Standard Model Higgs search in the 4-lepton final state

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The discovery potential of the ATLAS detector at the LHC for a neutral SM Higgs boson decaying to purely leptonic final states, that is $\mathrm{H} \rightarrow \mathrm{ZZ}^{(*)} \rightarrow 4$ leptons (electrons or muons), is presented. The signal is characterized by the presence of isolated leptons associated to the main proton-proton interaction vertex in the events, and constitutes one of the most promising channels for SM Higgs discovery in the mass region $130 < m_H < 700$ GeV/c^2. Analysis techniques for signal reconstruction and for background rejection are discussed.

1 Introduction

One of the main LHC physics goals is the understanding of Standard Model (SM) electroweak symmetry breaking mechanism, that requires the existence of a scalar Higgs boson to provide mass terms to fermions and gauge bosons. Precision electroweak measurements set an upper limit on the SM Higgs boson mass that is $m_H < 157$ GeV/c^2 at 95% Confidence Level (CL). This increases to $m_H <$186 GeV/c^2 95%CL including the LEP2 direct search limit [1]. CDF and D0 experiments at Tevatron are directly searching the SM Higgs boson and the most recent combined results excludes the mass range between 163 GeV/c^2 and 166 GeV/c^2 at 95% CL [2]. The dominant production mechanism of the Higgs boson with proton-proton collisions at the LHC in the full m_H mass range is the gluon fusion mediated by the heavy quark loop. The vector boson fusion (VBF) process is one order of magnitude smaller than the gluon fusion but plays also an important role providing a good signature of two forward quark jets for which a forward jet tagging and a central jet veto allow better background rejection. Other production processes are: Higgs-strahlung and associated production with tt or W/Z bosons.

2 The $H \rightarrow ZZ^{(*)} \rightarrow 4l$ channel and backgrounds

Due to its experimentally clean signature, the $H \rightarrow ZZ^{(*)} \rightarrow 4l$ $(l = e, \mu)$ is a "golden" decay channel for the Higgs boson discovery. In fact, after the signal selection, a clear peak in the four leptons invariant mass distribution on top of a smooth background is expected. The gluon fusion process is known at NNLO with an uncertainty of 10-20% coming from parton distribution functions and QCD scale while the vector-boson fusion at NLO with uncertainty smaller than 10%.

In Table 1 the $H \rightarrow ZZ^{(*)} \rightarrow 4l$ cross sections at NLO are shown for different values of the Higgs boson masses, corresponding to some of the event samples processed through the

ATLAS [3] full simulation and reconstruction chain.

The $qq, gg \rightarrow ZZ^{(*)} \rightarrow 4l$ process represents the irreducible background to Higgs decaying into four leptons and its cross section, rescaled to NLO, is $34.8 \cdot [K(M_{ZZ}) + 0.3]$ fb, with $K(M_{ZZ})$ being a mass dependent K-factor and 0.3 factor taking into account the gluon initiated process. The reducible background is given by the processes $qq \rightarrow Zb\bar{b} \rightarrow 4l$ and $qq, gg \rightarrow t\bar{t}$ with leptonic W and b decays and their cross section, including the $4l$ branching ratio, is 812.1 fb for the former and 6.1 pb for the latter. The signal cross section is several orders of magnitude smaller than the reducible background so it is necessary to achieve large rejection factors against this background. Leptons from semileptonic b-decays, in contrast to those coming from Z decays, are less isolated, and are more likely to originate from a displaced vertex; hence, lepton isolation and the significance of the transverse impact parameter $d_0/\sigma(d_0)$ of final state leptons can be used as discriminating variables, as shown in Fig. 1.

m_H[GeV/c^2]	$\sigma_{NLO} \cdot$ BR[fb]
130	6.25
150	10.56
180	5.38
200	20.53
300	13.32
600	2.53

