Combination of Higgs boson pair production and single Higgs production in the ATLAS experiment

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on behalf of the ATLAS collboration

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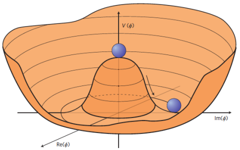
Introduction - Probing the Higgs boson self-coupling



SM Higgs Potential

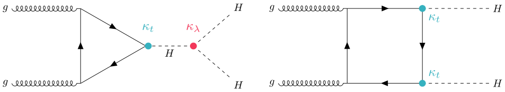
- The **Higgs self-couplings** λ_i are one of the properties of the Higgs boson that are still **largely unconstrained** experimentally.
- These couplings provide key information on the **shape of the Higgs potential** $V(H)$ which has important physics implications (e.g. stability of the universe [JHEP08(2012)098]).

$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda_3 \nu H^3 + \frac{1}{4}\lambda_4 H^4 \quad \lambda_3 = \lambda_4 \text{ in SM}$$

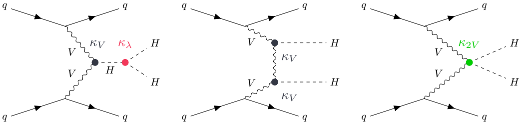
- The quartic coupling λ_4 is out of reach for the LHC [PRD 72, 053008], but a handle on the **trilinear coupling** λ_3 is possible.
- In particular, λ_3 can be directly accessed through the production of **Higgs boson pairs (HH)**.
- Additional contributions also come from **single Higgs production (H)** via **NLO EW corrections**.
- Deviation of the coupling strength from SM (measured by the coupling modifier $\kappa_\lambda = \lambda_3/\lambda_3^{\text{SM}}$) may point to **new physics**.

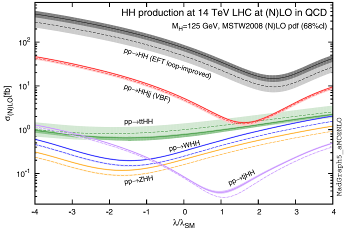
Higgs boson pair (HH) production

- The two dominant HH production modes are **gluon-glupn fusion (ggF)** and **vector boson fusion (VBF)** which contribute to over 95% of the HH production cross section in the SM.
- In addition to the **Higgs self coupling** (κ_λ), the ggF production mode is also sensitive to the **top Yukawa coupling** (κ_t), while the VBF production mode allows the probe of **couplings with one or two vector bosons** (κ_V and κ_{2V}).



SM $\sigma_{\text{HH}}^{\text{ggF}} = 31.0\ \text{fb}^{-1}$ at NNLO (m_{H}=125.09 GeV)





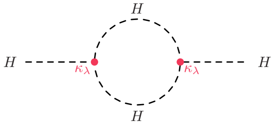
SM $\sigma_{\text{HH}}^{\text{VBF}} = 1.72\ \text{fb}^{-1}$ at N3LO (m_{H}=125.09 GeV)

- The SM HH production is an **extremely rare process**, with only $\sim$4000 events expected in Run 2 ($\int \mathcal{L}$=139 fb^{-1} @ 13 TeV).

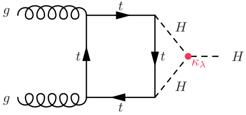
Single Higgs (H) production

- The Higgs self-coupling also contributes to single Higgs processes via NLO EW corrections.

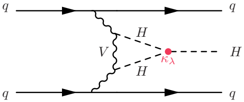
Higgs boson self-energy



Production modes

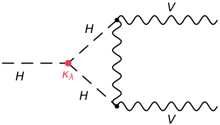


ggF

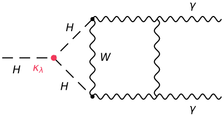


VBF

Decay channels



$H \to VV$



$H \to \gamma\gamma$

- These corrections affect the inclusive **cross-sections**, Higgs-boson **branching fractions** and **differential distributions**.

