EFT interpretations in HH

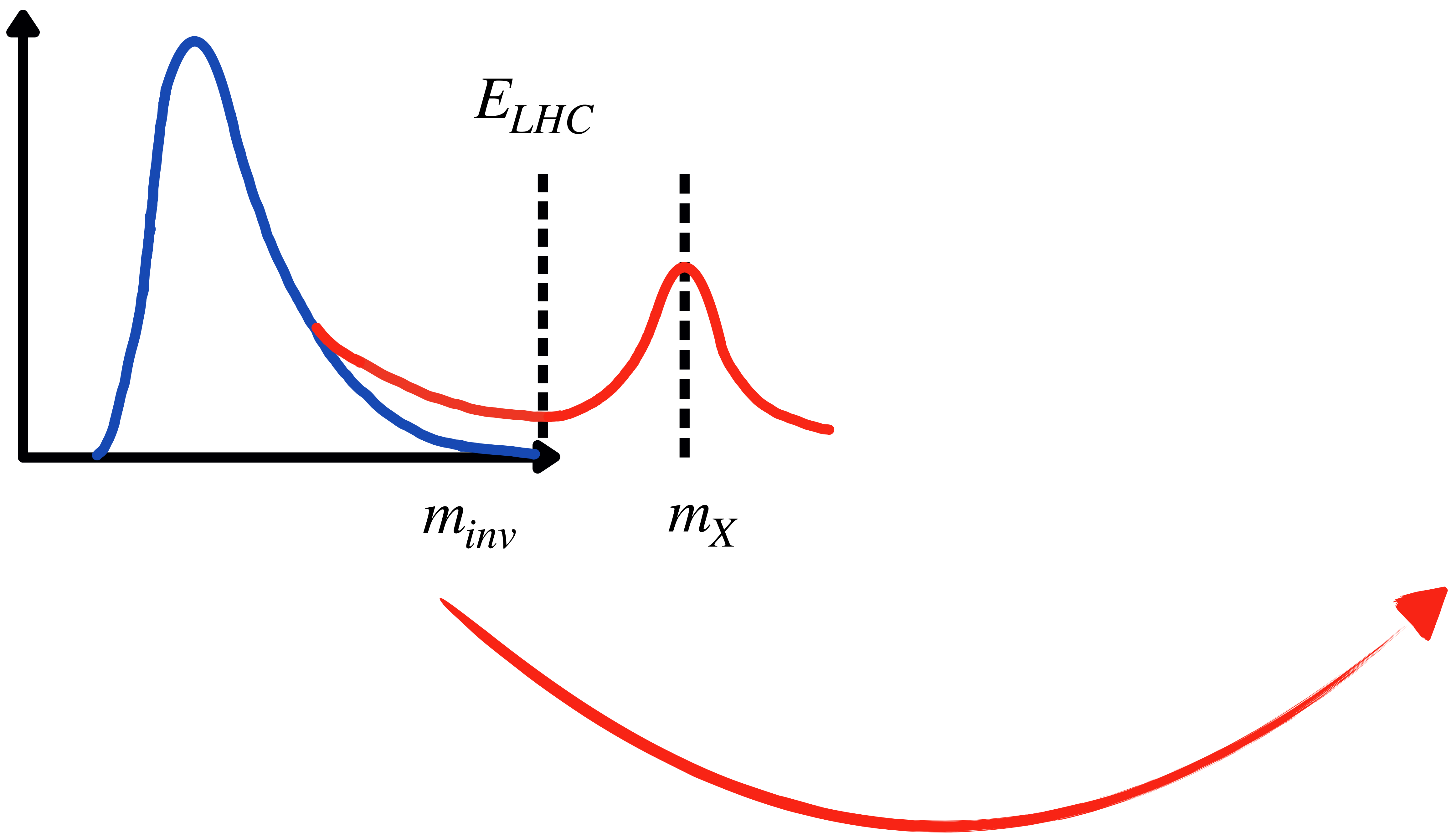
Anna Tegetmeier
on behalf of the ATLAS collaboration

Multi-Boson Interactions, 25-27 September 2024

Introduction

Introduction

- Effective Field Theories (EFTs) can be used to parametrize BSM physics at energy scales above the range of the LHC



What is seen in a lot of analyses:

- BSM physics leads to deviations in the tales of the distributions

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- Full Run 2 di-Higgs ATLAS analyses included **EFT interpretations for di-Higgs searches** for the **first time**!

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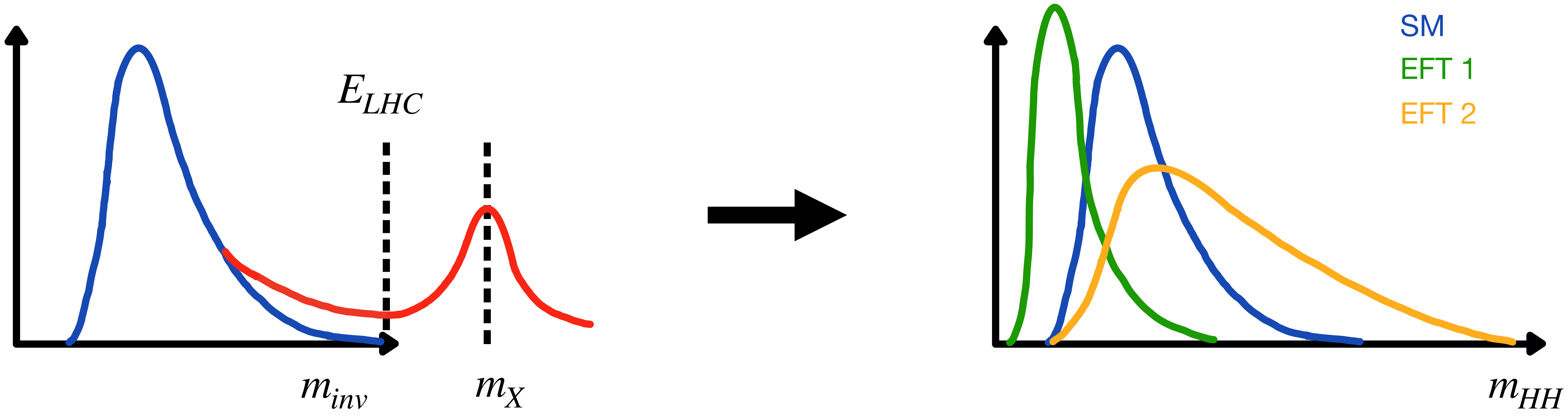
- What can be seen for di-Higgs
  - EFT effects are not only visible in the tails of the m_{HH} distribution
  - Can lead to enhancements at **lower** as well as **higher** m_{HH} values



Comparison HEFT and SMEFT

- Two different EFT parameterizations are considered in di-Higgs searches
  - SM effective field theory (**SMEFT**)
  - Higgs effective field theory (**HEFT**)

Comparison HEFT and SMEFT

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SMEFT

- BSM physics is described by an effective Lagrangian

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + ...$$

HEFT

- Organization of the HEFT Lagrangian is guided by chiral perturbation theory

$$\mathcal{L}_{\mathrm{HEFT}} = -c_{hhh}\frac{m_h^2}{2\nu}h^3 - m_t\left(c_{tth}\frac{h}{\nu} + c_{tthh}\frac{h^2}{\nu^2}\right)t\bar{t} + \frac{\alpha_S}{8\pi}\left(c_{ggh}\frac{h}{\nu} + c_{gghh}\frac{h^2}{\nu^2}\right)G_{\mu\mu}G^{\alpha,\mu\nu}$$

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- Higgs boson is in a **doublet**

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EFT Analyses

- **ATLAS analyses (SMEFT and HEFT):**
  - $HH \rightarrow b\bar{b}b\bar{b}$ (Phys. Rev. D 108 (2023) 052003)
  - $HH \rightarrow b\bar{b}\tau\tau$ (Phys. Rev. D 110 (2024) 032012)
  - $HH \rightarrow b\bar{b}\gamma\gamma$ (JHEP 01 (2024) 066)

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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%

The three golden channels of di-Higgs:

$bbbb$: Large statistics but difficult multijet background

$bb\tau\tau$: Good balance between statistic and background

$bb\gamma\gamma$: Small statistics but very clear final state

ATLAS analyses

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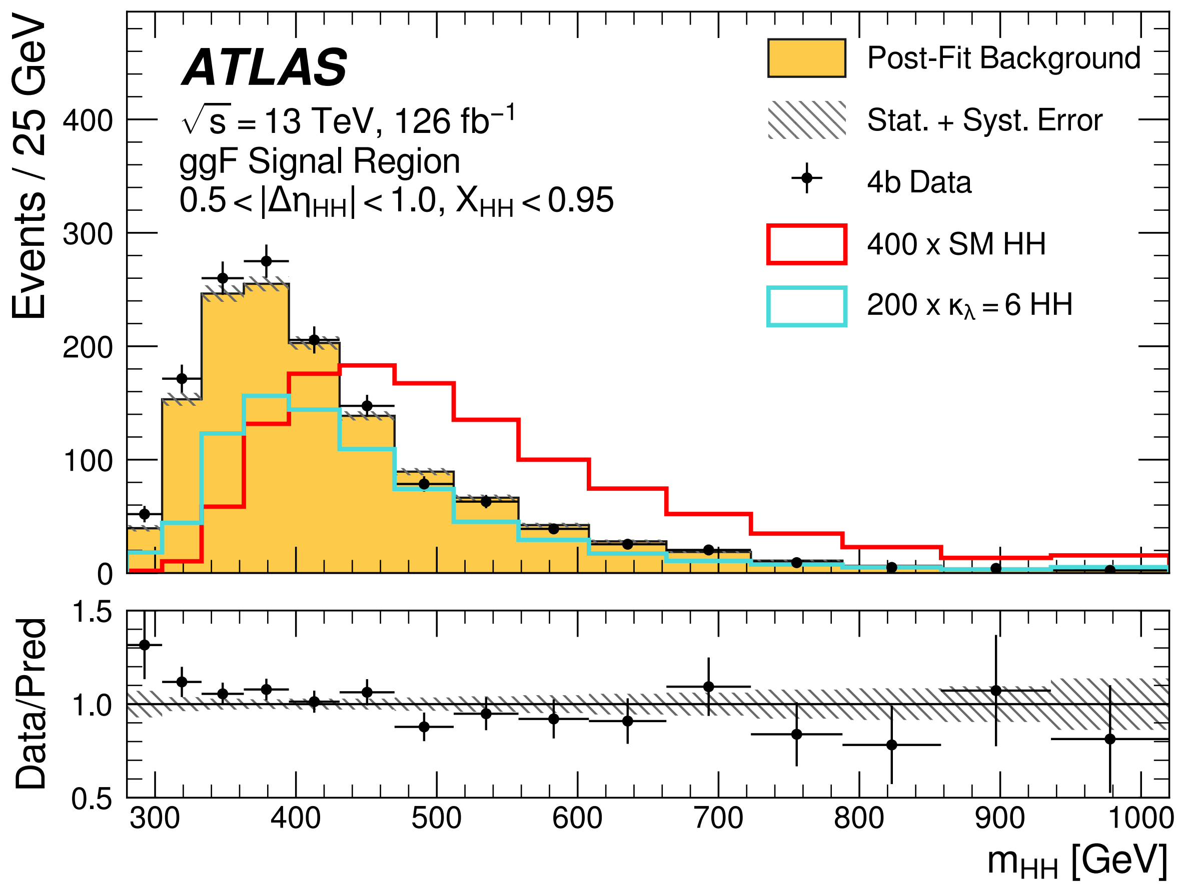

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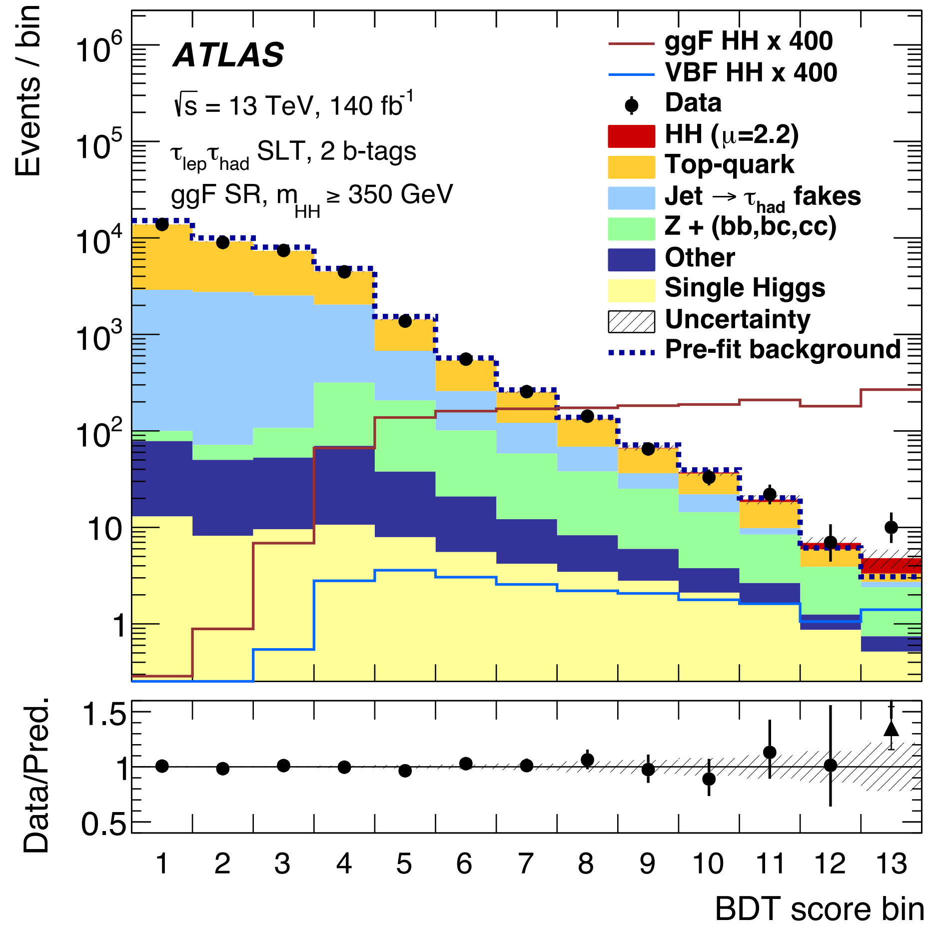

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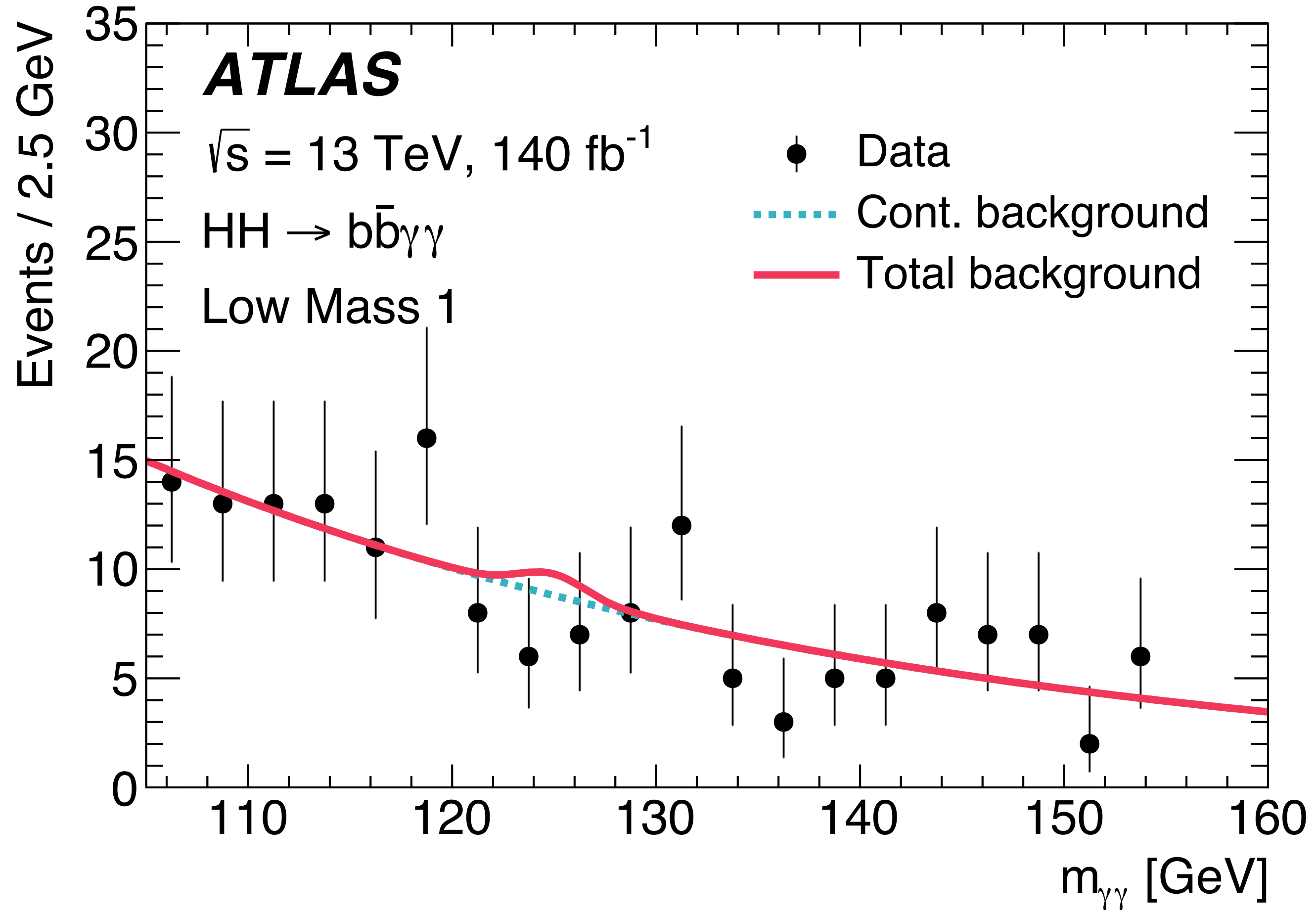

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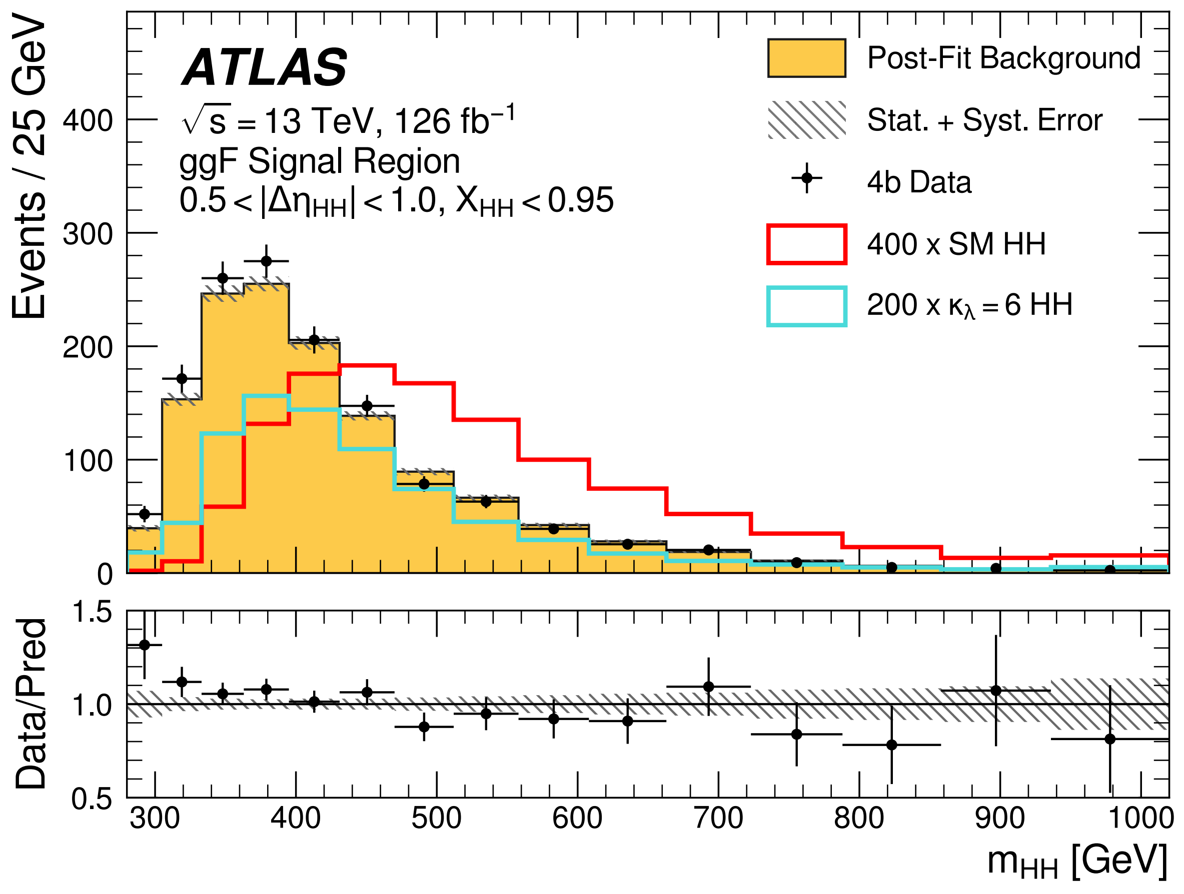
  - $|\Delta\eta_{HH}|$, X_{HH} (di-Higgs discriminant)



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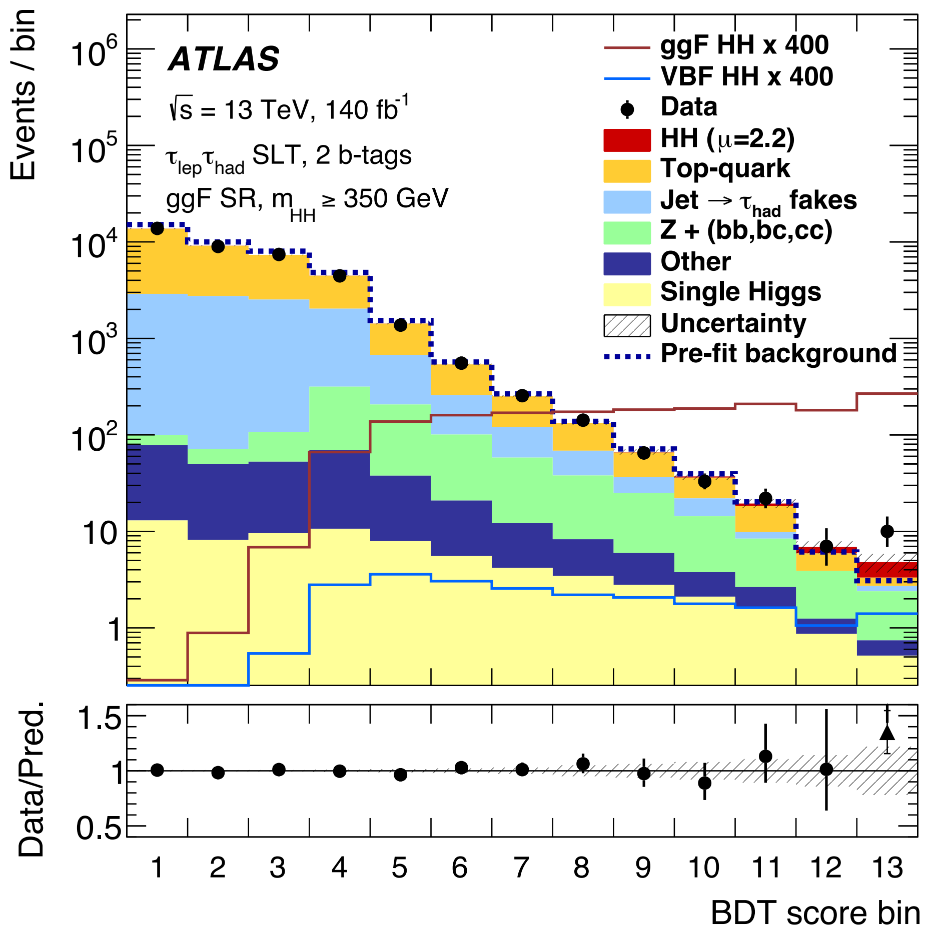

bbγγ

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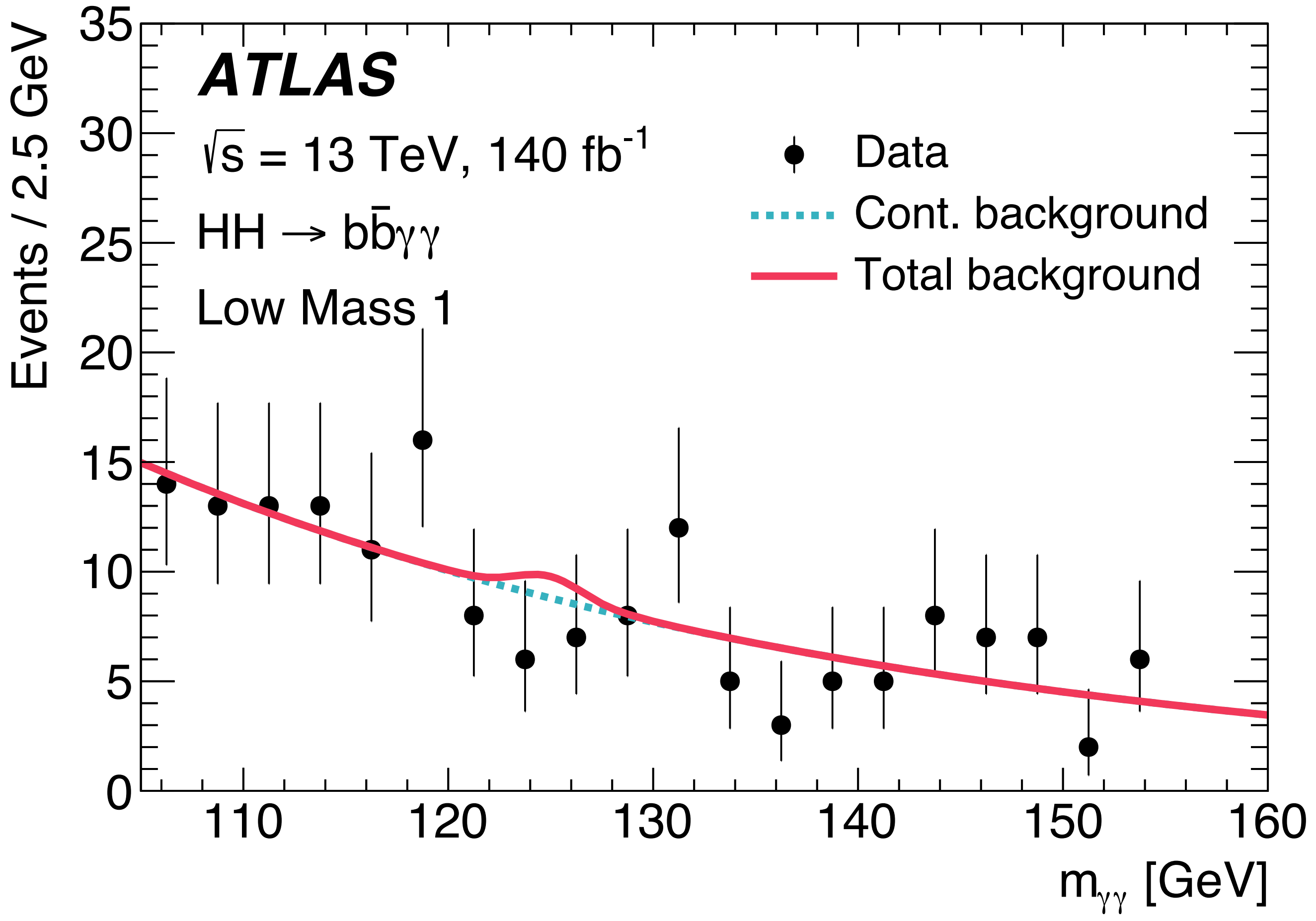
- In total 7 regions
  - Low-$m^*_{bb\gamma\gamma}$ vs. high-$m^*_{bb\gamma\gamma}$
  - BDT score



