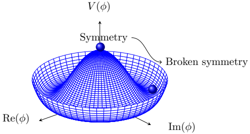
Institut für Physik, Humboldt-Universität zu Berlin

Probing the nature of electroweak symmetry breaking with Higgs boson pairs in ATLAS

XII International Conference on New Frontiers in Physics
OAC conference center, Kolymbari, Crete, Greece
July 10-23, 2023

Daariimaa Battulga on behalf of the ATLAS Collaboration

Motivation
Why is it important to measure Higgs self-coupling?

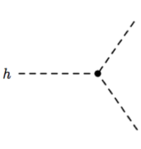


Higgs potential field: $V(\phi) = \mu^2(\phi^\dagger\phi) + \lambda(\phi^\dagger\phi)^2$

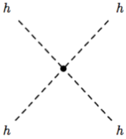
- Spontaneous symmetry breaking when VEV: $\upsilon \neq 0$
- $\lambda > 0,\ \mu^2 < 0$ minimum at $\upsilon = \sqrt{-\frac{\mu^2}{2\lambda}} = 246\,\text{GeV}$

Rewriting the $\phi(x)$ as a function of the mass scalar Higgs field:

$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda\upsilon H^3 + \frac{\lambda}{4}H^4 - \frac{\lambda}{4}\upsilon^4, \qquad \lambda_{SM} = \frac{m_H^2}{2\upsilon^2} \simeq 0.129$$



$$= -i\lambda v \cdot 3! = -6i\lambda v = -3i\frac{m_h^2}{v}$$



$$= -i\frac{\lambda}{4} \cdot 4! = -6i\lambda = -3i\frac{m_h^2}{v^2}$$

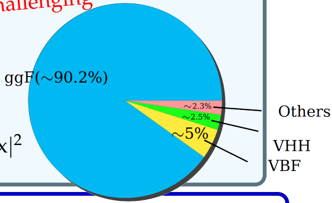
What could we tell about the shape of the Higgs potential?

- Higgs boson couplings to SM particles are known $\Rightarrow$ but not Higgs self coupling, λ_{HHH}
- Its form determines minimum, electroweak phase transition, and stability of the universe

Direct measurement

k-framework: $\kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{HHH}^{SM}}$

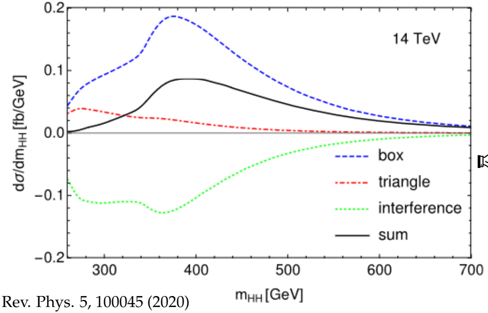
- Higgs-pair production to probe the λ_{HHH}
- Very rare process, $\sigma_{HH} \simeq \frac{1}{1000}\sigma_H$ $\Rightarrow$ Experimentally challenging
- Dominant production mode: $\sigma_{ggF}^{SM} \simeq 31$ fb



✎ $\sigma_{HH}^{SM} \simeq |\text{triangle}|^2 + Re\{\text{box} \times \text{triangle}^* + h.c.\} + |\text{box}|^2$

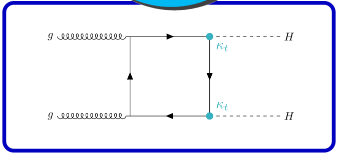
destructive!

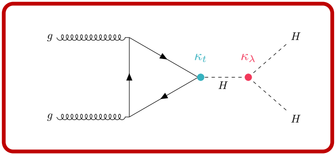
interference



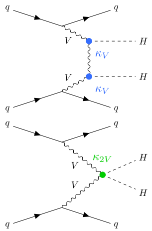
Rev. Phys. 5, 100045 (2020)

☞ggF



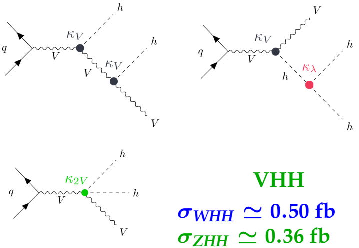


Higgs self-coupling measurement at LHC



VBF

$\sigma_{HH} \simeq$ **1.73 fb**



VHH

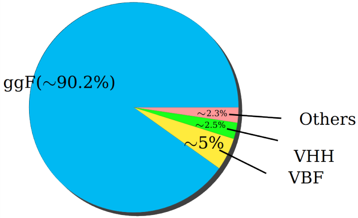
$\sigma_{WHH} \simeq$ **0.50 fb**

$\sigma_{ZHH} \simeq$ **0.36 fb**

Direct measurement

- Higgs-pair production to probe the λ_{HHH} via κ_λ, κ_V, κ_{2V}
- κ_{2V} could indirectly probe quartic Higgs coupling

☞ **Otherwise not sensitive at the LHC!**



Higgs self-coupling measurement in ATLAS

λ_{HHH} measurement in ATLAS:

- Di-Higgs to $b\bar{b}b\bar{b}$, $bb\bar{\tau}\tau$, $b\bar{b}\gamma\gamma$ via ggF and VBF with full Run 2 dataset of $\mathcal{L} = 126 - 139\text{fb}^{-1}$
- *VHH* and indirect measurement via single Higgs production
- In addition, their combinations will be covered in this talk!

	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	33%				
WW	25%	4.6%			
$\tau\tau$	7.4%	2.4%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
$\gamma\gamma$	0.26%	0.1%	0.029%	0.013%	0.0005%

ATLAS measures these decay channels!

Most sensitive!

- $b\bar{b}b\bar{b}$ Highest BR, large background
- $b\bar{b}\tau\tau$ Medium BR, good rejection of background
- $b\bar{b}\gamma\gamma$ Small BR, very clean signature

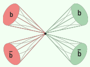
Today, these decay channels will be discussed!