Contribution of κ_λ in single Higgs: cross section and branching ratio

- The single Higgs production **cross section** and decay **branching ratios** can be written in terms of κ_λ:

$$\mu_i(\kappa_\lambda, \kappa_i) = \frac{\sigma^{\text{BSM}}}{\sigma^{\text{SM}}} = Z_H^{\text{BSM}}(\kappa_\lambda)\left[\kappa_i^2 + \frac{(\kappa_\lambda - 1)C_1^i}{K_{EW}^i}\right]$$

$$\mu_f(\kappa_\lambda, \kappa_i) = \frac{\text{BR}_f^{\text{BSM}}}{\text{BR}_f^{\text{SM}}} = \frac{\kappa_f^2 + (\kappa_\lambda - 1)C_i^f}{\sum_j \text{BR}_j^{\text{SM}}\left[\kappa_j^2 + (\kappa_\lambda - 1)C_1^i\right]}$$

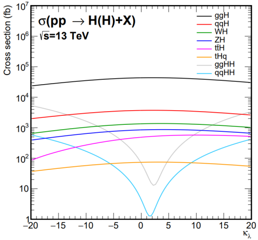
$$Z_H^{BSM}(\kappa_\lambda) = \frac{1}{1 - (\kappa_\lambda^2 - 1)\delta Z_H}, \text{ with } \delta Z_H = -1.536 \times 10^{-3}$$

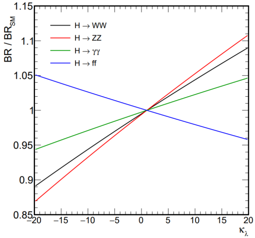
κ_i, κ_f: Additional coupling modifiers such as κ_F or κ_V

Z_H^{BSM}: **Universal** $O(\lambda_3^2)$ correction from wavefunction renormalization

C_1^i: Linear $O(\lambda_3)$ correction from interference between LO amplitude and the virtual NLO EW λ_3 correction (**process and kinematic dependent**)

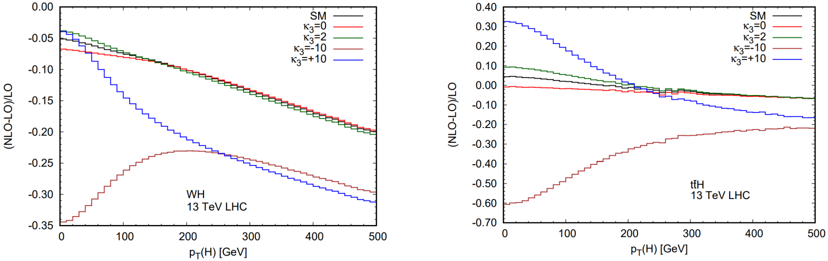
K_{EW}^i: k-factor for the full set of NLO EW correction





[JHEP 1612, 080 (2016)]
[Eur. Phys. J. C77 (2017) 887]
[LHCHWG-2022-002]

- The production modes with the largest kinematic dependence on λ_3 are VH, $t\bar{t}H$ [Eur. Phys. J. C (2017) 77]. They provide **additional sensitivity on λ_3 at differential level**.



- The differential information is encoded through the **simplified template cross-section (STXS)** framework available for $t\bar{t}H$, VH and VBF processes. Only inclusive information is available for ggH and tHj due to missing differential calculations.

Combination Input Analyses

- Combination of HH and H productions using the **full Run 2 data** (126–139 fb^{-1}) of pp collisions at $\sqrt{s} = 13$ TeV from the ATLAS detector [ATLAS-CONF-2022-050].

