HIGGS $H \to \gamma\gamma$ IN ASSOCIATION WITH Z/W BOSONS

B. BRELIER
Université de Montréal, LPSC Grenoble,
E-mail : bertrand.brelier@cern.ch
On behalf of the ATLAS Collaboration

Electro-weak precision measurements strongly suggest that the mass of the Standard Model Higgs boson, if it exists, should not be much higher than the present experimental limit of 114.4 GeV/c^2. The LHC experiments will allow us to look for a Higgs boson in this mass range for which the decay into photons is one of the most important channels. The isolation of events from Higgs boson production in association with Z/W bosons may increase the statistical significance of the Higgs boson discovery and these production modes can be used to access the Higgs boson couplings to the weak bosons, thus helping to confirm the nature of the observed resonance.

1. Introduction

Precision electroweak measurements constrain the mass of a Standard Model (SM) Higgs boson, to be less than 144 GeV/c^2 at 95% CL [1] , with the most likely value close to the present lower limit of 114.4 GeV/c^2, obtained from direct searches [2]. In the low mass region (110 - 140 GeV/c^2), the di-photon channel is one of the most important channels at the LHC. Although it suffers from a low branching ratio ($\sim$ 0.2%), it benefits from good mass resolution ($\sim$ 1.3%). In this mass range, the dominant Higgs boson production process at the LHC is the gluon-gluon fusion through a top quark loop, $gg \to h$. The vector boson fusion process : $qq' \to qq'H$ has a cross-section approximately ten times lower in the mentioned mass range. The search for associated Higgs boson production with W, Z, or $t\bar{t}$ could help to look for a Higgs boson in addition to the inclusive analysis ($H \to \gamma\gamma$) and can be used to determine the coupling constants to the SM gauge bosons and the Yukawa coupling to the top quark [3], [4]. All these measurements would provide consistency checks of the Standard Model which predicts all couplings of the Higgs boson, given its mass. Associated Higgs boson production cross-sections involve couplings $\sigma_{WH} = \alpha_{WH} g_W^2$ and $\sigma_{ZH} = \alpha_{ZH} g_Z^2$. The α coefficients are the proportionality constants

between the couplings squared (g_W^2 and g_Z^2) and the cross-sections (σ_{WH}, σ_{ZH}) and have to be calculated from theory.
The decay $H \to \gamma\gamma$ proceeds either by a W or a top loop with destructive interference between both loops. By combining all the different channels in the production and decay mode, we have access to the Higgs couplings with the Standard Model particles. The couplings are more difficult to measure in the low mass region, as we have to take into account all the possible channels. Here, we report on a search for a SM Higgs boson in the associated production channels. Two distinct signal topologies are considered separately, where $H \to \gamma\gamma$ is accompanied by : (i) a lepton, resulting mostly from the WH channel and (ii) high missing transverse momentum, largely due to the ZH channel. The main backgrounds are prompt $\gamma\gamma$, $W\gamma \to e\nu\gamma$, and $\gamma + jet$. Therefore, electron/photon discrimination, $\gamma - jet$ rejection and missing transverse momentum reconstruction are of utmost importance in our analyses.

2. The $H \to \gamma\gamma$ channels

The main contributions come from gluon-gluon fusion (inclusive channel) and Vector Boson fusion, but we have also a contribution from the associated production with a top quarks pair and with a Z or W boson. The main difficulty of these channels arises from the very high level of backgrounds, both irreducible, due to prompt di-photon events, and reducible, due to jets misidentified as photons. To suppress the contribution coming from the fake photons, we developed an algorithm based on the analysis of shower shape in the calorimeter combined with the isolation using the tracker. The fine segmentation of the electromagnetic calorimeter provides a very good γ/π^0 discrimination.
A photon in the detector can also convert into two electrons, which makes the photon identification more difficult. In this case, an energy deposition in the calorimeter is associated with one or two tracks in the tracker. The conversion vertex can be reconstructed where two tracks are identified but we can also keep the photon associated with one track.

3. Z/WH channels

We evaluate the feasibility of di-photon searches in association with weak bosons, Z, W using a full detector simulation. This involves searches for di-photons in association with missing transverse energy, $\not{E}_T$, and charged leptons (electrons and muons) when the Z and W bosons decay into leptons.

We performed two analyses depending on the event topology : two photons and at least one isolated lepton (electron or muon) topology mainly coming from the $WH \to \ell\nu\gamma\gamma$ signal and two photons with large tranverse energy coming from $ZH \to \nu\bar{\nu}\gamma\gamma$.
The next sections describe the analysis cuts optimized for a higgs mass $m_H = 120$ GeV/c^2. A full simulation of the detector was used for the signal and background events. Effects due to misalignment are included.

3.1. *Di-photon, missing energy and isolated leptons topology*

The main signal contributing to this category of events will be from $WH \to \ell\nu\gamma\gamma$. The basic selection requires the presence of two energetic photons, missing transverse momentum, and one high energetic lepton. The main background for this channel is $W\gamma\gamma \to \ell\nu\gamma\gamma$ and $W\gamma \to e\nu\gamma$. By including both of these backgrounds, some double counting is introduced since final state QED radiation produces a second photon in the latter case. Since the cross-section is much higher, other effects which will mimic the signal can become important, such as an additional photon radiated by the lepton, secondary bremsstrahlung in the detector material or an electron mis-reconstructed as a photon. Another important background turns out to be $\gamma\gamma$ and $\gamma + jets$, when fake electrons or muons are reconstructed.
The first selection criterion sets bounds on the transverse momenta of the two reconstructed photons. It is found that an optimum cut requires the p_T of the most energetic photon to be greater than 60 GeV/c and the p_T of the second most energetic photon to be greater than 25 GeV/c. Requiring a cut on the transverse momentum of the most energetic isolated lepton to be greater than 20 GeV/c suppresses efficiently the di-photon and $W\gamma$ backgrounds with little loss in signal. The di-photon background can further be suppressed by a factor of 4.5 by requiring a transverse missing energy to be greater than 20 GeV/c. After applying the analysis cuts, we are able to see an excess of events (Fig. 1) in the photons invariant mass distribution. We expect to measure the Higgs mass equal to $m_H = 119.4$ GeV/c^2 after taking into account all the detector effects.

