EFT in LHC

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Higgs EFT interpretation in LHC

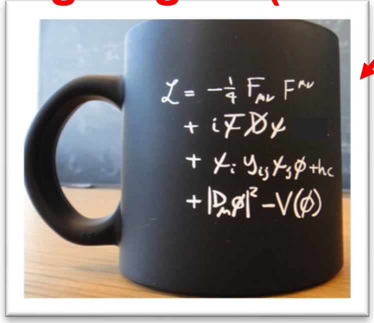
- No any BSM evidence in LHC (so far) from direct searches
- Effective Field Theory (EFT) can set model-independent constraint on BSM physics and indirectly searches beyond LHC reach
- LHC often uses SMEFT (Warsaw basis)

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \underbrace{\sum_{i}^{N_{d=6}} \frac{c_i}{\Lambda^2} O_i^{(6)}}_{\text{dim6}} + \underbrace{\sum_{j}^{N_{d=8}} \frac{b_j}{\Lambda^4} O_j^{(8)}}_{\text{dim8}} + \dots,$$

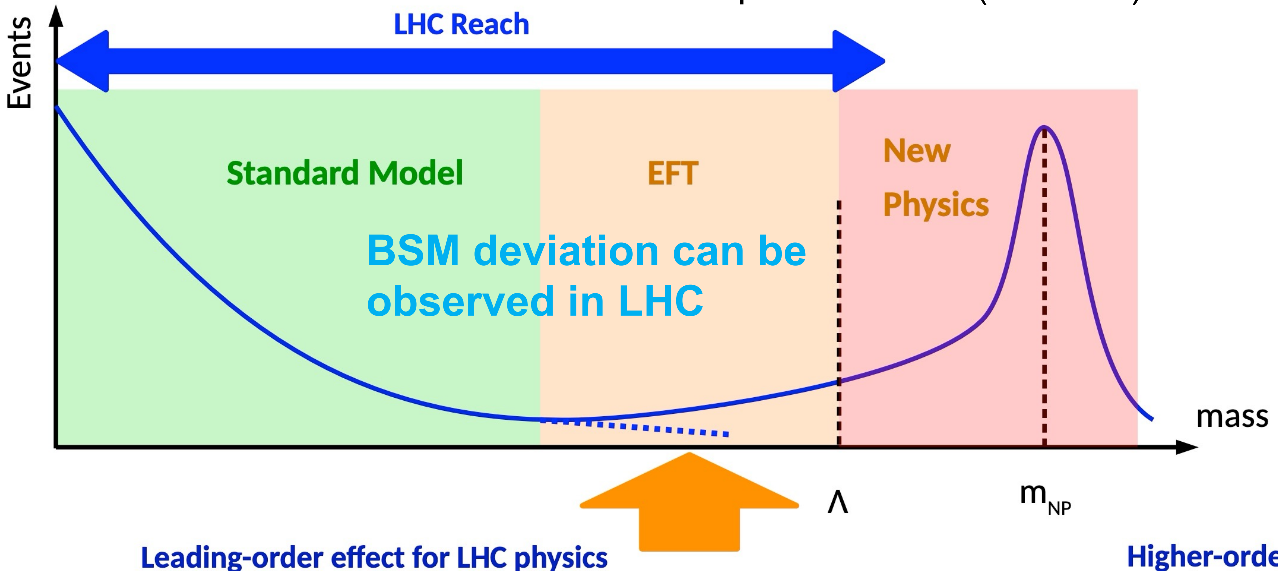
c_i, b_j: Wilcon coefficients

O_i^6, O_j^8:dim6/8 operators

SM Lagrangian (dim4)



* dim5/7 violate Baryon and/or Lepton numbers (not used)



- ✓ dim6(8) suppressed by $1/\Lambda^2(\Lambda^4)$
- ✓ dim8 is not available
- ✓ Common and powerful tool for other measurements ➔ Allow one to combine various measurements