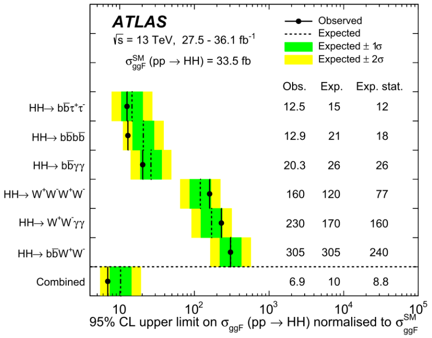
Channel	Integrated luminosity [fb^{-1}]	Reference
$HH \to b\bar{b}\gamma\gamma$	139	[PRD 106, 052001]
$HH \to b\bar{b}\tau\bar{\tau}$	139	[ATLAS-CONF-2021-030]
$HH \to b\bar{b}b\bar{b}$	126	[ATLAS-CONF-2022-035]
$H \to \gamma\gamma$	139	[CERN-EP-2022-094]*
$H \to ZZ^* \to 4\ell$	139	[Eur. Phys. J. C 80 (2020) 957]
$H \to \tau^+\tau^-$	139	[JHEP 08 (2022) 175]
$H \to WW^* \to e\nu\mu\nu$ (ggF, VBF)	139	[CERN-EP-2022-078]**
$H \to b\bar{b}$ (VH)	139	[Eur. Phys. J. C 81 (2021) 178]
$H \to b\bar{b}$ (VBF)	126	[Eur. Phys. J. C 81 (2020) 537]
$H \to b\bar{b}$ $(t\bar{t}H)$	139	[JHEP 06 (2022) 097]

*to appear in JHEP **to appear in PRD

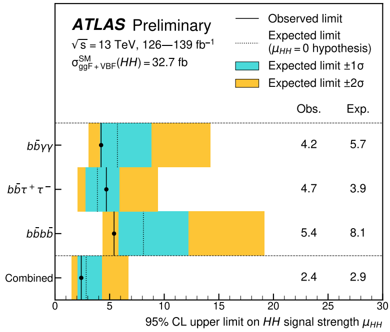
- In addition to κ_λ, the coupling modifiers κ_t, κ_V, κ_{2V} (κ_t, κ_b, κ_τ, κ_V) are considered in the double (single) Higgs processes.
- The **overlap** between/within HH and H analyses is **negligible** or has minor impact on the statistical results.
- **Uncertainties** across channels are **correlated** when relevant.

HH Combination Results: Limit on HH Production

- Upper limit on $\mu_{HH} = \sigma_{\text{HH}}/\sigma_{\text{HH}}^{SM}$ at 95% CL assuming no HH production.
- The HH cross section includes both ggF and VBF production modes.



2019 Combination



2022 Combination

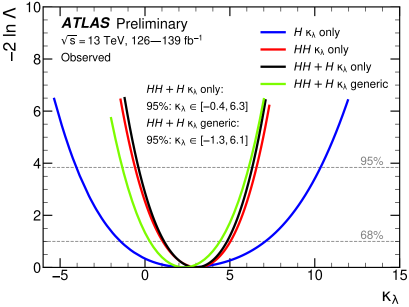
- **Improvement of around 50%** on top of the luminosity increase compared to the 2019 combination [PRB 800 (2020) 135103].

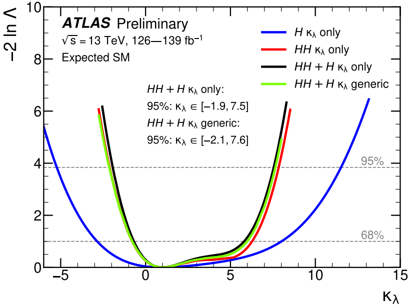
HH + H Combination Results: κ_λ-only and κ_λ generic constraints

- Assuming **BSM only affect** κ_λ.
- Expected result derived from Asimov dataset generated under the SM assumption with all coupling modifiers at unity.
- Two scenarios considered:

κ_λ only: Fit with κ_λ floating and all other coupling modifiers fixed to unity.

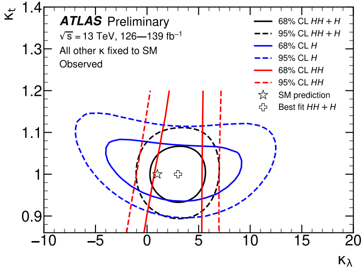
κ_λ generic: Fit with all coupling modifiers (κ_λ, κ_t, κ_b, κ_τ, κ_V) floating with the exception of κ_{2V} that is fixed to unity (no available parameterisation of single-Higgs NLO EW correction as a function of κ_{2V})

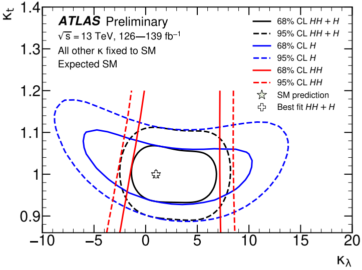




- **Dominant contribution** from the **combined HH** channels.
- The **constraints on** κ_λ is still **substantial** even in the **generic model** (where $\kappa_t, \kappa_b, \kappa_\tau, \kappa_V$ are floating).