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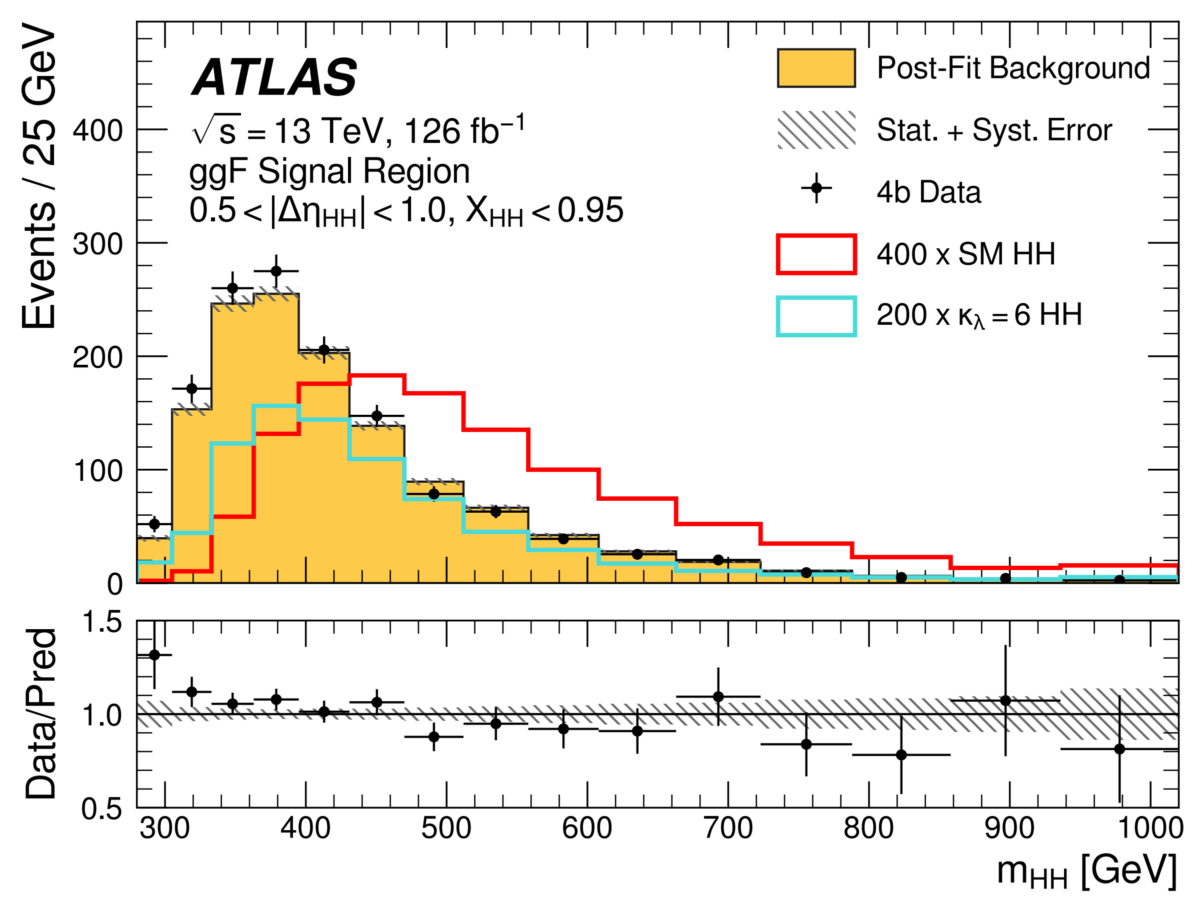

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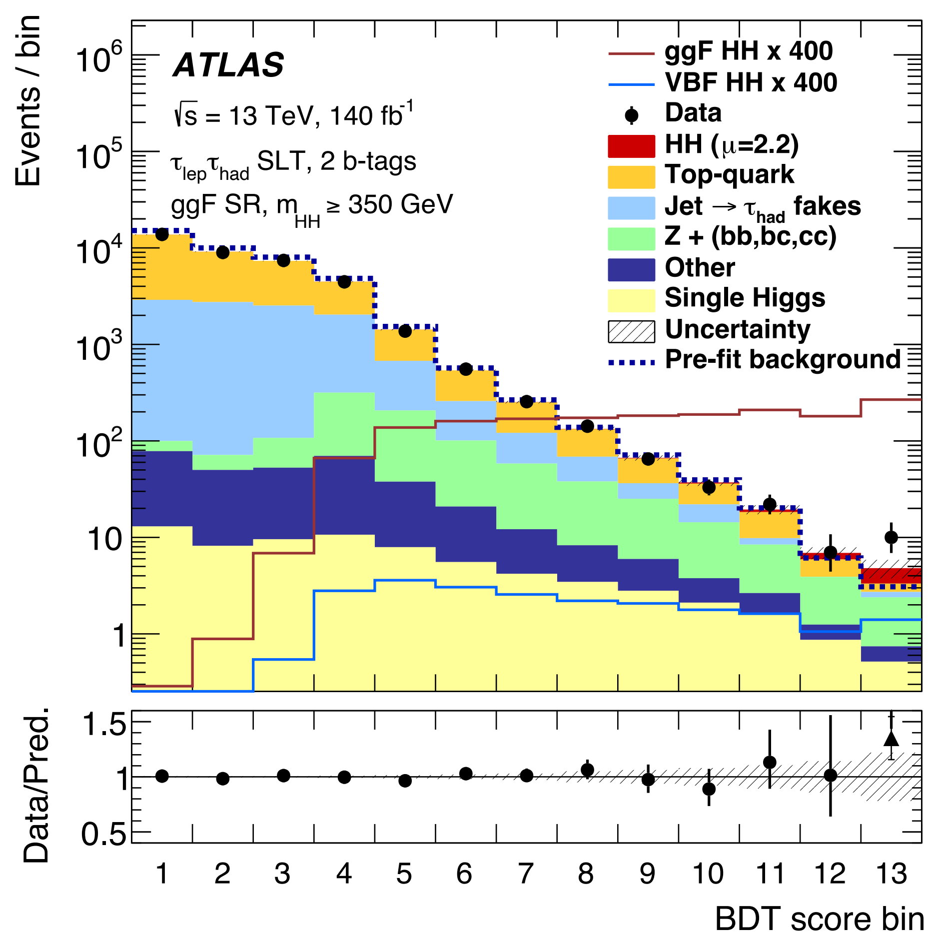

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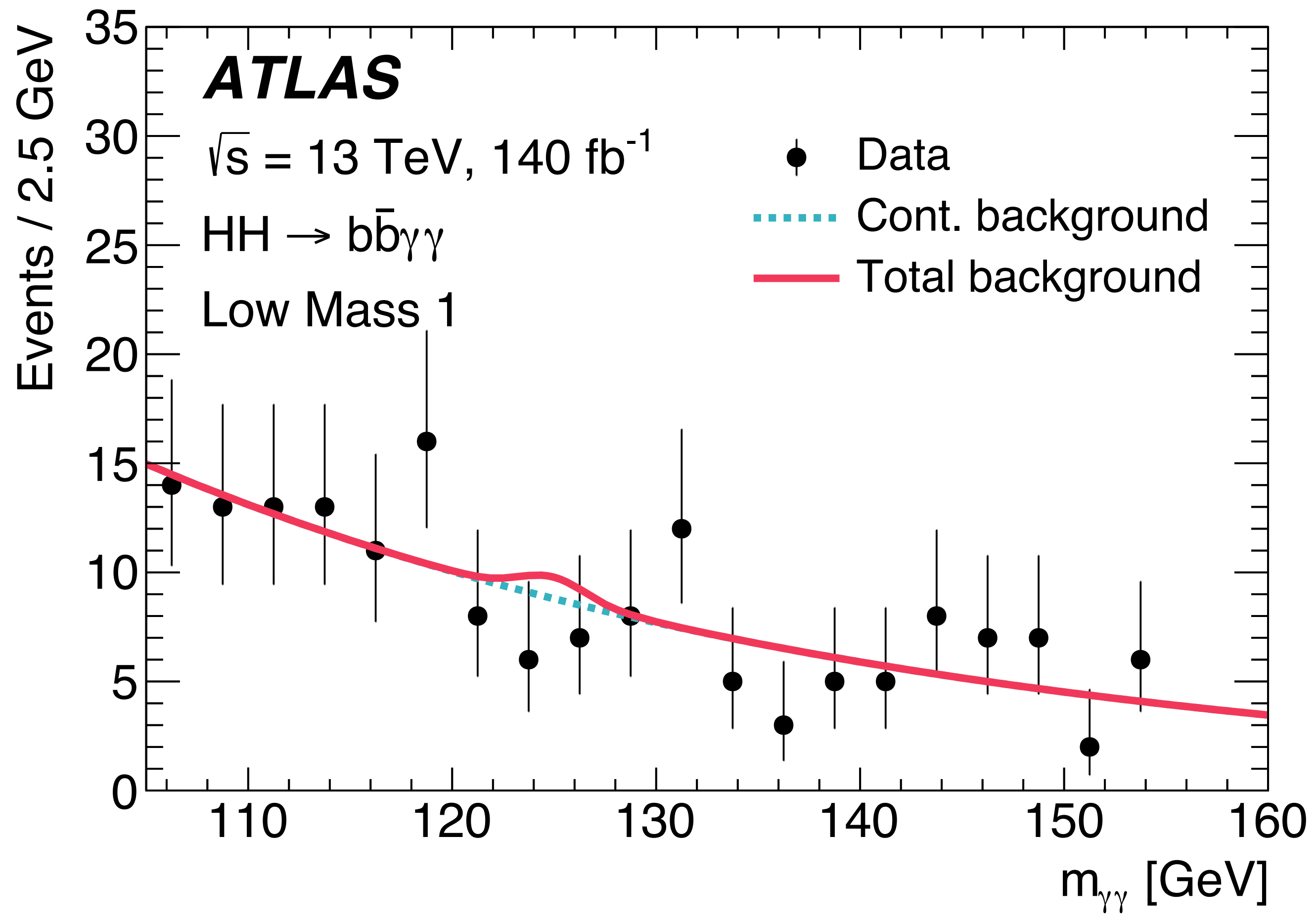

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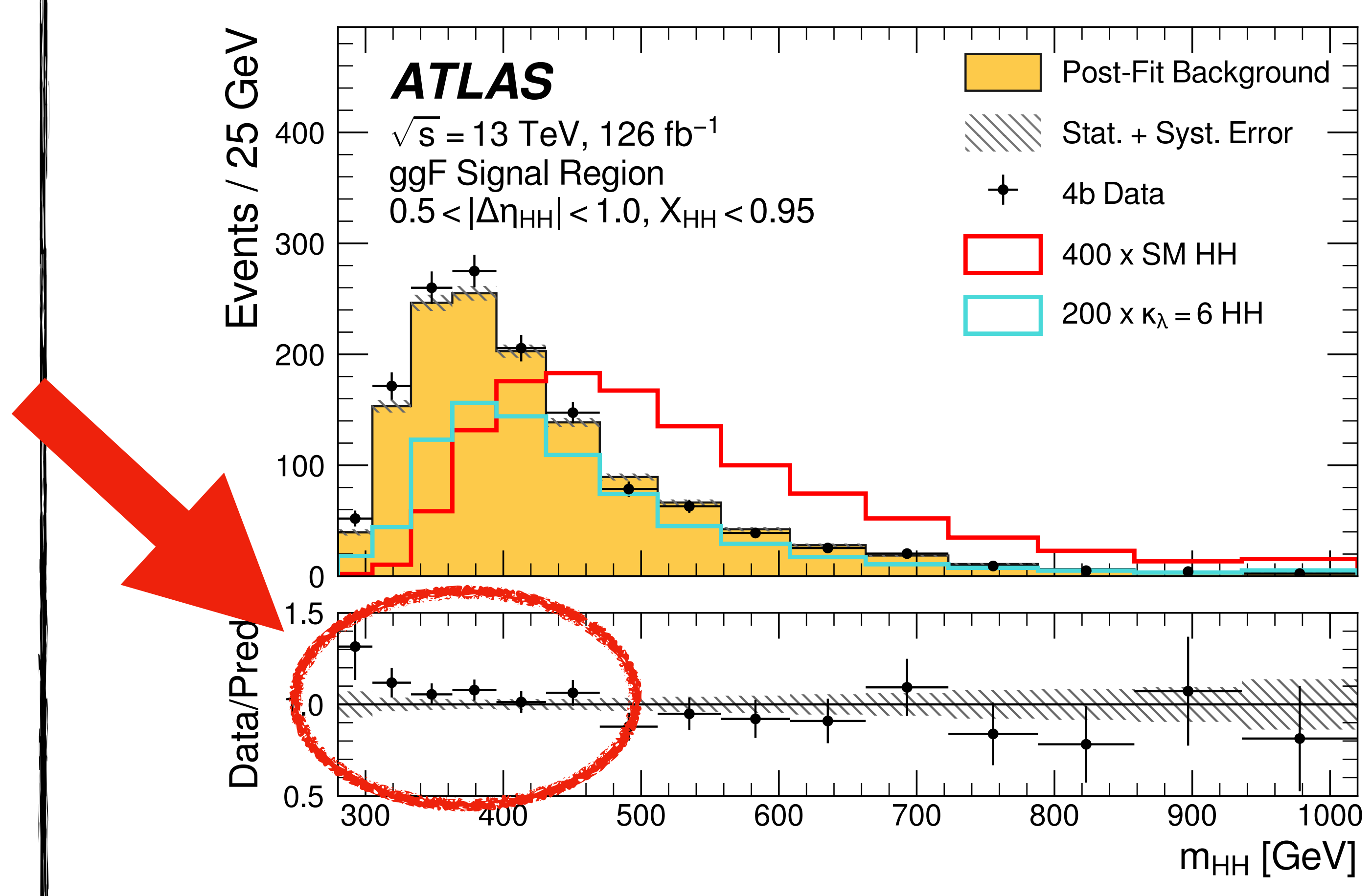

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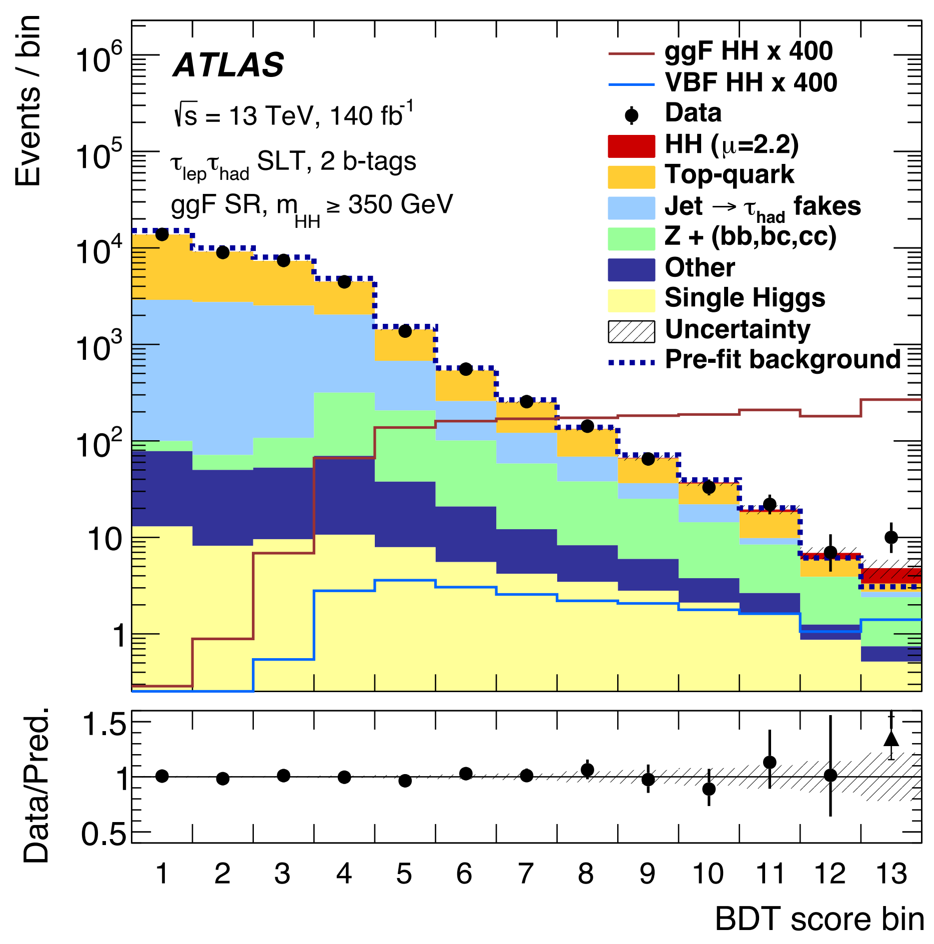

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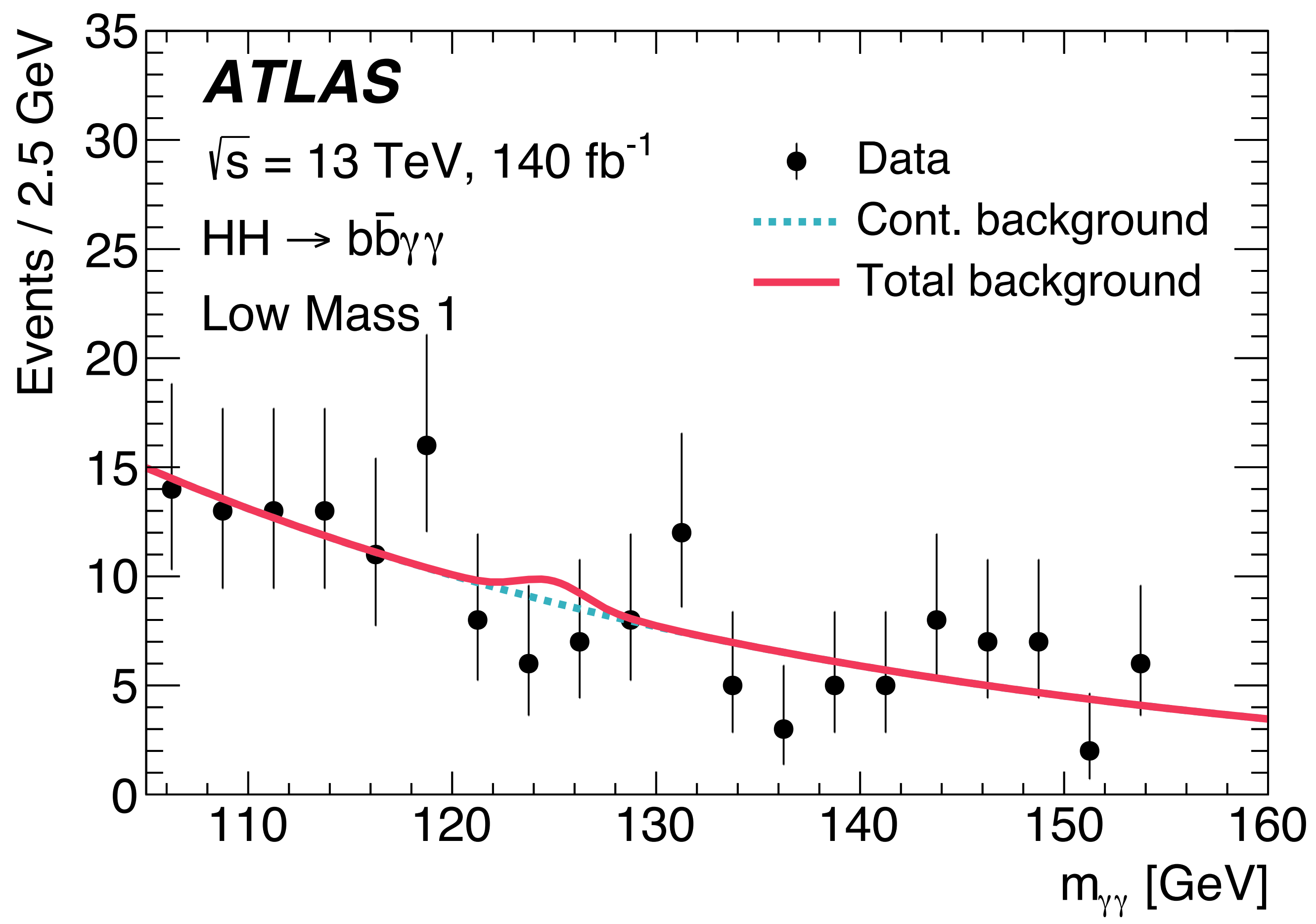

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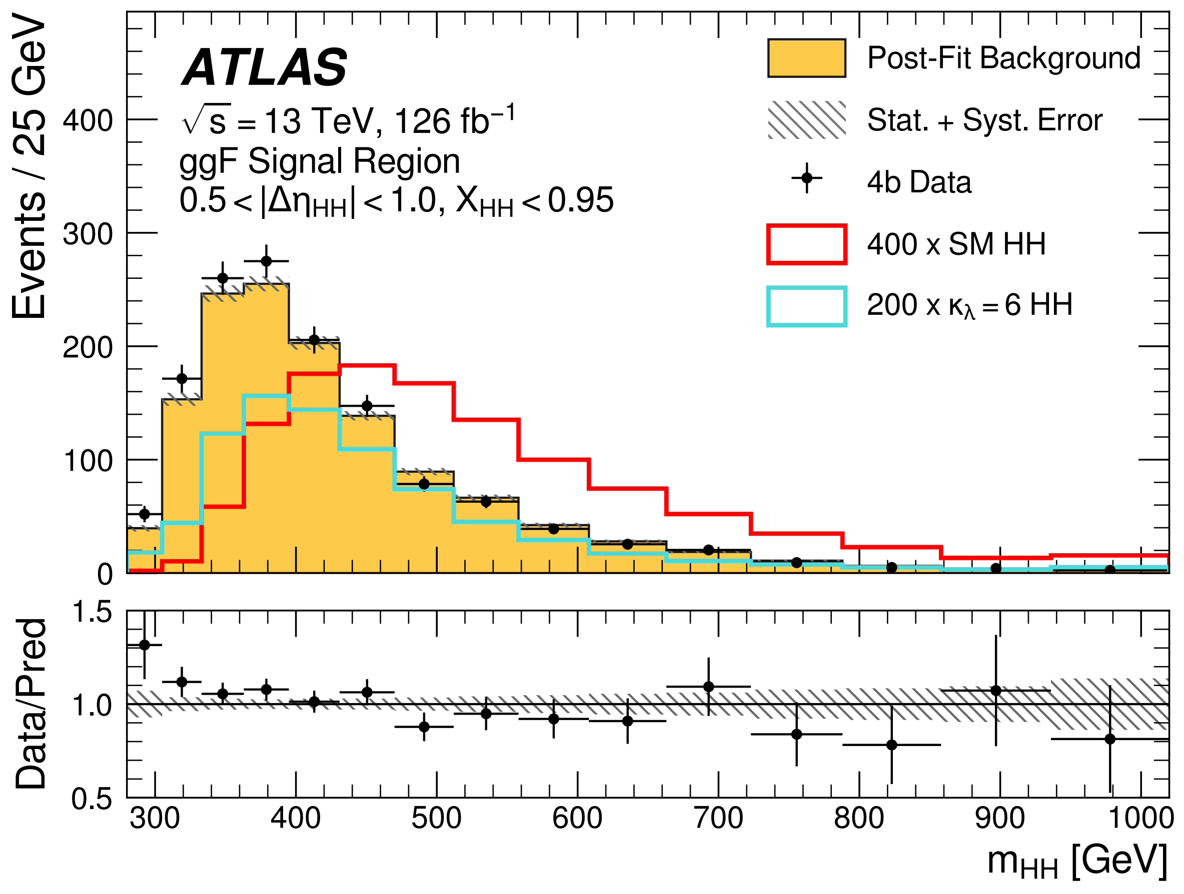

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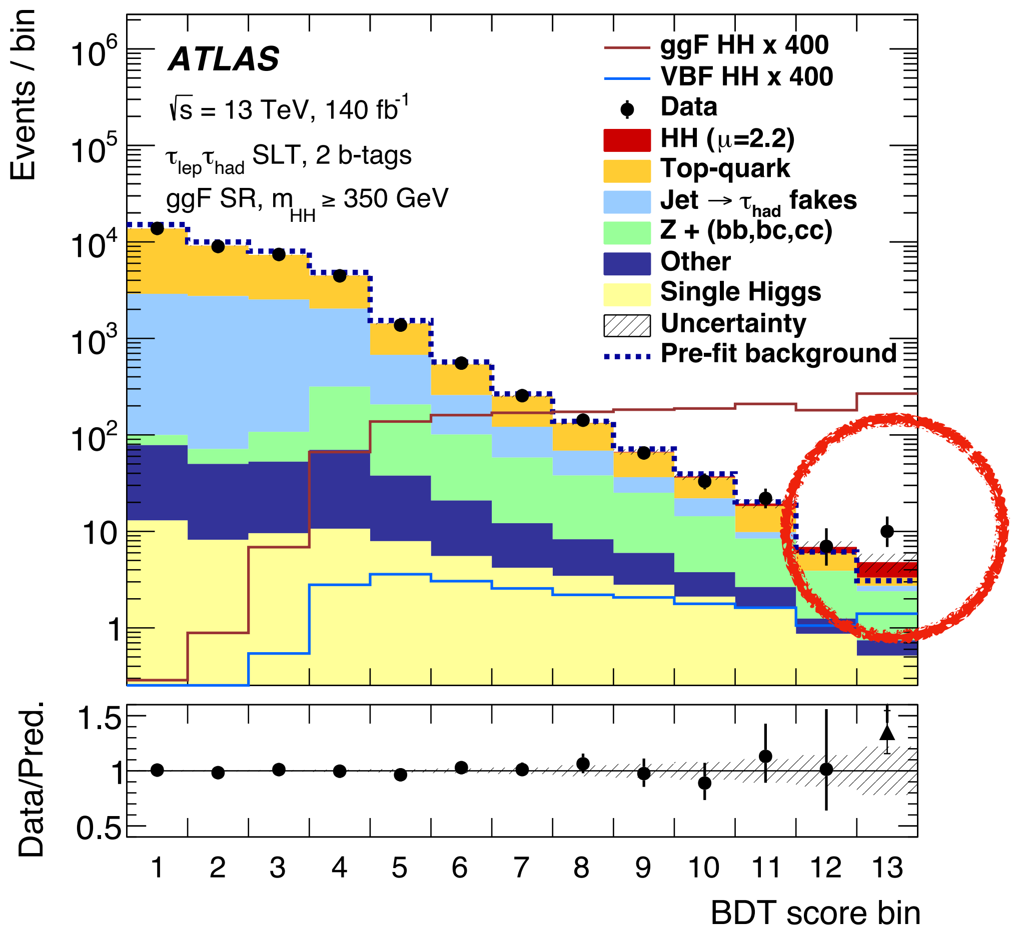

