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Search for Higgs to WW ($\ell\nu\ell\nu$, $\ell\nu qq$) with the ATLAS Detector

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Higgs boson searches in the $H\to WW^{(*)}\to\ell\nu\ell\nu$ ($\ell = e,\mu$) and the $H\to WW^{(*)}\to\ell\nu qq$ decay modes, using 1.04 fb^{-1} of proton-proton collision data delivered by the large hadron collider (LHC) at a centre-of-mass energy of 7 TeV collected with the ATLAS detector, are presented. An upper bound is placed on the Higgs boson production cross-section as a function of m_H. The $H\to WW^{(*)}\to\ell\nu\ell\nu$ analysis excludes a Higgs boson with a mass in the range from 158 GeV to 186 GeV at 95% confidence level, while the expected Higgs boson mass exclusion range is $142 \leq m_H \leq 186$ GeV. An excess of events in data corresponding to more than 2σ significance is observed for the Higgs boson mass range from 126 GeV to 158 GeV. The $H\to WW^{(*)}\to\ell\nu qq$ analysis place limits on the Higgs boson cross section that are between 1.4 to 20 times the expected standard model cross section in the mass range from 240 GeV to 600 GeV.

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1. Introduction

The Higgs boson is the only particle in the standard model (SM) which has not been experimentally verified. This particle, which appears as a consequence of the breaking of electroweak symmetry, is responsible for giving masses to all other massive particles. Direct searches at LEP and the Tevatron have excluded, at 95% Confidence Level (CL), a Higgs boson with a mass below 114.4 *GeV* and in the region $158 < m_H < 175$ GeV [1] [2]. Indirect limits of $m_H < 185$ GeV at 95% CL have also been set using global fits to electroweak precision results [3].

In these proceedings, two Higgs boson searches in the $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$ ($\ell = e, \mu$) and $H \rightarrow WW^{(*)} \rightarrow \ell\nu qq$ ($\ell = e, \mu$) channels are presented. For a more detailed description, see [4, 5, 6].

2. Samples, Event and Object Selections

The analyses are based on a data sample corresponding to 1.04 fb^{-1} of pp collisions at $\sqrt{s} =$ 7 TeV recorded with the ATLAS detector. The sample has been collected with unprescaled single lepton triggers requiring presence of an electron with E_T of at least 20 GeV or a muon with p_T of at least 18 GeV, or 40 GeV if it is reconstructed using only the muon spectrometer in the barrel region. The events are further required to have a primary vertex with at least three tracks that is consistent with the beam spot position.

The basic signature of a $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$ candidate event is the presence of two high p_T opposite sign leptons and large $E_\mathrm{T}^\mathrm{miss}$ (missing transverse momentum), with little jet activity inside the detector acceptance. Candidate events are required to have exactly two leptons, with the leading lepton fulfilling $p_\mathrm{T} > 25$ GeV and the sub-leading electron (muon) fulfilling $p_\mathrm{T} > 20$ GeV ($p_\mathrm{T} >$ 15 GeV). The leptons are isolated from nearby tracks with requirements on the scalar sum of the transverse momenta of nearby charged tracks and of the calorimeter energy deposits within $\Delta R = 0.2$ of the candidate. Further, the dilepton invariant mass is required to be $m_{\ell\ell} > 15(10)$ GeV for the ee and $\mu\mu$ channels ($e\mu$ channel). An additional requirement of $|m_Z - m_{\ell\ell}| > 15$ GeV is performed to suppress the Z boson background while the QCD and Drell-Yan background events are suppressed using $E_\mathrm{T,rel}^\mathrm{miss}$, defined as $E_\mathrm{T}^\mathrm{miss}$ if $\Delta\phi \geq \pi/2$ and $E_\mathrm{T}^\mathrm{miss} \cdot \sin\Delta\phi$ if $\Delta\phi < \pi/2$. Here, $\Delta\phi$ is the absolute value of the difference in the azimuthal angle ϕ between the $E_\mathrm{T}^\mathrm{miss}$ and the nearest lepton or jet. The $E_\mathrm{T,rel}^\mathrm{miss}$ is requiered to be > 40 GeV (ee and $\mu\mu$ channels) and > 25 GeV ($e\mu$ channel). To reduce the top quark pair production background, the multiplicity of reconstructed jets is required to be less than two. The jet multiplicity distribution after the $E_\mathrm{T,rel}^\mathrm{miss}$ selection is shown in Fig. 1 (left). Using this sample, the analysis is performed separately for events with no jets, referred to as $H+0$ jets channel, and events with exactly one jet, referred to as the $H+1$ jets channel. In the $H+0$ jets analysis, it is required that the transverse momentum of the dilepton system, $|\mathbf{P}_\mathrm{T}^{\ell\ell}|$, is at least 30 GeV. In the $H+1$ jet analysis the following selections are made instead: Remove events where the jet tagged as originating from a b-quark, require that the total p_T of the Higgs boson plus jet system (defined as the magnitude of the vector sum $\mathbf{P}_\mathrm{T}^\mathrm{tot} = \mathbf{P}_\mathrm{T}^\mathrm{l1} + \mathbf{P}_\mathrm{T}^\mathrm{l2} + \mathbf{P}_\mathrm{T}^\mathrm{j} + \mathbf{P}_\mathrm{T}^\mathrm{miss}$) is less than 30 GeV and reject $Z \rightarrow \tau\tau$ events by requiring that the $\tau\tau$ invariant mass $m_{\tau\tau}$ (reconstructed using the approximation that the neutrinos are collinear with the visible products of the corresponding τ decays) does not fulfill $|m_{\tau\tau} - m_Z| < 25$ GeV. Finally the following selections are made in both the $H+0$ jets and the $H+1$ jet channels:

- The dilepton invariant mass is required to satisfy $m_{\ell\ell} < 50$ GeV or $m_{\ell\ell} < 65$ GeV for predicted Higgs boson masses in the regions $m_H < 170$ GeV and $m_H \geq 170$ GeV, respectively.
- The dilepton opening angle in the transverse plane, $\Delta\Phi_{\ell\ell}$, is required to be less than 1.3 (1.8) radians for $m_H < 170$ GeV ($m_H \geq 170$ GeV).
- The transverse mass, m_{T}, is required to satisfy $0.75 < m_{\mathrm{T}}/m_H < 1$, where transverse mass is defined as $m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{P}_{\mathrm{T}}^{\ell\ell} + \mathbf{P}_{\mathrm{T}}^{\mathrm{miss}})^2}$, where $E_{\mathrm{T}}^{\ell\ell} = \sqrt{(\mathbf{P}_{\mathrm{T}}^{\ell\ell})^2 + m_{\ell\ell}^2}$, $|\mathbf{P}_{\mathrm{T}}^{\mathrm{miss}}| = E_{\mathrm{T}}^{\mathrm{miss}}$ and $\mathbf{P}_{\mathrm{T}}^{\ell\ell}$ is the transverse momentum of the dilepton system.

The basic signature of a $H \to WW^{(*)} \to \ell\nu qq$ candidate event is the presence of one high p_{T} leptons, large $E_{\mathrm{T}}^{\mathrm{miss}}$ and two jets. Candidate events are required to have exactly one electron or muon with $p_{\mathrm{T}} > 30$ GeV. In order to ensure that this analysis is statistically independent from the $H \to WW^{(*)} \to \ell\nu\ell\nu$ analysis, events are vetoed if there are any additional leptons with $p_{\mathrm{T}} > 20$ GeV. The events are further required to have $E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV and to have exactly two or three jets. The event is rejected if any of the jets are tagged as orgiginating from a *b*-quark. Analogously to the $H \to WW^{(*)} \to \ell\nu\ell\nu$ analysis, the events are further split into two channels, the $H+0$ ($H+1$) jets channel for events with exactly two (three) jets. An approximate invariant mass for the Higgs boson candidate is reconstructed by solving the mass constraint equation $M_{l\nu} = M_W$ for the unmeasured *z*-momentum of the neutrino. The hadronically decaying W candidate is reconstructed by selecting the pair of jets whose dijet invariant mass is closest to the W mass. A maximum likelihood fit is then performed to this distribution to normalize the background to data and to extract the signal. The fit models the background as a sum of two falling exponential functions. The determination of the background normalization in the fit is dominated by the sidebands in $M_{\ell\nu qq}$, the mass of the Higgs boson candidate.

