Search for Higgs boson pair production in $\gamma\gamma$bb final state in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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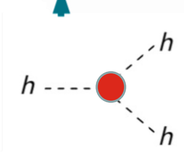
Motivation

- Since the discovery of **the Higgs boson** in 2012, one of the goals of the Large Hadron Collider has been to measure **the shape of the Higgs potential $V(\phi)$.**
- We can probe the Higgs potential by measuring the **Higgs self-coupling (λ).**
- We could directly probe the **trilinear Higgs self-coupling (λ_{HHH})** by studying **di-Higgs (HH) production.**

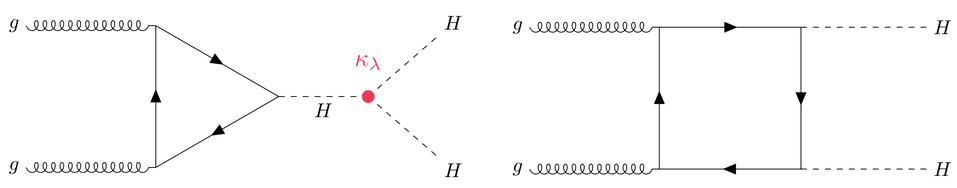
$$V(\phi) = \mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$$
$$= V_0 + \lambda v^2 h^2 + \lambda v h^3 + \tfrac{1}{4}\lambda h^4$$

$$\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda^{SM}_{HHH}}$$

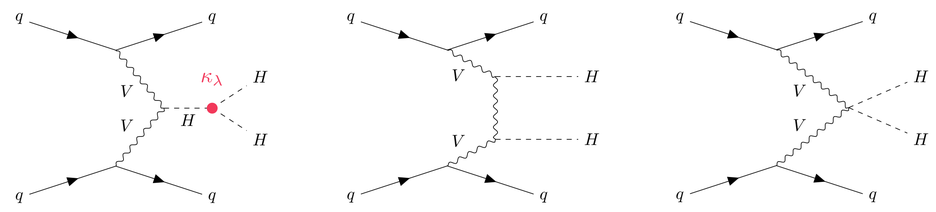


HH production

Gluon-gluon fusion (ggFHH) σNNLO = **31.02** [fb] @13 TeV, mH = 125.09 GeV



Vector boson fusion (VBFHH) σN3LO = **1.723** [fb] @13 TeV, mH = 125.09 GeV



Any deviation of the **low HH production rate** from the Standard Model prediction would point to new physics **beyond the Standard Model (BSM).**

HH→ $\gamma\gamma bb$ analysis overview

Very **rare** but **clean** channel

- $H \to bb$: large branching ratio
- $H \to \gamma\gamma$: excellent photon resolution

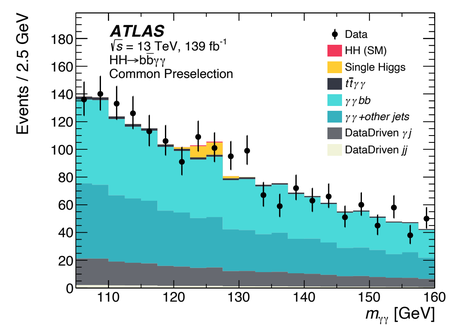
✓ Main backgrounds

- Non-resonant $\gamma\gamma$ backgrounds
- Single Higgs production

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

✓ Common Preselection

- 2 identified and isolated photons
- 2 b-tagged jets (77% b-tagging efficiency)
- < 6 central jets (reject $t\bar{t}H$ events)
- Veto events containing an electron or muon



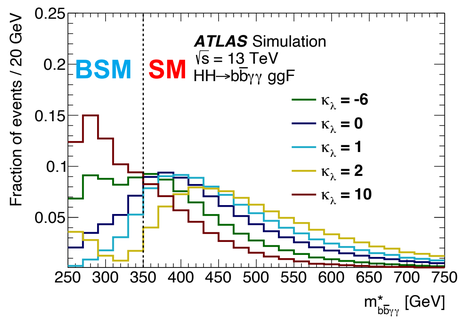
Event categorization

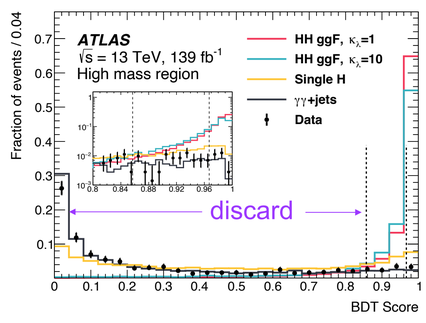
✓ Events are first divided into signal mass regions using the **modified 4-body mass**: $m^*_{\gamma\gamma bb} = m_{\gamma\gamma bb} - m_{\gamma\gamma} - m_{bb} + 250\ GeV$;

✓ Then in each mass region, **boosted decision trees (BDTs)** are trained against the $\gamma\gamma$ and single Higgs backgrounds.