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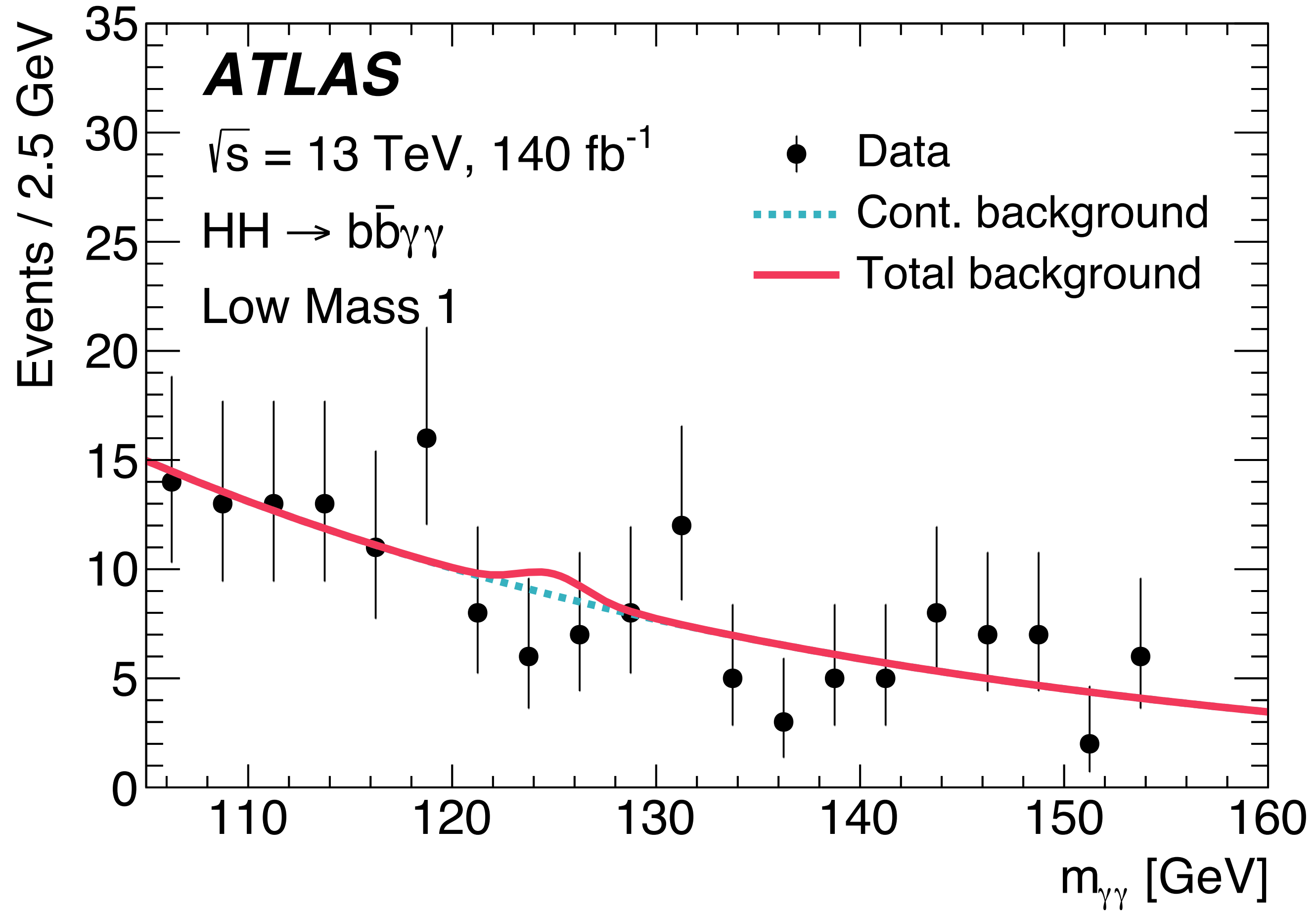

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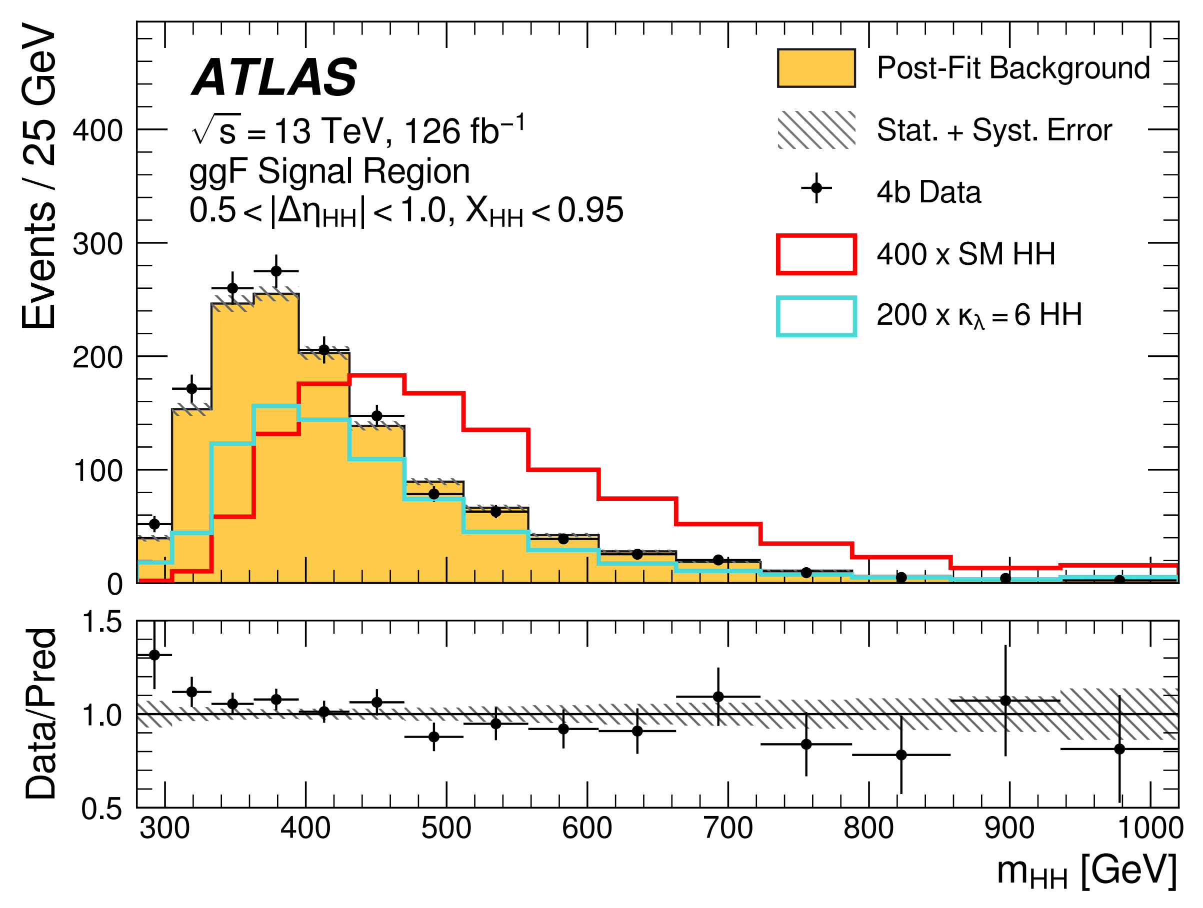

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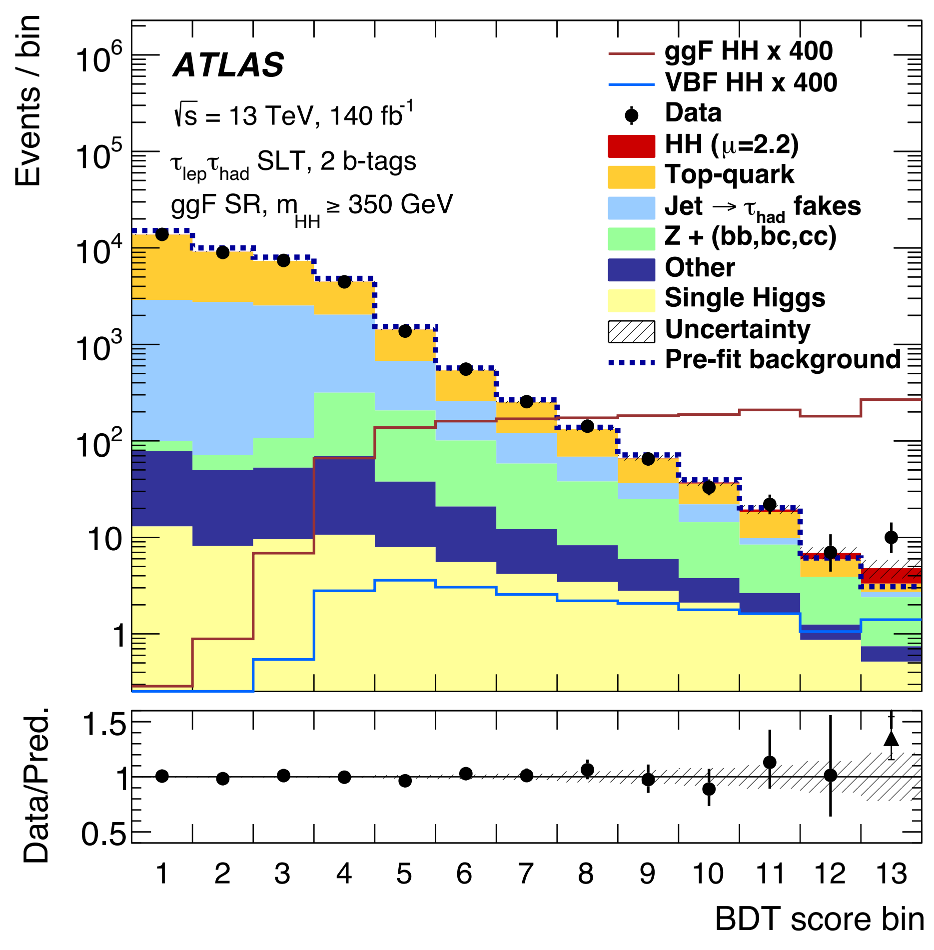

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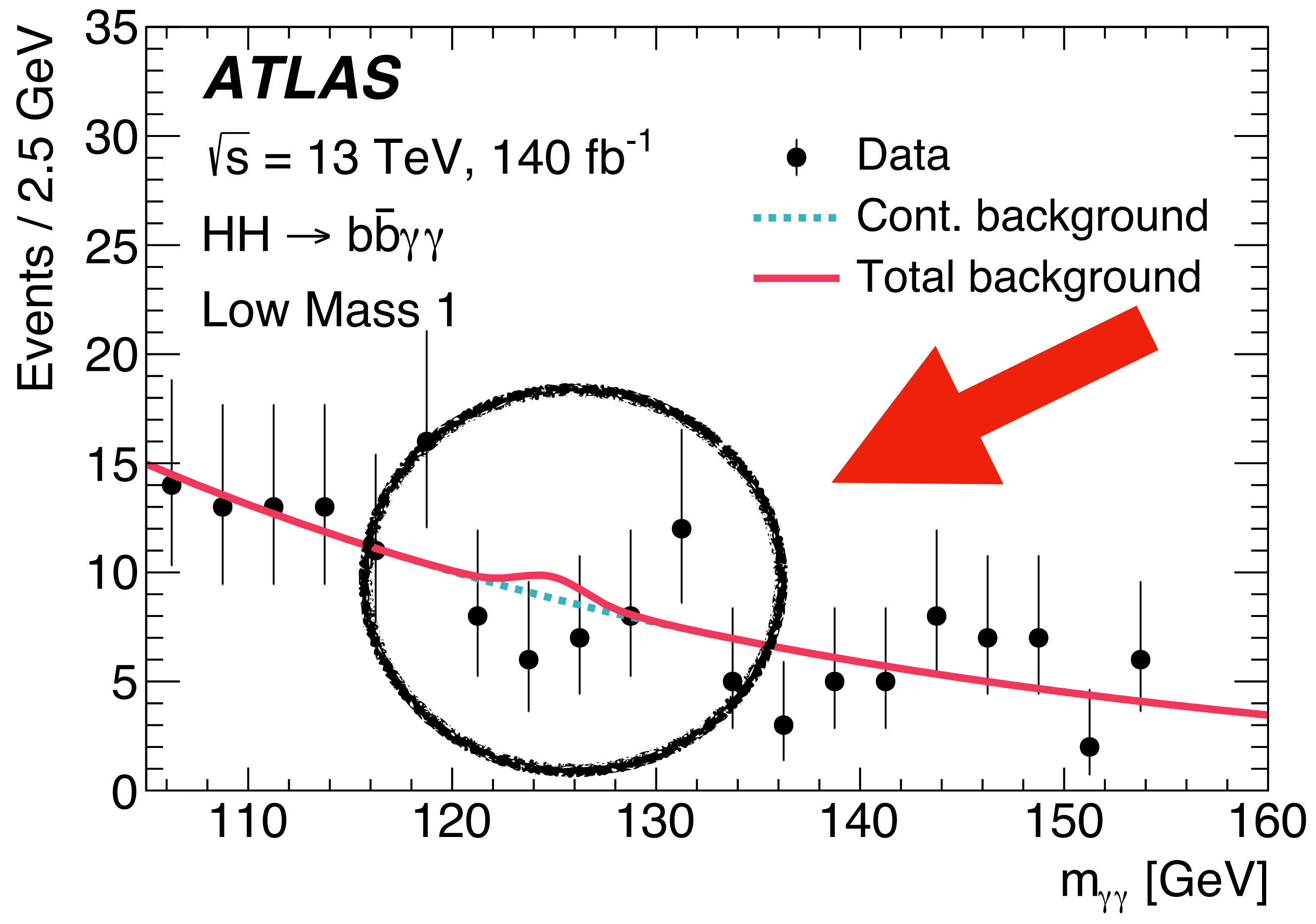
- Unbinned fits to the $m_{\gamma\gamma}$ distribution
- Deficit in data in the most sensitive signal regions



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- **ATLAS combinations (HEFT)**
  - $HH \to (b\bar{b}\gamma\gamma + b\bar{b}\tau\tau)$ combination (ATL-PHYS-PUB-2022-019)
  - HH combination (Phys. Rev. Lett. 133 (2024) 101801)
    - Use the $bbbb$, $bb\gamma\gamma$ and $bb\tau\tau$ channel

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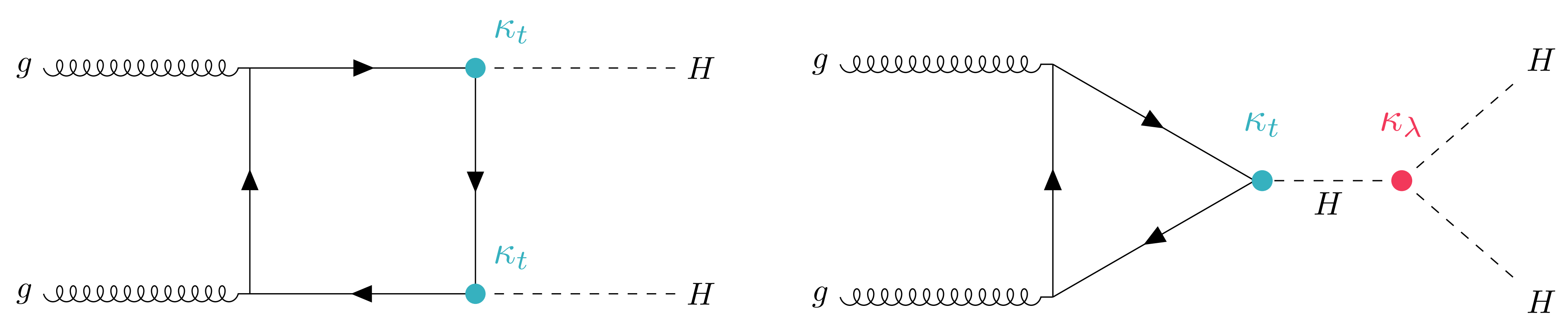
Difference to the main analysis

- Only the **ggF production mode** is considered
- VBF production mode is ignored
  - Much smaller cross-section
  - Not sensitive to most of the considered operators in HEFT
  - Cancellations between the VHH and VVHH vertices in SMEFT

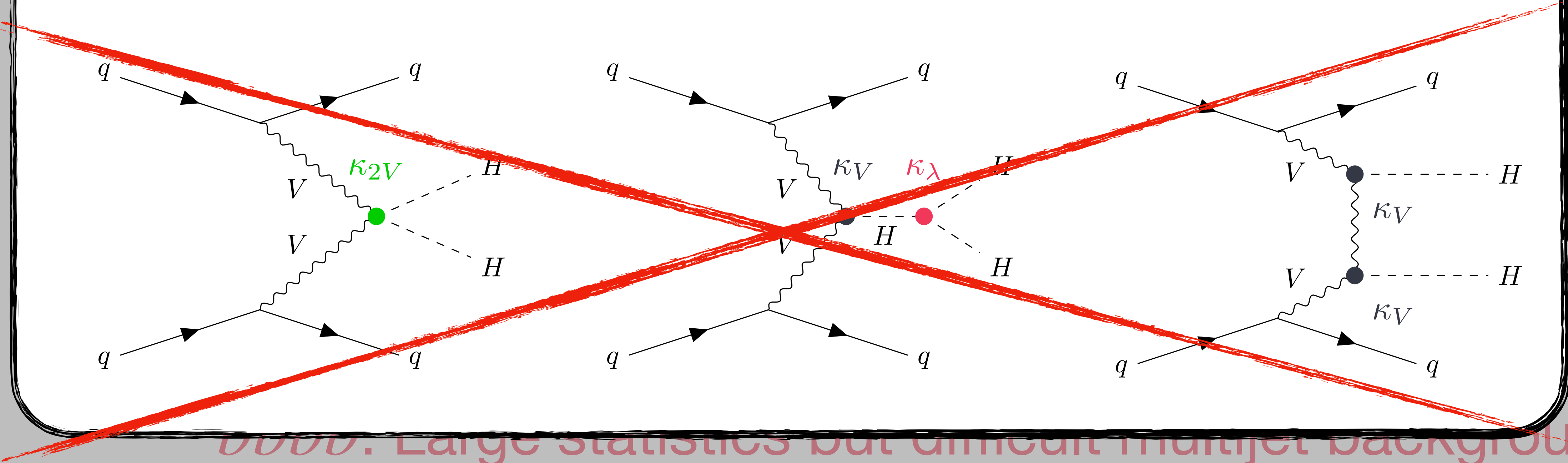
		ττ	ZZ	γγ
ττ	7.3%	2.7%	0.39%	

- **ATLAS combinations (HEFT)**

gluon-gluon Fusion (ggF)



Vector Boson Fusion (VBF)



... Single
... and di-Higgs couplings to fermions and gluons
  - EFT effects on single Higgs can be ignored

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EFT predictions from Monte-Carlo

- Predictions for different EFT scenarios are obtained by using an **event-level reweighting technique** based on the m_{HH} distribution with the **SM ggF sample**
  - The inclusive and differential HH production cross section for a set of Wilson coefficients can be parametrized with a polynomial
  - The coefficients A can be determined by generating a set of truth-level MC samples
  - With the polynomials weights are defined that allow to reweight the SM ggF events to any wanted combination of the Wilson coefficients

- **Amplitudes for SMEFT**
  - $bbbb$: Madgraph samples at LO using the SMEFT@NLO model additional k-Factors are applied to account for NLO effects
  - $bb\gamma\gamma, bb\tau\tau$: Powheg samples at NLO using the SMEFT@NLO model

- **Amplitudes for HEFT**
  - Amplitudes are taken from literature (NLO) (bbbb, bbyy/bbtautau)

- $bb\tau\tau$ additionally uses a linear combination method based on six (SMEFT) or ten (HEFT) reco-level base samples produced with Powheg

$$
\begin{aligned}
&\sigma_{hh}^{\mathrm{NLO}}(c_{hhh}, c_{thh}, c_{tthh}, c_{ggh}, c_{gghh}) \\
&= Poly(\mathbf{c}, \mathbf{A}) \\
&= A_1 c_{thh}^4 + A_2 c_{tthh}^2 + (A_3 c_{thh}^2 + A_4 c_{ggh}^2) c_{hhh}^2 \\
&+ A_5 c_{gghh}^2 + (A_6 c_{tthh} + A_7 c_{thh} c_{hhh}) c_{thh}^2 \\
&+ (A_8 c_{thh} c_{hhh} + A_9 c_{ggh} c_{hhh}) c_{tthh} + A_{10} c_{tthh} c_{gghh} \\
&+ (A_{11} c_{ggh} c_{hhh} + A_{12} c_{gghh}) c_{thh}^2 \\
&+ (A_{13} c_{hhh} c_{ggh} + A_{14} c_{gghh}) c_{thh} c_{hhh} \\
&+ A_{15} c_{ggh} c_{gghh} c_{hhh} + A_{16} c_{thh}^3 c_{ggh} \\
&+ A_{17} c_{thh} c_{tthh} c_{ggh} + A_{18} c_{thh} c_{ggh}^2 c_{hhh} \\
&+ A_{19} c_{thh} c_{ggh} c_{gghh} + A_{20} c_{thh}^2 c_{ggh}^2 \\
&+ A_{21} c_{tthh} c_{ggh}^2 + A_{22} c_{ggh}^3 c_{hhh} \\
&+ A_{23} c_{ggh}^2 c_{gghh}
\end{aligned}
$$

$$
\frac{d\sigma_{hh}^{\mathrm{NLO}}}{dm_{hh}}(c_{hhh}, c_{thh}, c_{tthh}, c_{ggh}, c_{gghh}) = Poly(\mathbf{c}, d\mathbf{A}|m_{hh})
$$

$$
w_{\mathrm{HEFT}} = \frac{Poly(\mathbf{c}, d\mathbf{A}|m_{hh})}{Poly(\mathbf{c}_{\mathrm{SM}}, d\mathbf{A}|m_{hh})}
$$

SMEFT

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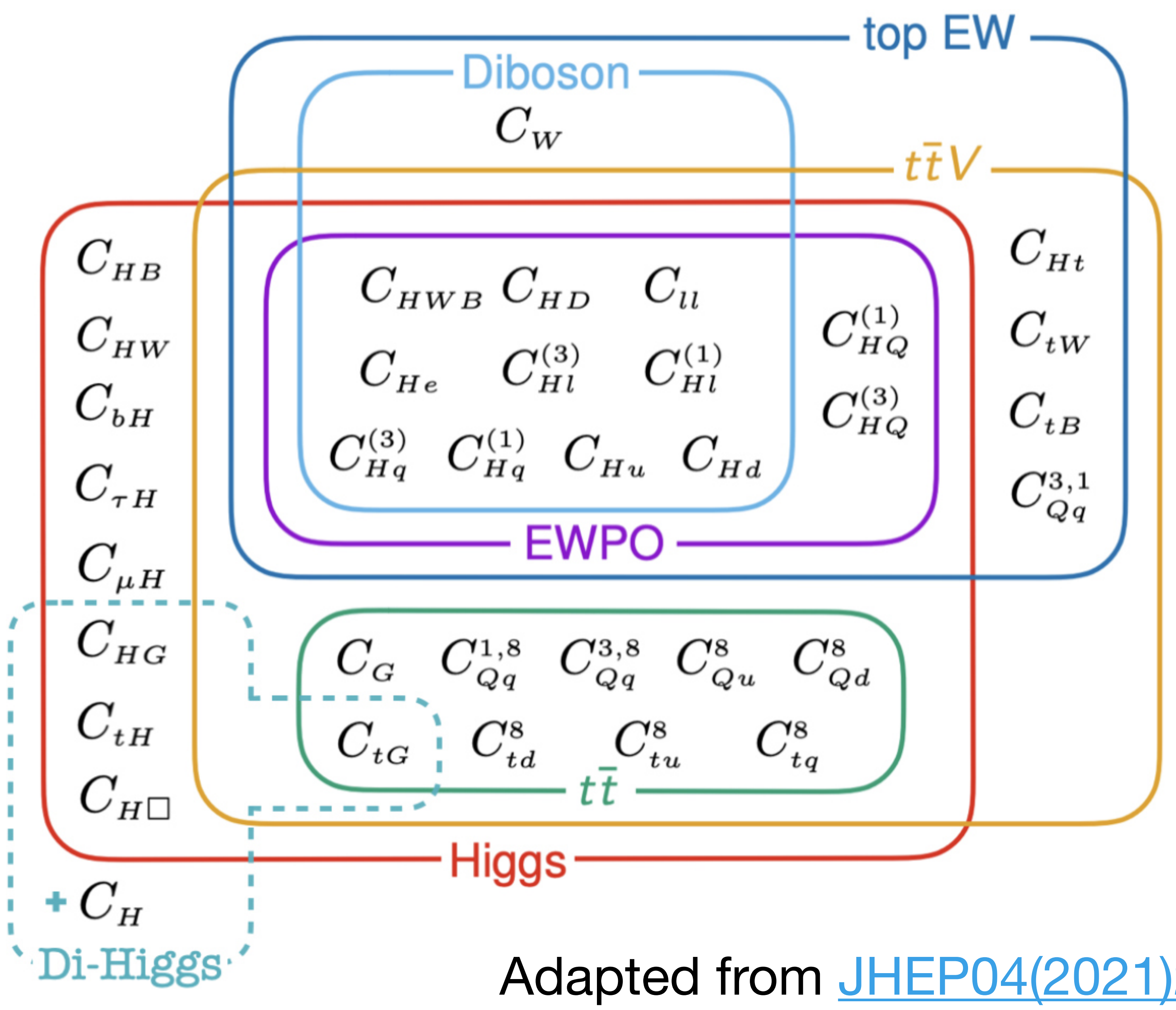
- Run-2 di-Higgs analyses looked at **dim-6** operators
- contributions from both the **linear and the quadratic** terms in the Wilson coefficient expansion are considered
- EFT effects on the **single Higgs background** are **included**
  - $bb\gamma\gamma, bb\tau\tau$: include EFT effects e.g with reweighting technique using $p_T(H)$
  - $bbbb$: EFT effects automatically included in data driven background estimation

SMEFT in di-Higgs

Basis

- Probe operators of the **Warsaw basis**
  - Basis provides a complete set of **dim-6 operators**
  - Used in a broad set of different ATLAS analyses
    - single-Higgs, $t\bar{t}$, Diboson, etc.



