SM@LHC 2023, Fermilab, 10th-13th July 2023

Recent EW, Higgs and diHiggs EFT interpretations

Ana Cueto (Universidad Autónoma de Madrid), on behalf of the ATLAS and CMS collaborations

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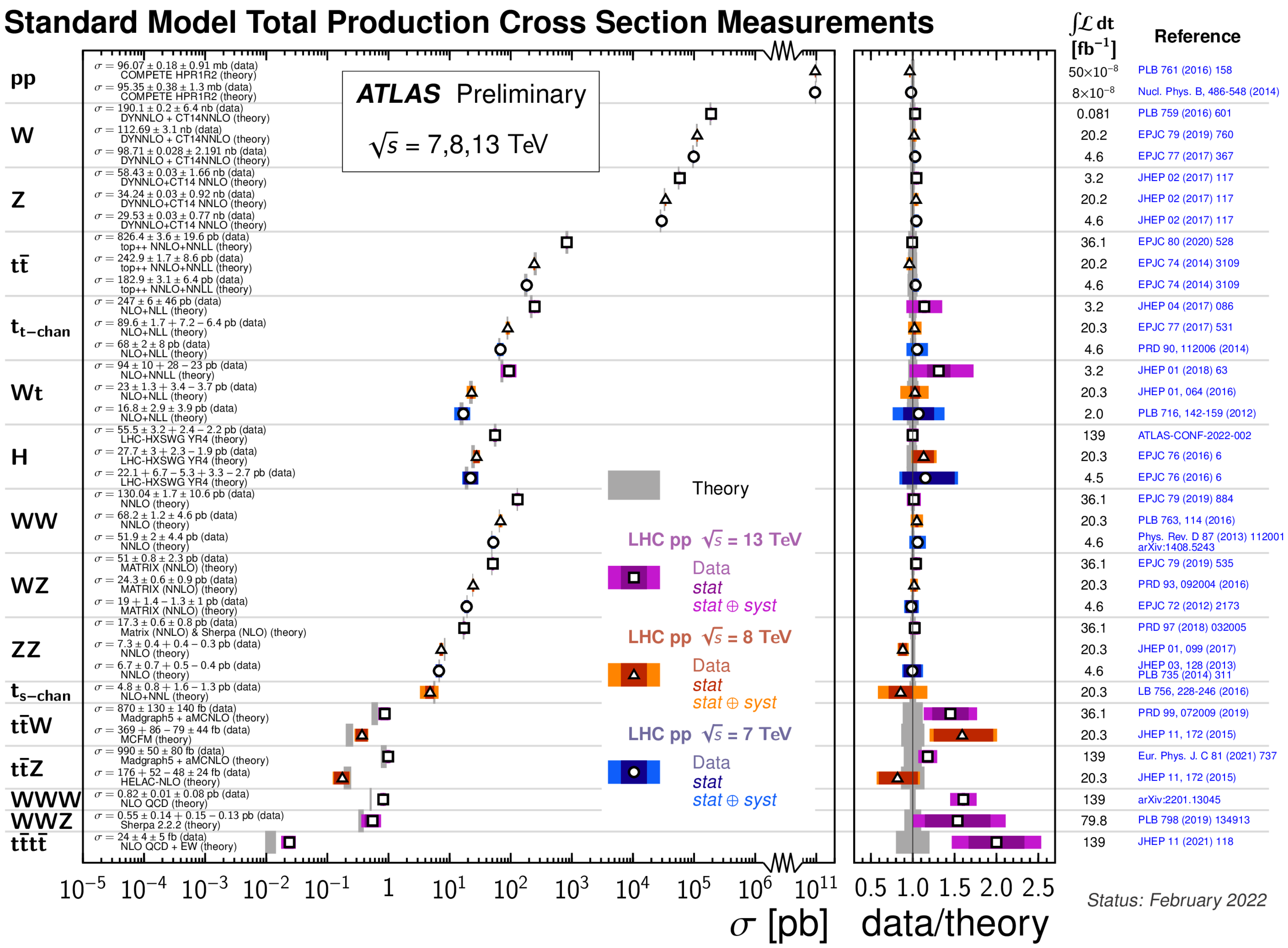
Motivation

- Large success of the SM so far at the LHC and no clear evidence of BSM physics from direct searches
- Motivates searching for BSM effects being as much model-independent as possible

Effective Field Theory approach

Allows to systematically interpret large datasets with the assumption that the new physics appears at larger scales.



SMEFT Introduction

- We assume that the SM is just an effective realisation of a higher-energy theory
- Take an energy cut-off Λ >> vev and write down the most general Lagrangian preserving symmetries, particle content, linearised EWSB, … from SM

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_i \frac{c_i^{d=6}}{\Lambda^2}\mathcal{O}^{d=6} + \sum_i \frac{c_i^{d=8}}{\Lambda^4}\mathcal{O}^{d=8} + \ldots$$

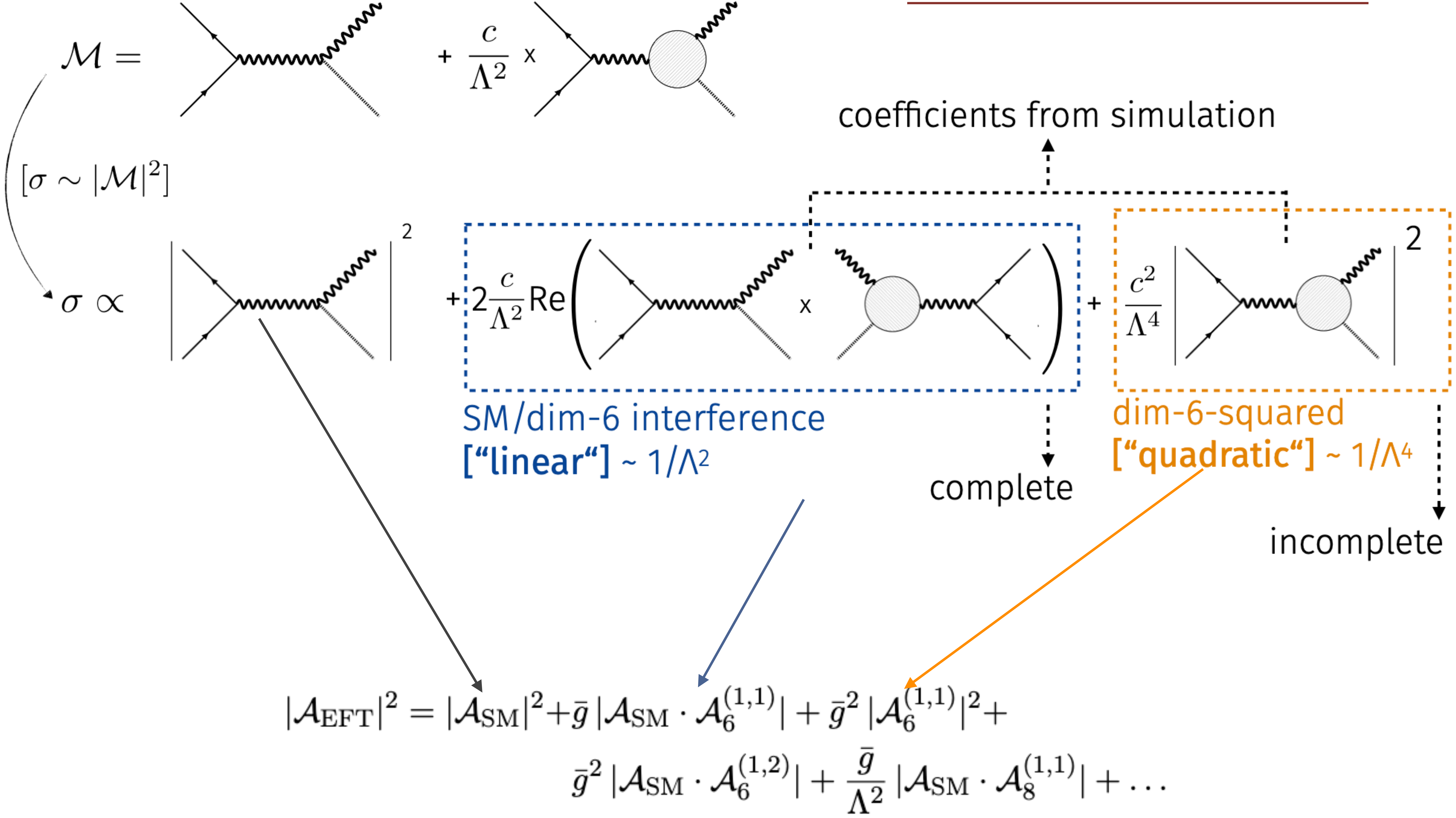
c_i are the so-called Wilson coefficients

- Only c_i/Λ^{d-4} is measurable
- Constrain EFT coefficients ➝ constrain large classes of UV theories
- SMEFT is a complete QFT compatible with higher-order calculations, in contradiction to kappa framework or anomalous couplings interpretations

EFT simulation

- EFT effects generally simulated at LO (or NLO for loop-induced processes)
- Dim-6 operators are the lowest order EFT operators for most processes
- EFT series can be truncated at different orders with different dependence on the cut-off scales

Brian Moser @ HIGGS2020



coefficients from simulation

SM/dim-6 interference
[“linear“] ~ 1/Λ²

complete

dim-6-squared
[“quadratic“] ~ 1/Λ⁴

incomplete

$$|\mathcal{A}_{\mathrm{EFT}}|^2 = |\mathcal{A}_{\mathrm{SM}}|^2 + \bar{g}\,|\mathcal{A}_{\mathrm{SM}} \cdot \mathcal{A}_6^{(1,1)}| + \bar{g}^2\,|\mathcal{A}_6^{(1,1)}|^2 + \bar{g}^2\,|\mathcal{A}_{\mathrm{SM}} \cdot \mathcal{A}_6^{(1,2)}| + \frac{\bar{g}}{\Lambda^2}\,|\mathcal{A}_{\mathrm{SM}} \cdot \mathcal{A}_8^{(1,1)}| + \ldots$$

Implementation of EFT analyses

Dedicated measurements → Measurements directly in terms of EFT coefficients, c_i

Reparametrisations →

- Parametrise measured observables (usually cross-sections) in terms of EFT coefficients.
- Measure c_i using the reparametrised likelihood

Reinterpretations → As reparametrisations but using gaussian assumptions

Recent analyses

Higgs

- H → WW* differential XS (ATLAS)
- ttH, tH CP(CMS, ATLAS)
- H → 4l VBF CP (ATLAS)
- *H → 4l off-shell (ATLAS), dedicated talk*

diHiggs

- HH → bbbb (ATLAS)
- HH→bbγγ+bb$\tau\tau$ (ATLAS)
- HH → WWbb (CMS)
- HH →WWγγ (CMS)
- HH → multilepton (CMS)

Electroweak

- ssWW (ATLAS)
- *4l VBS (ATLAS)*
- Wγjj (CMS)

Other aQGCs interpretations in Despoina's talk

- *Global EFT interpretation of Higgs+EW+LEP data covered in tomorrows talk (ATLAS)*

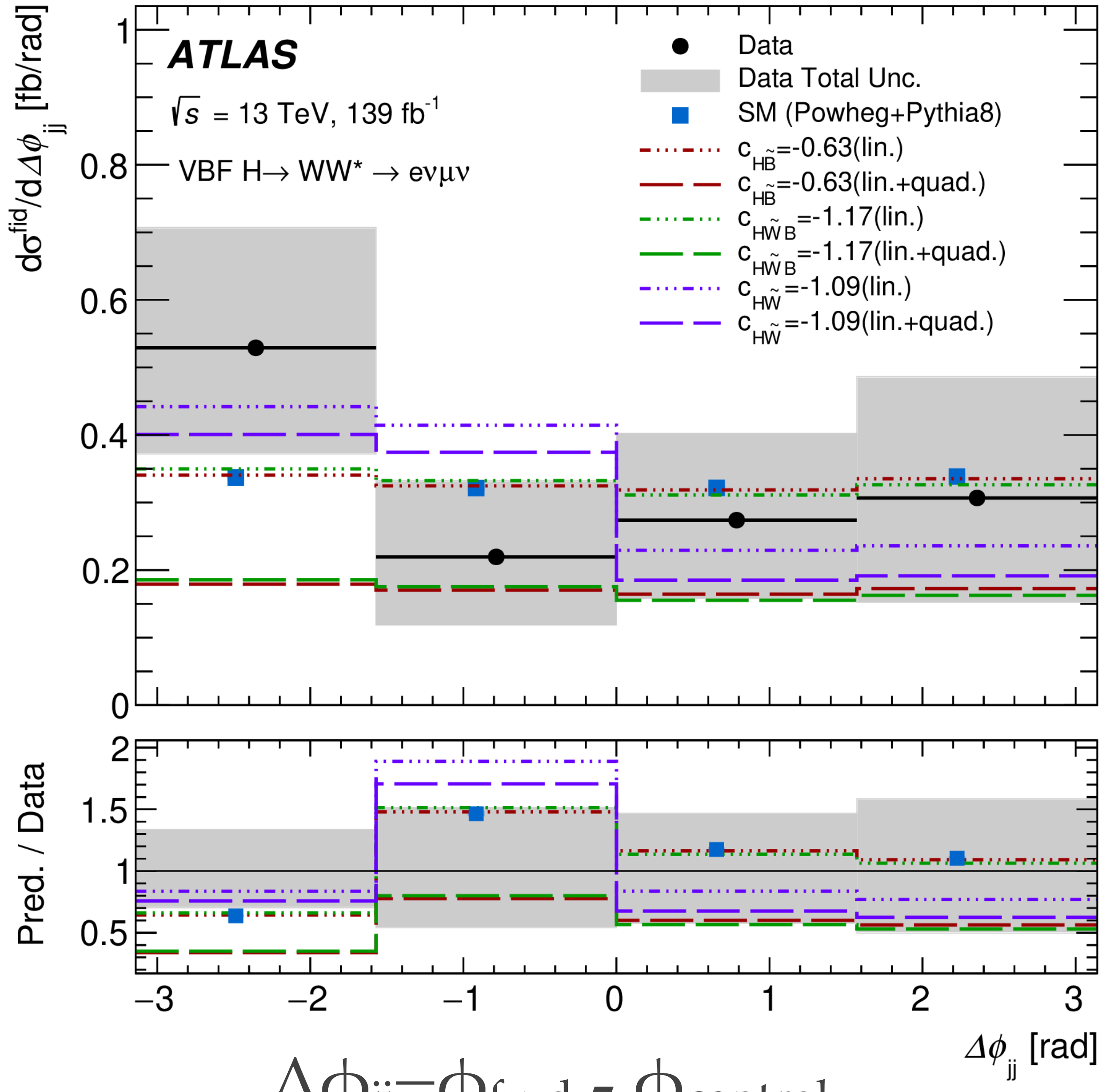
H→WW VBF differential cross sections (ATLAS)

- Full Run 2 fiducial and differential cross sections in the H→WW*→$e\nu\mu\nu$ channel

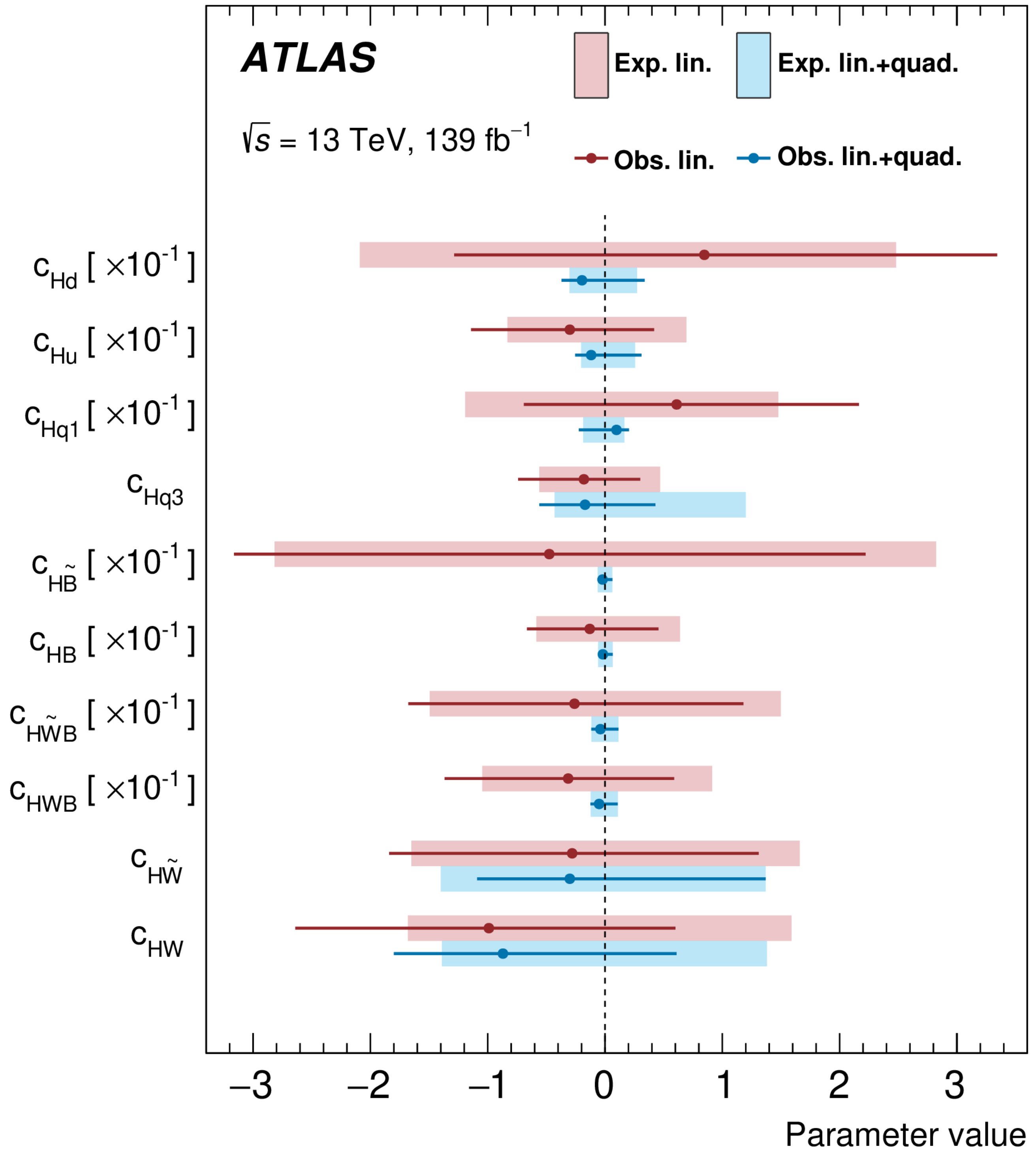
HIGG-2020-25

  - Optimised VBF cuts to enhance the signal and suppress the background: e.g., b-jet , central-jet and outside lepton vetos, m_{jj}>450 GeV, $|\Delta y_{jj}| > 2.1$ and $|\Delta y_{ll}|<1.4$

