Combined EFT interpretation of ATLAS Higgs measurements

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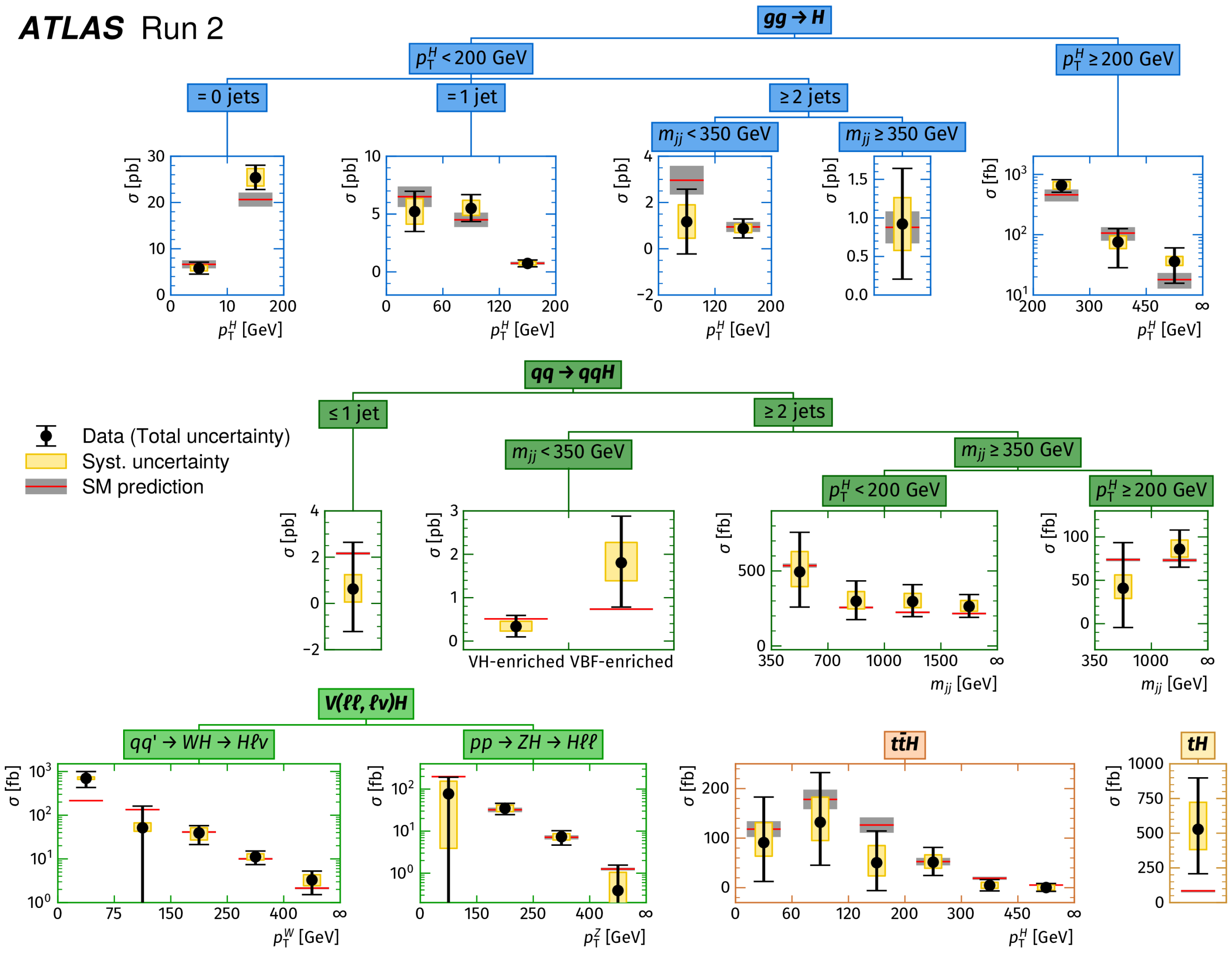
Higgs measurement

- The Nature paper presents the most precise measurement of Higgs property up to now
- Simplified Template cross-section (STXS) binning gives more information than inclusive measurement, which gives stronger constraints on EFT parameter space

A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery

The ATLAS Collaboration



SMEFT operators

- SMEFT: extension of SM by adding higher-dimensional operators built upon SM fields

Wilson coefficient

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i}^{N_{d=6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_{j}^{N_{d=8}} \frac{b_j}{\Lambda^4} \mathcal{O}_j^{(8)} + \ldots,$$

- Warsaw basis used: complete set of d=6 operators, assuming $\Lambda = 1$ TeV
- 'Top' flavor scheme:

$$U(2)_q \times U(2)_u \times U(2)_d \times U(1)_e \times U(1)_\mu \times U(1)_\tau$$

  - First two generation quarks treated similarly
  - All lepton generations separately
  - 204 CP-even operators, 50 related to higgs measurement considered in this analysis

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}	$\left(H^\dagger D^\mu H\right)^* \left(H^\dagger D_\mu H\right)$
c_{HG}	$H^\dagger H\, G_{\mu\nu}^A G^{A\mu\nu}$
c_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
c_{HW}	$H^\dagger H\, W_{\mu\nu}^I W^{I\mu\nu}$
c_{HWB}	$H^\dagger \tau^I H\, W_{\mu\nu}^I B^{\mu\nu}$
$c_{Hl,11}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_1 \gamma^\mu l_1)$
$c_{Hl,22}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_2 \gamma^\mu l_2)$
$c_{Hl,33}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_3 \gamma^\mu l_3)$
$c_{Hl,11}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{l}_1 \tau^I \gamma^\mu l_1)$
$c_{Hl,22}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{l}_2 \tau^I \gamma^\mu l_2)$
$c_{Hl,33}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{l}_3 \tau^I \gamma^\mu l_3)$
$c_{He,11}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_1 \gamma^\mu e_1)$
$c_{He,22}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_2 \gamma^\mu e_2)$
$c_{He,33}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_3 \gamma^\mu e_3)$
$c_{Hq}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q} \gamma^\mu q)$
$c_{Hq}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{q} \tau^I \gamma^\mu q)$
c_{Hu}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
c_{Hd}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
$c_{HQ}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{Q} \gamma^\mu Q)$
$c_{HQ}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{Q} \tau^I \gamma^\mu Q)$
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
$c_{Qq}^{(1,1)}$	$(\bar{Q}\gamma_\mu Q)(\bar{q}\gamma^\mu q)$
$c_{Qq}^{(1,8)}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{q}T^a\gamma^\mu q)$
$c_{Qq}^{(3,1)}$	$(\bar{Q}\sigma^i\gamma_\mu Q)(\bar{q}\sigma^i\gamma^\mu q)$
$c_{Qq}^{(3,8)}$	$(\bar{Q}\sigma^i T^a\gamma_\mu Q)(\bar{q}\sigma^i T^a\gamma^\mu q)$
$c_{qq}^{(3,1)}$	$(\bar{q}\sigma^i\gamma_\mu q)(\bar{q}\sigma^i\gamma^\mu q)$
$c_{tu}^{(1)}$	$(\bar{t}\gamma_\mu t)(\bar{u}\gamma^\mu u)$
$c_{tu}^{(8)}$	$(\bar{t}T^a\gamma_\mu t)(\bar{u}T^a\gamma^\mu u)$
$c_{td}^{(1)}$	$(\bar{t}\gamma_\mu t)(\bar{d}\gamma^\mu d)$
$c_{td}^{(8)}$	$(\bar{t}T^a\gamma_\mu t)(\bar{d}T^a\gamma^\mu d)$
$c_{Qu}^{(1)}$	$(\bar{Q}\gamma_\mu Q)(\bar{u}\gamma^\mu u)$
$c_{Qu}^{(8)}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{u}T^a\gamma^\mu u)$
$c_{Qd}^{(1)}$	$(\bar{Q}\gamma_\mu Q)(\bar{d}\gamma^\mu d)$
$c_{Qd}^{(8)}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{d}T^a\gamma^\mu d)$
$c_{tq}^{(1)}$	$(\bar{q}\gamma_\mu q)(\bar{t}\gamma^\mu t)$
$c_{tq}^{(8)}$	$(\bar{q}T^a\gamma_\mu q)(\bar{t}T^a\gamma^\mu t)$
$c_{eH,22}$	$(H^\dagger H)(\bar{l}_2 e_2 H)$
$c_{eH,33}$	$(H^\dagger H)(\bar{l}_3 e_3 H)$
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}	$(\bar{Q}\sigma^{\mu\nu} T^A t)\widetilde{H}\, G_{\mu\nu}^A$
c_{tW}	$(\bar{Q}\sigma^{\mu\nu} t)\tau^I \widetilde{H}\, W_{\mu\nu}^I$
c_{tB}	$(\bar{Q}\sigma^{\mu\nu} t)\widetilde{H}\, B_{\mu\nu}$
$c_{ll,1221}$	$(\bar{l}_1\gamma_\mu l_2)(\bar{l}_2\gamma^\mu l_1)$