Adapted from JHEP04(2021)279

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}	$(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{H}G^A_{\mu\nu}$

Phys. Rev. D 108 (2023) 052003

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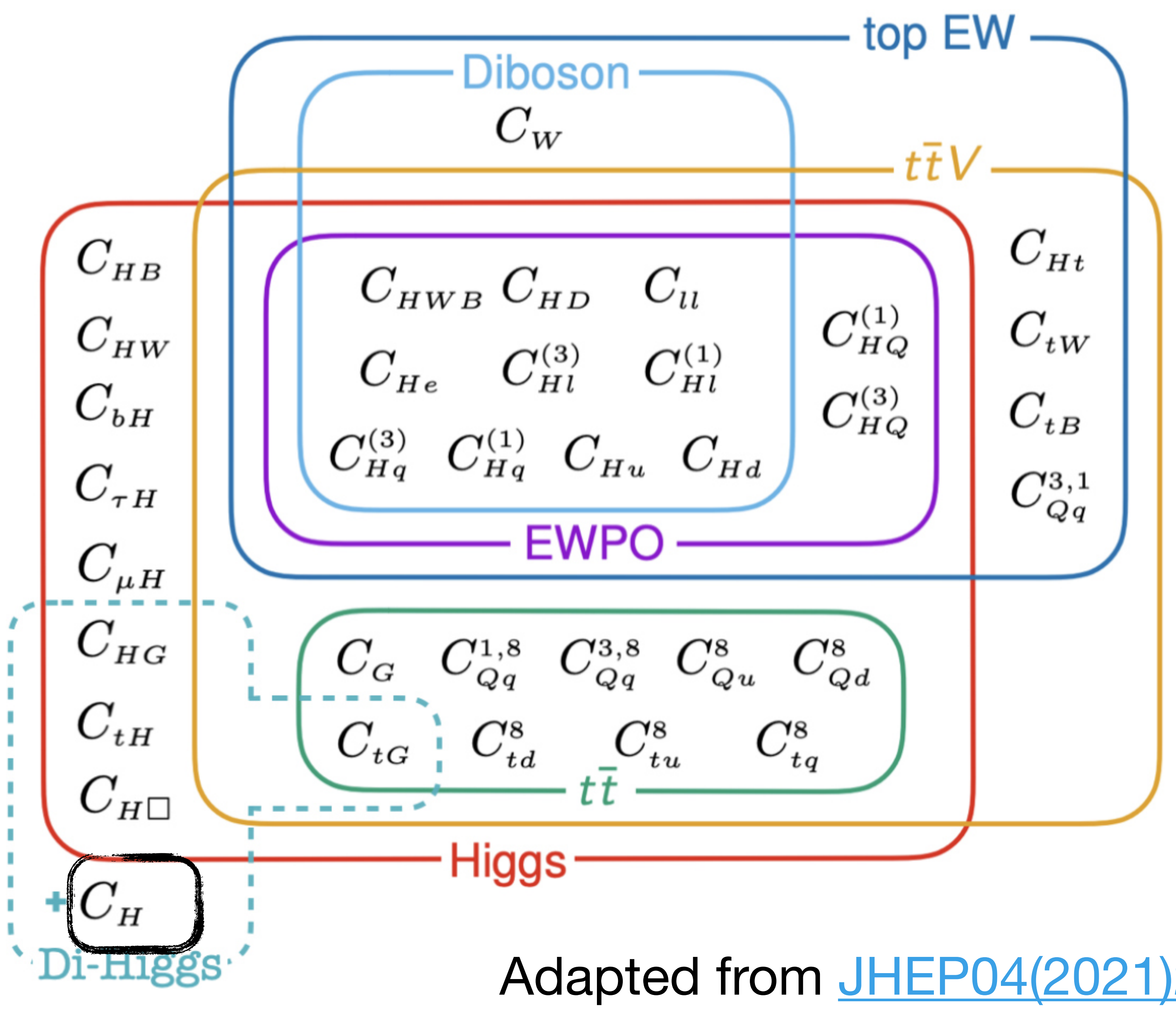

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SMEFT in di-Higgs

- Five operators relevant for di-Higgs:

c_H → **Unique sensitivity from di-Higgs**
affects the Higgs-self coupling

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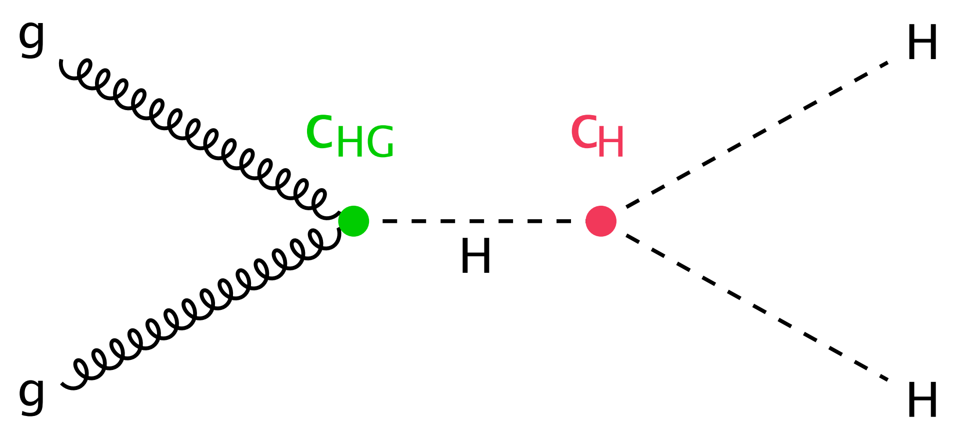

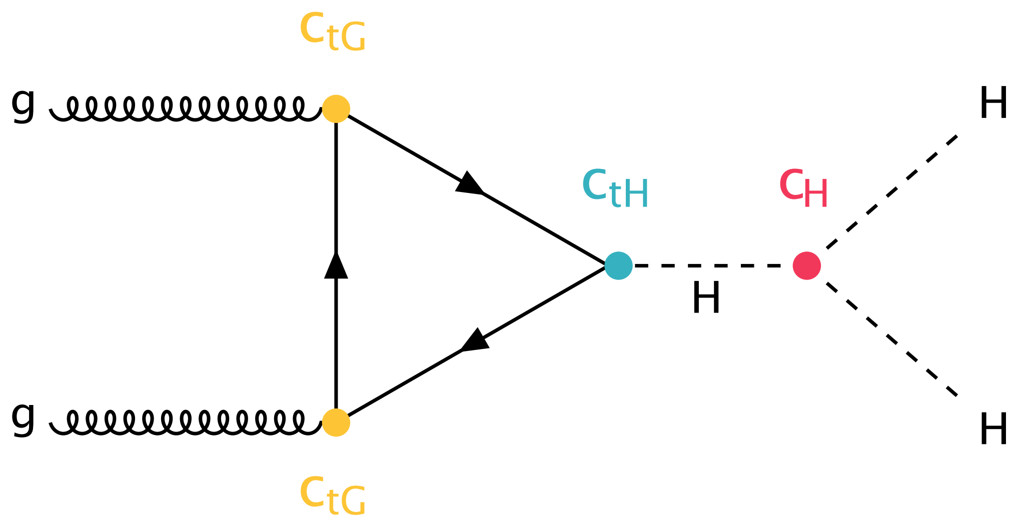

Phys. Rev. D 108 (2023) 052003

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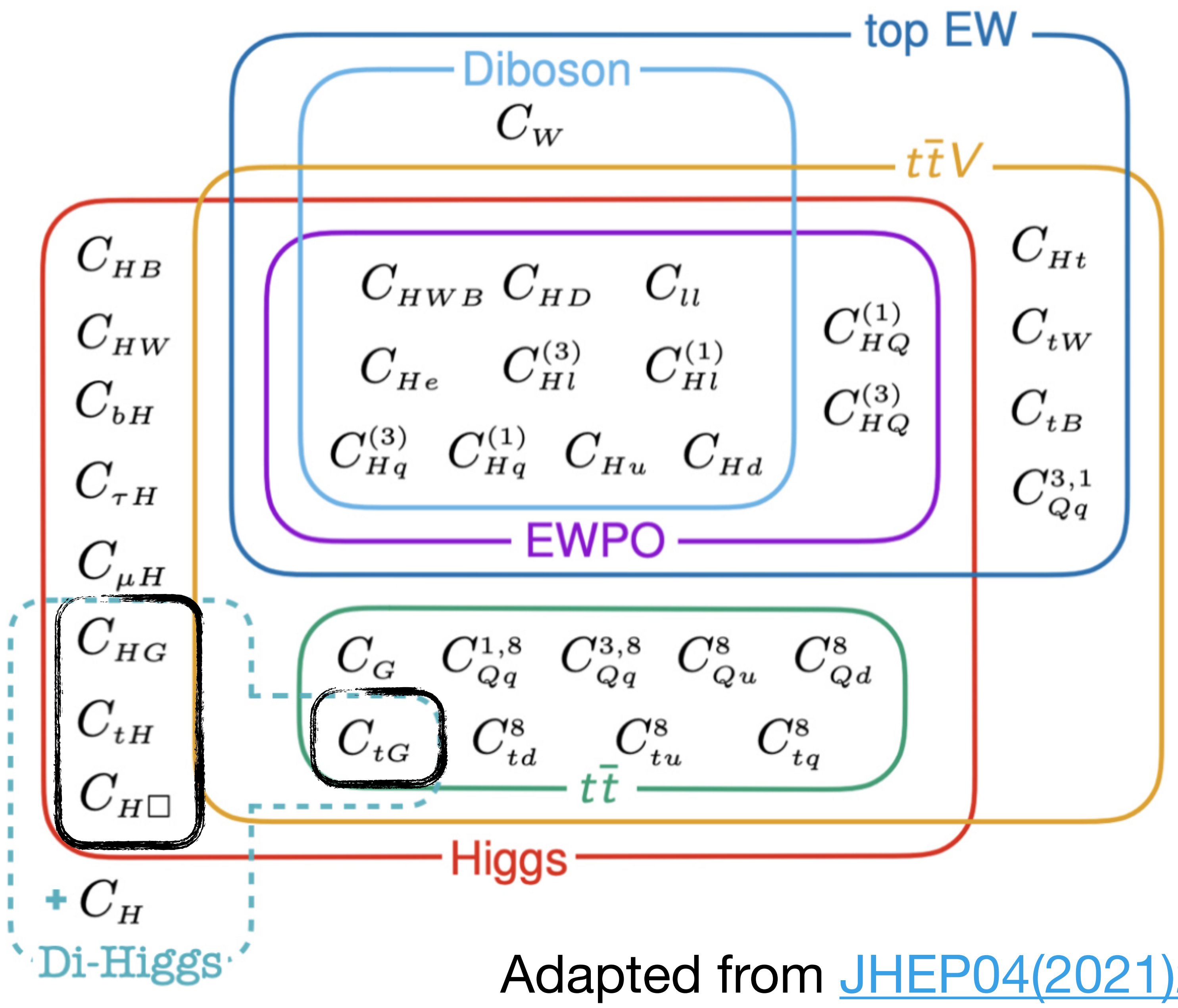


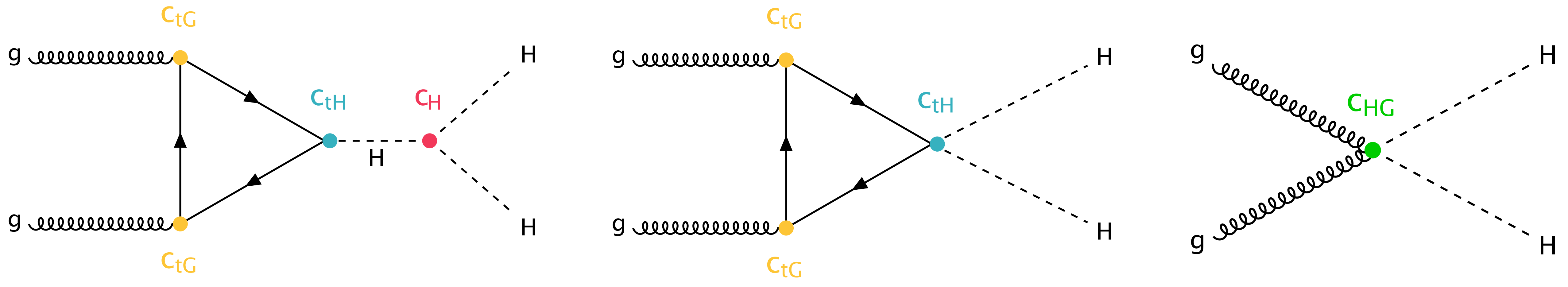
Adapted from JHEP04(2021)279

SMEFT in di-Higgs

- Five operators relevant for di-Higgs:

c_H ⟶ **Unique sensitivity from di-Higgs**
affects the Higgs-self coupling

$c_{H\Box}$, c_{tH}, c_{HG}, c_{tG} } **Also affect single Higgs production**
affect e.g the interaction of the Higgs boson to top quarks or lead to new effective Higgs-gluon interactions



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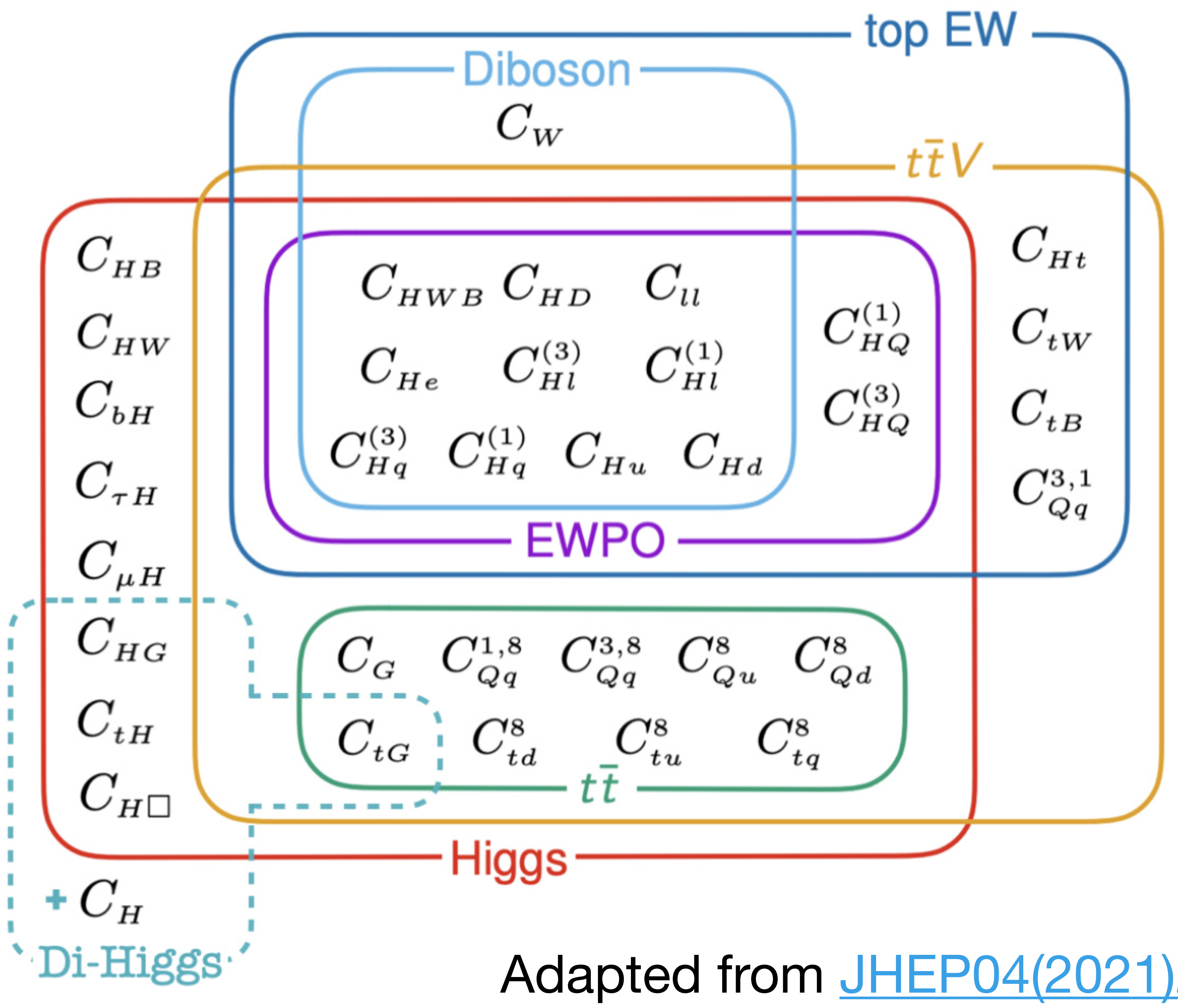
  - Basis provides a complete set of **dim-6 operators**
  - Used in a broad set of different ATLAS analyses
    - single-Higgs, $t\bar{t}$, Diboson, etc.

SMEFT in di-Higgs

- Five operators relevant for di-Higgs:

c_H, $c_{H\Box}$ — Probed by $bb\gamma\gamma$ and $bb\tau\tau$

c_H, $c_{H\Box}$, c_{tH}, c_{HG}, c_{tG} — Probed by $bbbb$



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Phys. Rev. D 108 (2023) 052003

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JHEP 01 (2024) 066
Phys. Rev. D 110 (2024) 032012

SMEFT results

- **1D constraints** are set on the individual Wilson coefficients while all other Wilson coefficients are fixed to zero (SM value)
  - c_H
    - **First limits** on c_H from ATLAS analyses
    - Best sensitivity from $bb\gamma\gamma$
  - $c_{H\Box}$
    - Best expected limits from $bb\tau\tau$
    - Best observed limits from $bb\gamma\gamma$
  - $bbbb$ additionally sets constraints on the Wilson coefficients c_{tH}, c_{tG}, c_{HG}

Wilson coefficient	analysis	95% CL Observed	95% CL Expected
c_H	$bbbb$	[-22, 11]	[-20, 11]
	$bb\gamma\gamma$	[-14.4, 6.2]	[-16.8, 9.7]
	$bb\tau\tau$	[-19.4, 10.0]	[-19.1, 8.6]
$c_{H\Box}$	$bbbb$	[-8.9, 14.5]	[-9.3, 13.9]
	$bb\gamma\gamma$	[-9.4, 10.2]	[-12.4, 13.7]
	$bb\tau\tau$	[-12.6, 11.6]	[-8.5, 11.1]

Wilson coefficient	analysis	95% CL Observed	95% CL Expected
c_{HG}	$bbbb$	[-0.067, 0.060]	[-0.056, 0.049]
c_{tH}		[-10.7, 6.2]	[-10.0, 6.4]
c_{tG}		[-1.12, 1.15]	[-0.97, 0.94]

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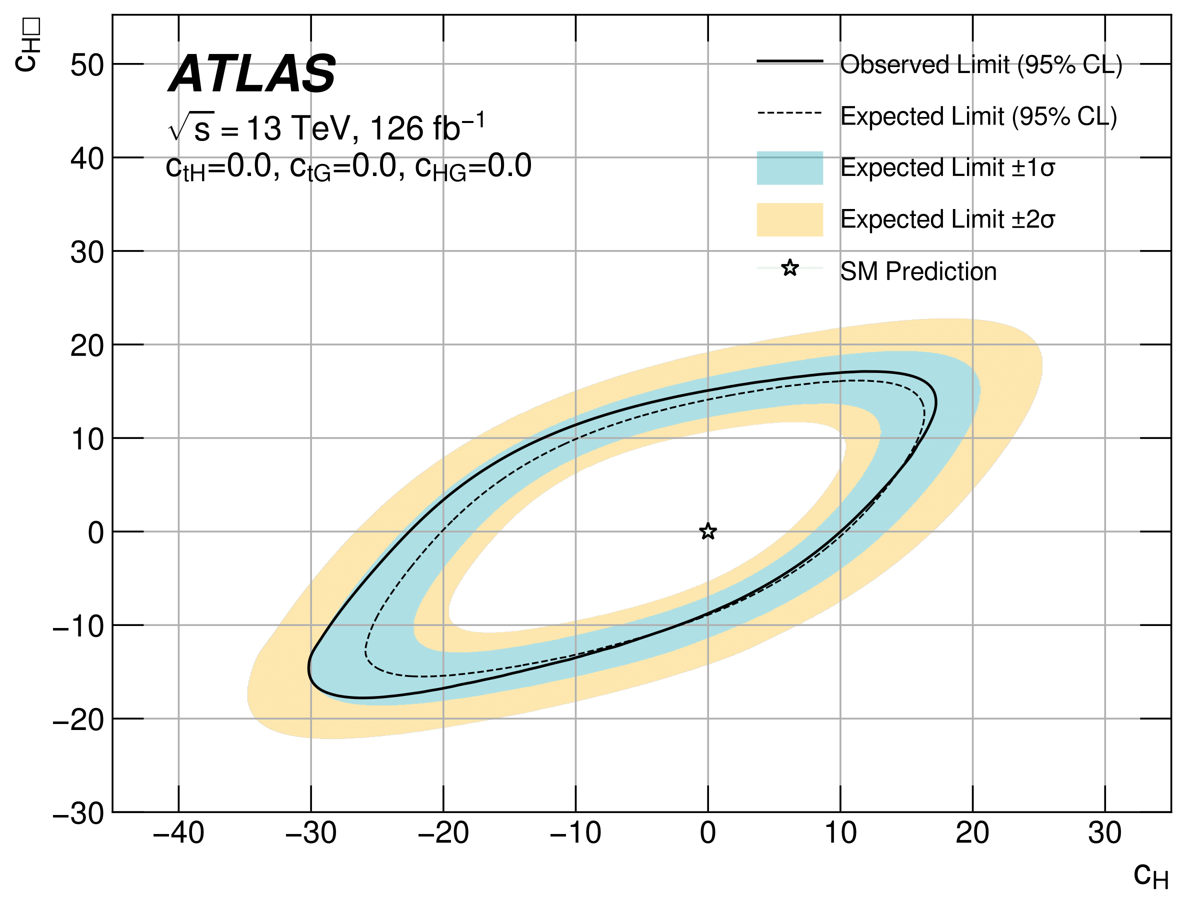
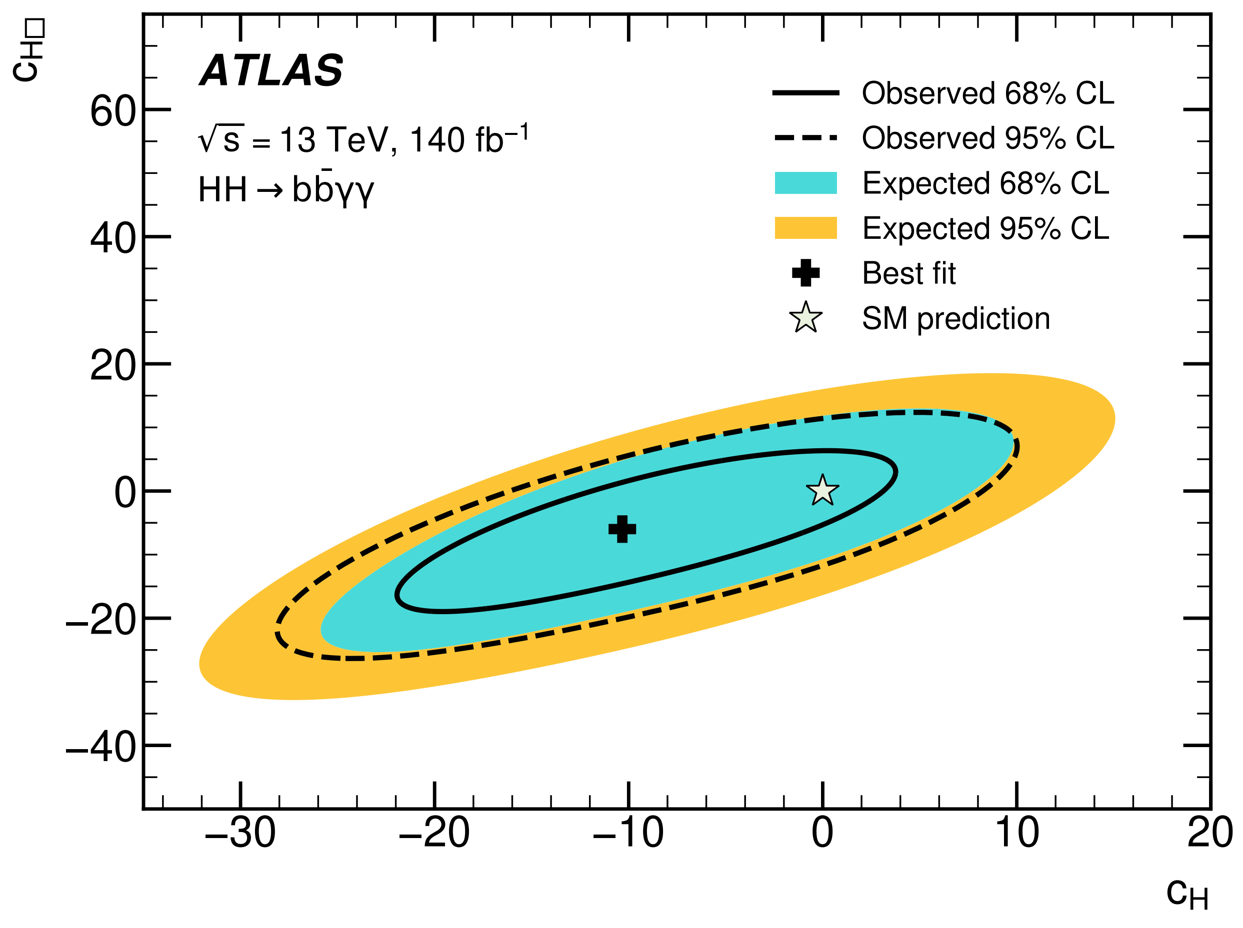
SMEFT results

- Additionally **2D limits** in the $(c_H, c_{H\Box})$ parameter space were set by the analyses
  - All other Wilson coefficients are fixed to zero (SM value)
  - No deviation from the SM found

