Higgs boson couplings and EFT constraints from Higgs boson measurements

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On behalf of the CMS and ATLAS Collaborations

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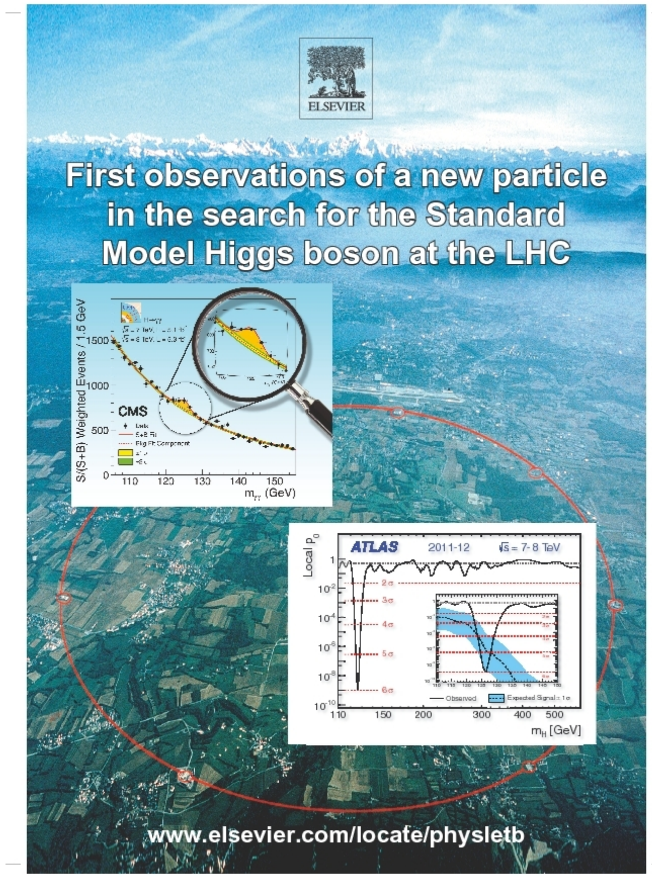
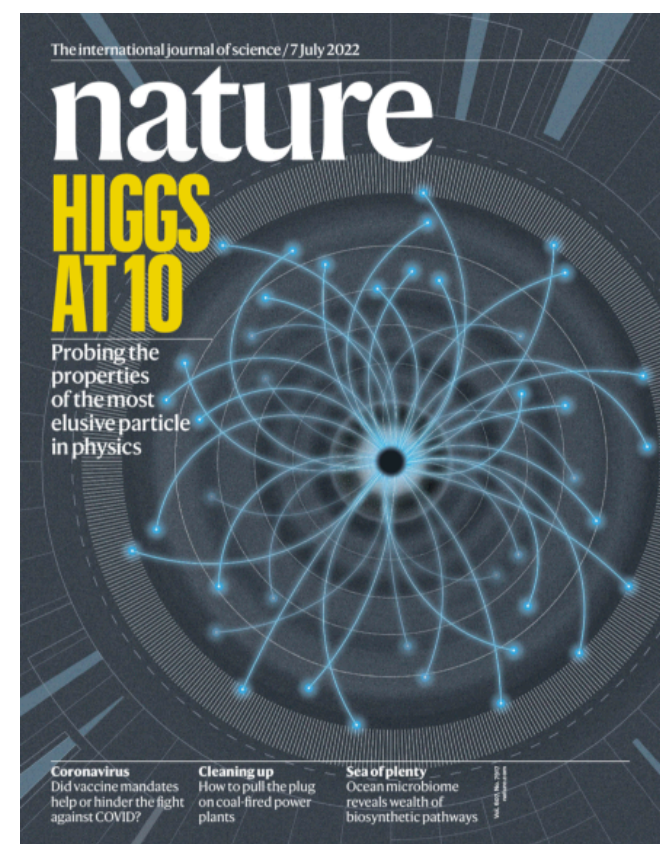
The Higgs boson

- **The Higgs boson discovery** opened a new way to refine our understanding of the electroweak sector
  - many studies of **Higgs boson coupling properties** have been performed
  - results can be interpreted using **kappa and EFT (effective field theory)** models
  - deviation from the Standard Model (SM) predictions on Higgs boson coupling properties would provide clues for new physics





Measurements of Higgs boson couplings with “kappa” framework

Coupling modifier (“kappa”)

- Leading order motivated framework: assign coupling modifier to each (effective) interaction vertex (e.g. κ_W, κ_t…)
- In this framework, production cross section times decay branch fraction of i→H→f can be parameterized as

$$\sigma_i \times B_f = \frac{\sigma_i(\boldsymbol{\kappa}) \times \Gamma_f(\boldsymbol{\kappa})}{\Gamma_H},$$

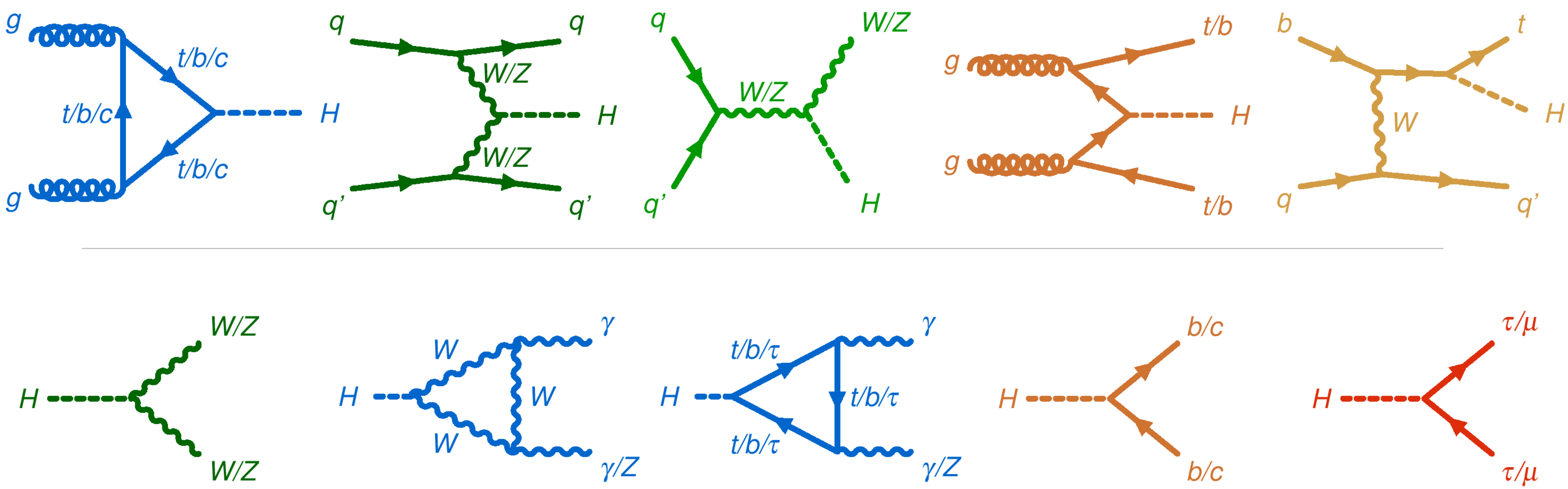
  - (this allows for a consistent treatment of production and decay)
- Total width of Higgs boson can be expressed as

$$\Gamma_H(\boldsymbol{\kappa}, B_{\text{i.}}, B_{\text{u.}}) = \kappa_H^2(\boldsymbol{\kappa}, B_{\text{i.}}, B_{\text{u.}})\,\Gamma_H^{\text{SM}}$$

$B_{i.}$= BSM contribution to BR of invisible decays which are identified through a missing transverse momentum signature

$B_{u.}$= BSM contribution to BR of undetected decays to which none of the analyses in the combination are sensitive

Higgs boson couplings with “kappa”

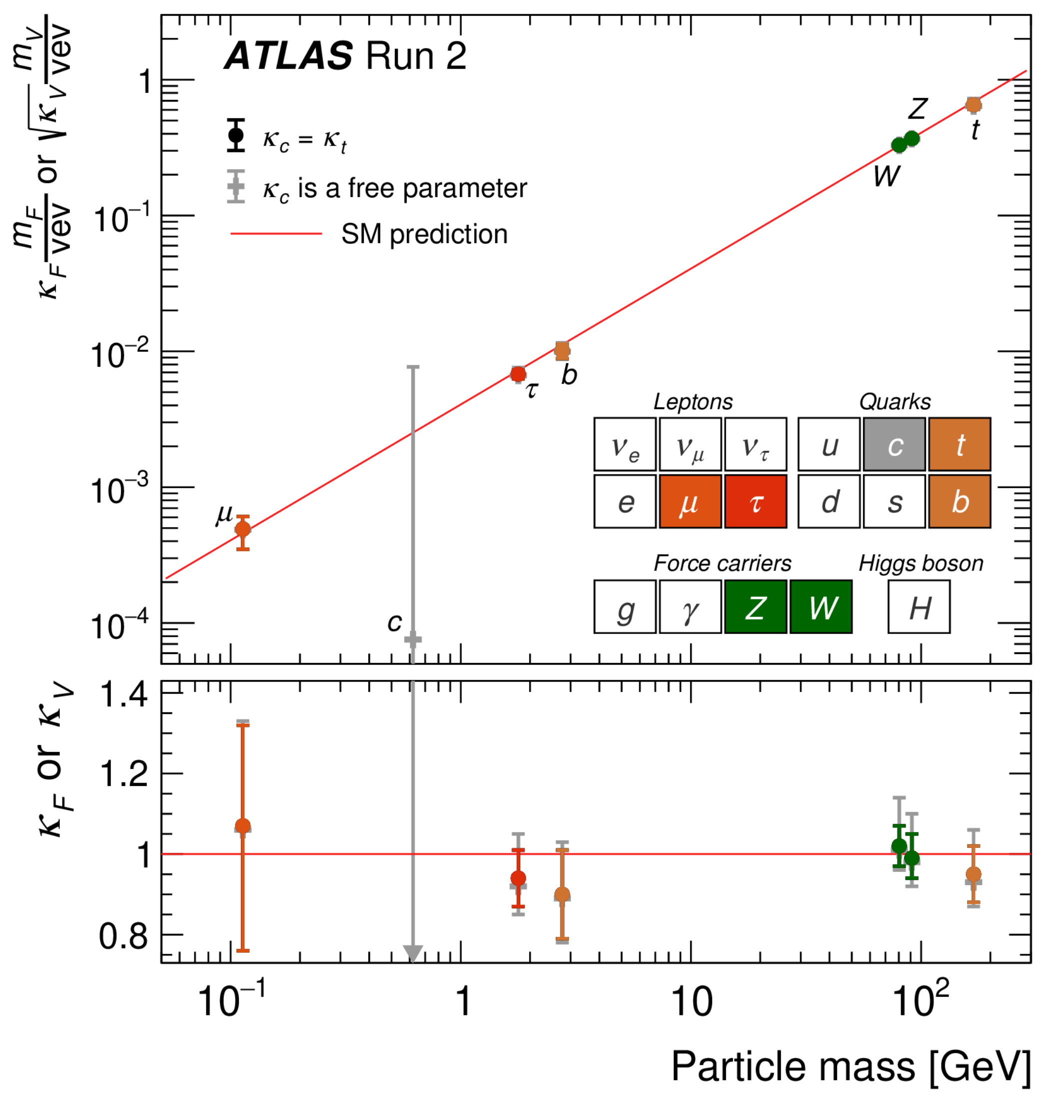


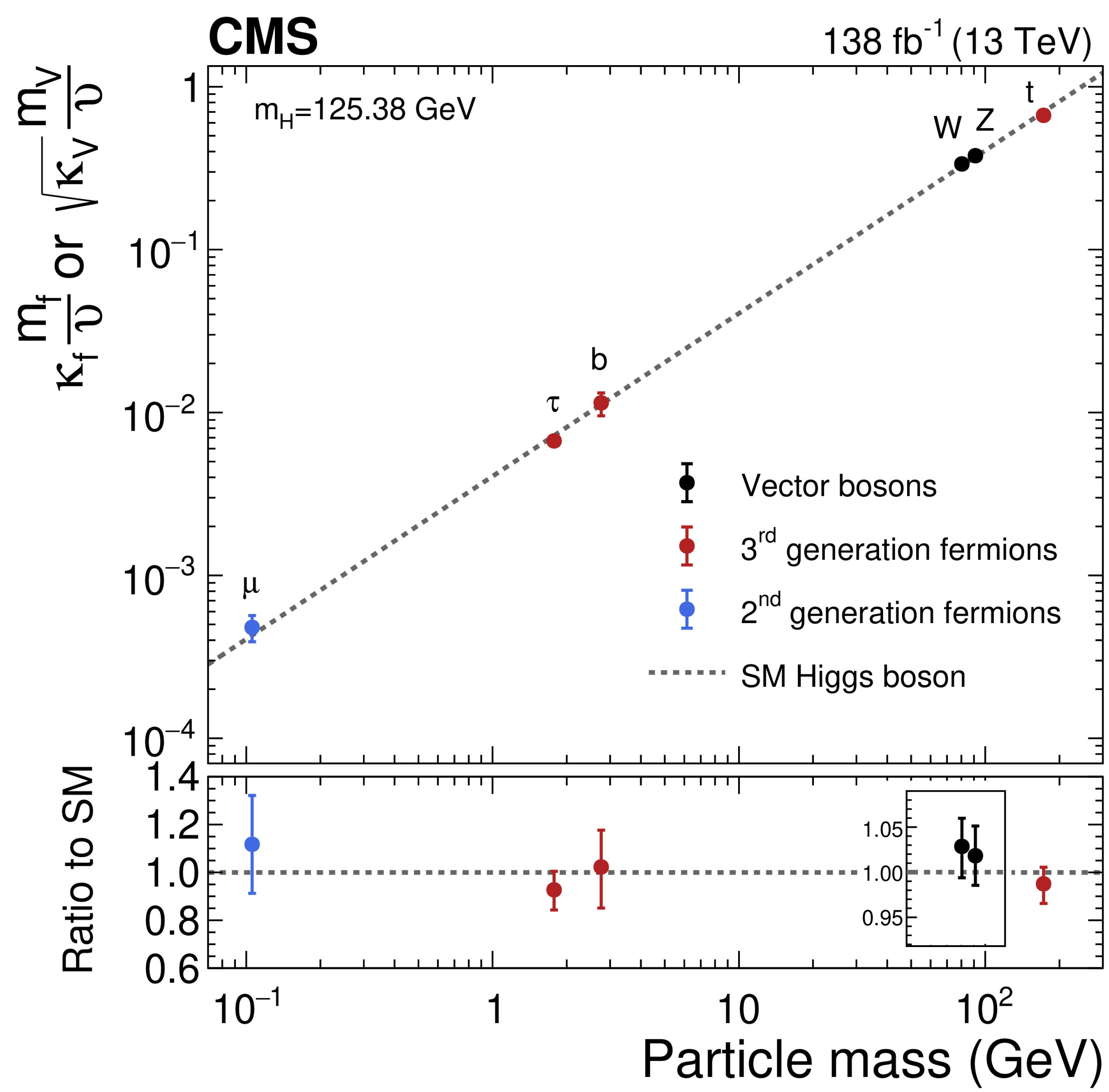
- ATLAS & CMS combine various Higgs production channels and various Higgs decay channels

Higgs boson couplings with “kappa”

ATLAS Nature 607 (2022) 52-59

Nature 607 (2022) 60-68

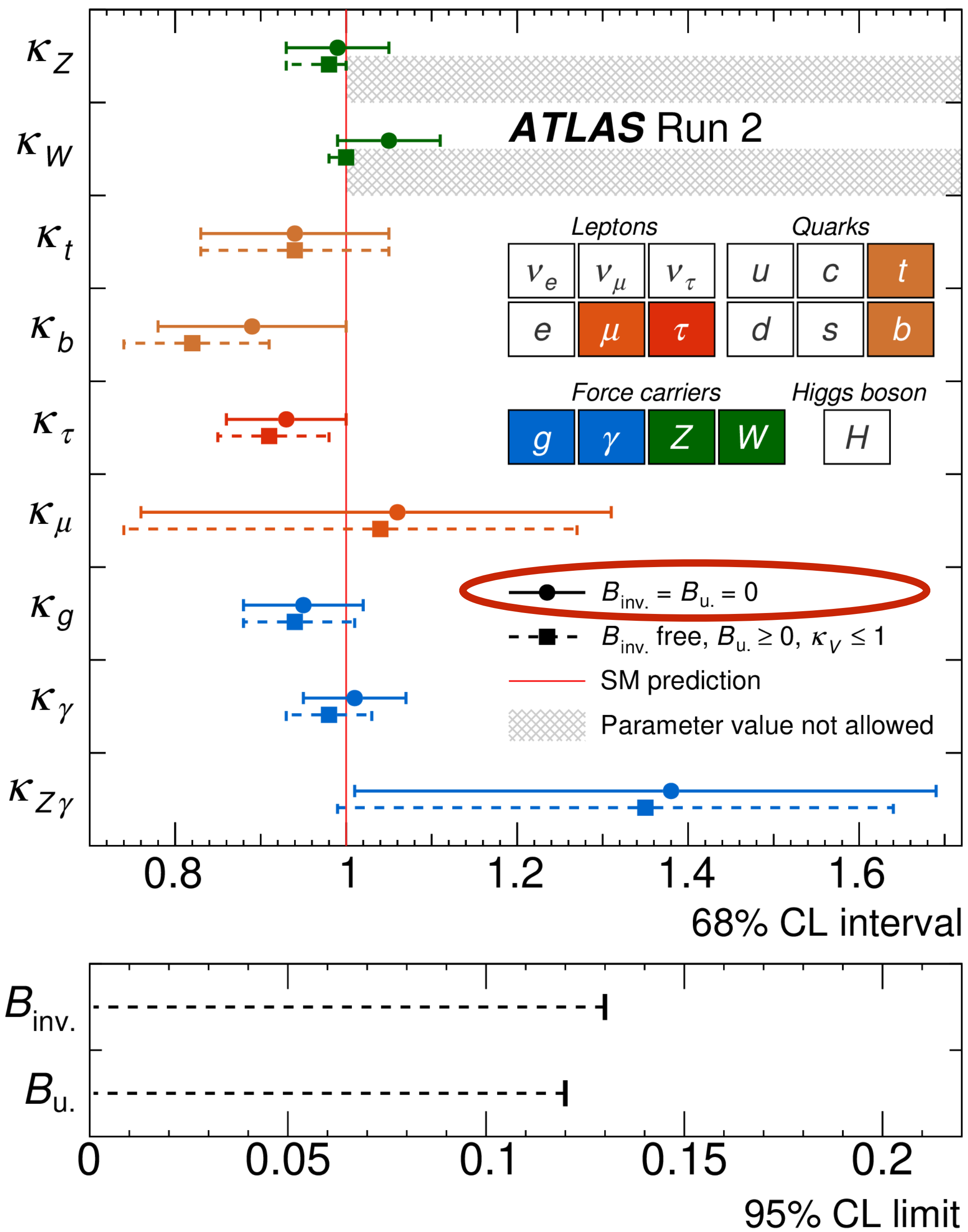




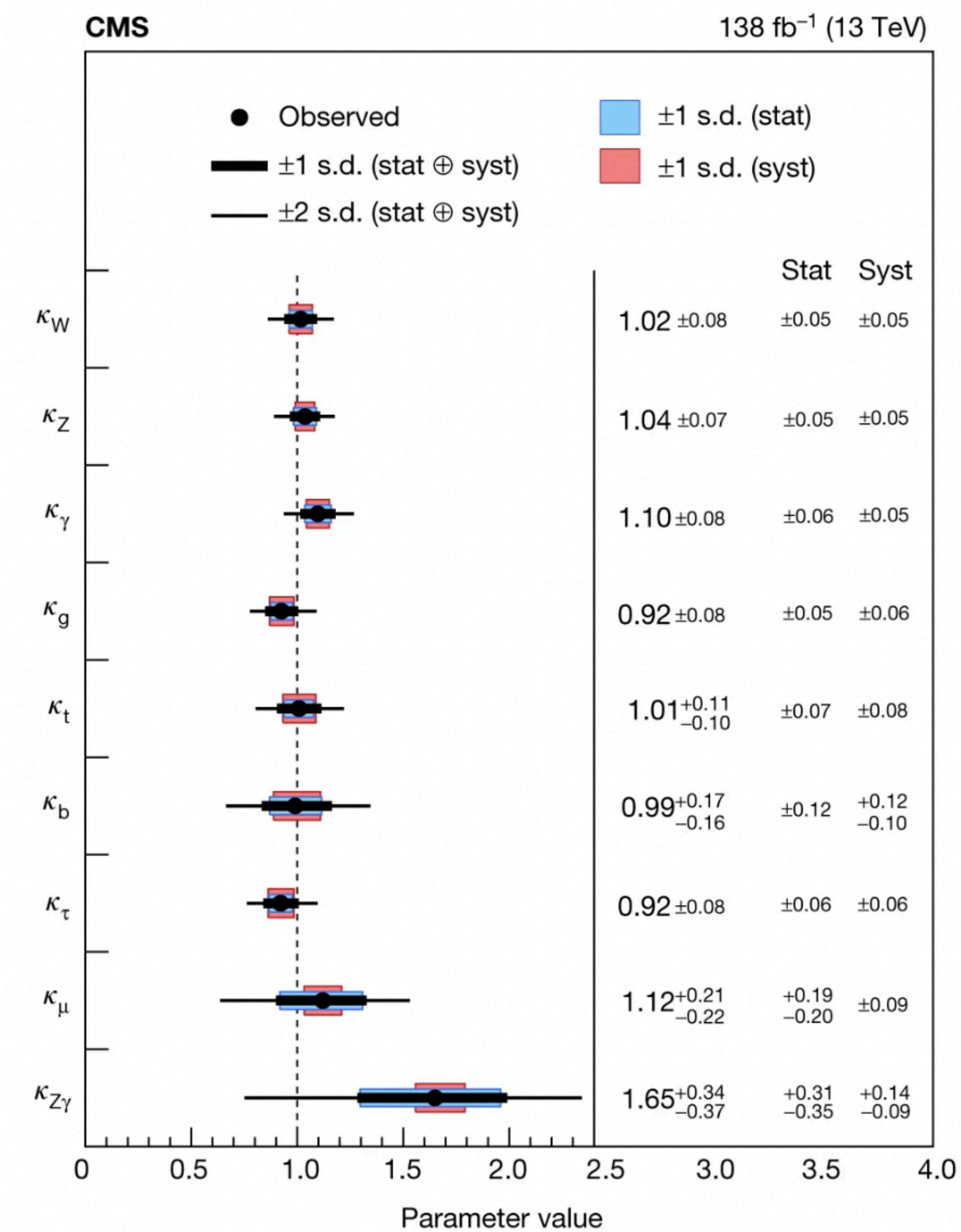
- Assume no BSM contribution in loop-induced processes (ggF, H→γγ, etc.) or total width. Resolve ggF and Hγγ effective vertices
- Good agreement with the SM across 3 orders of magnitude of particle mass

Higgs boson couplings with "kappa"