Introduction

- EFT & BSM model interpretation using the updated measurement of Higgs boson cross-section and decay rates

Decay channel	Analysis: Production mode	$\mathcal{L}$ [fb^{-1}]	Reference	Binning	SMEFT	2HDM and (h)MSSM
$H \to \gamma\gamma$	(ggF, VBF, WH, ZH, ttH, tH)	139	[24] [20]	STXS-1.2 differential	✓ ✓(subset)	✓
$H \to ZZ^*$	($ZZ^* \to 4\ell$: ggF, VBF, $WH + ZH$, $ttH + tH$)	139	[23] [19]	STXS-1.2 differential	✓ ✓(subset)	✓
	($ZZ^* \to \ell\ell\nu\bar{\nu}/\ell\ell q\bar{q}$: ttH multileptons)	36.1	[35]	STXS-0*		✓
$H \to \tau\tau$	(ggF, VBF, $WH + ZH$, $ttH + tH$)	139	[30]	STXS-1.2	✓	✓
	(ttH multileptons)	36.1	[35]	STXS-0*		✓
$H \to WW^*$	(ggF, VBF)	139	[31]	STXS-1.2	✓	✓
	(WH, ZH)	36.1	[47]	STXS-0*		✓
	(ttH multileptons)	36.1	[35]	STXS-0*		✓
$H \to bb$	(WH, ZH)	139	[25, 26]	STXS-1.2	✓	✓
	(VBF)	126	[27]	STXS-1.2	✓	✓
	($ttH + tH$)	139	[29]	STXS-1.2	✓	✓
	(boosted Higgs bosons: inclusive production)	139	[28]	STXS-1.2	✓	✓
$H \to Z\gamma$	(inclusive production)	139	[32]	STXS-0*	✓	✓
$H \to \mu\mu$	(ggF + ttH + tH, VBF + WH + ZH)	139	[33]	STXS-0*	✓	✓

Parameterization

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

Quadratic term

Linear term

- Linear term: interference between dim-6 operators and SM (Λ^{-2})
- Quadratic term: Pure BSM term, product of two dim-6 operators (Λ^{-4})

- Thus the STXS binning can be parameterized in terms of the Wilson coefficient:

Linear model:

$$\left(\frac{1+\sum_j\left(A_j^{\sigma_{i,k'}}+A_j^{\Gamma^{H\to X}}\right)c_j+O\left(\Lambda^{-4}\right)}{1+\sum_j A_j^{\Gamma^H}c_j+O\left(\Lambda^{-4}\right)}\right)$$

Quadratic model:

$$\left(\frac{1+\sum_j\left(A_j^{\sigma_{i,k'}}+A_j^{\Gamma^{H\to X}}\right)c_j+\sum_{j,l\geq j}\left(B_{jl}^{\sigma_{i,k'}}+B_{jl}^{\Gamma^{H\to X}}+A_j^{\sigma_{i,k'}}A_l^{\Gamma^{H\to X}}+A_l^{\sigma_{i,k'}}A_j^{\Gamma^{H\to X}}\right)c_jc_l+O\left(\Lambda^{-6}\right)}{1+\sum_j\left(A_j^{\Gamma^H}\right)c_j+\sum_{j,l\geq j}\left(B_{jl}^{\Gamma^H}\right)c_jc_l+O\left(\Lambda^{-6}\right)}\right)$$

$$\frac{\sigma^{i,k'}_{\text{int}}}{\sigma^{i,k'}_{\text{SM}}} = \sum_j A_j^{\sigma_{i,k'}}c_j \qquad \frac{\sigma^{i,k'}_{\text{BSM}}}{\sigma^{i,k'}_{\text{SM}}} = \sum_{j,l\geq j} B_{jl}^{\sigma_{i,k'}}c_jc_l$$

$$\frac{\Gamma^{H\to X}_{\text{int}}}{\Gamma^{H\to X}_{\text{SM}}} = \sum_j A_j^{\Gamma^{H\to X}}c_j \qquad \frac{\Gamma^{H\to X}_{\text{BSM}}}{\Gamma^{H\to X}_{\text{SM}}} = \sum_{j,l\geq j} B_{jl}^{\Gamma^{H\to X}}c_jc_l$$

$$\frac{\Gamma^{H}_{\text{int}}}{\Gamma^{H}_{\text{SM}}} = \sum_j A_j^{\Gamma^{H}}c_j \qquad \frac{\Gamma^{H}_{\text{BSM}}}{\Gamma^{H}_{\text{SM}}} = \sum_{j,l\geq j} B_{jl}^{\Gamma^{H}}c_jc_l,$$

with

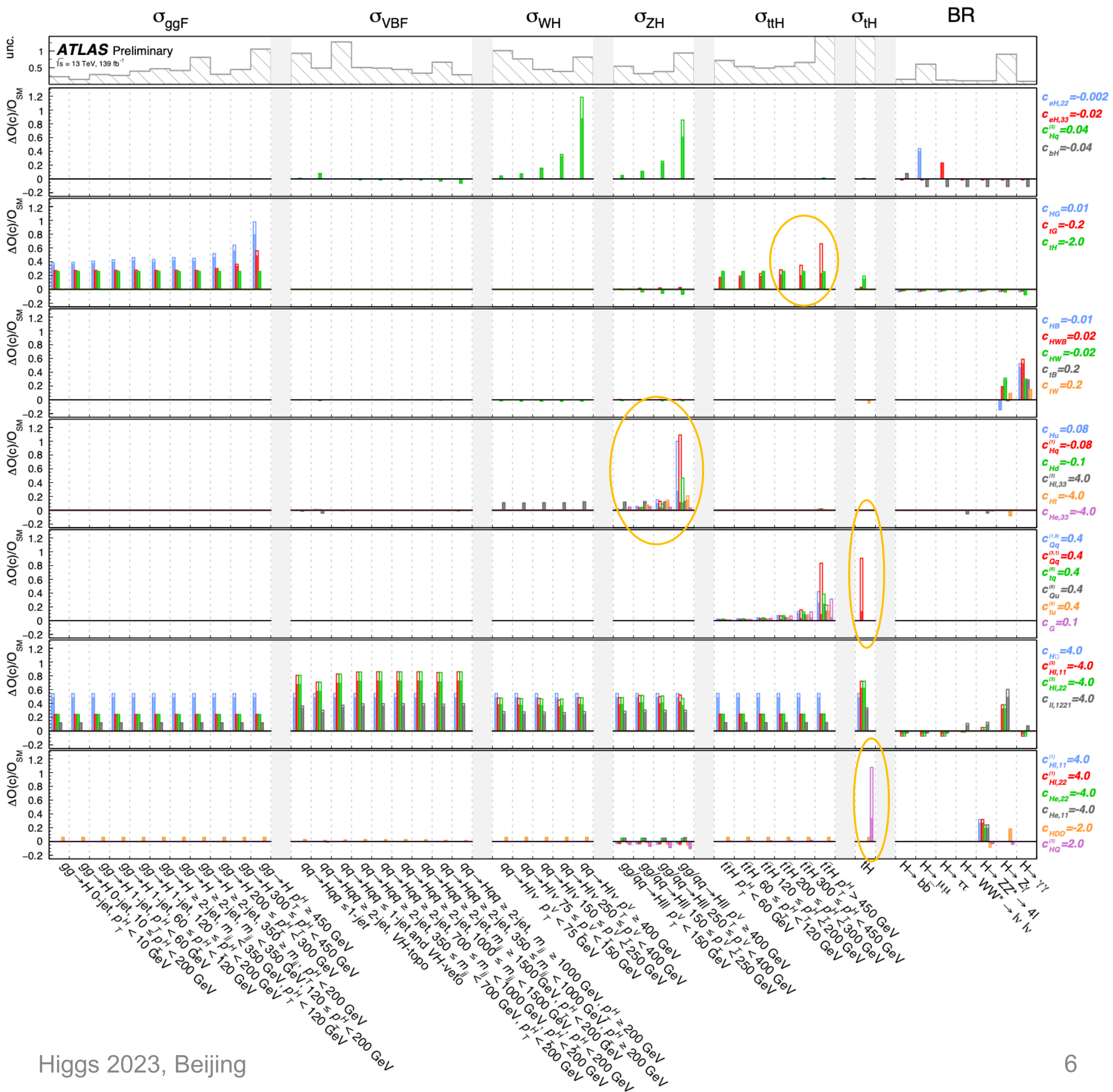
$$A_j^{\Gamma^H} = \frac{\sum_X \Gamma^{H\to X}_{\text{SM}}A_j^{\Gamma^{H\to X}}}{\sum_X \Gamma^{H\to X}_{\text{SM}}} \qquad B_{jl}^{\Gamma^H} = \frac{\sum_X \Gamma^{H\to X}_{\text{SM}}B_{jl}^{\Gamma^{H\to X}}}{\sum_X \Gamma^{H\to X}_{\text{SM}}}.$$