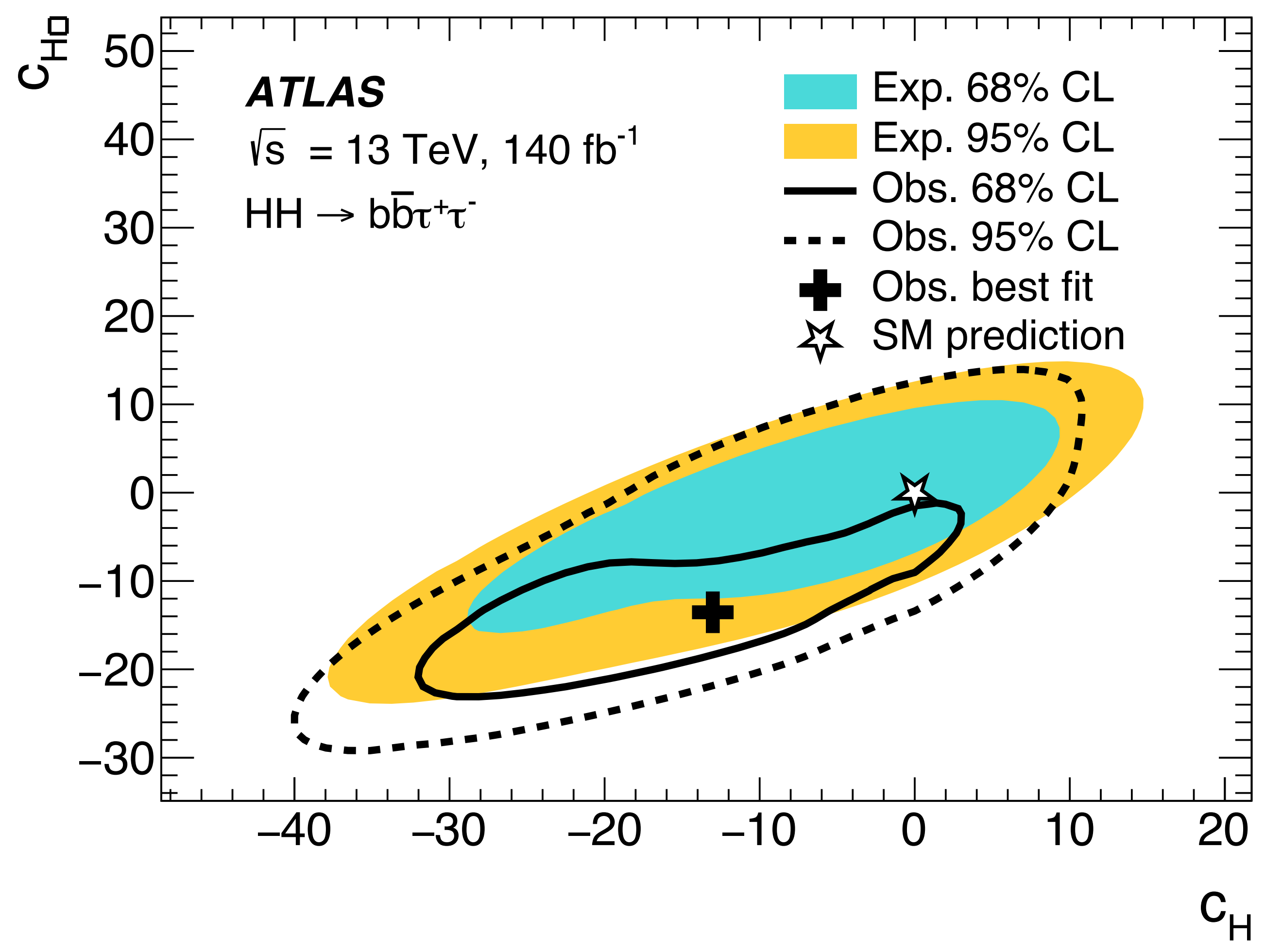
$bbbb$



$bb\gamma\gamma$



$bb\tau\tau$



Additional 2D limits in the (c_H, c_{tH}), (c_H, c_{GH}) and (c_H, c_{tG}) parameters space from $bbbb$ in backup

HEFT

Comparison HEFT and SMEFT

- Two different EFT parameterizations are considered in di-Higgs searches

SMEFT

- BSM physics is described by an effective Lagrangian

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \ldots$$

- Preserves the SM $SU_C(3) \times SU(2)_L \times U(1)_Y$ symmetry
- Higgs boson is in a **doublet**
- Operators can affect multiple vertices at the same time
  - Couplings of single Higgs bosons and Higgs boson pairs to fermions and gluons are **correlated**

→ More useful for combinations with other ATLAS analyses

HEFT

- Organization of the HEFT Lagrangian is guided by chiral perturbation theory

$$\mathcal{L}_{\mathrm{HEFT}} = -c_{hhh}\frac{m_h^2}{2\nu}h^3 - m_t\left(c_{tth}\frac{h}{\nu} + c_{tthh}\frac{h^2}{\nu^2}\right)t\bar{t} + \frac{\alpha_S}{8\pi}\left(c_{ggh}\frac{h}{\nu} + c_{gghh}\frac{h^2}{\nu^2}\right)G_{\mu\mu}G^{\alpha,\mu\nu}$$

- Nonlinear realization of the gauge symmetry groups $SU(2)_L \times U(1)_Y$
- Higgs boson is in a **singlet**
- One-to-one relations between operators and effective interactions
  - Couplings of single Higgs bosons and Higgs boson pairs to fermions and gluons are **uncorrelated**

→ Simplified HH interpretations

HEFT

- Besides the individual analyses also the **di-Higgs combination** performed HEFT interpretations
  - Focus will be on the combination results

- EFT effects on the **single Higgs background** are **not included**
  - Most interesting operators for di-Higgs not affected by single Higgs at tree level

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$$\mathcal{L}_{\mathrm{HEFT}} = -c_{hhh}\frac{m_h^2}{2\nu}h^3 - m_t\left(c_{tth}\frac{h}{\nu} + c_{tthh}\frac{h^2}{\nu^2}\right)t\bar{t} + \frac{\alpha_S}{8\pi}\left(c_{ggh}\frac{h}{\nu} + c_{gghh}\frac{h^2}{\nu^2}\right)G_{\mu\mu}G^{\alpha,\mu\nu}$$

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→ Simplified HH interpretations

HEFT in di-Higgs

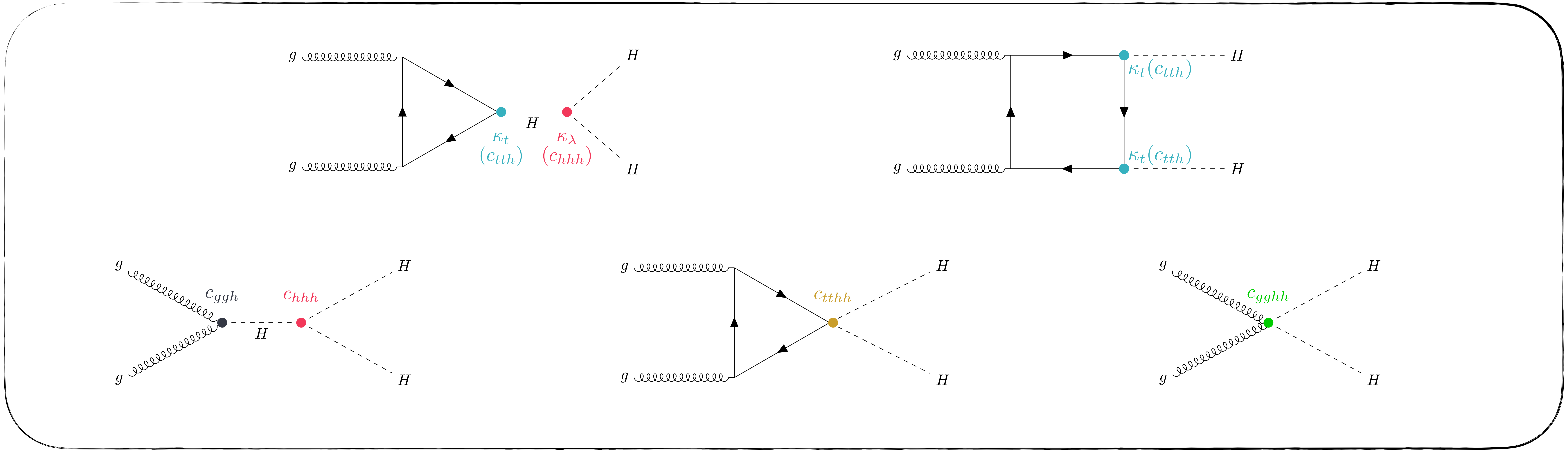
HEFT in di-Higgs

- ggF production mode described by five relevant operators and their associated Wilson coefficients:

$$\mathcal{L}_{\text{HEFT}} = -c_{hhh}\frac{m_h^2}{2\nu}h^3 - m_t\left(c_{tth}\frac{h}{\nu} + c_{tthh}\frac{h^2}{\nu^2}\right)t\bar{t} + \frac{\alpha_S}{8\pi}\left(c_{ggh}\frac{h}{\nu} + c_{gghh}\frac{h^2}{\nu^2}\right)G_{\mu\mu}G^{\alpha,\mu\nu}$$

SM

BSM



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Trilinear Higgs coupling equivalent to κ_λ

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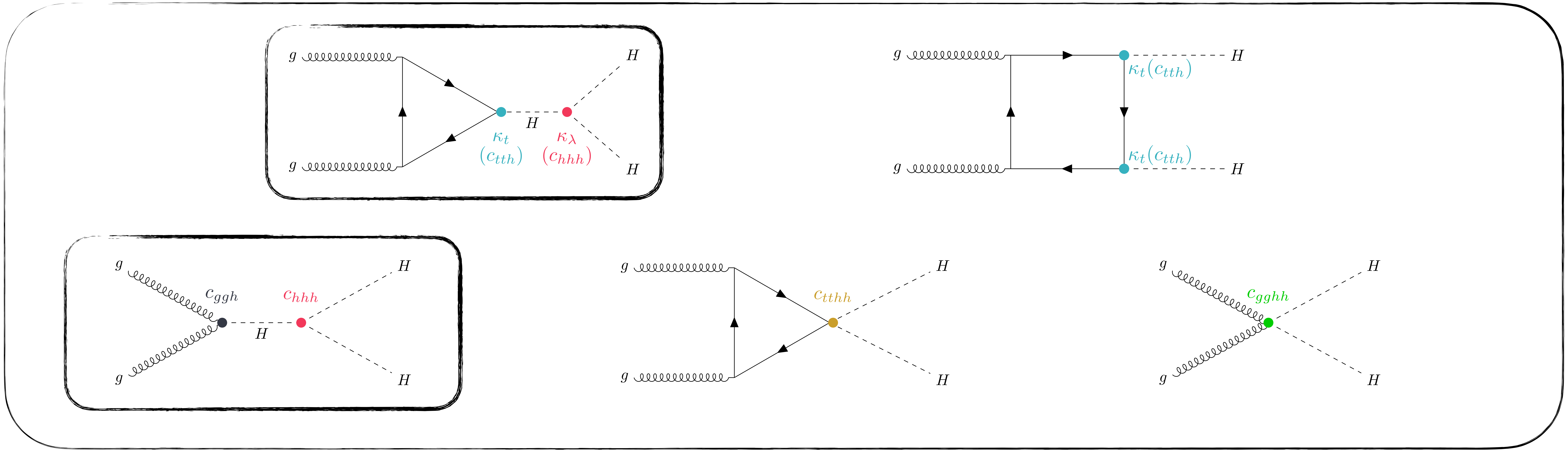

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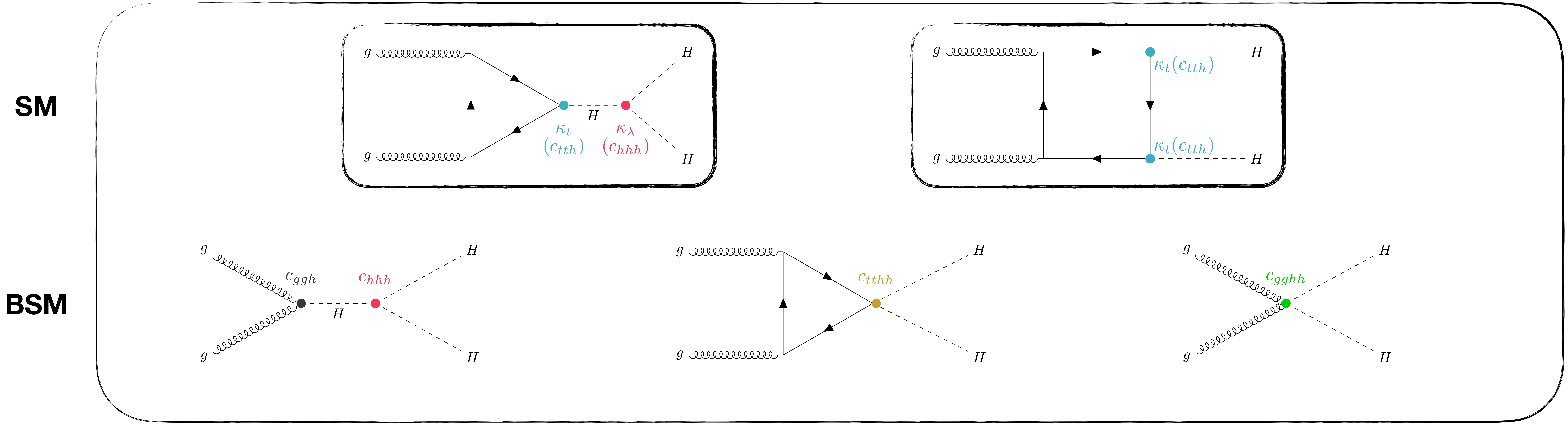
Trilinear Higgs coupling equivalent to κ_λ

Coupling single Higgs to tops



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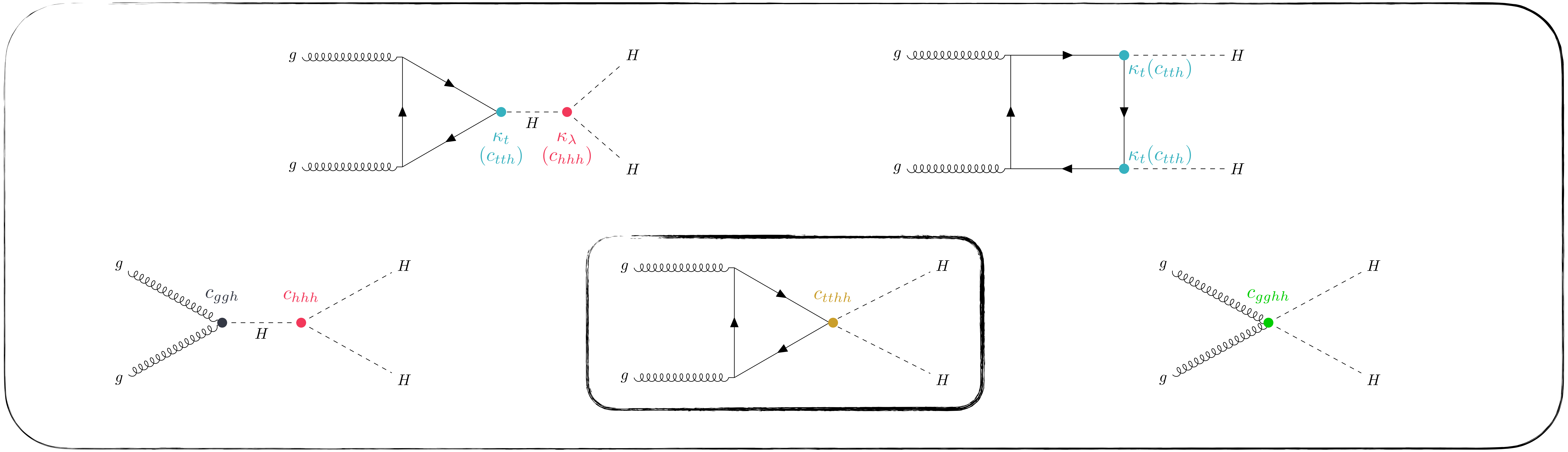
Trilinear Higgs coupling equivalent to κ_λ

Coupling single Higgs to tops

Effective coupling two Higgs to tops

SM

BSM



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Trilinear Higgs coupling equivalent to κ_λ

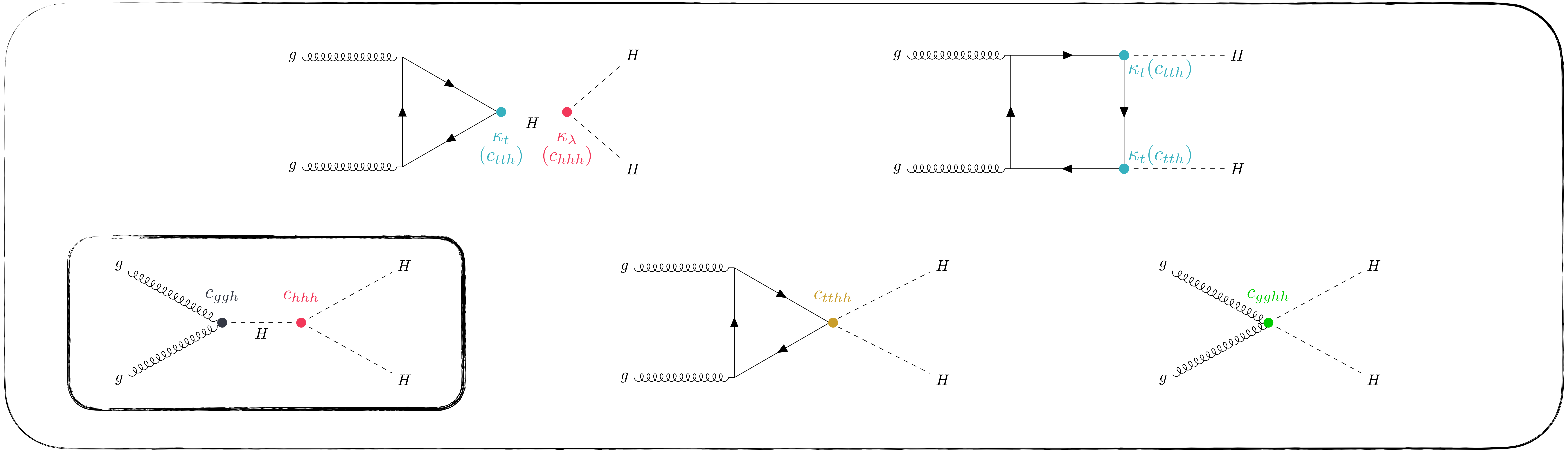
Coupling single Higgs to tops

Effective coupling two Higgs to tops

Effective coupling single Higgs to gluons

SM

BSM



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Trilinear Higgs coupling equivalent to κ_λ | Coupling single Higgs to tops | Effective coupling two Higgs to tops | Effective coupling single Higgs to gluons | Effective coupling two Higgs to gluons

SM

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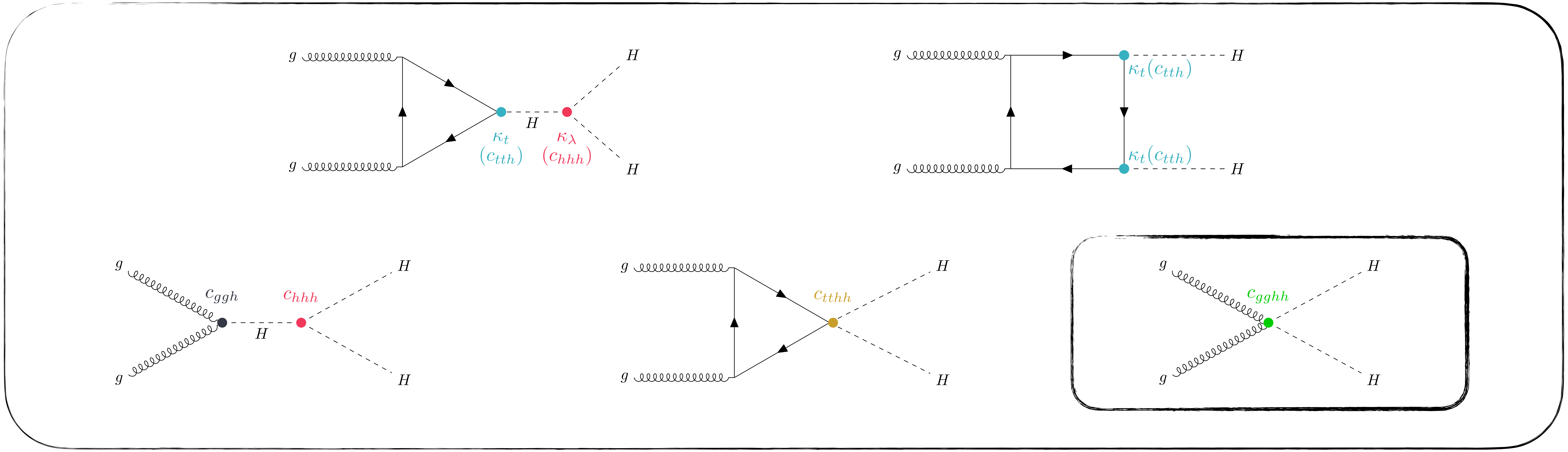
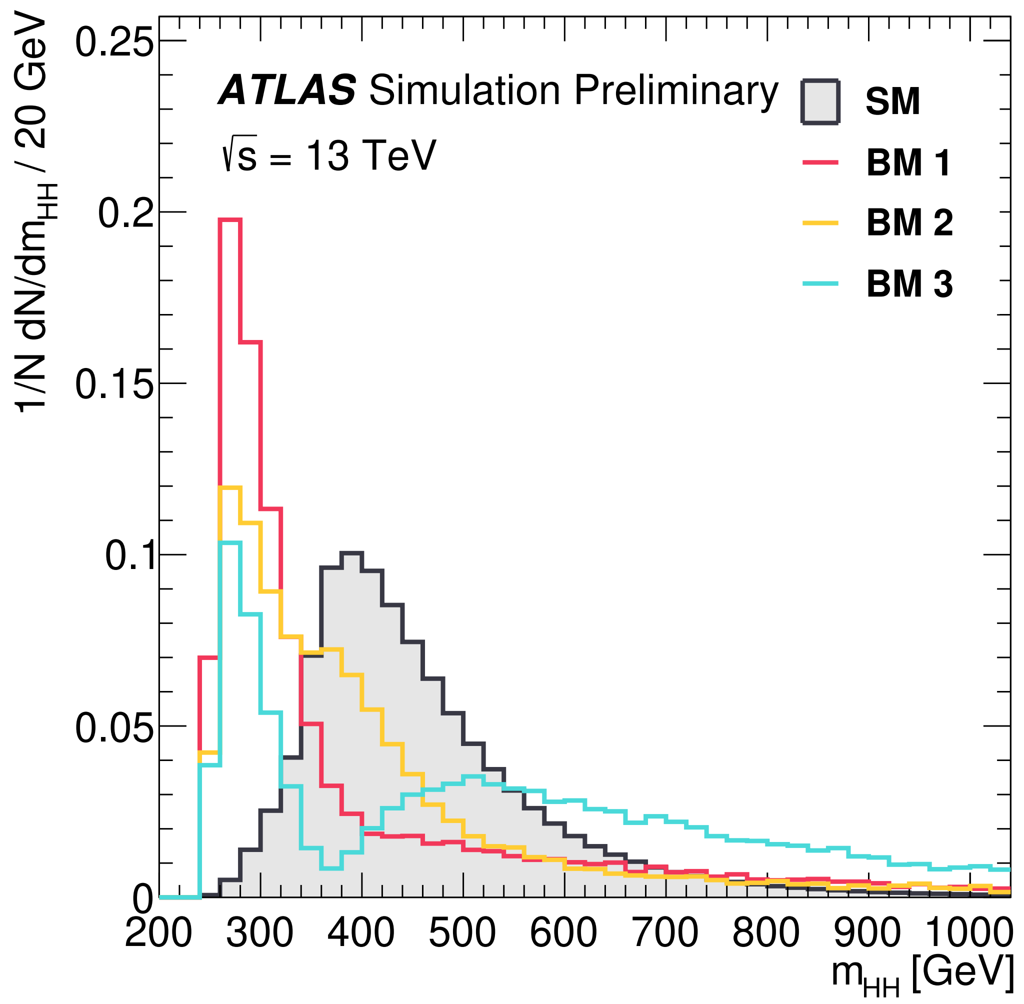


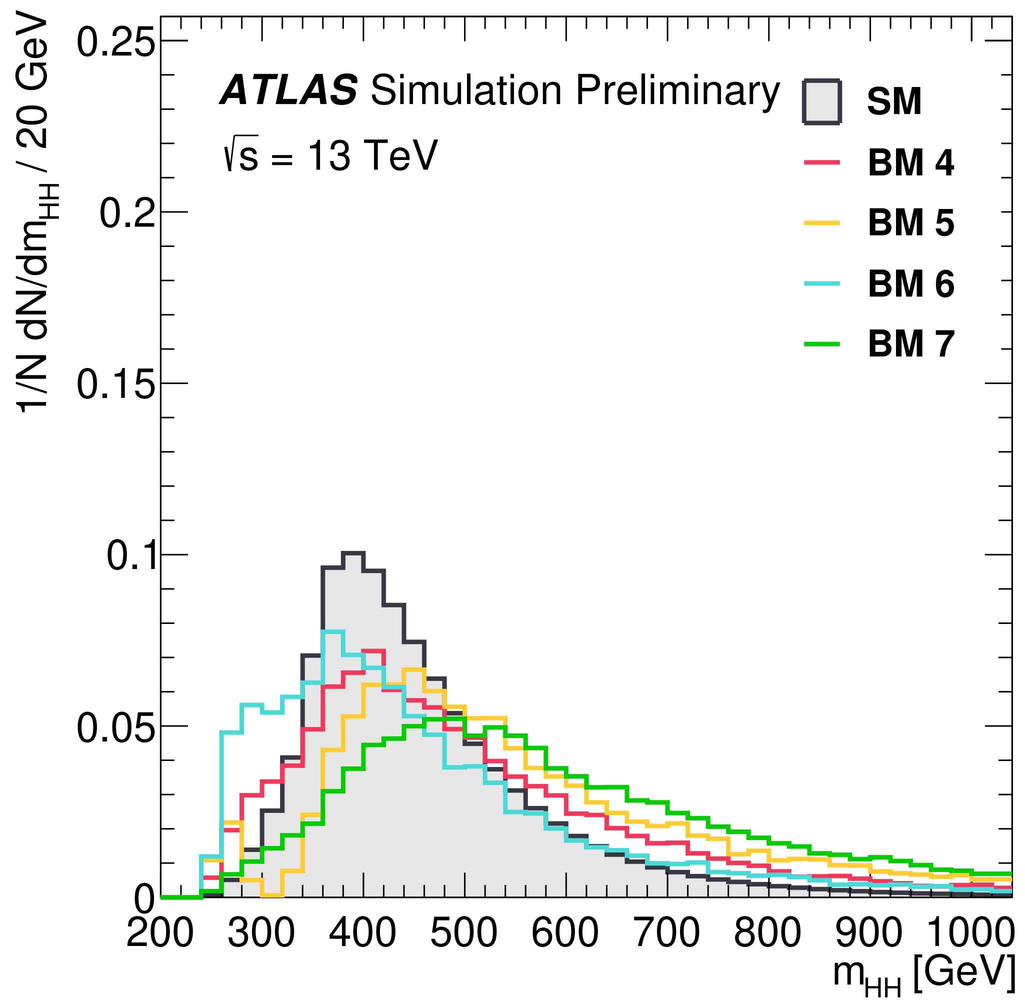
ATL-PHYS-PUB-2022-019
JHEP 01 (2024) 066

