Studies of new Higgs boson interactions through nonresonant HH production in the $b\bar{b}\gamma\gamma$ final state in the pp collisions at $\sqrt{s}$ = 13TeV with the ATLAS detector

Ligang Xia (Nanjing University)

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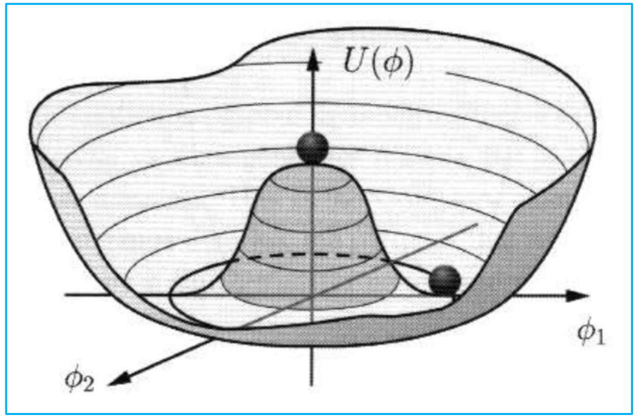
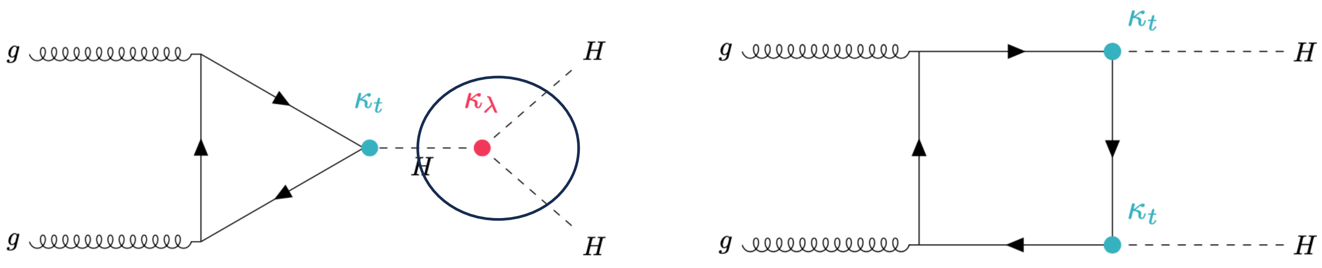
Motivation (I)

- In SM, spontaneous eletroweak symmetry breaking follows from the special shape of the Higgs potential.



$$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_{HHH} v H^3 + \frac{1}{4} \lambda_{HHHH} H^4$$

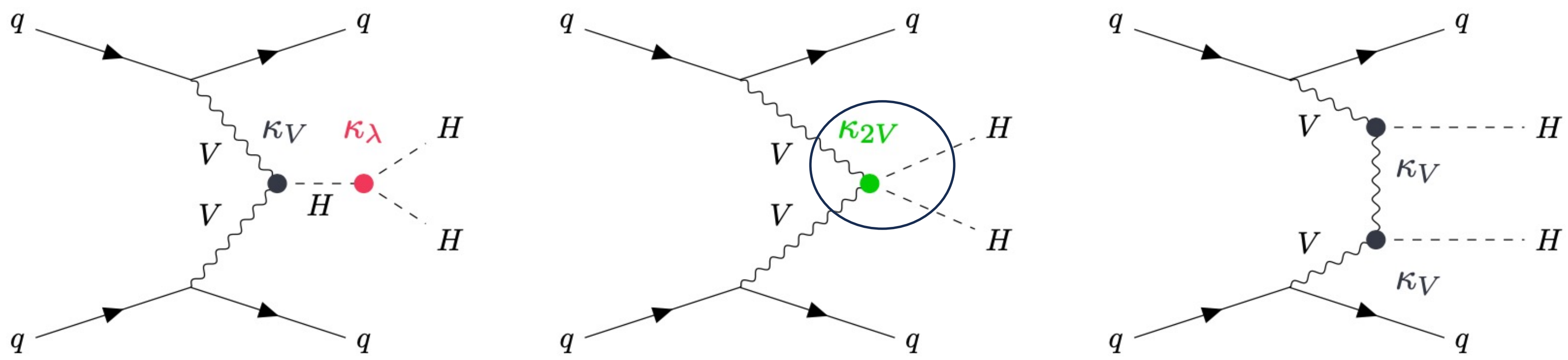
- SM prediction is $\lambda_{HHH} = \lambda_{HHHH} = \frac{1}{2}\left(\frac{m_H}{v}\right)^2 \approx \frac{1}{8}$.
- Experimentally, the only direct way to probe Higgs self coupling is to study the HH production.
- Two diagrams contribute with destructive interference.



