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Standard Model Higgs boson production in the decay mode H$\rightarrow b\bar{b}$ in association with a W or Z boson for High Luminosity LHC Running

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A key outstanding observation is the decay of the Higgs boson to *b*-quarks, motivating a study into the prospects of this channel in future LHC runs. This proceeding summarises a simulated analysis of Standard Model H$\rightarrow b\bar{b}$ decay, produced where the Higgs boson is in association with a vector boson at the ATLAS detector for 14 TeV proton-proton collisions at the high-luminosity LHC. Efficiency and resolution smearing functions were applied to generator-level Monte Carlo samples to reproduce the expected performance of the upgraded ATLAS detector for the foreseen amount of pile-up due to multiple overlapping proton-proton collisions. The expected signal significance and signal strength is presented for an integrated luminosity of 300 fb^{-1} and 3000 fb^{-1} with an average number of pile-up collisions of 60 and 140 respectively.

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1. Introduction

The first operational period of the Large Hadron Collider (LHC), from 2010 - 2012, was very successful, including the discovery of a new particle with mass of about 125 GeV compatible, within uncertainties, with the Higgs boson predicted by the Standard Model (SM). Precise measurements of the properties of this boson, and the discovery of new physics beyond the Standard Model, are primary goals of the future LHC programme.

The High-Luminosity LHC (HL-LHC) is the planned upgrade of the LHC and has an aim to enable precise measurements of the Higgs boson properties. The electroweak symmetry breaking mechanism, as described by the SM, predicts in a well-defined way all related properties as a function of the gauge couplings, the vacuum expectation value and the Higgs mass. The Higgs boson discovery (and the subsequent determination of its mass) provided the measurement of the last of these free parameters, yielding concrete SM predictions for all the Higgs properties. However, the SM leaves many open questions such as the hierarchy problem and the nature of dark matter [**?**, **?**]. Many alternative theories addressing these issues predict that the SM Higgs couplings are modified or the existence of additional Higgs bosons [**?**]. The present LHC programme is expected to deliver a total integrated luminosity of about 300 fb^{-1} by the year 2022. The peak instantaneous luminosity will be in the range from 2 to 3 $\times$ 10^{34} cm^{-2}s^{-1}. This data is assumed to have an average number of pile-up interactions per bunch crossing, which is denoted here by μ_{PU}, of 50 - 60. The HL-LHC is scheduled to start in 2026, and will deliver a total luminosity of about 3000 fb^{-1}, at a peak luminosity of 5 $\times$ 10^{34} cm^{-2}s^{-1}, with a value of μ_{PU} = 140.

These LHC accelerator upgrades require major upgrades of the ATLAS [**?**] detector in order to maintain the current performance capabilities under new challenging operating conditions. The upgrade of the detector is absolutely central to the exploitation of the rich physics potential provided by the HL-LHC datasets.

2. HL-LHC H→ $b\bar{b}$ prospects

At the LHC, the largest Higgs boson production cross section is through gluon-gluon fusion (*ggF*). Other production mechanisms include, in descending size of cross section, vector boson fusion (VBF), associated production with a vector boson (WH, ZH), and associated production with a pair of top quarks ($t\bar{t}$H). The SM Higgs boson decays to a pair of bottom quarks with the largest branching ratio (58%). However, the search for H $\rightarrow b\bar{b}$ in the *ggF* production mode suffers from a huge background from direct *b*-quark production. For this reason, this analysis focuses on searches in the production modes associated with a vector boson (WH, ZH), where the Z and W boson decay leptonically (ZH $\rightarrow e^+e^-b\bar{b}$, $\mu^+\mu^-b\bar{b}$ and W$^{\pm}$H $\rightarrow e^{\pm}\nu_e b\bar{b}$, $\mu^{\pm}\nu_\mu b\bar{b}$) [**?**]. The channel Z $\rightarrow \nu\nu b\bar{b}$ was not considered due to the lack of studies on the feasibility of a low threshold missing transverse momentum ($E_{\text{T}}^{\text{miss}}$) trigger in the high pile-up environment. The results are quoted as relative uncertainties in the signal strength $\mu = \sigma_{\text{obs}}/\sigma_{\text{SM}}$, where σ_{obs} is the observed cross section and σ_{SM} is the SM cross section for a Higgs boson of $m_H = 125$ GeV. The results assume a SM Higgs, hence all the signal strengths are presumed to be $\mu = 1$. Current Run 1 analysis results on H $\rightarrow$ $b\bar{b}$ yield an observed (expected) signal significance of 1.4 σ (2.6 σ) and measured signal strength of μ = 0.5 $\pm$ 0.4 [**?**].