- The Wilson coefficients were constrained one at a time using the differential distribution that showed the largest sensitivity ($\Delta\phi_{jj}$ and p_T^{j1})
  - Effects in the production mode, decay channel and signal fiducial acceptance considered



$\Delta\phi_{jj}=\phi_{fwd} - \phi_{central}$



- Sensitivity to cHB, cHWB, cHB~, cHWB~ (Warsaw basis) mainly through Higgs total width while cHW, cHW~ affect directly the H→WW* BR

ttH and tH CP

- CP-odd components in the Higgs couplings would represent a clear sign of BSM physics
  - These analyses try to set limits on the CP-odd component of the top Yukawa coupling
- Higgs characterisation model used, effective lagrangian modifying the top-quark Yukawa coupling in the mass eigenstates:

$$\mathcal{L}_Y^{\mathrm{dim}=6} = (\phi^\dagger\phi)Q_L\tilde{\phi}t_R \quad \longrightarrow \quad \mathcal{L}_{t\bar{t}H} = -\kappa'_t y_t \phi \bar{\psi}_t (\cos\alpha + i\gamma_5 \sin\alpha)\psi_t$$

$\alpha \equiv$ cp-mixing angle

Pure CP-even

Pure CP-odd

- Signal parametrisation:

CP interference tH

$$N_{t\bar{t}H}(k'_t,\alpha) = k'^2_t c^2_\alpha N_{\text{CP-even}} + k'^2_t s^2_\alpha N_{\text{CP-odd}} \qquad N_{tH}(k'_t,\alpha) = A\, k'^2_t c^2_\alpha + B\, k'^2_t s^2_\alpha + C\, k'_t c_\alpha + D\, k'_t s_\alpha + E\, k'^2_t c_\alpha s_\alpha + F$$

CP interference tH and WH

WH

- Several fully reconstructed samples with different CP assumptions

ttH, tH CP (ATLAS)

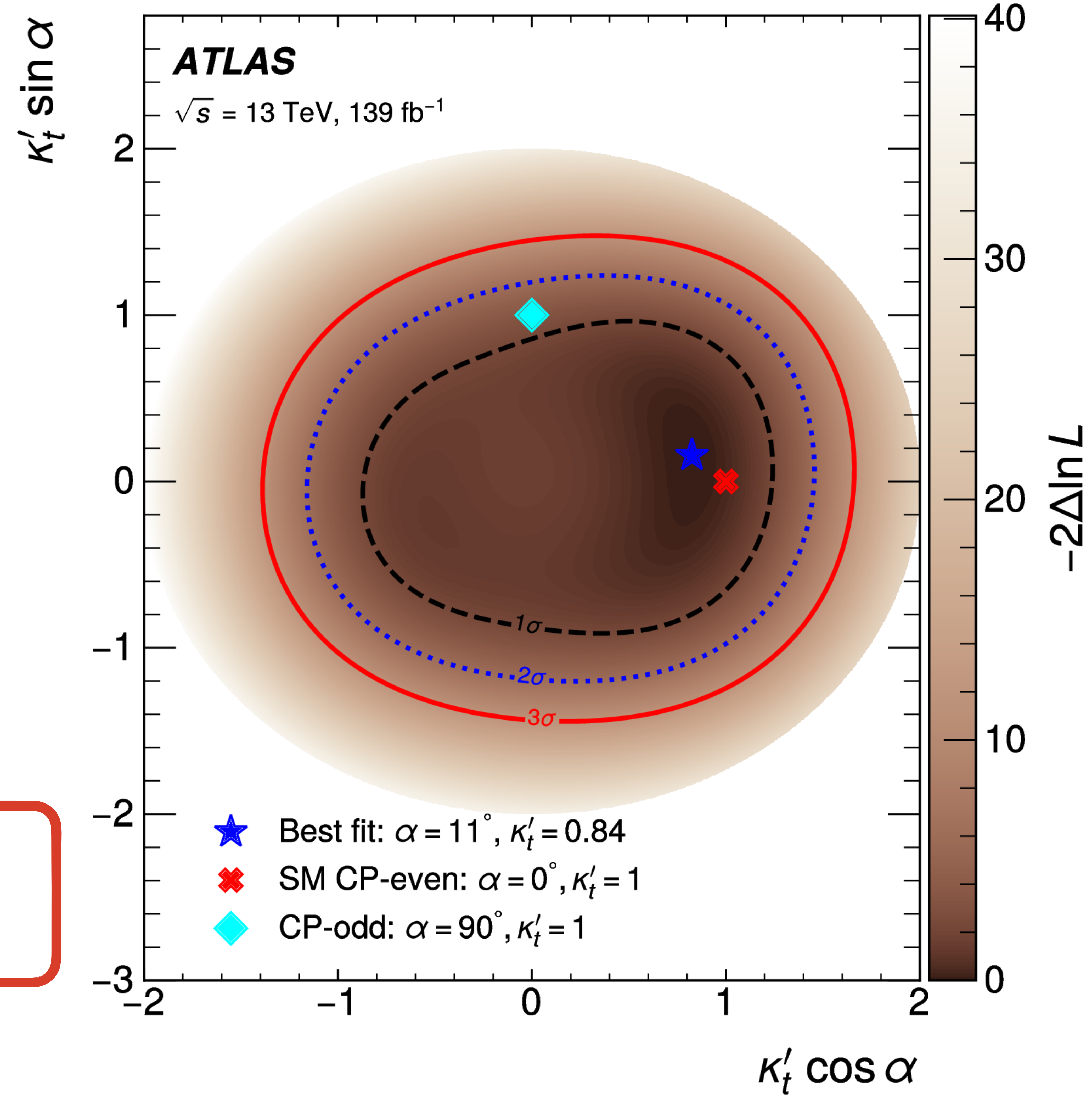
HIGG-2020-03

- Performed in the H→bb decay channel
  - Different analysis regions: boosted (pTH > 300 GeV), dileptonic (≥4jets, ≥4 b-jets, 2l) and single lepton (≥6jets,≥4bjets, 1l)
  - Large background from tt+jets difficult to model. Nuisance to model tt+≥1b normalisation
- Dedicated CP-sensitive observables are used to determine the CP-properties of the top Yukawa

$$b_2 = \frac{(\vec{p}_1 \times \hat{z}) \cdot (\vec{p}_2 \times \hat{z})}{|\vec{p}_1||\vec{p}_2|}, \quad \text{and} \quad b_4 = \frac{(\vec{p}_1 \cdot \hat{z})(\vec{p}_2 \cdot \hat{z})}{|\vec{p}_1||\vec{p}_2|}.$$

- Combined LH fit in all analysis categories: free floating α and κ'
  - Pure CP-odd outside the 1σ contour

$$\boxed{\begin{array}{c}\alpha=11^{o}\ {}^{+55^{o}}{}_{-77^{o}} \\ \kappa'=0.83^{+0.30}_{-0.46}\end{array}}$$

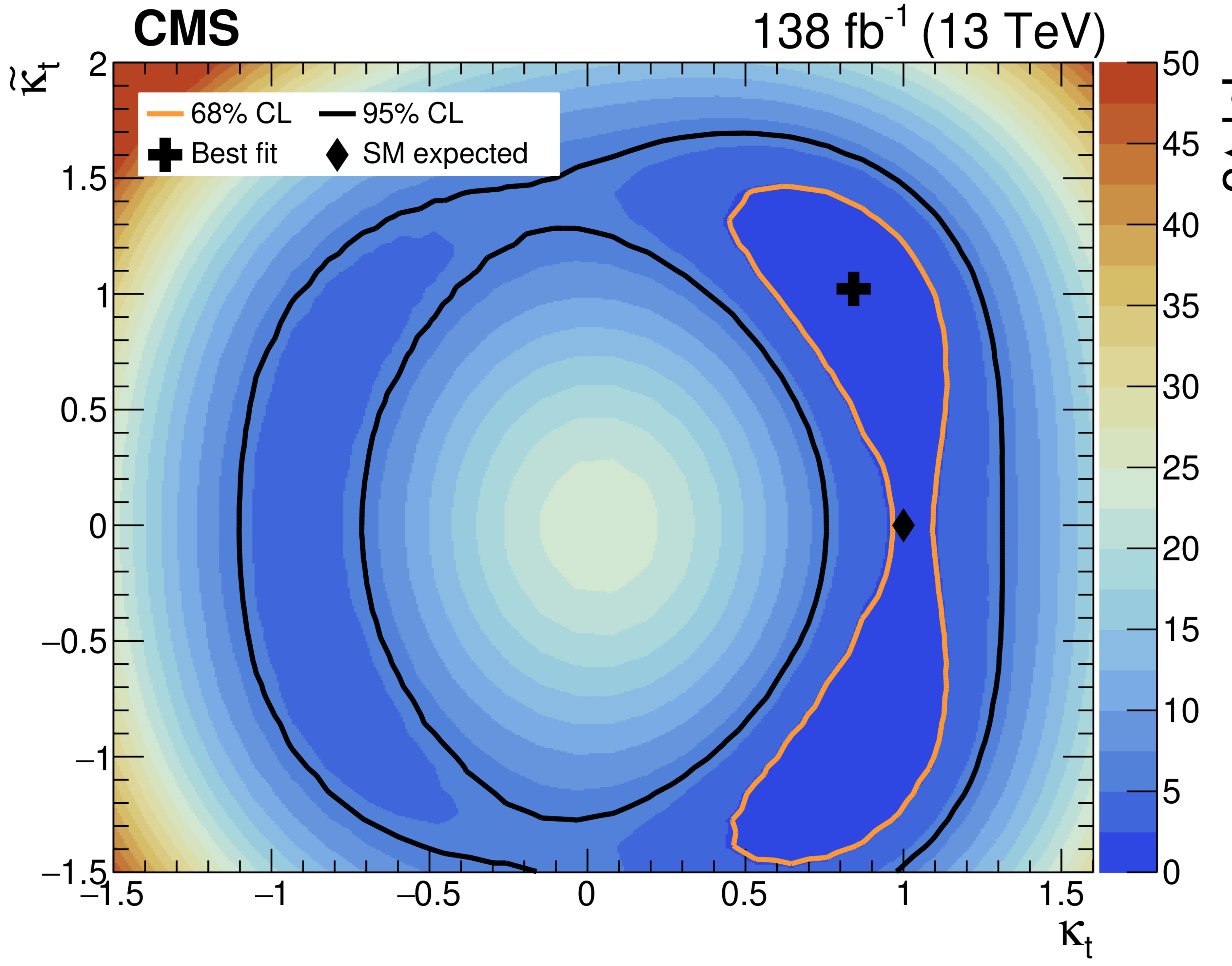


ttH and tH CP (CMS)

HIG-21-006

- Search for CP violation in the top yukawa coupling using H→WW and H→$\tau\tau$
  - 3 different signatures: 2lSS+0τh, 2lSS+1τh, 3l+0τh in events with at least one top quark decaying leptonically
  - Discrimination between different CP scenarios using BDT classifiers
    - Signal extracted through a simultaneous maximum likelihood fit to the SRs and 3l and 4l CRs

Parameter	68% CL	95% CL
	Expected	
κ_t	(0.87, 1.14)	(0.74, 1.27)
$\tilde{\kappa}_t$	(-0.71, 0.71)	(-1.01, 1.01)
	Observed	
κ_t	(0.89, 1.17)	(-1.09, -0.74) or (0.77, 1.3)
$\tilde{\kappa}_t$	(0.37, 1.16) or (-1.16, -0.37)	(-1.4, 1.4)



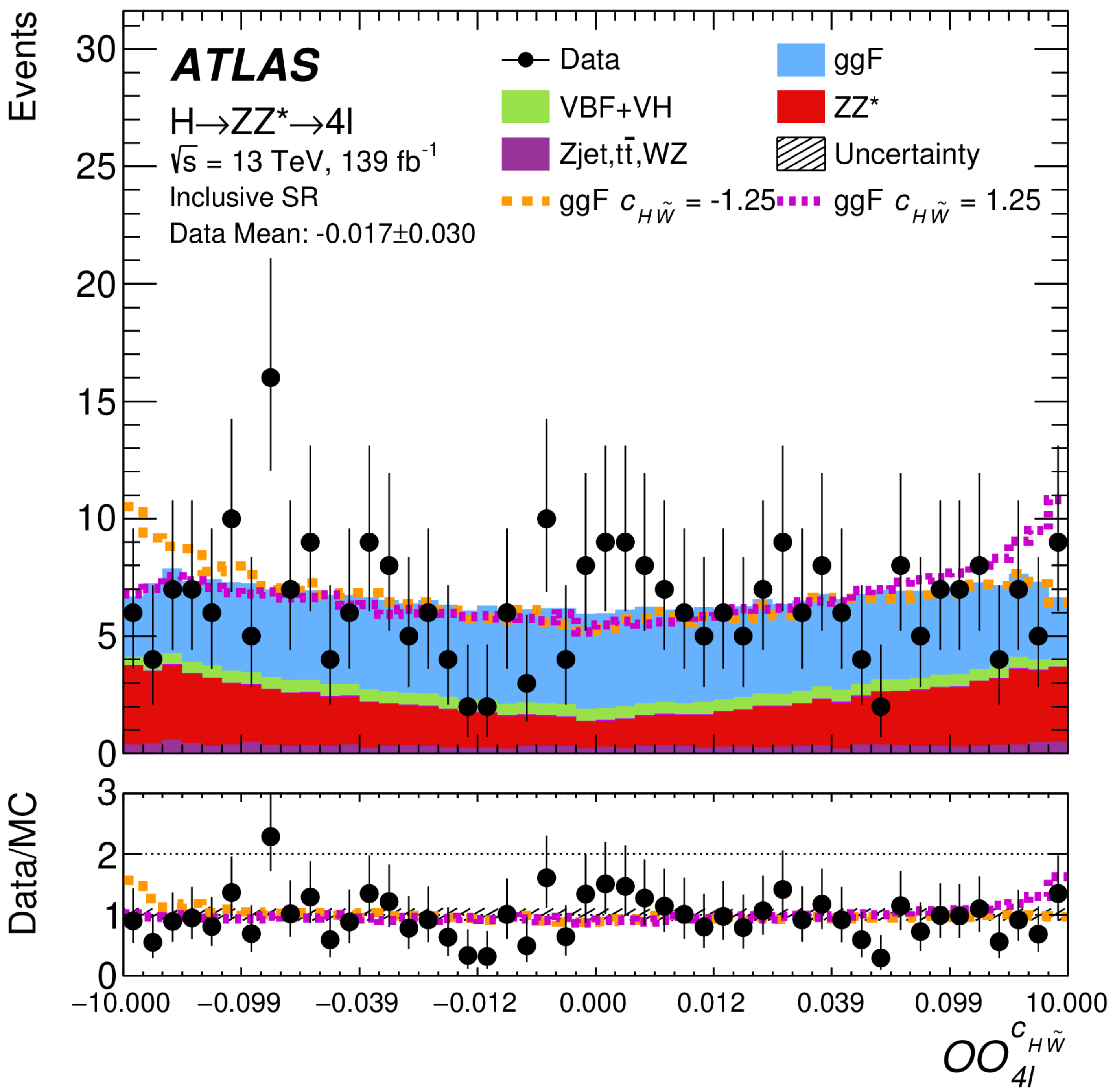
H→4l VBF CP (ATLAS)