(a) Trilinear coupling (b) Box diagram

Motivation (II)

- We also want to constraint the strength of the quartic couplings between two Higgs bosons and two W or Z bosons, g_{HHVV}.
- This can be readily studied in the VBF production of HH events.
- In SM, the prediction is $g_{HHVV} = g_{HVV}/2v$.
- Three types of diagrams contribute coherently.



(a) Trilinear coupling (b) $HHVV$ vertex (c) VVH Production mode

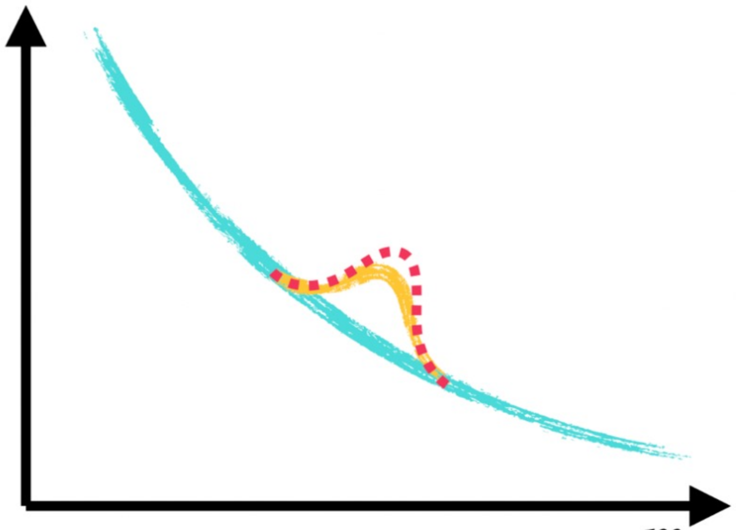
Event Selection

- bbyy channel benefits from high branching fraction of H→ bb and precise Higgs mass reconstruction through H→ yy.

- Preselection:
  - Pass diphoton triggers
  - Two photon candidates with pT>35%m(yy) or 25%m(yy).
  - Two b-tagged central jets using DL1r b-tagging algorithm at 77% WP.
  - Veto events with 6 or more central jets or 1 or more leptons to suppress ttH and inclusive backgrounds.
  - Focus on events with 105<m(yy)<160 GeV

- Signal strength obtained from fitting to m(yy) spectra.

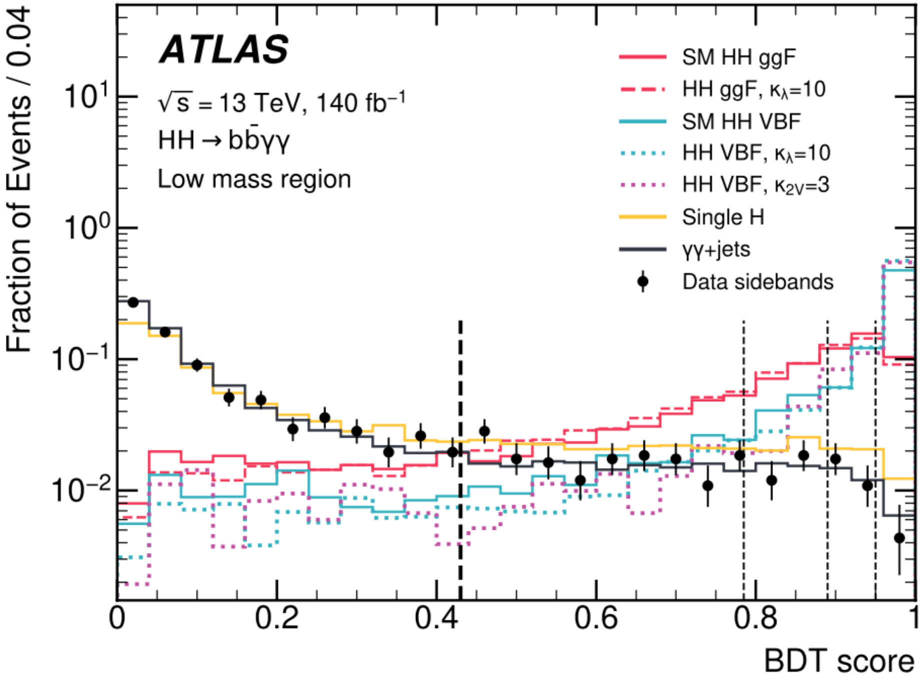
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

