May 2004

Search for Standard Model Higgs Boson at CMS

R. Godang, L. Cremaldi, D. Sanders and D. Summers

Department of Physics and Astronomy
University of Mississippi-Oxford, University, MS 38677

Abstract

We are proposing to search a heavier scalar Standard Model Higgs boson, H^0 using CMS Detector at the LHC Collider. The channel $H^0 \to \ell^+\ell^-\nu\nu$ ($\ell = e$ and μ) is considered with a larger branching ratio compared to $H^0 \to \ell^+\ell^-\ell^+\ell^-$. The Higgs mass, $m_{H^0} > 500\ GeV$ (up to 1 TeV) is considered with a clear distinct signatures of two high p_t leptons (from the Z decay) and high E_t^{miss} due to the missing ν.

Work supported in part by the U.S. Department of Energy contract DE-FG05-91ER40622.

Contents

List of Figures

1 Introduction

The Higgs mechanism is an important step for discovery the Standard Model (SM) and the Minimum Supersymmetry Standard Model (MSSM) Higgs bosons. In the SM mechanism, we only have a single neutral Higgs with its mass as a free parameter, however, in the MSSM as a result of adding a second complex Higgs doublets (to preserve supersymmetry) to the SM gives us five elementary Higgs particle bosons: one pseudoscalar boson A^0 (CP-odd scalar), two charged scalar bosons H^+ and H^-, and two neutral scalar bosons H^0 and h^0 (CP-even scalars).

If the Higgs bosons exist, its signature can certainly be seen at the LHC. The Higgs boson mass measurements at the LHC are predicted at the level of 10^{-3} [1]. The measurements of the Higgs boson couplings is predicted at the 5-10% level [2]. At the LHC pp collider, the production of the Standard Model Higgs boson is mainly dominated by the gluon-gluon fusion process: $pp \rightarrow gg \rightarrow H$ with the mass range of 100 $GeV < m_H < 1\ TeV$.

2 Motivation

The theoretical calculation at the lowest order (LO) all the couplings and the masses of the MSSM Higgs sector are determined by two independent input parameters: the parameter $tan\beta$ and the pseudoscalar Higgs boson mass m_A. The $tan\beta$ is defined as v_1/v_2 where v_1 and v_2 are two vacuum expectation values.

At the LO calculation the gluon fusion mechanism $gg \rightarrow H$ provides the dominant production of Higgs bosons in the relevant mass range up to 1 TeV. This gluon fusion mechanism is mediated by heavy bottom, top and squark loops as seen in Fig. 1 [3].

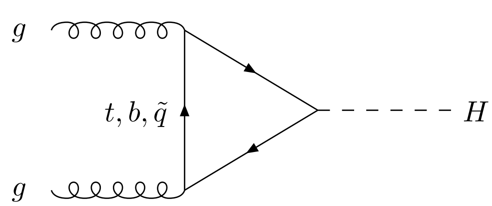

Figure 1: The Feynman diagram contributing to $gg \rightarrow H$ at the lowest order.

The Next Leading Order (NLO) is based on the QCD correction that consists of two-loop virtual corrections and one-loop real corrections as shown in Fig. 2.

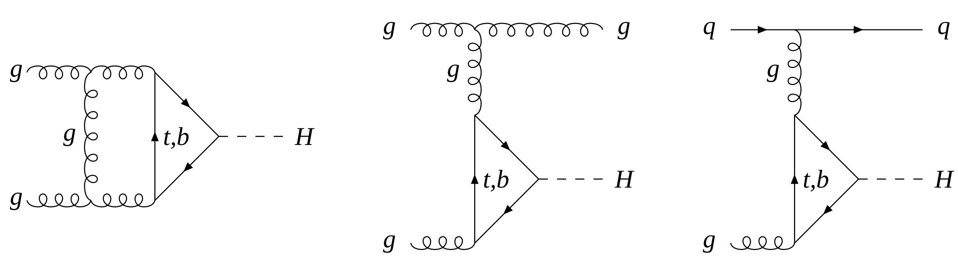

Figure 2: The Feynman diagrams contributing to the virtual and real QCD corrections to $gg \rightarrow H$ at the next leading order.