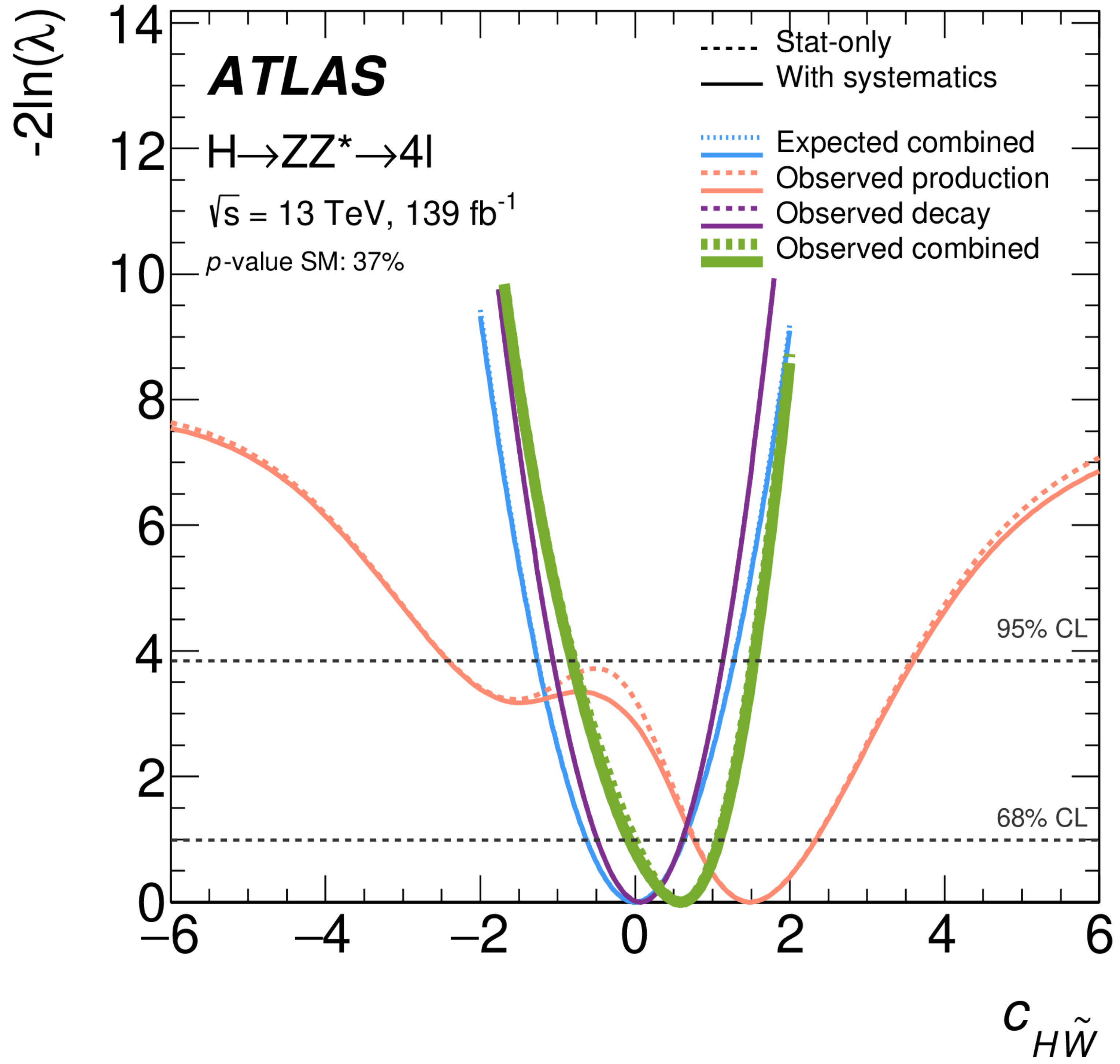
HIGG-2018-30

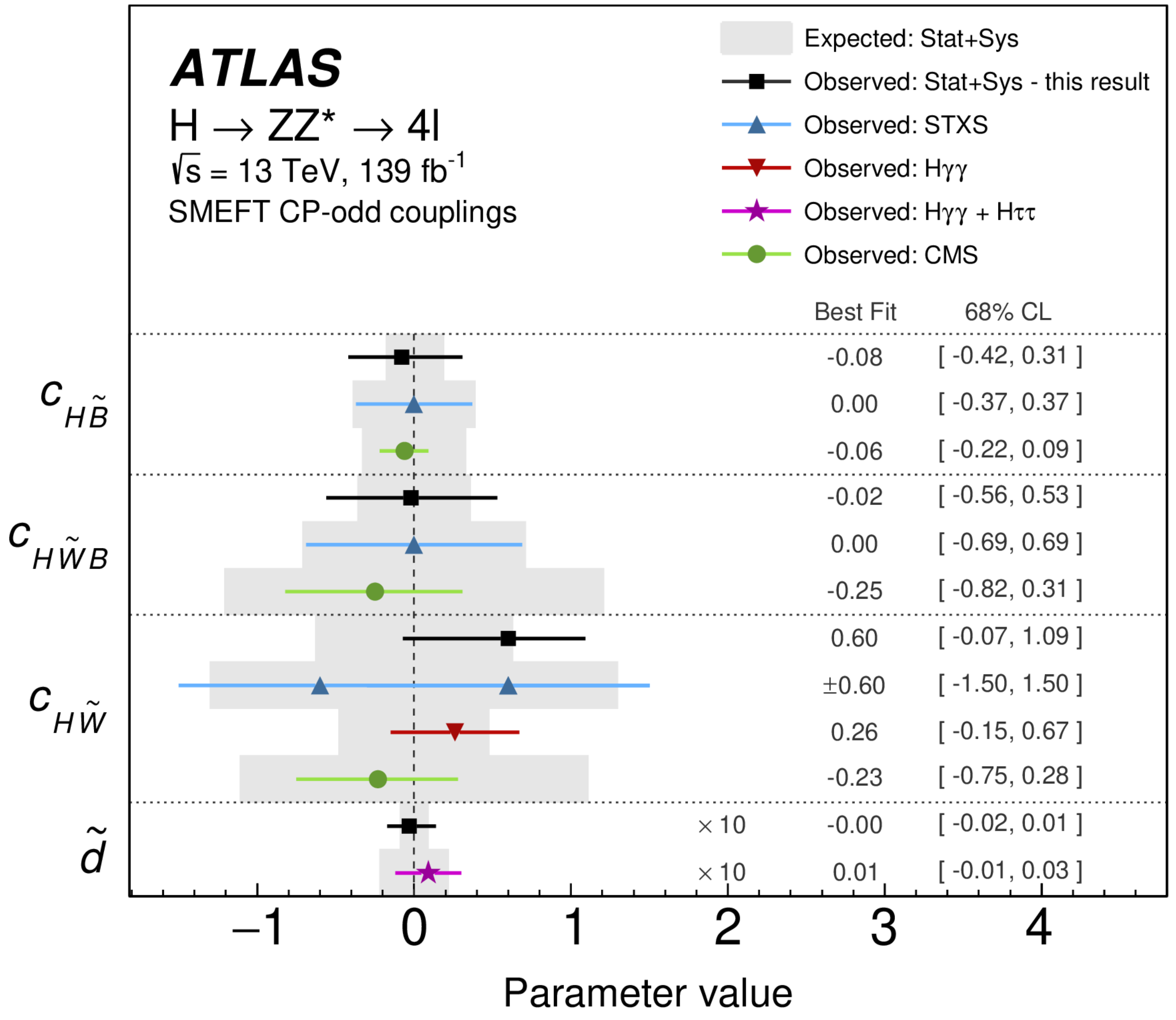
- Search for CP violation in the HVV couplings with H→4l decays
  - Employs Optimal Observables which are CP-odd by construction
  - Distributions are unfolded to allow for future interpretations
  - VBF phase-space with mjj>400GeV, | Δηjj | > 3 (59.3% VBF purity)
  - Only shape information exploited from production mode or decay-level analysis

$$OO = \frac{2\Re\left(\mathcal{M}^*_{\mathrm{SM}}\mathcal{M}_{\mathrm{BSM}}\right)}{|\mathcal{M}_{\mathrm{SM}}|^2}$$

Matrix-element analytical expression obtained with MadGraph5 at LO





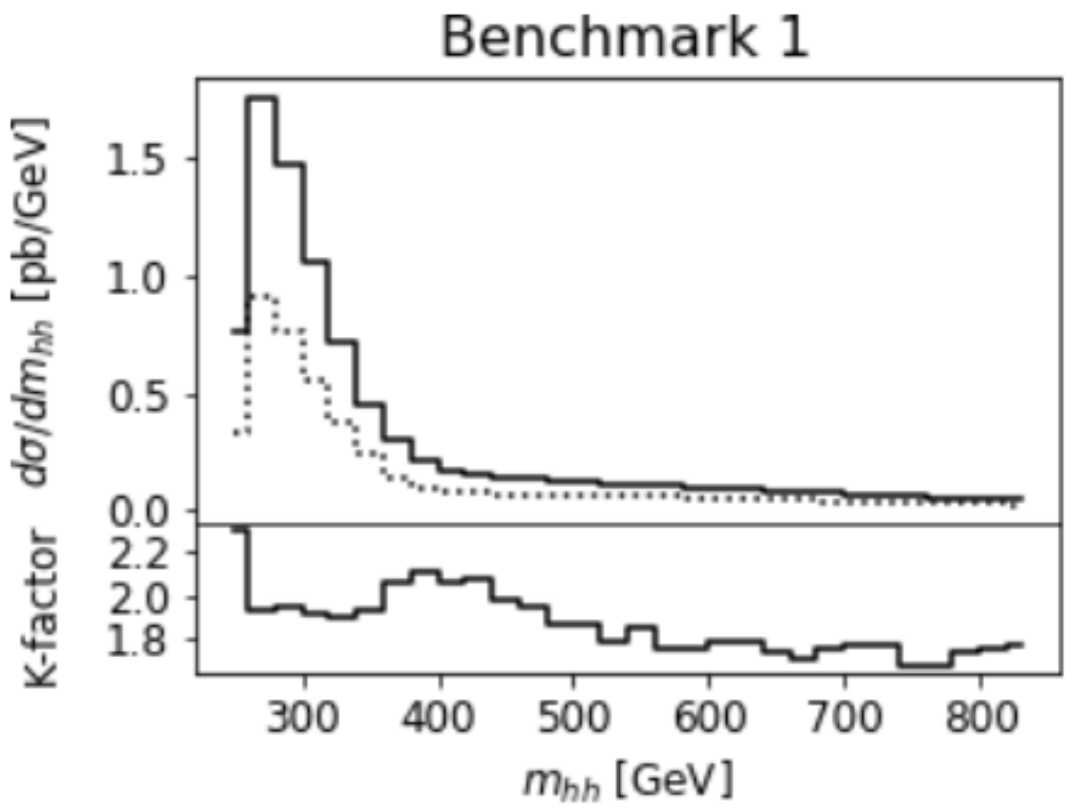


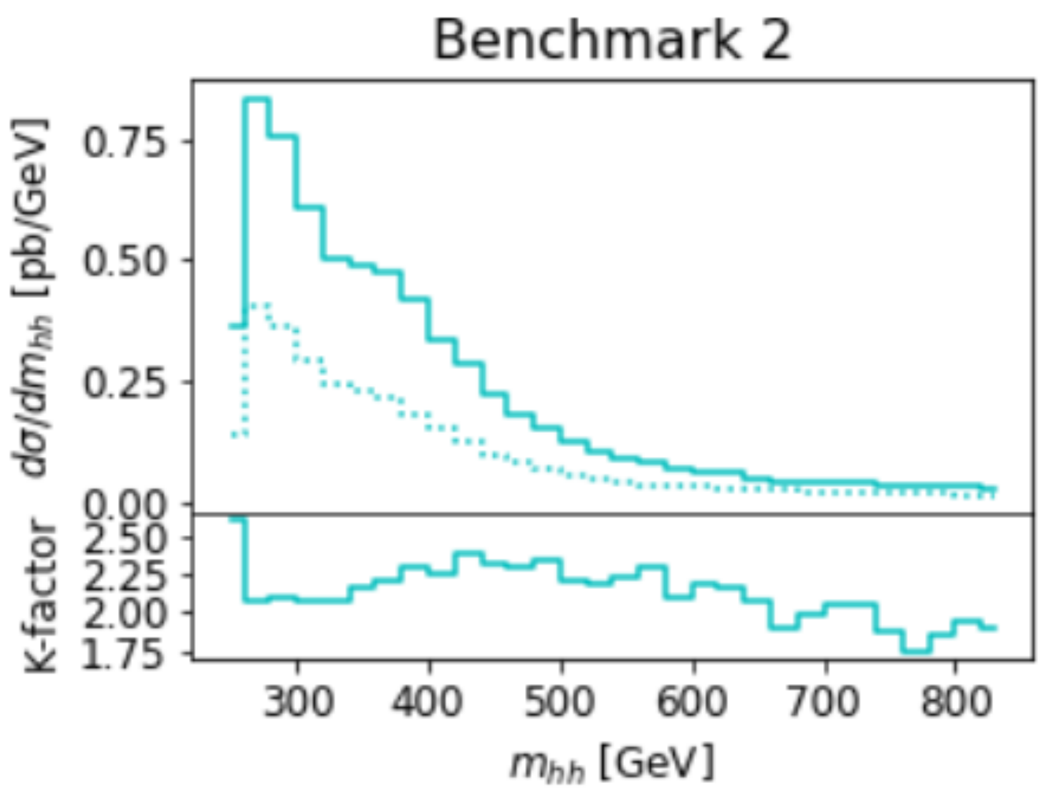
Better limits, except in cHW~, than H→γγ + H→ττ

EFTs for diHiggs

- Higgs EFT (HEFT) currently used in most diHiggs interpretations
  - Low energy dynamics of EW symmetry breaking with non-linear realisation of SU(2)xU(1)

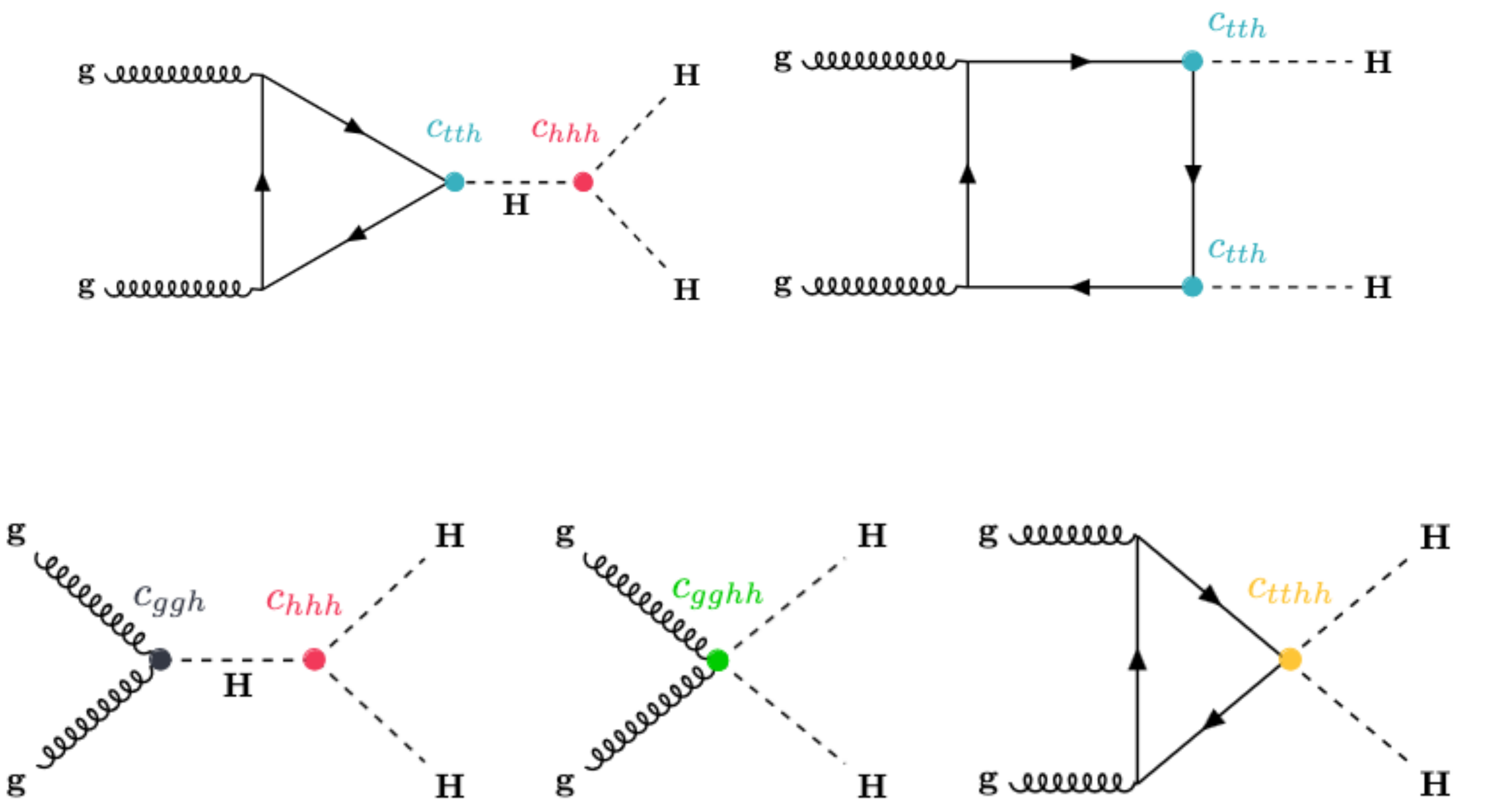
- Combine operators to define a 7 or 12 benchmark scenario based on mHH distribution at NLO spanning the 5-dimensional space