HH + H Combination Results: Summary of κ_λ constraints





Combination assumption	Obs. 95% CL	Exp. 95% CL	Obs. value$^{+1\sigma}_{-1\sigma}$
HH combination	$-0.6 < \kappa_\lambda < 6.6$	$-2.1 < \kappa_\lambda < 7.8$	$\kappa_\lambda = 3.1^{+1.9}_{-2.0}$
Single-H combination	$-4.0 < \kappa_\lambda < 10.3$	$-5.2 < \kappa_\lambda < 11.5$	$\kappa_\lambda = 2.5^{+4.6}_{-3.9}$
HH+H combination	$-0.4 < \kappa_\lambda < 6.3$	$-1.9 < \kappa_\lambda < 7.6$	$\kappa_\lambda = 3.0^{+1.8}_{-1.9}$
HH+H combination (2019)	$-2.3 < \kappa_\lambda < 10.3$	$-5.1 < \kappa_\lambda < 11.2$	$\kappa_\lambda = 4.6^{+3.2}_{-3.8}$
HH+H combination, κ_t floating	$-0.4 < \kappa_\lambda < 6.3$	$-1.9 < \kappa_\lambda < 7.6$	$\kappa_\lambda = 3.0^{+1.8}_{-1.9}$
HH+H combination, κ_t, κ_V, κ_b, κ_τ floating	$-1.4 < \kappa_\lambda < 6.1$	$-2.2 < \kappa_\lambda < 7.7$	$\kappa_\lambda = 2.3^{+2.1}_{-2.0}$
HH+H combination (2019), κ_t, κ_V, κ_b, κ_ℓ floating	$-3.7 < \kappa_\lambda < 11.5$	$-6.2 < \kappa_\lambda < 11.6$	$\kappa_\lambda = 5.5^{+3.5}_{-5.2}$

- The **single Higgs** processes allow the **constrain of κ_λ with fewer model-dependent assumptions** (by allowing other coupling modifiers to be free parameters)
- **Improvement of around 50%** over the **2019 combination** [PRB 800 (2020) 135103].

Conclusion

- Combination of **single** and **double Higgs** boson production using the **full Run 2 dataset** in the ATLAS experiment to **constrain the Higgs boson self-coupling** λ_3.
- Input analyses considered

  single Higgs: $\gamma\gamma$, ZZ^*, WW^*, $\tau^+\tau^-$ and $b\bar{b}$ final states

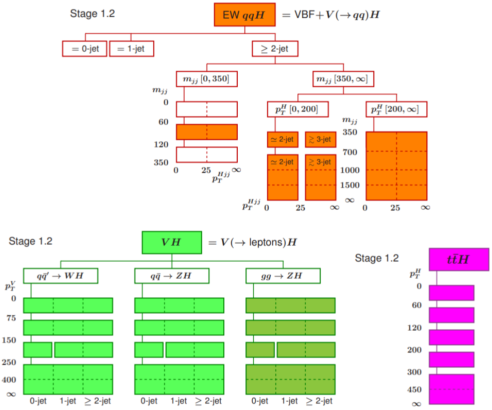
  double Higgs: $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\bar{\tau}$ and $b\bar{b}b\bar{b}$ decay channels
- Constraints in terms of the coupling modifier $\kappa_\lambda = \lambda_3/\lambda_3^{\text{SM}}$:

  κ_λ-only : $-0.4 < \kappa_\lambda < 6.3$ (obs. 95% C.L.), best fit $\kappa_\lambda = 3.0^{+1.8}_{-1.9}$

  κ_λ + κ_t, κ_V, κ_b, κ_τ : $-1.4 < \kappa_\lambda < 6.1$ (obs. 95% C.L.), best fit $\kappa_\lambda = 2.3^{+2.1}_{-2.0}$

  Big improvement ($\sim 50\%$) **over the previous combination** (2019).
- The results provide the **most stringent constraint on the Higgs self-coupling to-date**.
- Stayed tuned for Run3 and the High Luminosity LHC (HL-LHC)!

