PROCEEDINGS OF SCIENCE

Inclusive search for the SM Higgs Boson in the channel $\mathrm{H} \to \gamma\gamma$ at CMS

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A prospective analysis of the inclusive search for the Standard Model Higgs Boson in the decay channel $H \to \gamma\gamma$ with the CMS experiment at the LHC is presented. The analysis relies on the determination of the background characteristics and the systematics uncertainties from data and is applied to a Monte Carlo model of the QCD background, with full simulation of the detector response. The discrimination between signal and background exploits information on the kinematics and isolation of the photons. The resolution of the reconstructed Higgs boson mass profits from the excellent energy resolution of the CMS electromagnetic calorimeter. A discovery significance above 5 sigma is expected at an integrated LHC luminosity below 30 fb^{-1} for Higgs boson masses below 141 GeV/c^2.

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1. Introduction

The CMS (Compact Muon Solenoid) [1] is one of the two multi-purpose experiments that will take data at the LHC proton-proton collider. It basically consists of a silicon central tracking device surrounded by the electromagnetic and hadron calorimetry (all immersed in a 4 T magnetic field) and by a muon detector in the return yoke.
The electromagnetic calorimeter (ECAL) [2] consists of about 76,000 $PbWO_4$ scintillating crystals covering the pseudo-rapidity (η) range from 0 to 3.0 by means of a barrel part ($0 < |\eta| < 1.48$) and two endcaps ($1.48 < |\eta| < 3$). The ECAL is organised in 36 super-modules (each containing 1700 crystals arranged in four modules) in the barrel and in 4 dees (each consisting of 3662 crystals) in the end-caps. Crystals in the barrel are read out by Avalanche PhotoDiodes (APD), while in the endcaps the scintillating light is detected by Vacuum Photo Triodes (VPT).

To fully exploit the discovery potential of a low-mass Higgs boson in the channel $H \to \gamma\gamma$ [3, 4], the resolution of the electromagnetic calorimeter must be controlled at the level of 0.5% at high energies. This is achieved through different (inter-)calibration procedures that started already before the installation in CMS on sub-units of the detector. A start-up inter-calibration accuracy of $\sim 1.5\%$ on average on the whole barrel and of $\sim 0.5\%$ on a quarter of it has been reached by means of cosmic rays and test-beam electrons respectively. The endcap parts of the calorimeter will have an initial precision of about 10%, obtained from laboratory measurements of the crystal light yield. Assuming an integrated luminosity of ~ 1 fb^{-1} in the first year, a series of procedures driven by physics events will allow to reach a calibration at a level of a few percent on the whole ECAL within a few days (ϕ-symmetry, π^0) while the ultimate precision will be achieved within some months ($Z \to e^+e^-$, $W \to e\nu$). A laser-based system will allow to monitor the radiation-induced variations of the crystal transparency to a level of a few parts per thousands. For more detail about the different inter-calibration procedures, see for example [5].

The results [4] presented here are based on a detailed Geant4-based description of the CMS detector and assume a precision on the calibration and alignment of CMS comparable to the one expected after 10 fb^{-1} of data has been collected.

2. Signal and background

The final state topology of the channel $H \to \gamma\gamma$ depends on the production mechanism and consists of two isolated photons ($gg \to H$), possibly with two additional jets in the forward region for vector boson fusion production (VBF) or with one associated boson ($q\bar{q} \to HW, HZ$). The corresponding cross-section as a function of the Higgs boson mass are given in table 1.

Final states topologies that can fake the signal events are generally divided into two categories according to whether they contain two real isolated photons in the event ("irreducible" background), or at least one of the two photons is given by a mis-identified jet, in which case the photon is very likely to be detected as non-isolated ("reducible" background). The main processes with their corresponding cross section are given in table 2.

$M_H\,[\mathrm{GeV}/c^2]$	115	120	130	140	150
σ gg fusion [pb]	39.2	36.4	31.6	27.7	24.5
σ VB fusion [pb]	4.7	4.5	4.1	3.8	3.6
σ $WH, ZH, t\bar{t}H$ [pb]	3.8	3.3	2.6	2.1	1.7
Total σ [pb]	47.6	44.2	38.3	33.6	29.7
$\mathscr{B}(H \rightarrow \gamma\gamma) \cdot 10^{-3}$	2.1	2.2	2.2	2.0	1.4
$\sigma \times \mathscr{B}$ [fb]	99.3	97.5	86.0	65.5	41.5

Table 1: Signal NLO cross sections and branching ratio as a function of the Higgs boson mass [6].