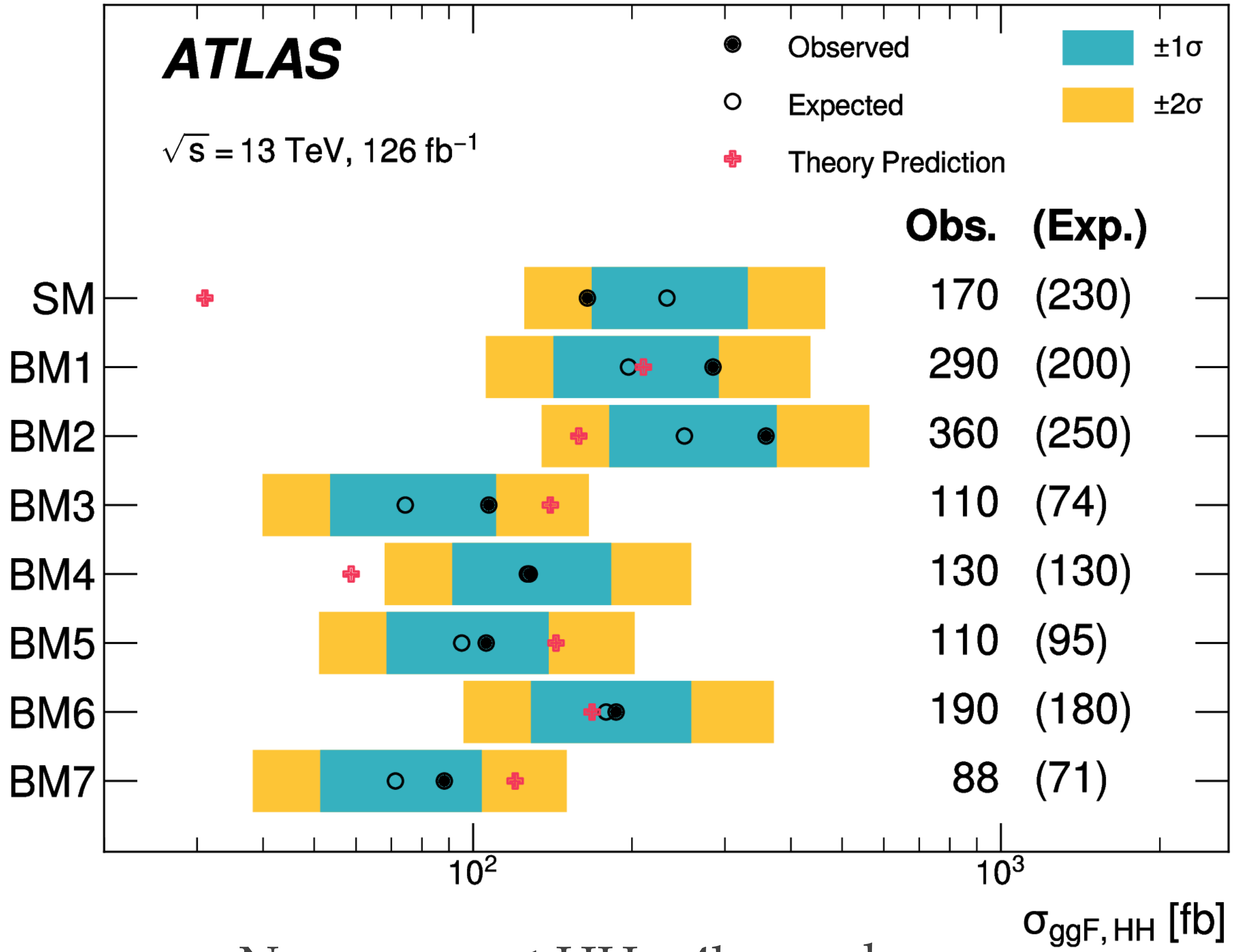
Example from 7 benchmark scenario

benchmark	c_t	c_{hhh}	c_{tt}	c_{ggh}	c_{gghh}
1	0.94	3.94	$-\frac{1}{3}$	0.5	$\frac{1}{3}$
2	0.61	6.84	$\frac{1}{3}$	0.0	$-\frac{1}{3}$



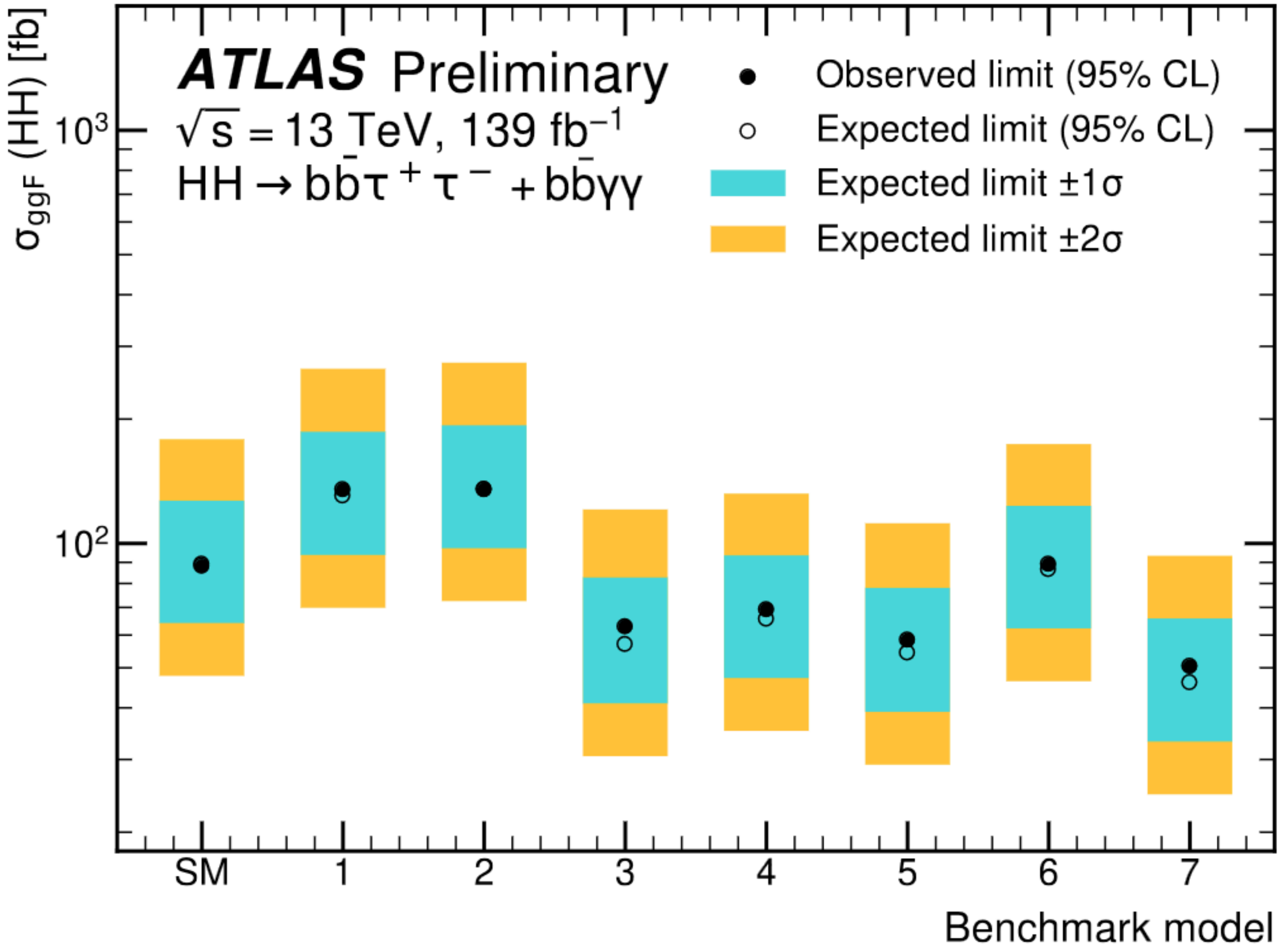
5 operators affecting ggF, ATL-PHYS-PUB-2022-019

EFT for diHiggs in ATLAS



Non-resonant HH→4b search

HDBS-2019-29

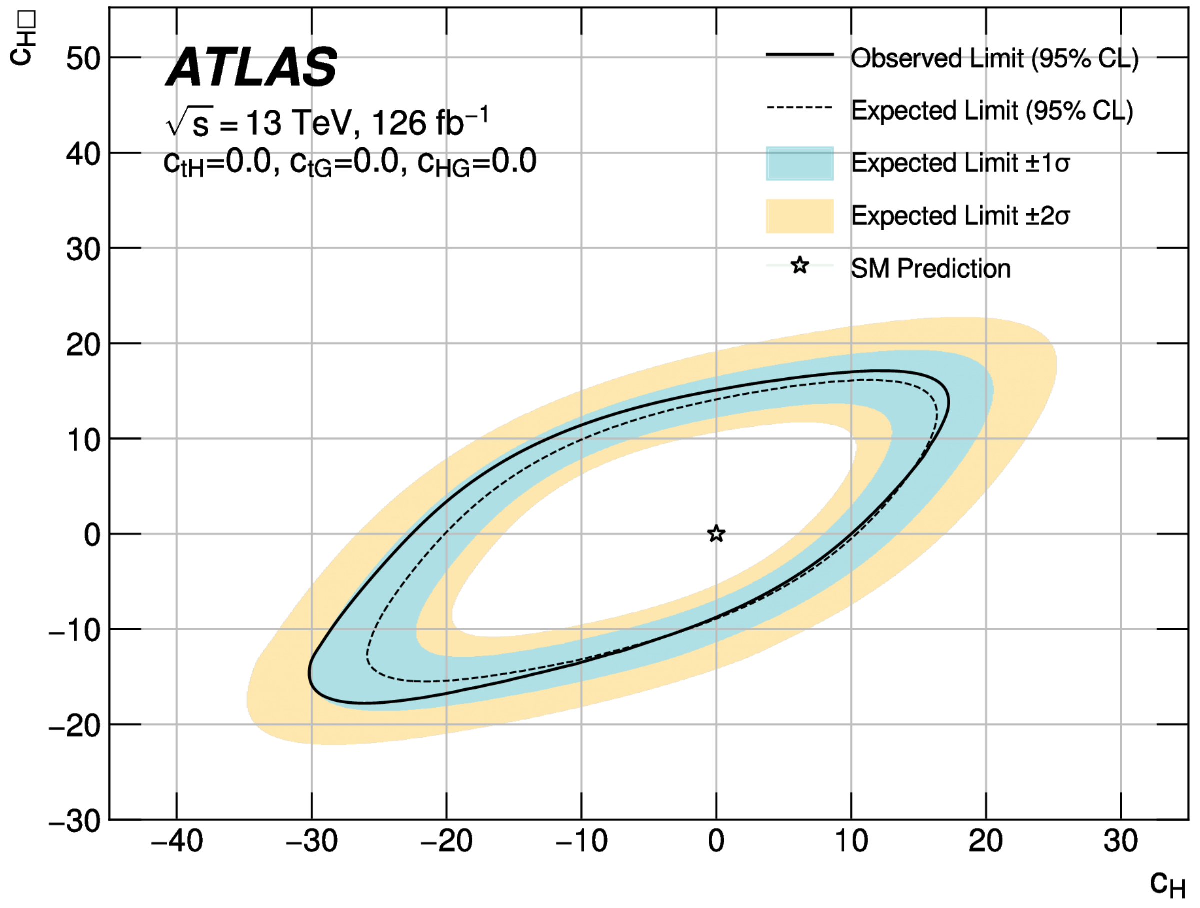


bb$\gamma\gamma$+bb$\tau\tau$ combination

ATL-PHYS-PUB-2022-019

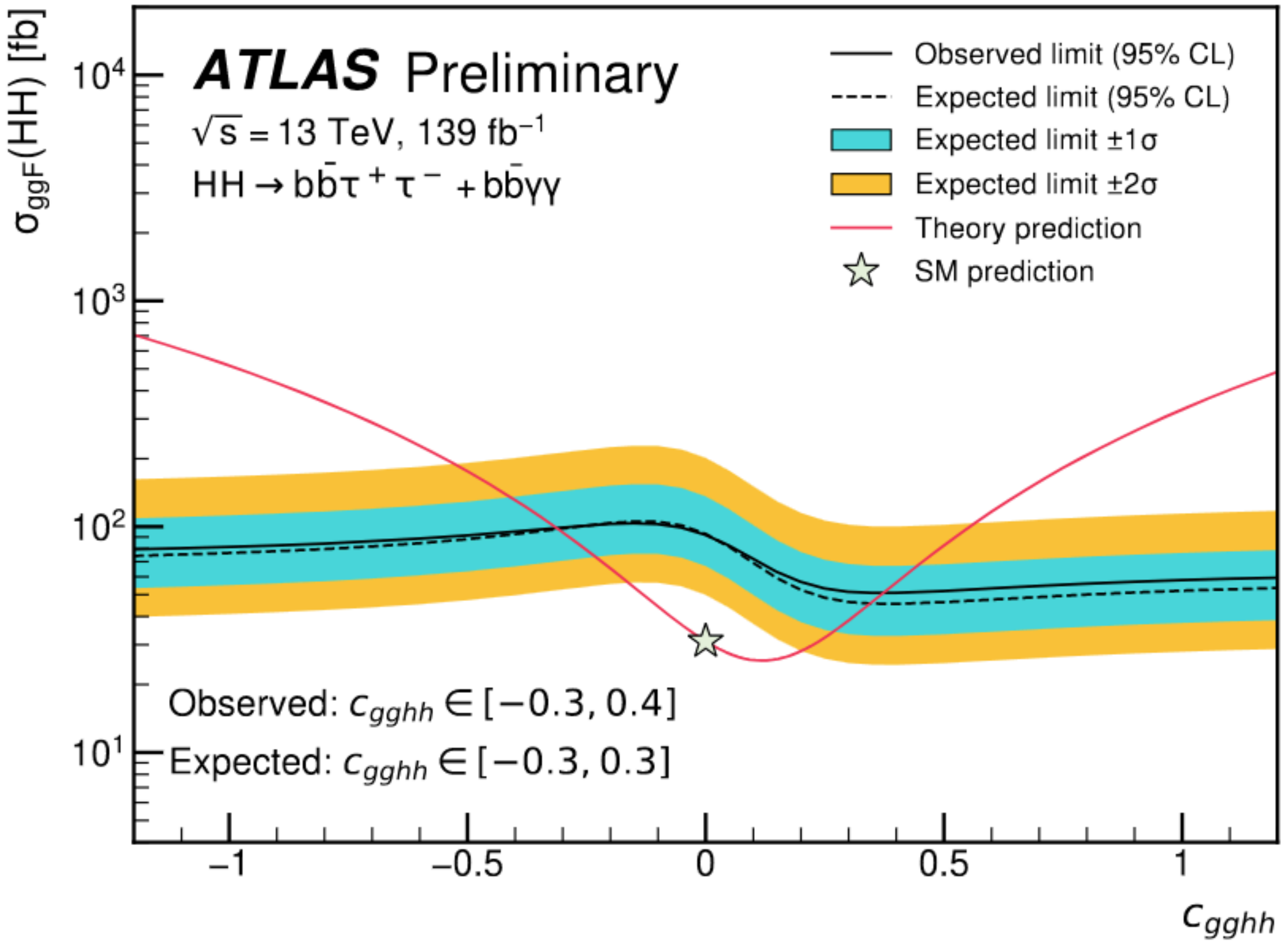
EFT for diHiggs in ATLAS

- Also limits provided in terms of single coefficients of HEFT (bb$\gamma\gamma$+bb$\tau\tau$ combination) or SMEFT (bbbb)

