PRAMANA © Indian Academy of Sciences Vol. 69, No. 5
— journal of November 2007
physics pp. 749–752

The standard model Higgs search at the large hadron collider

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Abstract. The experiments at the large hadron collider (LHC) will probe for Higgs boson in the mass range between the lower bound on the Higgs mass set by the experiments at the large electron positron collider (LEP) and the unitarity bound (∼1 TeV). Strategies are being developed to look for signatures of Higgs boson and measure its properties. In this paper results from full detector simulation-based studies on Higgs discovery from both ATLAS and CMS experiments at the LHC will be presented. Results of simulation studies on Higgs coupling measurement at LHC will be discussed.

Keywords. Higgs; large hadron collider; CMS; ATLAS.

PACS Nos 10.30.Pb; 10.30.Qc; 12.60.Fr; 12.60.Jv; 14.80.Bn; 14.80.Cp

1. Introduction

Higgs boson, the massive scalar particle responsible for giving mass to gauge bosons and fermions and for the renormalizability of the standard model (SM) of particle physics has remained elusive so far. The large electron positron collider program at CERN, Geneva concluded with no definitive discovery signal of Higgs. The Tevatron data have not revealed any signature of Higgs boson so far. The large hadron collider (LHC), under construction at CERN will collide protons at a center-of-mass energy of 14 TeV. The LHC is expected to start operating in the year 2007. The design startup luminosity is 2×10^{33} cm^{-2}/s. Search for Higgs boson is the most important physics goal of the experiments at the LHC. Two experiments at the LHC, CMS and ATLAS will carry out searches for Higgs bosons. Detailed search strategies are being designed to look for signatures of Higgs. Studies have also been done on measurement of Higgs properties such as coupling, spin etc. at the LHC. The existing LEP lower limit on SM Higgs mass is 114.4 GeV, at 95% CL. The experiments at the LHC are capable of scanning a Higgs mass range starting from the LEP lower bound up to more than a TeV. It is strongly expected that experiments at the LHC will discover Higgs if it exists. In the following sections we will give an overview of the results obtained from simulation studies done by the CMS [1] and the ATLAS on Higgs search at the LHC.

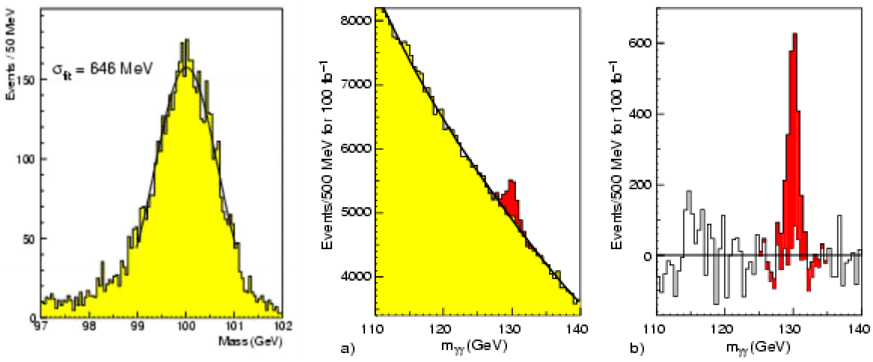

Figure 1. Mass distribution from a Pythia simulated sample of 100 GeV Higgs decaying to two photons (left). A signal (in red) + background (yellow) mass distribution for a 130 GeV Higgs (center) and background subtracted signal peak (right) are also shown.

2. Search for SM Higgs boson

SM Higgs boson production proceeds mainly via gluon–gluon fusion at low x, due to high gluon flux at LHC energies. Other important mechanisms for Higgs production are $qq{\rightarrow}Hqq$ via vector boson fusion (VBF), associated production of Higgs with $t\bar{t}$ or $b\bar{b}$.

2.1 *Low mass region*

Below the $W^{\pm}$ and Z^0 boson pair production thresholds, $H^0{\rightarrow}b\bar{b}$ has the highest branching fraction followed by Higgs decay to $\tau^+\tau^-$. Beyond $2m_W(2m_Z)$, $W^{\pm}(Z^0)$ pair production becomes dominant. For $m_H > 2m_{\rm top}$, $H^0 \rightarrow t\bar{t}$ becomes significant.

Higgs can also decay to two photons through loop process (predominantly through top or $W^{\pm}$ triangle). In spite of small branching fraction $H^0 \rightarrow \gamma\gamma$ is foreseen to be an important search channel in the so-called low mass range (roughly below $2m_W$) due to its clean signature of two isolated photons in the electromagnetic calorimeter. If the Higgs is produced via VBF channel, two additional forward–backward jets are present [2]. Monte Carlo studies predict that CMS can make a 5σ discovery of a 120 GeV Higgs with 15 fb^{-1} data or about 9 months of running at low luminosity. With its high precision electromagnetic calorimetry, CMS can achieve ∼650 MeV mass resolution for a 100 GeV Higgs (see figure 1).