Non-resonant search: target SM HH → $\gamma\gamma bb$, and possible modifications to κ_λ

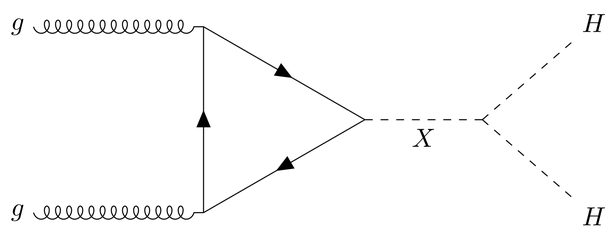
- Two mass regions cut at 350 GeV targeting different κ_λ values
- Two signal-enriched BDT categories in each mass region



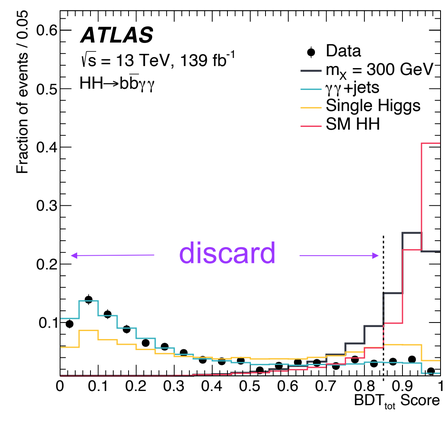


Resonant search: target $X \to$ HH → $\gamma\gamma bb$, with $m_X \in [251, 1000]$ GeV

- 2σ window cut around each m_X value
- One BDT category for each m_X region



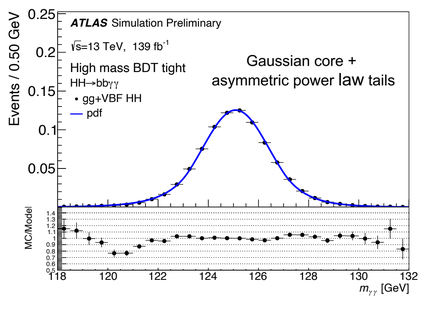
X is a narrow-width scalar particle

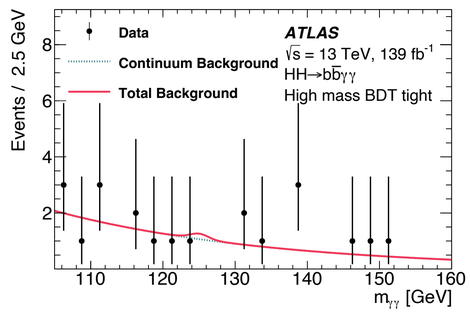


Signal extraction

The HH signals are obtained from a **maximum-likelihood fit** to the diphoton mass spectrun $m_{\gamma\gamma}$ across all categories.

- **Signal model:** Double sided crystal ball (DSCB) function
- **Background model:** Exponential function





No significant excess is observed and upper limits are set at 95% CL.

Results

Non-resonant search

The observed (expected) limit on the **HH signal strength:** 4.2 (5.7) times SM prediction

✓ Improved by a factor of 5 w.r.t 36 fb^{-1} ATLAS publication

The observed (expected) **constraint on κ_λ**: $-1.5 < \kappa_\lambda < 6.7$ ($-2.4 < \kappa_\lambda < 7.7$)

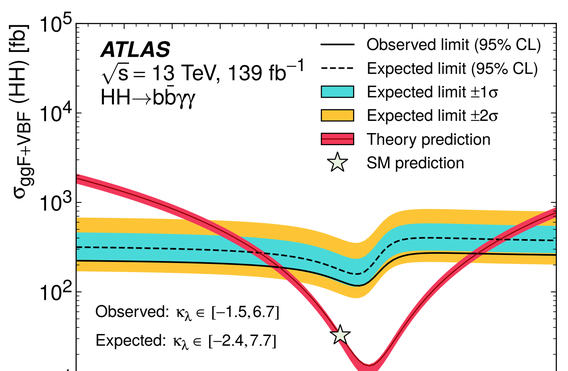
✓ Shrinks by a factor of ~2 w.r.t 36 fb^{-1} ATLAS publication

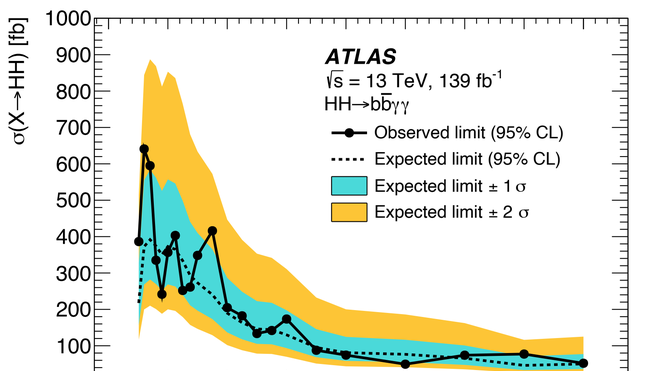
Resonant search

The observed (expected) limit on $\sigma(X \to HH)$ vary between 610 fb and 47 fb (360 fb and 43 fb)

✓ Improved by a factor of 2-3 depending on the m_X value w.r.t 36 fb^{-1} ATLAS publication

✓ The analyzed mass range expanded to lower values





Reference

arXiv:2112.11876 (this poster)

JHEP 11 (2018) 040 (ATLAS 36 fb^{-1})

JHEP 03 (2021) 257 (CMS)

Enlightening the beauty of the Higgs