Impact

- Simulation tools:

  `SMEFTsim & SMEFTatNLO`

- The operators' impact on background is not simulated as they are considered to small and the backgrounds are constrained well by Control Regions
- Contribution shown in right plot:
- Linear model in filled bars
- Linear+quadratic in open bars
- ZH and tH are significantly affected by quadratic term

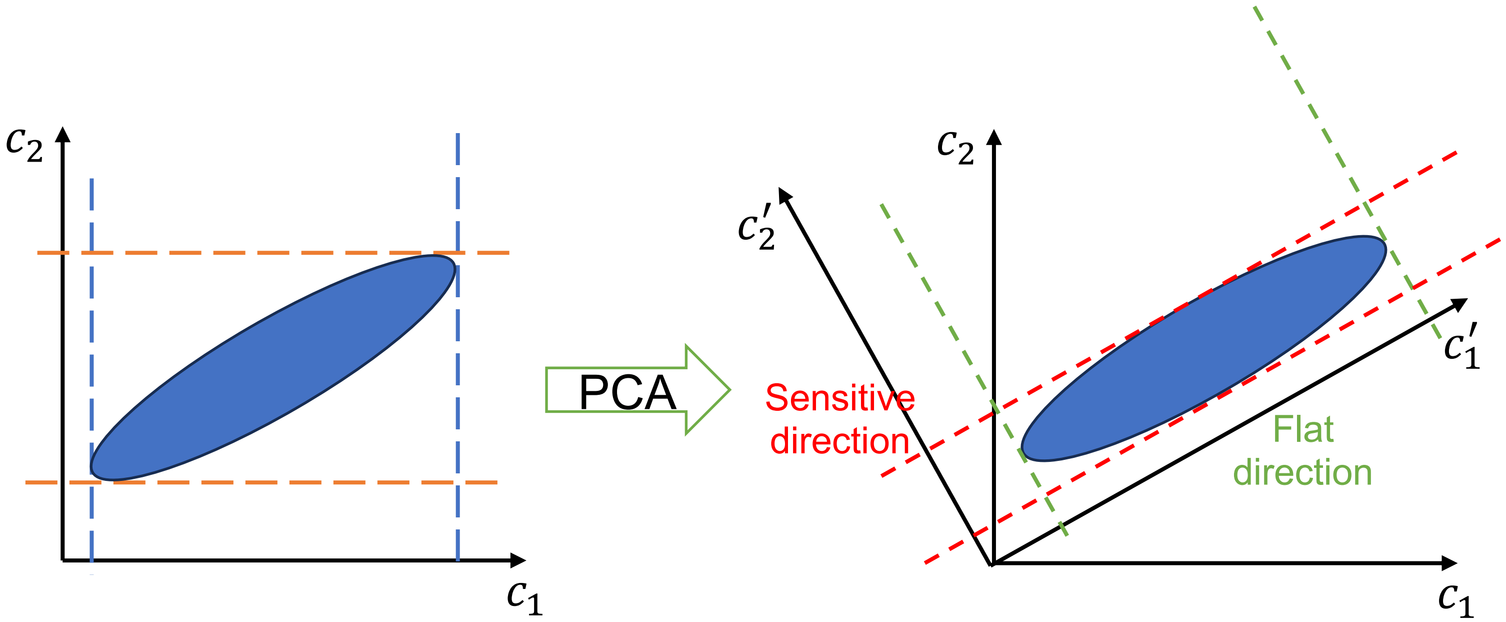


Sensitive directions

- It's not feasible to constrain all the Wilson coefficient at the same time due to large number of degrees of freedom and degeneracies in SMEFT impact

→ Principle component analysis (PCA) is used to select the sensitive directions

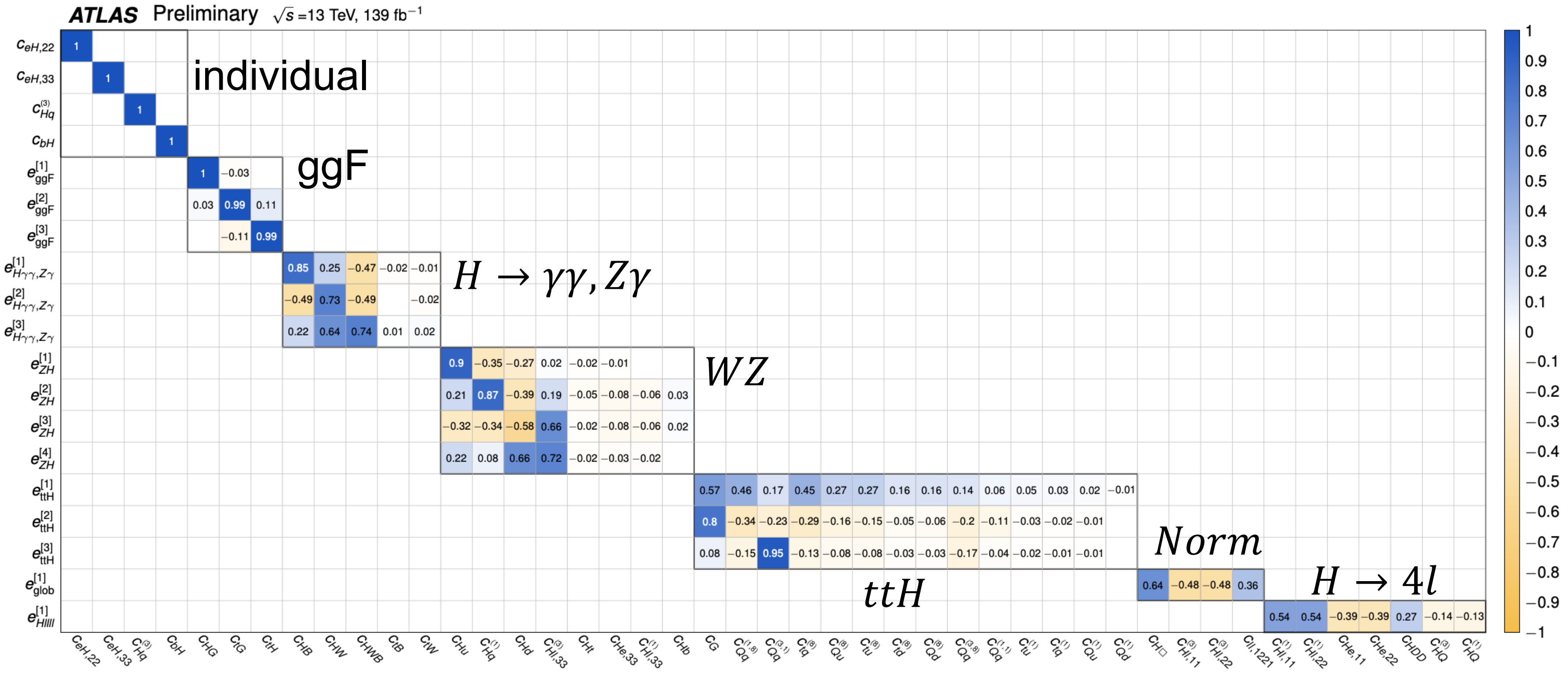
  - The new basis is the eigenvectors of the covariance matrix