3.2. *Di-photon and missing transverse energy*

This analysis is intended to select principally the $ZH \to \nu\nu\gamma\gamma$ events. The main features are the presence of two energetic photons from the Higgs boson and a large transverse missing energy. The two dominant backgrounds for this channel are the $\gamma\gamma$ and $W\gamma \to e\nu\gamma$ channels where, in the latter case, the electron can be mis-reconstructed as a photon. To be sure that we have no double counting, we will consider only the events which have not been selected in Section 3.1. As in Section 3.1, a cut on the transverse momentum of the the most energetic photon to be greater than 60 GeV/c and the p_T of the second most energetic photon to be greater than 25 GeV/c are first applied to suppress the di-photon background. The selection is then based mostly on the requirement of high missing transverse momentum. A cut of $\not{E}_T > 65$ GeV/c suppresses almost completely the $\gamma\gamma$ background while reducing the $W\gamma$ background by a factor 9 and the $ZH \to \nu\nu\gamma\gamma$ signal by a factor 1.65. In order to suppress further the $W\gamma$ background, where the electron is often reconstructed as a converted photon, we reject events where one of the two photons is converted and associated with one or two tracks. After applying the analysis cuts, we are able to see an excess of events (Fig. 1) in the photon invariant mass distribution. We expect to measure the Higgs mass equal to $m_H = 119.7$ GeV after taking into account the detector effects.

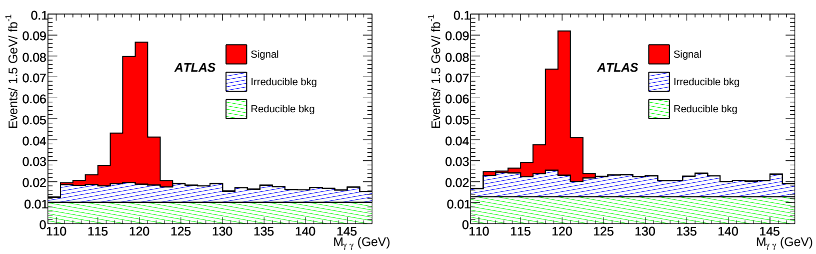

Figure 1. Expected distribution of the invariant mass of the two photons for the signals and main backgrounds after applying the analysis cuts for events having one reconstructed lepton on the left plot and having $\not{E}_T$ on the right plot.

4. Statistical combination of the Associated Production channels

The Roofit tool was used to evaluate the statistical significance of the associated production combination. We defined two categories corresponding to the di-photon and lepton analysis and di-photon and $\not{E}_T$ analysis. We generated pseudo-experiments in the signal + background hypothesis and background hypothesis. The background was generated for each category following an exponential function in $m_{\gamma\gamma}$ (invariant mass of the two reconstructed photons) and a Gaussian function for the signal. The signal and background shapes have been tuned to reproduce the results of the Monte-Carlo analyses. After having generated events in each category, we fitted the invariant mass of the photons with the exponential functions with and without a gaussian function for the signal + background and background hypothesis respectively. After one year at high luminosity (100 fb^{-1}), we will be able to see a signal with a statistical signifiance of 4.96 σ and after three years at low luminosity (30 fb^{-1}), we would see a signal with a statistical significance equal to 3.27 σ. The statistical significance for 100 fb^{-1} does not take into account pile-up effects. Due to the fact that we do not know the uncertainty of the background contribution, we estimate also the significance assuming a background contribution which is 50% higher. In the latter case, we expect to see a signal with a significance of 3.03 σ after three years of data taking at low luminosity.

5. Conclusions

After 30 fb^{-1} with the ATLAS detector, we would be able to see the associated Higgs production decaying into photons with a statistical significance $\sigma = 3.27$. This channel would increase the statistical significance in case of the higgs discovery by combining the results with the rest of the $H \to \gamma\gamma$ analyses. With higher integrated luminosity, the coupling strengths could be evaluated and comparison of the observed signal with expectations could serve as a test of the SM.

Acknowledgments

I thank the conveners of the ATLAS Higgs group Louis Fayard and Aleandro Nisati, the conveners of the Higgs to Gamma Gamma group Leonardo Carminati and Bruce Mellado, my PhD supervisors Georges Azuelos and Fairouz Malek and the ATLAS Collaboration.

References

1. M. W. Grunewald, arXiv:0709.3744 [hep-ph].
2. R. Barate *et al*, *Phys. Lett.* **B565**, 61 (2003).
3. D. Zeppenfeld, R. Kinnunen, A. Nikitenko and E. Richter-Was, Phys. Rev. D **62**, 013009 (2000) [arXiv:hep-ph/0002036].
4. M. Dührssen, Prospects for the measurement of Higgs boson coupling parameters in the mass range from 110 - 190 GeV, *Atlas Internal Note* ATL-PHYS-2003-030