than 30 GeV, and the p_T^{miss} is less than 40 GeV are assigned to the 2-Jet category. The p_T^{miss} is defined as the transverse momentum of the sum of the dimuon and dijet four-vectors. All events not assigned to the 2-Jet category are assigned to the 0,1-jet category. The 2-Jet category has a high signal-to-background ratio (S/B) due to the 2-Jet topology of VBF Higgs boson production, while the 0,1-jet category has a large efficiency for GF Higgs boson production.

Events in the 2-Jet category are further assigned to one of three subcategories. The 2-Jet VBF Tight subcategory is optimized for VBF production, the 2-Jet GF Tight category is optimized for GF production, while the remaining 2-Jet events are assigned to the 2-Jet Loose category. Events in the 0,1-Jet categories are assigned to one of 15 subcategories depending on the dimuon p_T and the $|\eta|$ of the muons. The dimuon p_T helps in separating the GF Higgs boson signal from background, while muon $|\eta|$ is related to the $m_{\mu\mu}$ resolution. The $m_{\mu\mu}$ mass resolution for different categories varies from 3.8 to 5.9 GeV, in terms of the signal peak full-width-at-half-maximum at $m_H = 125$ GeV.

The rates of signal and background production are then extracted from the $m_{\mu\mu}$ distribution in each category. A parameterized signal shape made of the sum of two Gaussian functions is used to model the shape of the Higgs boson signal, while the function,

$$f(m_{\mu\mu}) = \frac{e^{p_1 m_{\mu\mu}}}{m_{\mu\mu} - p_2}, \quad (1)$$

is used to model the shape of the background. Example fits of the background model to the data are shown in Figure 1.

3 Results

Results are extracted by simultaneous fits of the parameterized signal and background shapes to the $m_{\mu\mu}$ distributions in each category. Upper limits on the rate of $H \rightarrow \mu^+\mu^-$ production divided by the expected SM $H \rightarrow \mu^+\mu^-$ rate ($\sigma/\sigma_{\text{SM}}$) for a Higgs boson mass between 120 and 150 GeV are shown in Figure 2 at

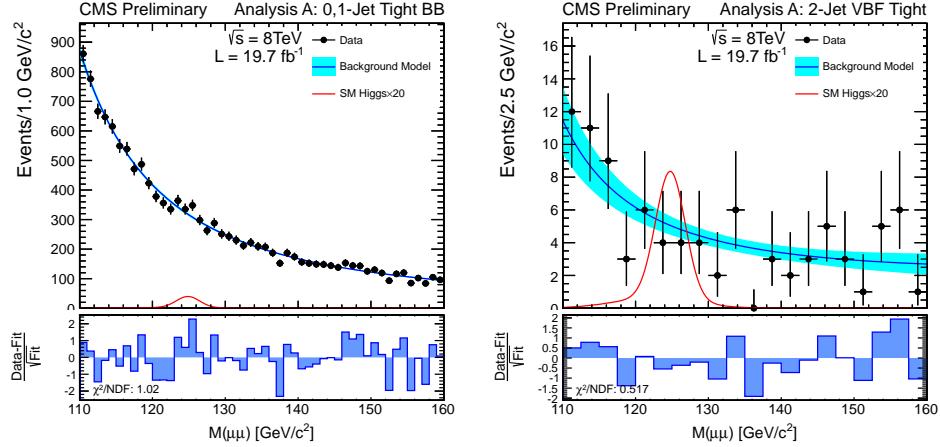


Figure 1: The dimuon invariant mass distribution for the 0,1-Jet Tight BB (left) and 2-Jet VBF Tight (right) categories. A fit of the parameterized background model used to estimate the background contribution is shown as a dark blue line, with its uncertainty shown as a light blue band. The expected SM Higgs boson signal magnified by a factor of twenty is shown by the red line, for $m_H = 125$ GeV.

the 95% confidence level. For $m_H = 125$ GeV, an expected (observed) 95% confidence level upper limit on the rate of $H \rightarrow \mu^+ \mu^-$ production is set at $5.1^{+2.3}_{-1.5} \times \text{SM}$ ($7.4 \times \text{SM}$). For a Higgs boson mass between 120 and 150 GeV, background-only p-values are shown in Figure 2. A small excess of events is observed near $m_H = 125$ GeV, with a significance of about 1σ . A larger excess is observed around 148 GeV with a local significance of 2.3σ and a global significance of 0.8σ .

Assuming a SM-like Higgs boson of mass 125.7 GeV decays to $\mu^+ \mu^-$, the best fit signal rate is $2.9^{+2.8}_{-2.7} \times \text{SM}$.

