SEARCH FOR THE STANDARD MODEL HIGGS BOSON AT THE LHC

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Discovery potential of the Standard Model Higgs boson with the ATLAS and CMS detectors is presented along with an estimates for the expected accuracy of the Higgs boson mass measurement.

1. Introduction

The Higgs mechanism is a cornerstone of the Standard Model (SM) and its supersymmetric extensions. Due to spontaneous symmetry breaking in the Higgs sector the gauge bosons W, Z as well as the fermions acquire masses through the interaction with the Higgs fields. The primary goal of the ATLAS and CMS collaboration is the discovery of the Higgs boson at LHC using its different production and decays modes. The complete review of the SM Higgs boson decays and production mechanisms at hadron colliders can be found in Ref. [1]. While the Higgs boson mass is the free parameter of the Standard Model, the direct LEP searches and the fit of the precision electro-weak data constraint its mass in the interval between 114.4 and $\simeq$ 200 GeV.

Preparing for the first data taking by the end of 2007, the ATLAS and CMS collaborations are permanently updating the simulation studies on observability of the Higgs boson. The recent analyses published in Ref. [2] and [3] take into account the latest trigger tables, expected systematic uncertainty and use the advanced event generators like ALPGEN, MadGraph, CompHEP, TopREX [4] for multi-jet background generations. In the CMS analyses a next-to-leading order (NLO) cross sections are used for the Higgs boson production and for background processes when available.

The experimental topologies for the SM Higgs boson discovery studied so far by ATLAS and CMS are relevant also for a number of the Standard Model extensions like MSSM (for review see Ref. [5]) or ESSM [6], where the SM like Higgs boson is predicted in some regions of the parameter space. It enforces the importance of the detailed experimental analyses of the SM Higgs boson discovery modes at LHC summarized in this paper.

2. Discovery modes with inclusive Higgs boson production

2.1. $H \to ZZ^* \to 4\ell$

The discovery of this "golden" LHC mode relays on the selection of four isolated leptons (electrons or muons) originated from the same primary vertex. Along with lepton isolation requirements an excellent di(four)-lepton invariant mass resolution allows almost complete suppression of the SM background from $t\bar{t}$, $\ell\ell b\bar{b}(c\bar{c})$, thus leaving only irreducible background from ZZ^*/γ^* production. Fig. 1 shows the expected four-lepton ($ee\mu\mu$) invariant mass distribution after all selections, except four-lepton mass window, for an integrated luminosity corresponding to a discovery significance of 5σ, for Higgs boson mass of 140 GeV. The background estimates include a variation of the next-to-leading order (NLO) ZZ background cross section as a function of four-lepton mass. The ZZ production cross section through "box" diagram ($gg \to$ZZ) is added as 20% of the $q\bar{q} \to$ZZ cross section.

2.2. $H \to \gamma\gamma$

Despite of the small $H \to \gamma\gamma$ branching ratio, the energy resolution of the CMS and ATLAS electromagnetic calorimeters together with the primary vertex position determination using tracks allows the signal selection from the huge QCD background. The irreducible background includes direct di-photon production from Born ($q\bar{q} \to \gamma\gamma$) and "box" ($gg \to \gamma\gamma$) diagrams and $gq \to \gamma q$, $q \to q'\gamma$ process. The reducible background come from the multi-jet production and $q\bar{q} \to \gamma g$ process when quark or gluon fragmentation leads to a high momentum π^0. The background is suppressed with the tracker and calorimeter isolation of the photon candidates. The both ATLAS and CMS analyses performed a traditional, cut based analysis and an "optimized" analysis which exploits more sophisticated techniques, like neural network and likelihood methods. Table 1 shows the signal significance of the ATLAS and CMS for the Higgs boson of 130 GeV for an integrated luminosity of 30 fb^{-1} using cut based and "optimized" analyses. One can see that the discovery potential of both experiments is very similar. The NLO cross sections for the signal and background were used in both analyses.

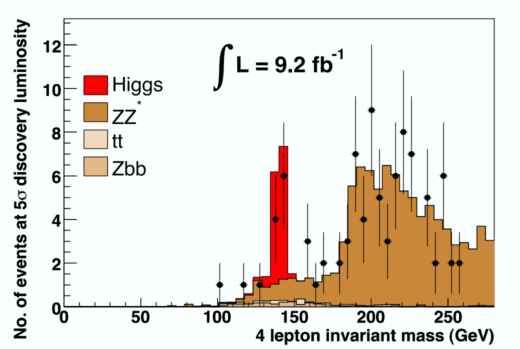

Fig. 1. The expected four-lepton ($ee\mu\mu$) invariant mass distribution after all selections, except four-lepton mass window, for an integrated luminosity corresponding to a discovery significance of 5σ, for Higgs boson mass of 140 GeV.

