Study of Higgs boson properties in H→ZZ(*)→4l decay channel with ATLAS

Motivation: In the past few years, the ATLAS and CMS Collaborations performed extensive studies of the Higgs-boson properties. The Higgs boson mass has ben measured to be m_H = 125.09 ± 0.24 GeV (Phys. Rev. Lett. **114** (2015) 191803) and no significant deviations from Standard Model (SM) predictions have been found in the cross sections measured per production mode, the branching ratios (JHEP **08** (2016) 045) or spin and parity quantum numbers (Phys. Lett. B **726** (2013) 120-144; Phys. Rev. Lett. C **114** (2015) 191803). The measurements of fiducial and differential cross sections of Higgs-boson production were also performed in proton-proton collisions at centre-of-mass energy of 8 TeV and found to be in agreement with respective SM predictions (Phys. Lett. **B738** (2014) 234-253, Eur. Phys. J. **C76** (2016) 13 and similar). Measurements of Higgs-boson cross sections at higher energies and with larger precision remain however major goals for LHC Collaborations in the years to come. Potential observation of deviations from SM predictions may open a new chapter in the modern High Energy Physics.

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Event selection and fiducial phase space

Presented results are based on 36.1 fb^{-1} proton-proton collision data sample collected at centre-of-mass energy of 13 TeV by the ATLAS experiment at the LHC. The combined effect of a higher centre-of-mass energy and larger luminosity increase the number of observed Higgs events by almost a factor of four compared to the previous analysis at centre-of-mass energy of 8 TeV. The differential cross sections are measured in a fiducial phase-space to avoid model-dependent extrapolations. The observed distributions are corrected for detector inefficiency and resolution.

Leptons and jets	
Muons:	$p_T > 5$ GeV, $\|\eta\| < 2.7$
Electrons:	$p_T > 7$ GeV, $\|\eta\| < 2.47$
Jets:	$p_T > 30$ GeV, $\|y\| < 4.4$
Jet-lepton overlap removal:	$\Delta R(\text{jet}, \ell) > 0.1\,(0.2)$ for muons (electrons)
Lepton selection and pairing	
Lepton kinematics:	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12}):	SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Subleading pair (m_{34}):	remaining SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection (at most one quadruplet per channel)	
Mass requirements:	$50 < m_{12} < 106$ GeV and $12 < m_{34} < 115$ GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1\,(0.2)$ for same- (different-) flavour leptons
J/ψ veto:	$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
Mass window:	115 $GeV < m_{4\ell} <$ 130 GeV

Measurement method

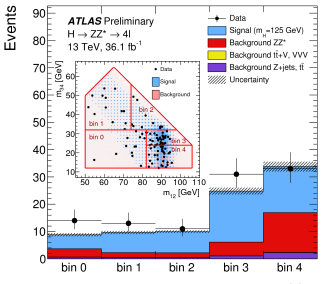
Background estimates and measure event yields

Largest contribution: non-resonant ZZ* production via qq and gg fusion. Monte Carlo estimates cross-checked against sidebands of the m_{4l} distribution.

Z+jets, $t\bar{t}$ and WZ where at least one object misidentified as prompt lepton.

llμμ: normalizations for Z+jets and tt backgrounds are determined using fits to the invariant mass of the leading lepton pair in dedicated control regions (CR). CR: relaxing vertex fit quality, lepton isolation and impact parameters requirements.
llee: CR with same charge sub-leading electron pair with relaxed ID and isolation requirements on the electron with lowest transverse energy.

The total observed and predicted event counts agree within 1.3 standard deviations.

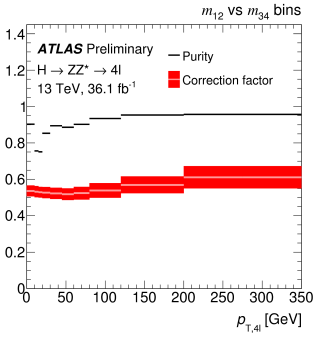


m_{12} vs m_{34} bins

Signal extraction

$$\sigma_{i,\text{fid}} = \sigma_i \times A_i \times \text{BR} = \frac{N_{i,\text{fit}}}{\mathcal{L} \times C_i}, \quad C_i = \frac{N_{i,\text{reco}}}{N_{i,\text{part}}}$$

where A_i is the acceptance in the fiducial volume, BR is the branching fraction and σ_i is the total cross section in bin i. $N_{i,\text{fit}}$ is the number of extracted signal events in data. C_i is the bin-by-bin correction factor for events in the fiducial volume to be reconstructed and selected.