ATLAS Nature 607 (2022) 52-59



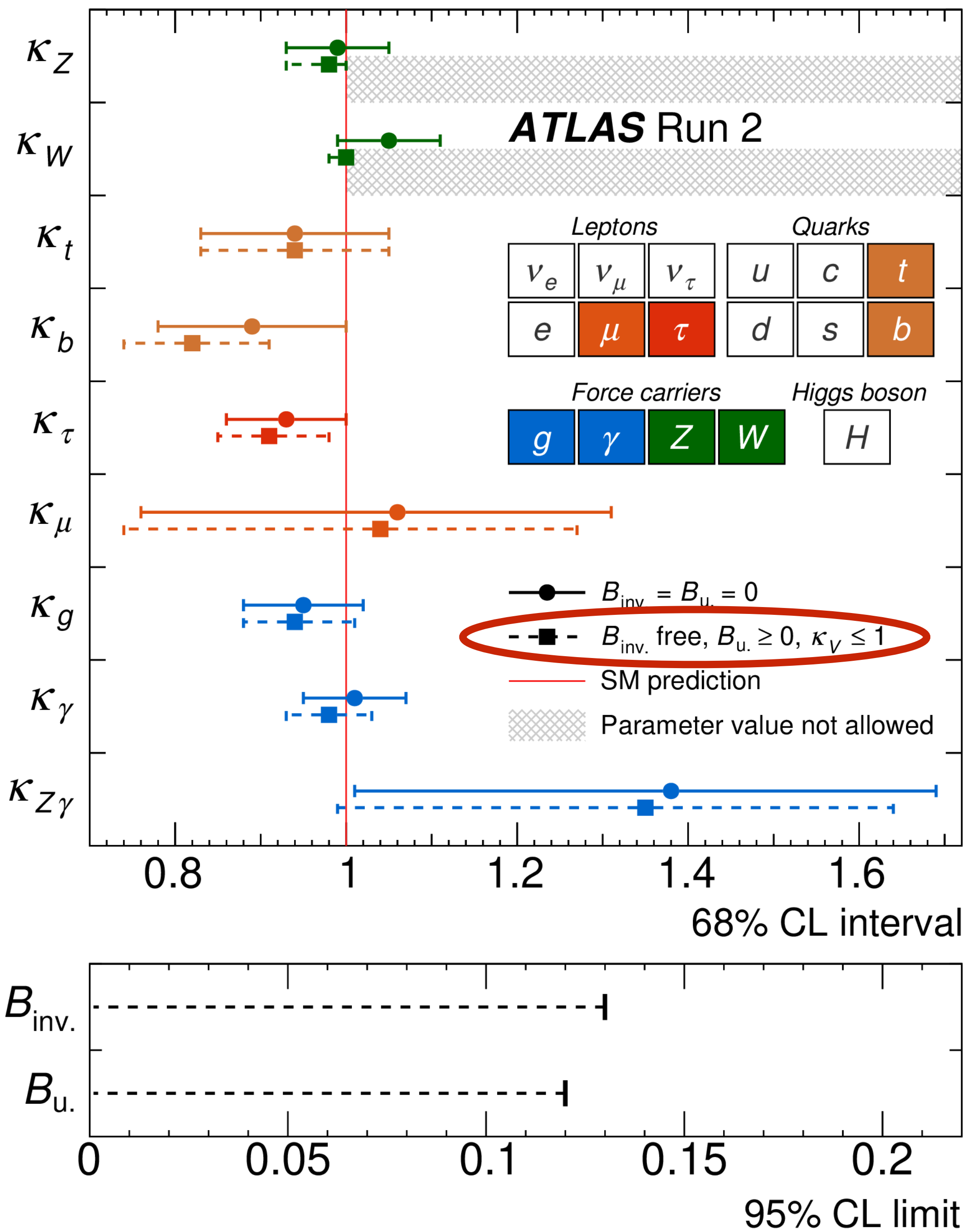
Nature 607 (2022) 60-68



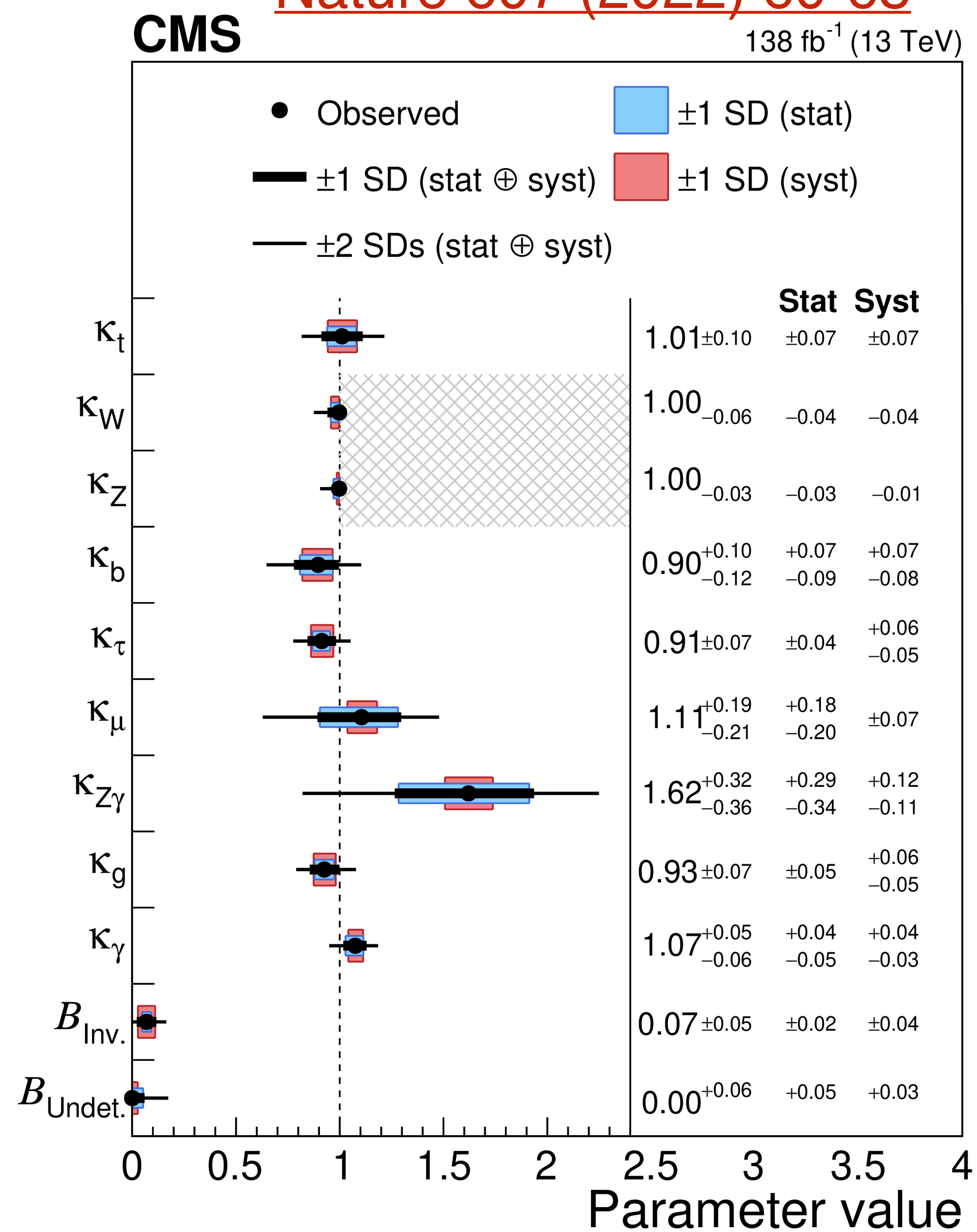
- Not resolving ggF and Hγγ effective vertices (and introducing coupling modifiers κ_g, κ_γ)
  - assume $B_{invisible}=B_{undetected}=0$
- All coupling modifiers are measured to be compatible with the SM

Higgs boson couplings with “kappa”

ATLAS [Nature 607 (2022) 52-59]

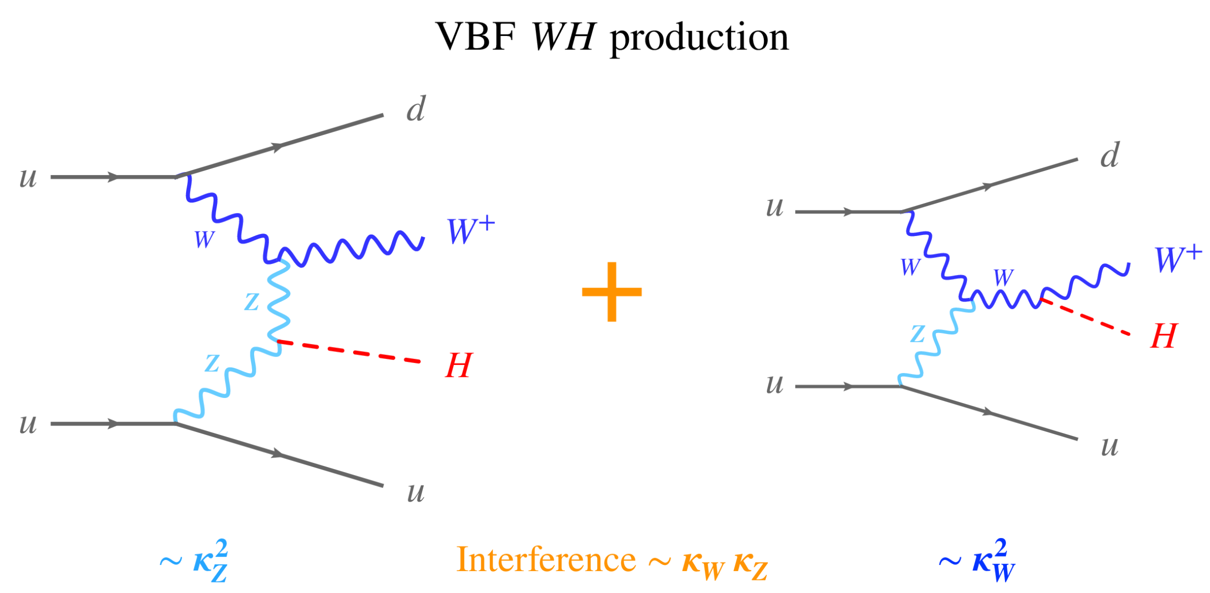


[Nature 607 (2022) 60-68]

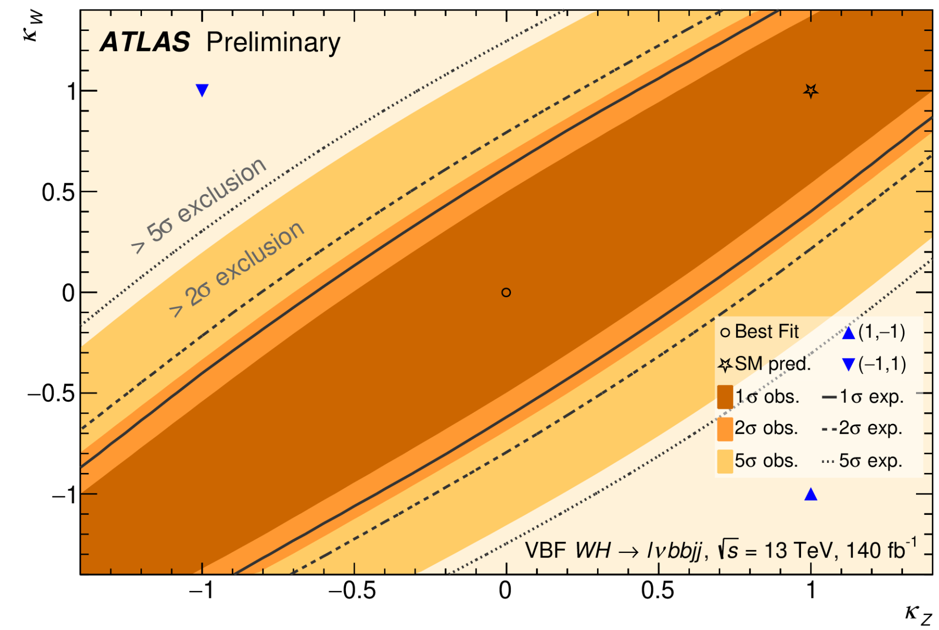


- Not resolving ggF and Hγγ effective vertices (and introducing coupling modifiers κ_g, κ_γ)
  - constrain $B_{invisible}$ and $B_{undetected}$ using H→invisible analysis and $\kappa_V < 1$
- Both invisible and undetected BR’s are compatible with zero

Relative sign of κ_W and κ_Z

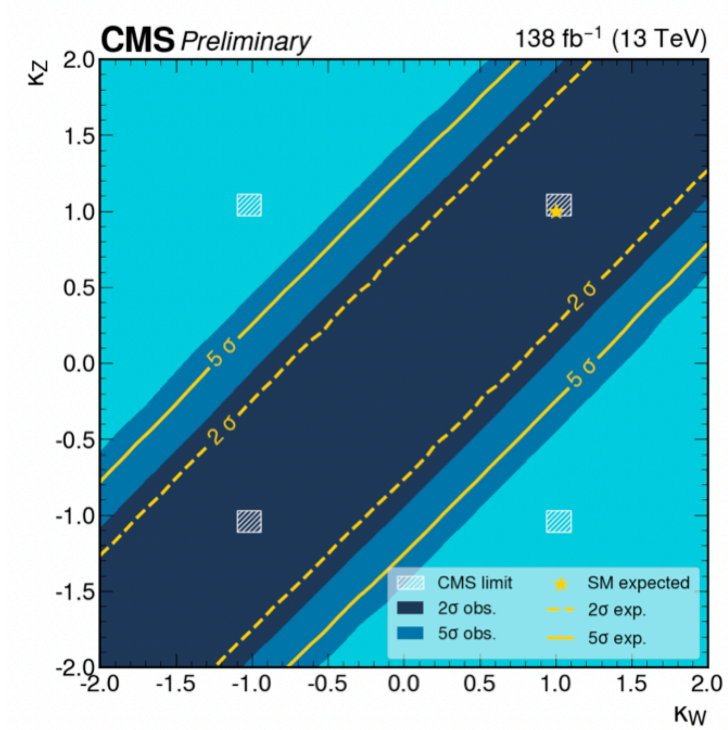


$$\sigma_{\mathrm{VBF},WH} \propto \kappa_Z^2 |\mathcal{M}_Z|^2 + \kappa_W^2 |\mathcal{M}_W|^2 - 2\,\kappa_Z\,\kappa_W\,\Re[\mathcal{M}_Z^\dagger \mathcal{M}_W]$$



ATLAS-CONF-2023-057

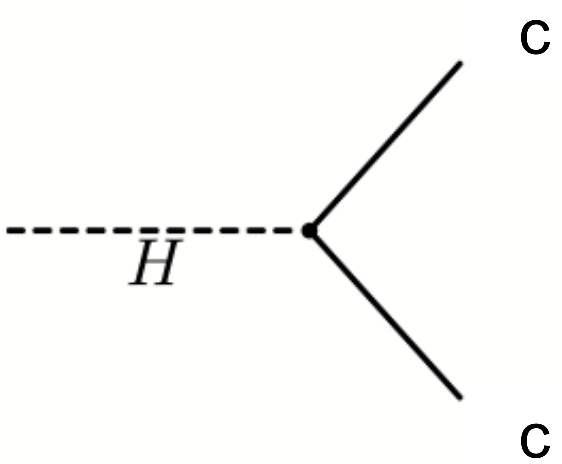
- VBF WH production mode offers sensitivity to the relative sign of κ_W and κ_Z
- Studied using Higgs decays to b-quarks and W decays with a lepton
- Opposite-sign coupling hypothesis is excluded with significance greater than 5σ by both ATLAS and CMS

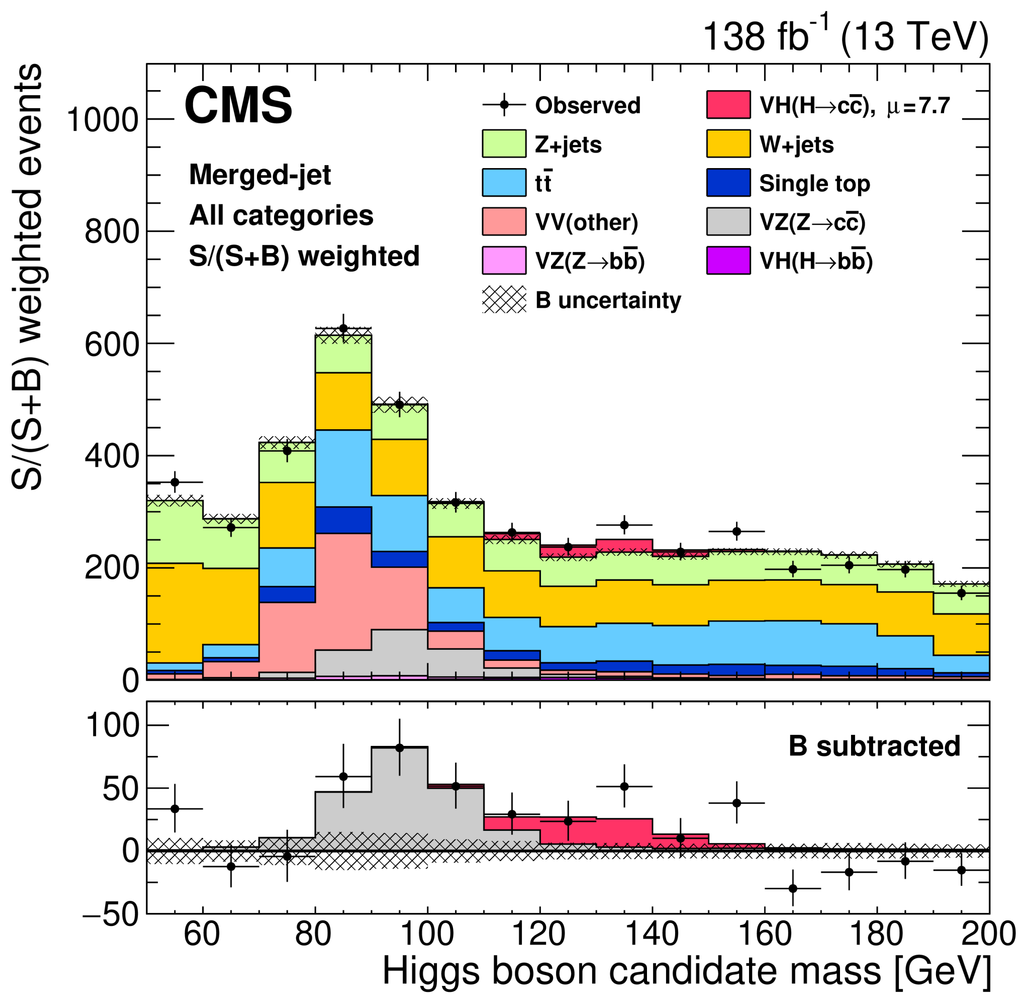


CMS-PAS-HIG-23-007 (NEW)

Higgs couplings to c quarks

- **H→c$\bar{c}$ decay** is currently the main channel to probe Higgs coupling to c quarks
  - branching ratio in SM: 2.8%





[Phys. Rev. Lett. 131 (2023) 061801]

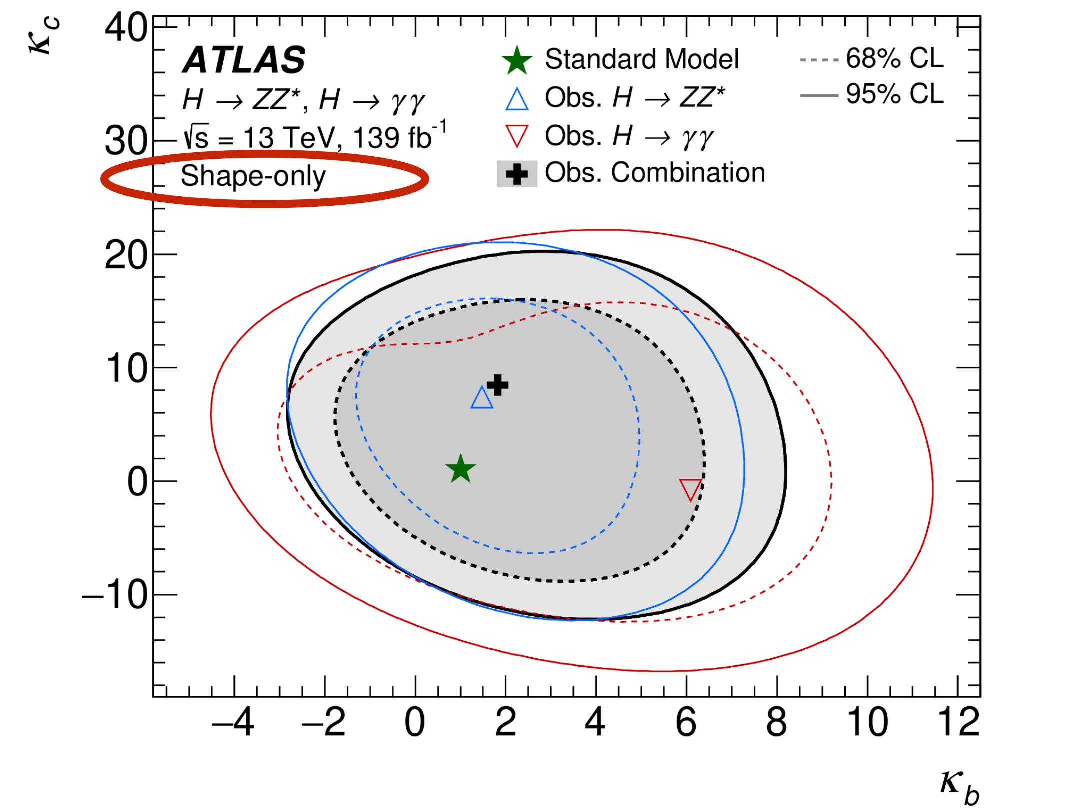
[Eur. Phys. J. C 82 (2022) 717]

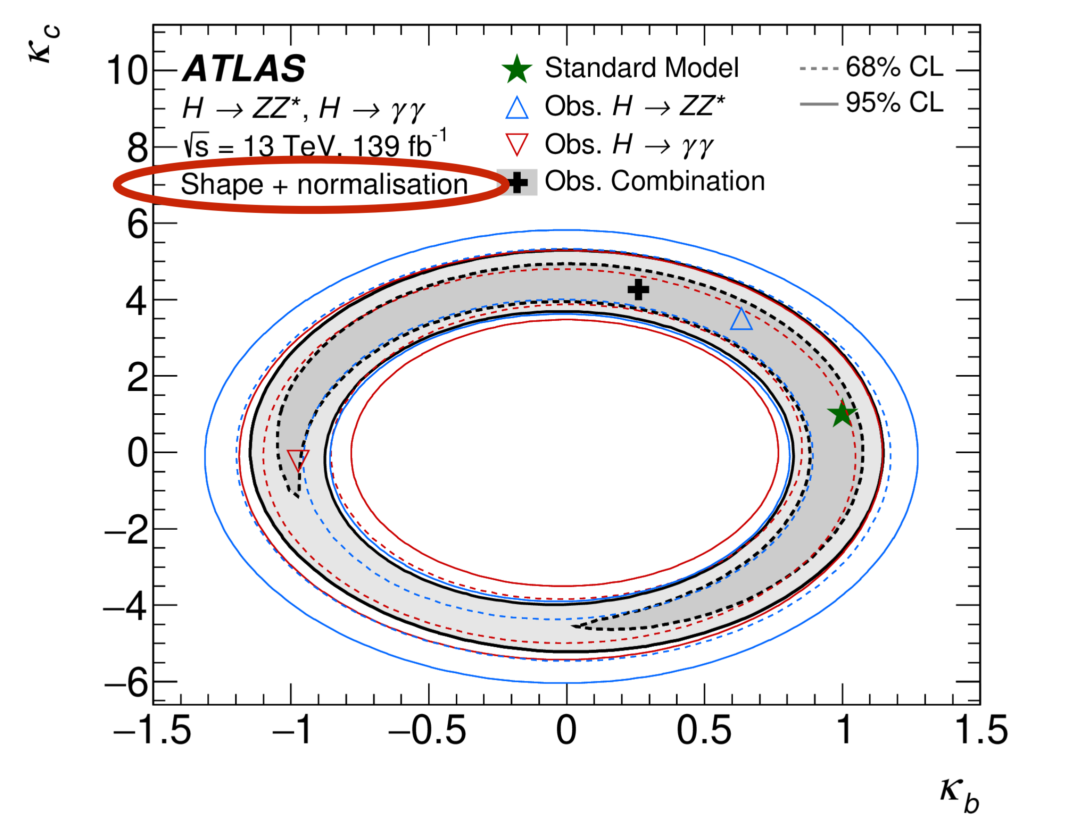
VH H→c$\bar{c}$

- Tag leptonically decaying W/Z boson
- Observed limit at 95% CL on H→c$\bar{c}$ signal strength: 14 (CMS) and 26 (ATLAS) times SM prediction
- Constraint on Higgs-charm Yukawa coupling modifier: **1.1 < |Kc| < 5.5 (CMS) and |Kc| < 8.5 (ATLAS)**

Higgs couplings to c quarks

- Higgs p_T distribution is sensitive to Yukawa couplings of Higgs boson to b- and c-quarks
  - driven by contributions of b- and c-quarks to loop-induced ggF production and by quark-initiated production of Higgs
- Constraints from ATLAS combination of Higgs p_T differential XS of H→γγ and H→ZZ channels:
  - $-8.6<\kappa_c<17.3$ (using only shape information)
  - $-2.27<\kappa_c<2.27$ (using shape+normalization information)
  - complementary with constraints from H→cc decay





