The sensitivity of the ATLAS detector to the Standard Model Higgs boson in the four lepton final state

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The Higgs boson is the only particle in the Standard Model (SM) that has not yet been discovered. Although its mass (m_H) is a free parameter, direct searches at the Large Electron Positron collider have set a lower limit on m_H of 114.4 GeV at 95% confidence level (CL) [1]. In addition, ongoing searches at the Tevatron have excluded the range $162 < m_H < 166$ GeV at 95% CL [2]. Assuming the overall validity of the SM, a global fit to precision electroweak data provides an indirect upper limit on m_H of 157 GeV at 95% CL [3].

The analyses described here were performed using detailed simulations of the ATLAS detector response to proton-proton collisions at a centre-of-mass energy of 14 TeV. Further details of the analyses can be found in [4].

The $H \rightarrow ZZ^{(*)} \rightarrow 4l$ channel is an important channel in the search for the SM Higgs boson as it provides one of the cleanest experimental signatures. In the range of m_H values considered, the dominant background to this channel is the $pp \rightarrow ZZ^{(*)} \rightarrow 4l$ continuum. Below about 200 GeV, where one of the Z bosons in the signal channel is produced off-shell, the $pp \rightarrow Zb\bar{b}$ and $pp \rightarrow t\bar{t}$ processes also contribute.

The online selection of candidate $H \rightarrow ZZ^{(*)} \rightarrow 4l$ events is performed either by single lepton or double lepton triggers. The offline event selection requires that the candidate events have at least four leptons that can be coupled into pairs of same flavour and opposite charge. The $4l$ invariant mass resolution is improved by 10% to 17% when applying a Z boson mass constraint to one (or both if $m_H > 200$) of the lepton pairs. The resulting 4μ invariant mass distribution in simulated signal events for $m_H = 130$ GeV is shown in Figure 1. A similar distribution is also observed for the $4e$ invariant mass.

The calorimeter isolation, track isolation and transverse impact parameter significance of the leptons in the candidate events are discriminating variables in the rejection of the $pp \rightarrow Zb\bar{b}$ and $pp \rightarrow t\bar{t}$ background processes. The track (calorimeter) isolation variable is defined as the total transverse momentum (total energy) deposit around the lepton, normalised to the transverse momentum of the lepton. The impact parameter significance is the transverse impact parameter of the lepton with respect to the primary vertex, divided by the corresponding measurement error. The $4l$ invariant mass distributions in simulated signal and background events after all event selection criteria are shown in Figure 2.

The signal significance is determined using two different approaches. In the first approach, the number of signal and background events are counted within a mass window of $m_H \pm 2\sigma$,

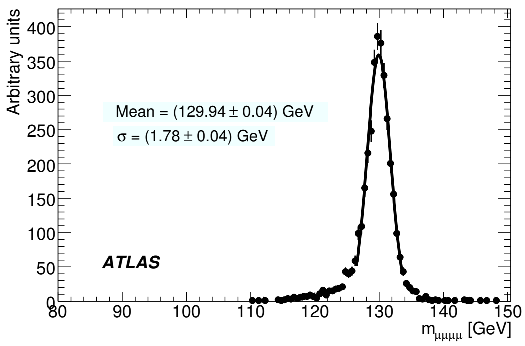

Figure 1: The 4μ invariant mass distribution in simulated signal events for $m_H = 130$ GeV.

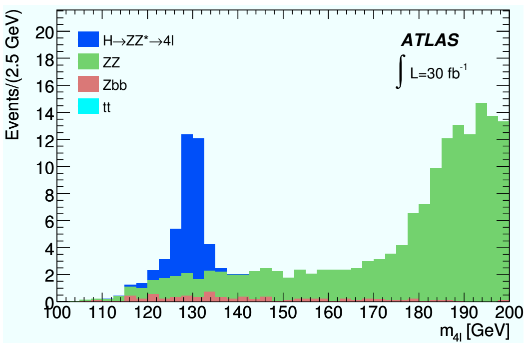

Figure 2: The $4l$ invariant mass distributions in simulated signal and background events after all event selection criteria for $m_H = 130$ GeV.

where σ is the experimental $4l$ invariant mass resolution. The significance is then calculated using Poissonian statistics without consideration of systematic uncertainties. In the second approach, the signal and background contributions are extracted from a fit to the $4l$ invariant mass distribution. The signal significance and exclusion limits are then calculated using a profile likelihood ratio method in which systematic uncertainties are taken into account. The 3% to 5% uncertainty on the signal selection efficiency is dominated by the experimental uncertainties relating to lepton reconstruction performance. The expected signal significance for an integrated luminosity of 30 fb^{-1} and the luminosity required for an exclusion at 95% CL in the $H \rightarrow ZZ^{(*)} \rightarrow 4l$ channel are shown in Figure 3 and Figure 4, respectively.