3. Results

Figure 1 (middle and right) shows the transverse mass m_{T} distribution in the $H+0$ and $H+1$ jet analyses after all the cuts except for the cut on the m_{T} itself, for a selection of a Higgs boson with $m_H = 150$ GeV. Table 1 shows the expected numbers of signal and background events as well as the number of events observed in data after applying all cuts in 1.04 fb^{-1} of integrated luminosity for the $H+0$ jets and $H+1$ jet analyses. The dominant contributions to the background in both channels comes from WW production. In the $H+0$ ($H+1$) jet channel the second largest background originates from W+jets (top pair) production. The normalizations of the major backgrounds are obtained with data-driven techniques, as described in more detail in [4].

Table 1: The expected numbers of signal ($m_H = 150$ GeV) and background events for the $H \to WW^{(*)} \to \ell\nu\ell\nu$ $H+0$ and $H+1$ jet analyses in 1.04 fb^{-1} of integrated luminosity together with the number of observed events in data.

Channel	Signal	WW	W+jets	Z/γ^*+jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Obs.
$H+0$ jets	21 ± 4	26 ± 3	2.9 ± 0.9	1 ± 2	1.6 ± 1.2	0.7 ± 0.4	0.6 ± 0.2	33 ± 5	49
$H+1$ jets	7.2 ± 1.6	6.2 ± 1.3	0.5 ± 0.9	0.4 ± 0.6	4.9 ± 1.7	2.3 ± 0.7	0.34 ± 0.16	15 ± 3	21

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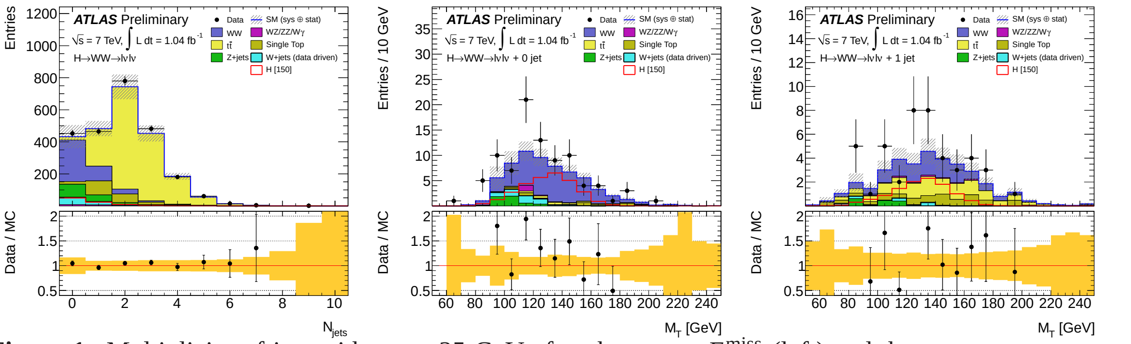

Figure 1: Multiplicity of jets with $p_T > 25$ GeV after the cut on $E_{\mathrm{T,rel}}^{\mathrm{miss}}$ (left) and the transverse mass m_{T} distribution in the $H+0$ (middle) and $H+1$ (right) jet analyses after all the cuts except for the cut on the m_{T} itself, for a selection of a Higgs boson with $m_H = 150$ GeV.

Figure 2 (left) shows the observed and expected limits at 95% confidence level for the combined $H\to WW^{(*)}\to\ell\nu\ell\nu$ $H+0$ jet and $H+1$ jet analyses. The procedure used to compute exclusion limits is based on the modified frequentist method known as CLs [7]. A Higgs boson with a mass in the range from 158 GeV to 186 GeV is excluded at 95% confidence level, while the expected Higgs boson mass exclusion range is $142 \leq m_H \leq 186$ GeV. The observed exclusion limit is more than 2σ larger than the expected exclusion limit in the Higgs boson mass range from 126 GeV to 154 GeV. Assuming the nominal standard model Higgs boson hypothesis, the expected and observed signal significances as functions of the Higgs boson mass are shown in Fig. 2 (right). An excess of events in data corresponding to more than 2σ significance is observed for the Higgs boson mass range from 126 GeV to 158 GeV, with the largest deviation being 2.7σ for a Higgs boson mass of 130 GeV.