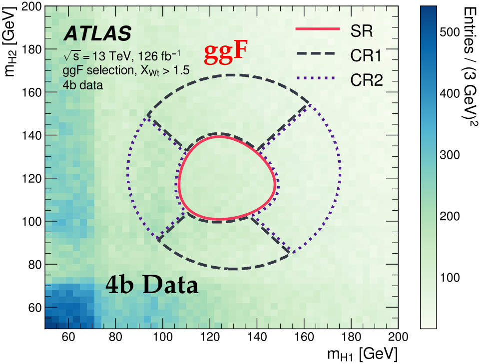
Non-resonant $HH \to b\bar{b}b\bar{b}$

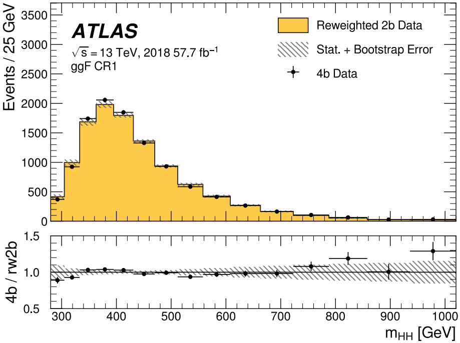
$HH \to b\bar{b}b\bar{b}$ (highest BR $\sim 33\%$) via ggF & VBF — CERN-EP-2022-235 (2023)

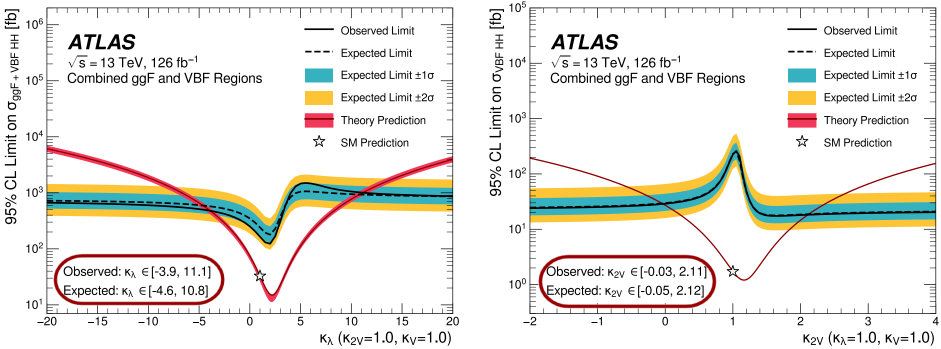
- Suffer from large background multijet $\sim 90\%$ & fully hadronic $t\bar{t} \sim 10\%$ events
- 4 b-tagged jets paired to H-candidates via min ΔR
- Data-driven background estimation for multijet using neural network

↪ NN trained in CR to reweight 2b data to 4b region







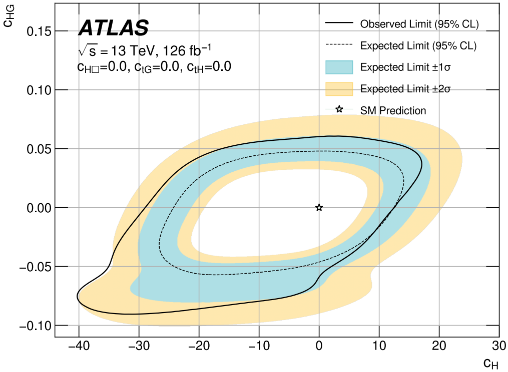


$HH \rightarrow b\bar{b}b\bar{b}$ results @ 95% CL

- ggF + VBF , $\mathcal{L} = 126\,\text{fb}^{-1}$
- **Observed cross section upper-limit:** $5.4 \times \sigma_{HH}^{SM}$

Non-resonant $HH \to b\bar{b}b\bar{b}$: SMEFT

c_{HG} vs c_H



CERN-EP-2022-235 (2023)

$HH \to b\bar{b}b\bar{b}$ **results @ 95% CL,** ggF + VBF , $\mathcal{L} = 126\,\text{fb}^{-1}$

- **HH couplings limit in SMEFT interpretation:**

  $-22 < c_H < 11$ & $-0.067 < c_{HG} < 0.060$ ☞ **First time measured in ATLAS**

Non-resonant $HH \to b\bar{b}\tau\tau$

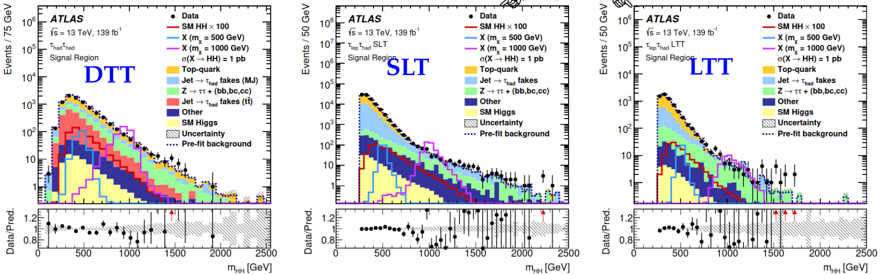
$\boldsymbol{HH \to b\bar{b}\tau\tau}$ (BR $\sim 7.3\%$) via ggF + VBF

- 3 SRs defined based on di-τ system and trigger selection

$\tau_{lep}\tau_{had}$: Single Lepton (SLT)
$\tau_{lep}\tau_{had}$: Lepton $-\ \tau$ (LTT)
$\tau_{had}\tau_{had}$: Single & di $-\ \tau$ (DTT)

- 1 lepton(e/μ) and 1 τ in $\tau_{lep}\tau_{had}$, 2τ in $\tau_{had}\tau_{had}$ & 2-b-tagged jets
- **Main backgrounds:** $t\bar{t} \to bbWW \to bb\tau\tau$, Z+Heavy Flavour jets - modelled in MC, & Jets are misidentified τ_{had} from $t\bar{t}$, & QCD multijet data-driven

$\tau_{had}\tau_{had}$ $\tau_{lep}\tau_{had}$ CERN-EP-2022-109 (2022)



To separate the signal from the background:

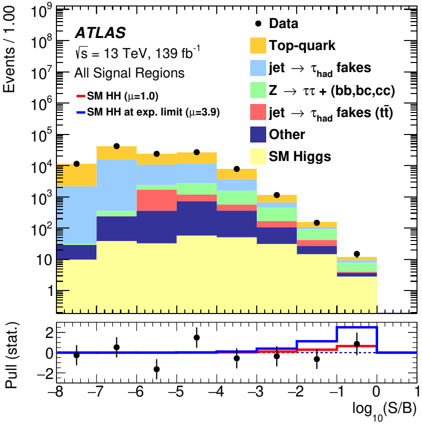
- MVA method employed for $\tau_{had}\tau_{had}$(BDT), $\tau_{lep}\tau_{had}$(NN)

Non-resonant $HH \to b\bar{b}\tau\tau$: Results

$HH \to b\bar{b}\tau\tau$, $\mathcal{L} = 139\,\text{fb}^{-1}$

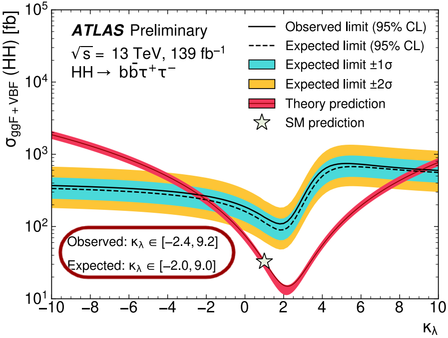
CERN-EP-2022-109 (2022)

- Final-discriminant bins from the $\tau_{\text{had}}\tau_{\text{had}}$, $\tau_{\text{lep}}\tau_{\text{had}}$ SLT and $\tau_{\text{lep}}\tau_{\text{had}}$ LTT categories are combined into bins of $\log_{10}(S/B)$.



