Inclusive Search for the Standard Model Higgs Boson in the $H \rightarrow \gamma\gamma$ Channel at the LHC with CMS

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A brief summary of the CMS discovery potential for the Standard Model Higgs boson in the $H \rightarrow \gamma\gamma$ channel is presented. We review both a standard cut-based search and a more optimized analysis that takes advantage of the wide range of signal/background expectations as function of the possible selection cuts. As the Higgs discovery in this channel will rely heavily on performance of the CMS electromagnetic calorimeter, the relevant aspects of its design and operation in situ at the LHC are also briefly discussed.

1. INTRODUCTION

In the Standard Model of electroweak and strong interactions (SM), the fermions acquire mass by interacting with the Higgs field, which is also assumed to be responsible for the spontaneous breaking of electroweak symmetry. At the LHC, the SM Higgs boson is expected to be produced mainly via the gluon fusion although the vector boson fusion production will also play a significant role. For a Higgs with a mass of 120 GeV, the corresponding production cross sections are $\sigma(gg \rightarrow H) = 36.4$ pb and $\sigma(qq \rightarrow Hqq) = 4.5$ pb.

The LEP2 experiments ruled out a SM Higgs boson lighter than 114 GeV (at 95% confidence level), whereas the current precision electroweak measurements indicate that the mass of the SM Higgs should be lower than about 154 GeV (95% C.L.) [1]. Despite its low branching ratio of about 0.002 in this region of interest, the $H \rightarrow \gamma\gamma$ decay channel will provide an exceptionally clean final-state topology due to the presence of two energetic photons. As a consequence, the $H \rightarrow \gamma\gamma$ decays are expected to provide one of most promising signatures for a discovery with the CMS detector at LHC.

2. $H \rightarrow \gamma\gamma$ SIGNAL AT CMS

The event selection requires two photon candidates with a $P_T > 35$ GeV each. The dominant backgrounds consist of 1) the irreducible background coming from the direct diphoton production ($\sigma \simeq 150$ pb), and 2) the reducible backgrounds from $pp \rightarrow jet + \gamma$ ($\sigma \simeq 5 \cdot 10^4$ pb) and $pp \rightarrow jet + jet$ ($\sigma \simeq 3 \cdot 10^7$ pb). The signal rate is thus rather small compared to backgrounds. To suppress contributions from the reducible background processes, both photon candidates are required to be well isolated, both in the tracker and in the hadron and electromagnetic calorimeters. Figure 1 shows the reconstructed $\gamma\gamma$ invariant mass for $M_H = 120$ GeV and $\int L = 1$ fb$^{-1}$ [2].

2.1. CMS Electromagnetic Calorimeter

Made of about 76,000 PbWO$_4$ crystals, the CMS ECAL is one of the best calorimeters in high-energy physics, designed to give CMS a superior discovery potential for the Higgs in the critical low-mass range. The target energy resolution of 0.5% for electrons and photons with an energy above about 50 GeV has been successfully achieved in several test beam studies. As shown in Figure 1, precise, in situ calibration and monitoring of the ECAL response will be crucial for a clean reconstruction of the $H \rightarrow \gamma\gamma$ signal. This task will be accomplished using a dedicated laser monitoring system and calibrations with $\pi^0 \rightarrow \gamma\gamma$, $Z \rightarrow e^+e^-$, and $W \rightarrow e\nu$ decays and the “$\phi$-invariance” method [3].
3. DISCOVERY POTENTIAL

To improve the search sensitivity, the selected events are split into categories based on the compactness of photon showers and the pseudo-rapidity of the photon candidates. This allows us to take advantage of better mass resolution when we expect it, yet still use all of the selected events. The confidence levels are then computed by using the Log Likelihood Ratio frequentistic method [2]. Figure 2 shows that for $M_H < 140$ GeV this “cut-based” approach should lead to a $5\sigma$ discovery with less than 30 fb$^{-1}$ of integrated luminosity. Moreover, if the Higgs boson will be discovered in this channel, we will be able to measure its mass with a statistical precision of $0.1 - 0.2\%$, already with about 30 fb$^{-1}$. On the other hand, approximately 5 fb$^{-1}$ are needed for a 95% C.L. exclusion in the same mass range if the SM Higgs boson does not exist in that mass range.

A different search strategy, referred to as the optimized analysis, consists in using a neural net to discriminate between the signal and background. Photon isolation and event kinematics variables are used as inputs. Signal significance is derived using the neural net output and reconstructed diphoton invariant mass. Figure 2 shows the mass distribution after a cut on the neural net output at 0.85, for $M_H = 120$ GeV. The optimized analysis should lead to a significantly better discovery potential. As shown in Figure 2, for $M_H < 140$ GeV the $H \rightarrow \gamma\gamma$ signal should be discovered with about 10 fb$^{-1}$ [2].

3.1. Vector Boson Fusion Production Mechanism

Establishing $qq \rightarrow Hqq$ production via vector-boson fusion (VBF) will be crucial for understanding the exact nature of the Higgs mechanism. Such events will be characterized by the presence of two back-to-back high-rapidity jets. Therefore, the forward jet tagging should result in a clean separation of the VBF signal from the gluon fusion signal and the majority of backgrounds. For $M_H < 140$ GeV, a $5\sigma$ discovery of the $H \rightarrow \gamma\gamma$ VBF signal can be achieved with about 50 – 100 fb$^{-1}$ of integrated luminosity [5].

4. SUMMARY

With a standard cut-based analysis with less than 30 fb$^{-1}$ of integrated luminosity we can discover the SM Higgs boson with $5\sigma$ significance between the LEP lower limit and 140 GeV. A significantly better discovery potential can
Figure 2: Left: The diphoton mass distribution for each source for barrel events with kinematic neural net output greater than 0.85. Events are normalized to an integrated luminosity of 7.7 fb$^{-1}$ and the signal ($M_H = 120$ GeV) is scaled by a factor 10. Right: Integrated luminosity needed for a $5\sigma$ discovery with the cut-based and optimized analyses.

be achieved using an optimized analysis, for which only about 10 fb$^{-1}$ will be needed to establish the $H \rightarrow \gamma\gamma$ signal. The detector resolution for the reconstructed Higgs boson mass profits from the excellent energy resolution of the CMS crystal calorimeter.

This paper provides only a brief sketch of the analysis methods and results. For more information, the reader is invited to consult the provided references as well as the CMS Physics TDR.

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