Sensitive directions

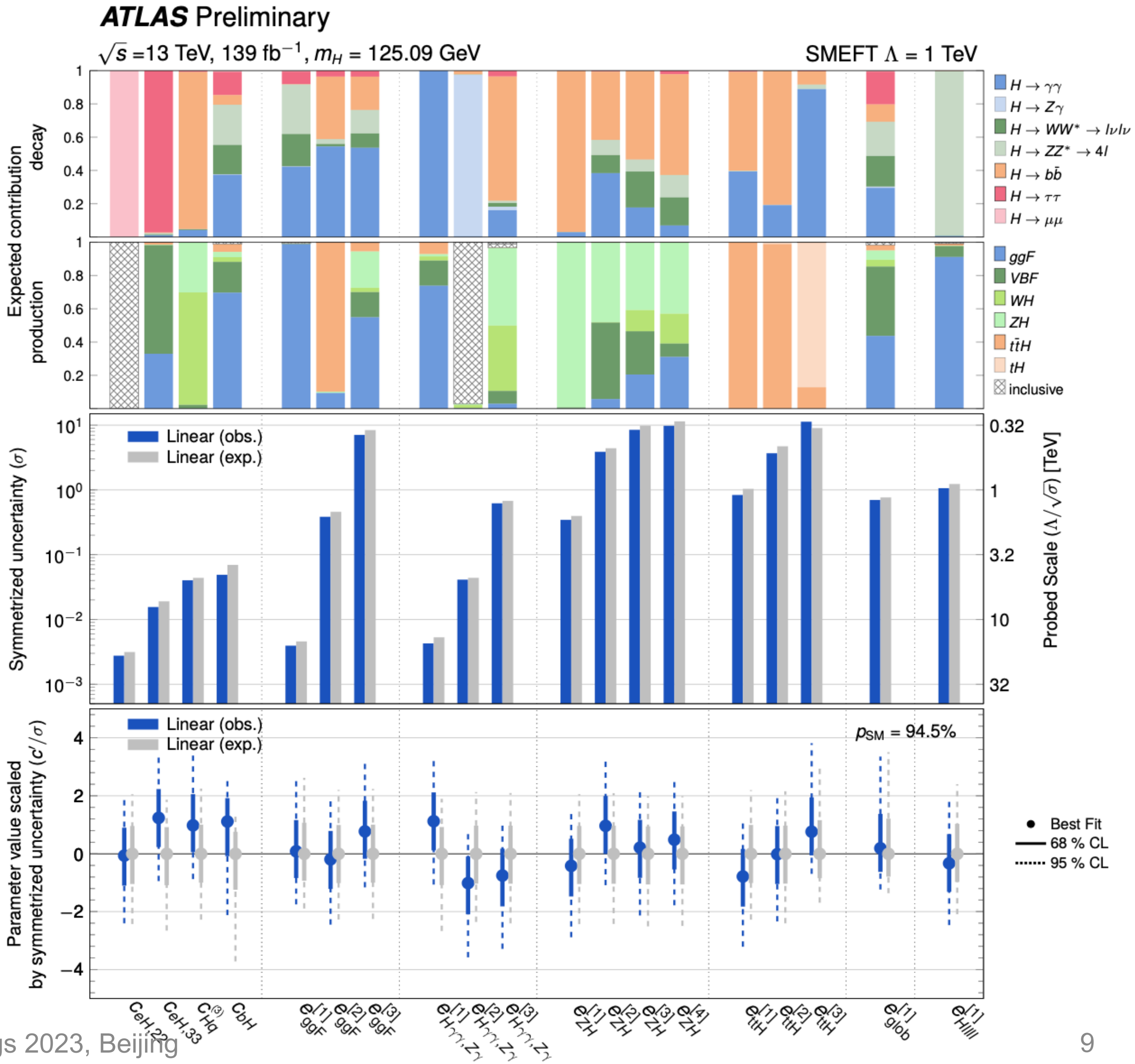
- A total of 19 directions are chosen with PCA within operators grouped according to physics meaning
- The rest flat directions are profiled to 0 when fitting

$$
\begin{aligned}
\boldsymbol{c} = \; & \{c_{eH,22}\} \cup & \boldsymbol{c}' = \; & \{c_{eH,22}\} \cup \\
& \{c_{eH,33}\} \cup & & \{c_{eH,33}\} \cup \\
& \{c_{Hq}^{(3)}\} \cup & & \{c_{Hq}^{(3)}\} \cup \\
& \{c_{bH}\} \cup & & \{c_{bH}\} \cup \\
& \{c_{HG}, c_{tG}, c_{tH}\} \cup & \rightarrow \quad & \{e_{\text{ggF}}^{[1]}, e_{\text{ggF}}^{[2]}, e_{\text{ggF}}^{[3]}\} \cup \\
& \{c_{HB}, c_{HW}, c_{HWB}, c_{tB}, c_{tW}\} \cup & \rightarrow \quad & \{e_{H\gamma\gamma,Z\gamma}^{[1]}, e_{H\gamma\gamma,Z\gamma}^{[2]}, e_{H\gamma\gamma,Z\gamma}^{[3]}\} \cup \\
& \{c_{Hu}, c_{Hq}^{(1)}, c_{Hd}, c_{Hl,33}^{(3)}, & & \\
& \quad c_{Ht}, c_{He,33}, c_{Hl,33}^{(1)}, c_{Hb}\} \cup & \rightarrow \quad & \{e_{ZH}^{[1]}, e_{ZH}^{[2]}, e_{ZH}^{[3]}, e_{ZH}^{[4]}\} \cup \\
& \{c_{G}, c_{Qq}^{(1,8)}, c_{Qq}^{(3,1)}, c_{tq}^{(8)}, c_{Qu}^{(8)}, c_{tu}^{(8)}, c_{td}^{(8)}, & & \\
& \quad c_{Qd}^{(8)}, c_{Qq}^{(3,8)}, c_{Qq}^{(1,1)}, c_{tu}^{(1)}, c_{tq}^{(1)}, c_{Qu}^{(1)}, c_{Qd}^{(1)}\} \cup & \rightarrow \quad & \{e_{\text{ttH}}^{[1]}, e_{\text{ttH}}^{[2]}, e_{\text{ttH}}^{[3]}\} \cup \\
& \{c_{H\Box}, c_{Hl,11}^{(3)}, c_{Hl,22}^{(3)}, c_{ll,1221}\} \cup & \rightarrow \quad & \{e_{\text{glob}}^{[1]}\} \cup \\
& \{c_{Hl,11}^{(1)}, c_{Hl,22}^{(1)}, c_{He,11}, c_{He,22}, c_{HDD}, c_{HQ}^{(3)}, c_{HQ}^{(1)}\} & \rightarrow \quad & \{e_{Hllll}^{[1]}\}.
\end{aligned}
$$



Results: Linear Model

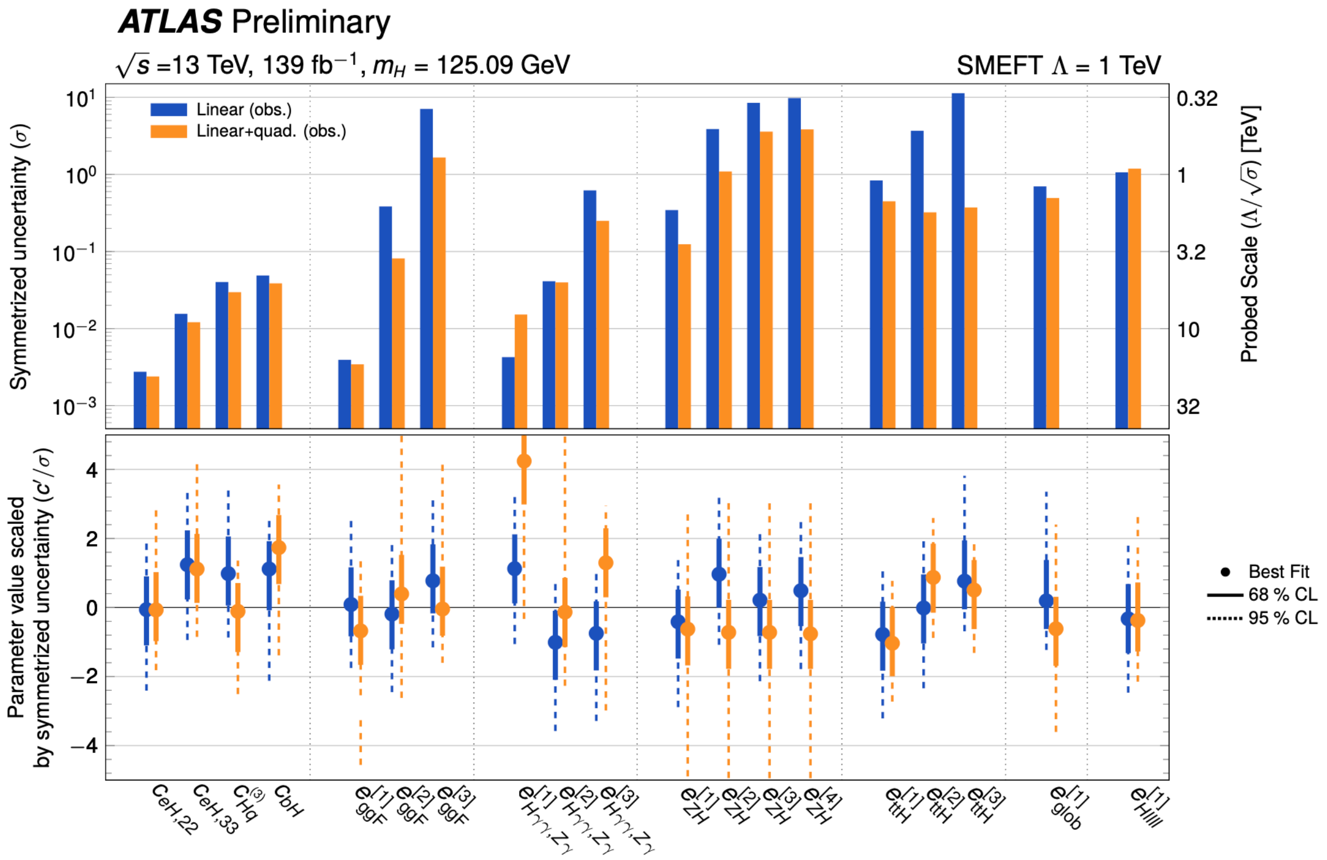
- In general, the tightest constraints are observed for process that is suppressed in SM, but not in SMEFT
  - E.g. $c_{eH,22}$ which is constrained by $H \to \mu\mu$ measurement. $H \to \mu\mu$ have a small BR in SM (suppressed), but $c_{eH,22}$'s contribution on $\mu\mu$ width is not
- The corresponding energy scales probed ($\Lambda/\sqrt{\sigma}$) are shown in the middle panel