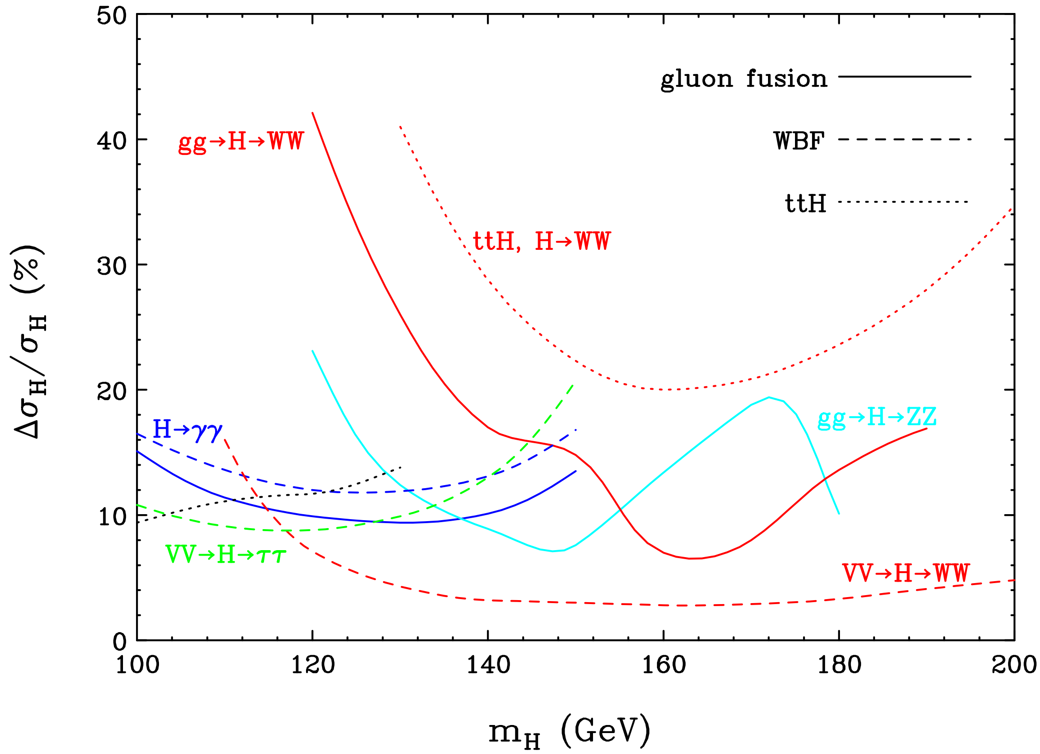

Figure 3: The relative error on the determination of cross section for several Higgs search channels at the LHC [2]

Based on the supersymmetry theoretical prediction that the cross section in the gluon fusion mechanism for the heavy Higgs production, H^0, with a small m_A, may dominated by the bottom quark loops for a larger value of parameter $tan\beta$. The range of $tan\beta$ is larger than 10 to limit the top quark background. Figure 3 shows the relative error on the determination of cross section for several Higgs search channels at LHC (200 fb^{-1}) [2]. From the same figure one could see that the inclusive Higgs production channels ($gg \to H$, $H \to WW$) are dominated by the gluon fusion process (solid line). The weak boson fusion are also shown in dashed line. The channels of $gg \to H$, $H \to W^+W^-$ is one of the very important for searching the Higgs masses since the branching fraction of heavy Higgs boson to W-pair is almost 100%, yet the background from the bottom-pair production is needed to suppress using the jet veto. This background is $t\bar{t} \to b\bar{b}W^+W^-$ where each W could go to lepton-neutrino pair.

In the full Next Next Leading Order (NNLO) calculation [4], there is an sizeable effect so called real gluon bremsstrahlung at NLO that could contribute to the gluon fusion process. This effect has been analyzed in applying the jet veto ($p_{T_j} > 15\ GeV$) by ATLAS Collaboration [5]

3 Analysis Technique

In the channel $H \to WW$, the dominant background for the cross section production is in the mass range of $m_H < 150\ GeV$. In this case the two missing neutrinos in the final state $H \to W^+W^- \to \ell^+\ell^-\nu\nu$ can be observed by the high p_T leptons since we cannot reconstruct the Higgs mass directly. We expected to see the wide observable transverse mass distribution which consists of the backgrounds. In order to estimate the background on the wide observable transverse mass distribution, we plan to extrapolate the sideband background in the poor signal region, if any. The challenging problem in here is to choose the appropriate choice of the sideband region in the poor signal region that depends on the uncertainty of the shape distribution. This study can be estimated using the appropriate signal Monte Carlo model such as LO or NLO QCD model.

The next considered backgrounds are from off-shell top-pair production including the tWb production. For this background we are rely on the Monte Carlo study where we could apply a nice theoretical analysis of $pp \rightarrow t^* \bar{t}^*$ including the full lepton correlations and the off-shell effects [6]. In the MSSM model the small background that could come from the channels of $gb \rightarrow tH^-$ and $g\bar{b} \rightarrow tH^+$ has been studied in the ISAJET Monte Carlo package that we could use directly.