HEFT results

- For HEFT **seven benchmark points** in the five Wilson coefficients c_{hhh}, c_{tth}, c_{ggh}, c_{gghh}, c_{tthh} are defined
- Benchmark points are chosen to **describe representative m_{HH} shapes features**
  - Selected by theorists using cluster analysis
  - Point 1, 2, 3, 6 : softer m_{HH} spectrum
  - Point 4, 5, 7 : harder m_{HH} spectrum
- $bbbb$, $bb\gamma\gamma$, $bb\tau\tau$ and the di-Higgs combination set 95% CL upper limits on these benchmarks

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





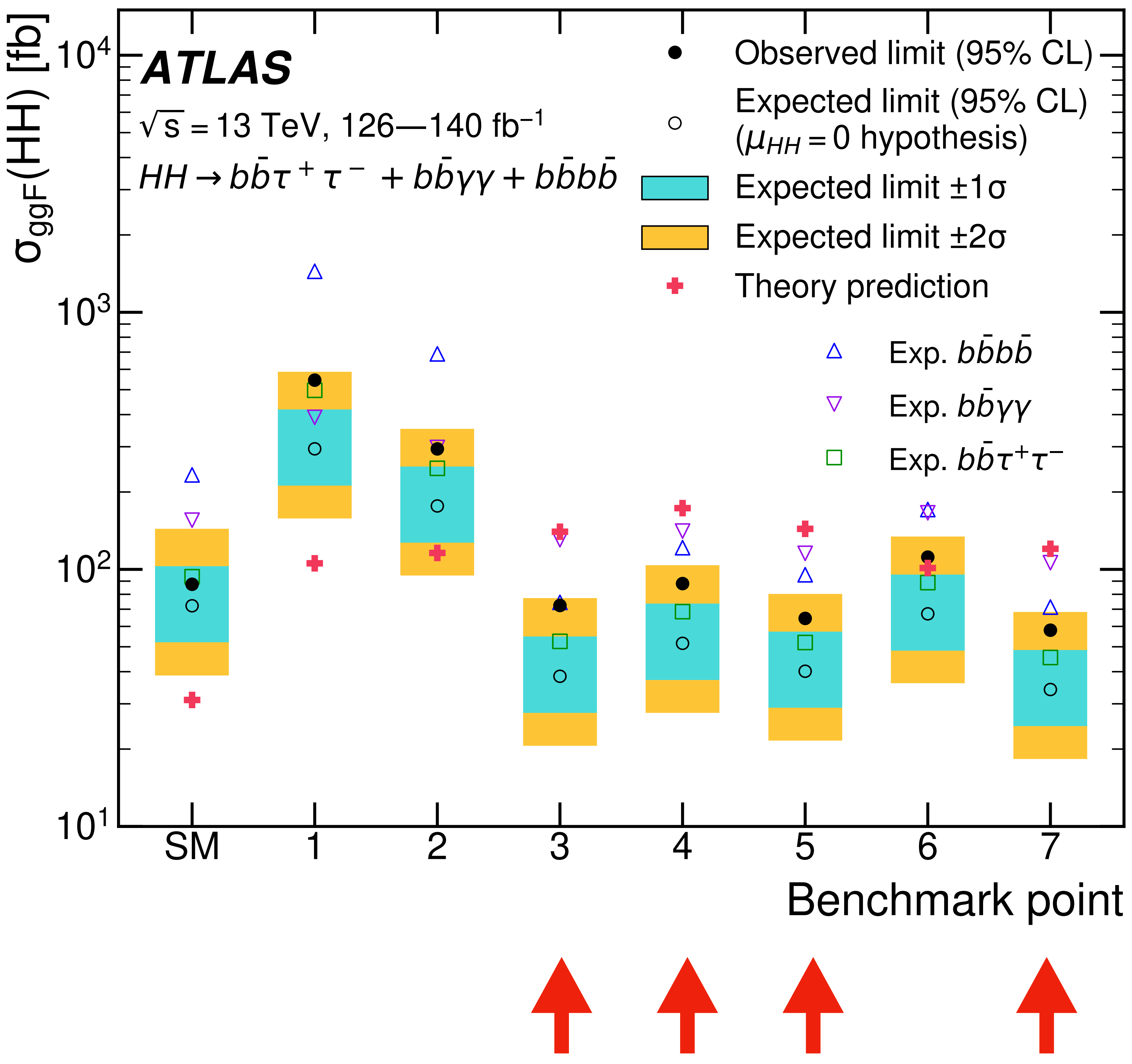
HDBS-2021-18

HEFT results

- 95% CL upper limits from the combination

- Expected sensitivity from the different analyses
  - △ $bbbb$: more sensitive to harder m_{HH} spectra
  - ▽ $bb\gamma\gamma$: more sensitive to softer m_{HH} spectra
  - □ $bb\tau\tau$: best expected sensitivity for most benchmark points
    observed sensitive worse due to excess in data

- A specific benchmark point is excluded if the observed limits (•) on the cross-section is smaller than the theory prediction (✚)
  - Benchmarks 3, 4, 5 and 7 are excluded



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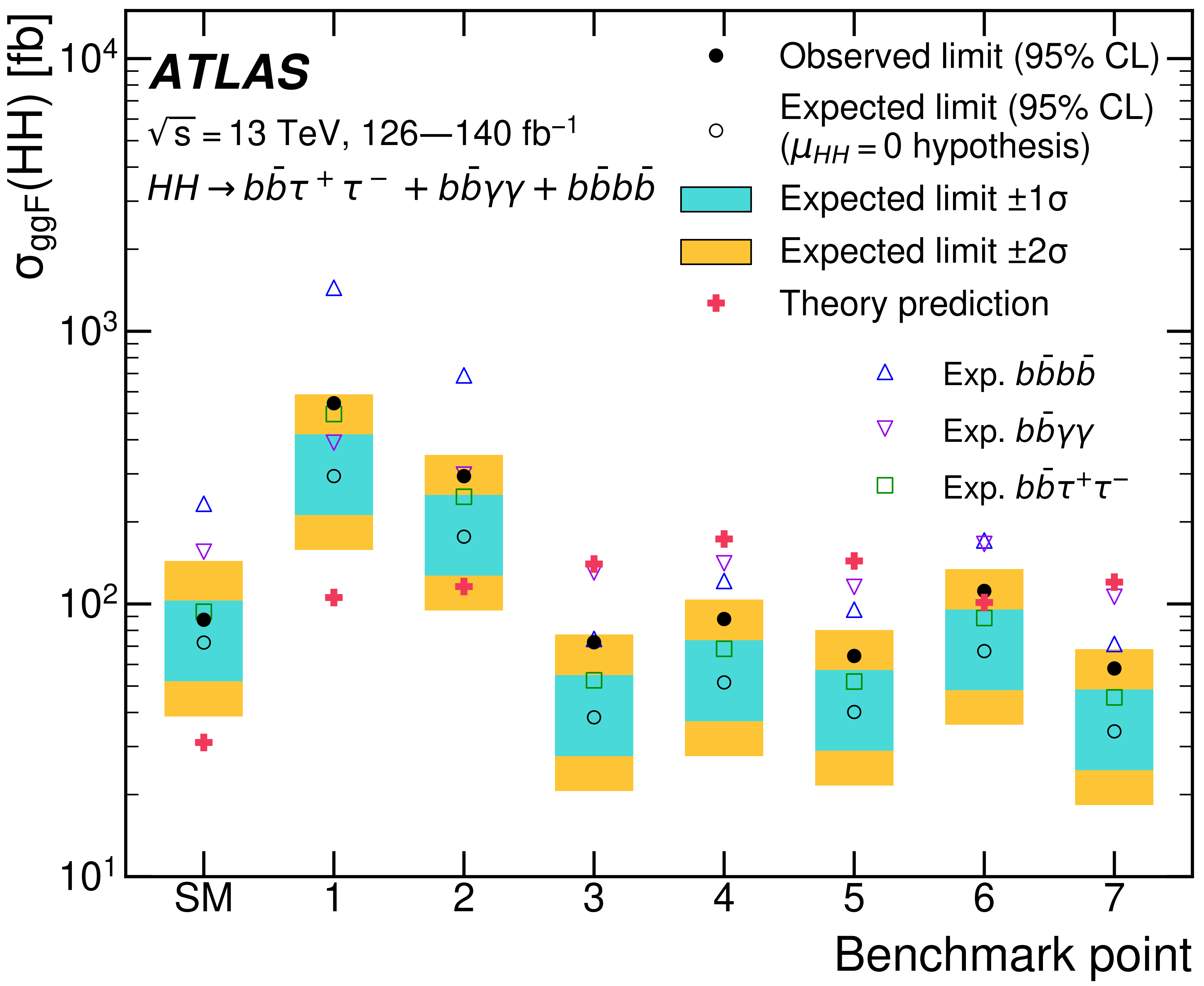
  - ! **However**: this does not mean that the full shape that is represented by the benchmark point is excluded! !



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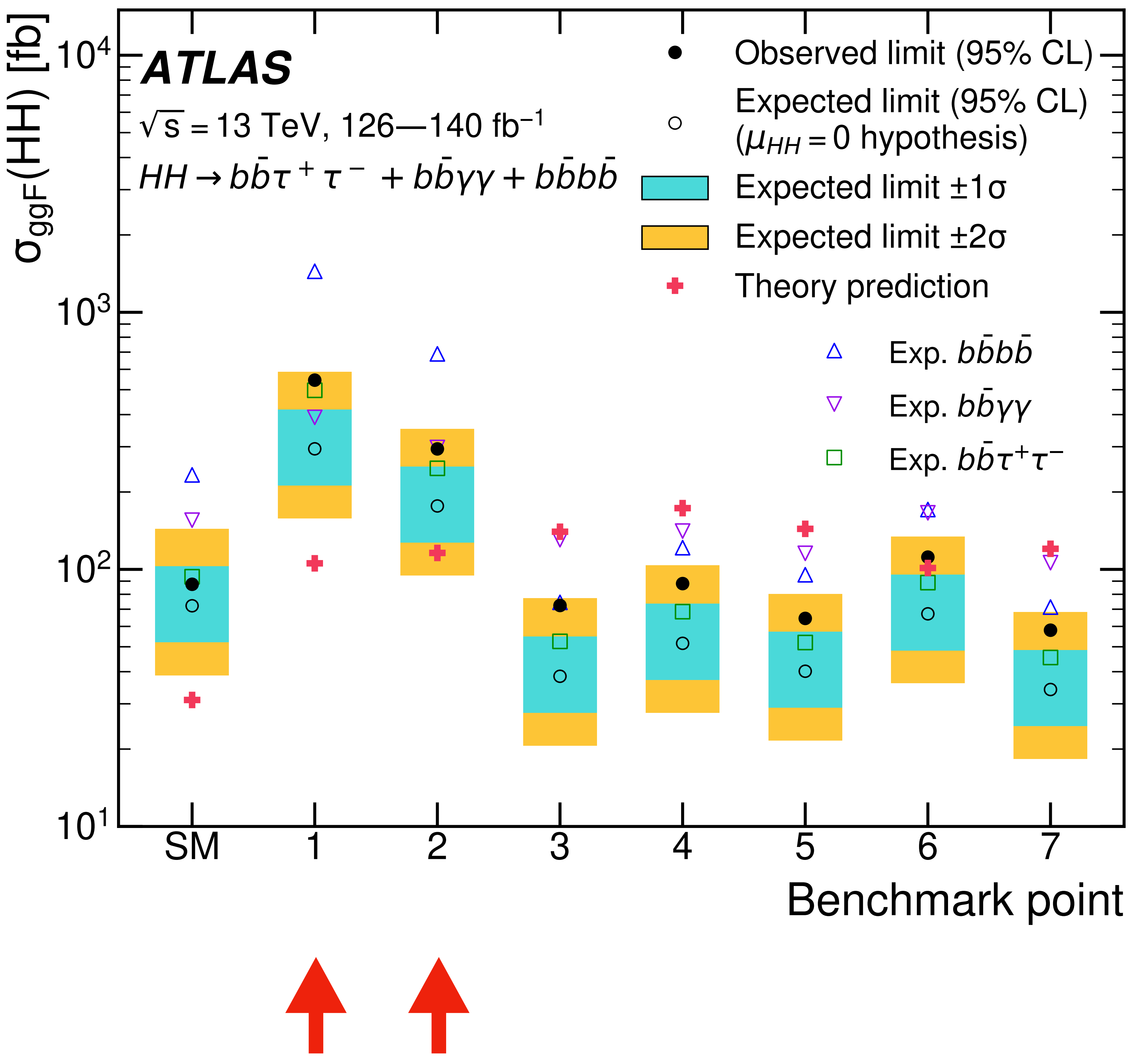
  - **However**: this does not mean that the full shape that is represented by the benchmark point is excluded!
  - Especially the two benchmark points with the softest m_{HH} spectrum (BM 1 and 2) lead to weaker constraints



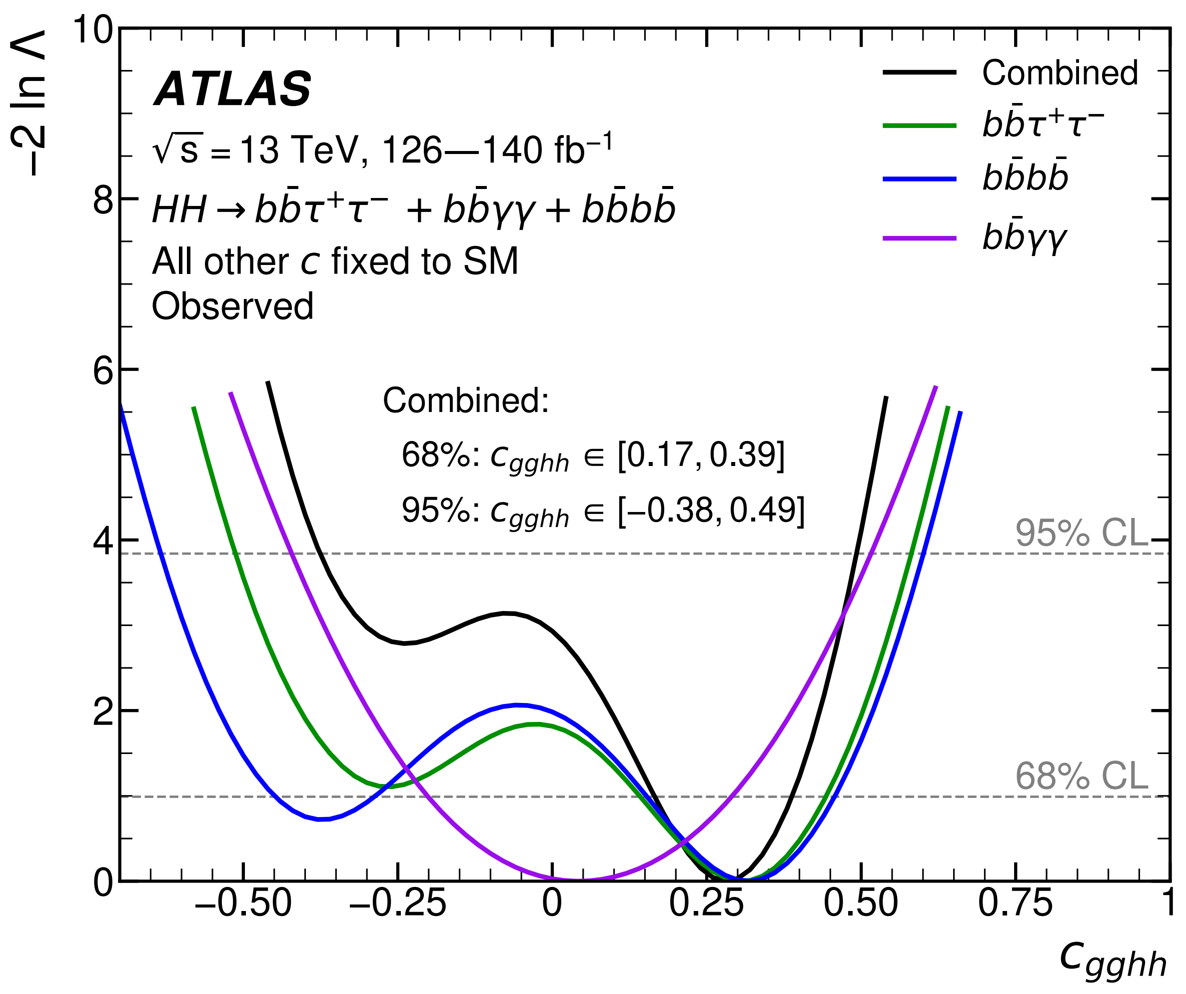
Phys. Rev. D 108 (2023) 052003
JHEP 01 (2024) 066
Phys. Rev. D 110 (2024) 032012
Phys. Rev. Lett. 133 (2024) 101801
HDBS-2021-18

HEFT results

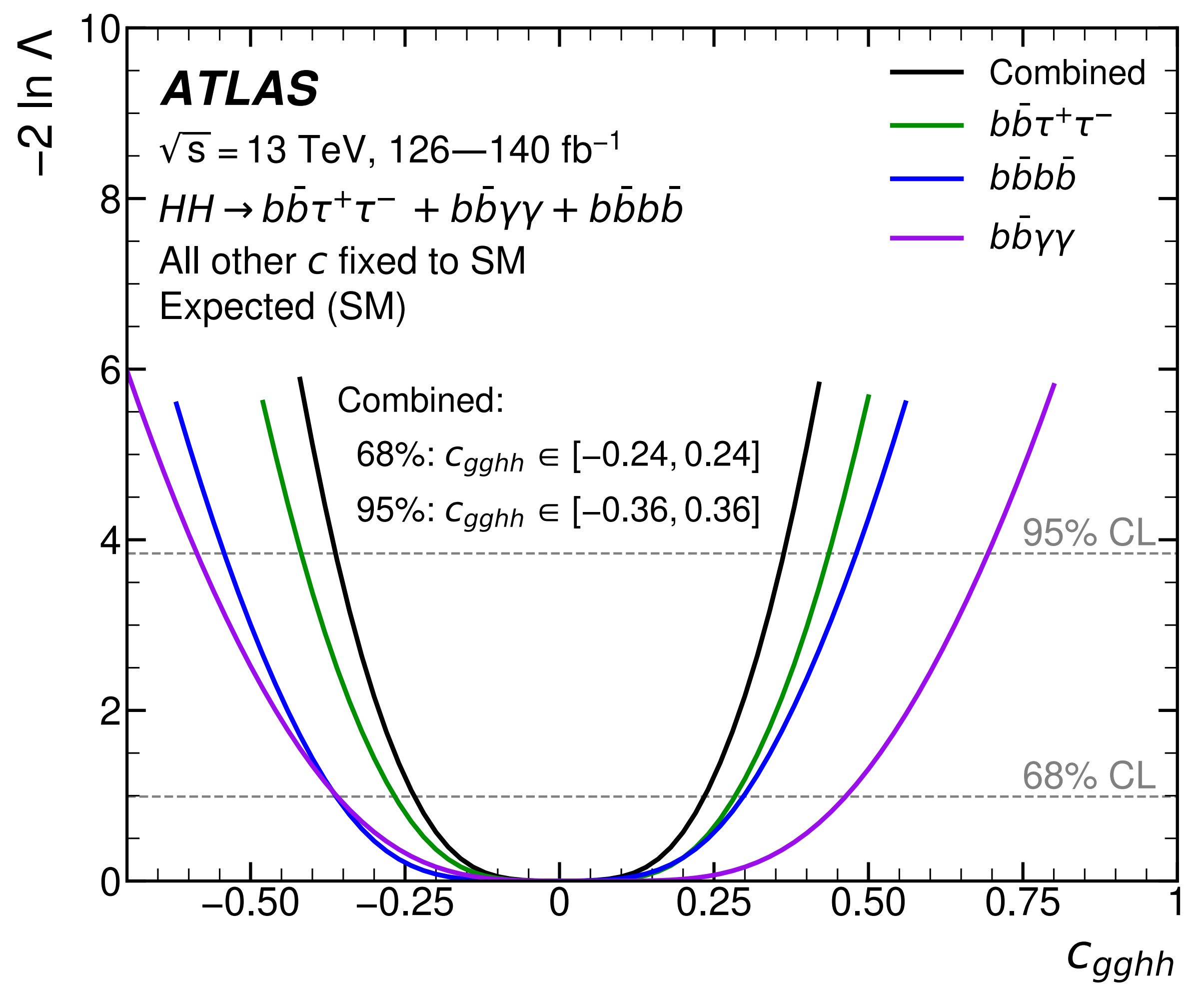
- Analyses set **1D limits** on the Wilson coefficients c_{tthh} and c_{gghh}
  - di-Higgs has a unique sensitivity to these operators at LO
  - Other Wilson coefficients are fixed to their SM value
    - One for c_{hhh}, c_{tth}
    - Zero for c_{ggh}, c_{gghh} and c_{tthh}
- Best limits from the di-Higgs combination
  - Expected limits driven by $bb\tau\tau$ and $bbbb$
  - Best observed limits from individual analyses by $bb\gamma\gamma$

Wilson coefficient	analysis	95% CL Observed	95% CL Expected
c_{gghh}	$bbbb$	[-0.36, 0.78]	[-0.42, 0.75]
	$bb\gamma\gamma$	[-0.42, 0.52]	[-0.59, 0.69]
	$bb\tau\tau$	[-0.51, 0.58]	[-0.42, 0.44]
	combination	[-0.38, 0.49]	[-0.36, 0.36]
c_{tthh}	$bbbb$	[-0.55, 0.51]	[-0.46, 0.40]
	$bb\gamma\gamma$	[-0.28, 0.73]	[-0.48, 0.94]
	$bb\tau\tau$	[-0.40, 0.84]	[-0.32, 0.72]
	combination	[-0.19, 0.70]	[-0.27, 0.66]

Observed



Expected

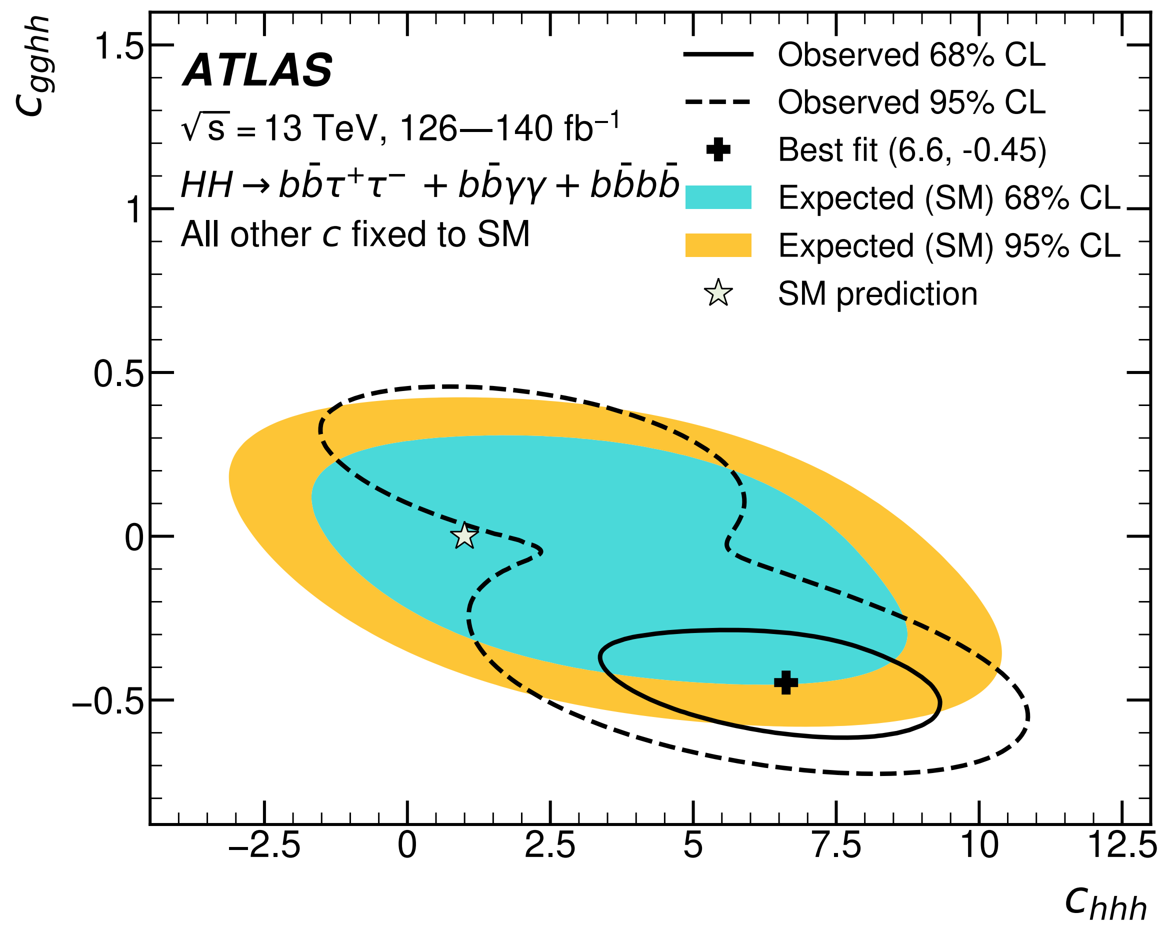


Phys. Rev. Lett. 133 (2024) 101801

HEFT results

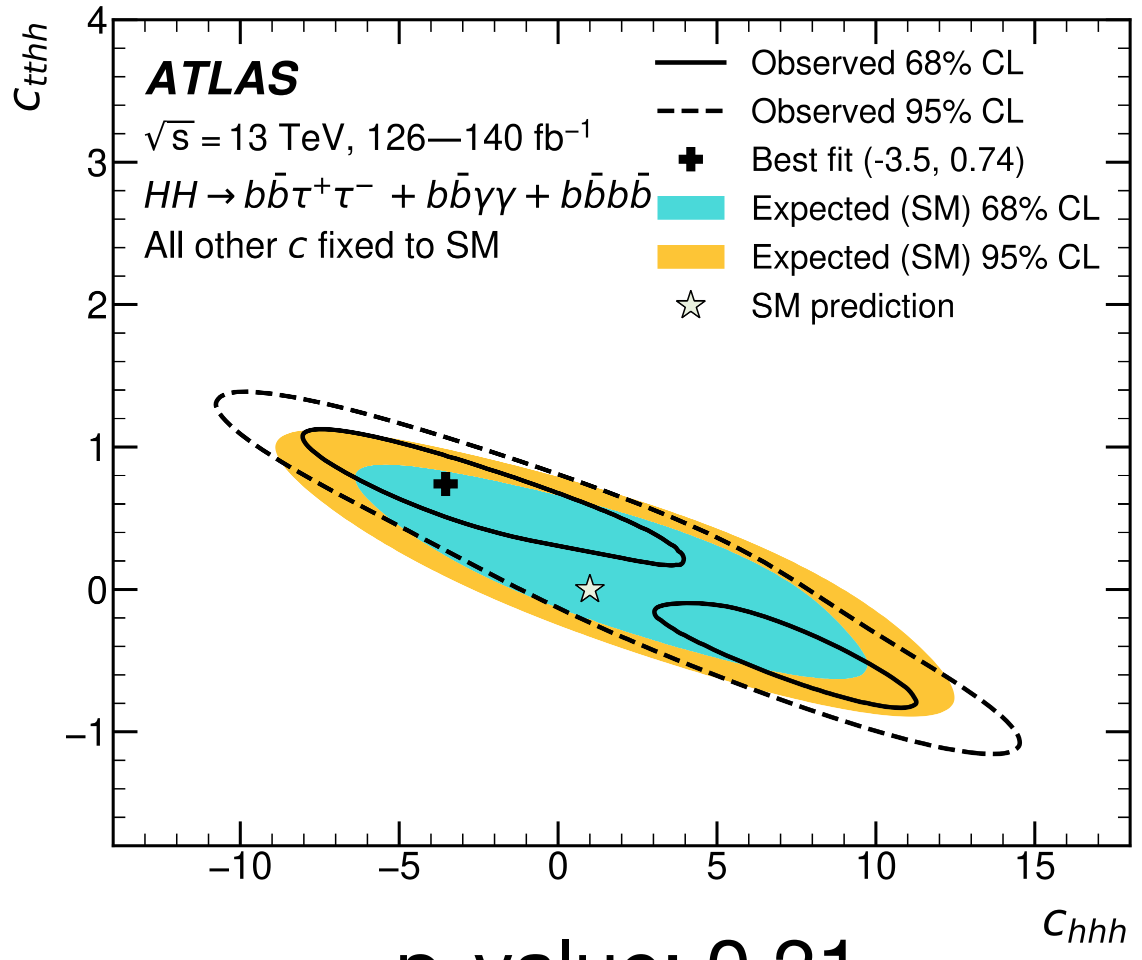
- **Two-dimensional test-statistic contours** are also performed in the coefficient spaces of (c_{hhh}, c_{gghh}), (c_{hhh}, c_{tthh}) and (c_{gghh}, c_{tthh})
  - Non-probed Wilson coefficients are fixed to their SM prediction
  - Two minima are expected because of the quadratic dependence of the cross-section on the coefficients
- Deviations mainly due to $bbbb$ analyses
  - Data-driven background modeling cannot perfectly describe the background distribution in data
  - Favours non-SM values in the fit