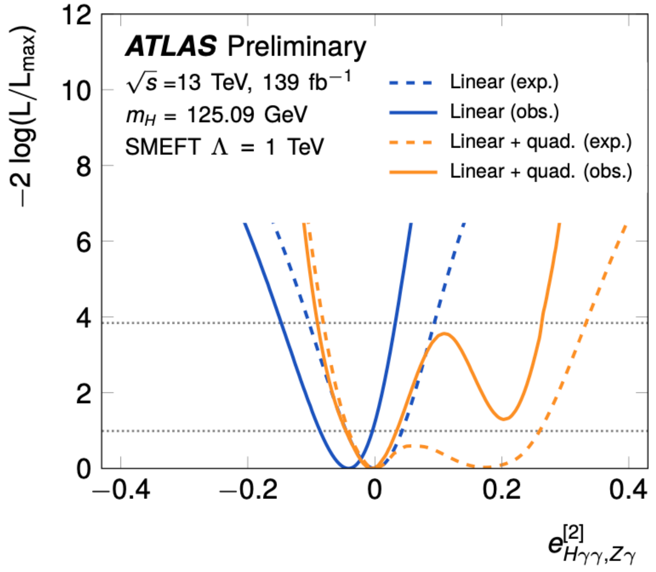


Results: Quadratic Model

- In general, most operators have more stringent constraints than linear models as the linear+quadratic impact is larger than linear one

- The observed bounds are usually smaller than the expected due to the two minimum shape of likelihood brought by the quadratic term

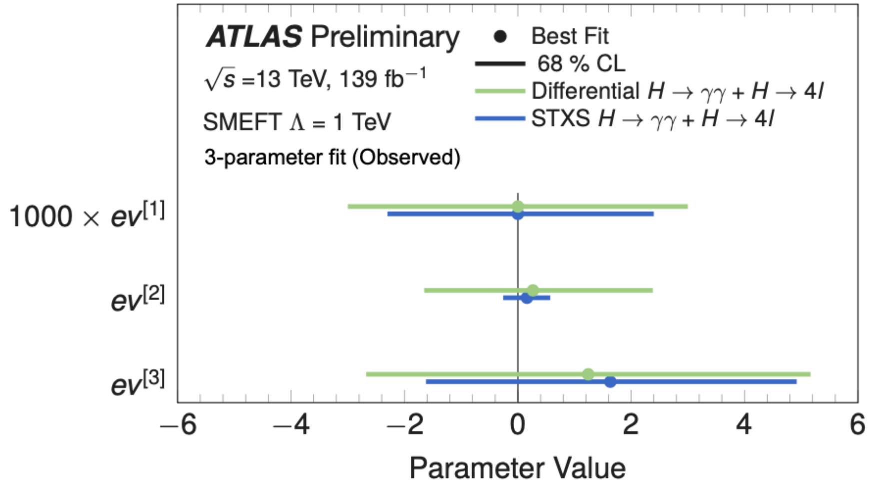




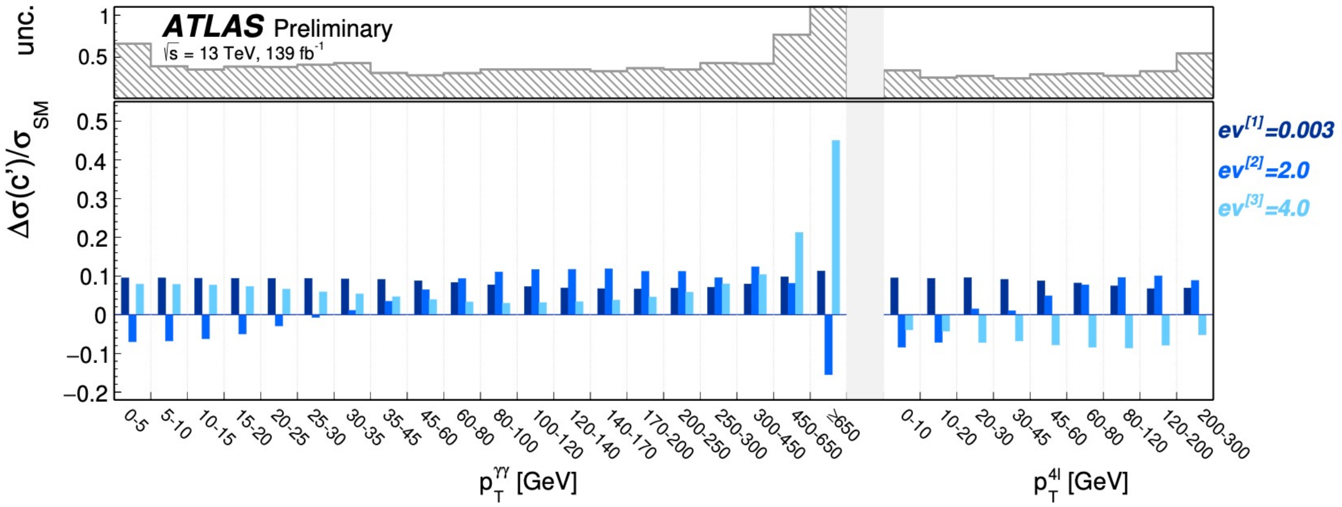
EFT based on differential measurements

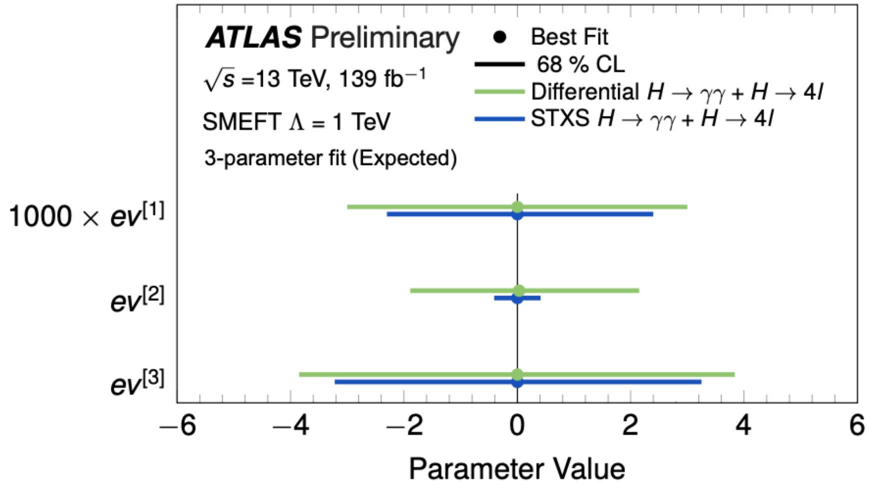
- The differential distribution provides more information of the final state kinematics, thus gives additional constrain power to Wilson coefficients.
- However the trade is the production mode is inclusive
- $H \to 4l$ & $H \to \gamma\gamma$ differential p_{T}^{H} distribution used in fit
- c_{HG}, c_{tG}, c_{tH} included