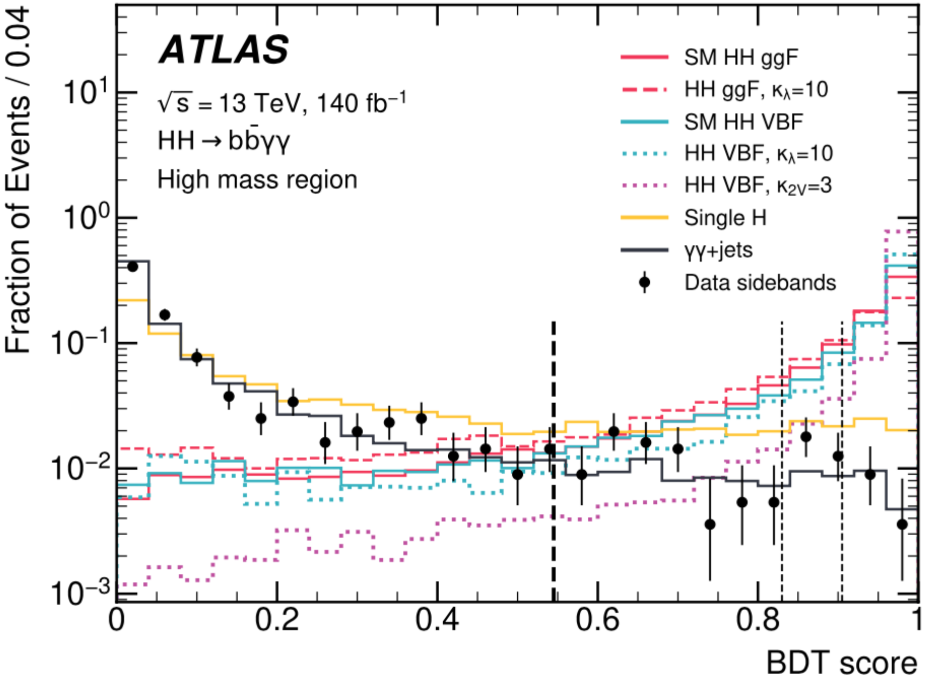


Event Categorization

$$m^*_{b\bar{b}\gamma\gamma} = m_{b\bar{b}\gamma\gamma} - (m_{b\bar{b}} - 125\ \text{GeV}) - (m_{\gamma\gamma} - 125\ \text{GeV})$$

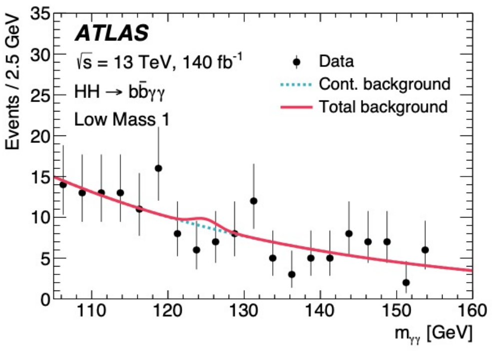
- The Higgs self-coupling strength modifier, κ_λ, is mostly sensitive to the m(HH) distribution.
- We split events into **Low** and **High m*(HH)** regions (< or >**360 GeV**).
- In each region, a **BDT model** is trained to suppress the continuum background (γγ+jets) and the peaking background (single Higgs).
- m(bb) is the most important feature in the BDT model.
- Further design 4+3 final categorization to maximize signal significance.