Having discussed the possibilities for taking care of the backgrounds $H \rightarrow W^+W^- \rightarrow \ell^+\ell^-\nu\nu$, there was some encouragement study when looking for the higher Higgs mass region, $m_H > 500\ GeV$, to reduce and dependency on the background model [1]. In this higher mass region the signal is a wide Jacobian peak in the two-lepton transverse momentum distribution. One needs to suppress the backgrounds so that its order is below the signal level. In another word, one needs to study the optimization of the $S/\sqrt{S+B}$ ratio to deal with the corresponding backgrounds. The corresponding backgrounds are:

- $H \rightarrow ZZ$
- $H \rightarrow ZW$
- $H \rightarrow t\bar{t}$
- $H \rightarrow Z + jets$

The first two backgrounds are hard to reduce since they come from the decay of real Z bosons and the second background has the high E_t^{miss}, however, the last two backgrounds can be reduced because they did not mimic the decay as the signal channel did. These last two background, however, have a larger cross section compared to the signal channel.

To preserve the wide Jacobian peak at the higher Higgs bosons mass, one could implement the chosen cuts as previously studied [7]. The other nice feature for this decay channel is the heavy Higgs boson mass could be observed up to 1 TeV level. Here are the set of cuts based on above studied that performed using $\sqrt{s} = 14\ TeV$ with integrated luminosity of $\mathcal{L} = 10^4\ pb^{-1}$ for the $m_H = 500\ GeV$:

- A large acceptance at the electromagnetic calorimeter $|\eta| < 1.8$, with two leptons required $p_t > 20\ GeV$ and $p_t^{\ell\ell} > 60\ GeV$
- $E_t^{miss} > 100\ GeV$.
- $|M_Z - M_{\ell\ell}| < 6\ GeV$
- To suppressed the background from $H \rightarrow ZW$, the $p_t > 5\ GeV$ of isolated lepton has been applied
- To reduce the jet background, its energy cut is $E_t > 150\ GeV$
- To eliminate the corresponding leptons pair with the jets events, the cosine angle between the momentum of pair lepton and sum of the momenta of jets been used where $cos_{p^{\ell\ell}-jets} > -0.8$

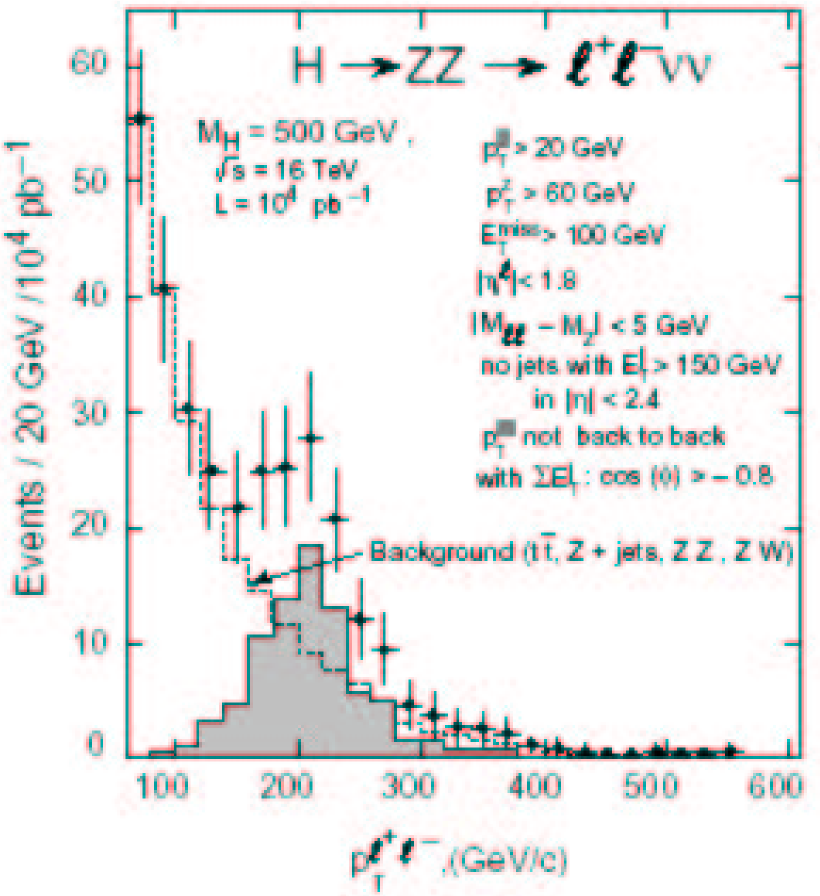

Figure 4: The signal and total background of the channel $H \to \ell\ell\nu\nu$ for the Higgs boson mass of $m_H = 500\ GeV$ [7].