Observed upper-limits @ 95 % CL:

- Cross section: $4.7 \times \sigma_{HH}^{SM}$

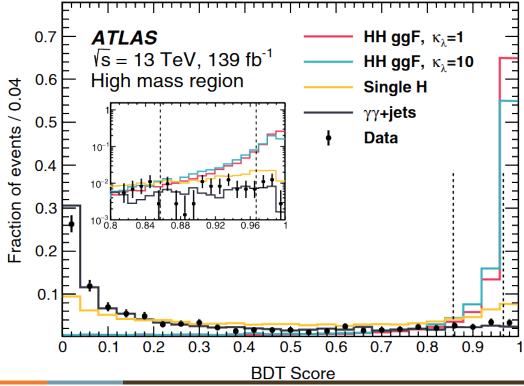


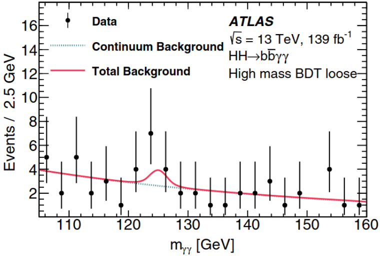
ATLAS-CONF-2021-052 (2021)

Non-resonant $HH \to b\bar{b}\gamma\gamma$

$HH \to b\bar{b}\gamma\gamma$ (BR $\sim 0.26\%$) via ggF + VBF — Phys. Rev. D 106, 052001 (2022)

- Requiring 2 photons & 2 b-tagged jets; $m_{\gamma\gamma} \in [105, 160]$ GeV
- Signal region is subdivided low & high mass, targeting $\kappa_\lambda = 10$ or $\kappa_\lambda = 1$
- **Main backgrounds:** $\gamma\gamma$ + jets with data-driven and single Higgs with MC based background estimation via analytical functional forms





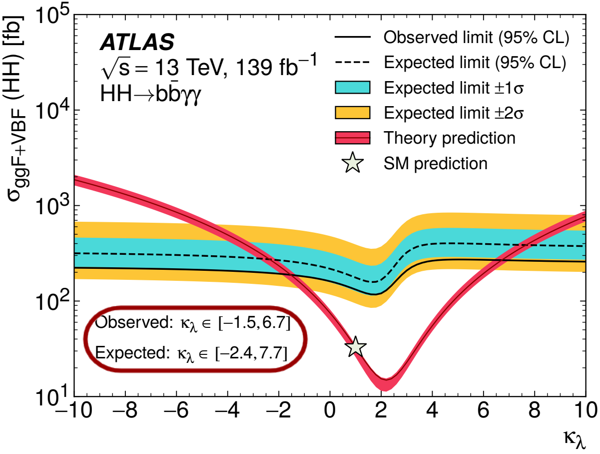
Train dedicated BDT for high & low mass SRs

Signal is extracted from $m_{\gamma\gamma}$ spectrum!

$HH \to b\bar{b}\gamma\gamma$ via ggF + VBF

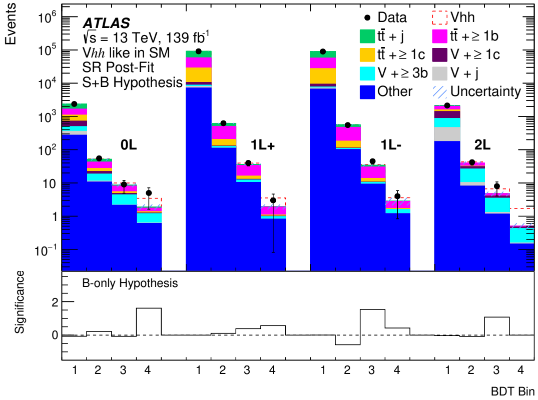
Phys. Rev. D 106, 052001 (2022)

- Observed upper-limit on cross section: $4.2 \times \sigma_{HH}^{SM}$



Non-resonant HH production of λ_{HHH} via VH production

- Higgs self coupling via κ_V, κ_λ, κ_{2V} Eur. Phys. J. C 83 (2023) 519
- VHH is sensitive to *WWHH*, *ZZHH* couplings separately compared to VBF! Unique in VHH!
- 3 SRs: 4 b-tagged jets with (0L, 1L, 2L) of $Z \to \nu\nu$, $W \to \ell\nu$, $Z \to \ell\ell$



BDT for signal and bkg. separation
⇒ Simultaneous fit to BDT distributions to extract potential signal contributions

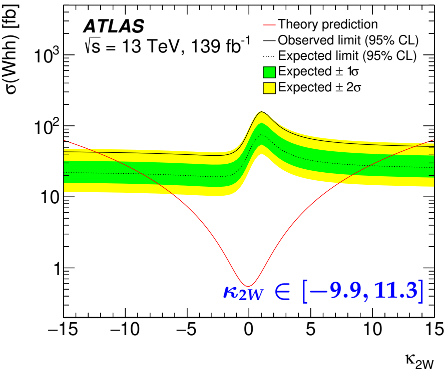
Search for non-resonant VHH: Results

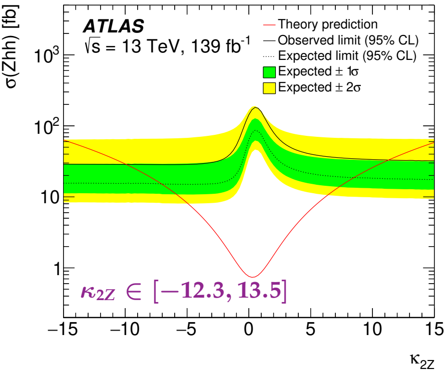
arXiv:2210.05415

Results @95% CL:

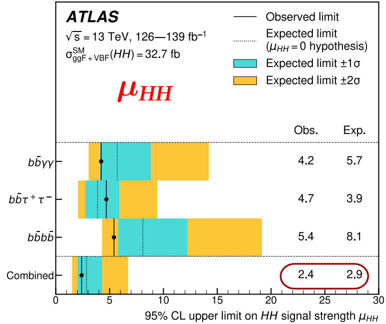
- $183(87) \times \sigma_{SM}$ observed(expected) upper-limit on cross section
- **Observed limit:**
  - $-34.4 < \kappa_\lambda < 33.3$
  - $-8.6 < \kappa_{2V} < 10.0$

★ **Measuring the κ_{2V} for W and Z separately!**





Di-Higgs combination with full Run 2 data



Combination of HH with $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$:

- ggF + VBF , $\mathcal{L} = 126 - 139\,\text{fb}^{-1}$

Higgs self coupling constraint @95% CL:

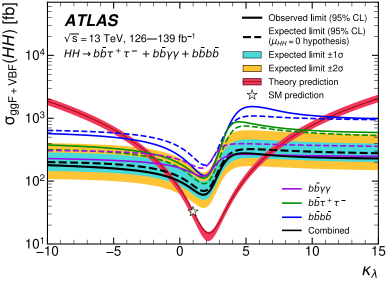
- $-0.6 < \kappa_\lambda < 6.6$
- $0.1 < \kappa_{2V} < 2.0$

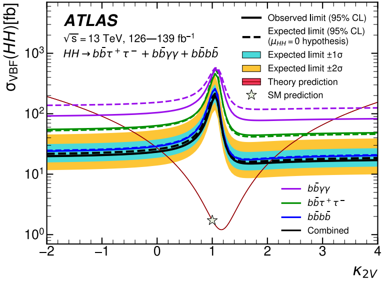
Most stringent constraints on λ_{HHH}

Less model-dependent combination of HH + H

$\Rightarrow -1.4 < \kappa_\lambda < 6.1$ @ 95% CL

Phys. Lett. B 843 (2023) 137745





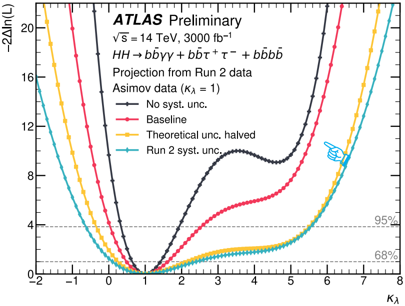
Non-resonant HH production of λ_{HHH} at the $\mathcal{L} = 3\text{ab}^{-1}$, $\sqrt{s} = 14$ TeV

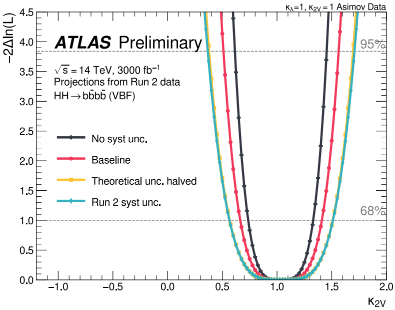
- 20x more data at High-Lumi LHC
  - ↪ High pile-up environment ⇒ detector upgrade
- Extrapolations of Run 2 Higgs self coupling measurements from $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$

☆ Predicted Higgs self coupling constraint @ 68% CL:
- $0.5 < \kappa_\lambda < 1.6$
- $0.7 < \kappa_{2V} < 1.4$

☞ **Large improvement from analysis techniques: b-tagging, τ-identification compared to previous projections!**

ATL-PHYS-PUB-2022-053

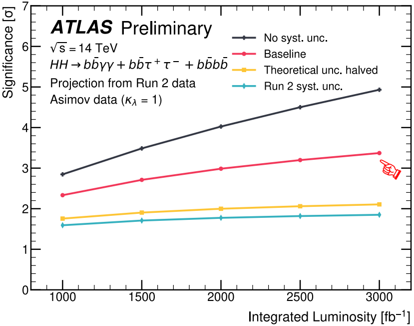




Conclusions

HH search and trilinear coupling of Higgs boson measurements in ATLAS:

- Measures many possible decay channels of the HH
- No observation of HH process with Run 2 datasets
- ☆ Most stringent coupling constraint up-to-date $\kappa_\lambda \in [-0.4, 6.3]$ by combining three most sensitive decay channels of $4b$, $bb\gamma\gamma$, $bb\tau\tau$
- New interpretation of SMEFT using $4b$ channels
- New HH results in VHH probing κ_{2W} & κ_{2Z}!



HH search HL-LHC:

- At HL-LHC, expected to 3.4σ evidence for HH production!
- Due to improved b-tagging, τ-identification with better projection analysis methods:

No syst. $\kappa_\lambda \in [0.7, 1.4]$ @ 68& CL
Before $\kappa_\lambda \in [0.4, 1.7]$

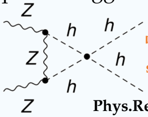
Thank you!

Backup

Higgs self-coupling measurement at LHC

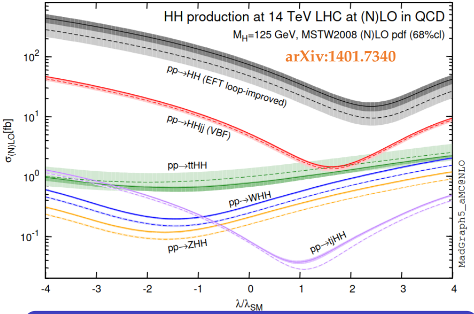
Direct measurement

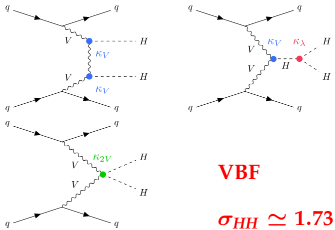
- Higgs-pair production to probe the λ_{HHH} via κ_λ, κ_V, κ_{2V}
- κ_{2V} could indirectly probe quartic Higgs coupling



☞Otherwise not sensitive at the LHC!