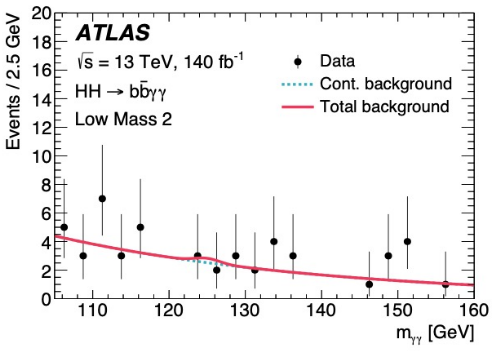


Fits and Signal strength extraction

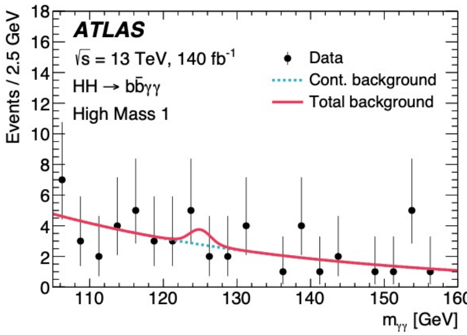
- Signal strength is obtained via fitting the m(yy) spectra.
  - Signal and peaking background are modeled using a DSCB function.
  - Background is modeled using an empiric smooth function, selected using the strategy of the spurious signal test.



