Draft version 0.0

ATLAS NOTE

March 30, 2012

Updated search for the Standard Model Higgs boson in the decay channel $H \to ZZ^{(*)} \to 4\ell$ with 4.8 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV

The ATLAS collaboration

Abstract

Contents

1 Introduction

2 Data and Simulation Samples

The data are subjected to quality requirements: events recorded during periods when the relevant detector components were not operating normally are rejected. The resulting integrated luminosity is 4.81 fb^{-1}, 4.81 fb^{-1} and 4.91 fb^{-1} for the 4μ, $2e2\mu$ and $4e$ final states, respectively.

The $H \to ZZ^{(*)} \to 4\ell$ signal is modelled using the POWHEG Monte Carlo (MC) event generator [?, ?], which calculates separately the gluon-gluon and vector-boson fusion production mechanisms with matrix elements up to next-to-leading order (NLO). The Higgs boson transverse momentum (p_{T}) spectrum in the gluon fusion process is reweighted to match the calculation of Ref. [?], which includes quantum chromodynamics (QCD) corrections up to NLO and QCD soft-gluon resummations up to next-to-next-to-leading logarithm (NNLL). POWHEG is interfaced to PYTHIA [?] for showering and hadronization, which in turn is interfaced to PHOTOS [?] for quantum electrodynamics (QED) radiative corrections in the final state and to TAUOLA [?, ?] for the simulation of τ lepton decays. PYTHIA is used to simulate the production of a Higgs boson in association with a W or a Z boson.

The Higgs boson production cross sections and decay branching ratios [?, ?, ?, ?], as well as their uncertainties, are taken from Refs. [?, ?]. The cross sections for the gluon fusion process have been calculated at next-to-leading order (NLO) in QCD [?, ?, ?], and then at next-to-next-to-leading order (NNLO) [?, ?, ?]. In addition, QCD soft-gluon resummations up to NNLL are applied for the gluon fusion process [?]. The NLO electroweak (EW) corrections are applied [?, ?]. These results are compiled in Refs. [?, ?, ?] assuming factorisation between QCD and EW corrections. The cross sections for the vector-boson fusion process are calculated with full NLO QCD and EW corrections [?, ?, ?], and approximate NNLO QCD corrections are available [?]. The associated productions with a W or Z boson are calculated at NLO [?] and at NNLO [?] in QCD, and NLO EW radiative corrections [?] are applied. The uncertainty in the production cross section due to the choice of QCD scale is $^{+12}_{-8}\%$ for the gluon fusion process, and $\pm 1\%$ for the vector-boson fusion, associated WH production, and associated ZH production processes [?]. The uncertainty in the production cross section due to the parton distribution function (PDF) and α_s is $\pm 8\%$ for gluon-initiated process and $\pm 4\%$ for quark-initiated processes [?, ?, ?, ?, ?]. The Higgs boson decay branching ratio to the four-lepton final state is predicted by PROPHECY4F [?, ?], which includes the complete NLO QCD+EW corrections, interference effects between identical final-state fermions, and leading two-loop heavy Higgs boson corrections to the four-fermion width. Table 1 gives the production cross sections and branching ratios for $H \to ZZ^{(*)} \to 4\ell$ for several Higgs boson masses.

The cross section calculations do not take into account the width of the Higgs boson, which is implemented through a relativistic Breit-Wigner line shape applied at the event-generator level. It has been suggested [?, ?, ?, ?] that effects related to off-shell Higgs boson production and interference with other SM processes may become sizeable for the highest masses ($m_H > 400$ GeV) considered in this search. In the absence of a full calculation, a conservative estimate of the possible size of such effects is included as a signal normalization systematic uncertainty following a parameterization as a function of m_H: $150\% \times m_H^3[\mathrm{TeV}]$, for $m_H \geq 300$ GeV [?].

The $ZZ^{(*)}$ continuum background is modelled using PYTHIA. The MCFM [?, ?] prediction, including both quark-antiquark annihilation and gluon fusion at QCD NLO, is used for the inclusive total cross section and the shape of the invariant mass of the $ZZ^{(*)}$ system ($m_{ZZ^{(*)}}$). The QCD scale uncertainty has a $\pm 5\%$ effect on the expected $ZZ^{(*)}$ background, and the effect due to the PDF and α_s uncertainties is $\pm 4\%$ ($\pm 8\%$) for quark-initiated (gluon-initiated) processes. An additional theoretical uncertainty of $\pm 10\%$ on the inclusive $ZZ^{(*)}$ cross section is conservatively included due to the missing higher-order QCD corrections for the gluon-initiated process, and a correlated uncertainty on the predicted $m_{ZZ^{(*)}}$ spectrum is estimated by varying the gluon-initiated contribution by 100% [?].

The $Z+$jets production is modelled using ALPGEN [?] and is divided into two sources: $Z+$light jets

Table 1: Higgs boson production cross sections for gluon fusion, vector-boson fusion and associated production with a W or Z boson in pp collisions at $\sqrt{s} = 7$ TeV [?]. The quoted uncertainties correspond to the total theoretical systematic uncertainty. The production cross section for associated production with a W or Z boson is negligibly small for $m_H > 300$ GeV. The decay branching ratio for $H \to 4\ell$, with $\ell = e$ or μ, is reported in the last column [?].