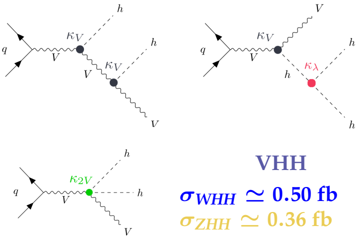
Phys.Rev.D 98, 093004 (2018)





VBF

$\sigma_{HH} \simeq$ **1.73 fb**



VHH

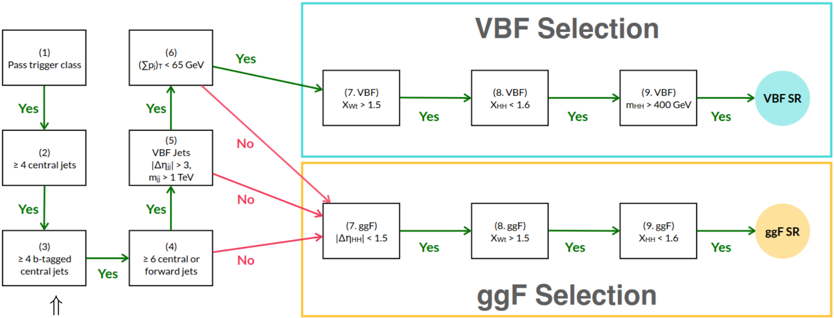
$\sigma_{WHH} \simeq$ **0.50 fb**

$\sigma_{ZHH} \simeq$ **0.36 fb**

Non-resonant $HH \to b\bar{b}b\bar{b}$
Event preselection

$HH \to b\bar{b}b\bar{b}$ via ggF & VBF CERN-EP-2022-235 (2023)

- Trigger selection: 2b2j + 2b1j, $p_{j1(j3)} > 170(70)$ GeV
- Suffer from large QCD multijet $\sim 90\%$ and fully hadronic $t\bar{t} \sim 10\%$ events



⇑

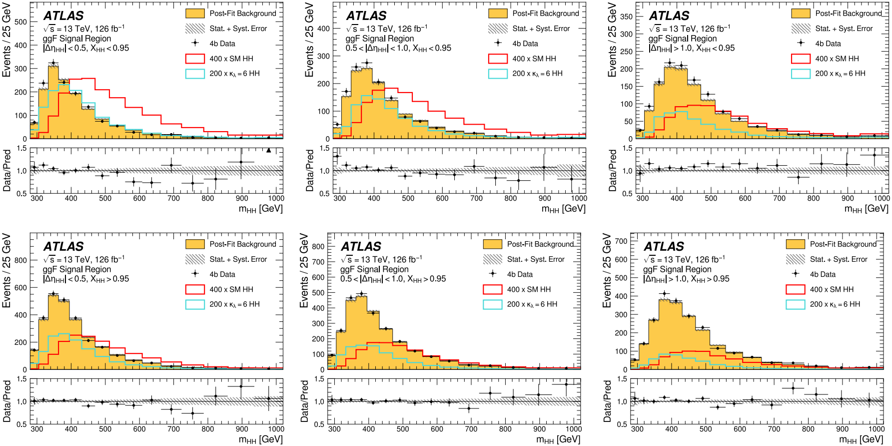
paired to H-candidates via min ΔR

$$X_{Wt} = \min\left[\sqrt{\left(\frac{m_{jj}-m_W}{0.1\cdot m_{jj}}\right)^2 + \left(\frac{m_{jjb}-m_t}{0.1\cdot m_{jjb}}\right)^2}\right] ; \quad X_{HH} \equiv \sqrt{\left(\frac{m_{H1}-124\text{ GeV}}{0.1\cdot m_{H1}}\right)^2 + \left(\frac{m_{H2}-115\text{ GeV}}{0.1\cdot m_{H2}}\right)^2}$$

Non-resonant $HH \to b\bar{b}b\bar{b}$
ggF categories

$HH \to b\bar{b}b\bar{b}$ via ggF — CERN-EP-2022-235 (2023)

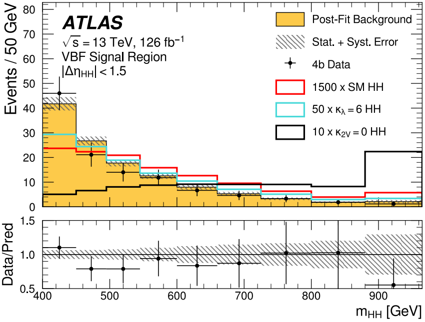
- 6 categories to improve the sensitivity $\hookrightarrow$ **ggF:** 6 categories using $|\Delta\eta_{HH}|$, $\&X_{HH}$,

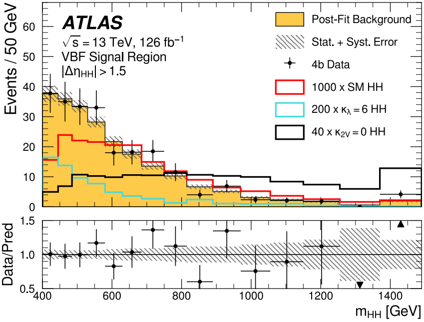


HH $\to$ $\boldsymbol{b\bar{b}b\bar{b}}$ via VBF

CERN-EP-2022-235 (2023)

- 2 categories to improve the sensitivity $\hookrightarrow$ **VBF:** 2 categories using $|\Delta\eta_{HH}|$

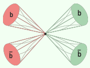




Non-resonant $HH \to b\bar{b}b\bar{b}$

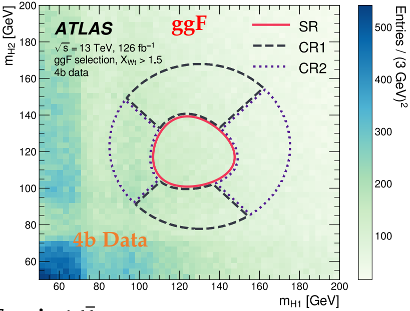
$HH \to b\bar{b}b\bar{b}$ (highest BR $\sim 33\%$) via ggF & VBF

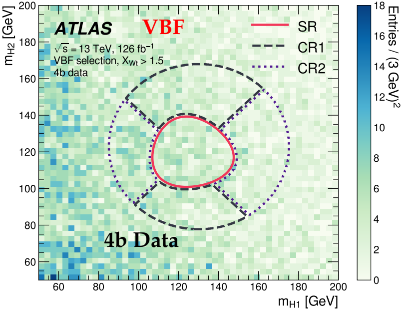
CERN-EP-2022-235 (2023)



- SR, CR defined in the 2D mass plane of H-candidates
- Data-driven background estimation for multijet using neural network