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



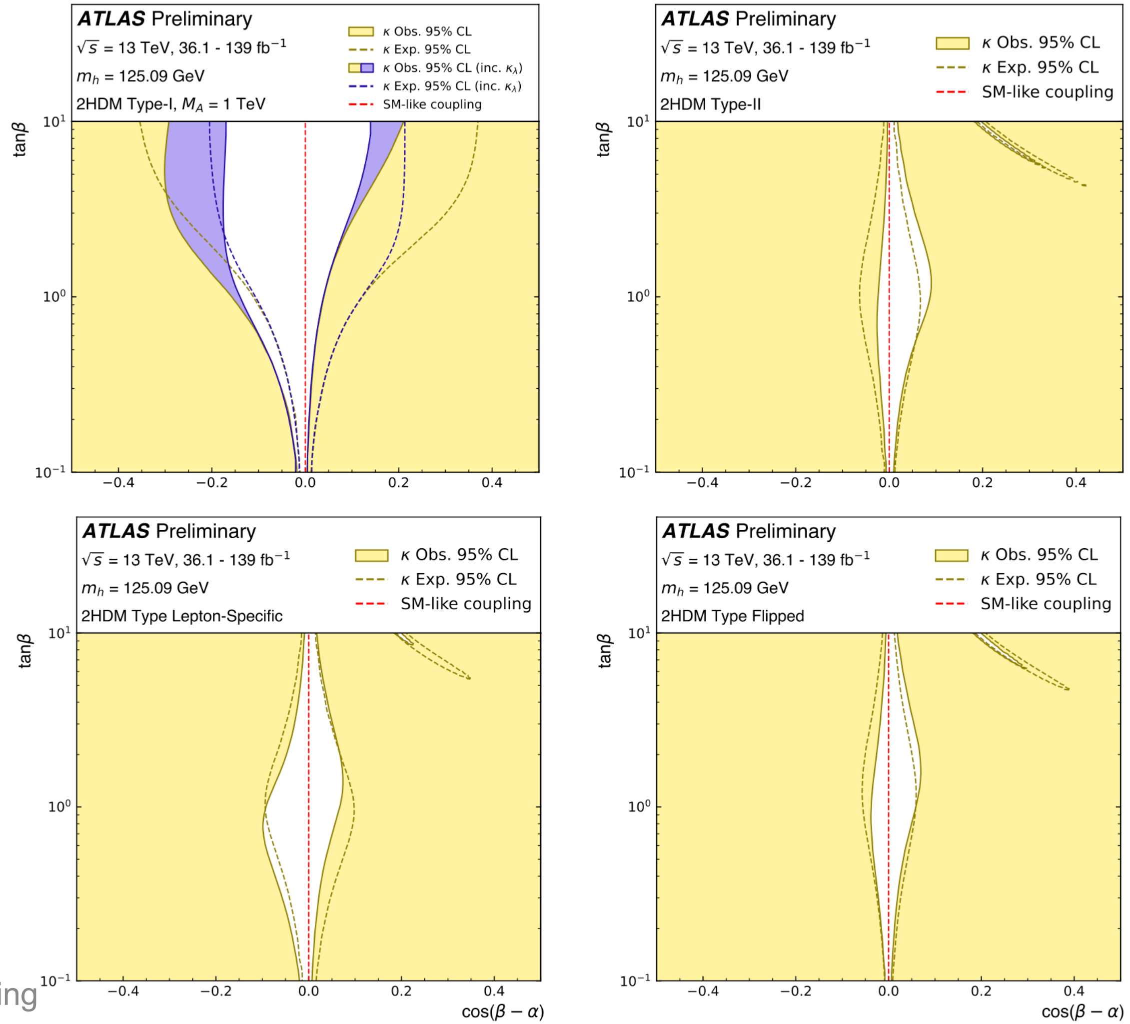
(a)





BSM interpretation

- The UV-complete models are also included in this study for interpretation
- 4 benchmarks of 2HDM and 7 benchmarks of MSSM + hMSSM



- Type I: All fermions couple to the same Higgs doublet.
- Type II: One Higgs doublet couples to up-type quarks while the other one couples to down-type quarks and charged leptons.
- Lepton-specific: One Higgs doublet couples to leptons while the other one couples to up- and down-type quarks.
- Flipped: One Higgs doublet couples to down-type quarks while the other one couples to up-type quarks and leptons.

Coupling	Type I	Type II	Lepton-specific	Flipped
u, c, t	$s_{\beta-\alpha} + c_{\beta-\alpha} / \tan\beta$			
d, s, b	$s_{\beta-\alpha} + c_{\beta-\alpha} / \tan\beta$	$s_{\beta-\alpha} - c_{\beta-\alpha} \times \tan\beta$	$s_{\beta-\alpha} + c_{\beta-\alpha} / \tan\beta$	$s_{\beta-\alpha} - c_{\beta-\alpha} \times \tan\beta$
e, μ, τ	$s_{\beta-\alpha} + c_{\beta-\alpha} / \tan\beta$	$s_{\beta-\alpha} - c_{\beta-\alpha} \times \tan\beta$	$s_{\beta-\alpha} - c_{\beta-\alpha} \times \tan\beta$	$s_{\beta-\alpha} + c_{\beta-\alpha} / \tan\beta$
W, Z	$s_{\beta-\alpha}$			
H	$s^3_{\beta-\alpha} + \left(3 - 2\frac{\bar{m}^2}{m_h^2}\right) c^2_{\beta-\alpha} s_{\beta-\alpha} + 2\cot(2\beta)\left(1 - \frac{\bar{m}^2}{m_h^2}\right) c^3_{\beta-\alpha}$			

MSSM benchmark results are shown in backup

EFT to UV model

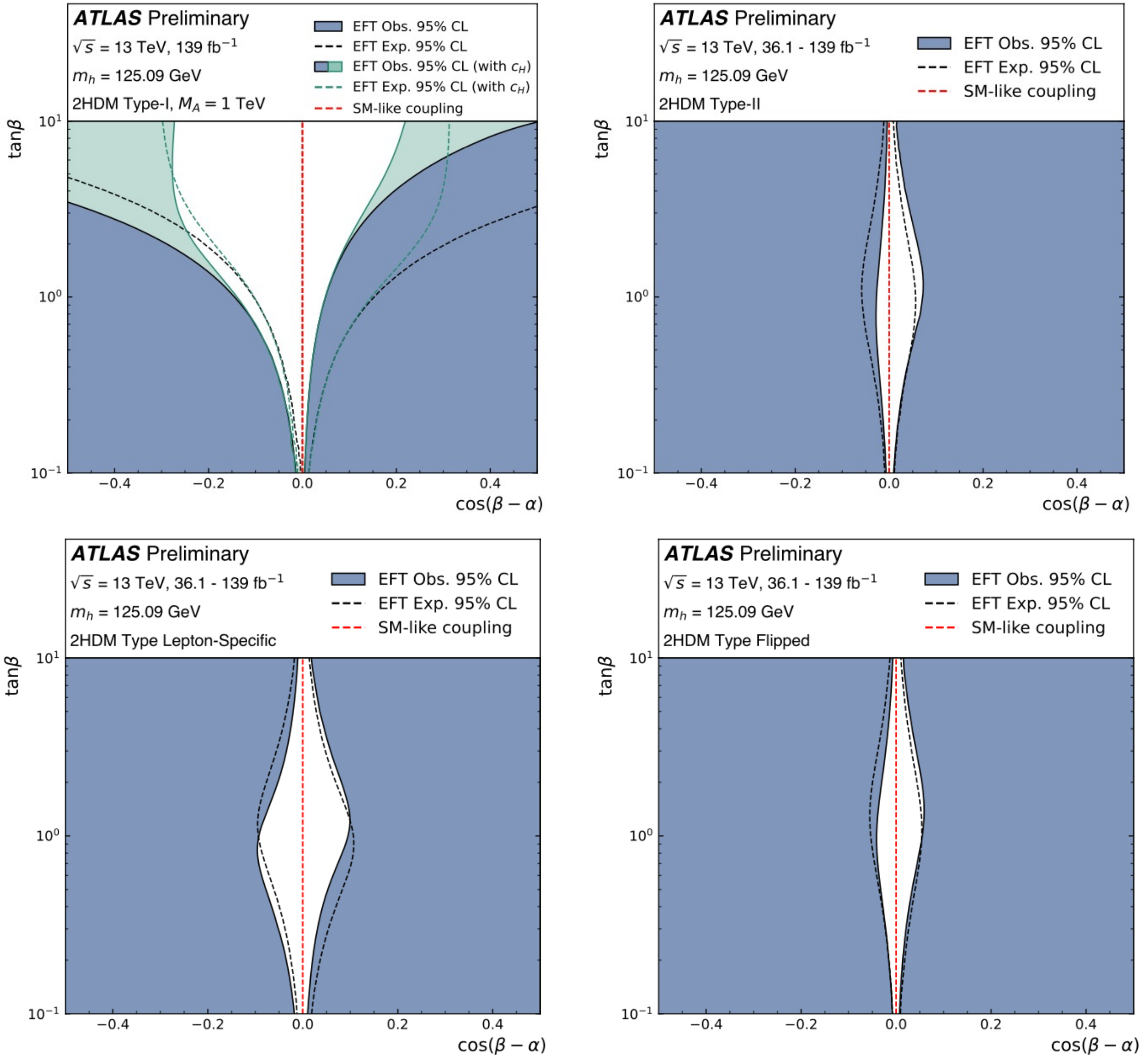
- EFT is seen as the low-energy approximation of high energy scale UV-complete model
- Theorists provide the translation from Wilson coefficient to several model's parameters [*Putting standard model EFT fits to work*, Sally Dawson, et al.]
- 2HDM are included to perform the matching
- Tree-level expansion near the alignment limit:

SMEFT parameters	Type I	Type II	Lepton-specific	Flipped
$\frac{v^2 c_{tH}}{\Lambda^2}$	$-Y_t c_{\beta-\alpha}/\tan\beta$	$-Y_t c_{\beta-\alpha}/\tan\beta$	$-Y_t c_{\beta-\alpha}/\tan\beta$	$-Y_t c_{\beta-\alpha}/\tan\beta$
$\frac{v^2 c_{bH}}{\Lambda^2}$	$-Y_b c_{\beta-\alpha}/\tan\beta$	$Y_b c_{\beta-\alpha}\tan\beta$	$-Y_b c_{\beta-\alpha}/\tan\beta$	$Y_b c_{\beta-\alpha}\tan\beta$
$\frac{v^2 c_{eH,22}}{\Lambda^2}$	$-Y_\mu c_{\beta-\alpha}/\tan\beta$	$Y_\mu c_{\beta-\alpha}\tan\beta$	$Y_\mu c_{\beta-\alpha}\tan\beta$	$-Y_\mu c_{\beta-\alpha}/\tan\beta$
$\frac{v^2 c_{eH,33}}{\Lambda^2}$	$-Y_\tau c_{\beta-\alpha}/\tan\beta$	$-Y_\tau c_{\beta-\alpha}\tan\beta$	$Y_\tau c_{\beta-\alpha}\tan\beta$	$-Y_\tau c_{\beta-\alpha}/\tan\beta$
$\frac{v^2 c_H}{\Lambda^2}$	$c^2_{\beta-\alpha}M^2_A/v^2$	$c^2_{\beta-\alpha}M^2_A/v^2$	$c^2_{\beta-\alpha}M^2_A/v^2$	$c^2_{\beta-\alpha}M^2_A/v^2$