The HL-LHC prospects analysis uses particle-level simulation. The response of the upgraded ATLAS detector to the final state particles is parameterised and applied to the output of the Monte Carlo generators. The parameterised response of the detectors expected at HL-LHC conditions is obtained from studies of ATLAS full simulation events samples [**?**, **?**]. All requirements on the final state objects are applied on the parameterised properties. At high luminosity, the theory uncertainties start playing an important role in the total uncertainty. For that reason, the results are quoted for two scenarios: one in which all systematic uncertainties are considered, including the theory uncertainties, and another where the theory uncertainties are not included.

Optimal sensitivity is achieved by classifying events depending on the number of charged leptons, transverse momentum of the vector boson candidate and jet multiplicity. Events are required to have at least two jets with $|\eta| < 2.5$, with a minimum p_{T} requirement of 60 GeV on the leading (highest-p_{T}) jet and $p_{\mathrm{T}} > 40$ GeV on the sub-leading jet, plus requirements on the ΔR between the two jets. Both leading jets are required to be b-tagged. The four-momenta of the two leading jets are used to reconstruct the di-jet invariant mass. A maximum of one additional jet in the event with $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 2.5$ is allowed.

In the one-lepton channel events must be consistent with the presence of a $\mathrm{W} \to \ell\nu$ decay. The transverse mass, m_{T}^{W}, is defined from the transverse momenta and the azimuthal angles between the charged lepton (p_{T}^{ℓ} and ϕ^{ℓ}) and missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$ and ϕ^{miss}): $m_{\mathrm{T}}^{W} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos(\phi^{\ell} - \phi^{\mathrm{miss}}))}$. The event must contain one well-indented lepton and no additional leptons and pass requirements on $E_{\mathrm{T}}^{\mathrm{miss}}$ and the transverse mass, m_{T}^{W}. In the two-lepton channel events must be consistent with the presence of a $\mathrm{Z} \to \ell\ell$ decay: two loose leptons are required with an invariant mass consistent with a Z boson. More details on the object and event selections criteria can be found in reference [**?**].

Figure **??** shows the di-b-jet mass distributions for all the signal regions for $\sqrt{s} = 14$ TeV and an integrated luminosity of 300 fb^{-1} after applying the selection criteria. The expected significance and uncertainties on μ are shown in Table **??**: 4.1 σ sensitivity, with μ uncertainties of 26% (25%) with (without) theory systematic uncertainties, for the 300 fb^{-1} estimates; and similarly, 9.6 σ, and 13% (11%) for the 3000 fb^{-1} scenario.