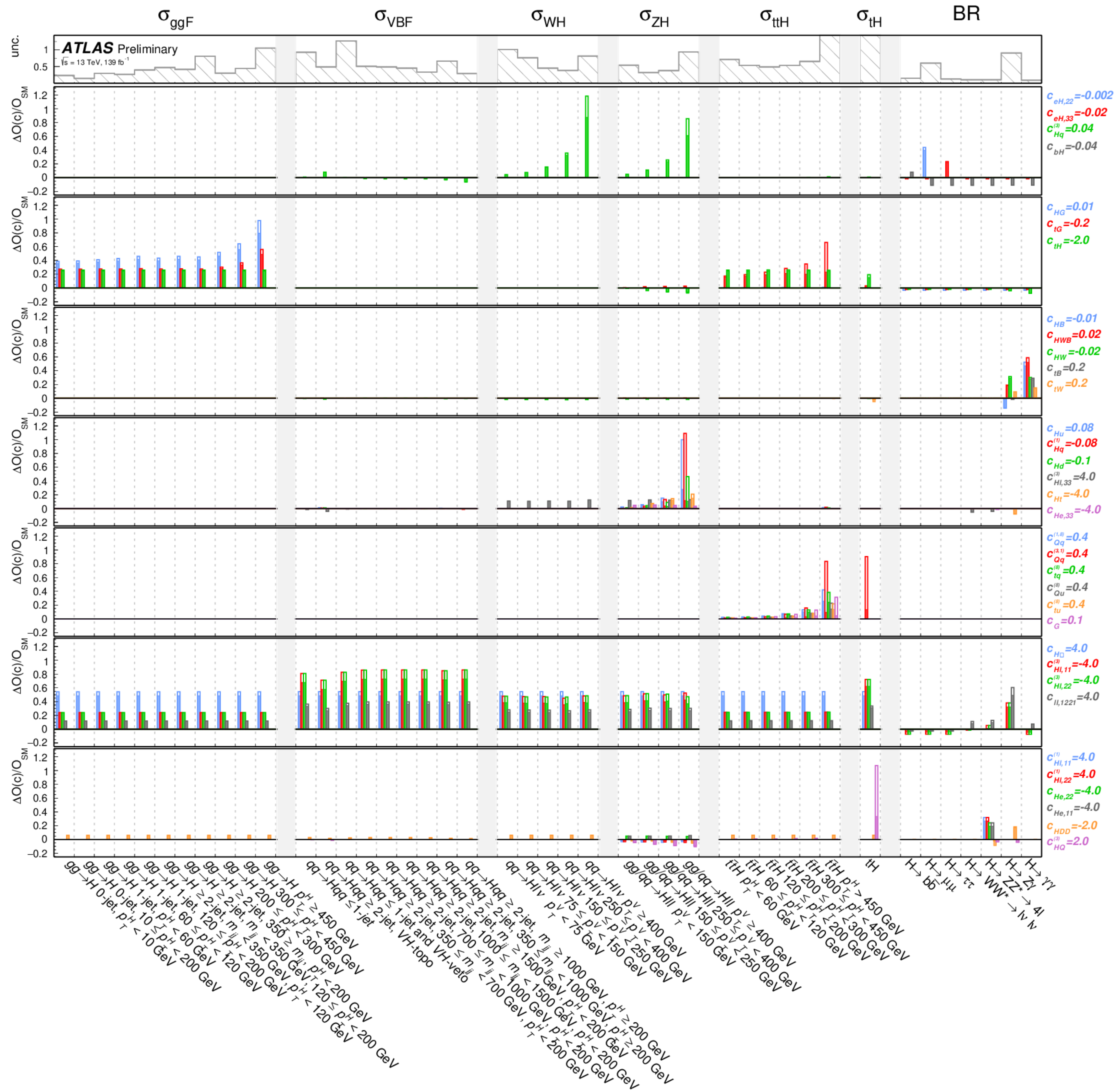
JHEP05(2023)028

EFT interpretation from Higgs measurements

Interpretation of STXS with EFT

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_{j}^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \ldots$$

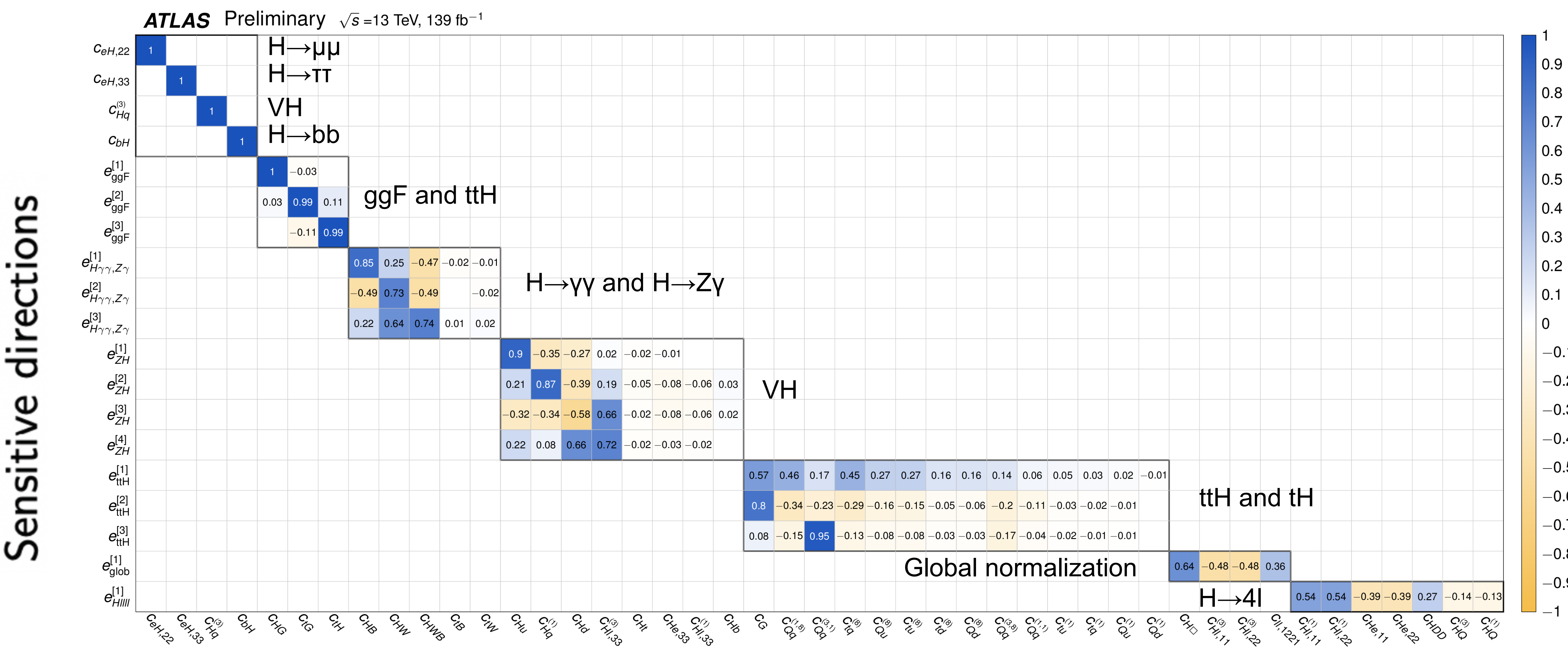
- Parameterize the signal strengths, (XS*BR)meas/(XS*BR)SM, directly with Wilson coefficients of d=6 SMEFT operators



ATLAS-CONF-2023-052

Interpretation of STXS with EFT

- Rotate the SMEFT basis cj to eigenvector cj' and fit sensitive eigenvectors simultaneously
  - these eigenvectors are obtained from identifying groups of operators with similar impact and performing eigenvector decomposition for the covariance matrix of the measurement

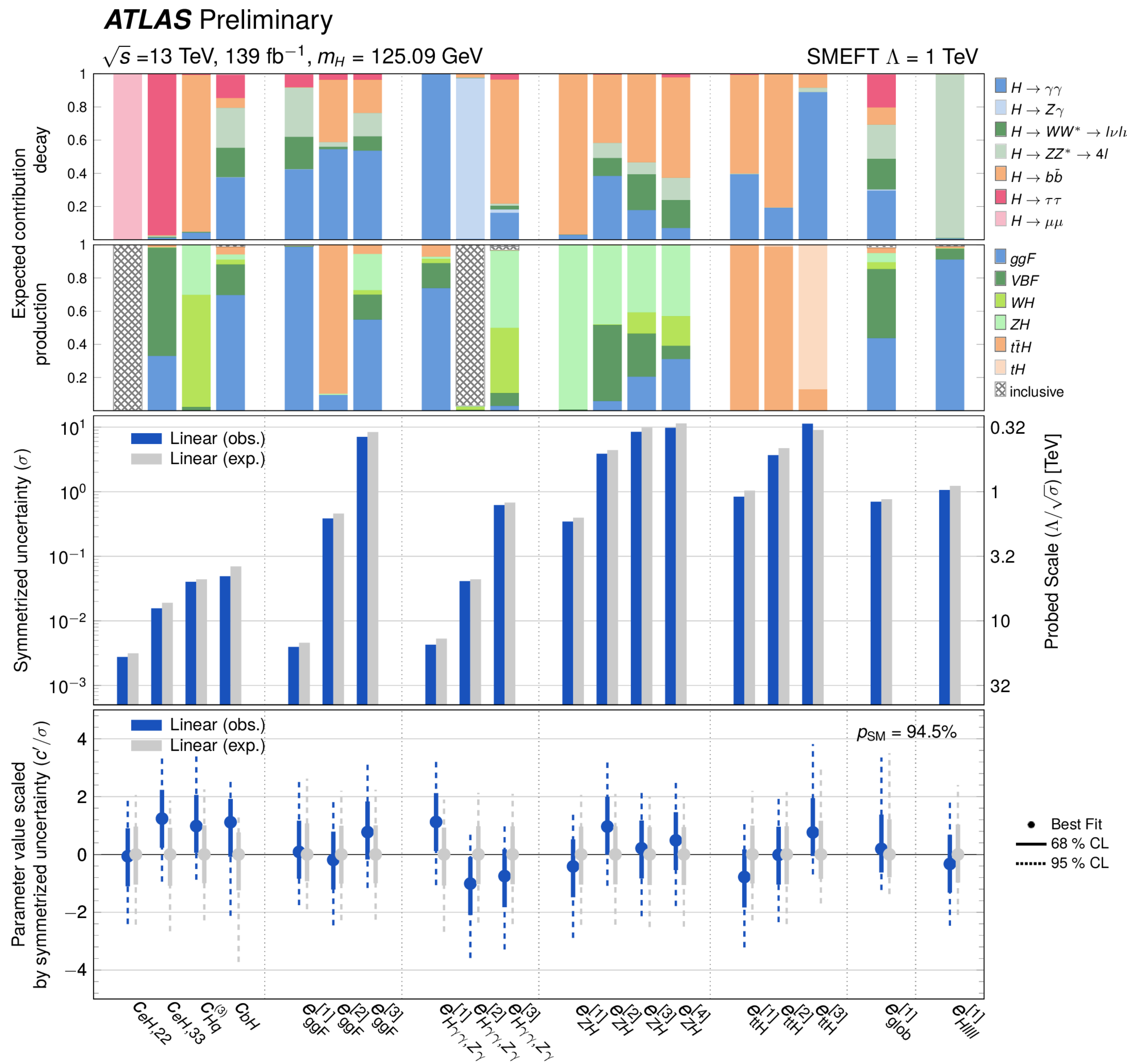


ATLAS-CONF-2023-052

Interpretation of STXS with EFT

- All measured parameters are consistent with the SM expectation within their uncertainties
- Six (five) parameters are almost exclusively measured by a single decay (production) mode

From a simultaneous fit; linear only results

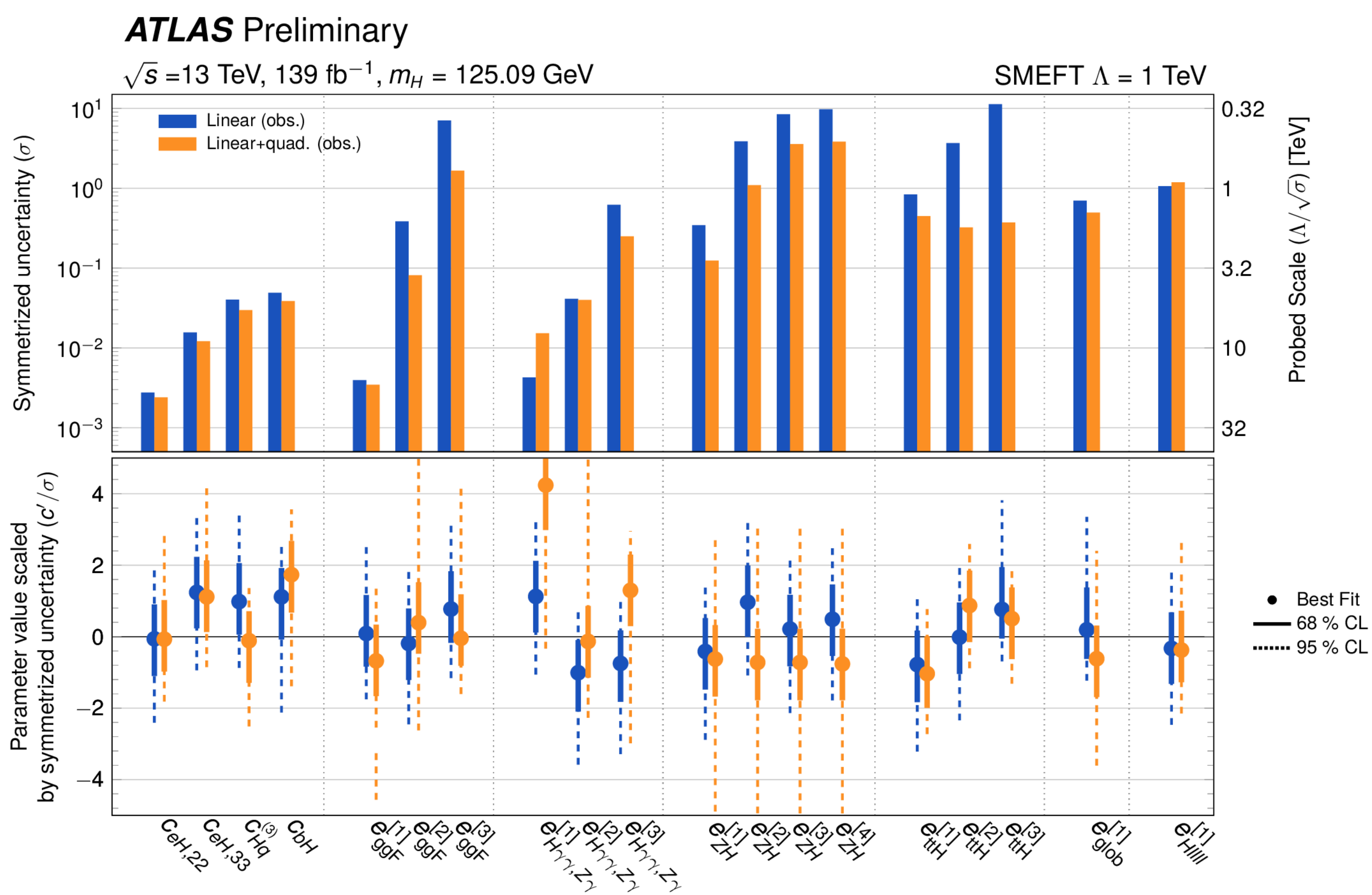


ATLAS-CONF-2023-052

Interpretation of STXS with EFT

$$(\sigma\times B)^{i,k',H\to X}_{\mathrm{SMEFT}} = \sigma^{i,k'}_{\mathrm{SMEFT}} \times B^{H\to X}_{\mathrm{SMEFT}} = \left(\sigma^{i,k'}_{\mathrm{SM}} + \sigma^{i,k'}_{\mathrm{int}} + \sigma^{i,k'}_{\mathrm{BSM}}\right) \times \left(\frac{\Gamma^{H\to X}_{\mathrm{SM}} + \Gamma^{H\to X}_{\mathrm{int}} + \Gamma^{H\to X}_{\mathrm{BSM}}}{\Gamma^{H}_{\mathrm{SM}} + \Gamma^{H}_{\mathrm{int}} + \Gamma^{H}_{\mathrm{BSM}}}\right)$$

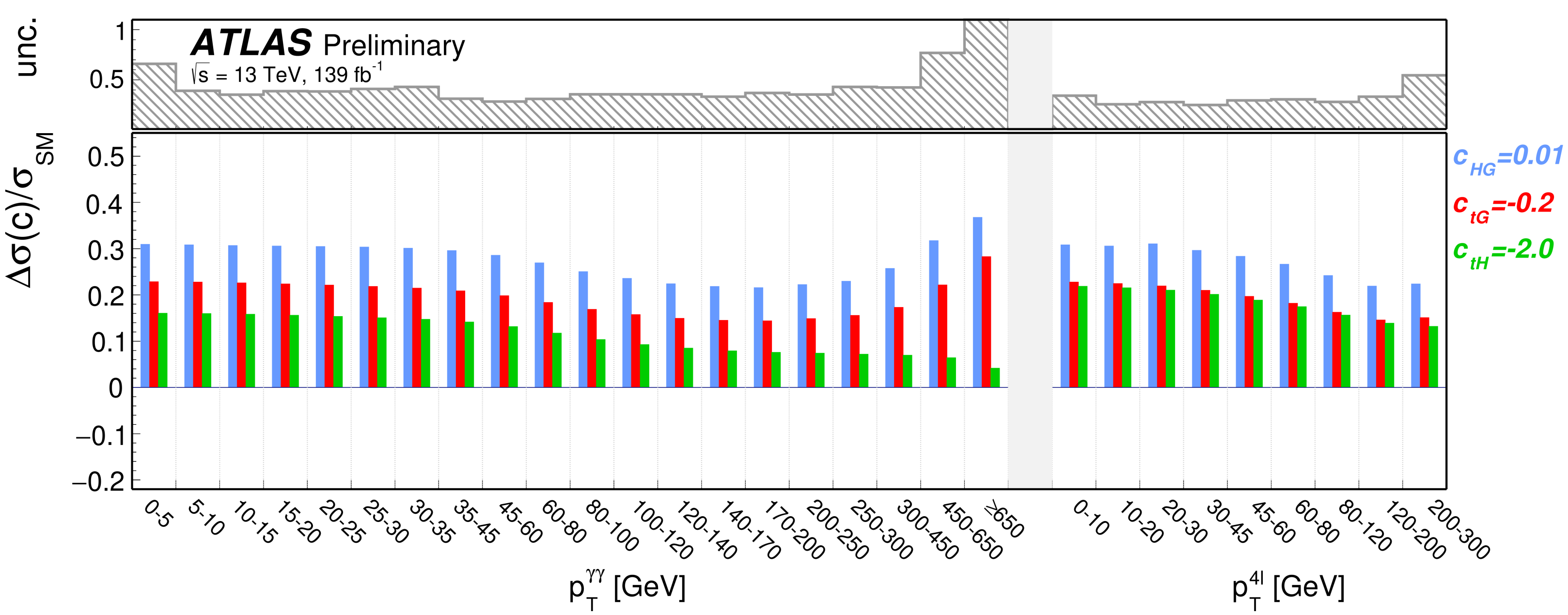
- Comparison of the linear model and the linear+quadratic model shows sizeable sensitivity to operators suppressed by Λ^4



ATLAS-CONF-2023-052

Interpretation of fiducial differential XS with EFT

- Differential distribution of Higgs transverse momentum are also affected by a few SMEFT operators (e.g. c_{HG}, c_{tG}, c_{tH})
  - $H\rightarrow\gamma\gamma$ and $H\rightarrow ZZ$ channels are used for the pT(H) interpretation
- A rotation in the parameter space is performed to define a new set of coefficients which are decorrelated



$$
\begin{aligned}
ev^{[1]} &= 0.999c_{HG} - 0.035c_{tG} - 0.003c_{tH}, \\
ev^{[2]} &= 0.035c_{HG} + 0.978c_{tG} + 0.205c_{tH}, \\
ev^{[3]} &= -0.005c_{HG} - 0.205c_{tG} + 0.979c_{tH}.
\end{aligned}
$$

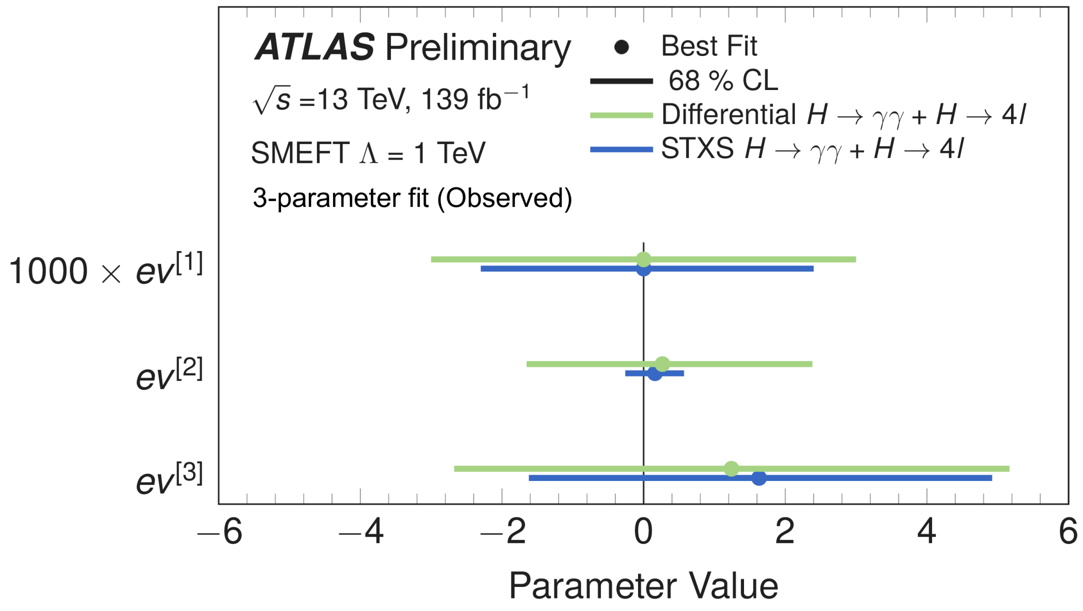
ATLAS-CONF-2023-052

Interpretation of fiducial differential XS with EFT

From 3 fits with one parameter of interest

Parameter	Observed 68% CL interval		Expected 68% CL interval	
	stat. + syst.	stat. only	stat. + syst.	stat. only
c_{HG}	$0.000^{+0.003}_{-0.003}$	$0.000^{+0.002}_{-0.002}$	$0.000^{+0.003}_{-0.003}$	$0.000^{+0.002}_{-0.002}$
c_{tG}	$0.00^{+0.08}_{-0.09}$	$0.00^{+0.05}_{-0.05}$	$0.00^{+0.08}_{-0.09}$	$0.00^{+0.05}_{-0.05}$
c_{tH}	$0.1^{+1.0}_{-1.1}$	$0.1^{+0.7}_{-0.7}$	$0.0^{+1.0}_{-1.1}$	$0.0^{+0.7}_{-0.7}$

From a simultaneous fit



- Using the same decay channels, the constraints from differential XS are weaker than STXS
  - differential measurements are inclusive in production mode
  - STXS separate different production modes whose cross-sections are affected in different ways by the different operators