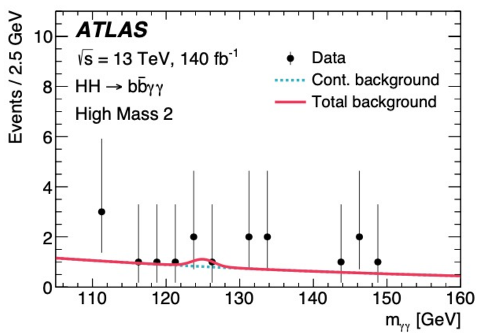
(a) Low Mass 1



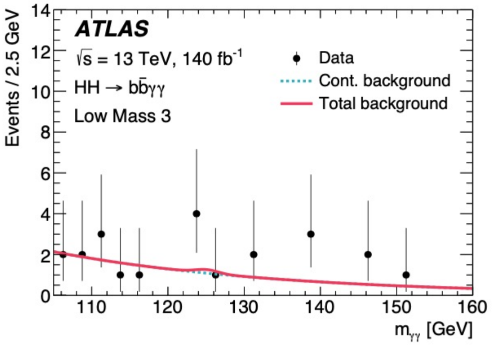
(b) Low Mass 2



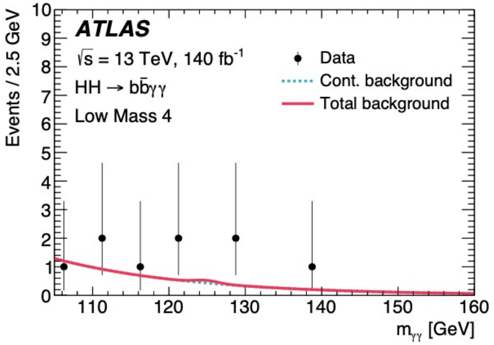
(e) High Mass 1



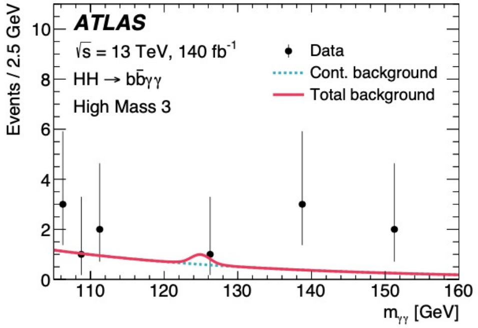
(f) High Mass 2



(c) Low Mass 3



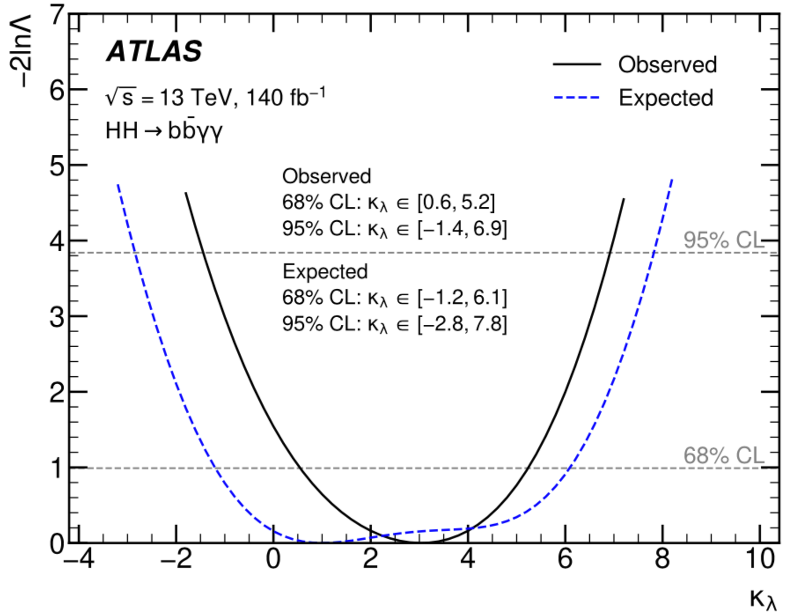
(d) Low Mass 4

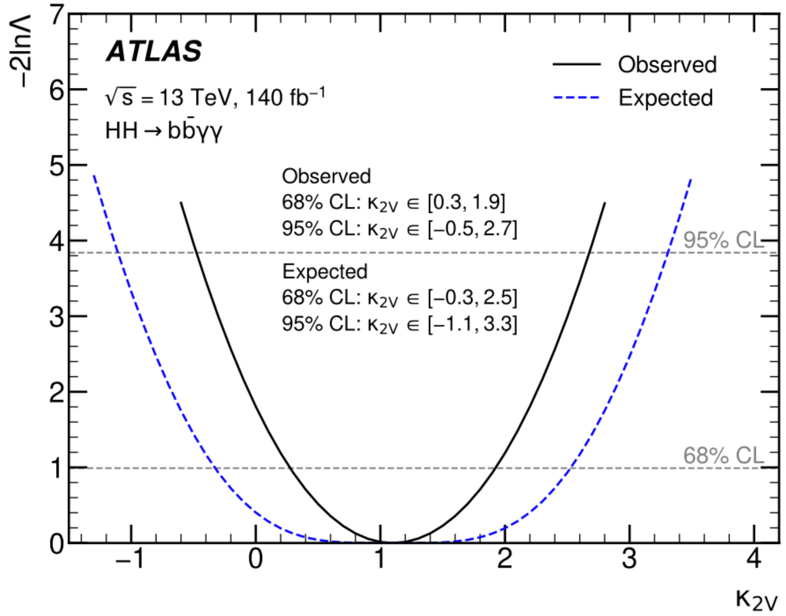


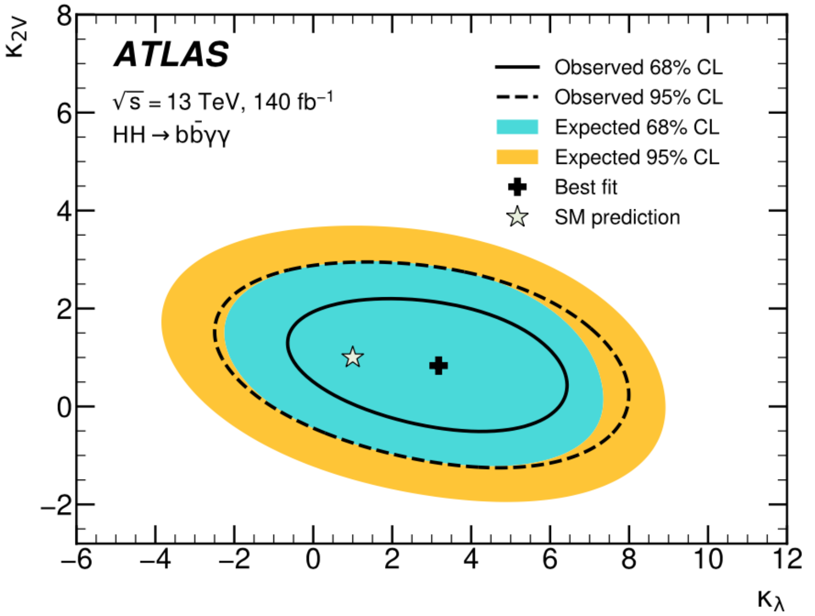
(g) High Mass 3

Results

- No evidence of signal is found!
- The upper limit of HH signal strength @ 95 CL is **4 of SM** preduction.
- The observed constraint @95 CL is **[-1.4, 6.9] for $\boldsymbol{\kappa_\lambda}$** and **[-0.5, 2.7] for $\boldsymbol{\kappa_{2V}}$**.