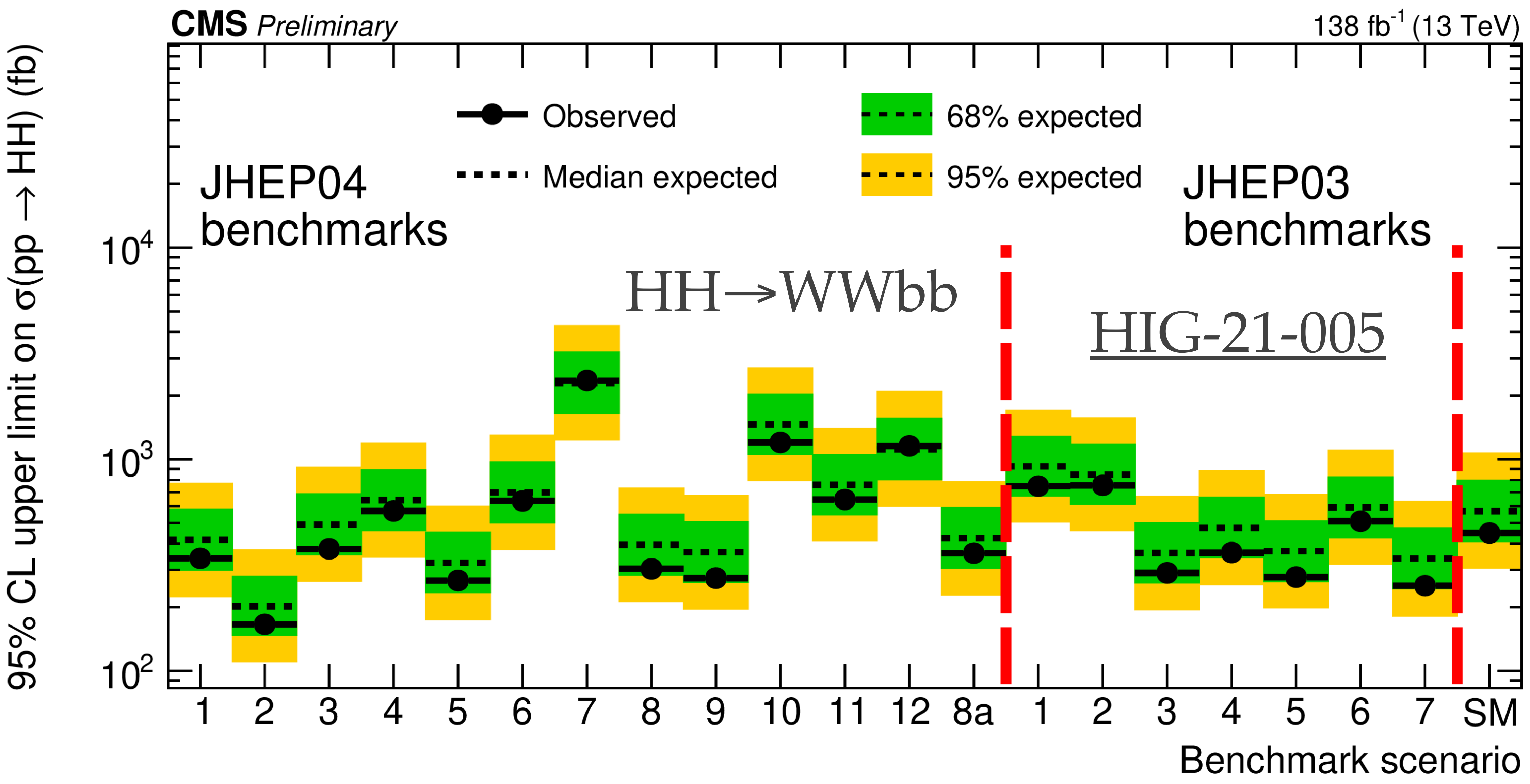


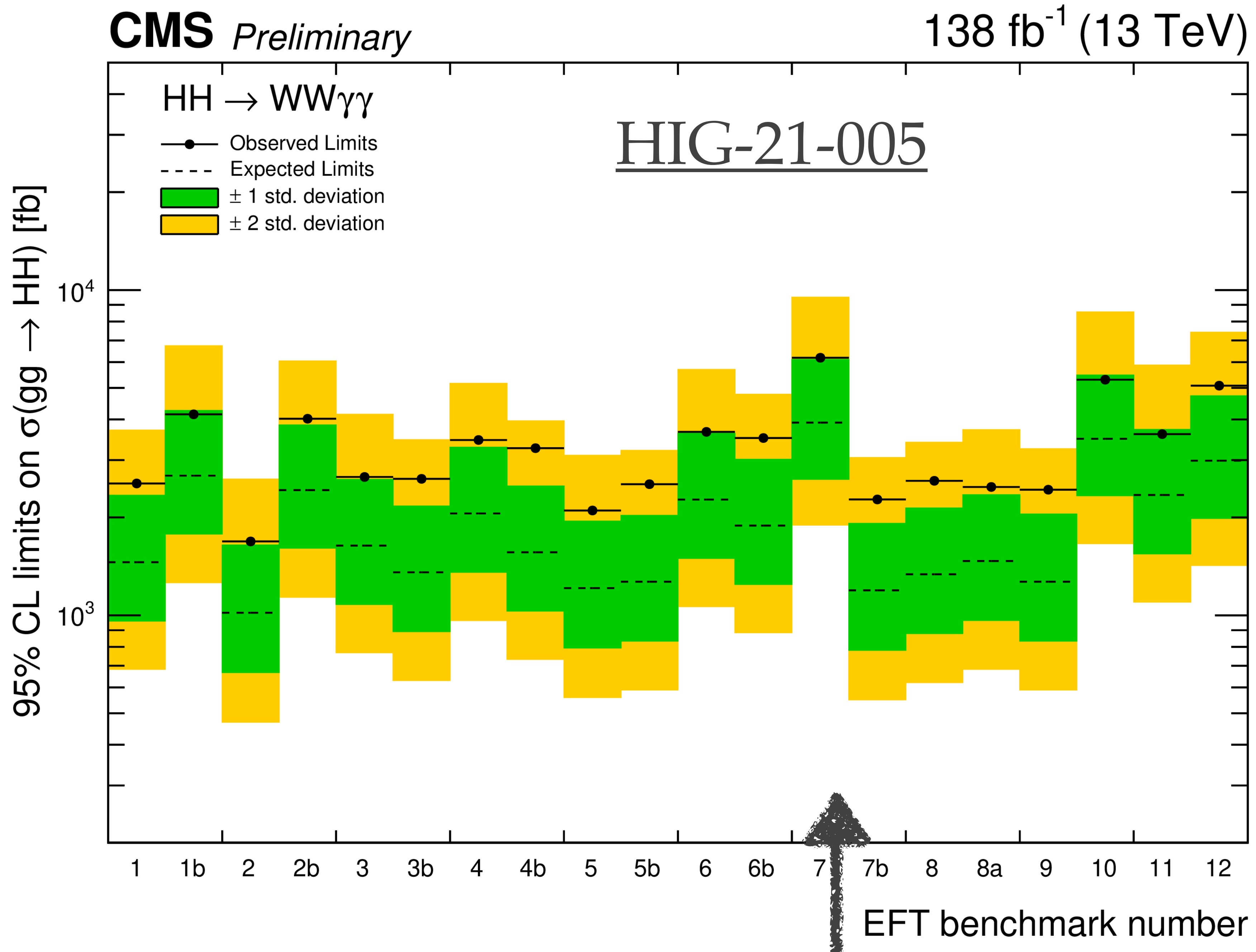
Parameter	Expected Constraint		Observed Constraint	
	Lower	Upper	Lower	Upper
c_H	-20	11	-22	11
c_{HG}	-0.056	0.049	-0.067	0.060
$c_{H\Box}$	-9.3	13.9	-8.9	14.5
c_{tH}	-10.0	6.4	-10.7	6.2
c_{tG}	-0.97	0.94	-1.12	1.15

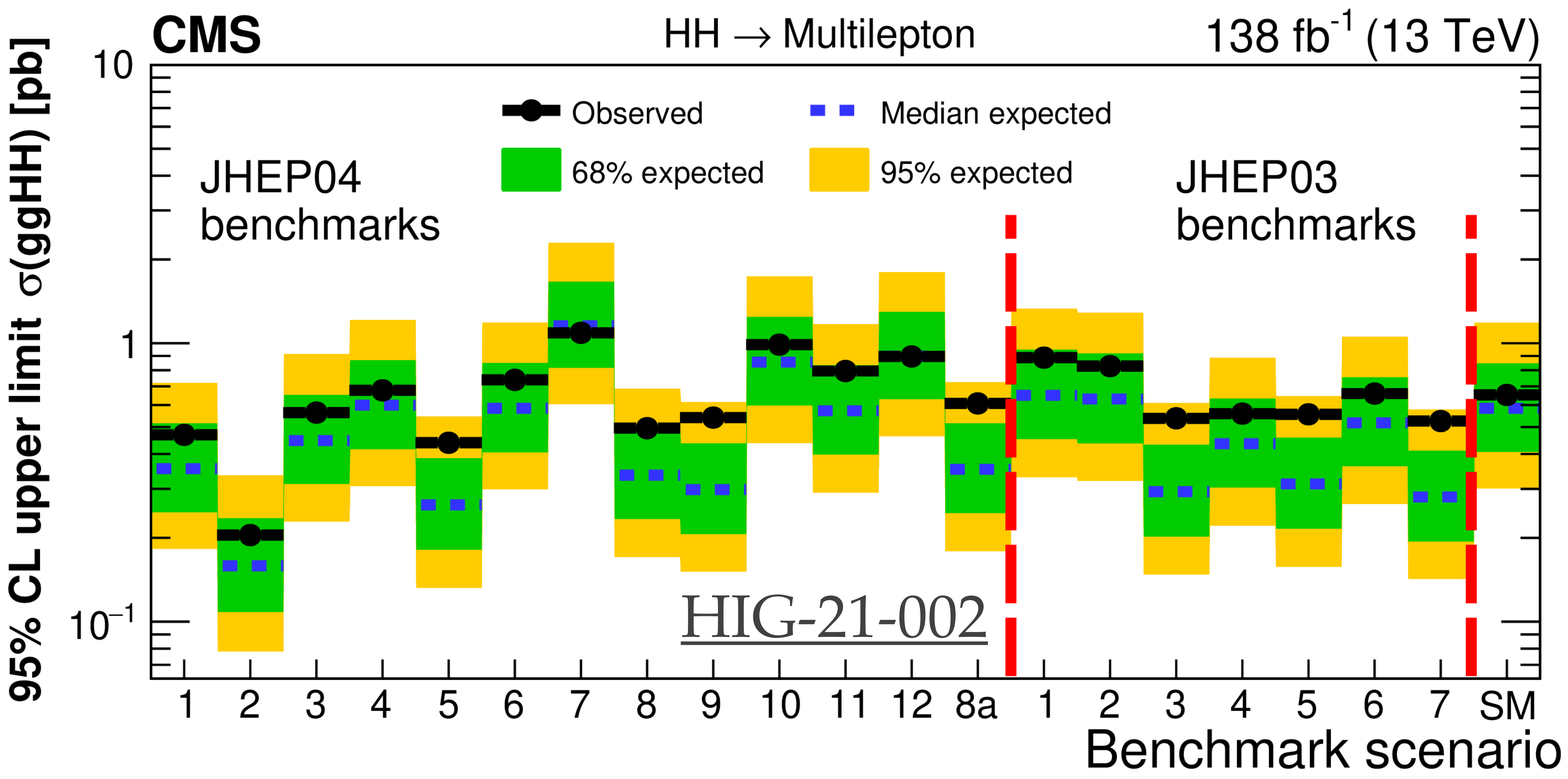
From HH→bbbb analysis



EFTs for diHiggs in CMS



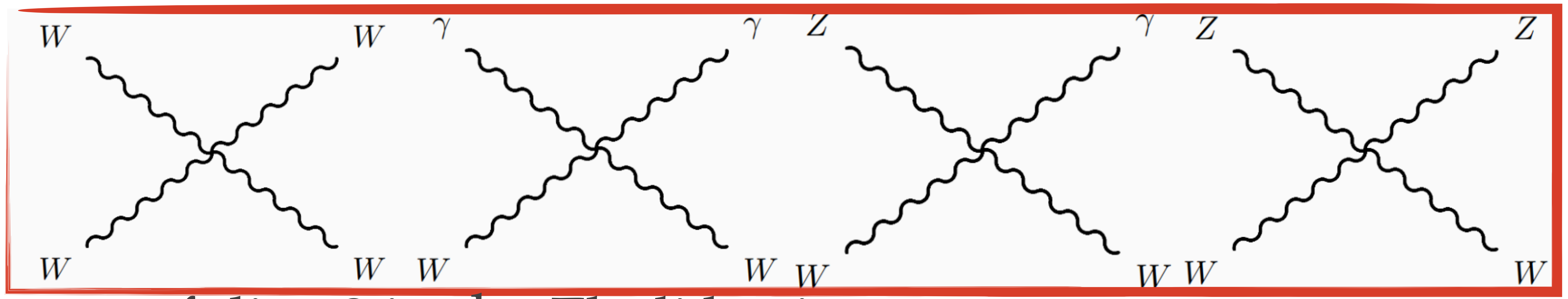




- Upwards fluctuation in the fully hadronic channel of HH→WW$\gamma\gamma$
  - Observed values above the expectation
- More stringent limits on BM2 as it has a pronounced tail of mHH.
- BM7 less stringent limits since it is characterised by low values of mHH

EFTs in the EW sector

- No recent EW measurement testing dimension-6 EFT operators
- Most of them measure triboson production or diboson production in VBS
  - Provide insights to electroweak symmetry breaking
  - The deviations of the QGC appear in dimension-8 operators in the EFT expansion

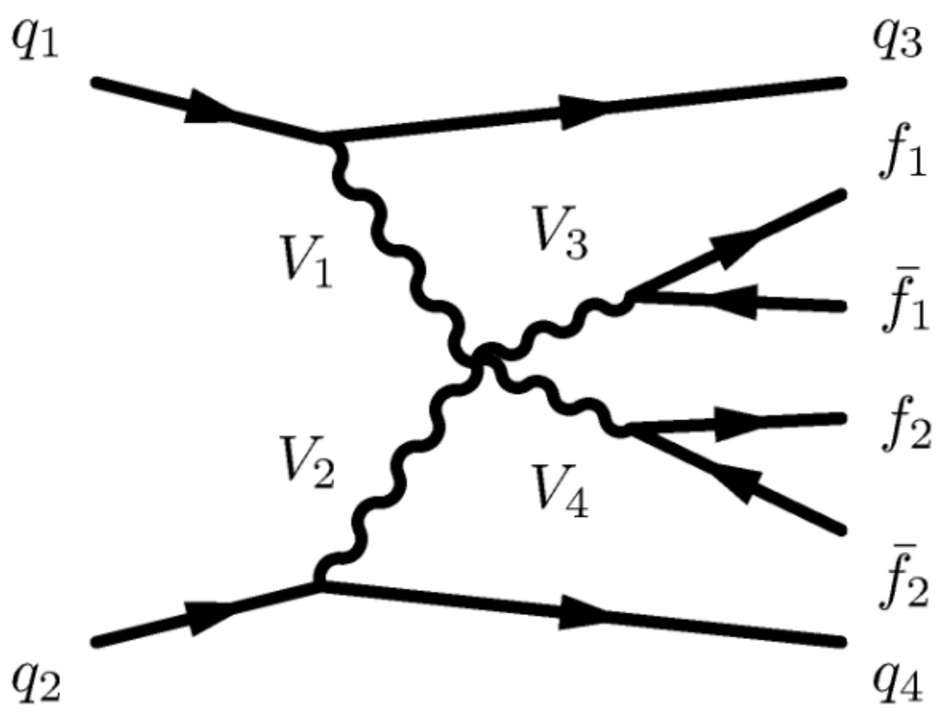


Only two examples provided, but many other results in Despoina's talk

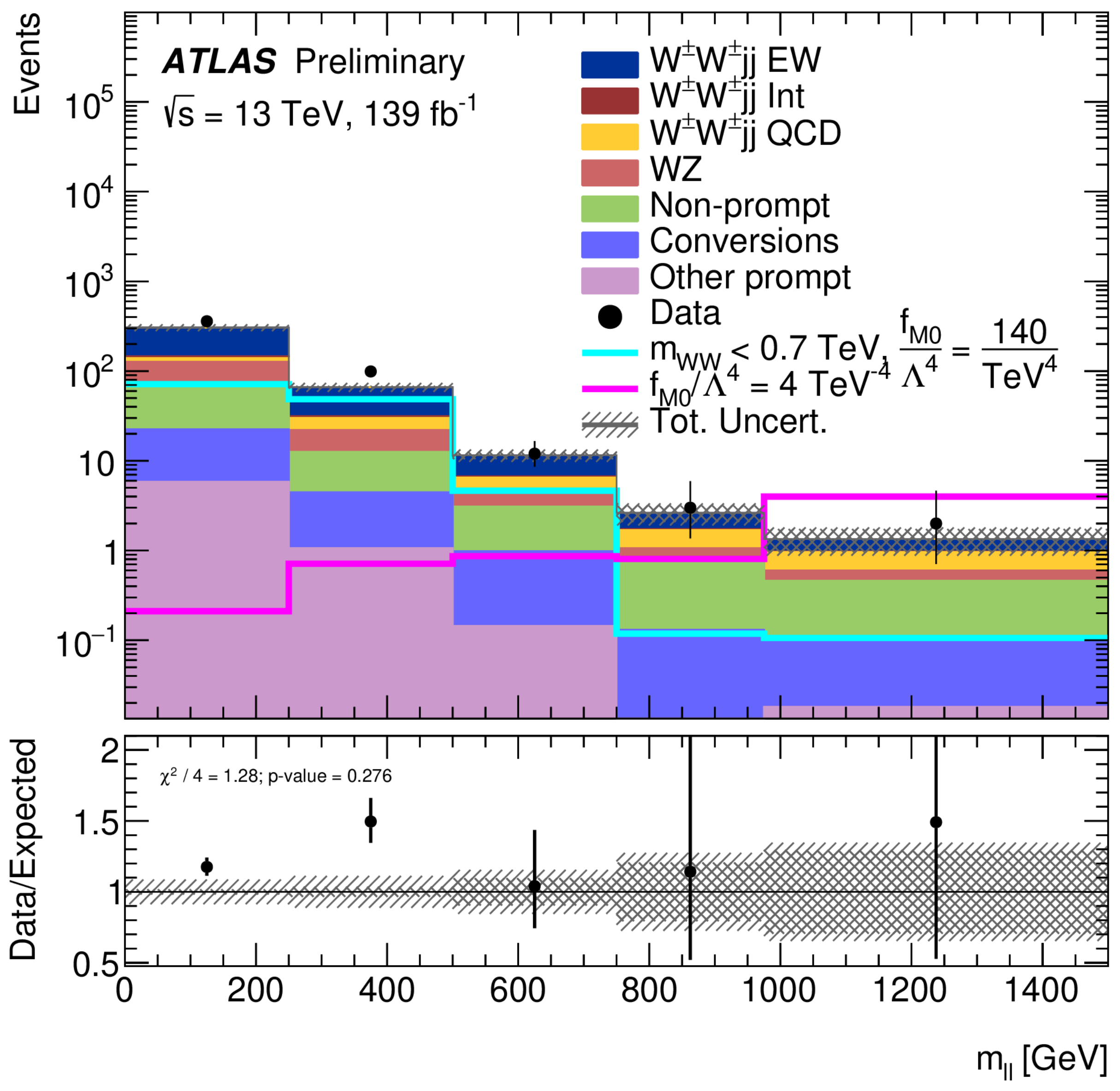
- 3 groups of operators of dim-8 in the Eboli basis
  - Operators with 4 covariant derivatives of the Higgs field ($\mathcal{O}_{\mathrm{S}0,1,2}$)
  - Operators with 2 covariant derivatives of the Higgs field and 2 field strength tensors ($\mathcal{O}_{\mathrm{M}0,1,2,3,4,5,6,7}$)
  - Operators with 4 field strength tensors ($\mathcal{O}_{\mathrm{T}0,1,2,3,4,5,6,7,8,9}$)