m_H [GeV]	$\sigma(gg \to H)$ [pb]	$\sigma(qq' \to Hqq')$ [pb]	$\sigma(q\bar{q} \to WH)$ [pb]	$\sigma(q\bar{q} \to ZH)$ [pb]	BR $\left(H \to ZZ^{(*)} \to 4\ell\right)$ [10^{-3}]
130	$14.1^{+2.7}_{-2.1}$	$1.154^{+0.032}_{-0.027}$	0.501 ± 0.020	0.278 ± 0.014	0.19
150	$10.5^{+2.0}_{-1.6}$	$0.962^{+0.028}_{-0.021}$	0.300 ± 0.012	0.171 ± 0.009	0.38
200	$5.2^{+0.9}_{-0.8}$	$0.637^{+0.022}_{-0.015}$	0.103 ± 0.005	0.061 ± 0.004	1.15
400	2.0 ± 0.3	$0.162^{+0.010}_{-0.005}$	–	–	1.21
600	0.33 ± 0.06	$0.058^{+0.005}_{-0.002}$	–	–	1.23

— which includes $Zc\bar{c}$ in the massless c-quark approximation and $Zb\bar{b}$ from parton showers — and $Zb\bar{b}$ using matrix element calculations that take into account the b-quark mass. The MLM [?] matching scheme is used to remove any double counting of identical jets produced via the matrix element calculation and the parton shower, but this scheme is not implemented for b-jets. Therefore, $b\bar{b}$ pairs with separation $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} > 0.4$ between the b-quarks are taken from the matrix-element calculation, whereas for $\Delta R < 0.4$ the parton-shower $b\bar{b}$ pairs are used. In this search the $Z+$jets background is normalized using control samples from data. For comparisons with simulation, the QCD NNLO FEWZ [?, ?] and MCFM cross section calculations are used for inclusive Z boson and $Zb\bar{b}$ production, respectively. The $t\bar{t}$ background is modelled using MC@NLO [?] and is normalized to the approximate NNLO cross section calculated using HATHOR [?]. The effect of the QCD scale uncertainty on the cross section is $^{+4}_{-9}\%$, while the effect of PDF and α_s uncertainties is $\pm 7\%$. Both ALPGEN and MC@NLO are interfaced to HERWIG [?] for parton shower hadronization and to JIMMY [?] for the underlying event simulation.

Generated events are fully simulated using the ATLAS detector simulation [?] within the GEANT4 framework [?]. Additional pp interactions in the same and nearby bunch crossings (pile-up) are included in the simulation. The MC samples are reweighted to reproduce the observed distribution of the mean number of interactions per bunch crossing in the data.

3 Lepton Reconstruction and Identification

4 Event Selection Optimization

The kinematic cuts applied at selection level have been otimized aiming at the maximal signal sensitivity. The focus has been on teh low mass region, between 120 and 130 GeV where the analysis is more challenging and the differences in kinematics between the signal and the reducible background are larger. The optimizatino procedure is based on a scan on the 6 main kinematic selectino parameters: M_{12} , M_{34}, and the transverse momenta of the four leading leptons. The position of the cut is chosen at the value that gives the maximum sensitivity at a given signal mass. The statistical variable used is the probability that the observed number of events, assumed to be equal to the sum of the expected background and signal events in a 6 GeV mass window around the signal mass, is as large or larger than the expected bacground, the expected P_0. This probability is computed on the basis of the signal and background events predicted by the MC assuming an integrated luminosity of 20 fb^{-1} at a centre-of-mass energy of 7 TeV. Two methods are used to compute the expected P_0: one is based on the χ^2 asymptotic approssimatin and the formula is described belwo1. In this case the probaility is expressed as the equivalent number of standard deviations for a Gaussian probability density function.

(1)

The second one is based on a simple Poisson marginal probability integral with a linear extrapolation between the two closest integers to the expected signal plus background number of events. Both approach give consistent results since the two probaility are a monotonic function one of the other.

The kinematic optimization was mainly based on teh 4 muon channels and the background estimates taken form the MC. Thsi is possible since the reducible background is negligible with respect to the irreducible one and therefore the optimizatin procedure is quite insensitive to its systematics. All kind of backgrounds described Section **??** are taken into account in this procedure and are taken form MC predictions. The optimal cuts have also been verified on teh 4 electron channels to be sure that the optimal point was not different for this final state where reducible background has an important role in the low mass region.In teh electron case teh reducible background has been estimated for data as described in Section **??**.

In this optimization procedure some constriants were applied to take into account trigegr limitations and the fact that some of the background samples are generated with kinematic cuts at geerator level so it does not make sense to explore kinematics too close to these cuts. The most sensitive variables for the optimization are found to be M_{12} and P_{t4}, the lowest transverse momentum of the quadruplet. Thsi is shown in figure **??** where the local expected P_0 is shown for the 4 muon channels as a function of M_{12} (left) and P_{t4} (right). The other variables showed a less strong dependency. In particular P_{t1} and P_{t3} have a quite flat behavior so we have decided to tighten the latter to 10 GeV with respect to teh 7 GeV of the previously pubished analysis. Also the cut on M_{34} variable has been tighten with respect to the published analisi with a small increase in the expected P_0. In general when a flat behavior on the expected $P_)$ was observed the choice has been to move the cut at the mor econservetive value with respect to teh redicible background contribution.

Contact : F. Cerutti

5 Event Selection

6 Trigger Considerations

Contact : S. Rosati

7 Data based study of the lepton selection criteria

Contact : A. Schaffer

7.1 Efficiency for signal-like leptons

7.1.1 $Z \to ee$

7.1.2 $Z \to \mu\mu$

7.2 Efficiency for background-like leptons

7.2.1 $Z + e$

7.2.2 $Z + \mu$

8 Background Estimation

Contact: C. Anastopoulos

8.1 Data driven cross-checks of the $t\bar{t}$ background

8.2 Estimate of the $Z + \mu\mu$ background

8.3 Estimate of the $Z + ee$ background

8.4 Data driven cross-checks of the QCD background

8.5 Background shapes

9 Results of Event Selection

10 Systematic Uncertainties

Contact : J. Hoffman

11 Exlusion limits and p-values

Contact : L. Flores

12 Conclusions

Appendices