Searches for non-resonant Higgs boson pair production at $\sqrt{s} = 13$ TeV with ATLAS detector at the LHC

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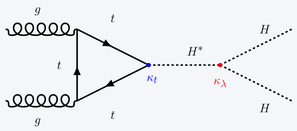
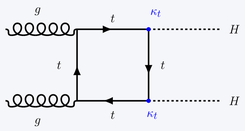
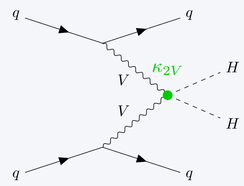
Motivation

- Standard Model (SM) predicts Higgs boson (trilinear) self-coupling (λ_{HHH}).
- λ_{HHH} is crucial ingredient in validating the Brout-Englert-Higgs (BEH) mechanism as well as in understanding the shape of Higgs potential.
- Deviation of λ_{HHH} from SM predicted value is an indication of new physics, which is measured by self-coupling modifier $\kappa_\lambda = \lambda_{HHH}/\lambda^{\text{SM}}_{HHH}$.
- A direct way of measuring λ_{HHH} is via observation of non-resonant Higgs boson pair (HH) production. It can also be used to measure κ_{2V} which is $VVHH$ coupling modifier.







	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

- At $\sqrt{s} = 13$ TeV, the HH production cross-section (σ_{HH}) is ≈ 33 fb (gluon-gluon fusion, ggF, mode + vector boson fusion, VBF, mode).
- Many Beyond-the-Standard-Model theories predict an enhancement in σ_{HH}.

HH Searches

- HH searches in several channels including $b\bar{b}\tau^+\tau^-$, $b\bar{b}\gamma\gamma$, and $bb\ell\ell$.
- ggF and VBF are used as signal, either in dedicated SRs or as a combined signal.
- Channels use at least one $H \to b\bar{b}$ decay in order to maximize branching ratio.
- The channels share common object definitions to ensure orthogonality so that they can be combined to maximize sensitivity.
- Limits are set on σ_{HH}, as well as on κ_λ and κ_{2V}.

Partial Run 2 Results[1]

- Integrated luminosity, $\mathcal{L} = 27.5 - 36.1$ fb^{-1}.
- Combined observed (expected) limit on σ_{HH} from $b\bar{b}\tau^+\tau^-$, $b\bar{b}b\bar{b}$, $b\bar{b}\gamma\gamma$, $W^+W^-W^+W^-$, $W^+W^-\gamma\gamma$, & $b\bar{b}W^+W^-$ searches at 95% CL:

$$\sigma_{\text{ggF}}(\text{HH}) < 6.9\ (10) \times \sigma^{\text{SM}}_{\text{ggF}}(\text{HH})$$

- Combined observed (expected) constraint on κ_λ from $b\bar{b}\tau^+\tau^-$, $b\bar{b}b\bar{b}$, & $b\bar{b}\gamma\gamma$ searches at 95 % CL:

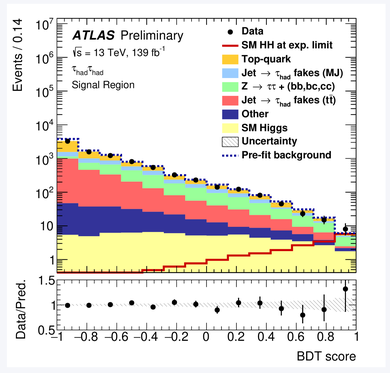
$$-5.0\ (-5.8) < \kappa_\lambda < 12.0\ (12.0)$$

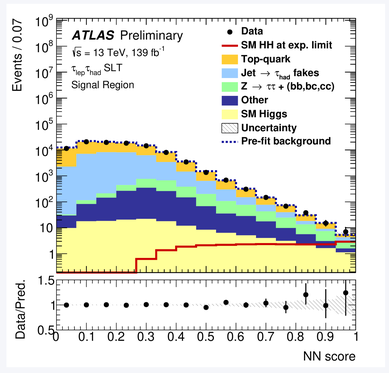
Full Run 2 Results

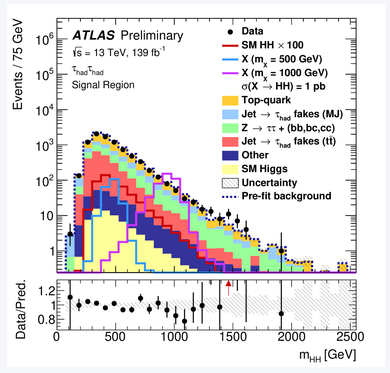
- Both ggF and VBF production modes are considered for $b\bar{b}\tau^+\tau^-$ and $b\bar{b}\gamma\gamma$ analyses, and integrated luminosity is $\mathcal{L} = 139$ fb^{-1}.