Y_i *is the Yukawa coupling,* $Y_i = \frac{\sqrt{2}m_i}{v}$, $tan\beta = \frac{v_2}{v_1}$, α *is the rotating angle diagonalize the mass matrix*

EFT to UV model

- Type-I: The EFT approach miss the constraint from HVV couplings, which will only present at dim-8 operators
- For the other types, the petal region is missing due to the linear expansion of EFT approach
- In general, the EFT approach has weaker constraint than direct BSM interpretation, due to the missing of dim-8 operators



Direct comparison of two approaches in backup

Summary

- The EFT & BSM interpretation of the ATLAS combined higgs measurements are presented
  - EFT: Warsaw basis, ‘Top’ flavor scheme
  - BSM: 4 2HDM benchmarks, 7 MSSM benchmarks + hMSSM in backup
- The linear and linear+quadratic model are used for the interpretation on STXS measurements
  - PCA is used to identify the sensitive direction and cut down the number of Wilson coefficients in fit
  - The results show that the quadratic term suppressed by Λ^{-4} will significantly affect the constraints
  - No significant deviation from SM is observed
- Differential measurements are also used to constrain a subset of Wilson coefficients and show comparable, less constraining power results with the STXS one
- EFT to UV-model matching is employed for the first time and show good consistency with kappa-framework results for most 2HDM benchmarks, indicating EFT is a good approximation of the High energy scale UV models

Backup

Fisher information

- The Fisher information matrix represents the contribution from measurement on the constraint of each POIs (c_i)

$$I_{c_i,meas_j} = \frac{\partial^2 L_{meas.}}{\partial c_i^2}$$

- The fraction of contribution from given measurement is calculated as:

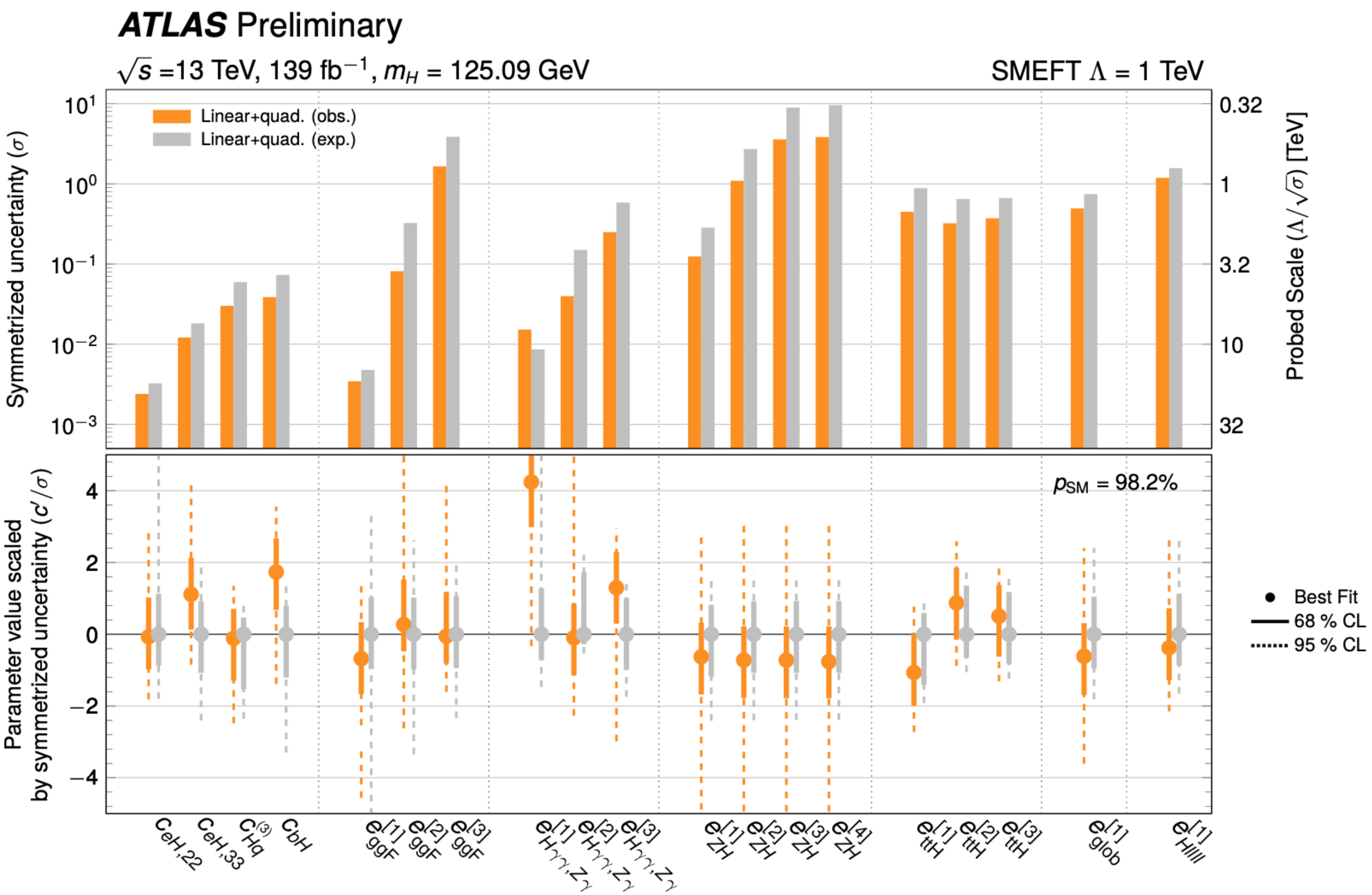
$$f_{meas_j} = \frac{I_{c_i,meas_j}}{\sum I_{c_i,meas_j}}$$

- In this analysis, it is calculated from the inverted covariance matrix with Asimov data

$$V_{\mathrm{SMEFT}}^{-1} = P_{(i,k',X)\rightarrow(j)}^{T}\, V_{\mathrm{STXS}}^{-1}\, P_{(i,k',X)\rightarrow(j)}.$$

  - The correlation matrix of STXS×BR is obtained with Gaussian assumption
  - The P matrix is composed of the linear term as the quadratic term is supposed to vanish when the Wilson coefficient is at 0

Quadratic Model results



hMSSM (habemus MSSM)

- A simplified MSSM model, its higgs sector also have two doublets, the coupling is same as 2HDM Type-II
- The SUSY constraint and additional assumptions will cut done the free parameters to two: $\tan\beta$ and m_A, see detail in LHC Yellow Report
  - Assuming all superparticles are too heavy to affect Higgs production and decay
  - Radiative correction to mass matrix other than (2,2) are negligible (which is not always the case in low mA region and large tanB)
- And the α is fixed (at tree level) by:

$$\alpha = \frac{1}{2}\arctan(\tan 2\beta \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2})$$

MSSM benchmarks

- Similar to hMSSM, these benchmark models cut down the free parameters to two:

$$m_A, \tan\beta$$

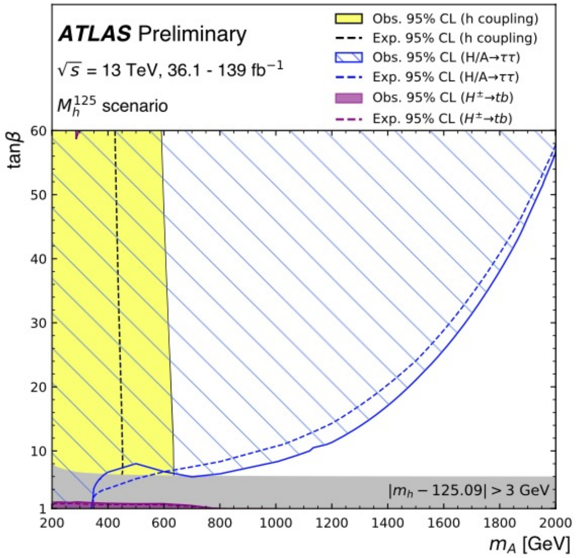
due to the assumptions, considering the radiative corrections