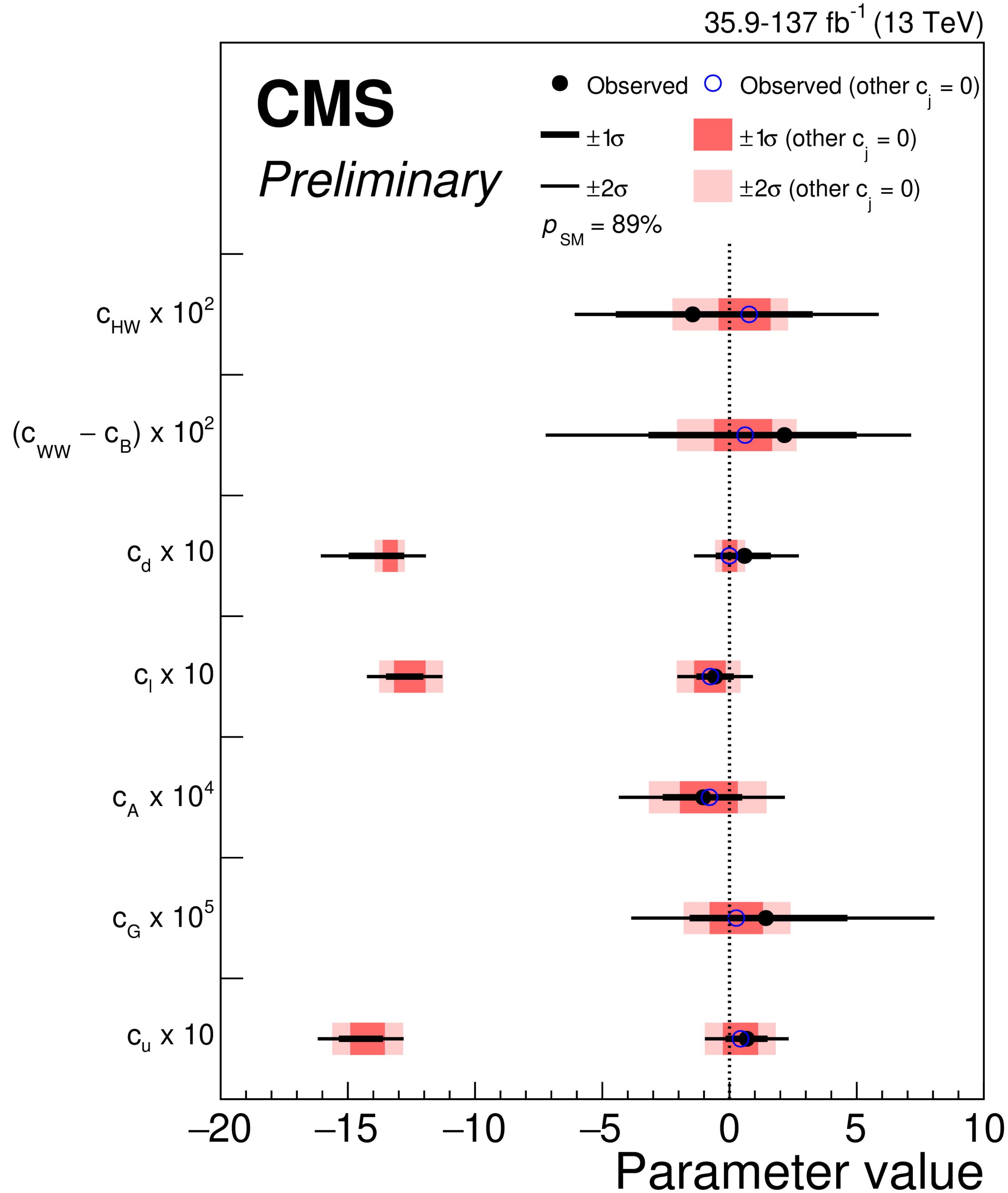
ATLAS-CONF-2023-052

Interpretation of STXS with EFT

$$\mathcal{L}_{\rm HEL} = \mathcal{L}_{\rm SM} + \sum_j \mathcal{O}_j f_j / \Lambda^2$$

- CMS provided constraints on the parameters of the Higgs Effective Lagrangian model

- For many of the parameters these results represented the strongest constraints



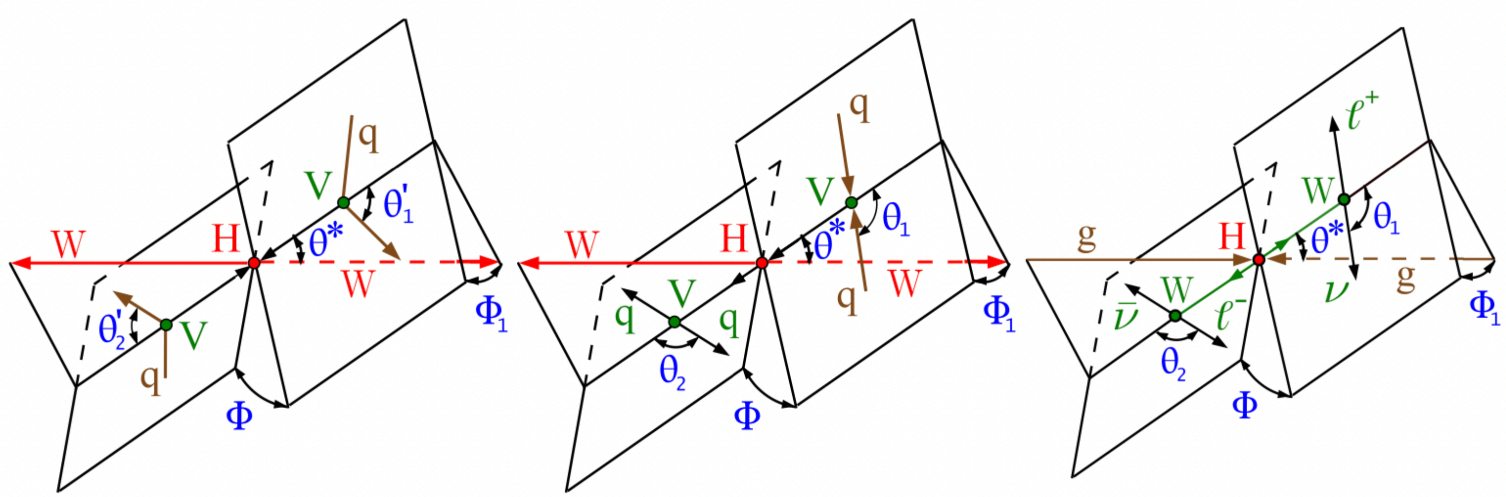
CMS-PAS-HIG-19-005

Anomalous Higgs couplings

Higgs anomalous coupling

$$\mathcal{A}(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_1^2 + \kappa_2^{\mathrm{VV}} q_2^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu},$$

- In BSM, interactions with the Higgs boson may occur through several anomalous couplings. The *CP*-odd anomalous couplings may generate *CP* violation in the Higgs boson interactions
- CMS searches for anomalous couplings using ggH, VBF and VH in H→ZZ, H→$\tau\tau$, and H→WW (NEW) decays
- Matrix element likelihood approach (MELA, the main CMS approach) is employed to construct observables that are optimal for the measurement of anomalous couplings or EFT operators



Higgs anomalous coupling

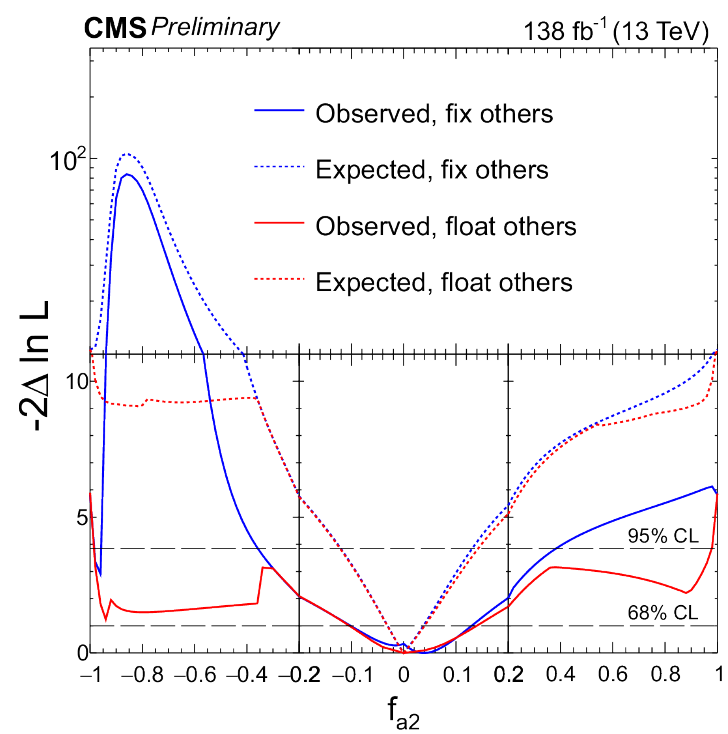
H→WW*

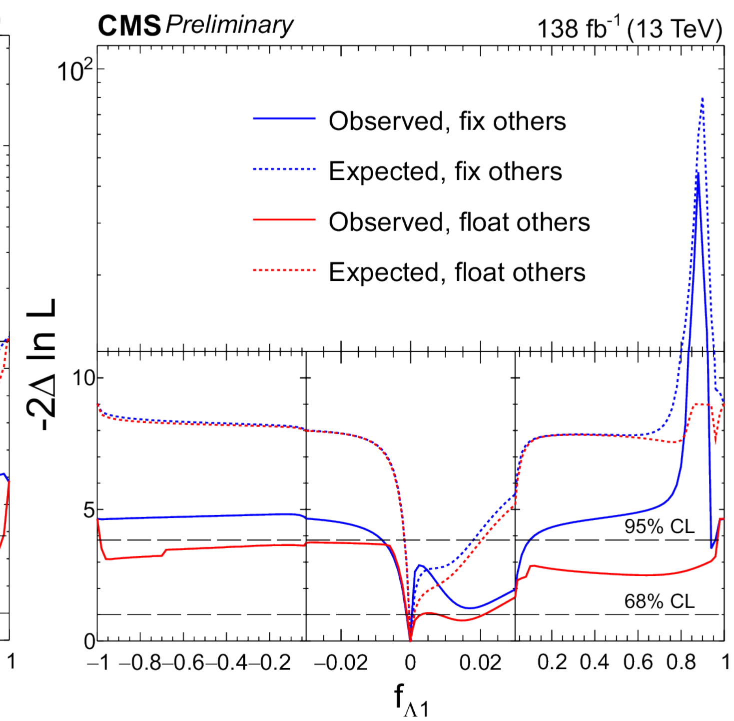
CMS-PAS-HIG-22-008

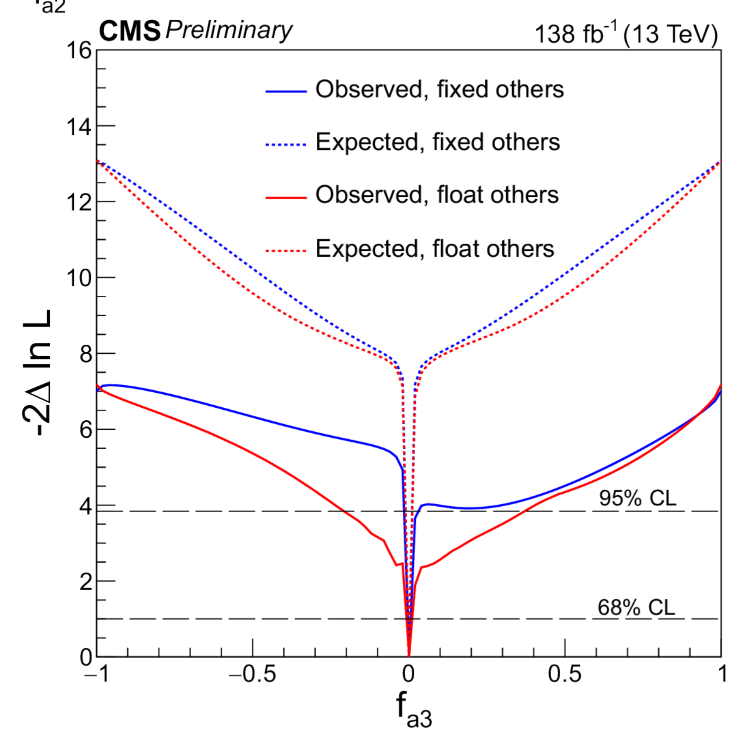
HVV vertex
Approach 2
SU2 x U1

$$a_1^{WW} = a_1^{ZZ},$$
$$a_2^{WW} = c_w^2 a_2^{ZZ},$$
$$a_3^{WW} = c_w^2 a_3^{ZZ},$$
$$\frac{\kappa_1^{WW}}{(\Lambda_1^{WW})^2} = \frac{1}{c_w^2 - s_w^2}\left(\frac{\kappa_1^{ZZ}}{(\Lambda_1^{ZZ})^2} - 2s_w^2 \frac{a_2^{ZZ}}{m_Z^2}\right),$$
$$\frac{\kappa_2^{Z\gamma}}{(\Lambda_1^{Z\gamma})^2} = \frac{2s_w c_w}{c_w^2 - s_w^2}\left(\frac{\kappa_1^{ZZ}}{(\Lambda_1^{ZZ})^2} - \frac{a_2^{ZZ}}{m_Z^2}\right),$$

$$f_{ai} = \frac{|a_i|^2\sigma_i}{\sum_j |a_j|^2\sigma_j} \operatorname{sign}\left(\frac{a_i}{a_1}\right),$$







- Studied individually or simultaneously
- Significant interference effects for certain values is evident

Higgs anomalous coupling

CMS-PAS-HIG-22-008

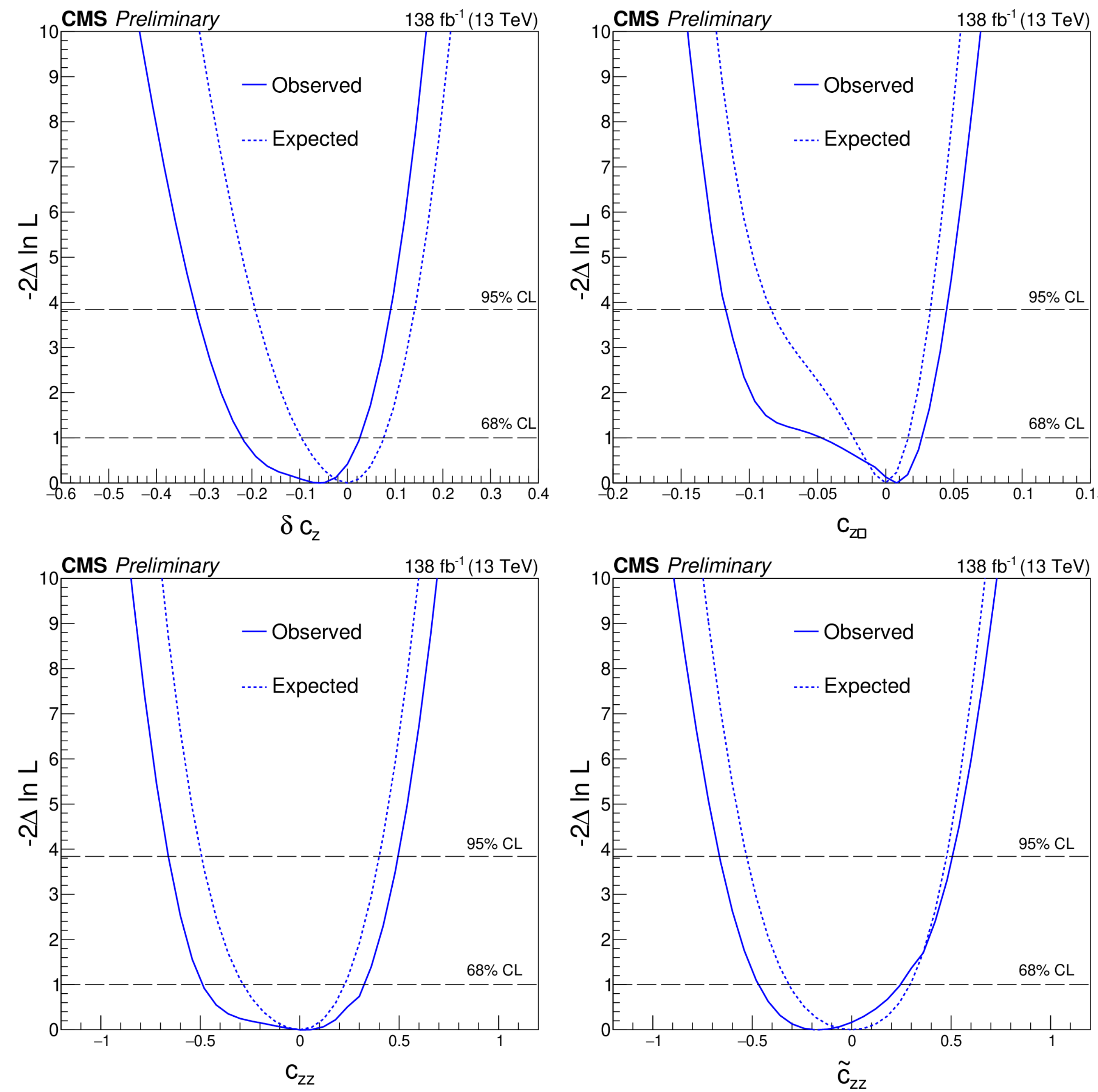
HVV vertex
SMEFT (Higgs basis)

$$\delta c_z = \frac{1}{2} a_1^{ZZ} - 1,$$

$$c_{zz} = -\frac{2 s_w^2 c_w^2}{e^2} a_2^{ZZ},$$

$$\tilde{c}_{zz} = -\frac{2 s_w^2 c_w^2}{e^2} a_3^{ZZ},$$

$$c_{z\Box} = \frac{m_Z^2 s_w^2}{e^2} \frac{\kappa_1^{ZZ}}{(\Lambda_1^{ZZ})^2}.$$



- Interpretation using Warsaw basis is also performed

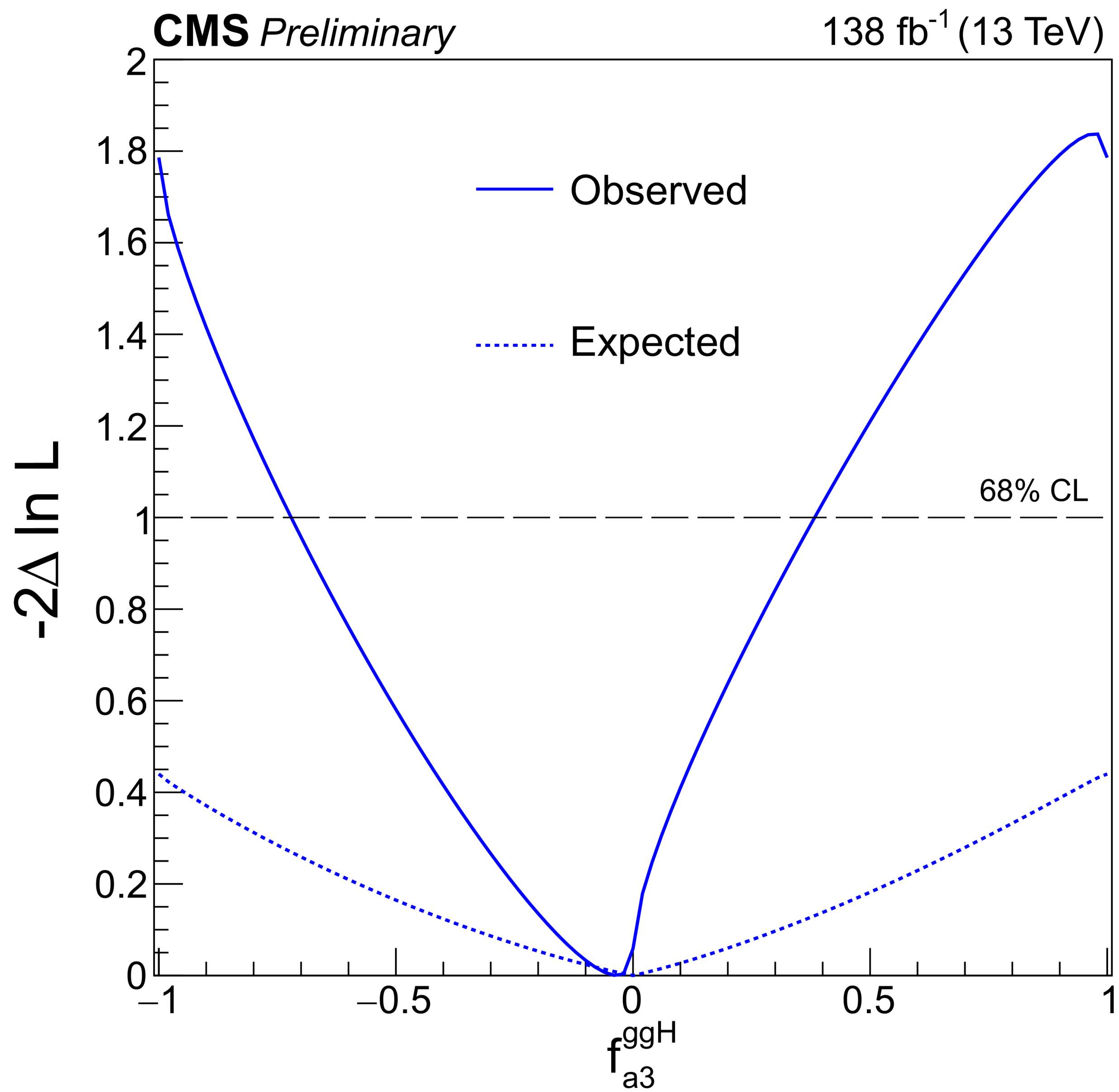
Higgs anomalous coupling

$H \rightarrow WW^*$

CMS-PAS-HIG-22-008

Hgg vertex

$$f_{a3}^{ggH} = \frac{|a_3^{gg}|^2 \sigma_3^{gg}}{|a_2^{gg}|^2 \sigma_2^{gg} + |a_3^{gg}|^2 \sigma_3^{gg}} \, \mathrm{sign}\left(\frac{a_3^{gg}}{a_2^{gg}}\right)$$



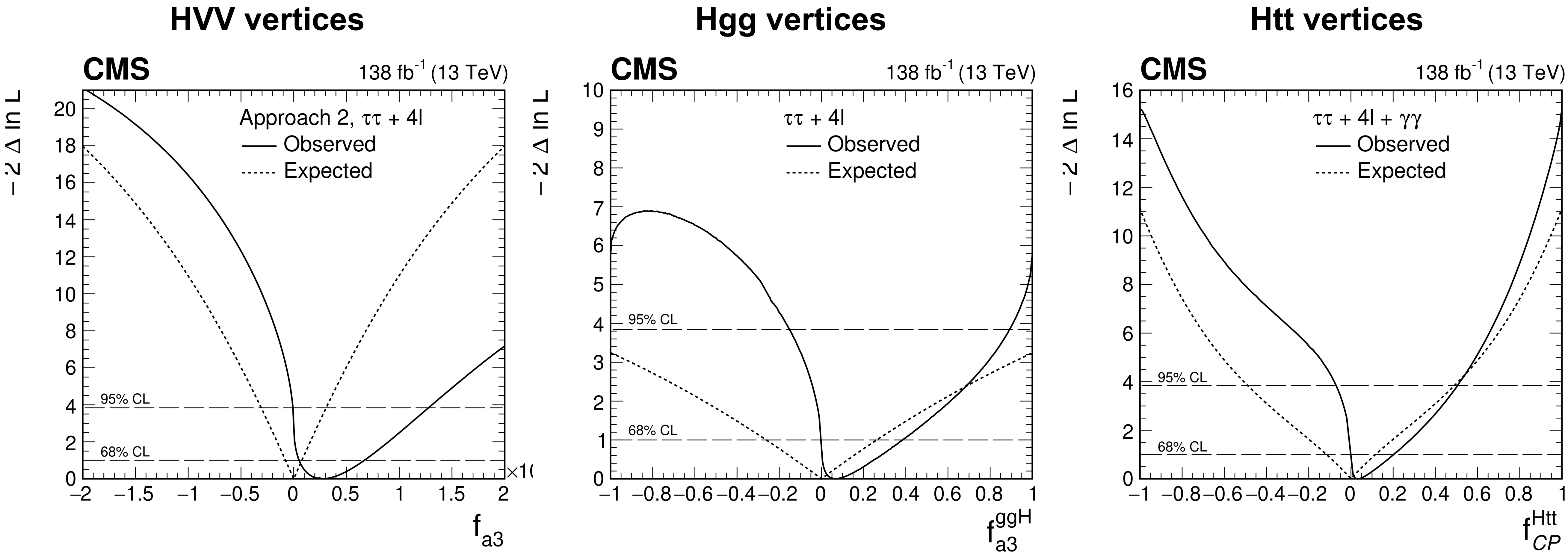
- Result is consistent with expectation of a SM Higgs boson

Higgs anomalous coupling

H→ZZ*→4l
H→ττ & H→γγ

[Phys. Rev. D 108 (2023) 032013]