Table 1. The signal significance of the ATLAS and CMS for the Higgs boson of 130 GeV for an integrated luminosity of 30 fb^{-1} using cut based and "optimized" analyses.

exp.	cut based	optimized
ATLAS	6.3	8.7
CMS	6.0	8.2

2.3. $H \to WW \to 2\ell 2\nu$

This mode could provide an early discovery of the SM Higgs boson if the mass of the Higgs boson is about of 165 GeV, when cross section times branching ratio reaches the maximum value. The backgrounds from the $\mathrm{WbW\bar{b}}$ and WW production can be suppressed by taking advantage of WW spin correlation, which turn into small $\ell\ell$ opening angle. Central-jet veto was used to suppress further the $\mathrm{WbW\bar{b}}$ background. The W+jet, Drell-Yan, WZ and ZZ backgrounds were found to be negligible. The presence of the signal is justified as an excess of the events above the expected background. Fig. 2 shows the angle between the leptons in the transverse plane for the signal and the different backgrounds at a luminosity of 10 fb^{-1} after all selections. The methods of the $t\bar{t}$ and WW background estimations from the data have been proposed. The estimates of the single top background (Wt) and "box" WW background ($gg \to$WW) are based on the theoretical predictions. Thus both experimental and theoretical uncertainties contribute to the background systematics. At the best mass point of 165 GeV, the Higgs boson discovery requires only $\simeq 0.8$ fb^{-1} of the data.

2.4. *Luminosity needed for discovery*

Fig. 3 shows an integrated luminosity needed for obtaining of the signal significance 5 as a function of the Higgs boson mass for inclusive

Higgs boson production with $\gamma\gamma$, ZZ$\rightarrow \ell\ell$ and WW$\rightarrow 2\ell 2\nu$ decay modes. For $\gamma\gamma$ decay mode the results of the cut based and "optimized" analyses are shown. One can see that for the low Higgs boson mass of $\simeq$ 120 GeV the $\gamma\gamma$ is the best discovery mode. Moving toward the higher Higgs boson mass up to 170 GeV, it followed by the ZZ$\rightarrow \ell\ell$ mode and then by the WW$\rightarrow 2\ell 2\nu$ decay mode.

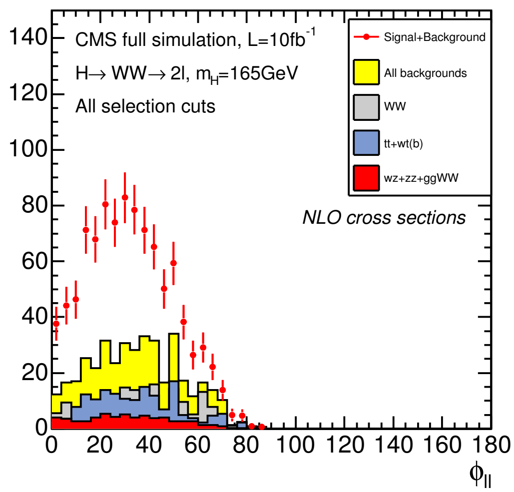

Fig. 2. The angle between the leptons in the transverse plane for the signal and the different backgrounds at an integrated luminosity of 10 fb^{-1}.

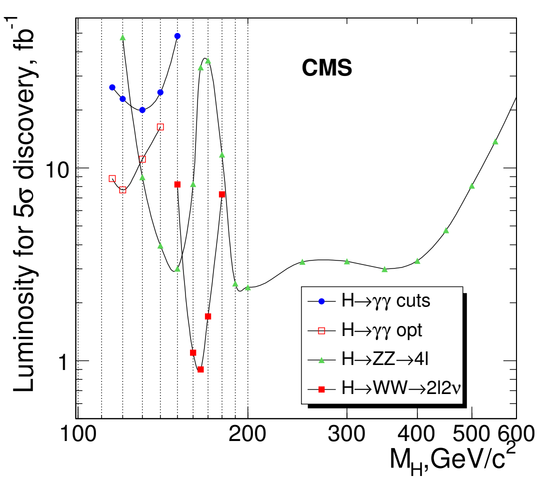

Fig. 3. The integrated luminosity needed for obtaining of the signal significance 5 as a function of the Higgs boson mass for inclusive Higgs boson production with $\gamma\gamma$, ZZ$\rightarrow \ell\ell$ and WW$\rightarrow 2\ell 2\nu$ decay modes.

2.5. *Accuracy of Higgs boson mass measurement*

Fig. 4 shows statistical accuracy of the Higgs boson mass measurement with H$\rightarrow \gamma\gamma$ and H$\rightarrow$ZZ* $\rightarrow 4\ell$ decay modes in CMS for 30 fb^{-1}. The systematical error related to the energy and momentum measurement uncertainties is expected to be smaller than the statistical one.