Appendix: The Simplified Template Cross Section (STXS) framework



- Physical cross sections defined in mutually exclusive regions of phase space ("bins").
- Provide more fine-grained measurements for individual Higgs production modes in various kinematic regions, and reduce the theoretical uncertainties that are directly folded into the measurements.
- Allow for the use of MVA techniques and **provide a common framework for the combination** of measurements in different decay channels and experiments.

Appendix: Calculation of C_1^i coefficients

- The C_1^i coefficients on the single Higgs production has been extended to the latest **STXS 1.2** framework with **higher phase-space granularity**. It allows the use of **more differential information** for additional sensitivity [LHCHWG-2022-002].
- The C_1^i coefficients are computed for the $t\bar{t}H$, V(lep)H and Hjj processes. The coefficients for the **ggH and tHj STXS bins are not computed** because the theoretical calculations at the differential level are not available (the inclusive coefficients are used instead).
- No available C_1^i calculation on tHW, bbH and $ggZH$ processes.
- Events are generated at LO using MadGraph5 for each single-Higgs process. They are classified into STXS bins via Rivet. In each STXS bin, the coefficient C_1^i is computed as

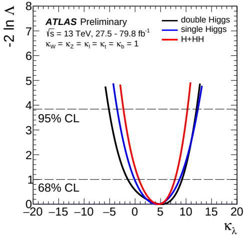
$$C_1^i = \frac{\sum_j w^j_{\text{NLO}}}{\sum_j w^j_{\text{LO}}}$$

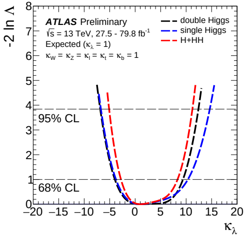
where w^j_{LO} is the weight from LO cross section, and w^j_{NLO} is the weight from LO cross section corrected for the κ_λ effect through NLO EW correction. The sums run over all the events in i-th STXS bin.

Appendix: Previous Combination Results (2019)

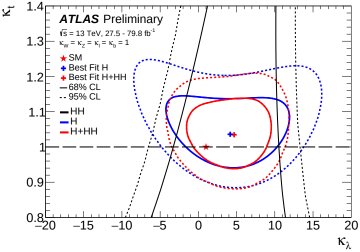
- In 2019, a combination of single-Higgs and double-Higgs production by ATLAS was performed using the partial Run2 dataset [ATLAS-CONF-2019-049].

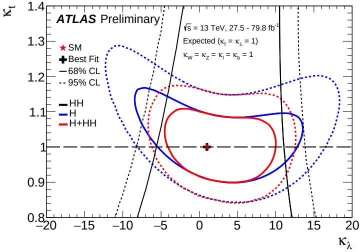
Channel	Integrated luminosity [fb^{-1}]	Reference
$HH \to b\bar{b}\gamma\gamma$	36.1	[JHEP 11 (2018) 040]
$HH \to b\bar{b}\tau\bar{\tau}$	36.1	[Phys. Rev. Lett. 121 (2018)]
$HH \to b\bar{b}b\bar{b}$	27.5	[JHEP 01 (2019) 030]
$H \to \gamma\gamma$ (excluding $t\bar{t}H$)	79.8	[Phys. Rev. D 98 (2018)]
$H \to ZZ^* \to 4\ell$	79.8	[JHEP 03 (2018) 095]
$H \to \tau^+\tau^-$	36.1	[Phys. Rev. D 99 (2019)]
$H \to WW^* \to e\nu\mu\nu$	36.1	[Phys. Lett. B 789 (2019) 508]
$H \to b\bar{b}$ (VH)	79.8	[Phys. Lett. B 786 (2018) 59]
$H \to b\bar{b}$ $(t\bar{t}H)$	36.1	[Phys. Rev. D 97 (2018)]
$H \to$ multilepton $(t\bar{t}H)$	36.1	[Phys. Rev. D 97 (2018)]