- CMS searched for anomalous couplings using H→4l, H→ττ and H→γγ decays
- **No indication of CP violation and non-SM couplings, most stringent constraints were given**

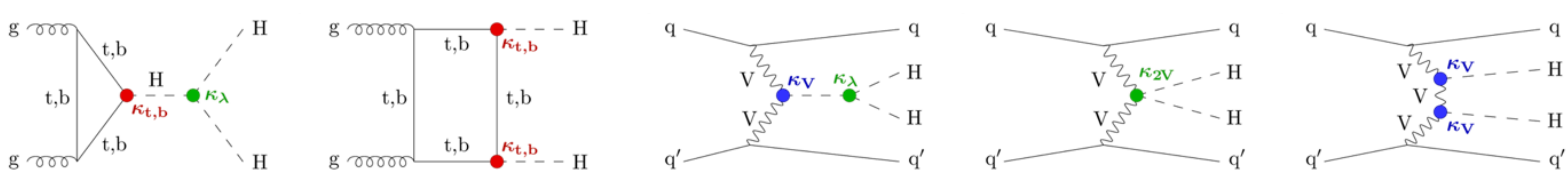


Higgs boson self-couplings

Higgs boson self-couplings

- **Higgs self-coupling is one of the deepest questions of SM and may provide a portal to new physics beyond it**
  - Vacuum stability, early universe evolvement, …
- **Double Higgs production is the way to directly probe Higgs self-couplings at the LHC**
  - Extremely low cross-section in the SM
  - Non-SM self-coupling strength can change cross-section and kinematics of double Higgs production

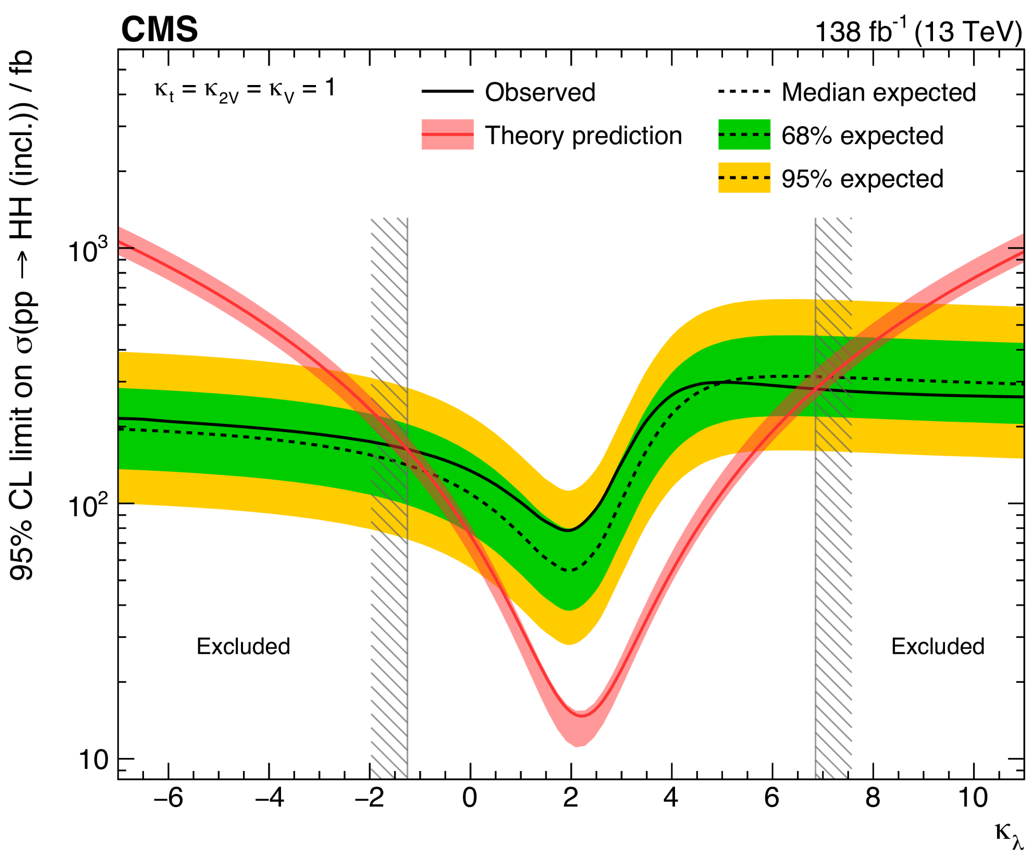
Higgs boson pair production

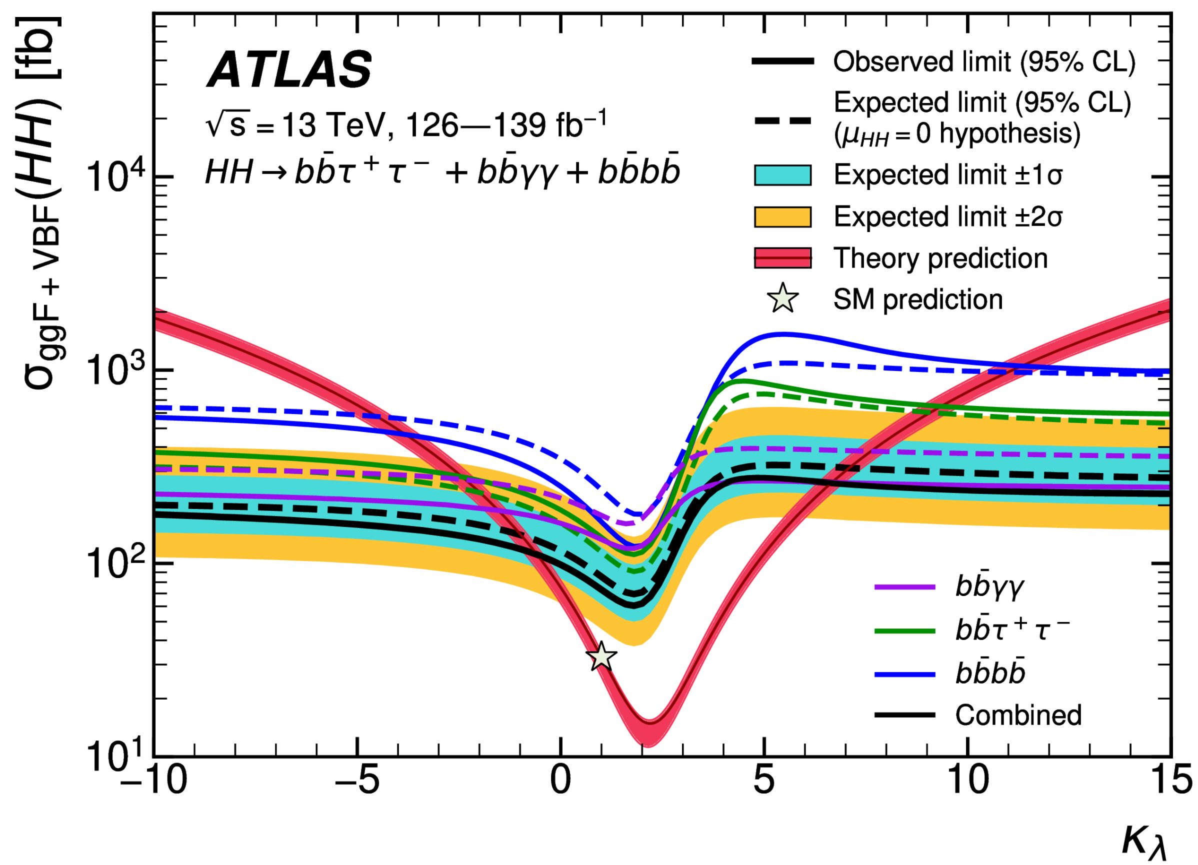


Double Higgs production combination

Nature 607 (2022) 60-68

Phys. Lett. B 843 (2024) 137745



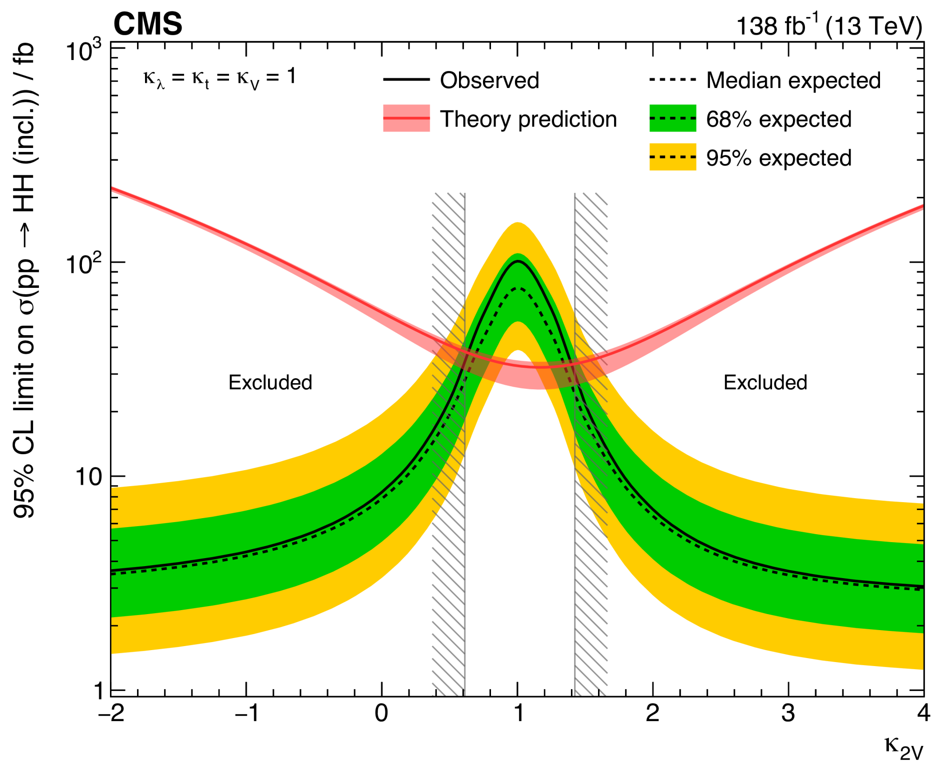


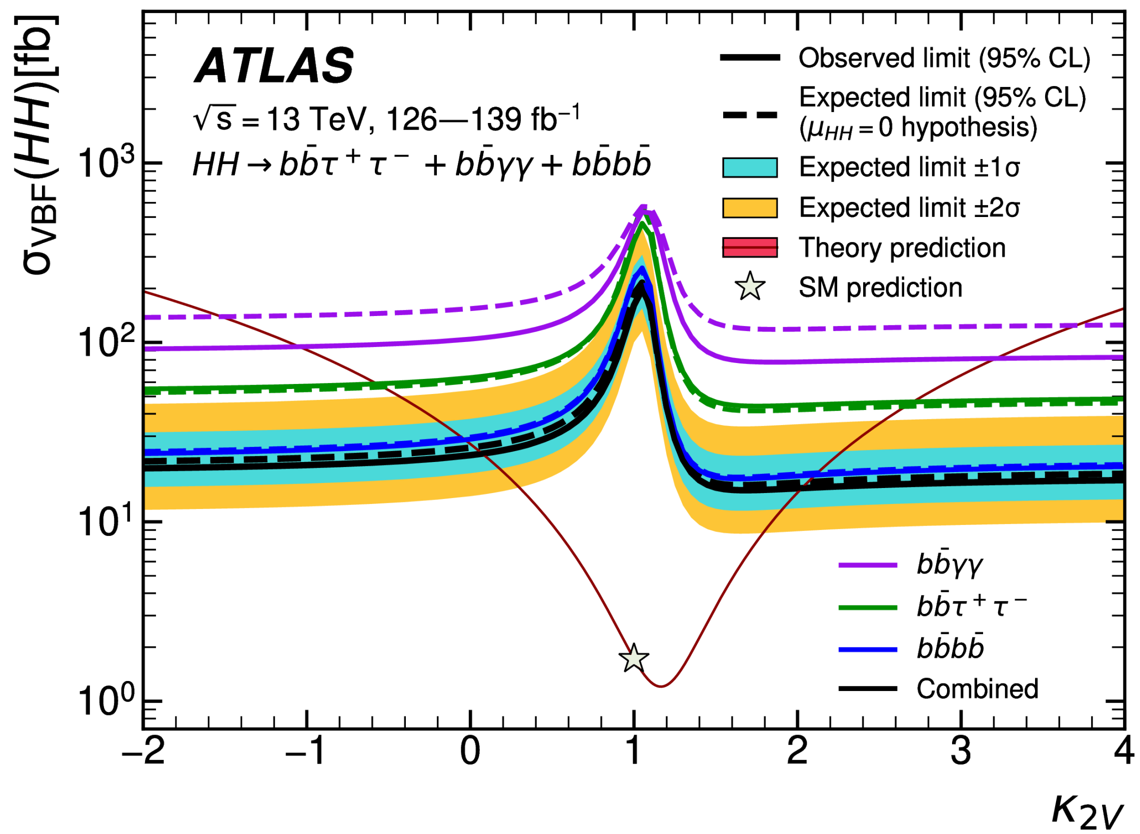
- HHH trilinear self-coupling modifier: $-1.2<\kappa_\lambda<6.5$ (CMS); $-0.6<\kappa_\lambda<6.6$ (ATLAS)

Double Higgs production combination

Nature 607 (2022) 60-68

Phys. Lett. B 843 (2024) 137745

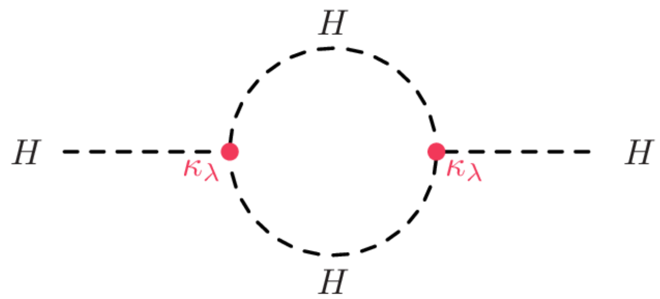


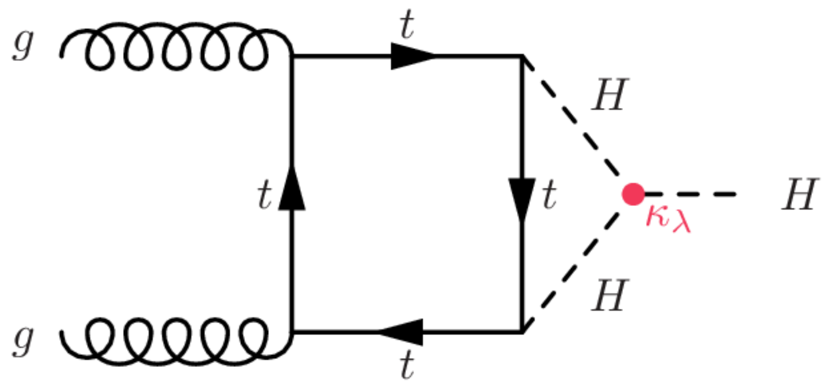


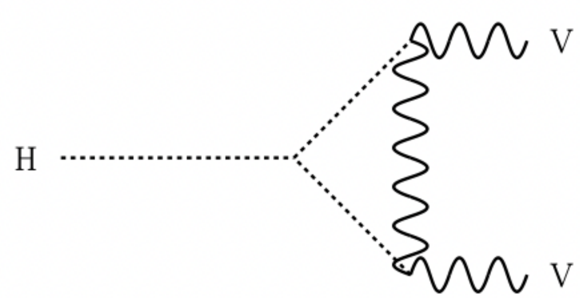
- HHVV quartic coupling modifier: $0.7<\kappa_{2V}<1.4$ (CMS); $0.1<\kappa_{2V}<2.0$ (ATLAS)

Higgs boson self-couplings

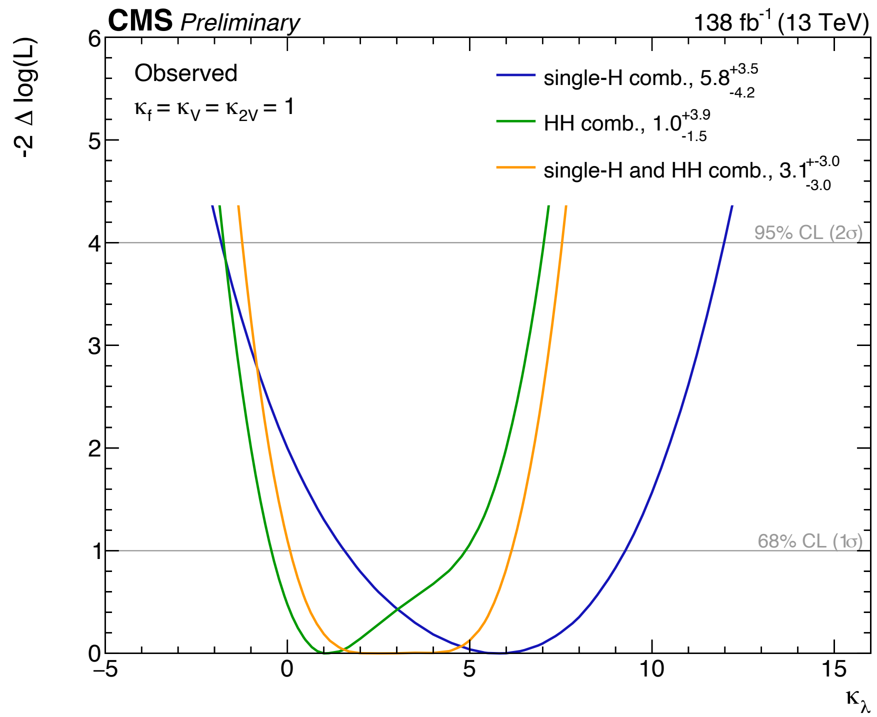
- Single Higgs boson production and decays can be modified by self-coupling modifier through NLO EW correction