↪ NN trained in CR to reweight $2b$ data to $4b$ region





To reject $t\bar{t}$

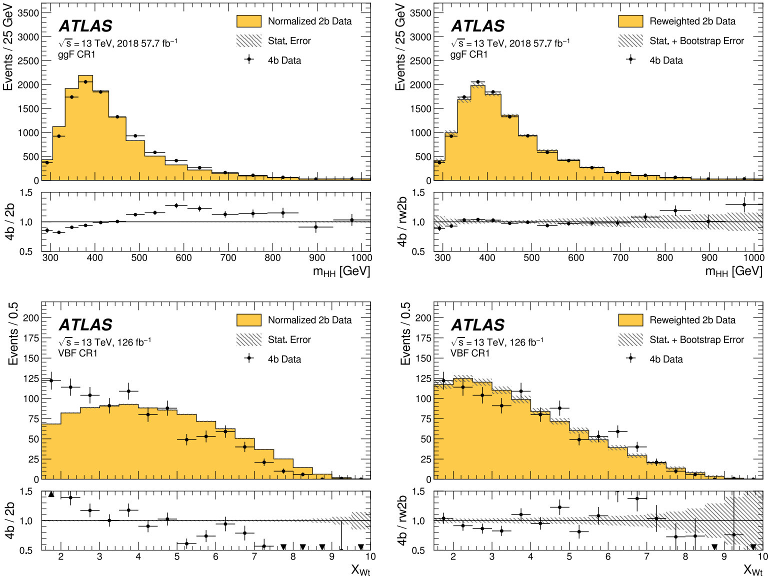
$$X_{Wt} = \min \left[\sqrt{\left(\frac{m_{jj} - m_W}{0.1 \cdot m_{jj}}\right)^2 + \left(\frac{m_{jjb} - m_t}{0.1 \cdot m_{jjb}}\right)^2} \right];$$

$$X_{HH} \equiv \sqrt{\left(\frac{m_{H1} - 124\ \text{GeV}}{0.1 \cdot m_{H1}}\right)^2 + \left(\frac{m_{H2} - 115\ \text{GeV}}{0.1 \cdot m_{H2}}\right)^2}$$

Signal region selection

ggF	VBF
1. $\log(p_\mathrm{T})$ of the 2nd leading Higgs boson candidate jet	1. Maximum dijet mass from the possible pairings of the four Higgs boson candidate jets
2. $\log(p_\mathrm{T})$ of the 4th leading Higgs boson candidate jet	2. Minimum dijet mass from the possible pairings of the four Higgs boson candidate jets
3. $\log(\Delta R)$ between the closest two Higgs boson candidate jets	3. Energy of the leading Higgs boson candidate
4. $\log(\Delta R)$ between the other two Higgs boson candidate jets	4. Energy of the subleading Higgs boson candidate
5. Average absolute η value of the Higgs boson candidate jets	5. Second-smallest ΔR between the jets in the leading Higgs boson candidate (from the three possible pairings for the leading Higgs candidate)
6. $\log(p_\mathrm{T})$ of the di-Higgs system	6. Average absolute η value of the four Higgs boson candidate jets
7. ΔR between the two Higgs boson candidates	7. $\log(X_{Wt})$
8. $\Delta\phi$ between jets in the leading Higgs boson candidate	8. Trigger class index as one-hot encoder
9. $\Delta\phi$ between jets in the subleading Higgs boson candidate	9. Year index as one-hot encoder (for years inclusive training)
10. $\log(X_{Wt})$	
11. Number of jets in the event	
12. Trigger class index as one-hot encoder	

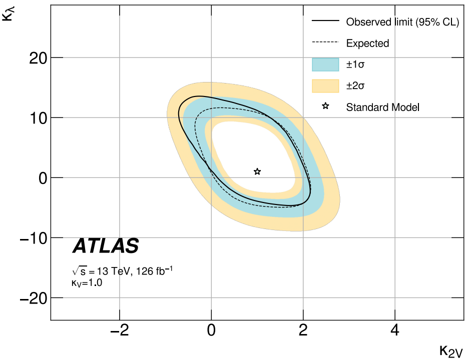
CERN-EP-2022-235 (2023)



CERN-EP-2022-235 (2023)

Source of Uncertainty	$\Delta\mu/\mu$
Theory uncertainties	
Theory uncertainty in signal cross-section	−9.0%
All other theory uncertainties	−1.4%
Background modeling uncertainties	
Bootstrap uncertainty	−7.1%
CR to SR extrapolation uncertainty	−7.5%
3b1f nonclosure uncertainty	−2.0%

CERN-EP-2022-235 (2023)



	Observed Limit	-2σ	-1σ	Expected Limit	$+1\sigma$	$+2\sigma$
μ_{ggF}	5.5	4.4	5.9	8.2	12.4	19.6
μ_{VBF}	130	70	100	130	190	280
$\mu_{\text{ggF+VBF}}$	5.4	4.3	5.8	8.1	12.2	19.1

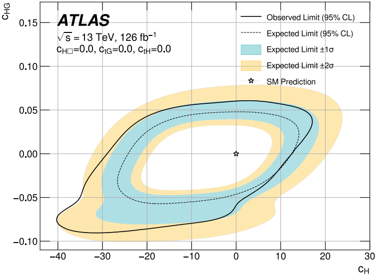
SMEFT interpretation in $HH \rightarrow b\bar{b}b\bar{b}$

SM Effective Field Theory (SMEFT)

- Linearly: $\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum_k c_k^{(6)} O_k^{(6)} + \frac{1}{\Lambda^4} \sum_k c_k^{(8)} O_k^{(8)} + \cdots$
- $O_k^{(6)}$ higher dimensional local operators in the Warsaw basis $\Rightarrow$ provides set of operators allowed by SM gauge symmetries
- $c_k^{(6)}$ Wilson coefficients are free parameters; & they are correlated
- SMEFT constraints include linear $\frac{1}{\Lambda_2}$ (interference between SM & new physics), and quadratic term $\frac{1}{\Lambda_4}$ which is pure new physics; (Λ is fixed at 1 TeV)

arXiv:2301.03212 (2023)

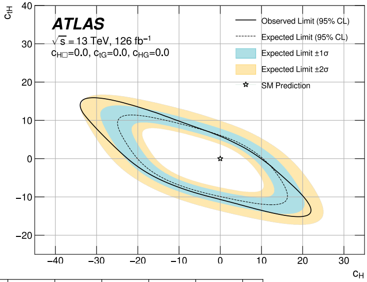
Wilson Coefficient	Operator
c_H	$(H^\dagger H)^3$
$c_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
c_{tH}	$(H^\dagger H)(\bar{Q}\tilde{H}t)$
c_{HG}	$H^\dagger H G^A_{\mu\nu} G^{\mu\nu}_A$
c_{tG}	$(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{H}G^A_{\mu\nu}$

