Higgs at CMS with 1, 10, 30 fb^{-1}

Sara Bolognesi

University of Torino - Dept of Experimental Physics
Via Giuria 1, Torino - Italy

The discovery strategies for the Standard Model Higgs boson at CMS are presented. The focus is on the results with 1, 10 and 30 fb^{-1} which should correspond respectively to about one year of data taking at the start-up luminosity and the first year and three years at low luminosity ($2 \times 10^{33} cm^{-2} s^{-1}$). [1]

1 Main Higgs channels studied at low luminosity

In Table 1 the accessible channels with less than 30 fb^{-1} are listed, the covered Higgs mass range and the order of magnitude of their cross sections are reported.

Between the early discovery channels, $H \to WW(^*) \to l\nu l\nu$ is the one with the biggest cross section and $H \to ZZ(^*) \to 4l$ is the cleanest one. Studying these decays, it is already possible to measure some Higgs properties (mass, width, cross section) with only 30 fb^{-1} [2] [3] [4] [5].

The Vector Boson Fusion (VBF) Higgs production process (qqH) can be studied with the Higgs decaying into $H \to \tau\tau$ or $H \to WW(^*)$ both in the fully leptonic ($l\nu l\nu$) and semileptonic final states ($jjl\nu$). These channels show a significance bigger than 3 or 5, respectively, with only 30 fb^{-1} but they requires a very good comprehension of the detector because of the complexity of the final states [6] [7] [8].

In the low Higgs mass region the $H \to \gamma\gamma$ decay is exploited: the preliminary results are encouraging but there are big uncertainties on the background because it strongly depends on the detector behavior and on the QCD physics at the LHC scale [9].

1.1 $H \to ZZ(^*) \to 4l$

These channels are very promising for the Higgs detection in the mass range 130 GeV-500 GeV, with the exception of a small interval near 160 GeV where the $H \to ZZ(^*)$ branching ratio (BR) has a big drop due to the opening of the WW on-shell production.

channel	$\sigma \times BR$	**studied** $M(H)$
$H \to WW(^*) \to l\nu l\nu$	0.5-2.5 pb	120-200 GeV
$H \to ZZ(^*) \to 4l$	5-100 fb	130-500 GeV
$qqH \to WW(^*) \to jjl\nu$	200-900 fb	120-250 GeV
$qqH \to WW(^*) \to l\nu l\nu$	50-250 fb	120-200 GeV
$qqH \to \tau\tau$	50-160 fb	115-145 GeV
$H \to \gamma\gamma$	50-100 fb	115-150 GeV

Table 1: Accessible channels with less than 30 fb^{-1}

The main backgrounds are $t\bar{t}$ ($\sigma \simeq 840\ pb$), $Zb\bar{b}$ ($\sigma \simeq 280\ pb$) and $ZZ(^*)/\gamma^*$ ($\sigma \simeq 30\ pb$), to be compared with the $H \rightarrow ZZ(^*)$ cross section of about 10-50 pb. Zcc has been found to be negligible.

The trigger and the offline cuts applied in the analysis rely on the presence of isolated charged leptons coming from the primary vertex and with high transverse momentum. The Z mass peak is also a powerful feature: more than 50% (80%) of the events have at least one on-shell Z for $M(H) > 115$ (150) GeV.

The studied final states are $2e2\mu$, 4μ and $4e$. The first has the biggest BR while the second is the cleanest one. The main concern of the last channel is the presence, for low Higgs masses, of very soft electrons, well below the range for which the reconstruction will be best controlled in CMS via single Z and W measurements.

In Figure 1 the luminosity needed for a 5σ discovery and the significance achievable with 30 fb^{-1}, combining the three possible final states, is plotted as a function of the Higgs mass.

1.2 $H \rightarrow WW(^*) \rightarrow l\nu l\nu$

The leptonic decays of both the W in the ee, $e\mu$ and $\mu\mu$ combinations have been studied. The signal has a cross section of 0.5-2.3 pb with a peak at $M(H) = 160\ GeV$. The main backgrounds are single and double top production ($\sigma \simeq 90\ pb$) and double boson production ($\sigma \simeq 15\ pb$), considering only the fully leptonic decays. The Drell-Yan background after the full selection should be less than 2% of the total background. Figure 1 shows the luminosity needed for a 5σ discovery and the significance obtained with 30 fb^{-1} as a function of the Higgs mass.