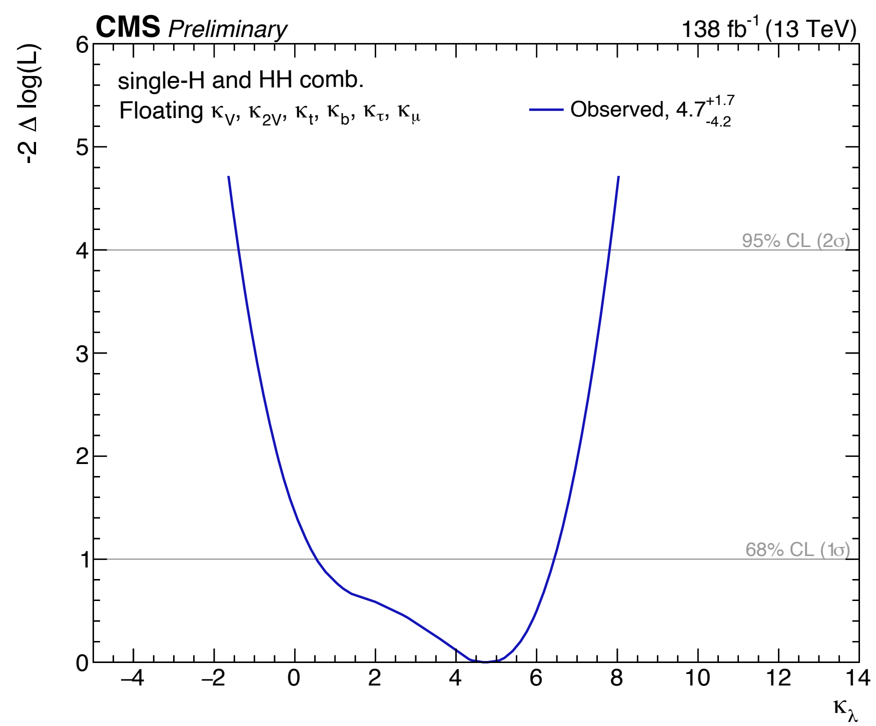


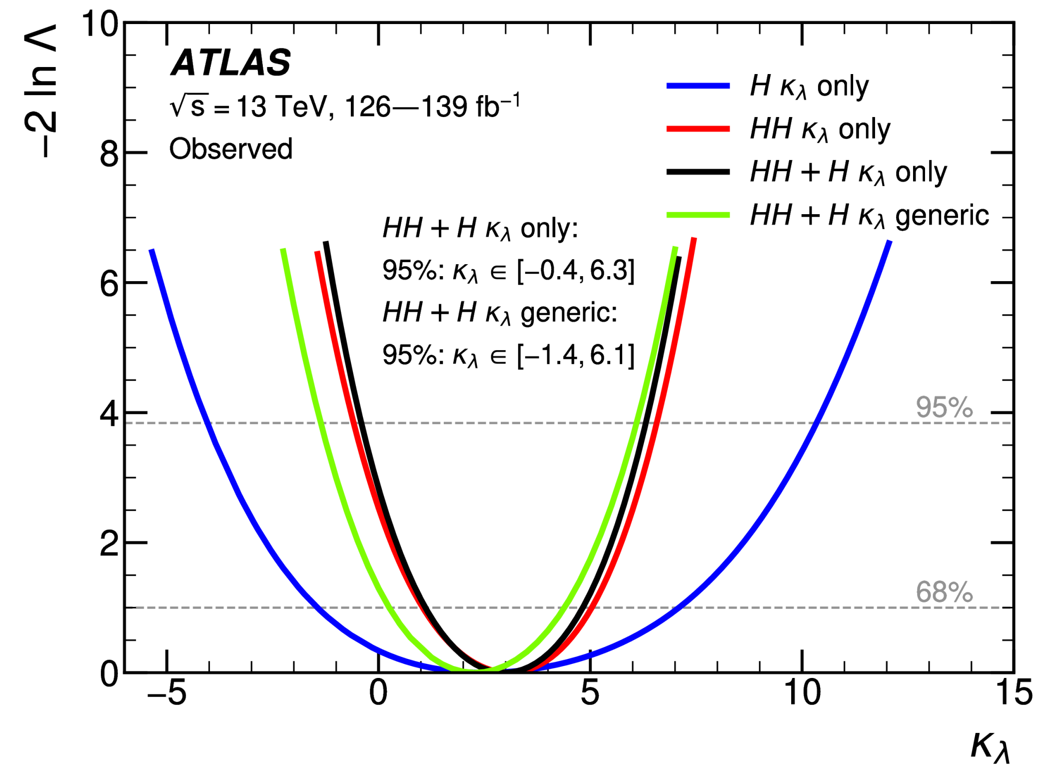




Double Higgs + Single Higgs Combination





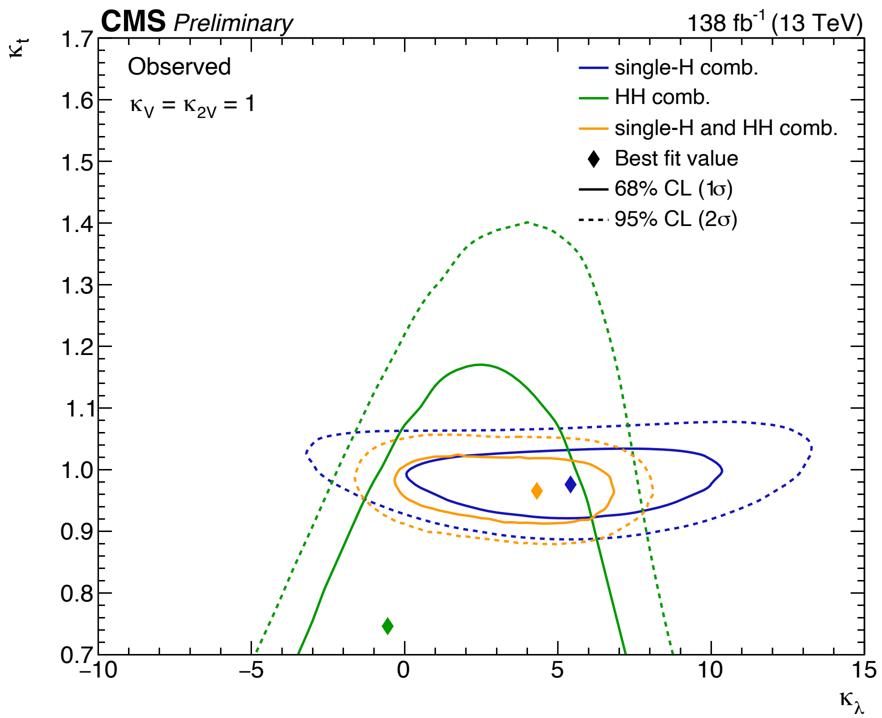


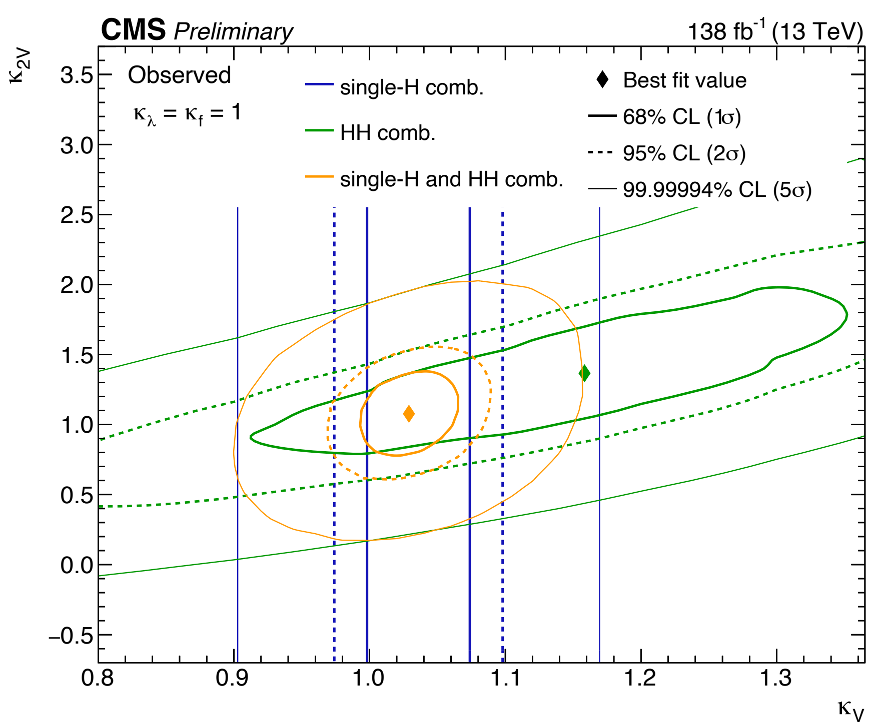
Phys. Lett. B 843 (2023) 137745

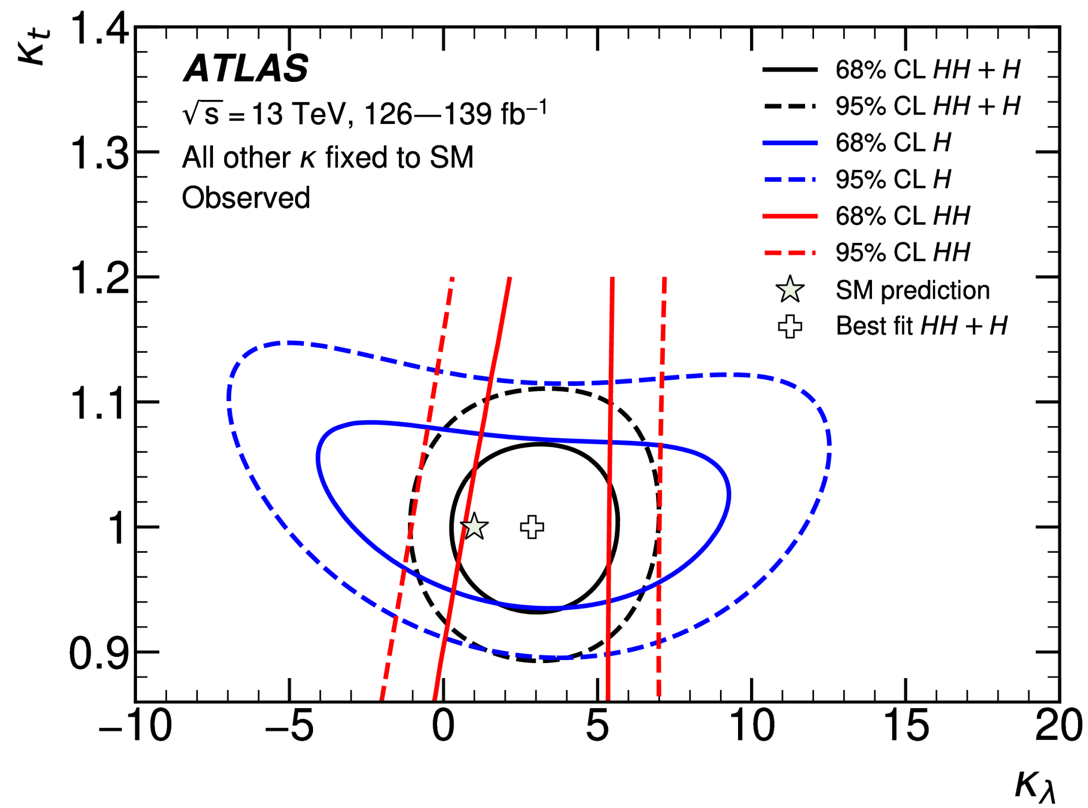
CMS-PAS-HIG-23-006 (NEW)

- Single Higgs measurements provide additional sensitivity to trilinear self-coupling

Double Higgs + Single Higgs Combination







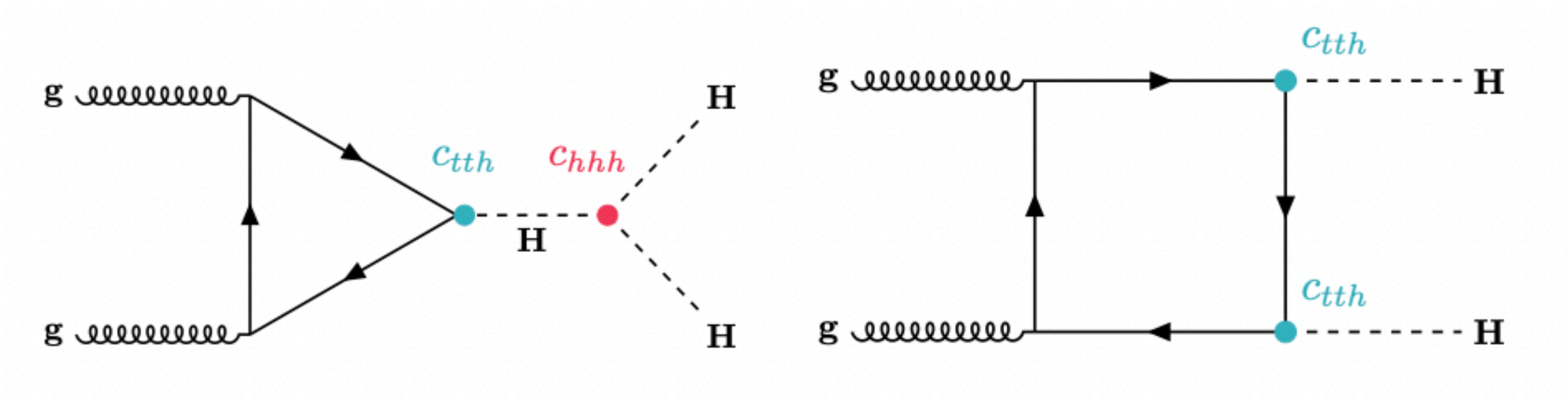
Phys. Lett. B 843 (2024) 137745

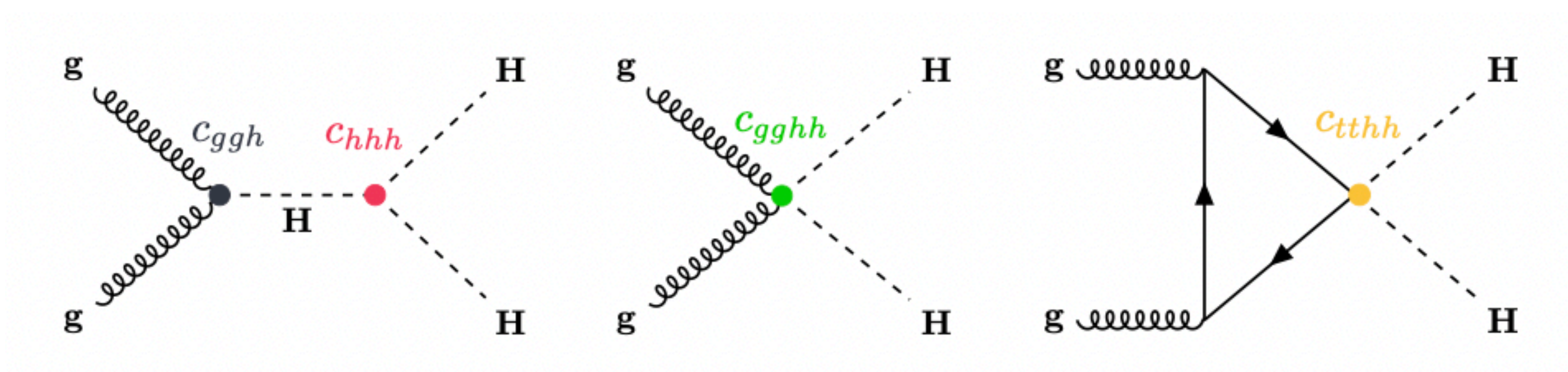
CMS-PAS-HIG-23-006 (NEW)

- Combined single-Higgs and double-Higgs analyses provide results with fewer assumptions

Interpretation of HH with EFT

HEFT currently used for most interpretations of HH

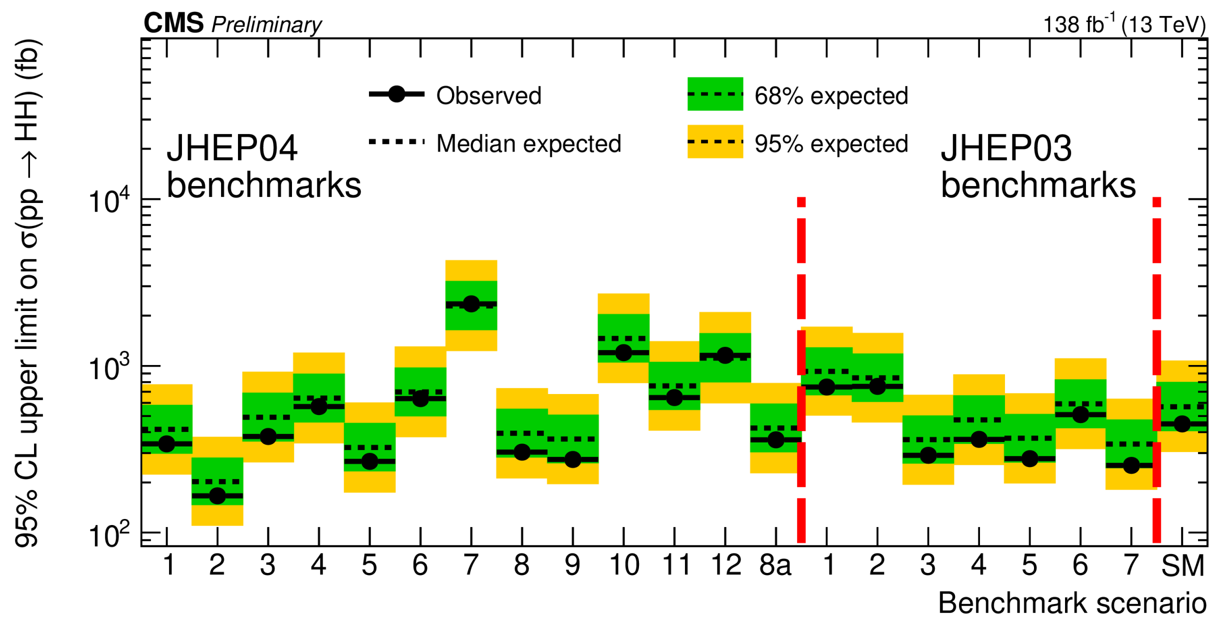


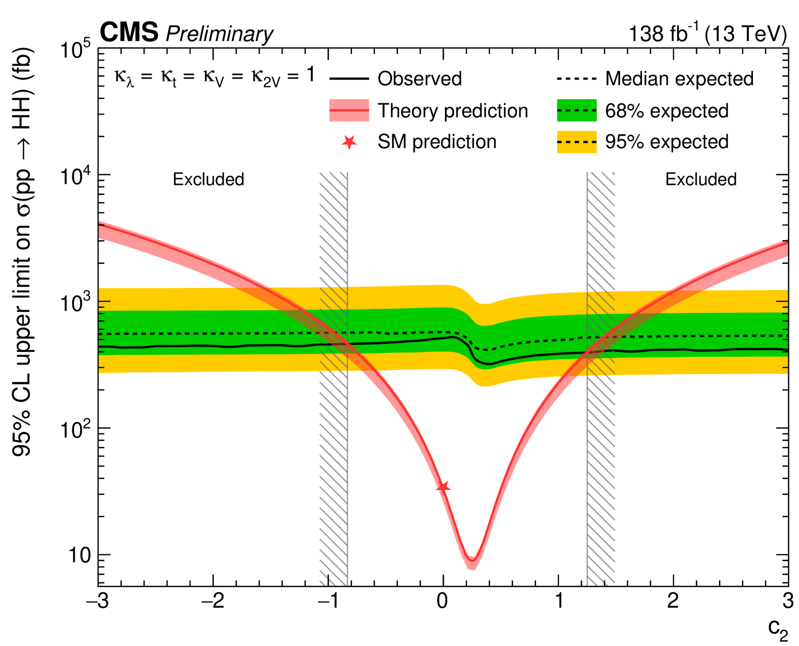


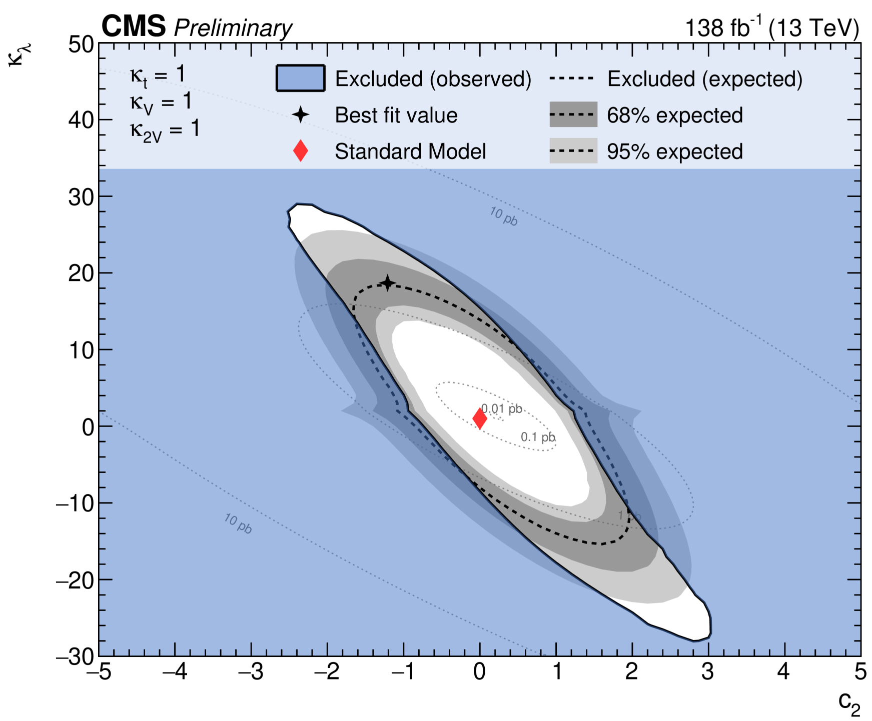
ATL-PHYS-PUB-2022-019

CMS HH→bbWW

CMS-PAS-HIG-21-005



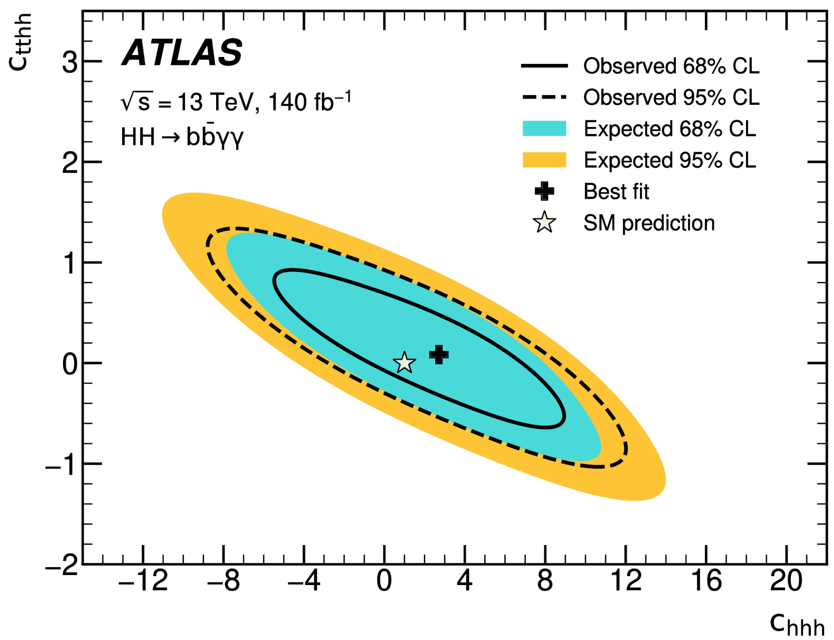


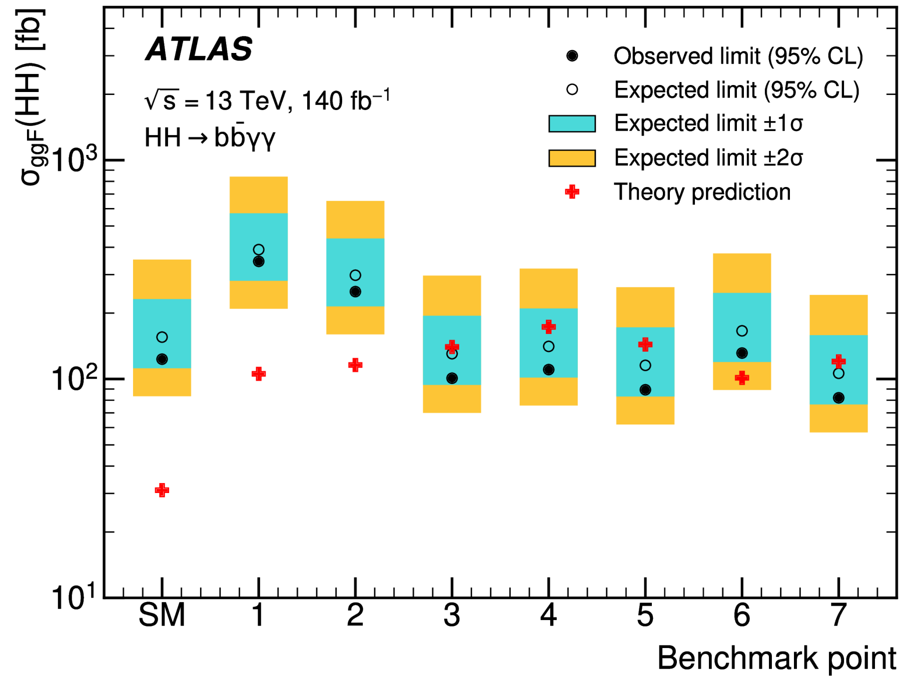


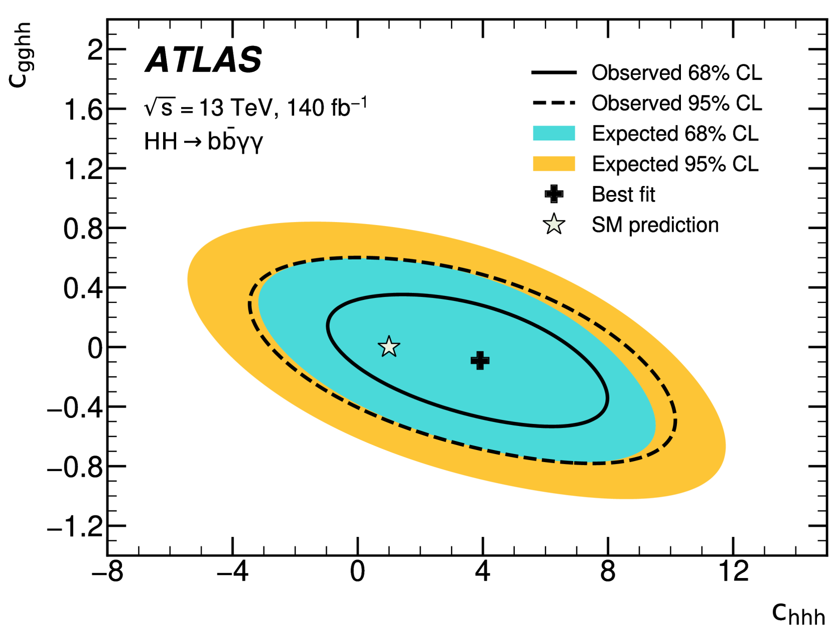
- Results are interpreted in HEFT
- BSM coupling c_2(=c_{ttHH}) is constrained between -0.8 and 1.3

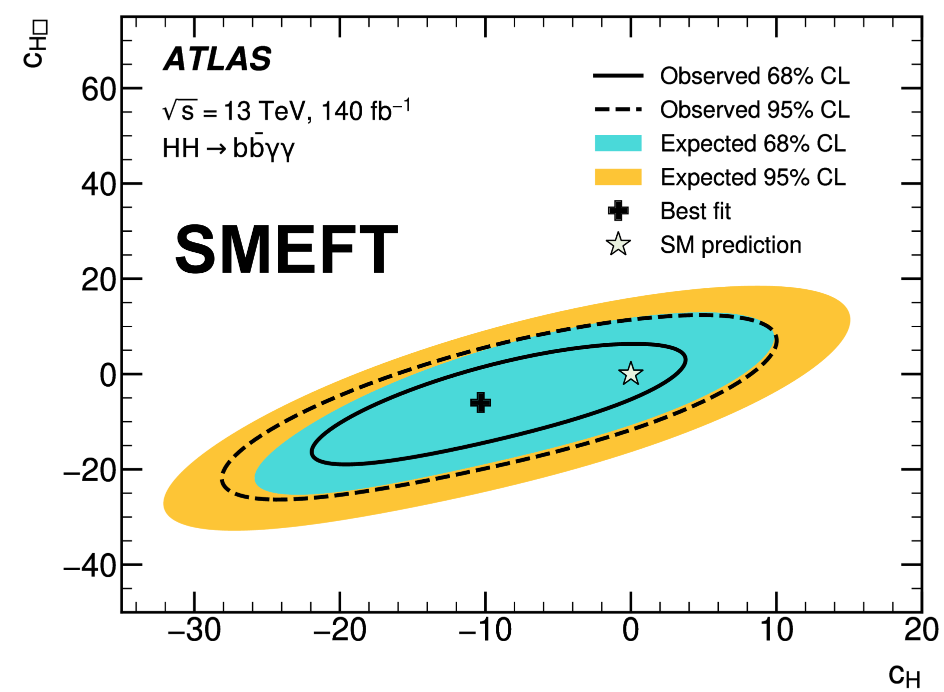
ATLAS HH→bbγγ

arxiv:2310.12301









- Results are interpreted in both HEFT and SMEFT
- Excluded four of the considered seven HEFT benchmark points

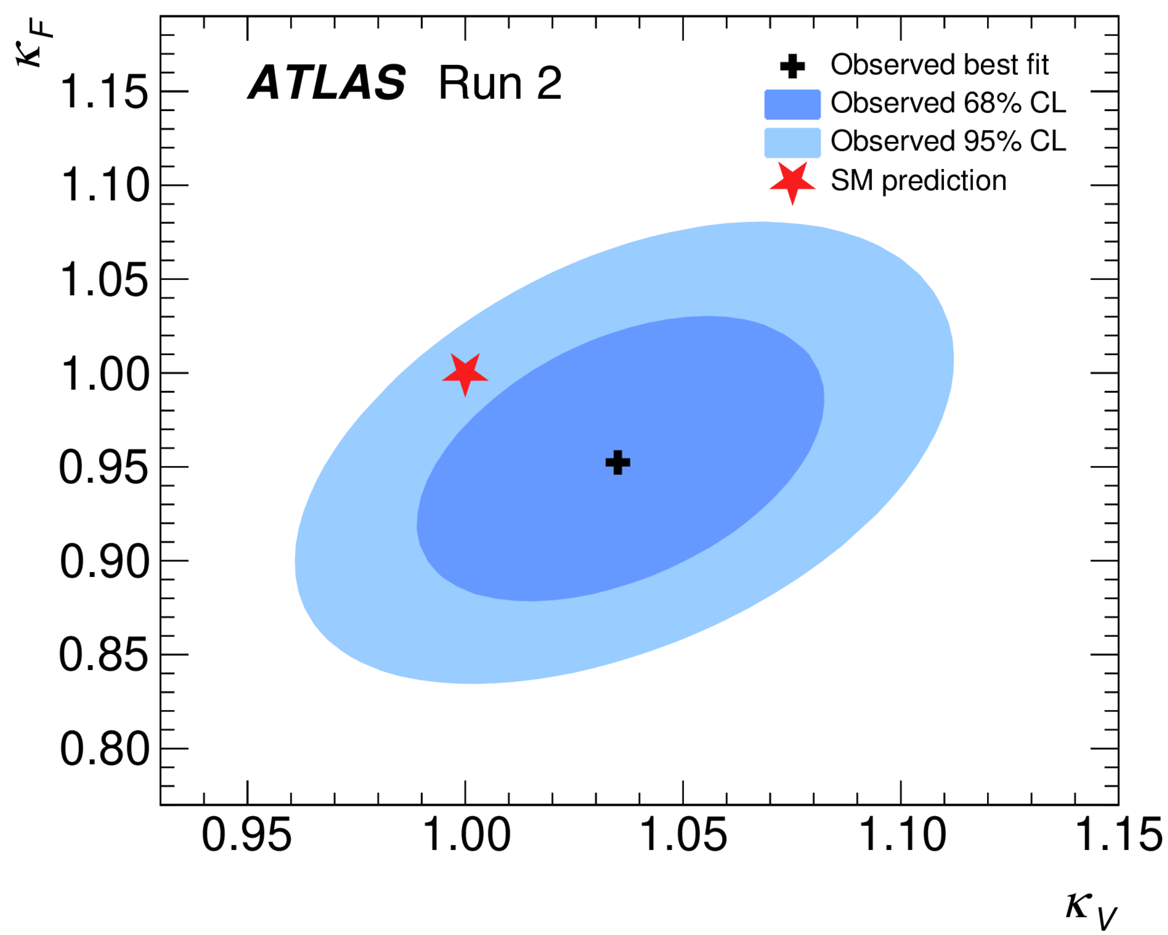
Summary

- ATLAS and CMS experiments keep **improving precision and granularity for Higgs coupling measurements**
  - Results can be interpreted using **kappa and EFT models**
  - O(10%) precision for most kappa coupling modifiers; tens of Wilson coefficients are probed
  - Currently in agreement with the SM predictions
- **Run 3 is ongoing and HL-LHC is coming**. Please stay tuned for the new results!