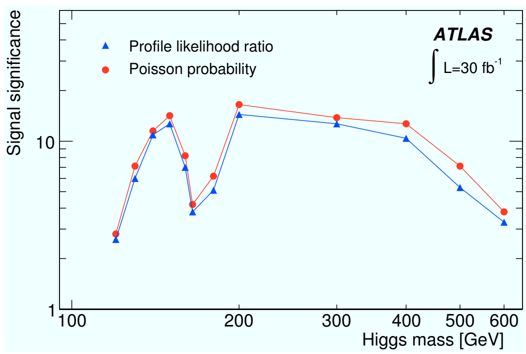

Figure 3: The expected signal significance for an integrated luminosity of 30 fb^{-1}.

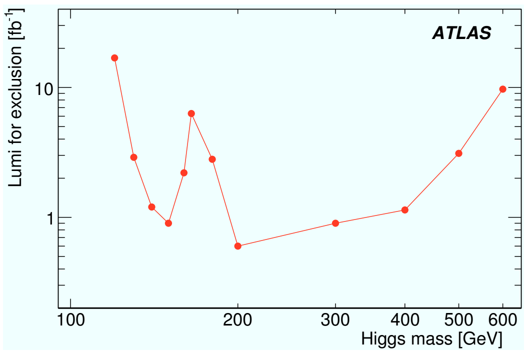

Figure 4: The luminosity required for an exclusion at 95% CL.

The $H \rightarrow ZZ^{(*)} \rightarrow 4l$ channel is combined with other important decay channels ($H \rightarrow W^+W^-$, $H \rightarrow \gamma\gamma$ and $H \rightarrow \tau^+\tau^-$) to provide a single measure of the significance of a discovery or an exclusion limit for various m_H values [4]. The expected combined discovery significances for an integrated luminosity of 10 fb^{-1} and the combined exclusion limits for an integrated luminosity of 2 fb^{-1} are shown in Figure 5 and Figure 6, respectively.

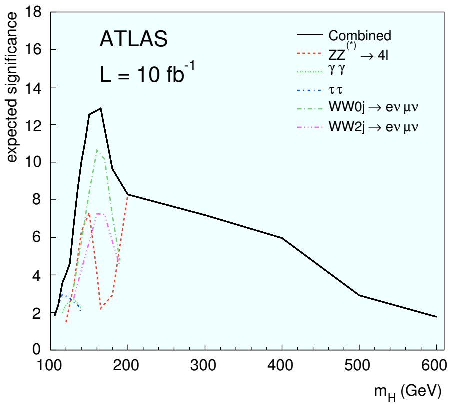

Figure 5: The expected combined discovery significances for an integrated luminosity of 10 fb^{-1}.

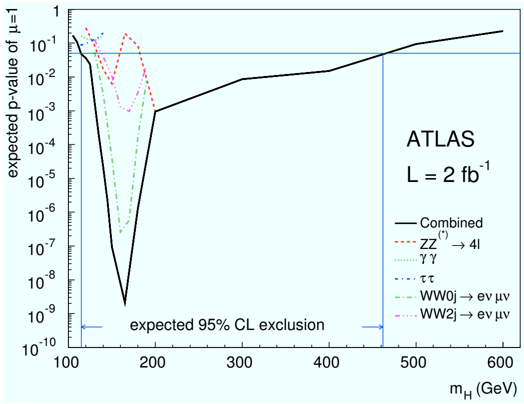

Figure 6: The expected combined exclusion limits for an integrated luminosity of 2 fb^{-1}.

With an integrated luminosity of 30 fb^{-1}, the expected sensitivity of the ATLAS detector to the discovery of the SM Higgs boson in the $H\to ZZ^{(*)}\to 4l$ channel alone is at the 5σ level or greater in the mass range $130 < m_H < 500$ GeV, with the exception of the region around 160 GeV where the branching ratio for $H\to ZZ^*$ decays is suppressed due to the opening of the phase space for the decay into two on-shell W bosons. With an integrated luminosity of 10 fb^{-1}, the expected combined sensitivity of the ATLAS detector to the discovery of the SM Higgs boson in the combination of channels is at the 5σ level or greater in the mass range $130 < m_H < 430$ GeV. For $m_H > 200$ GeV, the $H\to ZZ^{(*)}\to 4l$ channel will play a key role in the discovery or exclusion of the SM Higgs boson.

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