(c_{hhh}, c_{gghh})



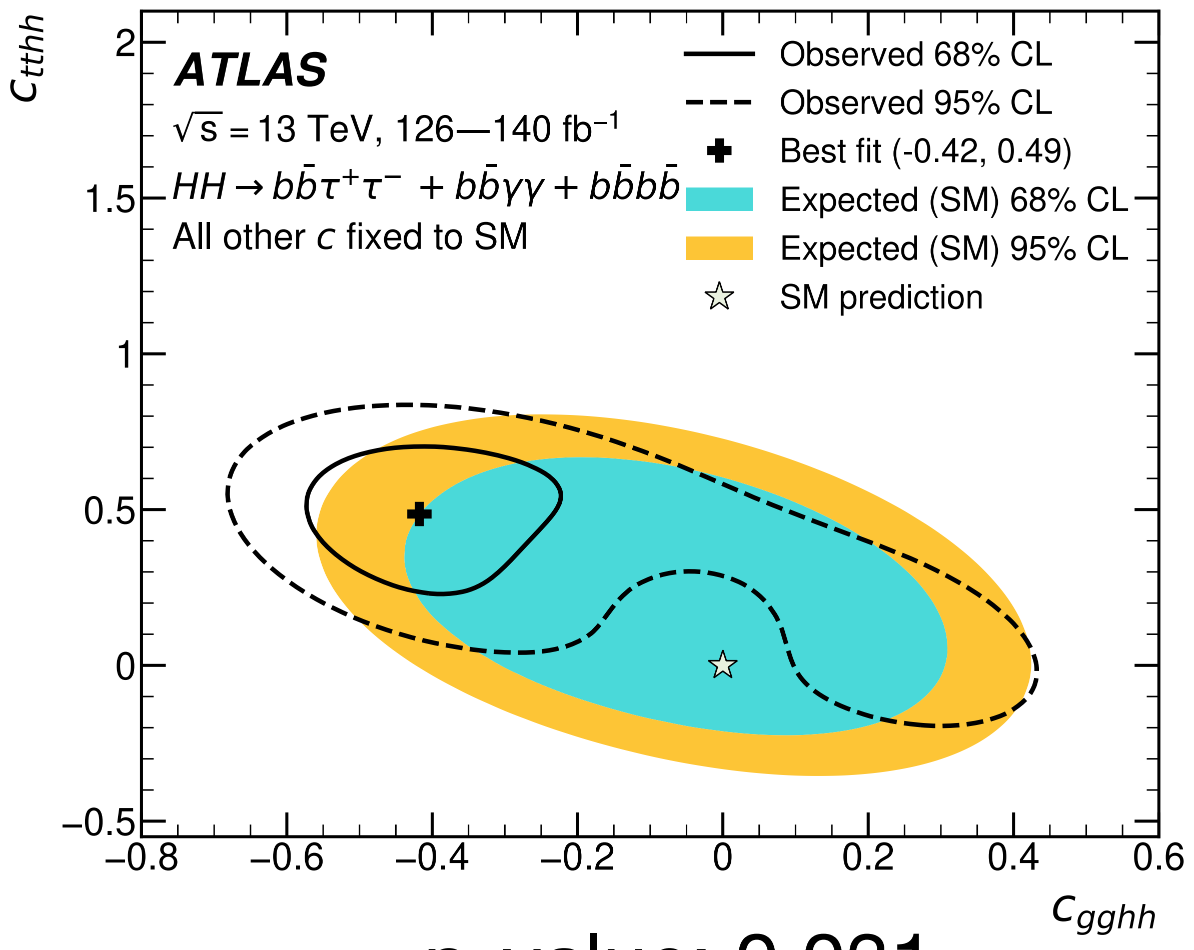
p-value: 0.044

(c_{hhh}, c_{tthh})



p-value: 0.21

(c_{gghh}, c_{tthh})



p-value: 0.031

Summary

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- First EFT interpretations from ATLAS di-Higgs analyses were performed
  - $bbbb$, $bb\tau\tau$ and $bb\gamma\gamma$
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  - First ATLAS

What else could be added for EFT in di-Higgs??

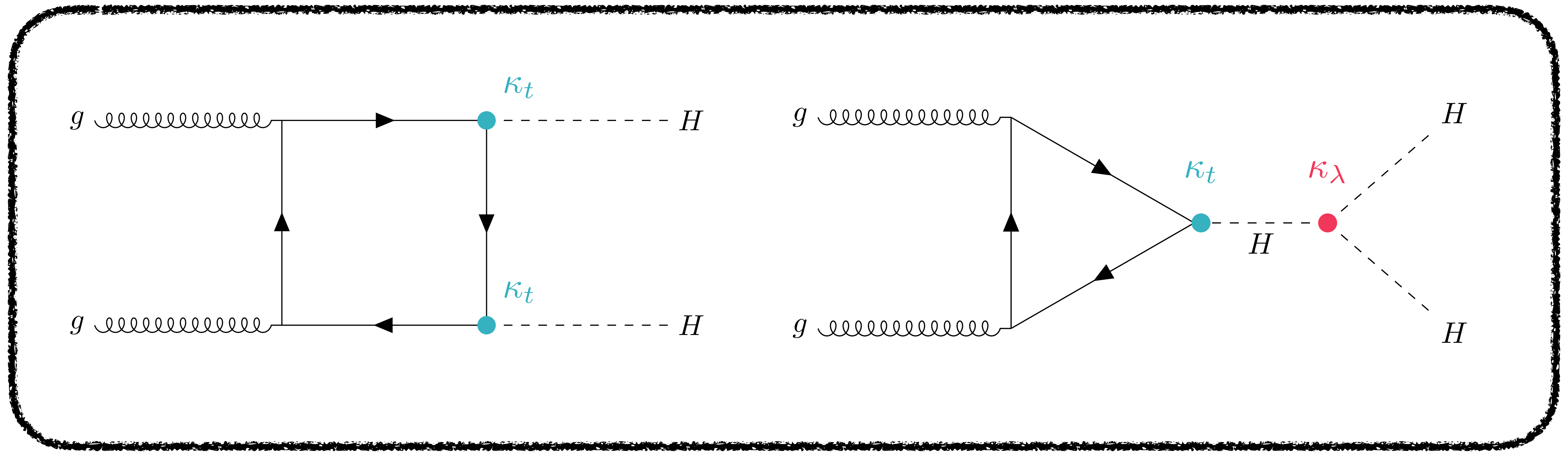
- Additional limits were set on benchmarks of the HEFT framework

EFT for VBF di-Higgs

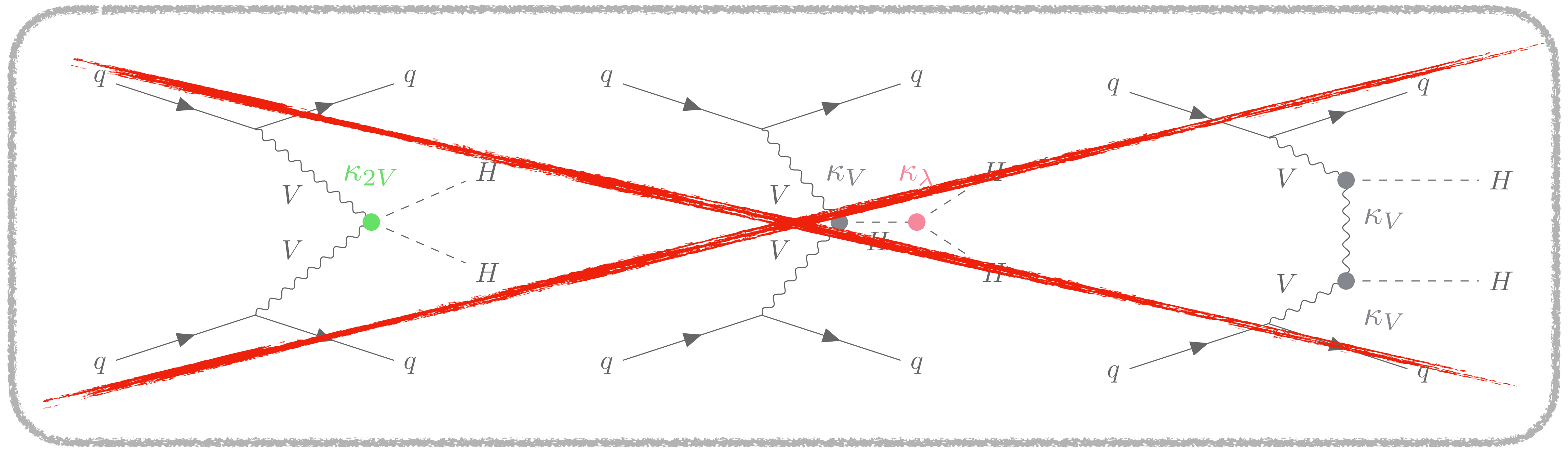
- So far di-Higgs SMEFT analyses focused on the ggF production mode using dim-6 operators
  - The VBF production mode is ignored

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \ldots$$

gluon-gluon Fusion (ggF)



Vector Boson Fusion (VBF)



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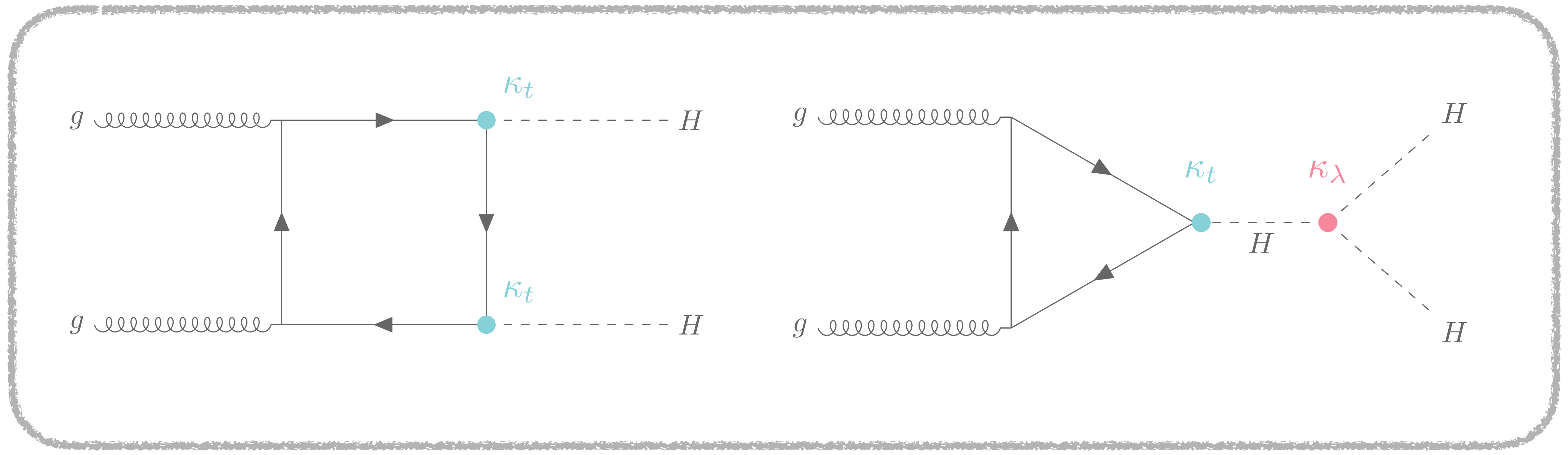

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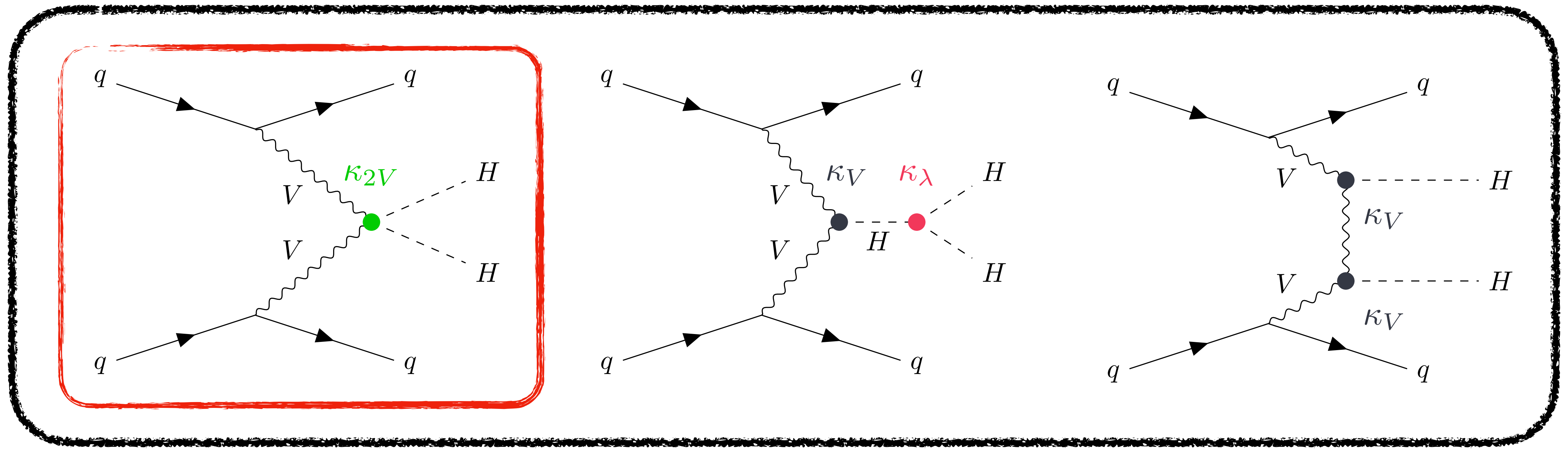

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    - VBF di-Higgs sensitive to the S and M operators of this model

	$WWWW$	$WWZZ$	$WW\gamma Z$	$WW\gamma\gamma$	$ZZZZ$	$ZZZ\gamma$	$ZZ\gamma\gamma$	$Z\gamma\gamma\gamma$	$\gamma\gamma\gamma\gamma$	$ZZHH$	$WWHH$	$Z\gamma HH$	$\gamma\gamma HH$
$\mathcal{O}_{S,0}$, $\mathcal{O}_{S,1}$, $\mathcal{O}_{S,2}$	✓	✓			✓					✓	✓		
$\mathcal{O}_{M,0}$, $\mathcal{O}_{M,1}$, $\mathcal{O}_{M,7}$	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
$\mathcal{O}_{M,2}$, $\mathcal{O}_{M,3}$, $\mathcal{O}_{M,4}$, $\mathcal{O}_{M,5}$		✓	✓	✓	✓	✓	✓			✓		✓	✓
$\mathcal{O}_{T,0}$, $\mathcal{O}_{T,1}$, $\mathcal{O}_{T,2}$	✓	✓	✓	✓	✓	✓	✓	✓	✓				
$\mathcal{O}_{T,5}$, $\mathcal{O}_{T,6}$, $\mathcal{O}_{T,7}$		✓	✓	✓	✓	✓	✓	✓	✓				
$\mathcal{O}_{T,8}$, $\mathcal{O}_{T,9}$					✓	✓	✓	✓	✓				

VBS (columns $WWWW$ to $\gamma\gamma\gamma\gamma$) — VBF (columns $ZZHH$ to $\gamma\gamma HH$)

Adapted from [AnomalousGaugeCoupling]

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  - Pheno paper:
    - Sensitivity study based on the cross-section
    - VBF di-Higgs is expected to have a similar sensitivity to the operators as VBS processes!

	VBS $W^{\pm}V$ semileptonic		VBF HH→ $b\bar{b}b\bar{b}$	
Coeff.	no unitarity	w/ unitarity	no unitarity	w/ unitarity
f_{M0}/Λ^4	[-1.0,1.0]	[-3.3,3.5]	[-0.95,0.95]	[-3.3,3.3]
f_{M1}/Λ^4	[-3.1,3.1]	[-7.4,7.6]	[-3.8,3.8]	[-13,14]
f_{M2}/Λ^4	[-1.5,1.5]	[-9.1,9.0]	[-1.3,1.3]	[-7.6,7.3]
f_{M3}/Λ^4	[-5.5,5.5]	[-32,30]	[-5.2,5.3]	[-29,30]
f_{M4}/Λ^4	[-3.1,3.1]	[-8.6,8.7]	[-4.0,4.0]	[-14,14]
f_{M5}/Λ^4	[-4.5,4.5]	[-10,10]	[-7.1,7.1]	[-26,26]
f_{M7}/Λ^4	[-5.1,5.1]	[-11,11]	[-7.6,7.6]	[-27,27]
f_{S0}/Λ^4	[-4.2,4.2]	[-8.5,9.5]	[-30,29]	/
f_{S1}/Λ^4	[-5.2,5.2]	/	[-11,10]	/
f_{S2}/Λ^4	-	[-21,25]	[-17,16]	/

arxiv.org/abs/2205.15959

EFT for VBF di-Higgs

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    - VBF di-Higgs sensitive to the S and M operators of this model
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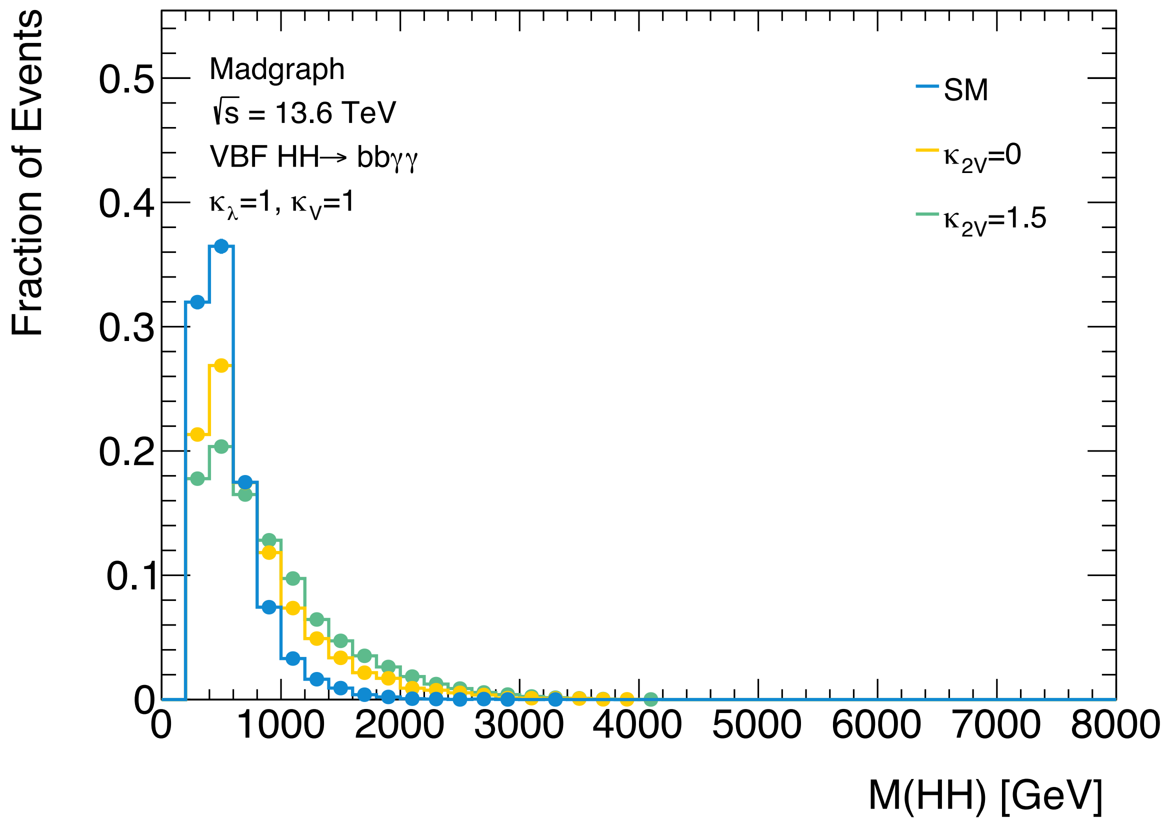
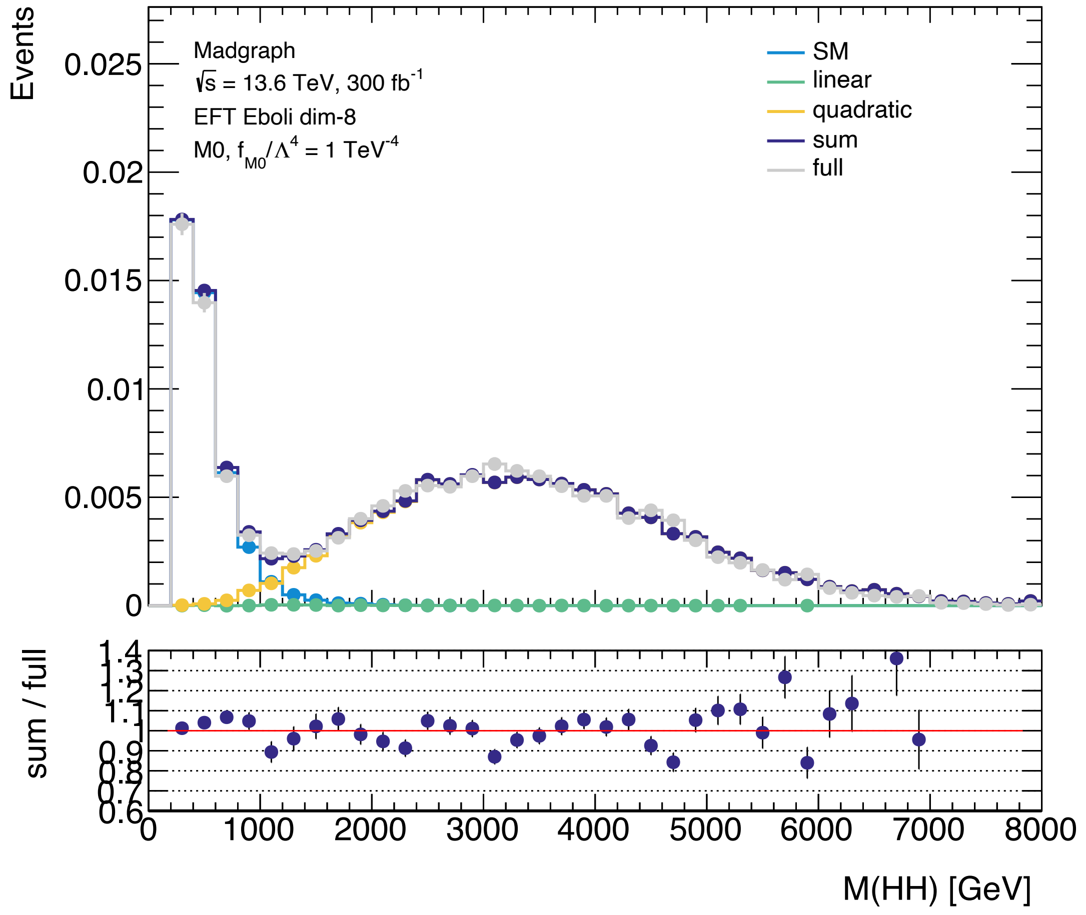
    - Sensitivity study based on the cross-section
    - VBF di-Higgs is expected to have a similar sensitivity to the operators as VBS processes!
  - Truth-level simulation of di-Higgs distributions for the different EFT operators using Madgraph with the amplitude decomposition approach indicated additional sensitivity when including shape information

κ_{2V} variations ←





→ EFT effects

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  - First ATLAS limits on c_H, c_{tthh} and c_{gghh}