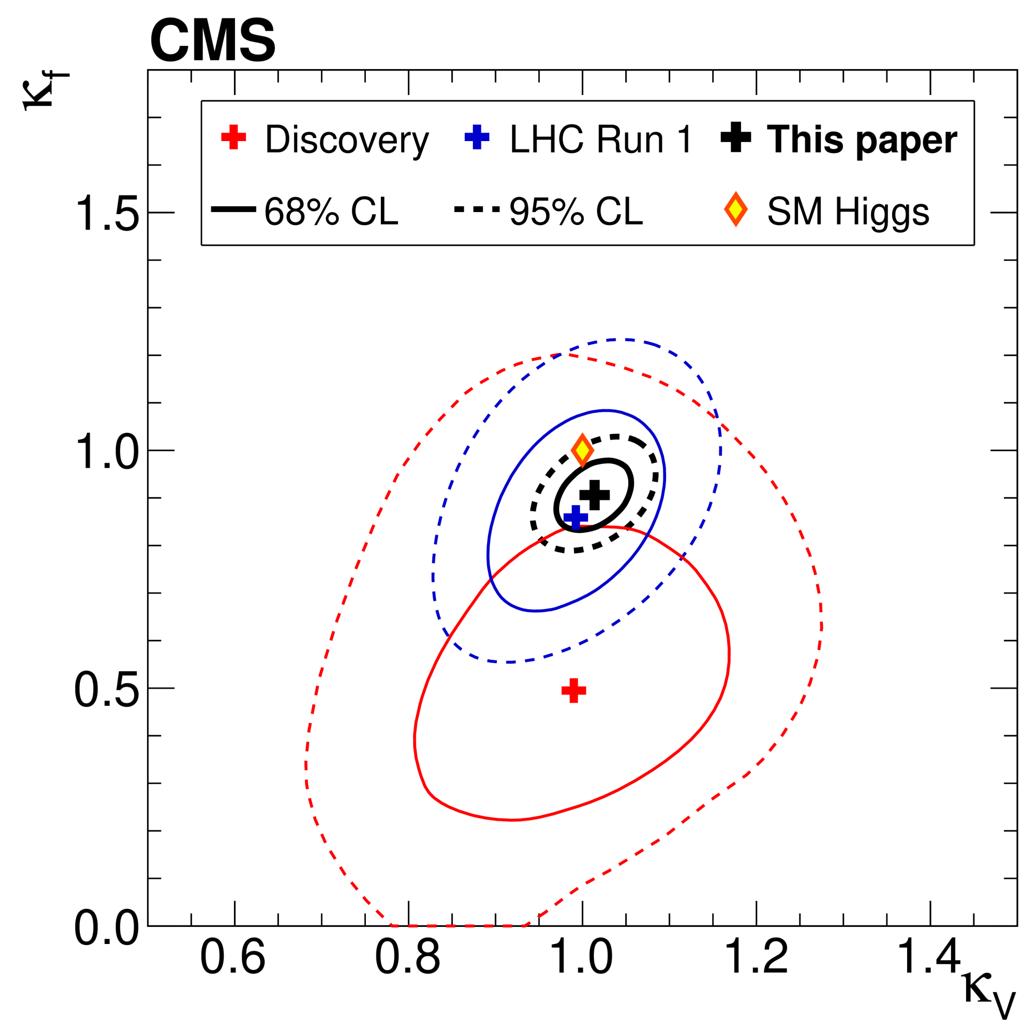
Thank you!

Higgs boson couplings with “kappa”

ATLAS Nature 607 (2022) 52-59 Nature 607 (2022) 60-68



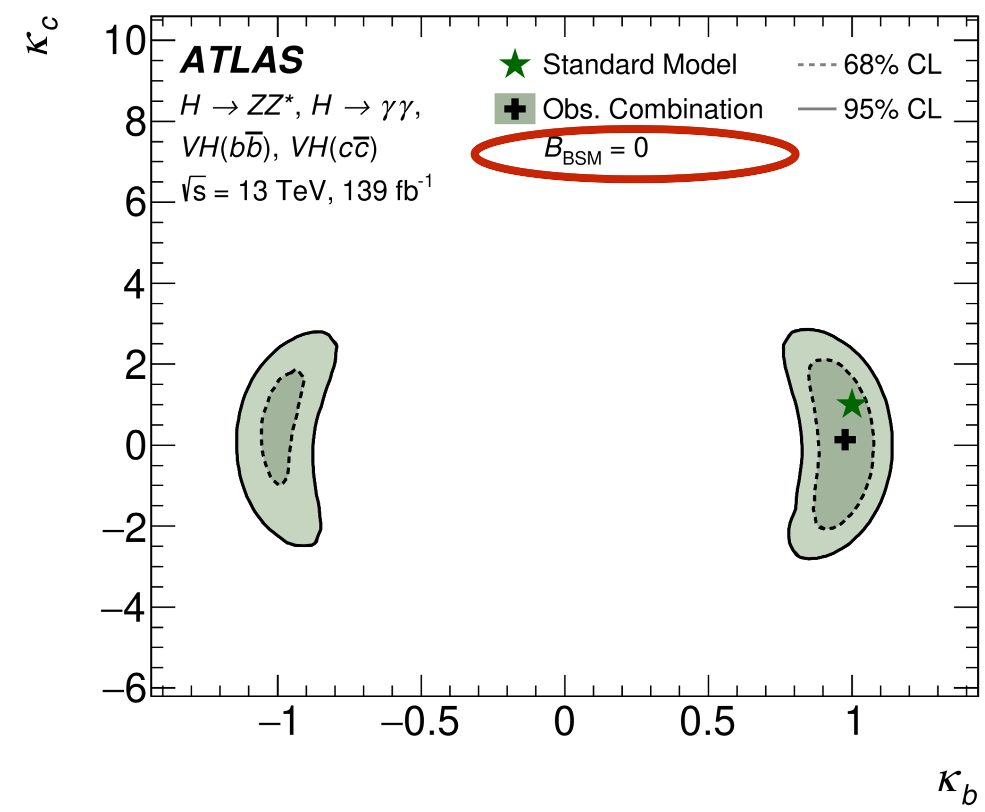
$\kappa_V = 1.035 \pm 0.031$ and $\kappa_F = 0.95 \pm 0.05$

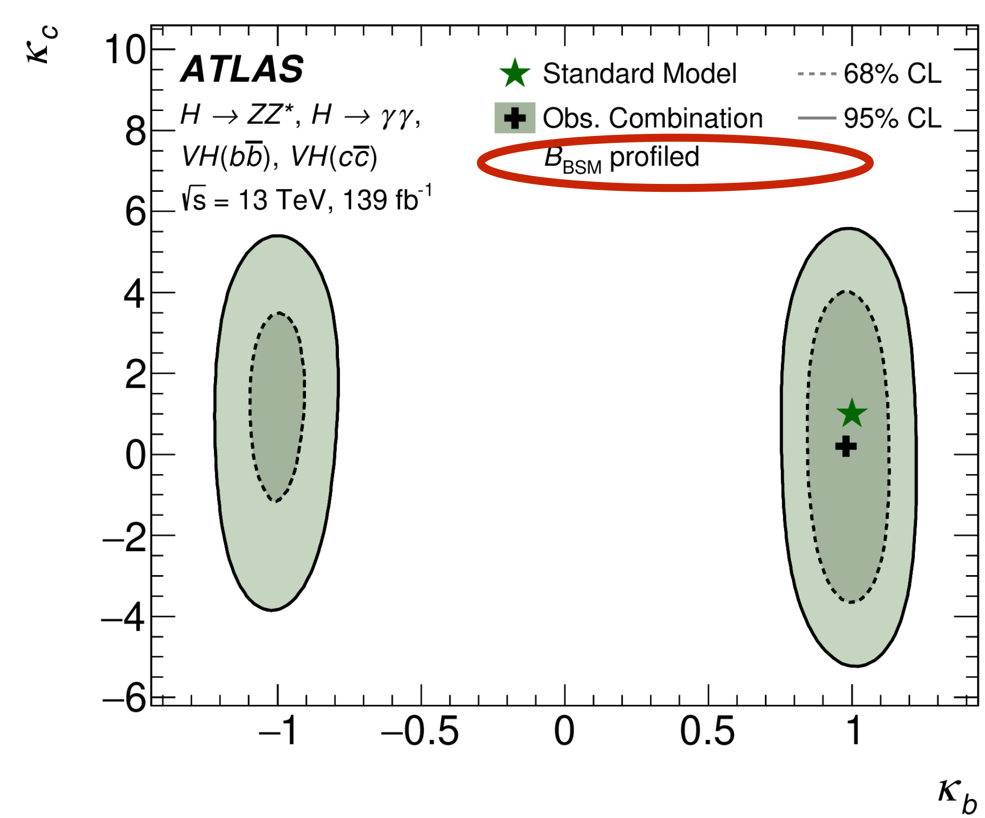


- κ_V for all vector bosons and κ_F for all heavy fermions are measured
- SM prediction is within 95% CL contour of measurement result

Higgs couplings to c quarks

- Constraints from ATLAS combination of VH(bb) & VH(cc), and Higgs p_T differential XS of H→γγ & H→ZZ:
  - $-1.61 < \kappa_c < 1.70$ ($B_{BSM}=0$)
  - $-2.63 < \kappa_c < 3.01$ (B_{BSM} profiled)





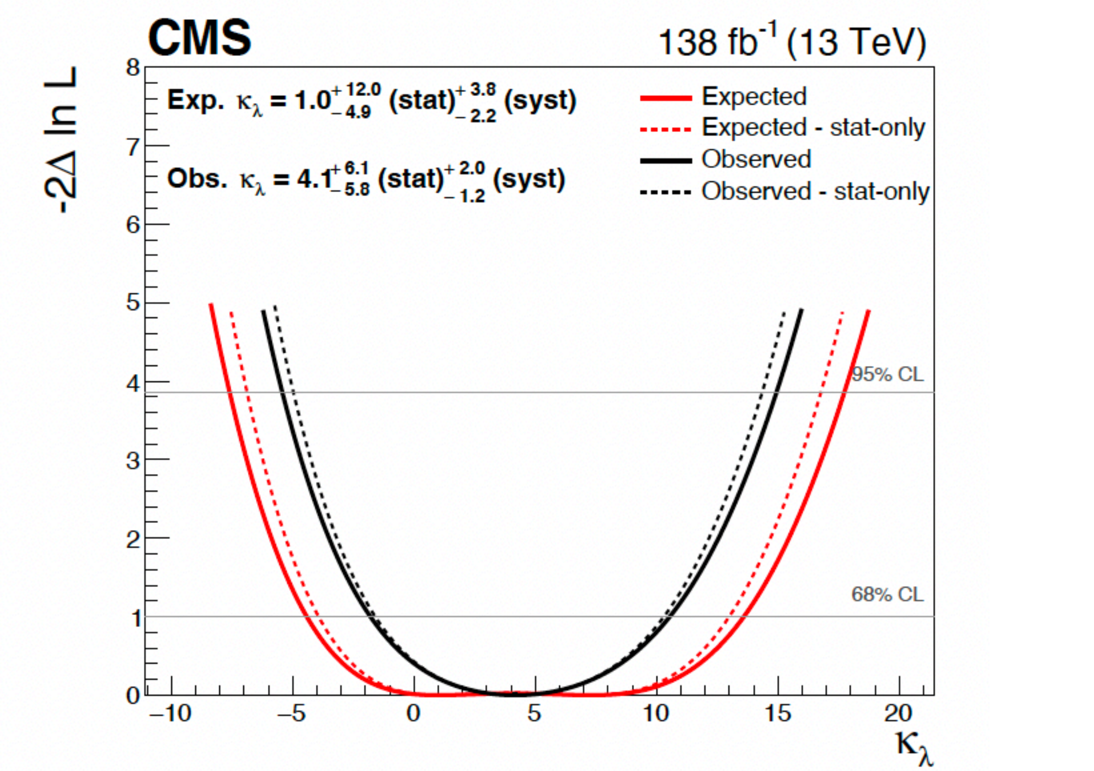
JHEP05(2023)028

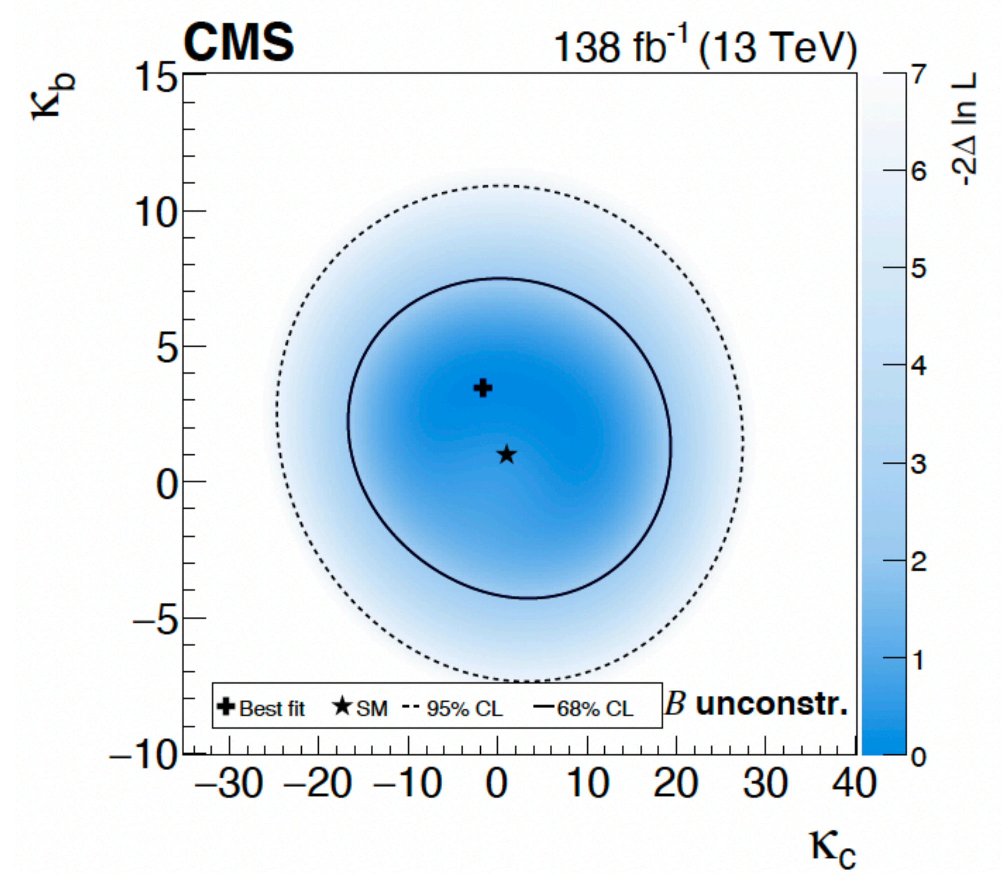
Interpretation with coupling modifiers

$H \to ZZ^* \to 4l$

- Interpretation from transverse momentum distribution:
  - Constraints on the trilinear self-coupling of the Higgs boson (κ_λ):
    - $-5.4 < \kappa_\lambda < 14.9$
    - can be used in future single and double Higgs boson combinations
  - Constraints on the Higgs boson couplings to b and c quarks (k_b and k_c):
    - $-5.6 < \kappa_b < 8.9$; $-20 < \kappa_c < 23$ (using only shape information)
    - complementary with constraints from $H \to cc$ decay

JHEP 08 (2023) 040





Interpretation of STXS with EFT

Wilson coefficient	Operator
c_H	$(H^\dagger H)^3$
$c_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
c_G	$f^{abc} G_\mu^{a\nu} G_\nu^{b\rho} G_\rho^{c\mu}$
c_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
c_{HDD}	$(H^\dagger D^\mu H)^* (H^\dagger D_\mu H)$
c_{HG}	$H^\dagger H\, G^A_{\mu\nu} G^{A\mu\nu}$
c_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
c_{HW}	$H^\dagger H\, W^I_{\mu\nu} W^{I\mu\nu}$
c_{HWB}	$H^\dagger \tau^I H\, W^I_{\mu\nu} B^{\mu\nu}$
$c^{(1)}_{Hl,11}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_1 \gamma^\mu l_1)$
$c^{(1)}_{Hl,22}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_2 \gamma^\mu l_2)$
$c^{(1)}_{Hl,33}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_3 \gamma^\mu l_3)$
$c^{(3)}_{Hl,11}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_1 \tau^I \gamma^\mu l_1)$
$c^{(3)}_{Hl,22}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_2 \tau^I \gamma^\mu l_2)$
$c^{(3)}_{Hl,33}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_3 \tau^I \gamma^\mu l_3)$
$c_{He,11}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_1 \gamma^\mu e_1)$
$c_{He,22}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_2 \gamma^\mu e_2)$
$c_{He,33}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_3 \gamma^\mu e_3)$
$c^{(1)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q} \gamma^\mu q)$
$c^{(3)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q} \tau^I \gamma^\mu q)$
c_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
c_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
$c^{(1)}_{HQ}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{Q} \gamma^\mu Q)$
$c^{(3)}_{HQ}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{Q} \tau^I \gamma^\mu Q)$
c_{Ht}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{t} \gamma^\mu t)$
c_{Hb}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{b} \gamma^\mu b)$

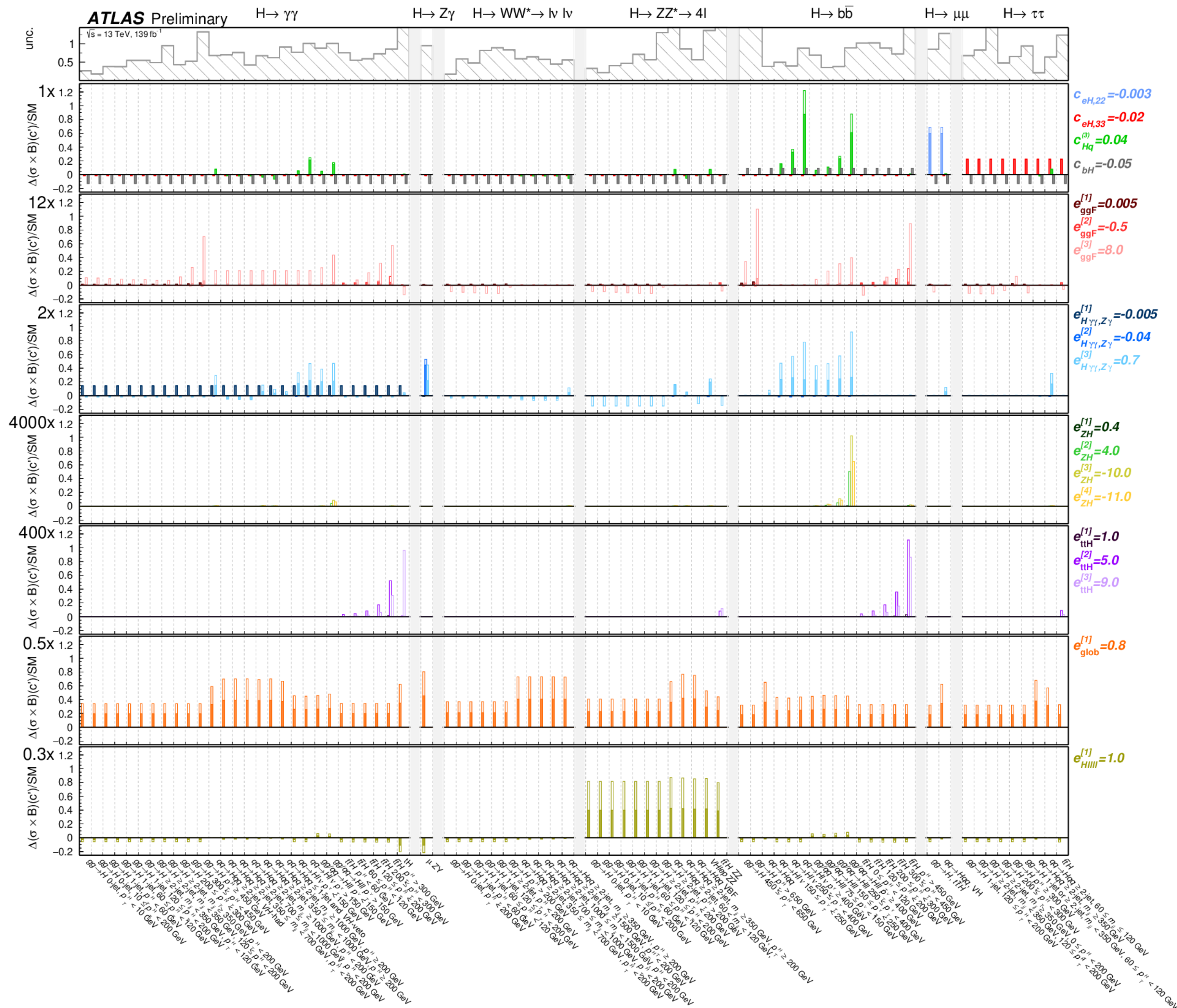
Wilson coefficient	Operator
$c^{(1,1)}_{Qq}$	$(\bar{Q}\gamma_\mu Q)(\bar{q}\gamma^\mu q)$
$c^{(1,8)}_{Qq}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{q}T^a\gamma^\mu q)$
$c^{(3,1)}_{Qq}$	$(\bar{Q}\sigma^i\gamma_\mu Q)(\bar{q}\sigma^i\gamma^\mu q)$
$c^{(3,8)}_{Qq}$	$(\bar{Q}\sigma^i T^a\gamma_\mu Q)(\bar{q}\sigma^i T^a\gamma^\mu q)$
$c^{(3,1)}_{qq}$	$(\bar{q}\sigma^i\gamma_\mu q)(\bar{q}\sigma^i\gamma^\mu q)$
$c^{(1)}_{tu}$	$(\bar{t}\gamma_\mu t)(\bar{u}\gamma^\mu u)$
$c^{(8)}_{tu}$	$(\bar{t}T^a\gamma_\mu t)(\bar{u}T^a\gamma^\mu u)$
$c^{(1)}_{td}$	$(\bar{t}\gamma_\mu t)(\bar{d}\gamma^\mu d)$
$c^{(8)}_{td}$	$(\bar{t}T^a\gamma_\mu t)(\bar{d}T^a\gamma^\mu d)$
$c^{(1)}_{Qu}$	$(\bar{Q}\gamma_\mu Q)(\bar{u}\gamma^\mu u)$
$c^{(8)}_{Qu}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{u}T^a\gamma^\mu u)$
$c^{(1)}_{Qd}$	$(\bar{Q}\gamma_\mu Q)(\bar{d}\gamma^\mu d)$
$c^{(8)}_{Qd}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{d}T^a\gamma^\mu d)$
$c^{(1)}_{tq}$	$(\bar{q}\gamma_\mu q)(\bar{t}\gamma^\mu t)$
$c^{(8)}_{tq}$	$(\bar{q}T^a\gamma_\mu q)(\bar{t}T^a\gamma^\mu t)$
$c_{eH,22}$	$(H^\dagger H)(\bar{l}_2 e_2 H)$
$c_{eH,33}$	$(H^\dagger H)(\bar{l}_3 e_3 H)$
c_{uH}	$(H^\dagger H)(\bar{q} Y_u^\dagger u \widetilde{H})$
c_{tH}	$(H^\dagger H)(\bar{Q} \widetilde{H} t)$
c_{bH}	$(H^\dagger H)(\bar{Q} H b)$
c_{tG}	$(\bar{Q}\sigma^{\mu\nu}T^A t)\widetilde{H}\, G^A_{\mu\nu}$
c_{tW}	$(\bar{Q}\sigma^{\mu\nu} t)\tau^I \widetilde{H}\, W^I_{\mu\nu}$
c_{tB}	$(\bar{Q}\sigma^{\mu\nu} t)\widetilde{H}\, B_{\mu\nu}$
$c_{ll,1221}$	$(\bar{l}_1\gamma_\mu l_2)(\bar{l}_2\gamma^\mu l_1)$