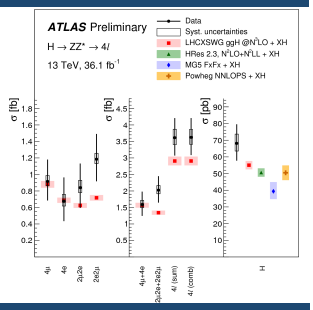
Systematic uncertainties

The overall analysis uncertainties are dominated by the limited data statistics. The statistical uncertainty on the inclusive fiducial cross section after combining all channels is about 15%. The systematic uncertainty is dominated by lepton and luminosity uncertainties and raises to 7%.
For the differential cross sections, the size of systematic uncertainties depend on the observable and of particular bin, dominated by lepton and jet-related uncertainties, luminosity and ZZ background theory uncertainties. The statistical uncertainties are mostly in range of 20-50%.

Inclusive fiducial cross sections

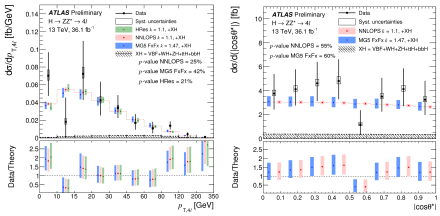
Overall the observed total cross section agrees well (level of 1.5 standard deviations) with gluon-Fusion N3LO prediction for the SM. Main deviations come from 2e2μ and 2μ2e final states.

All Monte Carlo generators predict the total cross sections which are lower than the N3LO calculation. In particular, the MG5_aMC@NLO_FxFx is lower than other predictions as its accuracy in the 0-jet bin is only NLO in QCD.

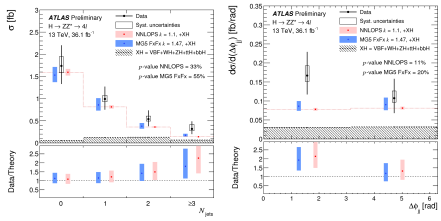


Differential fiducial cross sections

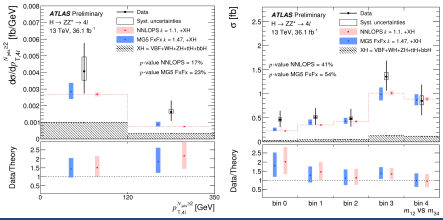
All ggF MC samples normalized to N3LO cross sections. Shaded bands: PDF and scale uncertainties of individual samples. Good agreement with predictions; consistency with SM Higgs spin and parity.



Jet-related observables. The agreement is satisfactory, but worsens at higher jet multiplicities. Consistent with precedent observations by ATLAS at centre-of-mass energy of 8 TeV.

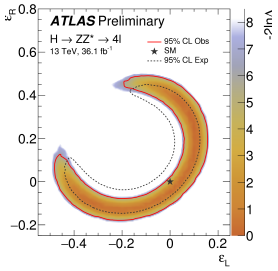


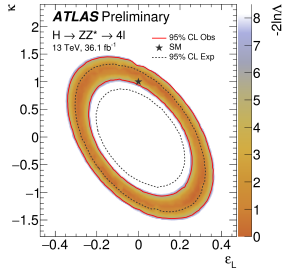
Probing the perturbative QCD calculations for different production modes by measuring the $p_{T,4l}$ in bins of jet multiplicity. Overall good agreement with predictions. Higher cross section in two-jet category reflects the corresponding n_{jet} observation.



BSM interpretations

Limits on modified Higgs decays within the framework of pseudo-observables (Eur. Phys. J. **C75** (2015) 128). $\varepsilon_{Z(\text{left})}$ and $\varepsilon_{Z(\text{right})}$ modify the terms responsible for contact interactions between Higgs and left- and right-handed leptons respectively, assuming lepton-flavor universality. k_{HZZ} modifies the Higgs coupling to Z bosons. Based on m_{12} vs m_{34} double differential cross section measurement.





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