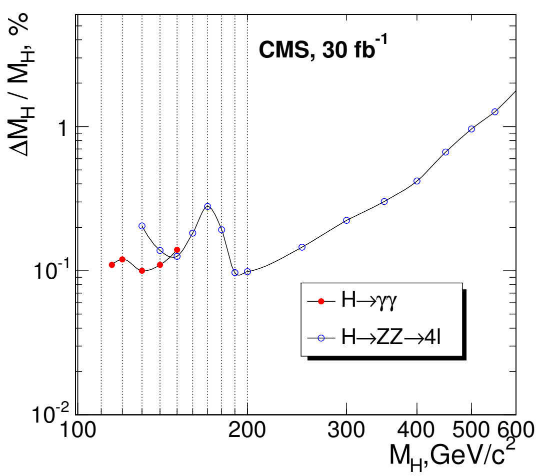

Fig. 4. Statistical accuracy of the Higgs boson mass measurement with H$\rightarrow \gamma\gamma$ and H$\rightarrow$ZZ* $\rightarrow 4\ell$ decay modes in CMS for 30 fb^{-1}.

3. Summary of discovery potential for 30 fb^{-1}

The Higgs boson production with Vector Boson Fusion (VBF) increases the discovery potential of the SM Higgs boson at LHC (ATLAS searches can be found in Ref. [3]) and significantly extends the possibility of the Higgs boson coupling measurement as shown in Ref. [7] and [8]. The discovery potential of the H$\rightarrow \tau\tau$ decay mode with VBF Higgs boson production have been recently confirmed by CMS with the full detector simulation.

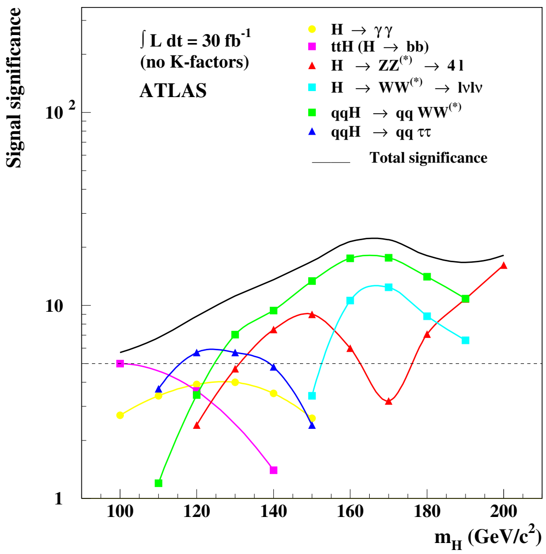

Fig. 6. The ATLAS sensitivity for the discovery of the Standard Model Higgs boson for integrated luminosity 30 fb^{-1}.

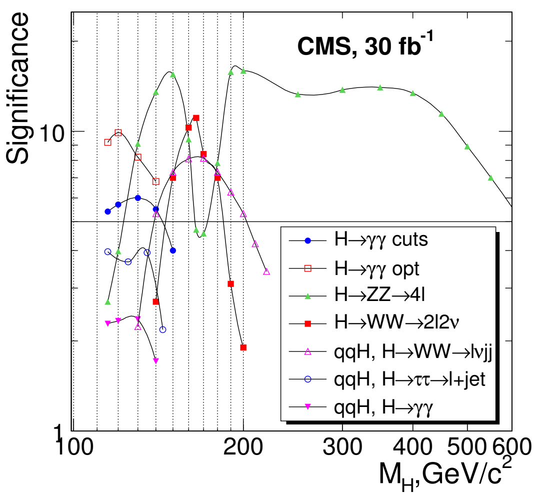

Fig. 7. The CMS sensitivity for the discovery of the Standard Model Higgs boson for integrated luminosity 30 fb^{-1}.

Fig. 5 shows the di-tau effective mass for the signal with $\tau\tau \to \ell$+jet final state and for the background with 30 fb^{-1} after all selections. The central-jet veto allowing an effective suppression of the Z plus multi-jet and $t\bar{t}$ backgrounds was suffering from the presence of the fake jets due to pile up and electronic noise. A dedicated technique with the usage of tracks and signal vertex have been developed and successfully applied to discard fake jets.

The ATLAS and CMS discovery potentials for 30 fb^{-1} are summarized in Fig. 6 and Fig. 7. Figures show the significance of the Higgs boson discovery as a function of the Higgs boson mass for different channels. One can see that the region between 115 GeV and 600 GeV is the 5σ discovery region with 30 fb^{-1}.

References

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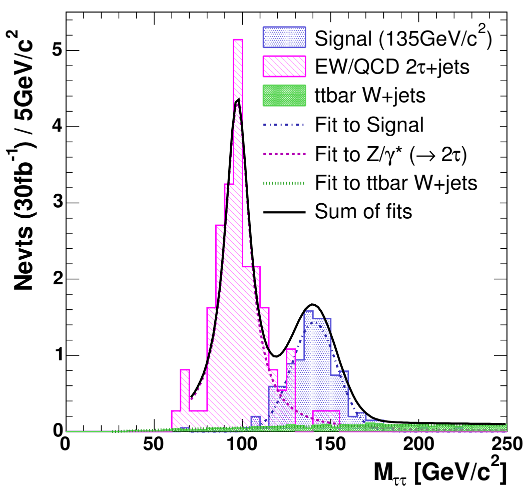

Fig. 5. The di-tau effective mass for the signal with $\tau\tau \to \ell$+jet final state and for the background with 30 fb^{-1}.

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