Table 1: $H \rightarrow ZZ^{(*)} \rightarrow 4l$ NLO cross section at 14 TeV

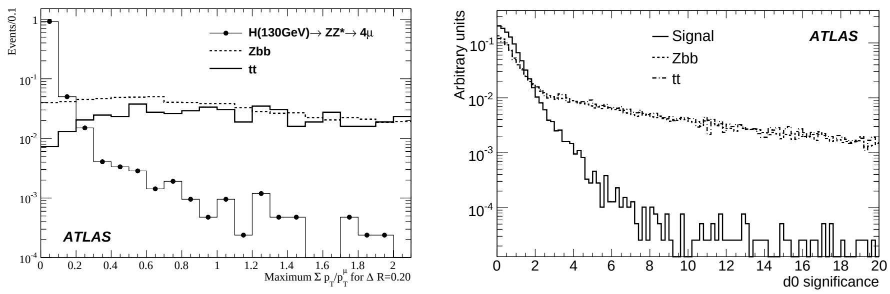

Figure 1: Left: Normalized track isolation $\sum p_T/p_T$ (in a cone of ΔR=0.2) for the signal, the $Zb\bar{b}$ and $t\bar{t}$ backgrounds for the 4μ channel. Right: Transverse impact parameter significance for muons from signal and reducible background events [3].

3 Signal Selection and Results

In order to select the $H \rightarrow ZZ^{(*)} \rightarrow 4l$ signal, a single lepton trigger requiring a muon ($p_T > 20$ GeV) or an isolated electron ($E_T > 22$ GeV) is used. Events are further selected offline requiring that they contain at least 4 leptons with $p_T > 7$ GeV and $|\eta| < 2.5$, with at least two having $p_T > 20$ GeV. To reconstruct the ZZ$^{(*)}$ coming from the Higgs boson decay, two leptons with the same flavour and opposite charge are coupled in pairs. Lepton quality cuts are also applied:

- Electrons: if $m_H > 200$ GeV/c^2 a *loose electron* criteria [3] were implemented (containment in the middle sampling of the ATLAS EM Calorimeter and hadronic leakage); if $m_H < 200$ GeV/c^2 they have to satisfy a *medium electron* quality criteria, which corre-

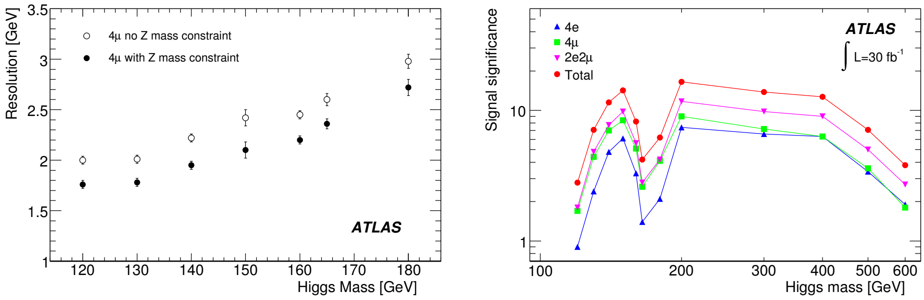

Figure 2: Left: $H \to 4\mu$ mass resolution as a function of the Higgs boson mass (open circles denote the resolution obtained without Z-mass constraint applied, while full circles show the resolution with the Z mass constraint). Right: Expected signal significances computed using Poisson statistics, for each of the three decay channels, and their combination.

sponds to *loose electron* requirements with additional lateral shower shape containment, and calorimetric isolation [3].

- Muons: are required to be either reconstructed by the *Combined* algorithm (Muon Spectrometer + Inner Detector (ID) track combination) or extrapolated from the ID.

To further filter the sample from the reducible backgrounds, isolation and vertexing cuts are applied (muon calorimetric isolation ($\sum E_T/p_T < 0.23$), lepton ID track isolation ($\sum p_T/p_T < 0.15$) and cuts on maximum lepton impact parameter $d_0/\sigma(d_0) < 3.5$ for muons and $d_0/\sigma(d_0) < 6.0$ for electrons). A Z mass constraint is applied to one or two ($m_H > 200$ GeV/c^2) lepton pairs to improve the resolution on the Higgs as shown in Fig. 2 (left). A set of kinematical cuts optimized using the expected signal and background distributions and the expected dilepton resolution is used for the Z invariant reconstructed mass. Events are finally selected within a $m_H \pm 2\sigma_{m_H}$ mass window where σ_{m_H} is the experimental 4-lepton mass resolution. The significance for the three different $H \to 4l$ decays, calculated using Poisson statistics, as a function of the Higgs boson mass is shown in Fig. 2 (right) where only statistical errors are taken into account while systematic errors on backgrounds are not included. For an integrated luminosity of 30 fb^{-1} at 14 TeV c.m. energy ATLAS will discover the SM Higgs in the $H \to ZZ^{(*)} \to 4l$ channel for Higgs masses between $130 - 500$ GeV/c^2 excepted the region around 160 GeV/c^2 where a 4σ significance is expected.

References

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