Process	$p_T\,[\mathrm{GeV}/c]$	σ_{LO}[pb]	K-factor
$pp \rightarrow \gamma\gamma$ (born)	> 25	82	1.5
$pp \rightarrow \gamma\gamma$ (box)	> 25	82	1.2
$pp \rightarrow \gamma +$ jet	> 30	$5 \cdot 10^4$	1 (1 prompt), 1.72 (2 prompt)
$pp \rightarrow$ jets	> 50	$2.8 \cdot 10^7$	1
Drell Yan e^+e^-	–	$4 \cdot 10^7$	1

Table 2: LO cross sections for backgrounds and corresponding K-factor [7].

The analysis is based on a events simulated with the PYTHIA generator [8]. The initial LO cross-sections for signal and background have been rescaled to their NLO value by means of overall K-factors, which are also indicated in table 2.

3. Results

Signal events for this analysis are selected with high efficiency by both the Level-1 trigger (99.7%) and the High Level Trigger (88.4%) in the range $|\eta| < 2.5$. Since most of the background events contain at least one jet mis-identified as photons, additional isolation criteria are applied in a cone of $\Delta R < 0.3$ around their direction. Photons with a track of $p_T > 1.5$ GeV or a deposited energy in the ECAL or HCAL barrel (endcap) of $\sum E_T < 6(3)$ GeV are rejected.
The identification of the interaction vertex is achieved using the hardest tracks in the event and is successful in 80% of cases.

A "conservative" approach based on sequential selections as well as an "optimized" approach based on Neural Networks have been developed in parallel. Both have to deal with the high probability for a photon to convert in the tracker material: a requirement on the shape of the deposited energy in the ECAL allows to discriminate the conversion radius and so to select photons whose energy is very well measured.
The discovery potential of these two techniques is shown in figure 1.
The systematic uncertainties considered in this analysis include contributions from the knowledge of the theoretical cross-section ($+15\% - 12\%$ from scale variation and $+4\% - 5\%$), of the integrated luminosity (5%), of the trigger efficiency (1%) and of the tracker material distribution (1%).

4. Conclusions

The results presented here, based on simulated data, show that CMS can discover a Standard

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Model Higgs boson of a mass below 140 GeV/c^2 with less than 30 fb^{-1} of data. The analysis strategies aim at the selection of isolated photons and rely on a data-driven method for the background estimation from the mass-peak side-bands. There is room for improvement by using more advanced tracking algorithms for the reconstruction of converted photons and by fully exploiting the ECAL preshower for the π^0/γ discrimination.

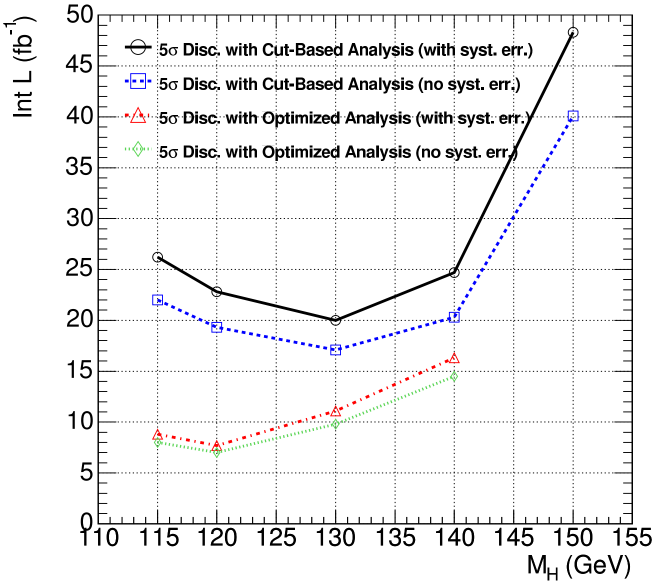

Figure 1: Integral luminosity required for a 5σ discovery as a function of the simulated Higgs boson mass.

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