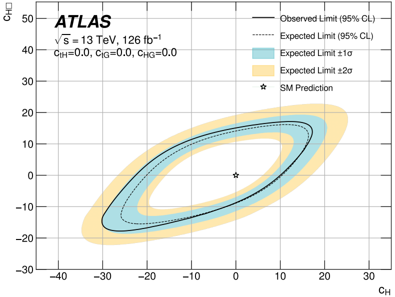


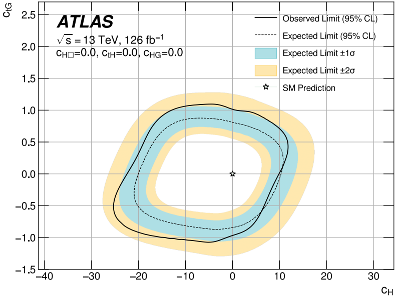
SMEFT interpretation in $HH \rightarrow b\bar{b}b\bar{b}$

Parameter	Expected Constraint		Observed Constraint	
	Lower	Upper	Lower	Upper
c_H	−20	11	−22	11
c_{HG}	−0.056	0.049	−0.067	0.060
$c_{H\Box}$	−9.3	13.9	−8.9	14.5
c_{tH}	−10.0	6.4	−10.7	6.2
c_{tG}	−0.97	0.94	−1.12	1.15

arXiv:2301.03212 (2023)







HEFT interpretation in $HH \rightarrow b\bar{b}b\bar{b}$

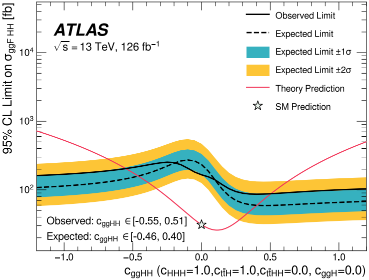
Non-linear Higgs Effective Field Theory (HEFT)

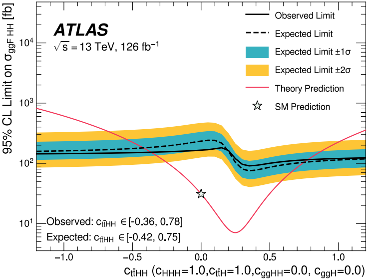
- No correlation between free parameters

Benchmark Model	c_{HHH}	c_{ttH}	c_{ggH}	c_{ggHH}	c_{ttHH}
SM	1	1	0	0	0
BM1	3.94	0.94	1/2	1/3	−1/3
BM2	6.84	0.61	0.0	−1/3	1/3
BM3	2.21	1.05	1/2	1/2	−1/3
BM4	2.79	0.61	−1/2	1/6	1/3
BM5	3.95	1.17	1/6	−1/2	−1/3
BM6	5.68	0.83	−1/2	1/3	1/3
BM7	−0.10	0.94	1/6	−1/6	1

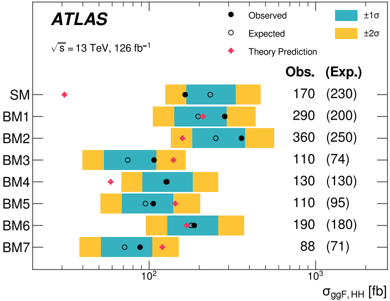
CERN-EP-2022-235 (2023)

HEFT interpretation in $HH \to b\bar{b}b\bar{b}$





CERN-EP-2022-235 (2023)

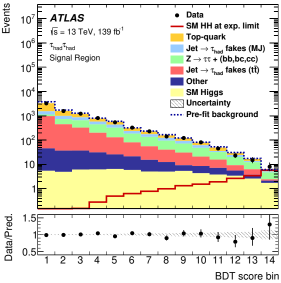


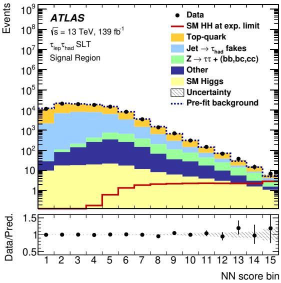
Non-resonant $HH \to b\bar{b}\tau\tau$
Background discrimination

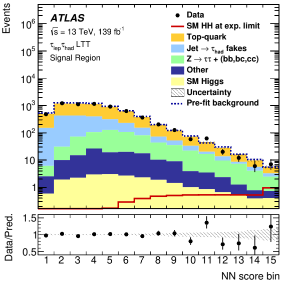
To separate the signal from the background: CERN-EP-2022-109 (2022)

3 SRs Single lepton trigger (SLT) & Lepton-τ trigger (LTT) for $\tau_{lep}\tau_{had}$
Single- and di-τ triggers for $\tau_{had}\tau_{had}$

- BDT for $\tau_{had}\tau_{had}$, NN for $\tau_{lep}\tau_{had}$
- High ranked input variables for trainings: m_{HH}, $m_{\tau\tau}^{MMC}$, m_{bb}
- MVA discriminants are used to extract possible signals



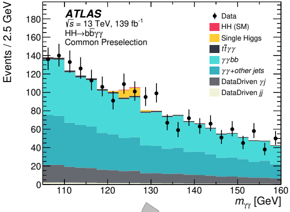




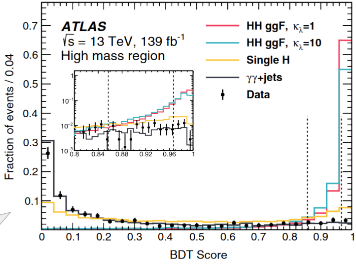
$HH \to b\bar{b}\gamma\gamma$ (BR $\sim 0.26\%$) via ggF + VBF

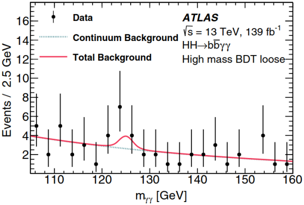
Phys. Rev. D 106, 052001 (2022)

- Requiring 2 photons & 2 b-tagged jets; $m_{\gamma\gamma} \in [105, 160]$ GeV
- Signal region is subdivided low & high mass, targeting $\kappa_\lambda = 10$ or $\kappa_\lambda = 1$
- **Main backgrounds:** $\gamma\gamma +$ jets with data-driven and single Higgs with MC based background estimation via analytical functional forms



$$m^*_{b\bar{b}\gamma\gamma} = m_{b\bar{b}\gamma\gamma} - m_{b\bar{b}} - m_{\gamma\gamma} + 250 \text{ GeV}$$

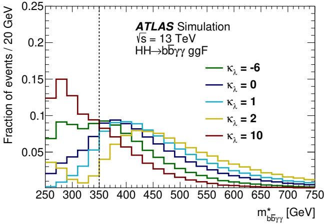




Train dedicated BDT for high & low mass SRs

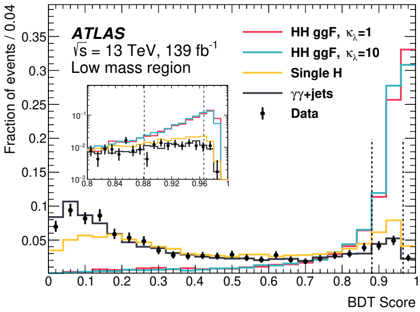
Signal is extracted from $m_{\gamma\gamma}$ spectrum!