2.2 *Intermediate-high mass region*

In this mass region the WW and ZZ decay modes of Higgs open up and become the dominant decay modes. ZZ decay to four (isolated) leptons (e/μ) gives the highest sensitivity in the Higgs mass range 200–500 GeV (see figure 3). Discovery

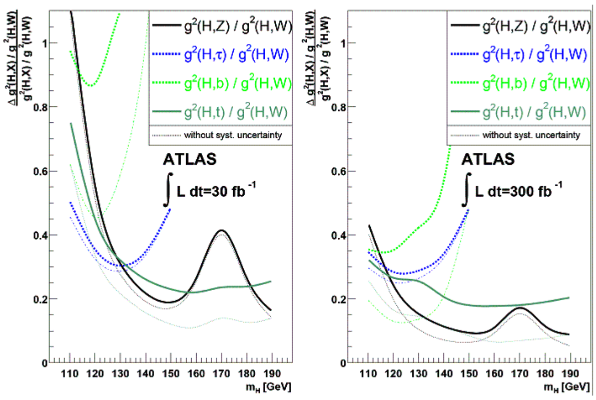

Figure 2. Relative error for the measurement of relative couplings. The dashed lines give the expected relative error without systematic uncertainties.

of luminosity in this channel decreases rapidly with the Higgs mass approaching the ZZ pair production threshold. For a 140 GeV Higgs one expects to get a 5σ discovery with about 15 fb^{-1}(31 fb^{-1}) in the $4\mu(4e)$ final state.

Figure 3 shows the discovery significance (number of sigmas) for 30 fb^{-1} integrated luminosity. In the entire mass range, CMS can make a more than 5σ discovery with 30 fb^{-1}. W^+W^- mode with both Ws decaying leptonically gives a high sensitivity in the mass range 150–180 GeV. If $m_H \approx 2m_W$ one can expect to make a 5σ discovery in this channel with 2 fb^{-1}.

3. Higgs coupling measurement

All Higgs decays and productions depend on the Higgs couplings $g_W, g_Z, g_b, g_t, g_\tau$ and it should be possible to determine the relative values of these couplings from the measured Higgs decay rates at the LHC. ATLAS has studied a method of global maximum likelihood fit to extract relative values of coupling constants from the measured ratio of partial width [3]. The study indicates that it should be possible to measure $\Gamma_\tau/\Gamma_W, \Gamma_\gamma/\gamma_W, \Gamma_Z/\Gamma_W$ within 15–60% accuracy with 30$\sim$ fb^{-1} of data. Corresponding ratios of coupling constant squares $g_\tau^2/g_W^2, g_\gamma^2/g_W^2, g_Z^2/g_W^2$ can be determined within 15–50% accuracy if Higgs mass is above 125 GeV. With 300 fb^{-1} one can expect to measure g_t^2/g_W^2 at 30% accuracy (see figure 2).

4. Summary

In this paper we discussed the search strategies of a SM Higgs boson in three broadly divided mass regions. We have discussed some of the dominant discovery modes as examples of MC studies of the MSSM Higgs search at the LHC.

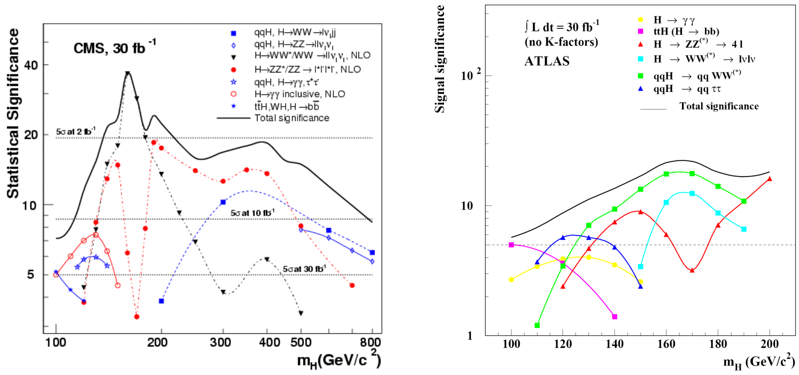

Figure 3. Discovery significance for 30 fb^{-1} of data from CMS (left) and ATLAS (right) Monte Carlo studies. The black line represents combined significance of all channels.

Full detector simulation-based studies have been performed in both the CMS and the ATLAS experiments for all major discovery channels in each mass region. Some promising channels, namely $H \to \gamma\gamma, H \to ZZ \to 4$ leptons (e/μ) in the low mass region, and $H \to WW \to ll$ (dilepton), $H \to ZZ \to lljj$ (dilepton+dijet) channels have been discussed in this paper. It is expected that the LHC will be able to discover Higgs with mass between the LEP limit and the perturbative bound within the first year of running at the design luminosity and center-of-mass energy. In the low mass region Higgs decay to two photons will play a significant role, while in the intermediate-high mass region $H \to WW$ and $H \to ZZ$ with W and Z decaying leptonically are the most promising search channels. For a low-intermediate mass Higgs it should be possible to measure the Higgs mass within few hundred MeV from the $H \to \gamma\gamma, H \to ZZ \to 4$ leptons (e/μ) channels. Higgs properties, such as coupling and CP should be measurable with 100 fb^{-1} of data.

References

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