ssWW in ATLAS

ATLAS-CONF-2023-023

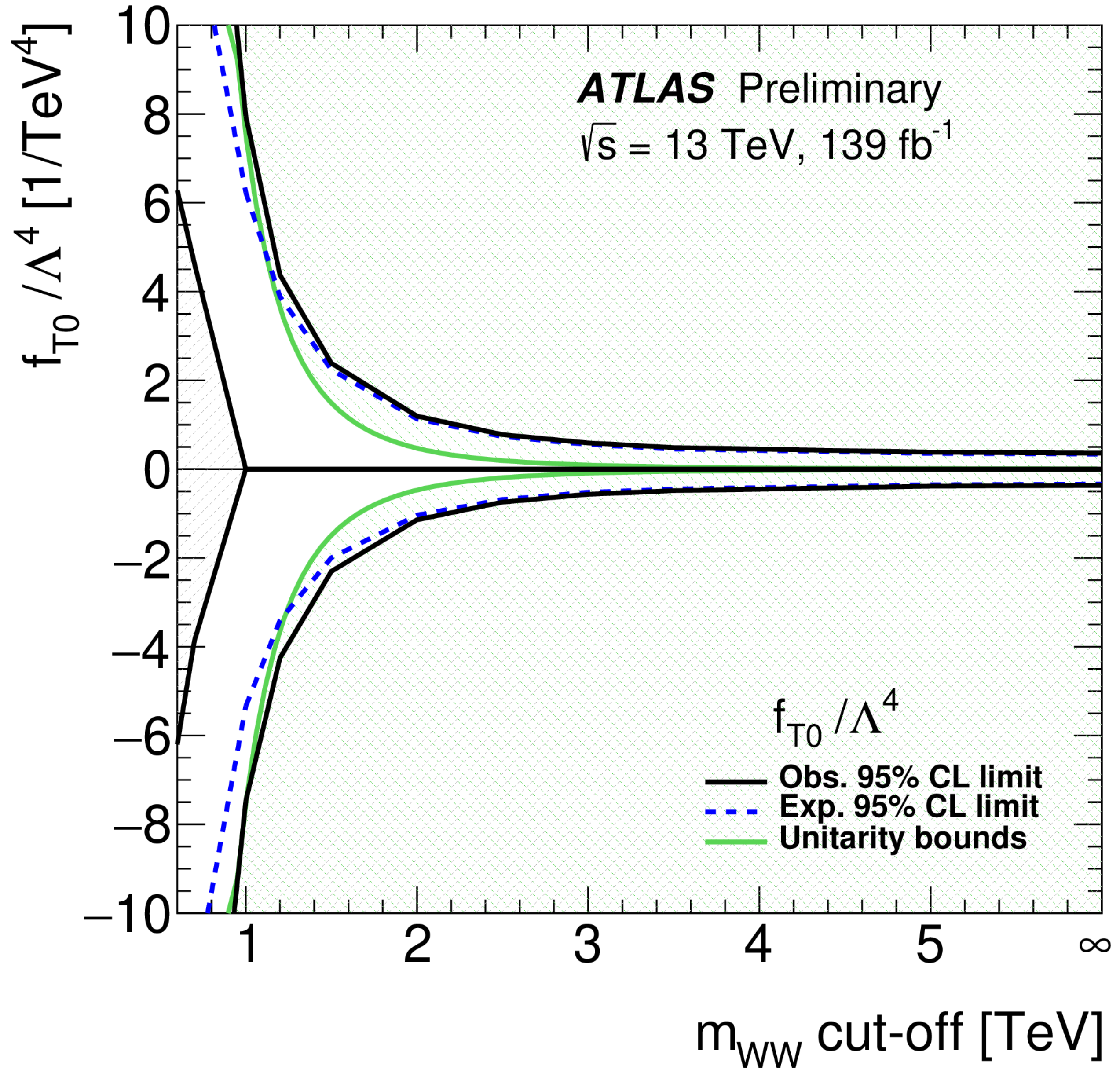


- Fiducial and differential cross section of the EW and inclusive production of ssWW in association with two jets in a VBS topology $m_{jj} > 500$ GeV, $|\Delta\eta_{jj}|>2$
- Unfolded differential mll distribution with optimised binning for EFT interpretation
- Tree-level unitarity violated at sufficiently large scales: clipping technique
  - Intersection between unitarity bounds from analytical formula and scan for limits as a function of Mcut-off with no EFT beyond the Mcut-off scale



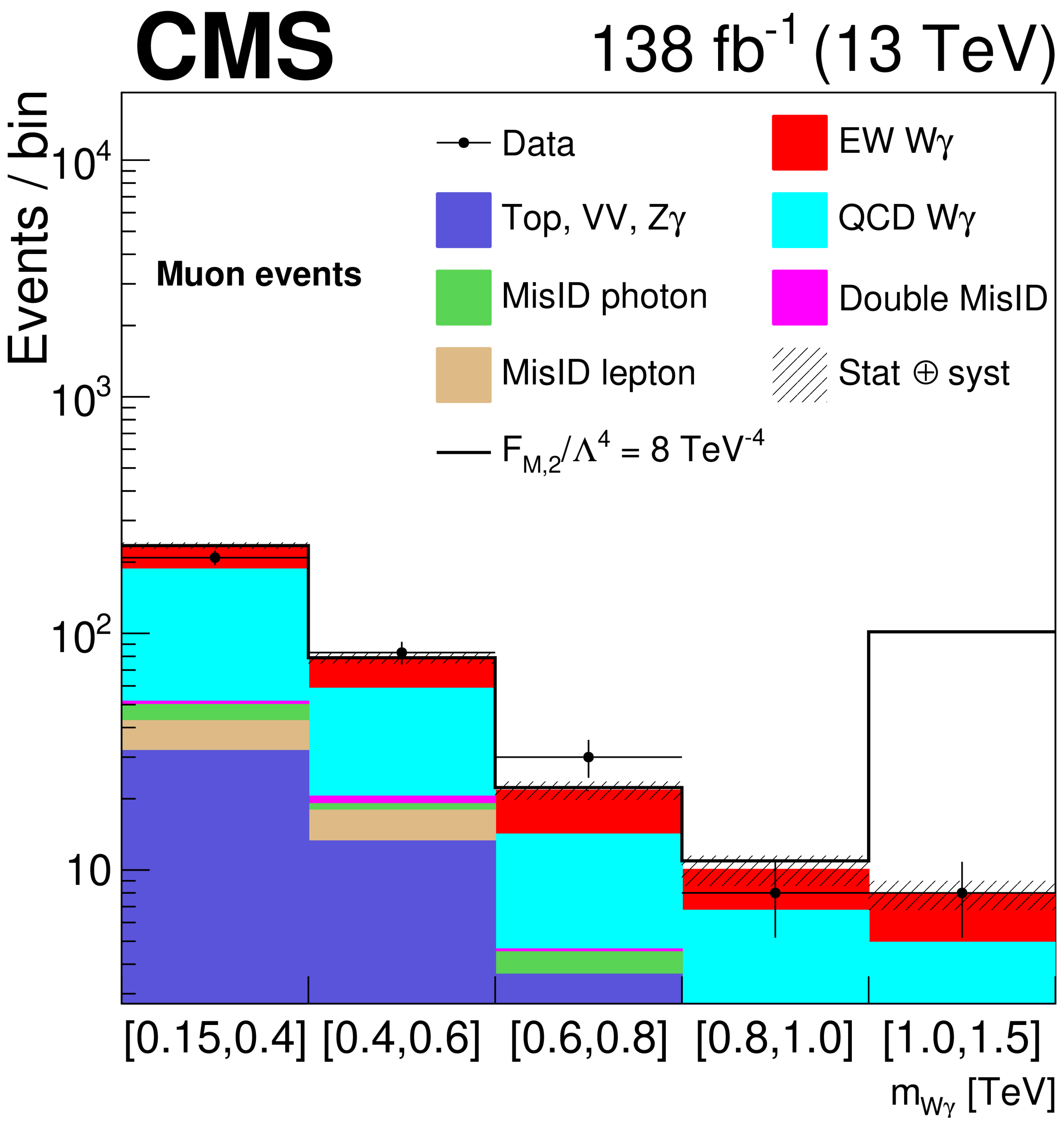
Coefficient	Type	No unitarisation cut-off [TeV^{-4}]	Lower and upper limit at the respective unitarity bound [TeV^{-4}]
f_{M0}/Λ^4	exp.	[-3.9, 3.8]	-64 at 0.9 TeV, 40 at 1.0 TeV
	obs.	[-4.1, 4.1]	-140 at 0.7 TeV, 117 at 0.8 TeV
f_{M1}/Λ^4	exp.	[-6.3, 6.6]	-25.5 at 1.6 TeV, 31 at 1.5 TeV
	obs.	[-6.8, 7.0]	-45 at 1.4 TeV, 54 at 1.3 TeV
f_{M7}/Λ^4	exp.	[-9.3, 8.8]	-33 at 1.8 TeV, 29.1 at 1.8 TeV
	obs.	[-9.8, 9.5]	-39 at 1.7 TeV, 42 at 1.7 TeV
f_{S02}/Λ^4	exp.	[-5.5, 5.7]	-94 at 0.8 TeV, 122 at 0.7 TeV
	obs.	[-5.9, 5.9]	–
f_{S1}/Λ^4	exp.	[-22.0, 22.5]	–
	obs.	[-23.5, 23.6]	–
f_{T0}/Λ^4	exp.	[-0.34, 0.34]	-3.2 at 1.2 TeV, 4.9 at 1.1 TeV
	obs.	[-0.36, 0.36]	-7.4 at 1.0 TeV, 12.4 at 0.9 TeV
f_{T1}/Λ^4	exp.	[-0.158, 0.174]	-0.32 at 2.6 TeV, 0.44 at 2.4 TeV
	obs.	[-0.174, 0.186]	-0.38 at 2.5 TeV, 0.49 at 2.4 TeV
f_{T2}/Λ^4	exp.	[-0.56, 0.70]	-2.60 at 1.7 TeV, 10.3 at 1.2 TeV
	obs.	[-0.63, 0.74]	–

Competitive with limits reported by CMS

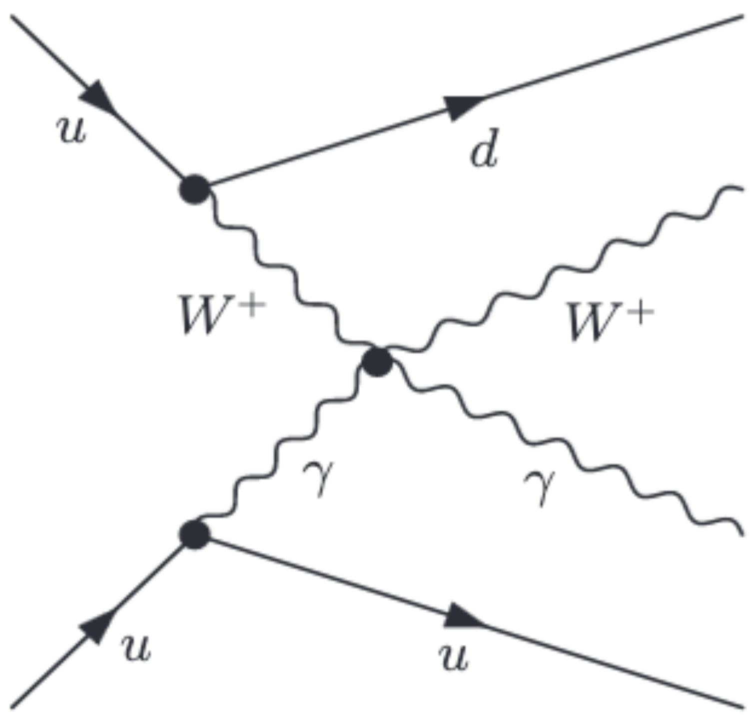


Wγ VBS (CMS)

SMP-21-011



- Measurement of the EW production of Wγ in association with two jets in VBS topology $m_{jj} > 500$ GeV, $|\Delta\eta_{jj}| > 2.1$
- $m_{W\gamma}$ used to extract aQGCs limits at the same time as the SM EW Wγjj in a phase -space with enhanced aQGC sensitivity
  - Expected negligible impact from NLO EW corrections (not included)



Expected limit	Observed limit	U_{bound}
$-5.1 < f_{M,0}/\Lambda^4 < 5.1$	$-5.6 < f_{M,0}/\Lambda^4 < 5.5$	1.7
$-7.1 < f_{M,1}/\Lambda^4 < 7.4$	$-7.8 < f_{M,1}/\Lambda^4 < 8.1$	2.1
$-1.8 < f_{M,2}/\Lambda^4 < 1.8$	$-1.9 < f_{M,2}/\Lambda^4 < 1.9$	2.0
$-2.5 < f_{M,3}/\Lambda^4 < 2.5$	$-2.7 < f_{M,3}/\Lambda^4 < 2.7$	2.7
$-3.3 < f_{M,4}/\Lambda^4 < 3.3$	$-3.7 < f_{M,4}/\Lambda^4 < 3.6$	2.3
$-3.4 < f_{M,5}/\Lambda^4 < 3.6$	$-3.9 < f_{M,5}/\Lambda^4 < 3.9$	2.7
$-13 < f_{M,7}/\Lambda^4 < 13$	$-14 < f_{M7}/\Lambda^4 < 14$	2.2
$-0.43 < f_{T,0}/\Lambda^4 < 0.51$	$-0.47 < f_{T,0}/\Lambda^4 < 0.51$	1.9
$-0.27 < f_{T,1}/\Lambda^4 < 0.31$	$-0.31 < f_{T,1}/\Lambda^4 < 0.34$	2.5
$-0.72 < f_{T,2}/\Lambda^4 < 0.92$	$-0.85 < f_{T,2}/\Lambda^4 < 1.0$	2.3
$-0.29 < f_{T,5}/\Lambda^4 < 0.31$	$-0.31 < f_{T,5}/\Lambda^4 < 0.33$	2.6
$-0.23 < f_{T,6}/\Lambda^4 < 0.25$	$-0.25 < f_{T,6}/\Lambda^4 < 0.27$	2.9
$-0.60 < f_{T,7}/\Lambda^4 < 0.68$	$-0.67 < f_{T,7}/\Lambda^4 < 0.73$	3.1

Most stringent limits in highlighted coefficients

Summary

- EFT is a powerful tool to search for deviations from the Standard model in measurements
- It has become ubiquitous in publications from ATLAS and CMS
- Constraints found on the values of the Wilson coefficients are compatible with the SM (c_i=0)
- Single measurements can typically allow to constraint one coefficient at a time or, at most, measure a subset of them (or combinations) simultaneously
- The full EFT space can only be covered in global EFT fits of EW + top + Higgs + … data
    - See talk from Hannes on Wednesday about challenges on these fits

Thanks!