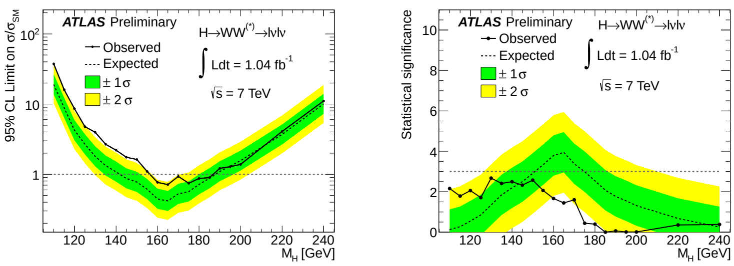

Figure 2: The expected (dashed) and observed (solid) 95% CL upper limits on the cross-section normalized to the SM cross-section (left) and the signal significance (right) as a function of the Higgs boson mass in the $H\to WW^{(*)}\to\ell\nu\ell\nu$ channel.

The invariant mass distributions in the $H\to WW^{(*)}\to\ell\nu qq$ analysis for the $H+0$ and $H+1$ jet channels are shown in Fig. 3 (left and middle). The shape of a potential signal at $m_H = 400$ GeV is also shown multiplied by a factor of one hundred. No significant $H\to WW^{(*)}\to\ell\nu qq$ excess is observed, so limits are extracted, as show in Fig. 3 (right).

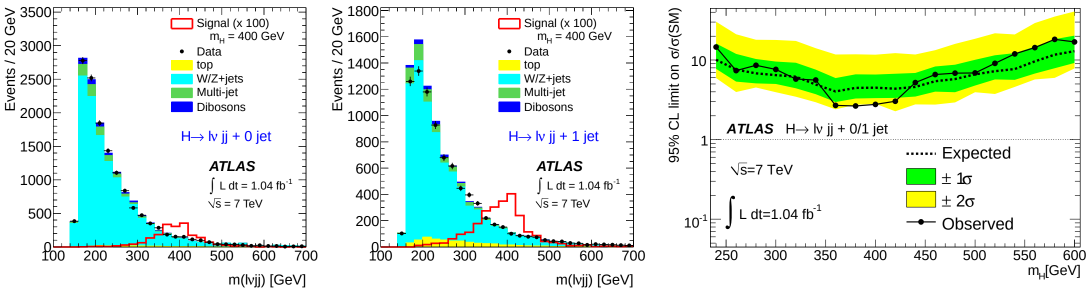

Figure 3: The distribution of the invariant mass of Higgs candidates ($M_{\ell\nu qq}$), for the $H+0$ jet analysis (left) and for the $H+1$ jet analysis (middle) as well as the expected (dashed) and observed (solid) 95% CL upper limits on the SM Higgs boson cross section in the $H\to WW^{(*)}\to\ell\nu qq$ analysis (right).

4. Conclusion

Higgs boson searches in the $H\to WW^{(*)}\to\ell\nu\ell\nu$ ($\ell = e,\mu$) and the $H\to WW^{(*)}\to\ell\nu qq$ decay modes, using 1.04 fb^{-1} of proton-proton collision data at a centre-of-mass energy of 7 TeV collected with the ATLAS detector, have been presented. An upper bound is placed on the Higgs boson production cross-section as a function of m_H. The $H\to WW^{(*)}\to\ell\nu\ell\nu$ analysis excludes a Higgs boson with a mass in the range from 158 GeV to 186 GeV at 95% confidence level, while the expected Higgs boson mass exclusion range is $142 \leq m_H \leq 186$ GeV. An excess of events in data corresponding to more than 2σ significance is observed for the Higgs boson mass range from 126 GeV to 158 GeV. The $H\to WW^{(*)}\to\ell\nu qq$ analysis place limits on the Higgs boson cross section that are between 1.4 to 20 times the expected standard model cross section in the mass range from 240 GeV to 600 GeV.

References

[1] G. Abbiendi et al., *Phys. Lett.* **B565** (2003) 61.

[2] T. Altonen et al., *Phys. Rev. Lett.* **104** (2010) 061802.

[3] ALEPH DELPHI L3 OPAL SLD CDF D0 Coll., The LEP Tevatron SLD Electroweak Working Group 2010, Cern-ph-ep-2010-095, 2010, arXiv:1012.2367 [hep-ex].

[4] ATLAS Collaboration, ATLAS-CONF-2011-005.

[5] ATLAS Collaboration, ATLAS-CONF-2011-111.

[6] ATLAS Collaboration, *Phys. Rev. Lett.* **107** (2011) 231801.

[7] A. L. Read, *J. Phys. G. Nucl. Part. Phys.* **28** (2002) 2693.