Measurement prospects for di-Higgs production in the $HH \to b\bar{b}\gamma\gamma$ decay channel with the ATLAS experiment

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On behalf of the ATLAS collaboration, LHCP2022

1. Introduction

- The nature of the Higgs boson self-coupling can be effectively probed through di-Higgs (HH) production at the LHC.
- In the SM at $\sqrt{s} = 13$ TeV, non-resonant HH production is extremely rare and proceeds mainly through gluon-fusion ($\sigma_{\text{ggF}} = 31$ fb) and vector-boson fusion ($\sigma_{\text{VBF}} = 1.7$ fb).

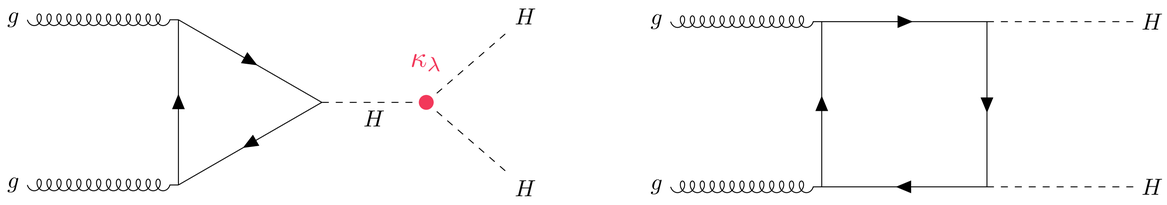

Figure 1: Leading order diagrams for HH ggF production.

- BSM modifications to the self-coupling modifier $\kappa_\lambda = \lambda_{HHH}/\lambda^{SM}_{HHH}$ can result in much higher cross-sections.

2. Run 2 $b\bar{b}\gamma\gamma$ Analysis Strategy

- ATLAS searched for HH production in the $b\bar{b}\gamma\gamma$ decay channel using Run 2 data (139 fb^{-1} at $\sqrt{s} = 13$ TeV).
- This channel combines the large $H \to bb$ branching ratio (58%) with the excellent ATLAS photon resolution (~ 1.5 GeV $m_{\gamma\gamma}$ signal width for $H \to \gamma\gamma$).
- No significant excess was observed (arXiv:2112.11876).

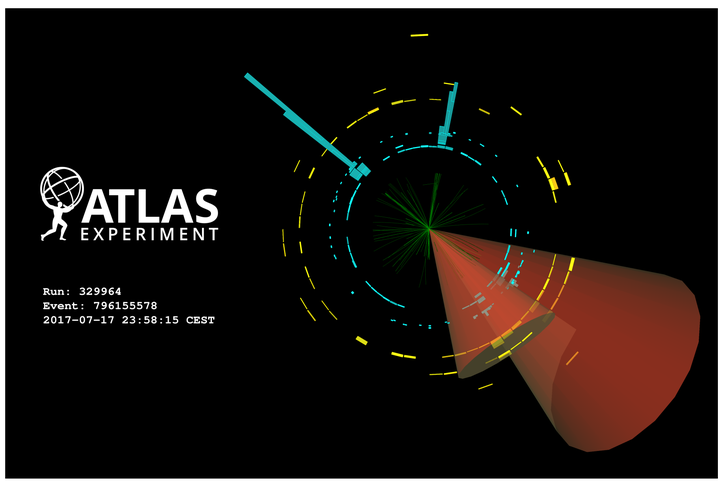

Figure 2: A candidate $HH \to b\bar{b}\gamma\gamma$ event in Run 2 data, showing two b-jets (red cones) and two photons (cyan towers).

- The potential of the $HH \to b\bar{b}\gamma\gamma$ channel with the future High Luminosity LHC (HL-LHC) dataset is explored by directly extrapolating the performance of the Run 2 analysis.
- Events with two photons and two b-jets are categorized based on boosted decision tree outputs and the modified 4-body mass $m^*_{b\bar{b}\gamma\gamma} = m_{b\bar{b}\gamma\gamma} - (m_{b\bar{b}} - 125\text{ GeV}) - (m_{\gamma\gamma} - 125\text{ GeV})$.
- The expected HH signal is obtained from a fit to $m_{\gamma\gamma}$.

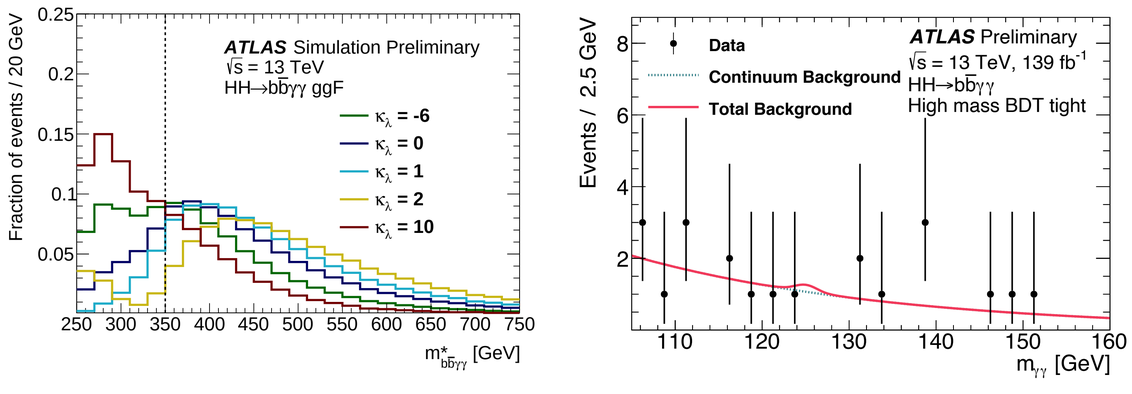

Figure 3: The $m^*_{b\bar{b}\gamma\gamma}$ distribution for various HH signals (left) and the observed $m_{\gamma\gamma}$ dataset in one of the Run 2 categories (right).