Back-up

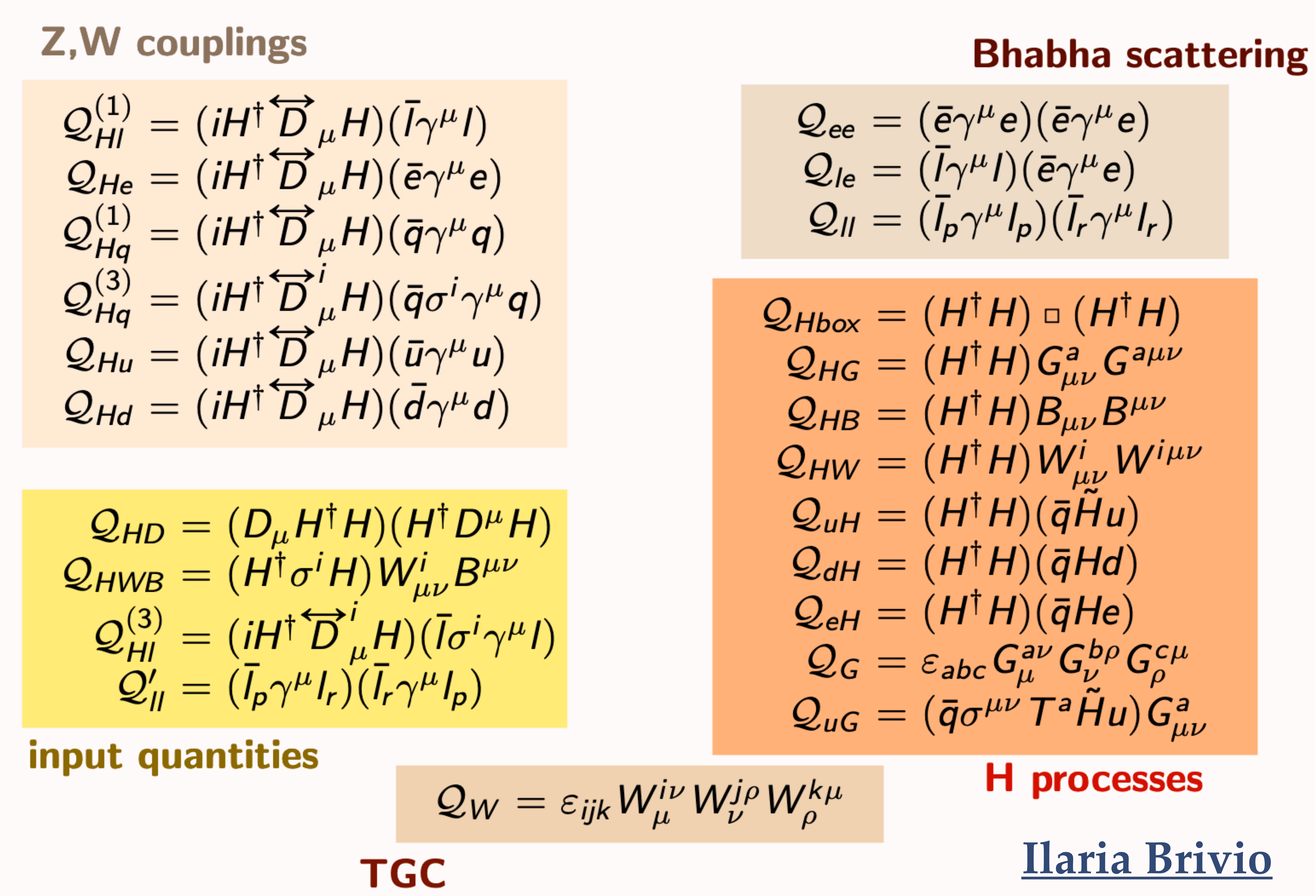
Dimension of EFT operators

- The first term of the SMEFT expansions come from operators or dimension 6
- Up to flavour indices only one dimension 5 operator, the Weinberg operator
  - Introduce neutrino masses (given the constraints, the cut off scale should be extremely large)

$$\overline{l_L^c}\tilde{\phi}^*\tilde{\phi}^\dagger l_L$$

- In general, odd-dimension operators can break lepton or barion number conservation

Some operators in the Warsaw basis



Z,W couplings

$$\begin{aligned}
\mathcal{Q}_{Hl}^{(1)} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{l}\gamma^\mu l)\\
\mathcal{Q}_{He} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}\gamma^\mu e)\\
\mathcal{Q}_{Hq}^{(1)} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}\gamma^\mu q)\\
\mathcal{Q}_{Hq}^{(3)} &= (iH^\dagger \overleftrightarrow{D}^i_\mu H)(\bar{q}\sigma^i\gamma^\mu q)\\
\mathcal{Q}_{Hu} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}\gamma^\mu u)\\
\mathcal{Q}_{Hd} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}\gamma^\mu d)
\end{aligned}$$

Bhabha scattering

$$\begin{aligned}
\mathcal{Q}_{ee} &= (\bar{e}\gamma^\mu e)(\bar{e}\gamma^\mu e)\\
\mathcal{Q}_{le} &= (\bar{l}\gamma^\mu l)(\bar{e}\gamma^\mu e)\\
\mathcal{Q}_{ll} &= (\bar{l}_p\gamma^\mu l_p)(\bar{l}_r\gamma^\mu l_r)
\end{aligned}$$

$$\begin{aligned}
\mathcal{Q}_{HD} &= (D_\mu H^\dagger H)(H^\dagger D^\mu H)\\
\mathcal{Q}_{HWB} &= (H^\dagger\sigma^i H)W^i_{\mu\nu}B^{\mu\nu}\\
\mathcal{Q}_{Hl}^{(3)} &= (iH^\dagger \overleftrightarrow{D}^i_\mu H)(\bar{l}\sigma^i\gamma^\mu l)\\
\mathcal{Q}'_{ll} &= (\bar{l}_p\gamma^\mu l_r)(\bar{l}_r\gamma^\mu l_p)
\end{aligned}$$

input quantities

$$\begin{aligned}
\mathcal{Q}_{Hbox} &= (H^\dagger H)\,\Box\,(H^\dagger H)\\
\mathcal{Q}_{HG} &= (H^\dagger H)G^a_{\mu\nu}G^{a\mu\nu}\\
\mathcal{Q}_{HB} &= (H^\dagger H)B_{\mu\nu}B^{\mu\nu}\\
\mathcal{Q}_{HW} &= (H^\dagger H)W^i_{\mu\nu}W^{i\mu\nu}\\
\mathcal{Q}_{uH} &= (H^\dagger H)(\bar{q}\tilde{H}u)\\
\mathcal{Q}_{dH} &= (H^\dagger H)(\bar{q}Hd)\\
\mathcal{Q}_{eH} &= (H^\dagger H)(\bar{q}He)\\
\mathcal{Q}_{G} &= \varepsilon_{abc}G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho\\
\mathcal{Q}_{uG} &= (\bar{q}\sigma^{\mu\nu}T^a\tilde{H}u)G^a_{\mu\nu}
\end{aligned}$$

$$\mathcal{Q}_W = \varepsilon_{ijk}W^{i\nu}_\mu W^{j\rho}_\nu W^{k\mu}_\rho$$

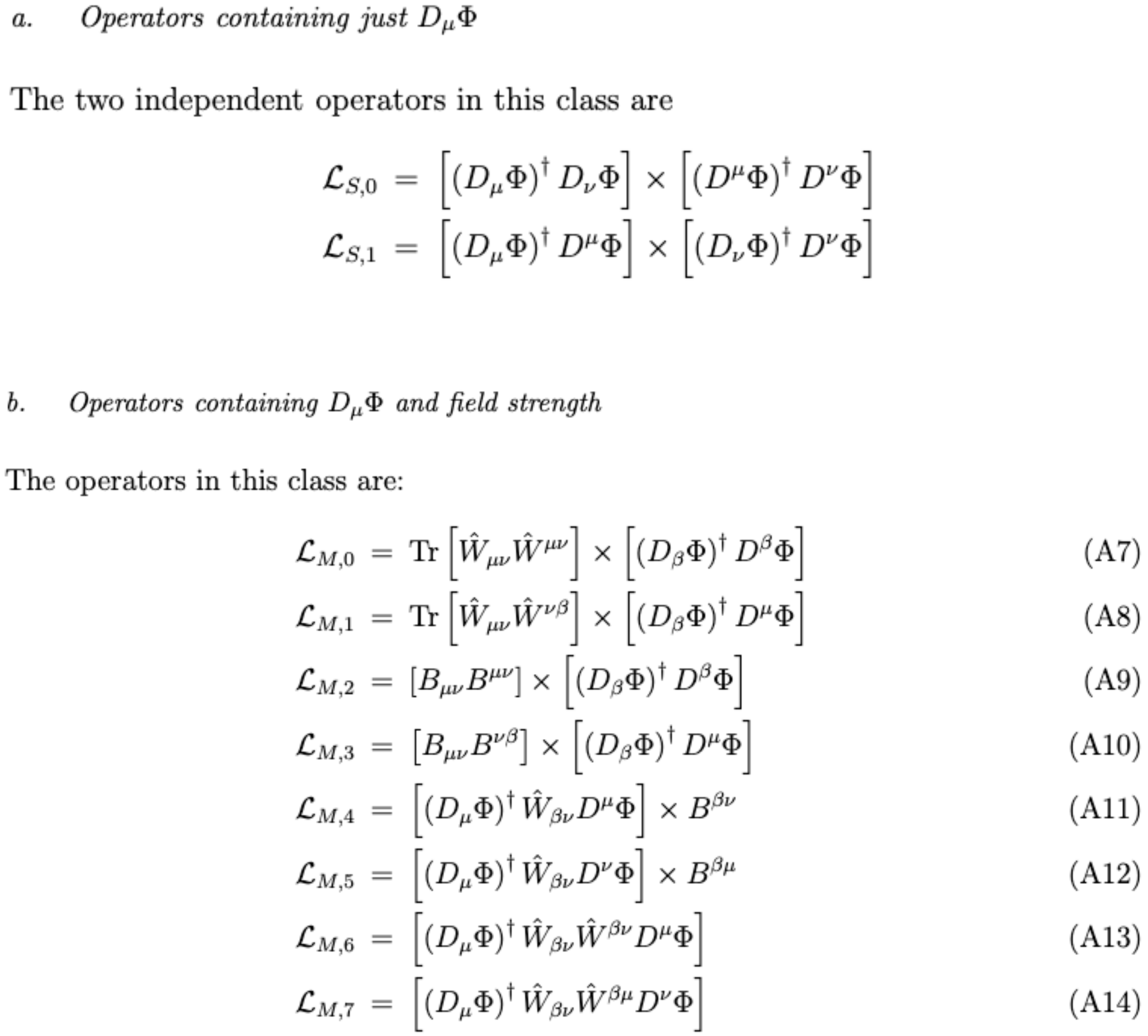
H processes

TGC

Ilaria Brivio

Common input schemes:
→ (mW,mZ,GF)
→ (α, mZ, GF)

Operators in the Eboli basis



a. Operators containing just $D_\mu\Phi$

The two independent operators in this class are

$$\mathcal{L}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$

$$\mathcal{L}_{S,1} = \left[(D_\mu\Phi)^\dagger D^\mu\Phi\right] \times \left[(D_\nu\Phi)^\dagger D^\nu\Phi\right]$$

b. Operators containing $D_\mu\Phi$ and field strength

The operators in this class are:

$$\mathcal{L}_{M,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right] \quad \text{(A7)}$$

$$\mathcal{L}_{M,1} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right] \quad \text{(A8)}$$

$$\mathcal{L}_{M,2} = \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right] \quad \text{(A9)}$$

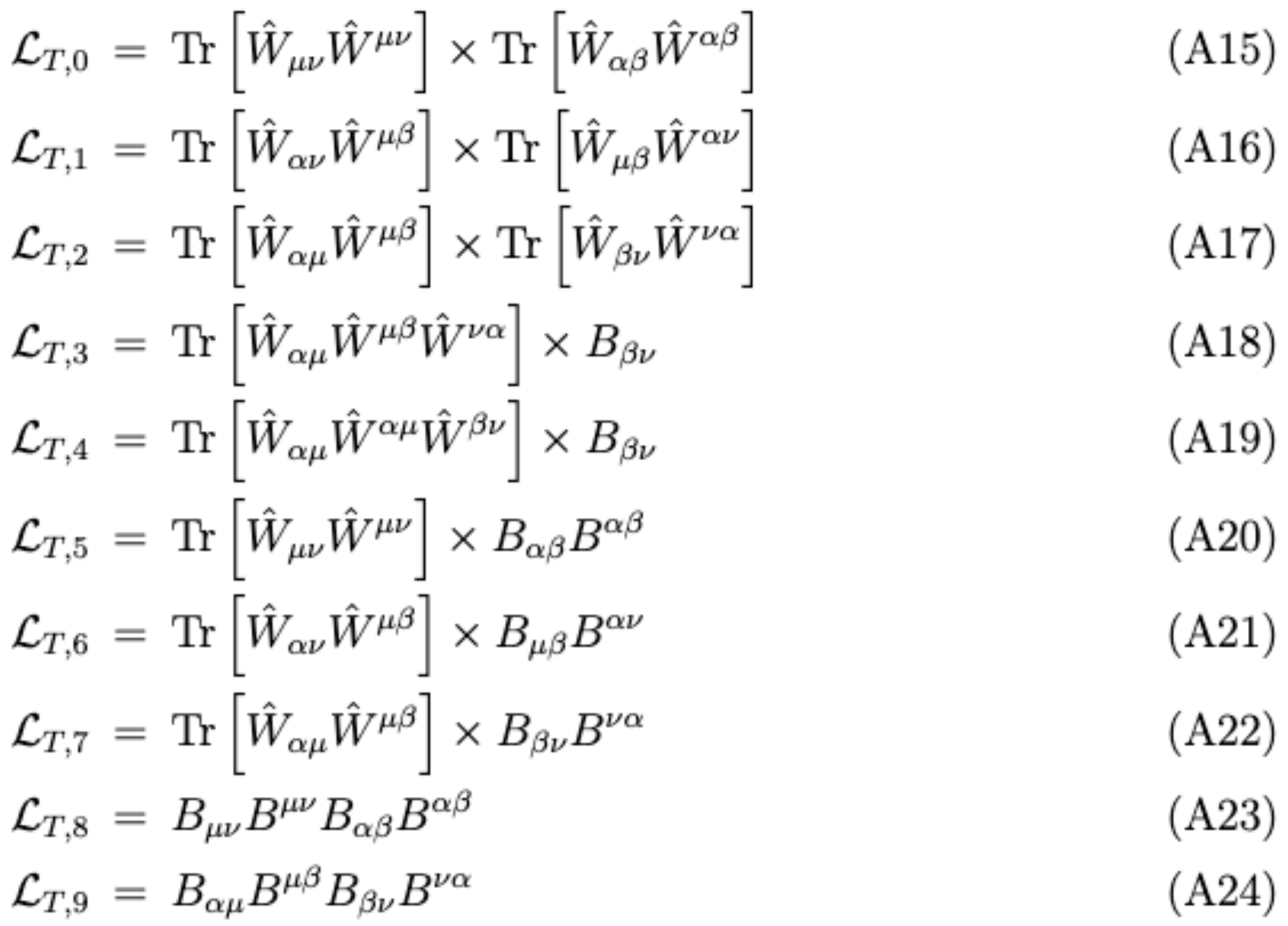
$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right] \quad \text{(A10)}$$

$$\mathcal{L}_{M,4} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\mu\Phi\right] \times B^{\beta\nu} \quad \text{(A11)}$$

$$\mathcal{L}_{M,5} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\nu\Phi\right] \times B^{\beta\mu} \quad \text{(A12)}$$

$$\mathcal{L}_{M,6} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\nu} D^\mu\Phi\right] \quad \text{(A13)}$$

$$\mathcal{L}_{M,7} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\mu} D^\nu\Phi\right] \quad \text{(A14)}$$



$$\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right] \quad \text{(A15)}$$

$$\mathcal{L}_{T,1} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}\right] \quad \text{(A16)}$$

$$\mathcal{L}_{T,2} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}\right] \quad \text{(A17)}$$

$$\mathcal{L}_{T,3} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\hat{W}^{\nu\alpha}\right] \times B_{\beta\nu} \quad \text{(A18)}$$

$$\mathcal{L}_{T,4} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\alpha\mu}\hat{W}^{\beta\nu}\right] \times B_{\beta\nu} \quad \text{(A19)}$$

$$\mathcal{L}_{T,5} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times B_{\alpha\beta}B^{\alpha\beta} \quad \text{(A20)}$$