- To eliminate the corresponding leptons pair with the missing transverse momentum candidate, the cosine of both parameters are used to be $cos_{p_t^{\ell\ell} - E_t^{miss}} > -0.8$

The result of the previous studied using integrated luminosity of $\mathcal{L} = 10^4\ pb^{-1}$ can be seen in Fig. 4.

For the higher Higgs boson mass range $700 < m_H < 1000\ GeV$, the ratio of $S/\sqrt{S+B}$ is smaller due to the Higgs witdh increases in this mass region, however, we could still observe a sufficient amount of signal by using a harder cuts on $E_t^{\ell\ell}$ as well as $p_t^{\ell\ell}$. The previous study showed that we could obtain 8-9σ signal up to $m_H = 800\ GeV$ when using an order higher of the integrated luminosity of $\mathcal{L} = 10^5\ pb^{-1}$ [8]. Here are the set of cuts based on above studied that performed using $\sqrt{s} = 14\ TeV$ with integrated luminosity of $\mathcal{L} = 10^5\ pb^{-1}$ for the $m_H = 800\ GeV$:

- A large acceptance at the electromagnetic calorimeter $|\eta| < 2.4$, with two leptons required $p_t > 50\ GeV$ and $p_t^{\ell\ell} > 250\ GeV$
- $E_t^{miss} > 250\ GeV$.

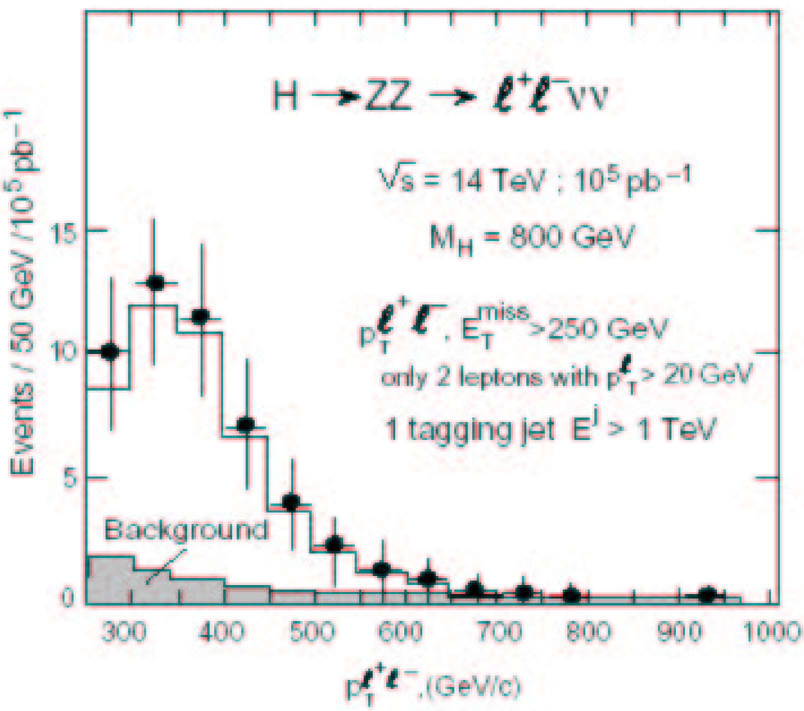

Figure 5:

- To suppressed the background from $H \rightarrow ZW$, the $p_t > 50\ GeV$ of isolated lepton has been applied
- At least one jet with its energy cut is $E_t > 1\ TeV$ and $2.4 < |\eta| < 4.7$

The result of the previous studied using integrated luminosity of $\mathcal{L} = 10^5\ pb^{-1}$ can be seen in Fig. 5.

4 Acknowledgments

The author would like to thank all members of the CMS collaboration. This work was supported in part by the U.S. Department of Energy DE-FG05-91ER40622.

References

[1] CMS Collaboration, Technical Proposal, CERN-LHCC 94-38 (1994).

[2] D. Zeppenfeld, R. Kinnunen, A. Nikitenko, E. Richter-Was, Phys. Rev. **D62**, 013009 (2000).

[3] M. Spira, CERN, Theory Division, CERN-TH 97-324, hep-ph/9711407.

[4] S. Catani, D. de Florian, M. Grazzini, JHEP **0201**, 015 (2002).

[5] ATLAS Collaboration, Technical Design Report, CERN-LHCC 99-14 (1999).

[6] N. Kauer and D. Zeppenfeld, Phy. Rev. **D65**, 014021 (2002).

[7] CMS Collaboration, N. Stepanov, Technical Note, CMS-TN/93-87 (1993).

[8] CMS Collaboration, N. Stepanov and A. Starodumov Technical Note, CMS-TN/92-49 (1992).