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3. HL-LHC $b\bar{b}\gamma\gamma$ Projection

- The Run 2 analysis inputs are modified for the conditions at the HL-LHC while keeping the same analysis strategy.
- Run 2 signal and background yields are scaled to account for increases in luminosity (from 139 fb^{-1} to 3000 fb^{-1}) and energy (from $\sqrt{s} = 13$ TeV to $\sqrt{s} = 14$ TeV).
- The efficiency of the detector is assumed to remain the same as for Run 2.

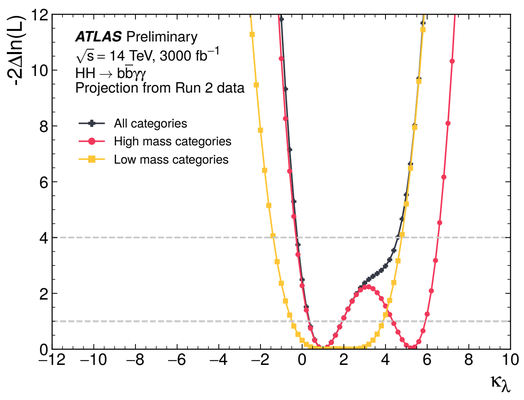
Category	High Mass BDT Tight	High Mass BDT Loose	Low Mass BDT Tight	Low Mass BDT Loose
HH signal	22	9.0	1.2	1.8
Single H background	17	40	5.8	35
Continuum background	120	240	95	630

Table 1: The projected number of events with the full HL-LHC dataset.

- Systematic uncertainties are reduced from Run 2 values assuming improved theory calculations or better constraints on experimental uncertainties.
- Dominant systematic uncertainties include background modelling, heavy flavour production in association with single Higgs, and photon energy resolution.

4. HL-LHC $b\bar{b}\gamma\gamma$ Projection Results

- Using only the $b\bar{b}\gamma\gamma$ channel, the projected significance for the SM HH signal is $\mathbf{2.2\sigma}$, with a precision of $\mathbf{50\%}$ on the signal strength measurement.
- The projected measurement of the Higgs boson self-coupling modifier is $\boldsymbol{\kappa_\lambda = 1.0^{+0.9}_{-0.7}}$



- High mass ($m^*_{b\bar{b}\gamma\gamma}$) categories provide most of the sensitivity near $\boldsymbol{\kappa_\lambda = 1}$ while low mass categories help reject higher values of $\boldsymbol{\kappa_\lambda}$.

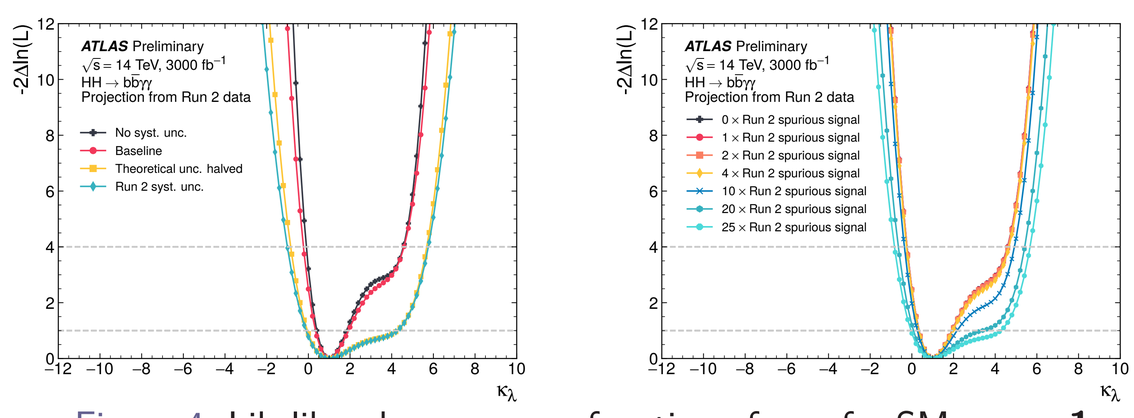


Figure 4: Likelihood curves as a function of $\boldsymbol{\kappa_\lambda}$, for SM $\boldsymbol{\kappa_\lambda = 1}$.

- Also shown are alternative scenarios in which uncertainties are not reduced for the HL-LHC. The degradation in sensitivity is primarily due to the pessimistic assumption on the background modelling uncertainty (spurious signal).
- Full details: ATL-PHYS-PUB-2022-001.