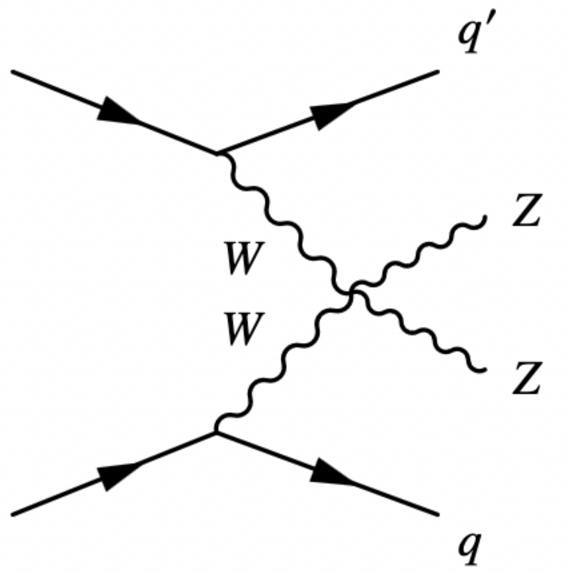
$$\mathcal{L}_{T,6} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times B_{\mu\beta}B^{\alpha\nu} \quad \text{(A21)}$$

$$\mathcal{L}_{T,7} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times B_{\beta\nu}B^{\nu\alpha} \quad \text{(A22)}$$

$$\mathcal{L}_{T,8} = B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta} \quad \text{(A23)}$$

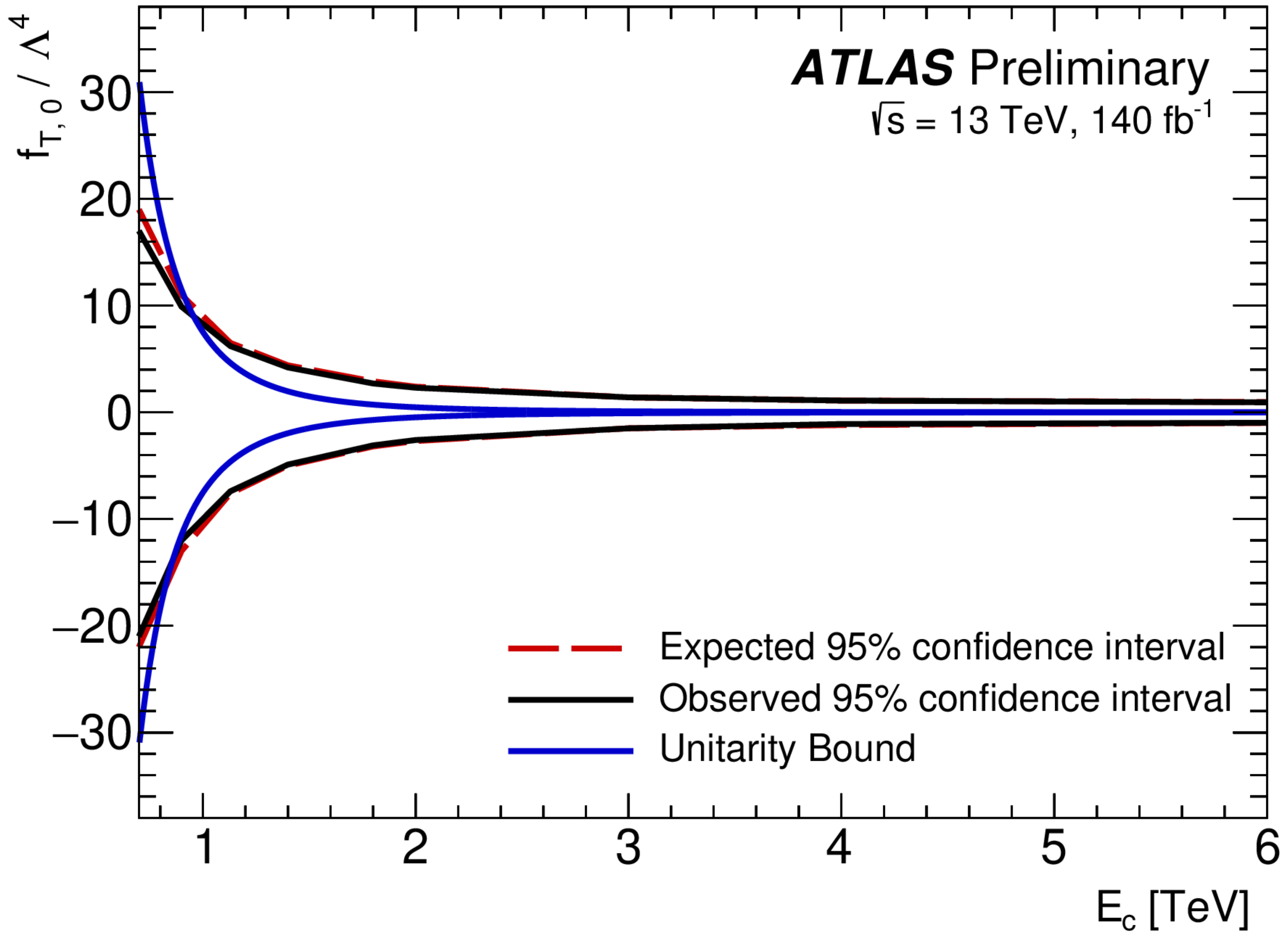
$$\mathcal{L}_{T,9} = B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha} \quad \text{(A24)}$$

4l VBS (ATLAS)



- Differential cross section of the production of 4 charged leptons in association with two jets in a VBS-suppressed and a VBS-enhanced (separated by 4l system centrality)
- Unfolded differential distributions of m_{4l} and m_{ll} used for EFT interpretation
- Most stringent constraints to the WCs associated with $\mathcal{O}_{T0}$ and $\mathcal{O}_{T1}$ operators

- Constraints for EFT effects in $m_{4l} < E_c$
  - 95%C.L reduce by a factor 4-5 for $E_c=\infty$ or $E_c=1$ TeV

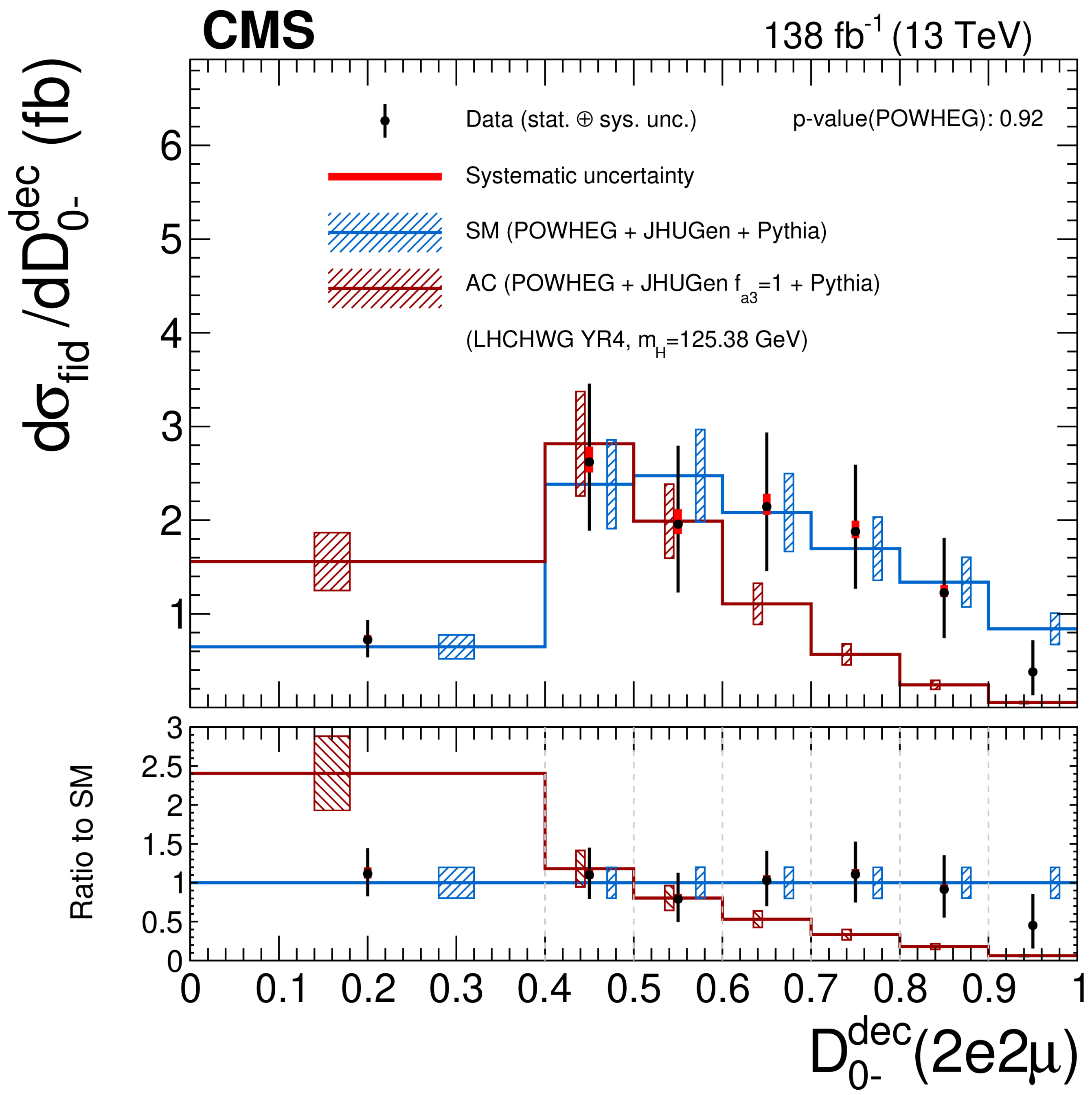


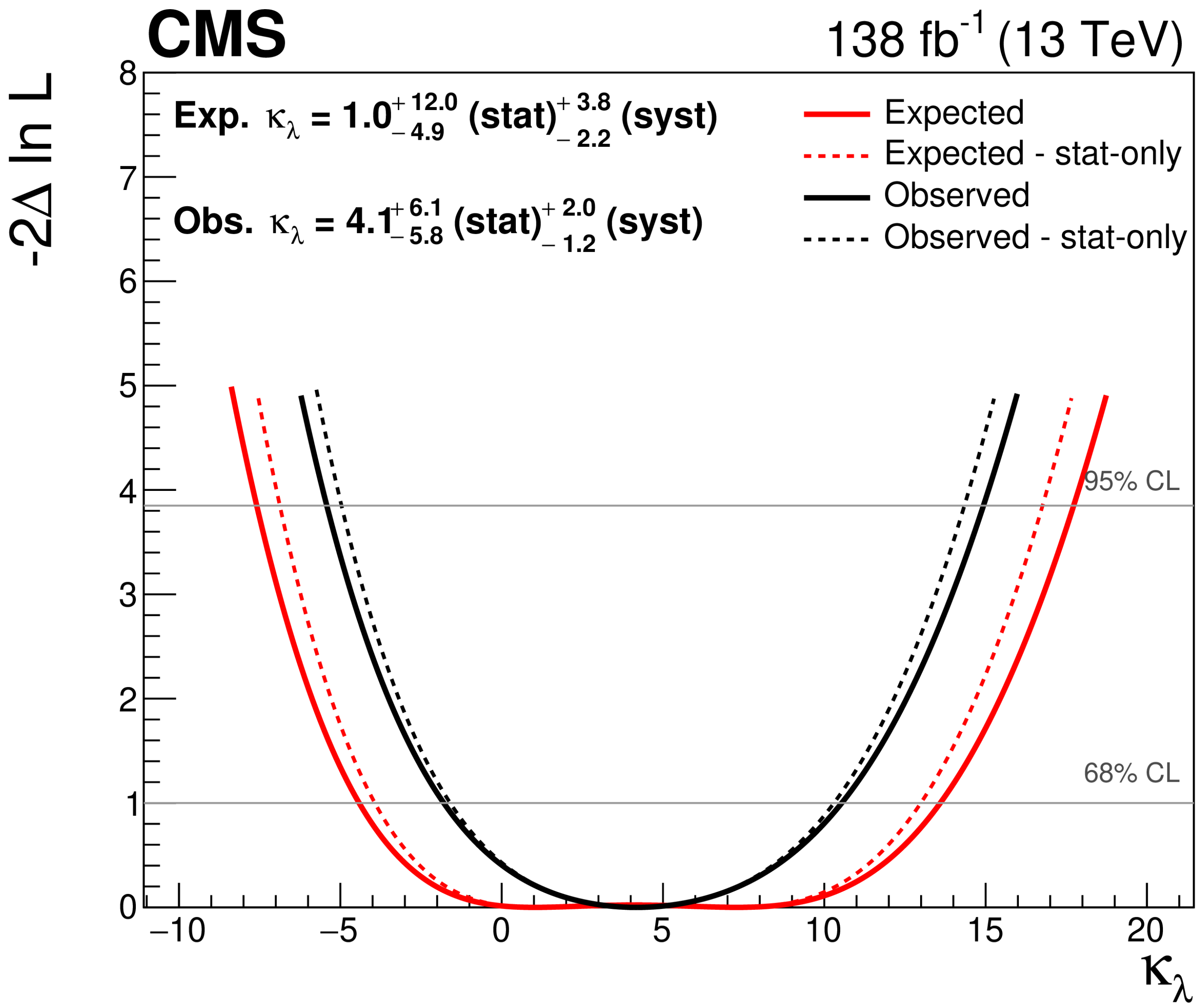
Wilson coefficient	$\lvert\mathcal{M}_{d8}\rvert^2$ Included	95% confidence interval [TeV^{-4}]	
		Expected	Observed
$f_{T,0}/\Lambda^4$	yes	[-0.98,0.93]	[-1.0,0.97]
	no	[-23, 17]	[-19, 19]
$f_{T,1}/\Lambda^4$	yes	[-1.2, 1.2]	[-1.3, 1.3]
	no	[-160, 120]	[-140, 140]
$f_{T,2}/\Lambda^4$	yes	[-2.5, 2.4]	[-2.6, 2.5]
	no	[-74, 56]	[-63, 62]
$f_{T,5}/\Lambda^4$	yes	[-2.5, 2.4]	[-2.6, 2.5]
	no	[-79, 60]	[-68, 67]
$f_{T,6}/\Lambda^4$	yes	[-3.9, 3.9]	[-4.1, 4.1]
	no	[-64, 48]	[-55, 54]
$f_{T,7}/\Lambda^4$	yes	[-8.5, 8.1]	[-8.8, 8.4]
	no	[-260, 200]	[-220, 220]
$f_{T,8}/\Lambda^4$	yes	[-2.1, 2.1]	[-2.2, 2.2]
	no	[-4.6, 3.1]$\times10^4$	[-3.9, 3.8]$\times10^4$
$f_{T,9}/\Lambda^4$	yes	[-4.5, 4.5]	[-4.7, 4.7]
	no	[-7.5, 5.5]$\times10^4$	[-6.4, 6.3]$\times10^4$

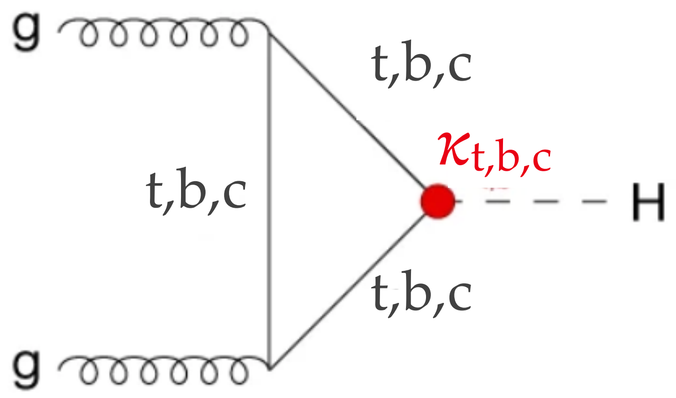
H→4l differential cross sections

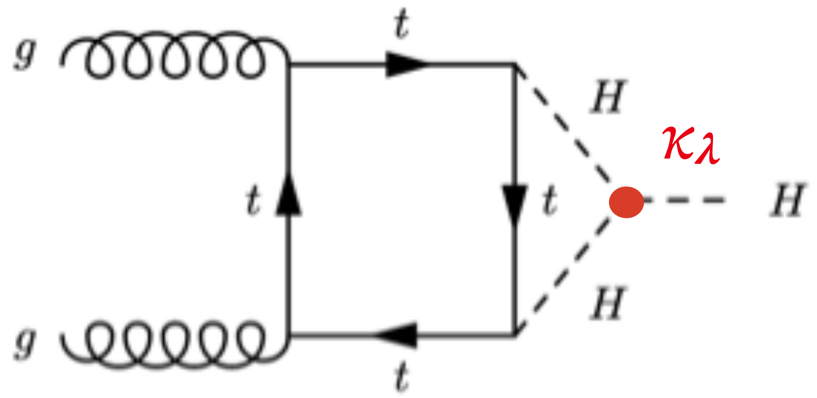
HIG-21-009

- Complete characterisation of the Higgs boson in the H→4l decay channel using fiducial cross sections
  - Many different observables explored including matrix element discriminants sensitive to anomalous HVV couplings
  - Interpretations in terms of kappa modifiers using the pTH spectrum









- $\kappa\lambda$ only enters in single Higgs production through EW corrections
  - But compatible with other diHiggs limits

$$-5.4\,(-7.6) < \kappa_\lambda < 14.9\,(17.7)$$

$$-1.1\,(-1.3) < \kappa_b < 1.1\,(1.2)$$
$$-5.3\,(-5.7) < \kappa_c < 5.2\,(5.7),$$

Assuming dependency on $\kappa_{b,c}$ in the branching ratio