$HH \to b\bar{b}\tau^+\tau^-$ Analysis[2]

- Targets $b\bar{b}\tau_{lep}\tau_{had}$ and $b\bar{b}\tau_{had}\tau_{had}$ final states.
- Events selected by single lepton (SLT), lepton plus tau (LTT), single tau (STT), and di-tau (DTT) triggers.
- Uses BDT and NNs to separate signal from background.







Observed (expected) limits @ 95% CL:
$\sigma_{\text{ggF+VBF}}(\text{HH}) < 4.7\ (3.9) \times \sigma^{SM}_{\text{ggF+VBF}}(\text{HH})$

Improvement by a factor of 2 of expected limits, over the partial dataset results, due to analysis optimization

$HH \to b\bar{b}\ell\nu\ell\nu$ Analysis[4]

- $\mathcal{L} = 139$ fb^{-1} analysis puts an observed (expected) limit on σ_{HH} at 95% CL of:

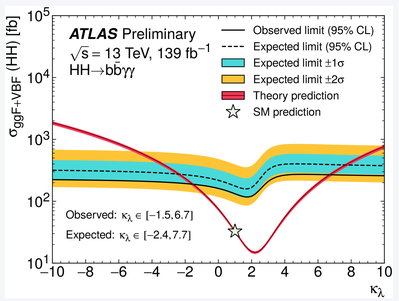
$$\sigma_{\text{ggF}}(\text{HH}) < 40\ (29) \times \sigma^{\text{SM}}_{\text{ggF}}(\text{HH})$$

$HH \to b\bar{b}\gamma\gamma$ Analysis[3]

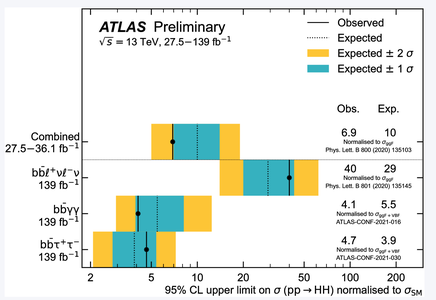
- Events selected using di-photon triggers.
- Events are separated into high mass and low mass regions using $m^{\star}_{b\bar{b}\gamma\gamma} = m_{b\bar{b}\gamma\gamma} - m_{b\bar{b}} - m_{\gamma\gamma} + 250$GeV.
- In each mass region, BDT is trained to discriminate between signal and background, and the BDT score is used to divide it into two categories.
- κ_λ scan is also performed in addition to setting limit on σ_{HH}.

Observed (expected) limits @ 95% CL :
$\sigma_{\text{ggF+VBF}}(\text{HH}) < 4.1\ (5.5) \times \sigma^{\text{SM}}_{\text{ggF+VBF}}(\text{HH})$;
$-1.5\ (-2.4) < \kappa_\lambda < 6.7\ (7.7)$

Improvement by about a factor of 2 of expected limits, over the partial dataset results, due to analysis optimization



(a) Limits at 95% CL on σ_{HH} (non-resonant) as a function of κ_λ in $b\bar{b}\gamma\gamma$ channel



(b) Upper limits at 95% CL on $\sigma_H H$ normalized to its SM expectation from $b\bar{b}\tau^+\tau^-$, $b\bar{b}\gamma\gamma$, & $b\bar{b}\ell\nu\ell\nu$ searches at $\mathcal{L} = 139$ fb^{-1}.

$HH \to b\bar{b}b\bar{b}$ VBF Analysis[5]

- It can be sensitive to κ_{2V}. Observed (expected) limits of $\mathcal{L} = 126$ fb^{-1} analysis at 95% CL are:

$$-0.43\ (-0.55) < \kappa_{2V} < 2.56\ (2.72)$$

References

[1] ATLAS Collaboration, Combination of searches for Higgs boson pairs in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Physics Letters B 800 (2020) 135103, arXiv:1906.02025 [hep-ex].

[2] ATLAS Collaboration, Search for resonant and non-resonant Higgs boson pair production in the $b\bar{b}\tau^+\tau^-$ decay channel using 13 TeV pp collision data from the ATLAS detector, ATLAS-CONF-2021-030, 2021.

[3] ATLAS Collaboration, Search for Higgs boson pair production in the two bottom quarks plus two photons final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, ATLAS-CONF-2021-016, 2021.

[4] ATLAS Collaboration, Searches for non-resonant Higgs boson pair production in the $bb\ell\nu\ell\nu$ final state with the ATLAS detector in pp collisions at $\sqrt{s} = 13$ TeV, Physics Letter B 801 (2020) 135145, arXiv: 1908.06765 [hep-ex].

[5] ATLAS Collaboration, Search for the $HH \to b\bar{b}b\bar{b}$ process via vector-boson fusion production using proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, JHEP 07 (2020) 108, arxiv:2001.05178[hep-ex].