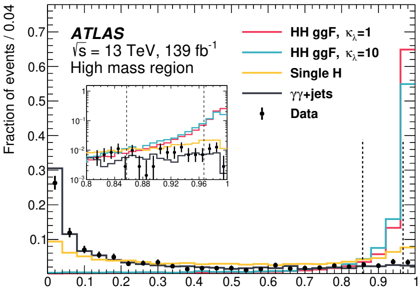
Non-resonant $HH \rightarrow b\bar{b}\gamma\gamma$



To separate the signal and background:

- BDT training used with inputs: m_{bb}
- Signal region is subdivided low & high mass in tight & loose BDT scores



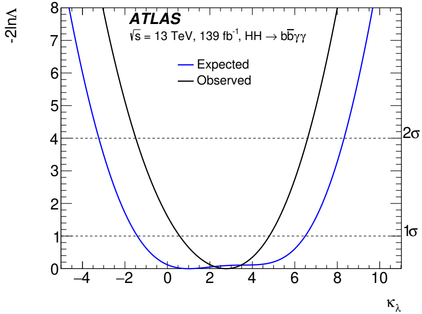


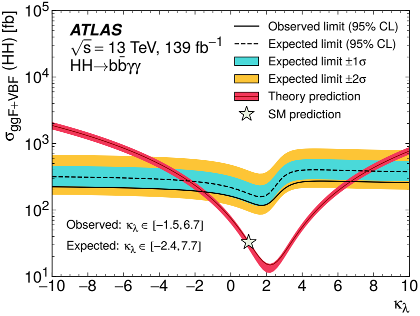
Phys. Rev. D 106, 052001 (2022)

$HH \to b\bar{b}\gamma\gamma$ via ggF + VBF

Phys. Rev. D 106, 052001 (2022)

- Observed limit on cross section:
  - $\sigma_{HH} \simeq 4.2\times$ SM
- Higgs self coupling constraint @ 95% CL:
  - $-1.5 < \kappa_\lambda < 6.7$

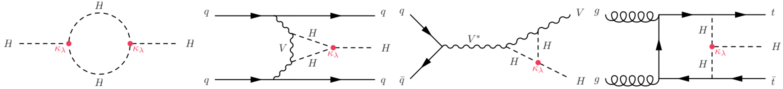


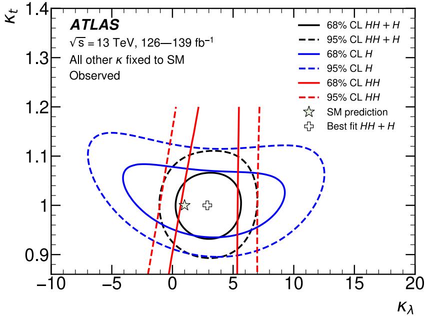


Indirect measurements of λ_{HHH} via single Higgs production

- Probe λ_{HHH} via precision measurement of single Higgs boson
  - $\hookrightarrow$ NLO EW correction via Higgs self coupling loop

$$\left\{ \begin{array}{c} \gamma\gamma \\ ZZ^* \rightarrow \ell\ell\ell\ell \\ \tau\tau \\ WW^* \rightarrow e\nu\mu\nu\ (ggF, VBF) \\ b\bar{b}\ (VH, VBF, t\bar{t}H) \end{array} \right.$$





Combination of HH & H:

- $\mathcal{L} = 126 - 139\,\text{fb}^{-1}$, $\sqrt{s} = 13$ TeV
- $\kappa_t,\ \kappa_V,\ \kappa_b,\ \kappa_\tau$ floating

Higgs self coupling constraint:

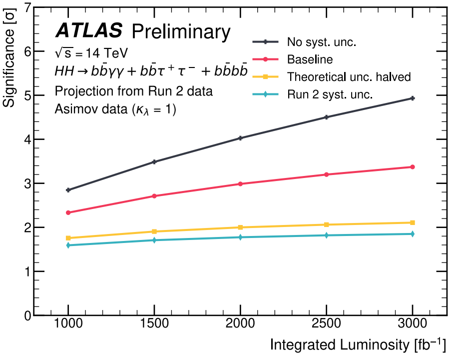
- $\mathbf{-1.4 < \kappa_\lambda < 6.1}$ @ 95% CL
- **Less model-dependent** ★

Phys. Lett. B 843 (2023) 137745

HL-LHC prospects for the HH measurement

Non-resonant HH production of λ_{HHH} at the $\mathcal{L} = 3\text{ab}^{-1}$, $\sqrt{s} = 14$ TeV

- 20x more data at High-Lumi LHC   ATL-PHYS-PUB-2022-053
  - ↪ High pile-up environment ⇒ detector upgrade
- Extrapolations of Run 2 Higgs self coupling measurements from $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$



Systematic uncertainties	Scale factors for HL-LHC baseline scenario
Theoretical uncertainty	0.5
b-jet tagging efficiency	0.5
c-jet tagging efficiency	0.5
Light-jet tagging efficiency	1.0
Jet energy scale and resolution	1.0
Luminosity	0.6
Background bootstrap uncertainty	0.5
Background shape uncertainty	1.0

Baseline scenario: 3.4σ predicted evidence of HH at HL LHC!

HL-LHC prospects for the HH measurement

Non-resonant HH production of λ_{HHH} at the $\mathcal{L} = 3\text{ab}^{-1}$, $\sqrt{s} = 14$ TeV

- Extrapolations of Run 2 Higgs self coupling measurements from $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$
- Predicted Higgs self coupling constraint @68% CL:
  - $0.5 < \kappa_\lambda < 1.6$
  - $0.7 < \kappa_{2V} < 1.4$

ATL-PHYS-PUB-2022-053