International Journal of Modern Physics A

Higgs Search with the Compact Muon Solenoid(CMS) detector at the Large Hadron Collider(LHC)

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Received (Day Month Year)
Revised (Day Month Year)

The Large Hadron Collider(LHC) is a proton proton collider being built at CERN, Geneva which will collide two 7 TeV proton beams giving a center of mass energy of 14 TeV. The Compact Muon Solenoid (CMS) is a multi-purpose detector at the LHC which is designed to discover the Higgs boson over the mass range of 90 to 1000 GeV. Since LEP searches have put a 95% C.L. lower bound on (standard model) Higgs mass of 114.4 GeV and theory excludes mass above about 1 TeV, CMS should discover the Higgs if it exists. In this paper, we will review CMS's Higgs-discovery potential both in the Standard Model and the Minimal Supersymmetric Standard Model for Higgs bosons produced in gluon-gluon fusion and in vector boson fusion mechanisms. Particular emphasis will be placed on discovery in the early years of running with luminosity of about $2 \times 10^{33} cm^{-2}/s$.

Keywords: Higgs; CMS; LHC.

1. The CMS Detector

CMS is a multipourpose detector at LHC, designed to do precision Standard Model(SM) parameter measurements as well as new particle discovery. CMS has the following main subdetector components:

- silicon pixel+microstrip tracker ($|\eta| < 2.5$).
- lead-tungstate electromagnetic calorimeter (precision calorimetry in $|\eta| < 2.5$).
- brass and stainless steel, hermetic, sampling hadron calorimeter ($|\eta| < 5$).
- drift tube and cathode strip chamber based muon system ($|\eta| < 2.4$).

(for details of detector design, performance see Ref. [3]).

All the components are in a 4 $Tesla$ solenoidal magnetic field used for p_T measurement.

CMS will start taking data in 2007 and should collect at least ten fb^{-1} in the first year. CMS is capable of searching for the Higgs boson in the entire mass range

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between the LEP lower bound (114.4 GeV for SM Higgs boson and $\sim$80 GeV for supersymmetric Higgs[1]) and the unitarity bound of about a TeV[2].

2. Standard Model(SM) Higgs Search

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 $qq \to Hqq$ via Vector Boson Fusion(VBF), associated production of Higgs with $t\bar{t}$ or $b\bar{b}$.

Below the $W^{\pm}$ and Z^0 boson pair production thresholds, $H^0 \to b\bar{b}$ 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 $m_H < 2m_{top}$, $H^0 \to t\bar{t}$ becomes significant.

ZZ decay to four (isolated) leptons(e/μ) gives the highest sensitivity in the Higgs mass range 200 – 500 GeV (See Fig. 1a). Discovery 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.

Higgs can also decay to two photons through loop process (predominantly through top or $W^{\pm}$ triangle). Inspite of small branching fraction $H^0 \to \gamma\gamma$ 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. Monte Carlo studies predict that CMS can make a 5σ discovery of a 120 GeV Higgs with $15fb^{-1}$ data or about 9 months of running at low luminosity. With its high precision electromagnetic calorimetry, CMS can achieve $\sim$ 650 MeV mass resolution for a 100 GeV Higgs.

Fig.1a) shows the discovery significance (number of sigmas) for $30fb^{-1}$ 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. Search for Minimal Supersymmetric Standard Model (MSSM) Higgs

The MSSM Higgs sector consists of two $SU(2)$ doublets which give rise to five real Higgs fields, namely a pseudoscalar(A^0) a heavy scalar(H^0), one light scalar(h^0) and a charged Higgs pair($H^{\pm}$). In the MSSM Higgs sector for given values of A_t, M_2 and μ, cross sections and branching fractions are determined by the pseudoscalar mass m_A and $tan\beta$ (for details on MSSM Higgs sector see e.g. Ref.[4]). The light Higgs is standard model-like for $m_{h^0} < m_A$. For A^0/H^0 and $H^{\pm}$ the search strategy depends on m_A–$tan\beta$.

A^0 and H^0 have similar masses and coupling strengths and consequently similar search strategies. At large $tan\beta$ H/A coupling enhancement to down type fermions

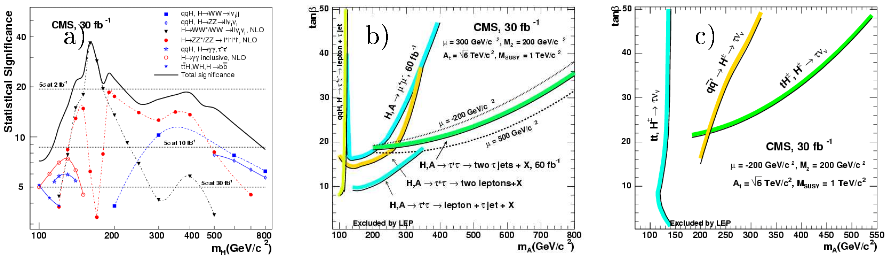

Fig. 1. a) Discovery luminosity for SM Higgs. b),c) 5σ discovery contours for A^0/H^0 and $H^{\pm}$ in $m_A - tan\beta$ plane[5].

makes search for $H/A \rightarrow \mu^+\mu^-$ or $\tau^+\tau^-$ and $H/A \rightarrow b\bar{b}$ in associated Higgs production $gg \rightarrow H/Ab\bar{b}$ possible. H/A decay to τ pair is particularly interesting. In large region of the $m_A - tan\beta$ plane CMS can make a 5σ discovery with $30fb^{-1}$ using $\tau^+\tau^-$ channel alone. The main background to this channel comes from $Z/\gamma^* \rightarrow \tau^+\tau^-$, $t\bar{t}$ and $W + jets$ with $W \rightarrow \tau\nu_\tau$. For a heavy $H^{\pm}$ search, associated production of $H^{\pm}$ with single top or $t\bar{t}$ pair and subsequent decay $H/A \rightarrow \tau^{\pm}$ are the most promising search channels. For probing a MSSM Higgs in the low $tan\beta$ region gaugino decay modes can be used.

4. Summary

Preliminary Monte Carlo studies with full detector simulation indicate that CMS is capable of making a 5 sigma discovery of a SM or MSSM Higgs boson in the entire mass range from LEP lower bounds upto unitarity upper bound($\sim 1\ TeV$). Higgs mass measurement with better than 1% mass resolution is achievable from the $H^0 \rightarrow ZZ \rightarrow 4\ leptons$ and $H^0 \rightarrow \gamma\gamma$ searches. Detailed study of systematics is underway.

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