The final state selection relies mainly on the request of high missing energy ($> 50\ GeV$) and on a central jet veto. The main kinematic peculiarity of this channel is the closeness of the two charged leptons. The absence of the Higgs peak requires an high signal over background ratio and a good control of the background shape. Therefore a procedure to normalize the background from the data is necessary: a different signal free region for each background has been defined varying the analysis cuts. The uncertainties for the various backgrounds are between 15% and 20%, with the exception of single top and $gg \rightarrow WW$ processes for which it's not possible to find a good normalization region so that the systematics ($\simeq 30\%$) are dominated by MC theorethical errors.

1.3 qqH with $H \rightarrow WW$

The analysis of the fully leptonic decay channel ($qql\nu l\nu$ final state) is similar to that described in the previous section (Sec. 1.2). This process has a lower cross section (50-250 fb) but the presence of the two additional quarks from the VBF, with high energy and pseudorapidity, can be exploited to disentangle the signal from the background.

The semileptonic decay channel ($qqqql\nu$ final state) has the advantage of a higher BR and it allows to reconstruct the Higgs mass peak. On the other hand it suffers from very high background: double top ($\sigma \simeq 840\ pb$), single top ($\sigma \simeq 100\ pb$), double boson plus jets ($\sigma \simeq 100\ pb$) and single boson plus jets (σ bigger than 1 mb), to be compared with the $qqH \rightarrow qqWW$ cross section of about 0.6-2.7 pb. Thus strong cuts are necessary and this implies a good knowledge of the physics involved. However the cross sections of the multiple jets processes at the LHC scale are not yet very well known and they will be measured precisely only from the LHC data themselves. Moreover many systematics about the jets detection and reconstruction are still quite uncertain, they can be understood and measured only from the data.

The preliminary estimation of the significance with 30 fb^{-1} is shown in Figure 1 (left).

1.4 qqH with $H \to \tau\tau$

This channel has been analyzed with one τ decaying into leptons and the other τ into hadrons ($\sigma \simeq$ 50-160 pb). The irreducible backgrounds are the QCD and EW production of two τ leptons from Z/γ^* with associated jets (QCD 2τ+2/3 jets $\sigma \simeq 1.6$ pb, EW 2τ+2 jets $\sigma \simeq 230$ fb). The reducible backgrounds considered are the $W+$ multi-jet production (W+3/4 jets $\sigma \simeq 14.5$ pb with $W \to \mu\nu$) and $t\bar{t}$ events ($\sigma \simeq 86$ pb with $W \to l\nu$), in which one of the jets can be misidentified as a τ-jet.

This analysis has to reconstruct a very complex final state. The hadronically decaying τ is reconstructed from a little ($\Delta R = 0.4$) isolated jet. A very low impurity (2.7%) is obtained thanks to the selection cuts, costing a low reconstruction efficiency (30%). The energy resolution on the reconstructed τ is 11.3%. The leptonically decaying τ is recognized from the electron or muon with highest transverse momentum, requiring $p_T > 15$ GeV. The τ energies are calculated using collinear approximation of visible part of τ decay products and neutrinos. A raw (not calibrated) missing transverse energy (MET) greater than 40 GeV is required. The MET resolution after all corrections is 20%, this is the largest contribution to the Higgs mass resolution. Finally the presence of the two quarks emitting the bosons in the VBF process can be exploited: they have very high energy and high rapidity gap because there is not color exchange between them, being produced trough an EW process. After having removed the τ jet and the two VBF jets, a central jet veto is applied using a Monte Carlo jet energy calibration.

The significance exceeds 3σ with 30 fb^{-1}, as reported in Figure 1 (left). The number of events is measured directly from the data fitting the $M(\tau\tau)$ distribution. The uncertainty on the number of background events (7.8% with 30 fb^{-1}) is computed from its spread in 10.000 toy Monte Carlo data distributions generated following the fit results.

1.5 Inclusive $H \to \gamma\gamma$

In this channel, because of the very low NLO BR ($\simeq 0.002$), the inclusive Higgs production is considered (mainly VBF and gg fusion).

The amount of background is very high: Drell-Yan e^+e^-, $pp \to \gamma\gamma$ (irreducible), $pp \to jets+\gamma$ and $pp \to jets$ where one or more jets are misidentified as γ (reducible). In particular this last kind of background has a big dependence on the detector performance and it involves not well known QCD physics. Therefore there is a great deal of uncertainty in the benchmark estimate of significance and of needed luminosity (shown in Figure 1). However this will not be a systematic error on real data since the background will be precisely measured from the data themselves, exploiting the big $M(\gamma\gamma)$ sidebands signal free. The analysis will be in fact based on a Neural Network trained on Monte Carlo for the signal and on the sidebands for the background: the systematic error achievable on the background interpolation under the Higgs peak with this method is very low ($\simeq 1\%$).