	κ_λ [95%CL]	
Double Higgs	[-5.0, +12.0]	obs
	[-5.8, +12.0]	exp
Single Higgs	[-3.2, +11.9]	obs
	[-6.2, +14.4]	exp
Combined	[-2.3, +10.3]	obs
	[-5.1, +11.2]	exp

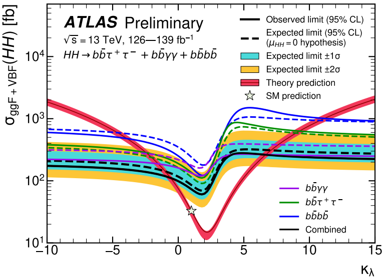




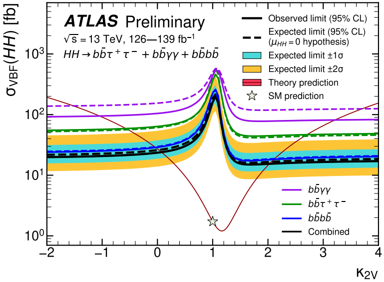
Model	$\kappa_W{}^{+1\sigma}_{-1\sigma}$	$\kappa_Z{}^{+1\sigma}_{-1\sigma}$	$\kappa_t{}^{+1\sigma}_{-1\sigma}$	$\kappa_b{}^{+1\sigma}_{-1\sigma}$	$\kappa_\ell{}^{+1\sigma}_{-1\sigma}$	$\kappa_\lambda{}^{+1\sigma}_{-1\sigma}$	κ_λ [95% CL]	
κ_λ-only	1	1	1	1	1	$4.6^{+3.2}_{-3.8}$	$[-2.3, 10.3]$	obs.
						$1.0^{+7.3}_{-3.8}$	$[-5.1, 11.2]$	exp.
Generic	$1.03^{+0.08}_{-0.08}$	$1.10^{+0.09}_{-0.09}$	$1.00^{+0.12}_{-0.11}$	$1.03^{+0.20}_{-0.18}$	$1.06^{+0.16}_{-0.16}$	$5.5^{+3.5}_{-5.2}$	$[-3.7, 11.5]$	obs.
	$1.00^{+0.08}_{-0.08}$	$1.00^{+0.08}_{-0.08}$	$1.00^{+0.12}_{-0.12}$	$1.00^{+0.21}_{-0.19}$	$1.00^{+0.16}_{-0.15}$	$1.0^{+7.6}_{-4.5}$	$[-6.2, 11.6]$	exp.

Appendix : HH Combination - Constraints on κ_λ and κ_{2V}

- Upper limit on HH production cross section at 95% CL as a function of κ_λ and κ_{2V}
- In the κ_{2V} case, the ggF production mode is considered as a background.



$-0.6 < \kappa_\lambda < 6.6$ (observed)
$-2.1 < \kappa_\lambda < 7.8$ (expected)



$0.1 < \kappa_{2V} < 2.0$ (observed)
$0.0 < \kappa_{2V} < 2.1$ (expected)

- The sensitivity on κ_λ mainly comes from the $b\bar{b}\gamma\gamma$ and $b\bar{b}\tau^+\tau^-$ channels.
- The $b\bar{b}b\bar{b}$ channel has a dominant contribution to the constraint on κ_{2V}.