ATLAS-CONF-2023-052

Interpretation of STXS with EFT

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_j^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \ldots$$

- Parameterize the signal strengths, $(XS*BR)_{meas}/(XS*BR)_{SM}$, directly with Wilson coefficients of d=6 SMEFT operators



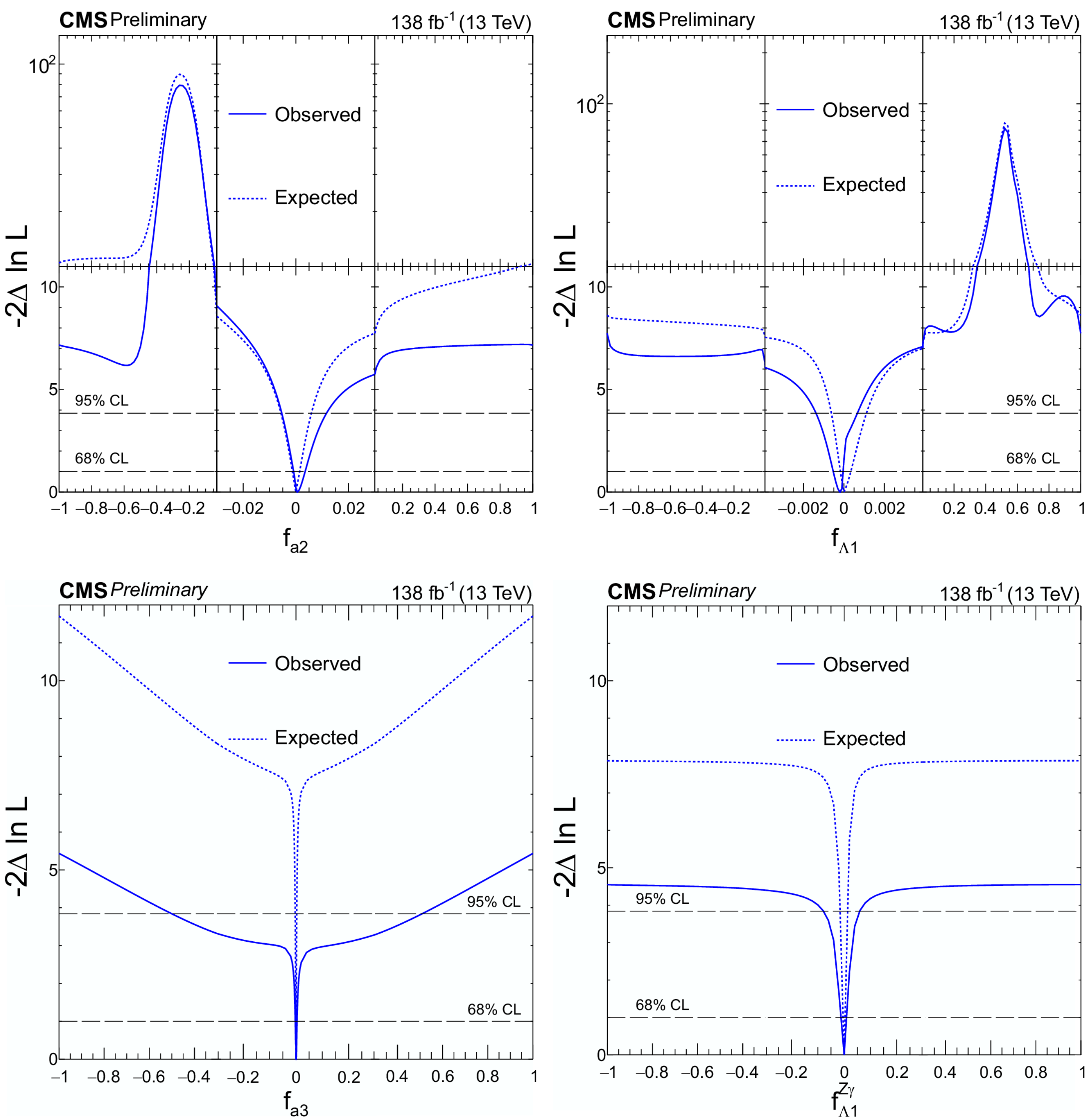
ATLAS-CONF-2023-052

Higgs anomalous coupling

$H \to WW^*$

CMS-PAS-HIG-22-008

HVV vertex
Approach 1
$a_i^{ZZ} = a_i^{WW}$



$$f_{ai} = \frac{|a_i|^2\sigma_i}{\sum_j |a_j|^2\sigma_j}\,\mathrm{sign}\left(\frac{a_i}{a_1}\right),$$

- Studied individually
- Significant interference effects for certain values is evident

Higgs anomalous coupling

$H \to WW^*$

CMS-PAS-HIG-22-008

HVV vertex
SMEFT (Warsaw basis)

$$\delta a_1^{ZZ} = \frac{v^2}{\Lambda^2}\left(2c_{H\Box} + \frac{6e^2}{s_w^2}c_{HWB} + (\frac{3c_w^2}{2s_w^2} - \frac{1}{2})c_{HD}\right),$$

$$\kappa_1^{ZZ} = \frac{v^2}{\Lambda^2}\left(-\frac{2e^2}{s_w^2}c_{HWB} + (1 - \frac{1}{2s_w^2})c_{HD}\right),$$

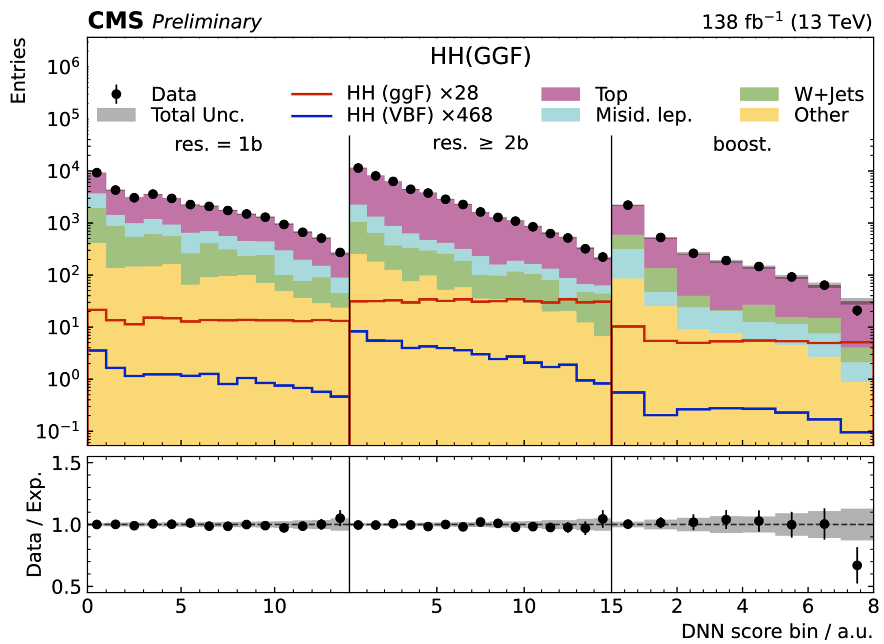
$$a_2^{ZZ} = -2\frac{v^2}{\Lambda^2}\left(s_w^2 c_{HB} + c_w^2 c_{HW} + s_w c_w c_{HWB}\right),$$

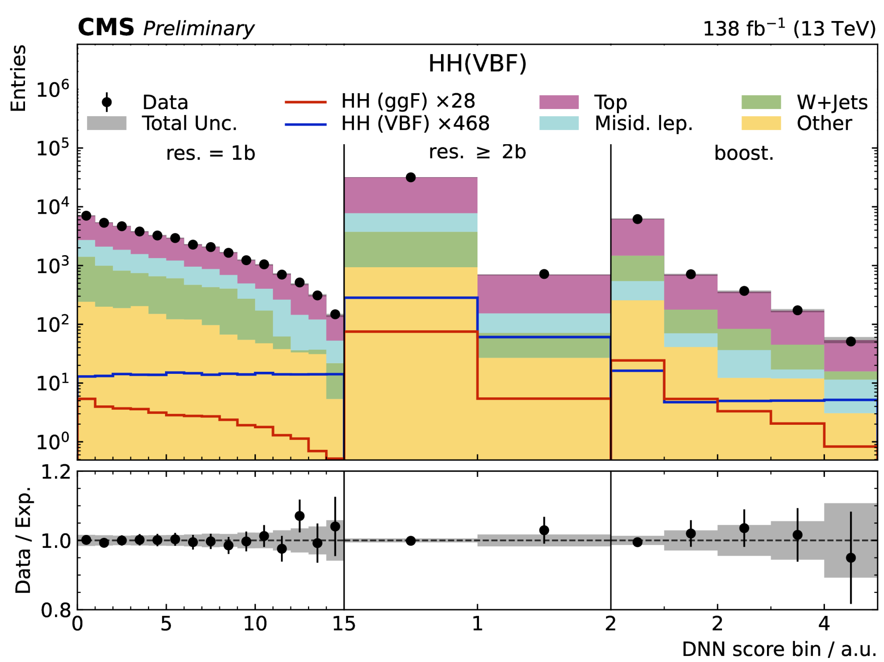
$$a_3^{ZZ} = -2\frac{v^2}{\Lambda^2}\left(s_w^2 c_{H\tilde{B}} + c_w^2 c_{H\tilde{W}} + s_w c_w c_{H\tilde{W}B}\right),$$

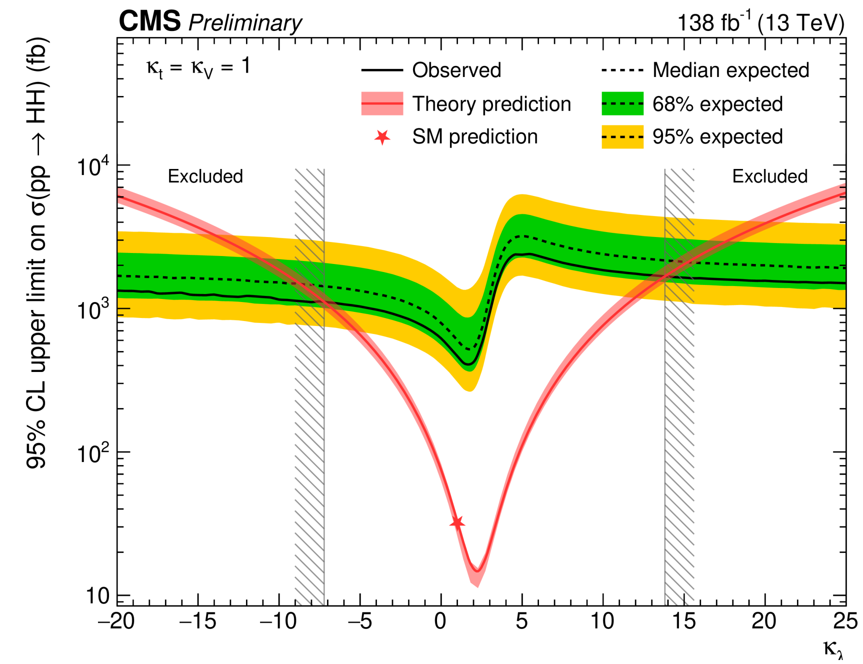
Coupling	Observed	Expected
$c_{H\Box}$	$-0.76^{+1.43}_{-3.43}$	$0.0^{+1.37}_{-1.84}$
c_{HD}	$-0.12^{+0.93}_{-0.32}$	$0.0^{+0.43}_{-0.30}$
c_{HW}	$0.08^{+0.43}_{-0.87}$	$0.0^{+0.37}_{-0.48}$
c_{HWB}	$0.17^{+0.88}_{-1.79}$	$0.0^{+0.77}_{-0.96}$
c_{HB}	$0.03^{+0.13}_{-0.26}$	$0.0^{+0.11}_{-0.14}$
$c_{H\tilde{W}}$	$-0.26^{+0.67}_{-0.50}$	$0.0^{+0.48}_{-0.52}$
$c_{H\tilde{W}B}$	$-0.54^{+1.37}_{-1.03}$	$0.0^{+0.99}_{-1.07}$
$c_{H\tilde{B}}$	$-0.08^{+0.20}_{-0.15}$	$0.0^{+0.15}_{-0.16}$

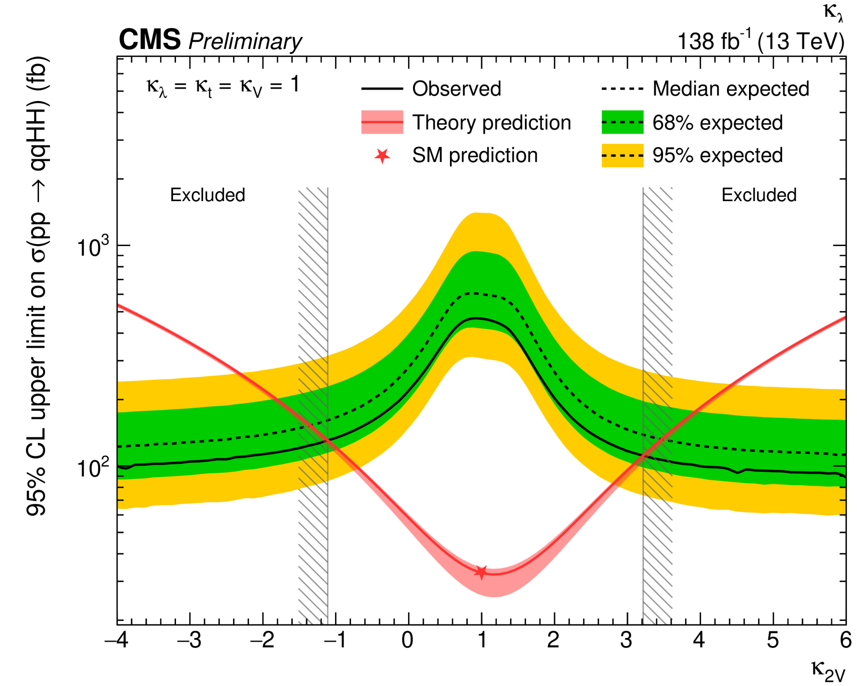
CMS HH→bbWW

CMS-PAS-HIG-21-005





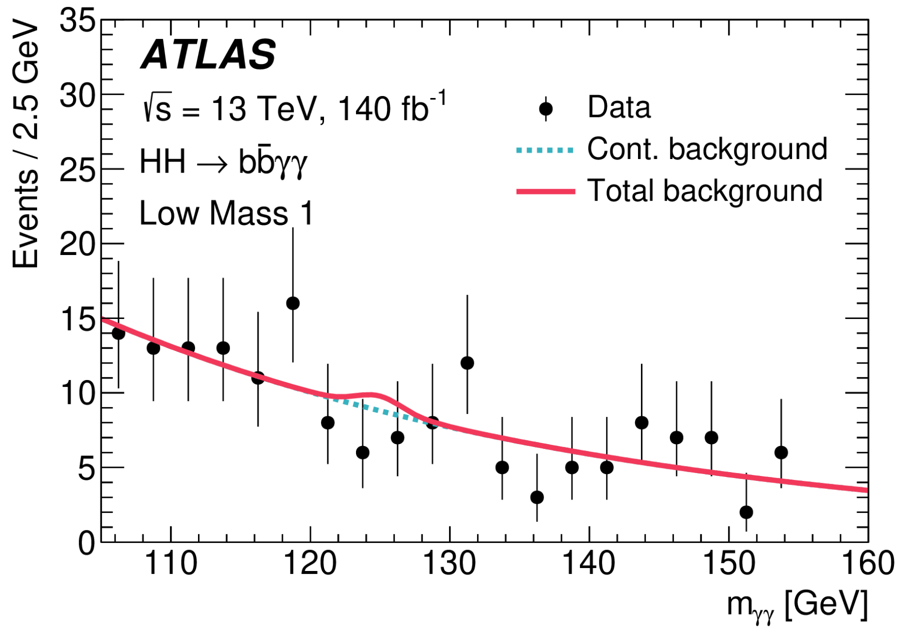


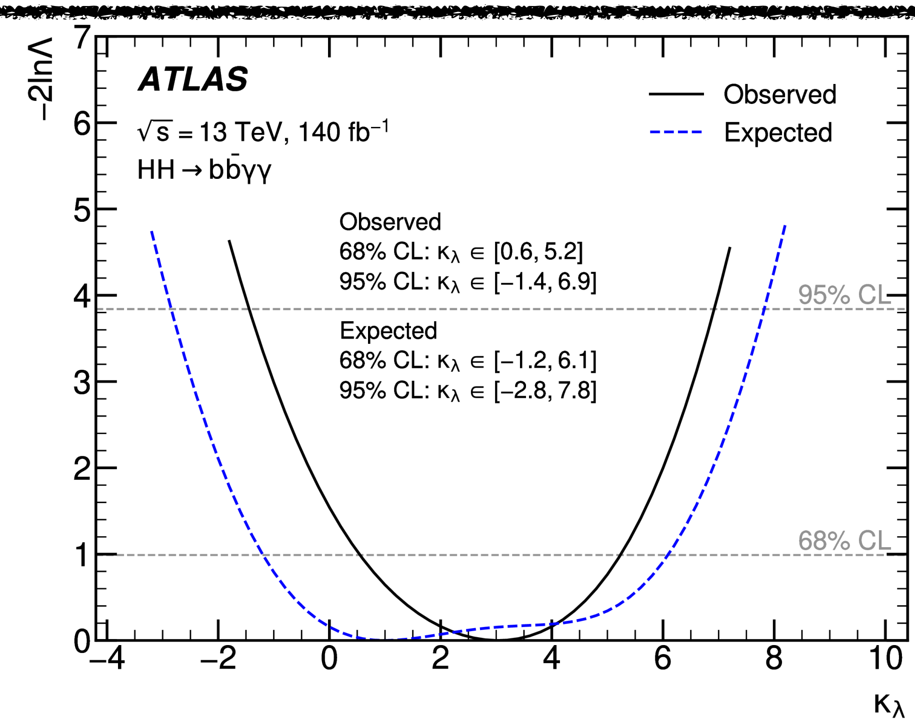


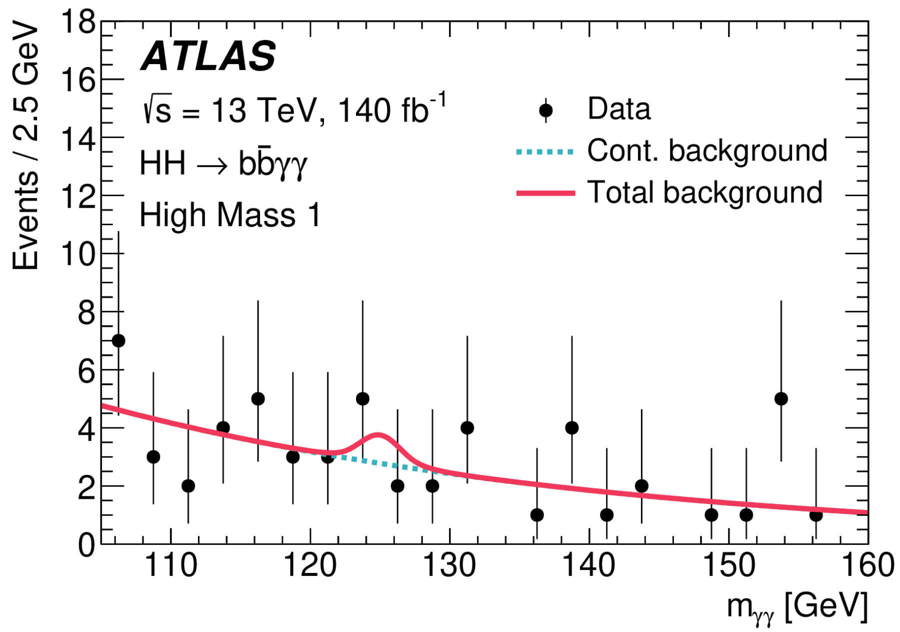
- CMS released HH→bbWW search result (with significant improvement from the partial run-2 result)

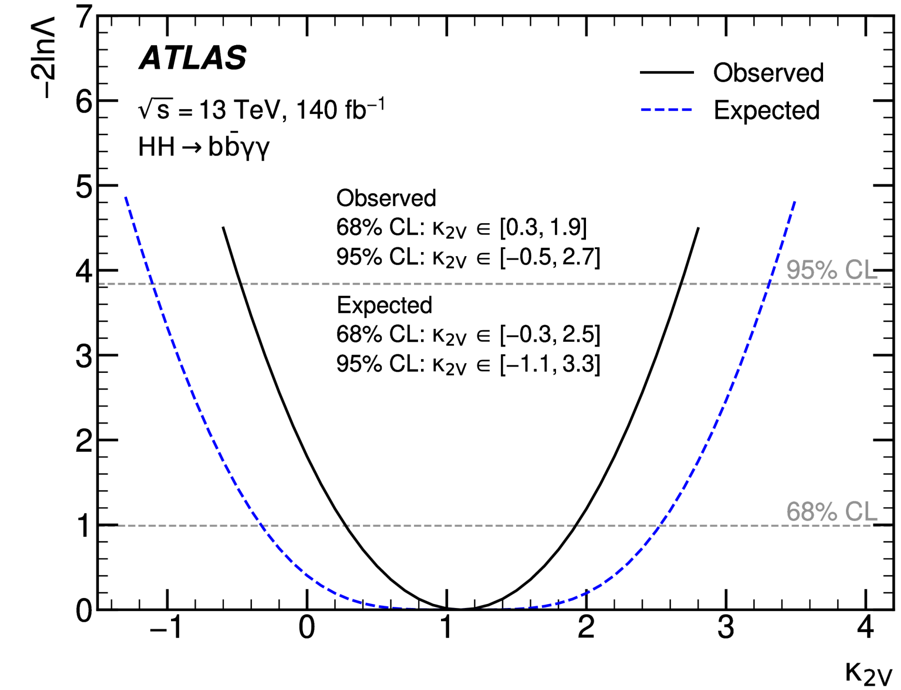
ATLAS HH→bbγγ

arxiv:2310.12301









- ATLAS reoptimize HH→bbγγ to optimize both HHH and HHVV couplings