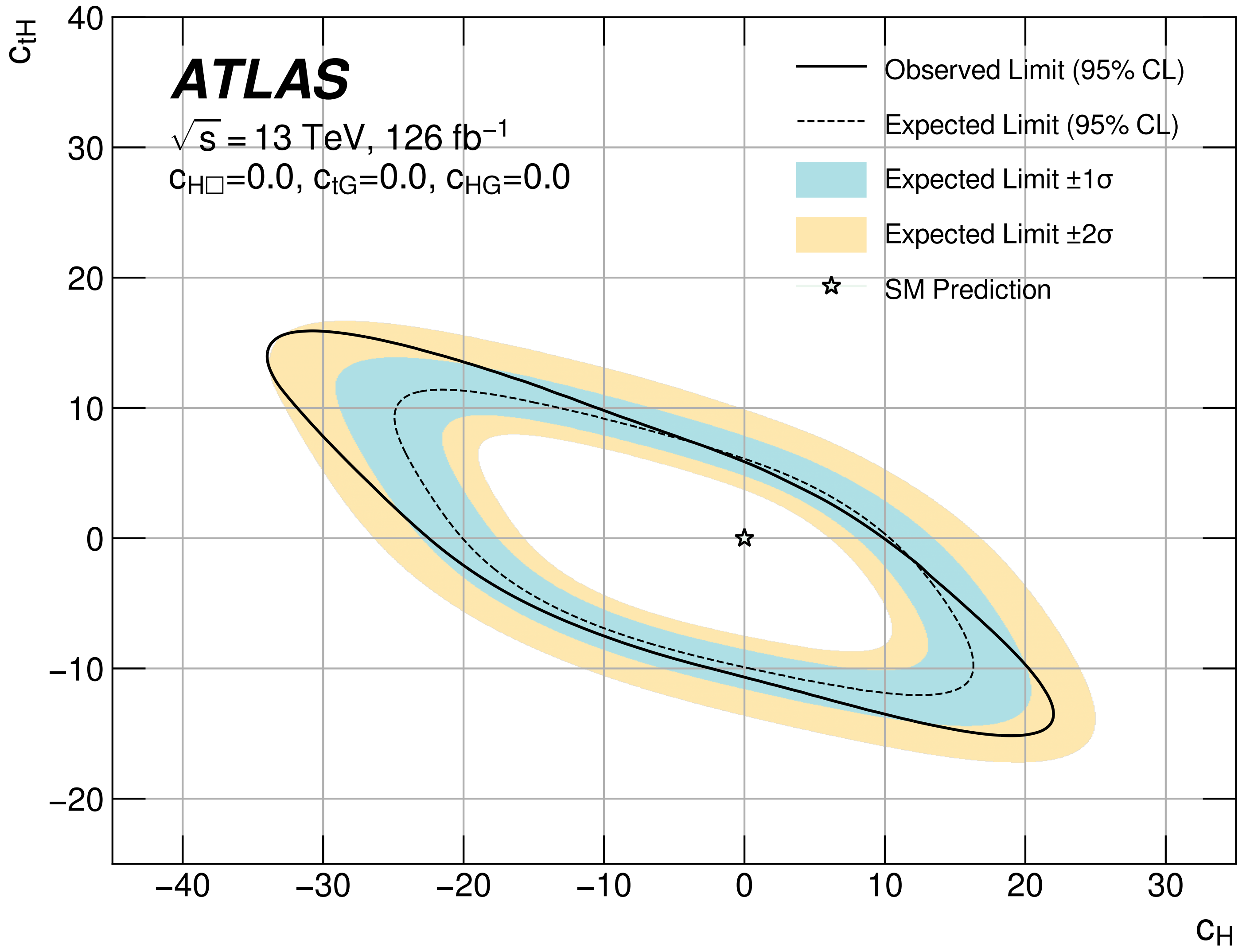
- Additional limits were set on benchmarks of the HEFT framework

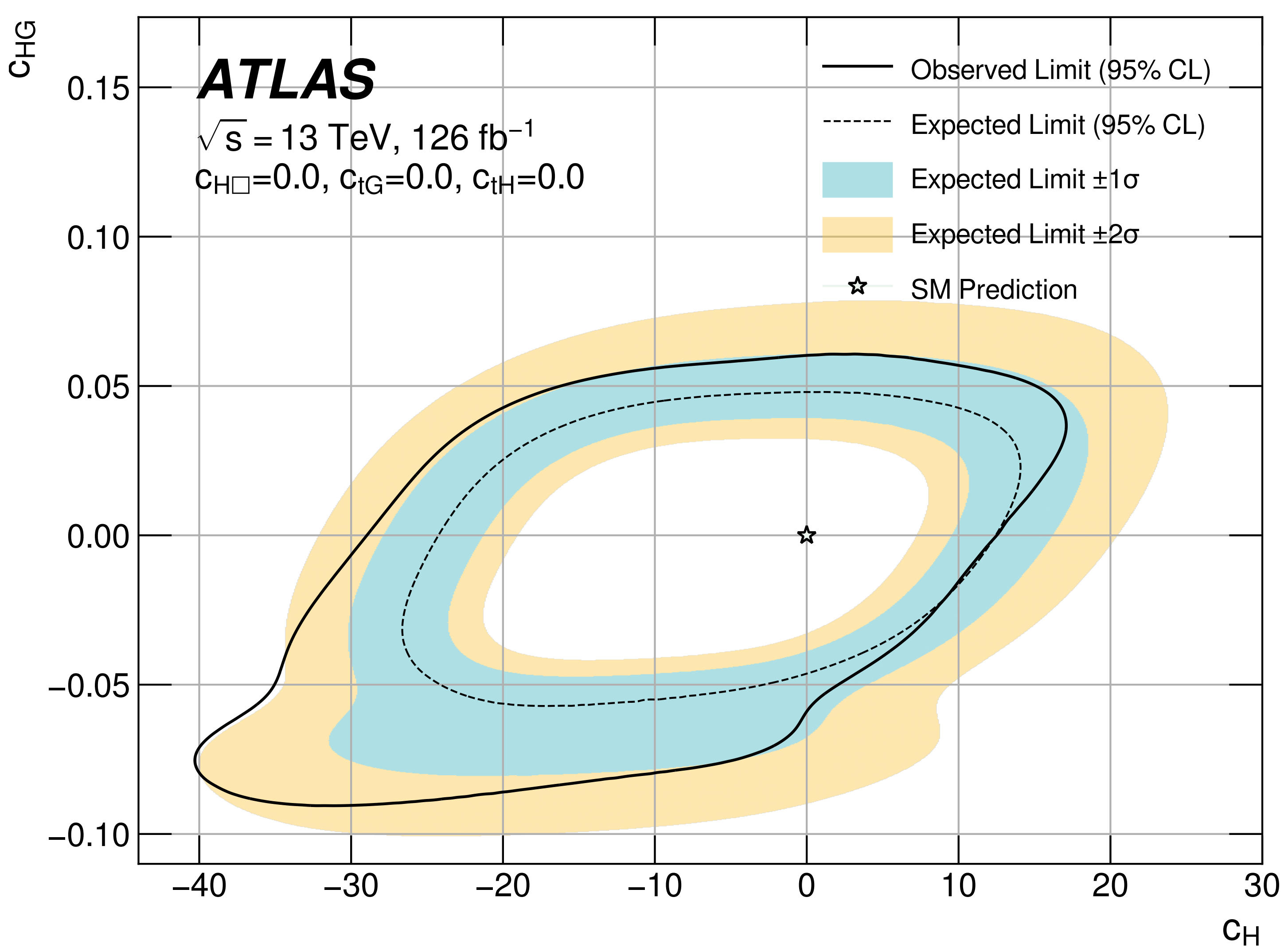
- What could be added in future analysis:
  - Including dim-8 VBF di-Higgs EFT interpretations at reco level promising
  - Potential for combination with VBS

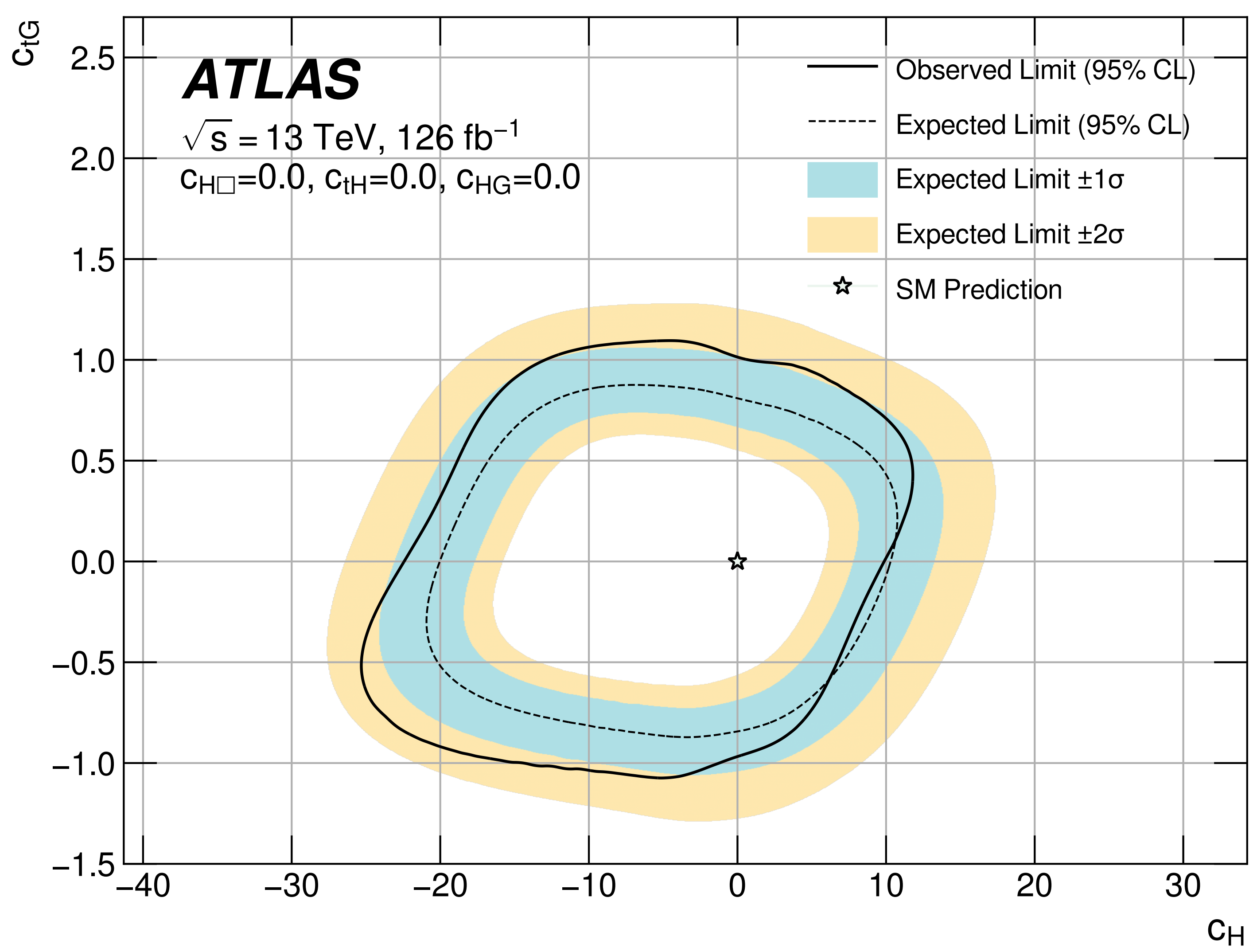
Backup

SMEFT results

- $bbbb$: additional 2D limits in the (c_H, c_{tH}), (c_H, c_{GH}) and (c_H, c_{tG}) parameters space





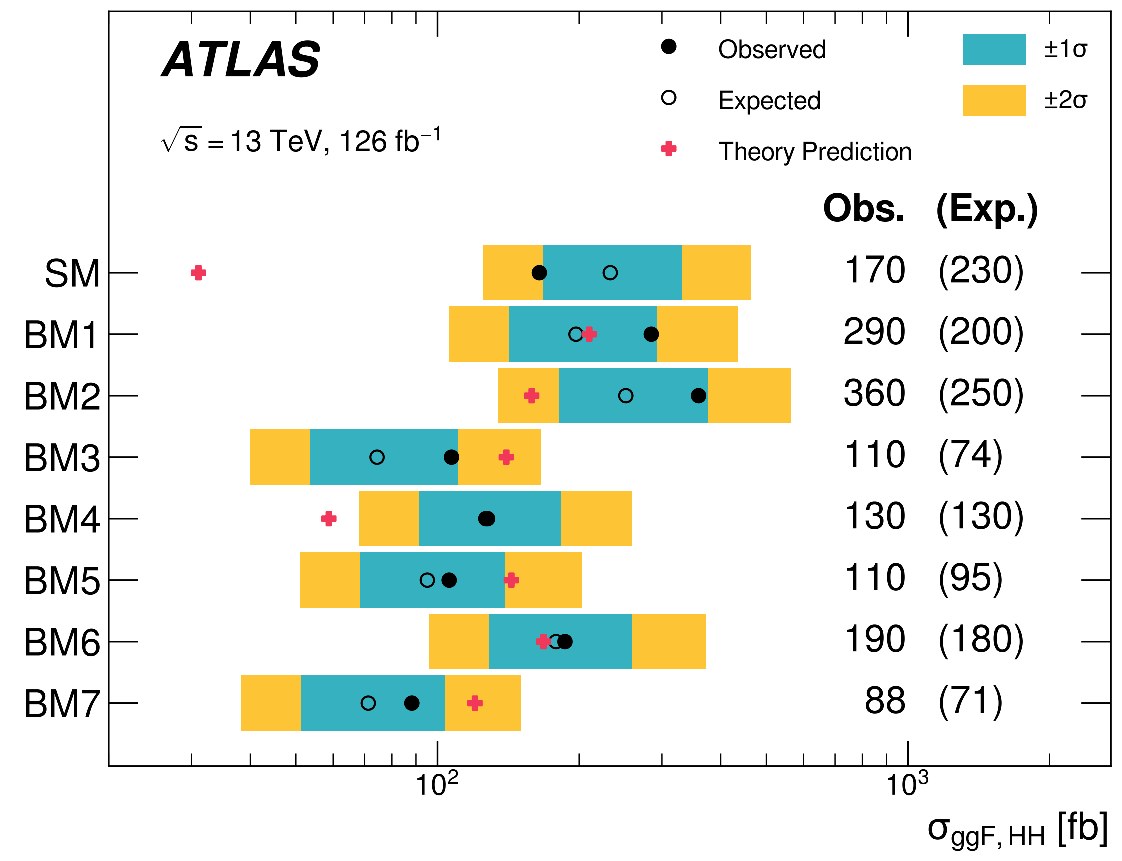


HEFT results

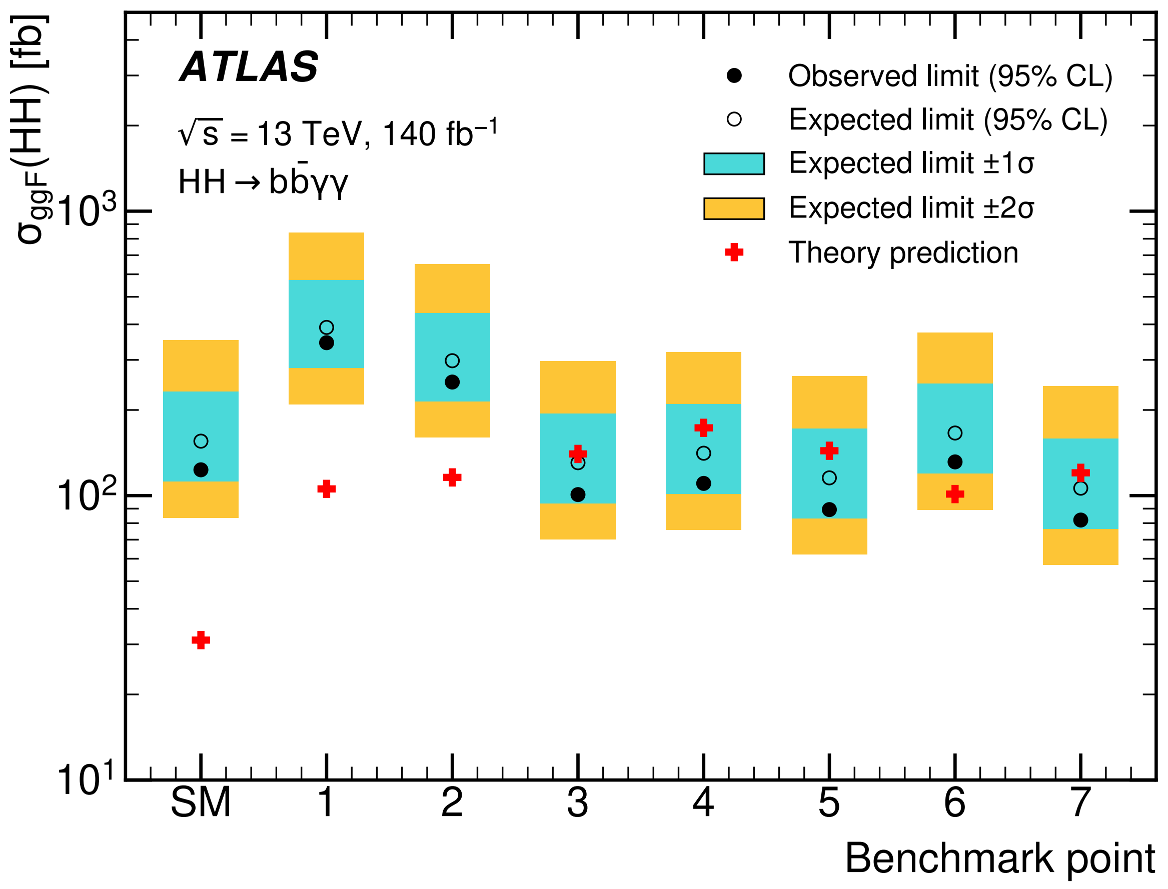
Phys. Rev. D 108 (2023) 052003
JHEP 01 (2024) 066
Phys. Rev. D 110 (2024) 032012

- Benchmark limits for the individual $bbbb$, $bb\gamma\gamma$ and $bb\tau\tau$ analyses
- $bbbb$
  - No direct comparison between $bbbb$ and the other analyses possible for benchmark points 1, 2, 4 and 6 since $bbbb$ uses an older definition of the benchmarks
  - excludes benchmarks 3, 5 and 7
- $bb\gamma\gamma$:
  - excludes benchmarks 3, 4, 5 and 7
  - Comparable limits to $bbbb$ for benchmarks 3,5 and 7
- $bb\tau\tau$
  - Uses the same benchmarks as $bb\gamma\gamma$

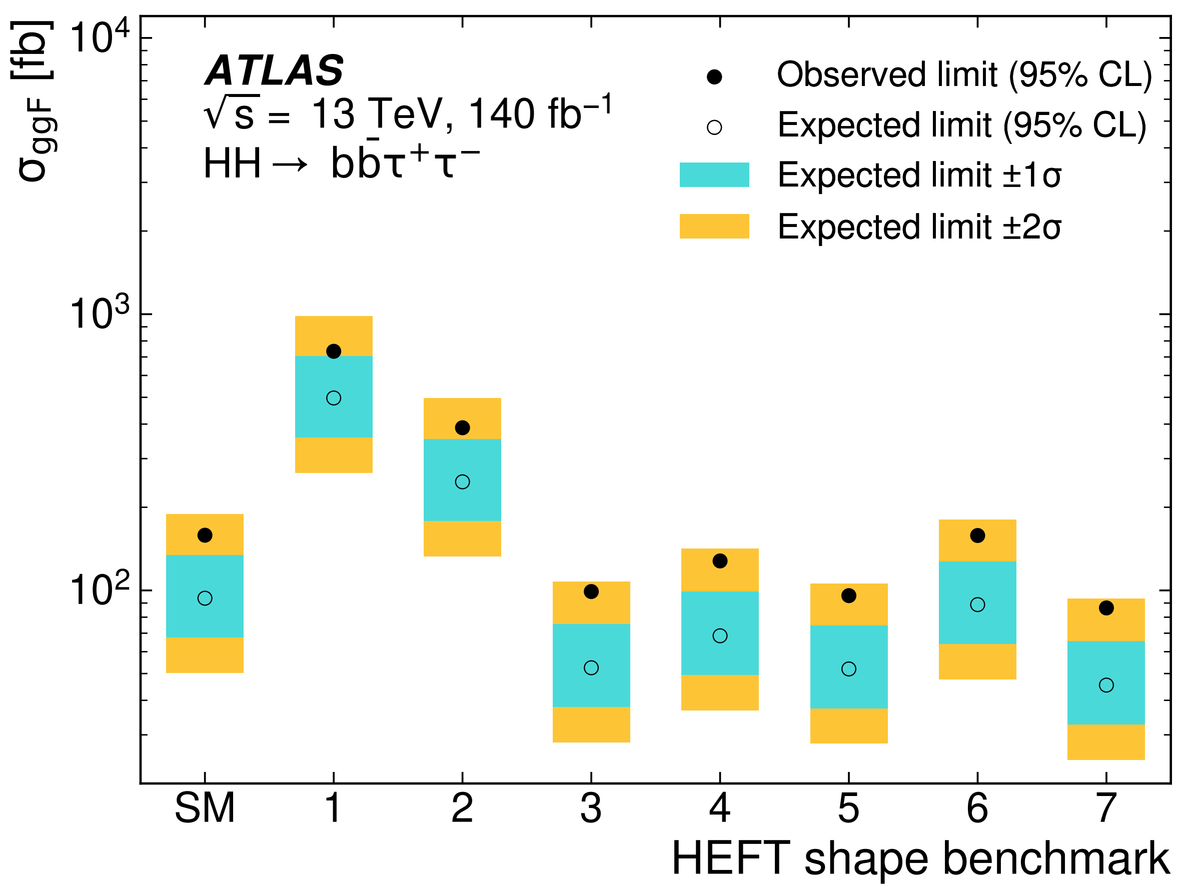
$bbbb$



$bb\gamma\gamma$



$bb\tau\tau$



JHEP 01 (2024) 066
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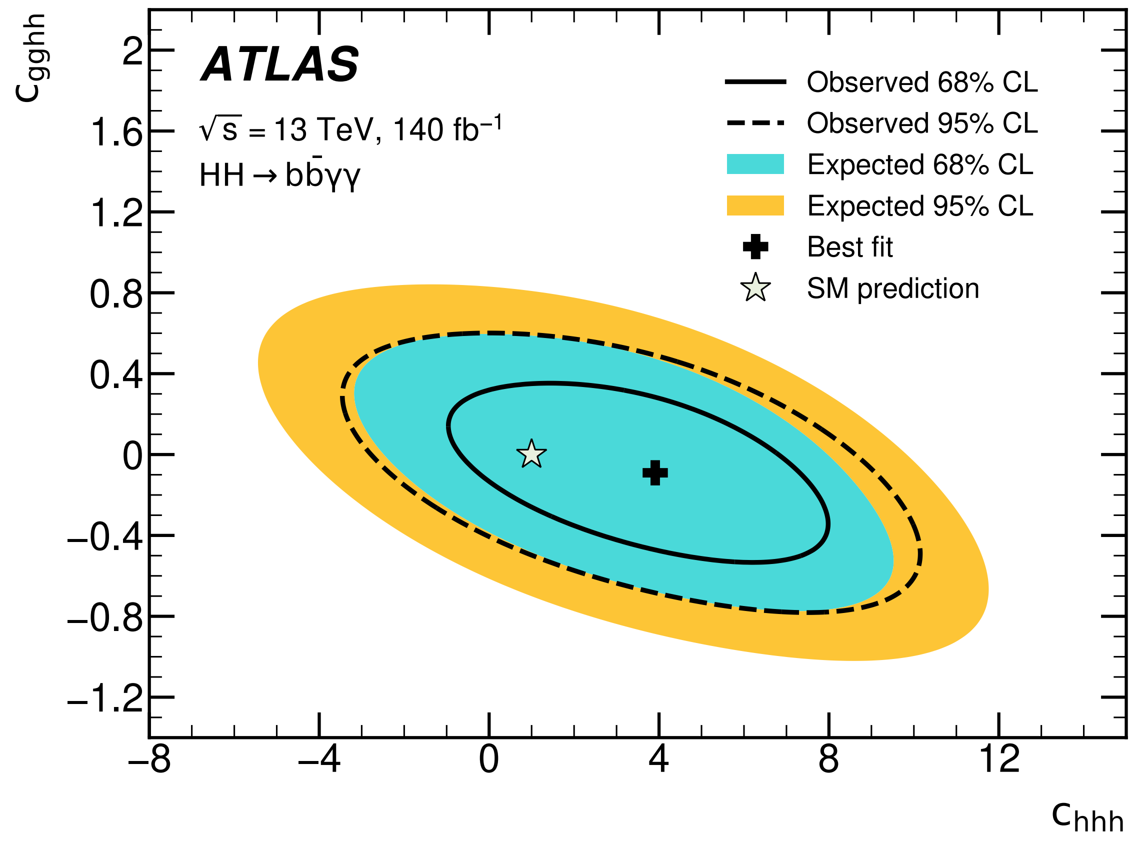
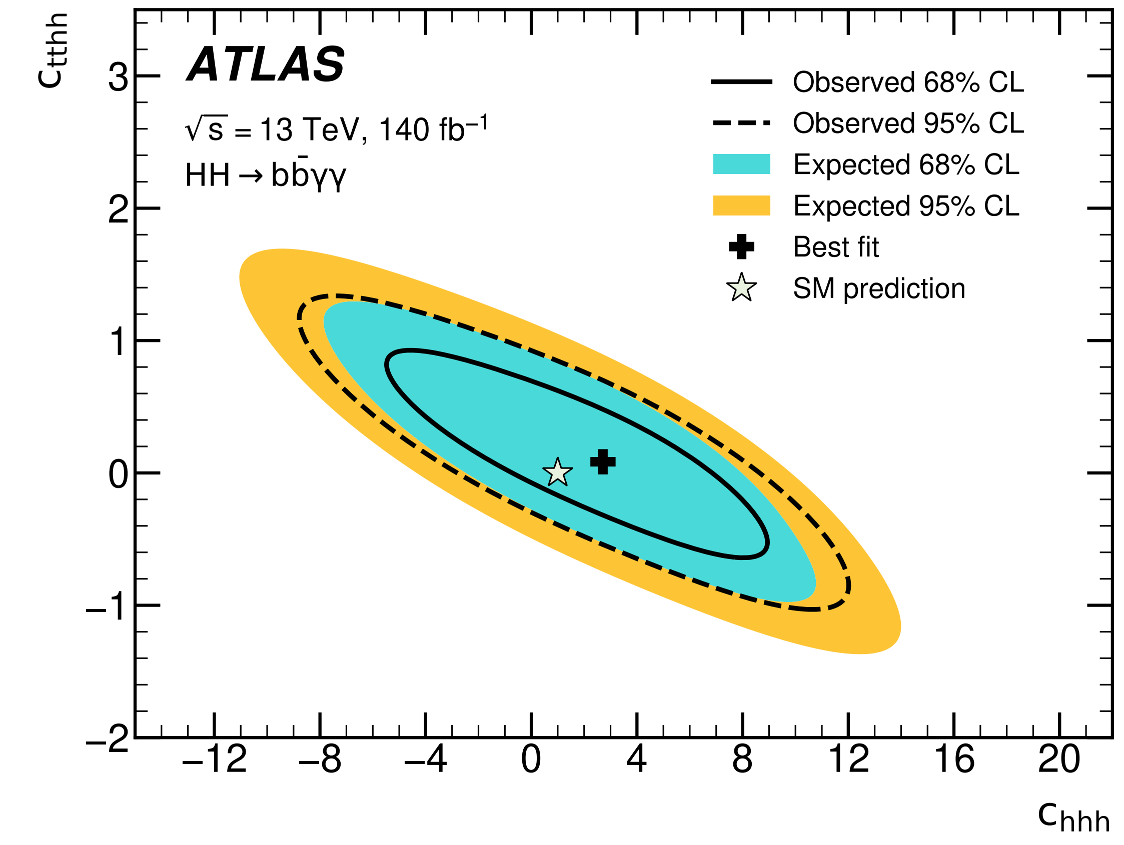
HEFT results

- 2D limits from the individual $bb\gamma\gamma$ and $bb\tau\tau$ anayses

$bb\gamma\gamma$





$bb\tau\tau$