Appendix: HH κ_λ Parameterisation - ggF

A reweighting procedure is used to model any value of κ_λ using a basis of 3 samples. This is possible due to the structure of ggF HH production. The two contributing diagrams are the box and triangle diagrams. These generate a differential cross-section of

$$\frac{d\sigma(\kappa_\lambda)}{dm_{HH}} = |A(\kappa_\lambda)|^2 = |\kappa_\lambda M_\triangle(m_{HH}) + M_\Box(m_{HH})|^2$$

which can be re-written as

$$\frac{d\sigma(\kappa_\lambda)}{dm_{HH}} = \kappa_\lambda^2 a_1(m_{HH}) + \kappa_\lambda a_2(m_{HH}) + a_3(m_{HH})$$

where a_1, a_2, and a_3 depend only on m_{HH}.

While the above equation should hold for any variable, m_{HH} is selected due to the assumption that acceptance times efficiency only depends on m_{HH}. The rest of the kinematics are assumed to vary coherently with the truth m_{HH} distributions. The values of the a_i are solved for using $\kappa_\lambda = 0, 1$ and 20 samples as a basis, with each sample consisting of over 10 million truth-level events simulated using Powheg at NLO+FT in m_{HH} bins of 10 GeV with a bin range of 200 to 1000 GeV. These samples have no decays or cuts and are common to all di-Higgs analyses.

The m_{HH} distributions of the basis set are linearly combined using the obtained values of the a_i to create distributions for each $\kappa_\lambda \in [-30, 30]$ in increments of 0.2. Weights for each κ_λ are then defined as the ratio of the given distribution to that of $\kappa_\lambda = 1$. These weights are applied to the generated SM samples based on their truth m_{HH} values to obtain reweighted samples corresponding to the full range of κ_λ under investigation. The reweighting procedure is only used to determine the signal shapes, with the results normalized to the theoretical cross-section.

The full cross section for the VBF to HH process involves three diagrams,

$$\sigma(\kappa_{VV}, \kappa_\lambda, \kappa_V) = |A|^2 = |\kappa_V \kappa_\lambda M_s + \kappa_V^2 M_t + \kappa_{VV} M_x|^2$$

Expanding the absolute square of the amplitude A then yields six terms:

$$\sigma = \kappa_V^2 \kappa_\lambda^2 a_1 + \kappa_V^4 a_2 + \kappa_{VV}^2 a_3 + \kappa_V^3 \kappa_\lambda a_4 + \kappa_V \kappa_\lambda \kappa_{VV} a_5 + \kappa_V^2 \kappa_{VV} a_6$$

This requires the combination of multiple different MC samples (in this case, six) in order to model the signal hypothesis at any arbitrary point in $\kappa_{VV}, \kappa_\lambda, \kappa_V$ space. Unlike with ggF, in the case of VBF these MC samples cannot be truth-level samples, but rather must be samples that have been run through reconstruction and selection.
Using the basis samples $(\kappa_\lambda, \kappa_{2V}, \kappa_V)$ = $(1, 1, 1)$, $(2, 1, 1)$, $(10, 1, 1)$, $(1, 1, 0.5)$, $(-5, 1, 0.5)$, the differential cross section can be expressed as