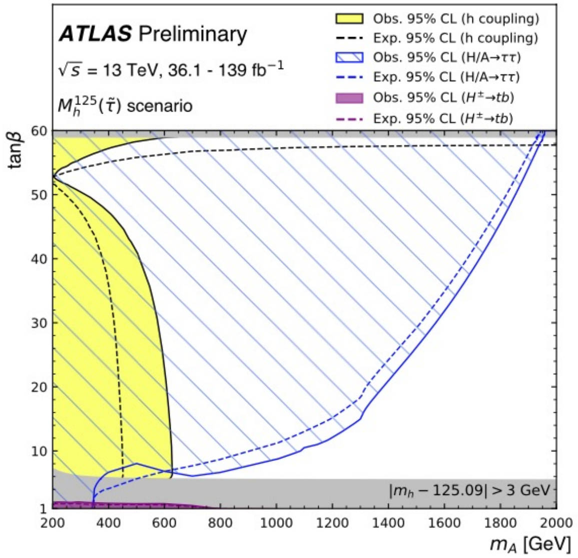
- Baseline benchmarks [1808.07542]:
  1. M_h^{125}: heavy superparticles, resemble 2HDM
  2. $M_h^{125}(\tilde{\chi})$: relatively light charginos ($\tilde{\chi}^{\pm}$) and neutralinos ($\tilde{\chi}^0$), significant higgsino-gaugino mixing, weanken $H/A \to \tau\tau$
  3. $M_h^{125}(\tilde{\tau})$: light staus ($\tilde{\tau}$) and gaugino-like charginos and neutralinos
  4. $M_h^{125}(alignment)$: alignment without decoupling
  5. $M_h^{125}(CPV)$: CP violation in the Higgs sector, interference effect in higgs (h2,h3) production and decay
- The sfermions mass are tied to TeV scale in these benchmarks, so the low tanB region is ruled out due to the SM-like higgs mass is much lower than measured value

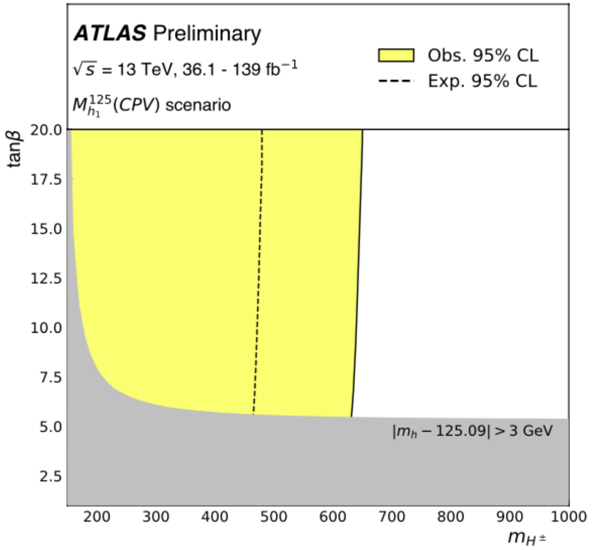
MSSM benchmarks

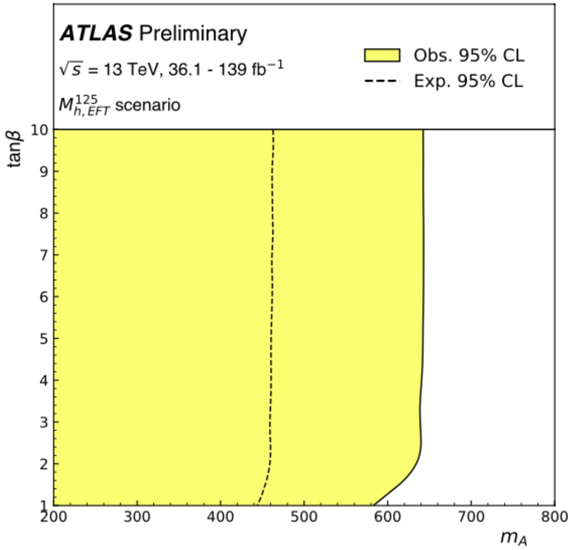
- **EFT benchmarks** [1901.05933]($M_{h,EFT}^{125}$, $M_{h,EFT}^{125}(\tilde{\chi})$):
  - Open up the low $\tan\beta$ region by adjustable sfermion mass(M_{SUSY}), can be raised up to 100TeV
  - At low scale, where all the Higgs mass is around electroweak scale, the Higgs sector are evaluated in effective 2HDM to ensure the correct resummation of high mass sfermion loop
  - $M_{h,EFT}^{125}$: All SUSY particles are chosen to be heavy, phenomenologically viable extension of the M_h^{125} scenario
  - $M_{h,EFT}^{125}(\tilde{\chi})$: relatively light charginos ($\tilde{\chi}^{\pm}$) and neutralinos ($\tilde{\chi}^{0}$), extension of $M_h^{125}(\tilde{\chi})$ scenario

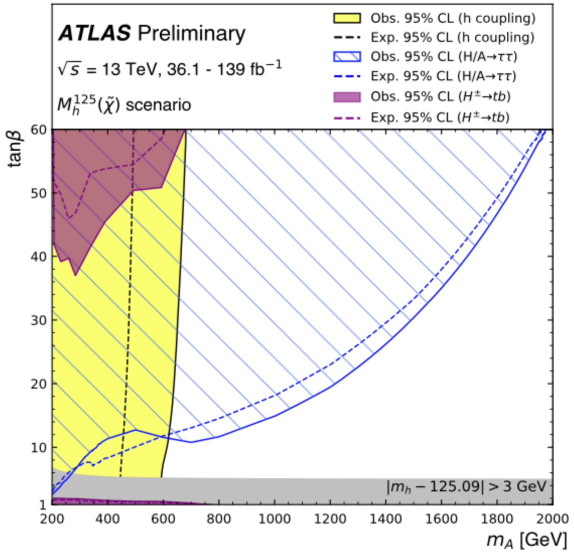
MSSM interpretation

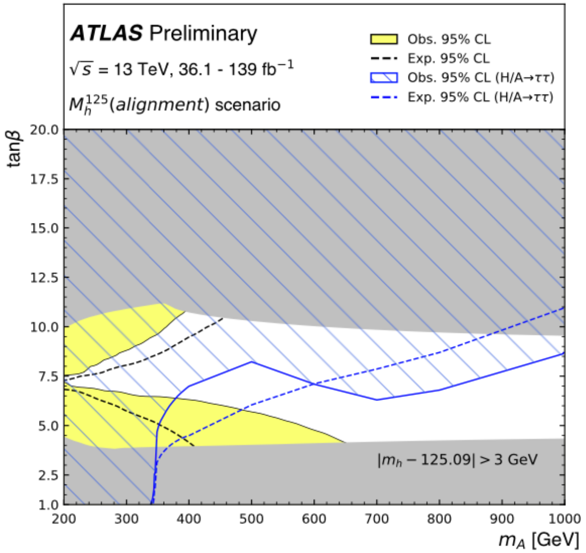


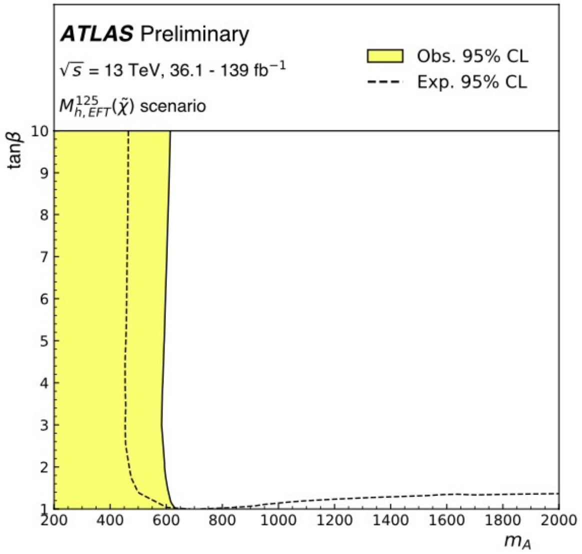


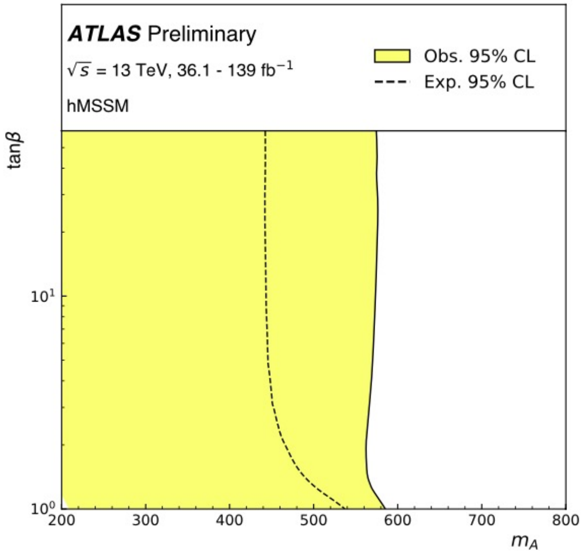












2HDM Comparison of EFT and kappa approach