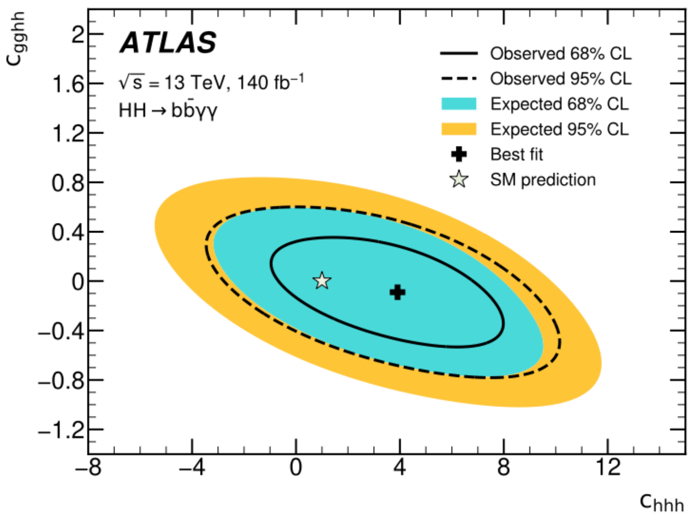
HEFT interpretation

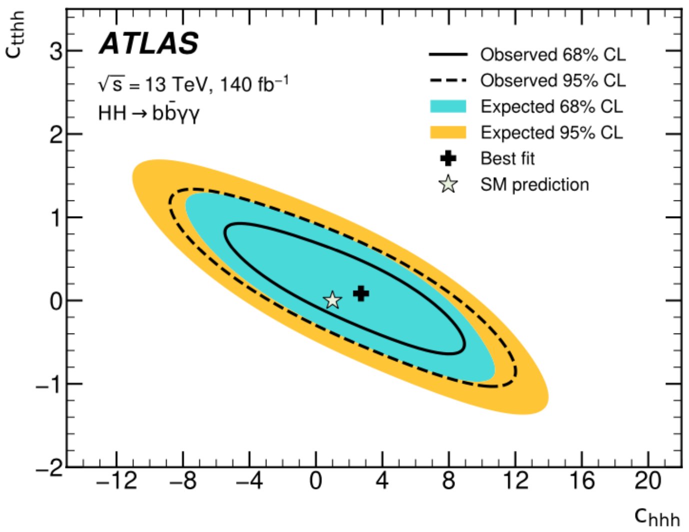
- Effective field theory (EFT) extension to the SM.
- Focus on 3 Wilson coefficients: c_{hhh}, c_{tthh}, c_{gghh}
- Consider 7 benchmark models

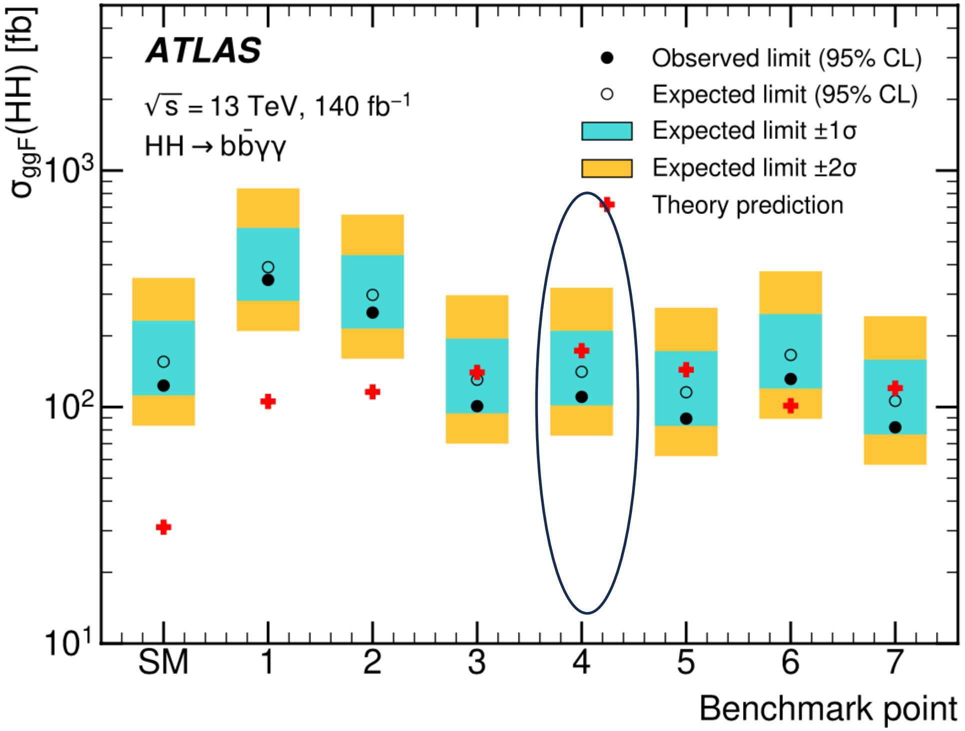
Benchmark	c_{hhh}	c_{tth}	c_{ggh}	c_{gghh}	c_{tthh}
SM	1.00	1.00	0	0	0
1	5.11	1.10	0	0	0
2	6.84	1.03	−1/3	0	1/6
3	2.21	1.05	1/2	1/2	−1/3
4	2.79	0.90	−1/3	−1/2	−1/6
5	3.95	1.17	1/6	−1/2	−1/3
6	−0.68	0.90	1/2	1/4	−1/6
7	−0.10	0.94	1/6	−1/6	1