$$\begin{aligned}
\frac{d\sigma_{\text{VBF}}}{d\Phi}(\kappa_\lambda, \kappa_{2V}, \kappa_V) = &\left(\frac{68\kappa_{2V}^2}{135} - 4\kappa_{2V}\kappa_V^2 + \frac{20\kappa_{2V}\kappa_V\kappa_\lambda}{27} + \frac{772\kappa_V^4}{135} - \frac{56\kappa_V^3\kappa_\lambda}{27} + \frac{\kappa_V^2\kappa_\lambda^2}{9}\right) \times \frac{d\sigma_{\text{VBF}}}{d\Phi}(1, 1, 1) \\
&+ \left(-\frac{4\kappa_{2V}^2}{5} + 4\kappa_{2V}\kappa_V^2 - \frac{16\kappa_V^4}{5}\right) \times \frac{d\sigma_{\text{VBF}}}{d\Phi}(1, 1.5, 1) \\
&+ \left(\frac{11\kappa_{2V}^2}{60} + \frac{\kappa_{2V}\kappa_V^2}{3} - \frac{19\kappa_{2V}\kappa_V\kappa_\lambda}{4} - \frac{53\kappa_V^4}{30} - \frac{13\kappa_V^3\kappa_\lambda}{6} - \frac{\kappa_V^2\kappa_\lambda^2}{8}\right) \times \frac{d\sigma_{\text{VBF}}}{d\Phi}(2, 1, 1) \\
&+ \left(-\frac{11\kappa_{2V}^2}{140} + \frac{11\kappa_{2V}\kappa_V\kappa_\lambda}{216} + \frac{13\kappa_V^4}{270} - \frac{5\kappa_V^3\kappa_\lambda}{54} + \frac{\kappa_V^2\kappa_\lambda^2}{72}\right) \times \frac{d\sigma_{\text{VBF}}}{d\Phi}(10, 1, 1) \\
&+ \left(\frac{88\kappa_{2V}^2}{45} - \frac{16\kappa_{2V}\kappa_V^2}{3} + \frac{4\kappa_{2V}\kappa_V\kappa_\lambda}{9} + \frac{152\kappa_V^4}{45} - \frac{4\kappa_V^3\kappa_\lambda}{9}\right) \times \frac{d\sigma_{\text{VBF}}}{d\Phi}(1, 1, 0.5) \\
&+ \left(\frac{82V^2}{45} - \frac{4\kappa_{2V}\kappa_V\kappa_\lambda}{9} - \frac{8\kappa_V^4}{45} + \frac{4\kappa_V^3\kappa_\lambda}{9}\right) \times \frac{d\sigma_{\text{VBF}}}{d\Phi}(-5, 1, 0.5)
\end{aligned}$$

Appendix: Statistical Framework

A combined likelihood $\mathcal{L}(\mathcal{D}|\mu, \theta)$ is constructed as a product of likelihoods from each channel.

$\mathcal{D}$: Data $\quad$ μ: Parameter of Interest (POI) $\quad$ $\boldsymbol{\theta}$ Nuisance Parameters

Profile likelihood ratio
$$\tilde{\lambda}(\mathcal{D}|\mu) = \begin{cases} \frac{\mathcal{L}(\mathcal{D}|\mu,\hat{\hat{\boldsymbol{\theta}}}(\mu))}{\mathcal{L}(\mathcal{D}|\hat{\mu},\hat{\boldsymbol{\theta}})} & \hat{\mu} \geq 0, \\ \frac{\mathcal{L}(\mathcal{D}|\mu,\hat{\hat{\boldsymbol{\theta}}}(\mu))}{\mathcal{L}(\mathcal{D}|0,\hat{\boldsymbol{\theta}}(0))} & \hat{\mu} < 0, \end{cases} \tag{1}$$

Test statistics
$$\tilde{q}_\mu = \begin{cases} -2\ln \tilde{\lambda}(\mathcal{D}|\mu) & \hat{\mu} \leq \mu, \\ 0 & \hat{\mu} > \mu, \end{cases} = \begin{cases} -2\ln \frac{\mathcal{L}(\mathcal{D}|\mu,\hat{\hat{\boldsymbol{\theta}}}(\mu))}{\mathcal{L}(0,\hat{\boldsymbol{\theta}}(0))} & \hat{\mu} \leq 0, \\ -2\ln \frac{\mathcal{L}(\mathcal{D}|\mu,\hat{\hat{\boldsymbol{\theta}}}(\mu))}{\mathcal{L}(\mathcal{D}|\hat{\mu},\hat{\boldsymbol{\theta}})} & 0 \leq \hat{\mu} \leq \mu, \\ 0 & \hat{\mu} > \mu. \end{cases} \tag{2}$$

- $\hat{\boldsymbol{\theta}}$ and $\hat{\mu}$ are the values of $\boldsymbol{\theta}$ and μ that maximizes the likelihood (i.e. unconditional ML).
- $\hat{\hat{\boldsymbol{\theta}}}(\mu)$ is the value of $\boldsymbol{\theta}$ that maximizes the likelihood for the specified μ (i.e. conditional maximum-likelihood (ML) estimator of $\boldsymbol{\theta}$).
- Exclusion upper limits on the POI are set following the CLs prescription.