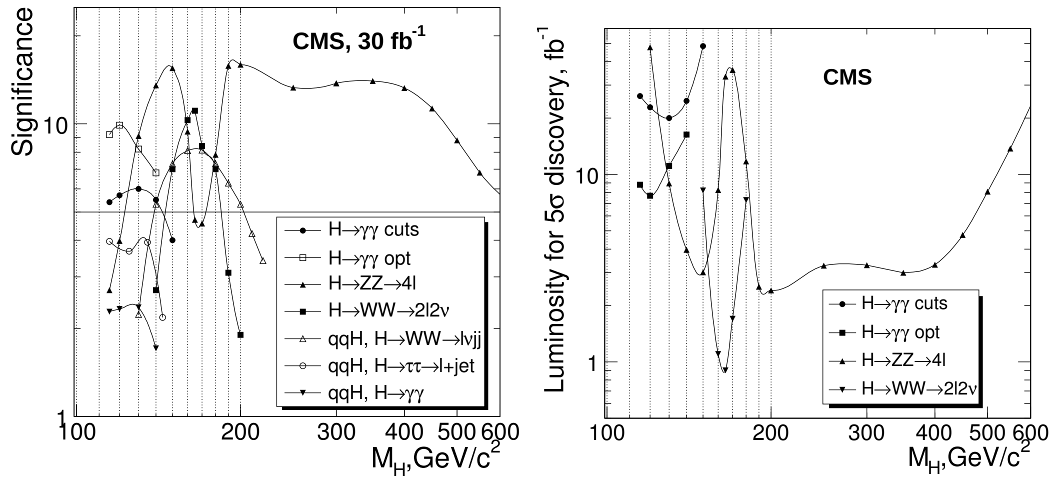

Figure 1: Significance achievable with 30 fb^{-1} (left) and luminosity needed for a 5σ discovery (right) in the various channels as a function of the Higgs mass.

1.6 Conclusions

Figure 1 is a good summary of the CMS potential for the Higgs discovery with low luminosity. However it should be noticed that a careful preliminary work must be done in order get those results: the first data will be used to study the detector systematics (in particular the control of the jets response and of the MET resolution will be difficult at the beginning) and to measure the cross sections of multi-jets background processes (mainly $t\bar{t}$ and single and double boson production in association with jets).

References

[1] Slides: `http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=42&sessionId=8&confId=1296`

[2] D. Futyan, D. Fortin and D. Giordano *Search for the Standard Model Higgs Boson in the Two-Electron and Two-Muon Final State with CMS*, CMS NOTE 2006/136

[3] S. Abdullin et al. *Search Strategy of the Standard Model Higgs Boson in the $H \to ZZ(^*) \to 4\mu$ Decay Channel using $M(4\mu)$-Dependent Cuts*, CMS NOTE 2006/122

[4] S. Baffioni et al. *Discovery potential for the SM Higgs boson in the $H \to ZZ(^*) \to e^+e^-e^+e^-$ decay channel*, CMS NOTE 2006/115

[5] G. Davatz, M. Dittmar and A.-S. Giolo-Nicollerat, *Standard Model Higgs discovery potential of CMS in the $H \to W^+W^- \to l\nu l\nu$ Channel*, CMS NOTE 2006/047

[6] , C. Foudas, A. Nikitenko and M. Takahashi *Observation of the Standard Model Higgs boson via $H \to \tau\tau \to$lepton+jet Channel*, CMS NOTE 2006/088

[7] E. Yazgan, et al. *Search for a Standard Model Higgs Boson in CMS via Vector Boson Fusion in the $H \to WW \to l\nu l\nu$ Channel*, CMS NOTE 2007/011

[8] H. Pi et al. *Search for Standard Model Higgs Boson via Vector Boson Fusion in the $H \to W^+W^- \to l^\pm\nu jj$ with $120 < m_H < 250 GeV/c^2$*, CMS NOTE 2006/092

[9] M. Pieri et al. *Inclusive Search for the Higgs Boson in the $H \to \gamma\gamma$ Channel*, CMS NOTE 2006/112