Wilson coefficient	95% CL Observed
c_{hhh}	$[-1.7\ ,7.7\ ]$
c_{tthh}	$[-0.28, 0.73]$
c_{gghh}	$[-0.42, 0.52]$

Benchmark 4 model is excluded for the first time @ 95 CL.





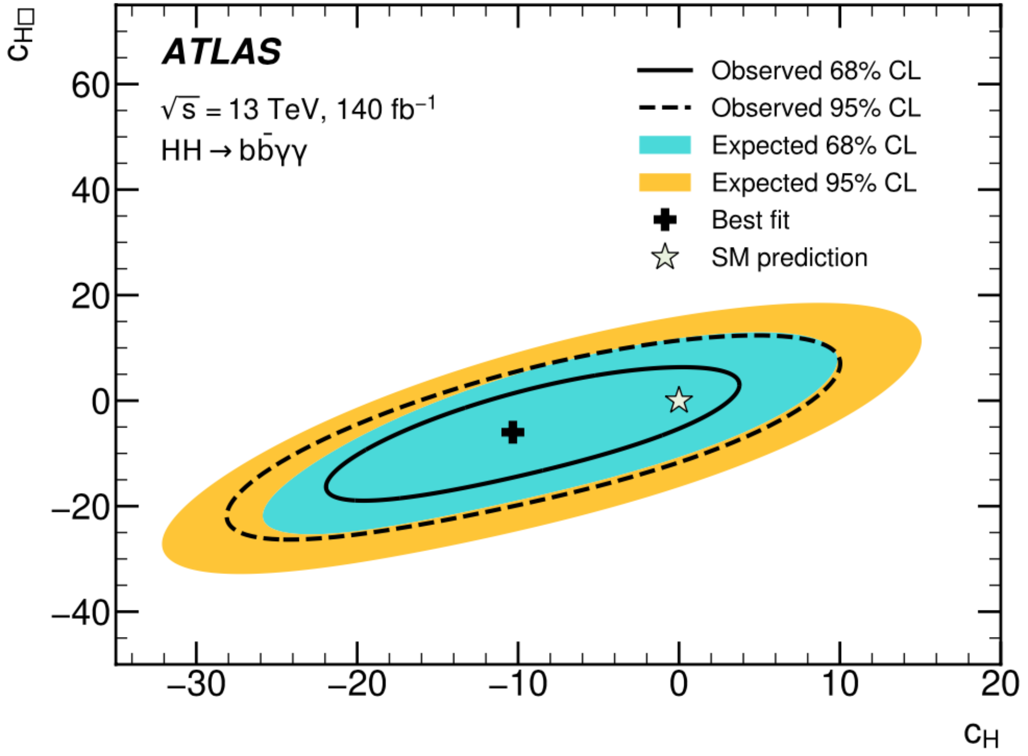


SMEFT interpretation

- Another EFT extension to the SM
- Consider only 2 dim-6 operators: cH and cHbox, others not sensitive.
- Include their contributions to both HH and H cross sections
- Consider linear + quadratic terms