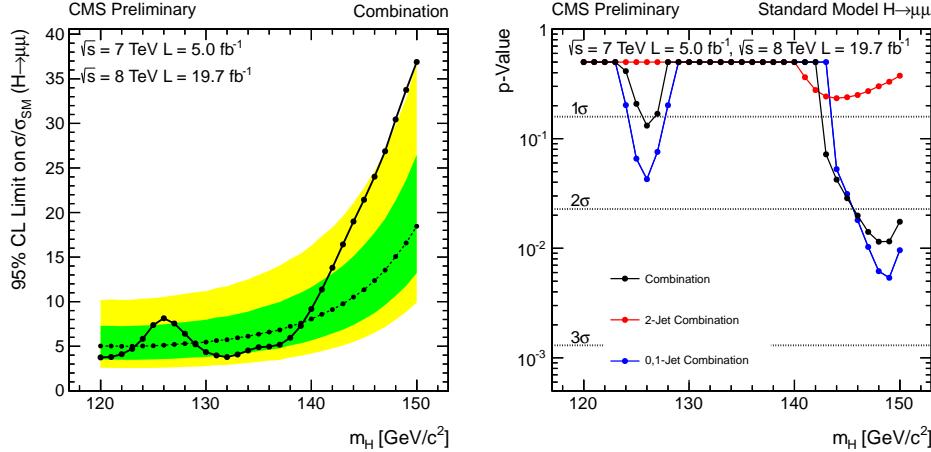


Figure 2: Upper limits on the signal strength (left) and p-values for the background-only hypothesis (right) for m_H from 120 to 150 GeV.

4 Projections to $\sqrt{s} = 14$ TeV

This section presents the results of Ref. [5] in relation to the projected performance of the CMS $H \rightarrow \mu^+ \mu^-$ search at $\sqrt{s} = 14$ TeV. The methodology of the projections is to use the current $H \rightarrow \mu^+ \mu^-$ search procedure and simulated data samples without modification, except for scaling the signal and background cross sections

Table 1: Projected $H \rightarrow \mu^+ \mu^-$ search sensitivity at $\sqrt{s} = 14$ TeV for integrated luminosities of 300 and 3000 fb^{-1} . See text for details.

	300 fb^{-1}	3000 fb^{-1}
Significance	2.5σ	7.9σ
Uncertainty on σ/σ_{SM} Scenario 1	42%	20%
Uncertainty on σ/σ_{SM} Scenario 2	40%	14%
Uncertainty on Muon Coupling Scenario 1	23%	8%
Uncertainty on Muon Coupling Scenario 2	23%	7.5%

from $\sqrt{s} = 8$ TeV to 14 TeV and similarly scaling the luminosity. In addition, two systematic uncertainty scenarios are investigated. In Scenario 1, all systematic uncertainties are assumed to be the same as in the current search, while in Scenario 2, the experimental uncertainties are scaled by $1/\sqrt{\mathcal{L}}$, where \mathcal{L} is the integrated luminosity, while the theoretical uncertainties are reduced by 50%.

The results of the projections are that SM $H \rightarrow \mu^+ \mu^-$ can be excluded with $175 \pm^{+150}_{-75} \text{ fb}^{-1}$ of integrated luminosity, for $m_H = 125$ GeV. The two scenarios differ little at this luminosity. Projections for 300 and 3000 fb^{-1} are shown in Table 1. The table shows, for $m_H = 125$ GeV, the expected significance of SM $H \rightarrow \mu^+ \mu^-$, the uncertainty on the best fit of the $H \rightarrow \mu^+ \mu^-$ rate, and the uncertainty on the best fit of the coupling of muons to the Higgs boson, when combined with other CMS Higgs boson measurements.

5 Summary

A search for a SM-like Higgs boson in the $\mu^+ \mu^-$ decay channel is reported. A narrow $H \rightarrow \mu^+ \mu^-$ peak in the $m_{\mu\mu}$ spectrum is sought over a smoothly falling background dominated by Drell-Yan and $t\bar{t}$. Search sensitivity is enhanced with an event categorization. The signal and background rates are extracted by fitting parameterized signal and background shapes to the $m_{\mu\mu}$ spectra in each category.

No significant excess is found, so upper limits are set on the rate of $H \rightarrow \mu^+ \mu^-$ production with respect to the SM prediction. For $m_H = 125$ GeV, a 95% confidence level upper limit on $H \rightarrow \mu^+ \mu^-$ production is set at $7.4 \times \text{SM}$. Assuming a SM-like Higgs boson of mass 125.7 GeV decays to $\mu^+ \mu^-$, the best fit rate is $2.9^{+2.8}_{-2.7} \times \text{SM}$.

Projections to $\sqrt{s} = 14$ TeV are also reported. For $m_H = 125$ GeV, SM Higgs boson decays to $\mu^+ \mu^-$ are projected to be excluded with $175 \pm^{+150}_{-75} \text{ fb}^{-1}$ of integrated luminosity. The expected significance of the SM $H \rightarrow \mu^+ \mu^-$ signal is projected to be 2.5σ (7.9σ) for 300 fb^{-1} (3000 fb^{-1}) of integrated luminosity.

References

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