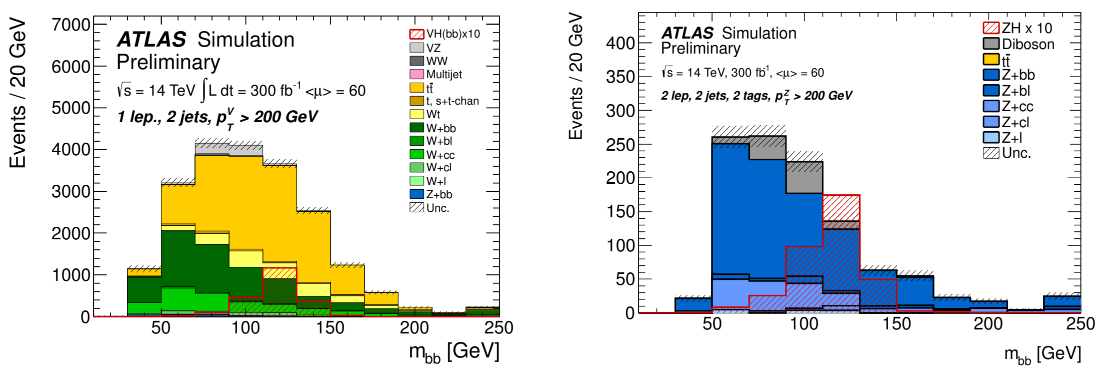

Figure 1: m_{bb} distribution for 1-lepton (left) and 2-lepton (right) final state signature for the 300 fb^{-1} estimate of signal and background in the most sensitive selection category: two jets in the final state and vector boson transverse momentum $p_{\mathrm{T}} > 200$ GeV. The dashed band corresponds to the statistical uncertainty [**?**].

300 fb^{-1}			
	One-lepton	**Two-lepton**	**One+Two-lepton**
Sensitivity	2.1 σ	3.5 σ	4.1 σ
μ w/theory	$\pm$0.48	$\pm$0.30	$\pm$0.26
μ wo/theory	$\pm$0.46	$\pm$0.29	$\pm$0.25
3000 fb^{-1}			
	One-lepton	**Two-lepton**	**One+Two-lepton**
Sensitivity	4.7 σ	8.4 σ	9.6 σ
μ w/theory	$\pm$0.23	$\pm$0.15	$\pm$0.13
μ wo/theory	$\pm$0.21	$\pm$0.14	$\pm$0.11

Table 1: Expected signal sensitivity (in number of σ) and precision on the signal strength measurement for $m_H = 125$ GeV for the one-lepton, two-lepton final state signatures and combined searches with 300 fb^{-1} and 3000 fb^{-1} integrated luminosity [**?**].

3. Summary

Detailed characterisation of the Higgs boson is essential to elucidate the nature of the electroweak symmetry breaking mechanism, and it may give insights as to where the next discoveries may occur. One of the most important components of this quest is the exploitation of the full potential of the upgraded LHC. The HL-LHC is going to be a Higgs factory, producing a total of 170 million Higgs bosons and 121 thousand HH events with accumulated dataset of 3000 fb^{-1} at $\sqrt{s} = 14$ TeV. This is an unique opportunity to study the SM Higgs rare decays and couplings, spin and parity properties, Higgs pair production, and to investigate if there are any hints of beyond SM in the Higgs sector.

A study of Higgs boson production in association with leptonically decaying W and Z bosons using parameterised functions to model the behaviour of the upgraded ATLAS detector has been performed. The expected significance to measure a SM Higgs boson of m_H = 125 GeV is 4.1σ and 9.6σ, at 300 fb^{-1} and 3000 fb^{-1} respectively. Similarly, the expected signal strength uncertainty is 26% for 300 fb^{-1} and 13% for 3000 fb^{-1}.

References

[1] M. Bustamante, L. Cieri, and J. Ellis, CERN-PH-TH-2009-225.

[2] R. Bousso, arXiv:1203.0307 [astro-ph].

[3] M. Dall'Osso et al., arXiv:1507.02245 [hep-ph].

[4] ATLAS Collaboration, 2008 JINST 3 S08003.

[5] ATLAS Collaboration, ATL-PHYS-PUB-2013-009.

[6] ATLAS Collaboration, ATL-PHYS-PUB-2013-004.

[7] ATLAS Collaboration, ATL-PHYS-PUB-2014-011.

[8] ATLAS Collaboration, JHEP **1501** (2015) 069, arXiv:1409.6212 [hep-ex].

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