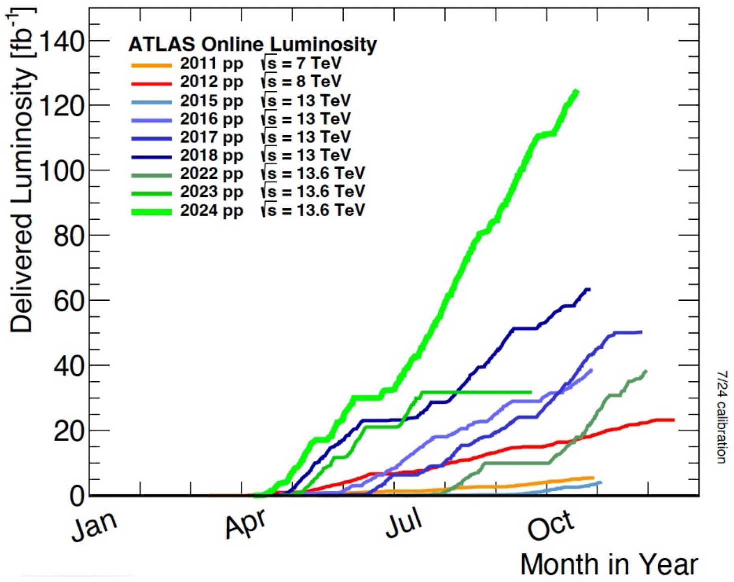
$$(H^\dagger H)^3 \text{ and } (H^\dagger H)\Box(H^\dagger H)$$

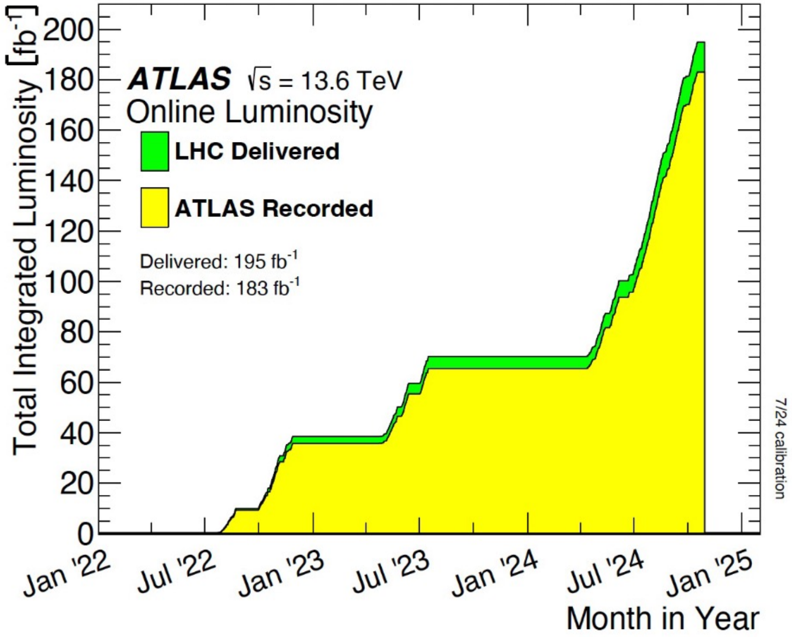
Wilson coefficient	95% CL Observed
c_H	$[-14.4,\ 6.2]$
$c_{H\Box}$	$[-\ 9.4, 10.2]$



Very-near future prospect for bbyy

- Run2 + Run3: larger luminosity (expeted 350 ifb at 13.6 TeV)
- Better b-tagging algorithm: DL1r → GN2
- More photon ID working points (+medium)
- Great efforts on finer event categorization
- Early results expected in 2025





Summary

- Search for **nonresonant HH production** using the **bbyy final state** based on full Run2 dataset
- Obtain the stringent constraint **[-1.4, 6.9] for $\boldsymbol{\kappa_\lambda}$ and [-0.5, 2.7] for $\boldsymbol{\kappa_{2V}}$**
- Interpret our measurements in **HEFT** and **SMEFT** frameworks
- **More exciting results** will come soon with Run2 + Run3 datasets