Constraints on Off-shell Higgs Boson Production and the Higgs Boson Total Width in ZZ Final states with the ATLAS Detector

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Abstract

The off-shell production of SM Higgs boson, at the high-mass off-peak region beyond $2m_Z$, well above the measured resonance mass of m_H=125 GeV, has a substantial cross section at the LHC, due to the increased phase space as the Z bosons become on-shell with the increasing energy scale. This presents a novel way of characterizing the properties of the Higgs boson in terms of the off-shell event yields, normalized to the SM prediction (referred to as signal strength μ), and the associated off-shell Higgs boson couplings. Assuming the ratio of the Higgs boson couplings to the SM predictions is independent of the momentum transfer of the Higgs boson production mechanism, a combination with the on-shell signal-strength measurement was used to set indirect limits on the total Higgs boson width with the 36 fb^{-1} ATLAS Run-2 data collected in proton-proton collisions at the centre-of-mass energy of $\sqrt{s}$ = 13 TeV.

Introduction & Motivation

- Main Purpose is to study the off-shell Higgs boson production in ZZ events above the m_H peak (~15% of the overall ggF cross-section)
  - Further characterize the Higgs boson properties:
    - measure the off-shell signal strength
    - probe new physics which can play a role in modifying the couplings structure
  - The SM Higgs total width, $\Gamma_H \sim 4$ MeV, is not directly measurable at the LHC due to experimental limits
    - indirectly constrain the Higgs total width, assuming identical on-shell and off-shell couplings

Analysis Overview

- The study is based on two independent analyses ($ZZ \to 4\ell, ZZ \to 2\ell 2\nu$) that are combined to derive the final constraints
- The event selections are performed inclusively in the number of jets to reduce QCD-corrections dependence
- Use data collected by the ATLAS experiment in 2015 and 2016 at an integrated luminosity of 36.1 fb^{-1}
- On-shell region is defined between 118-129 GeV, while the off-shell is defined between 220-2000 GeV ($ZZ \to 4\ell$) and 250-2000 GeV ($ZZ \to 2\ell 2\nu$)

Analysis Strategy

Two-steps strategy:

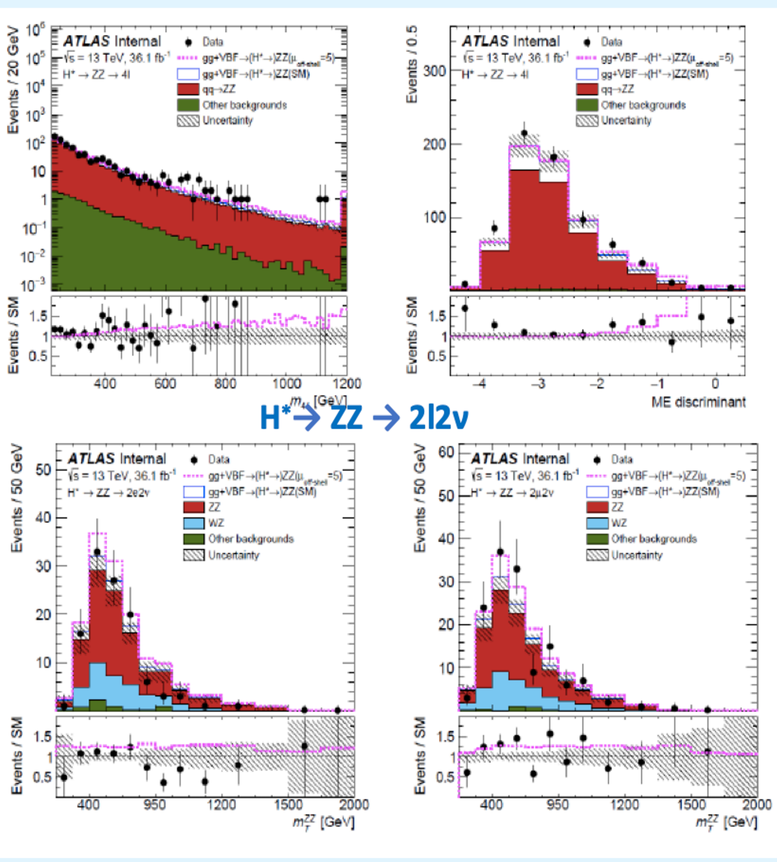
1. Off-shell signal strength measurement
   - Interpetation of off-shell when fixing the ratio of the signal strength in ggF and VBF to the SM prediction
2. Higgs total width measurenent
   - Interpretation of the Higgs total width when assuming the same on-shell and off-shell couplings $\frac{\mu_{off-shell}}{\mu_{on-shell}} = \frac{\Gamma_H}{\Gamma_H^{SM}}$

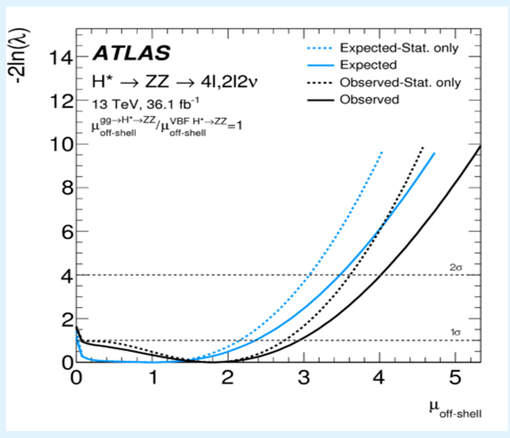
References:
1. Phys. Lett. B 786 (2018) 223
2. Eur. Phys. J. C (2015) 75:335

Analysis Results

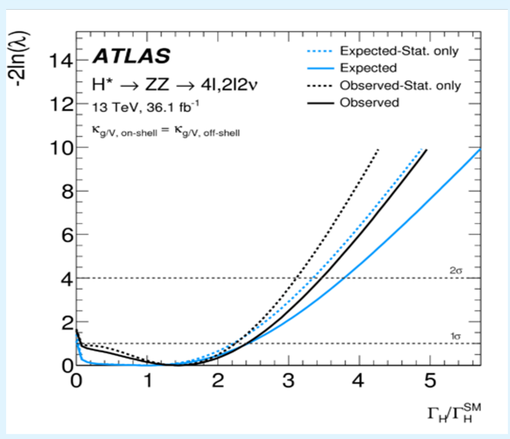
- For the $ZZ \to 4\ell$ channel, the shape fits to a Matrix Element -based kinematic discriminant, while the $ZZ \to 2\ell 2\nu$ fits to the transverse mass ZZ distribution
- Main backgrounds: $qq \to ZZ$, $gg \to ZZ$
- Interference (negative) between signal and $gg \to ZZ$ continuum is considered
- The experimental systematics are almost negligible. The dominant systematic is the theory uncertainty on the high-order QCD corrections for ZZ background and signal

$H^* \to ZZ \to 4l$





$H^* \to ZZ \to 2l2\nu$



Conclusions

- Measurement of off-shell Higgs boson production in $ZZ \to 4\ell$ and $ZZ \to 2\ell 2\nu$ (ℓ = e or μ)
- Using LHC ATLAS Run-2 36.1 fb^{-1} data at $\sqrt{s}$=13 TeV
- Observed (expected) upper limit at 95% CL on **off-shell Higgs signal strength** of 3.8 (3.4)
  - Off-shell Higgs signal strength: event yield normalized to SM prediction
- Combination with the on-shell signal-strength measurements yields observed (expected) 95% CL upper limit on **Higgs boson total width** of 14.4 (15.2) MeV
  - Assuming ratio of Higgs boson couplings to SM predictions independent of momentum transfer of Higgs production mechanism

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