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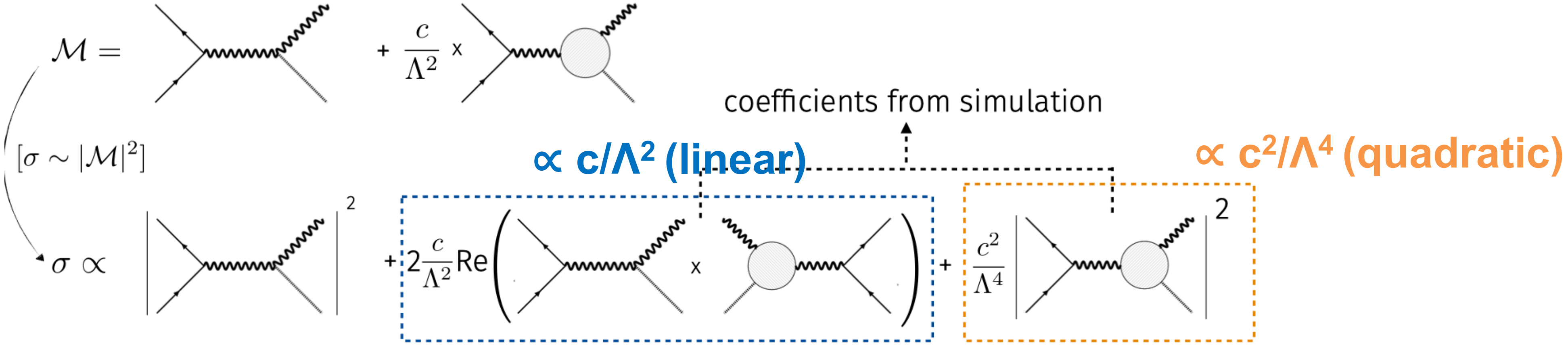
Higgs EFT formalism

$$\sigma_{\mathrm{SMEFT}} = \left|\mathcal{L}_{SM} + \mathcal{L}_{BSM}^{dim6}\right|^2 = \sigma_{SM} + \sigma_{int} + \sigma_{BSM}$$



Assuming, Λ=1 TeV

➔ **Observe cross-section enhancement(kinematic dependence)**

- Only CP-even dim-6 operators
- Describe 3rd generation from first two generations independently (Top flavor symmetry scheme)
- All lepton generations are modeled independently

EFT operators in Higgs

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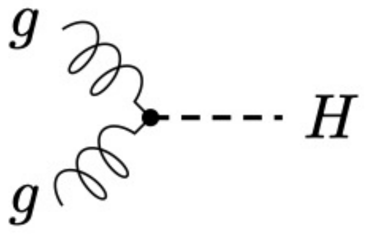
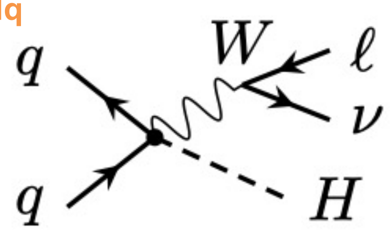
C_{HG}



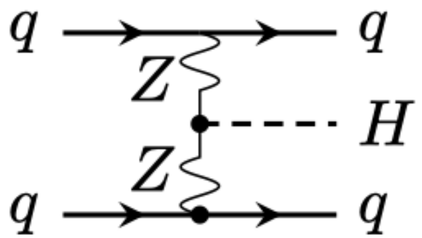
C^3_{Hq}



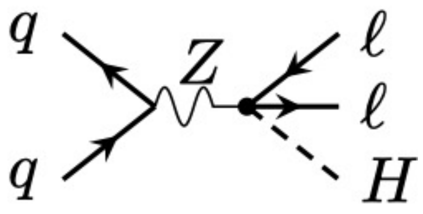
Wilson coefficient	Operator
c_H	$(H^\dagger H)^3$
$c_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
c_G	$f^{abc}G_\mu^{a\nu}G_\nu^{b\rho}G_\rho^{c\mu}$
c_W	$\epsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$
c_{HDD}	$\left(H^\dagger D^\mu H\right)^*\left(H^\dagger D_\mu H\right)$
c_{HG}	$H^\dagger H\, G^A_{\mu\nu}G^{A\mu\nu}$
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}	$(H^\dagger H)(\bar{Q}Hb)$
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}	$(\bar{Q}\sigma^{\mu\nu}t)\widetilde{H}\,B_{\mu\nu}$
$c_{ll,1221}$	$(\bar{l}_1\gamma_\mu l_2)(\bar{l}_2\gamma^\mu l_1)$

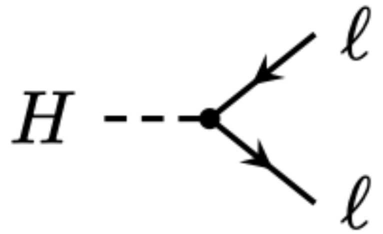
C_{HDD}



C_{Hl}



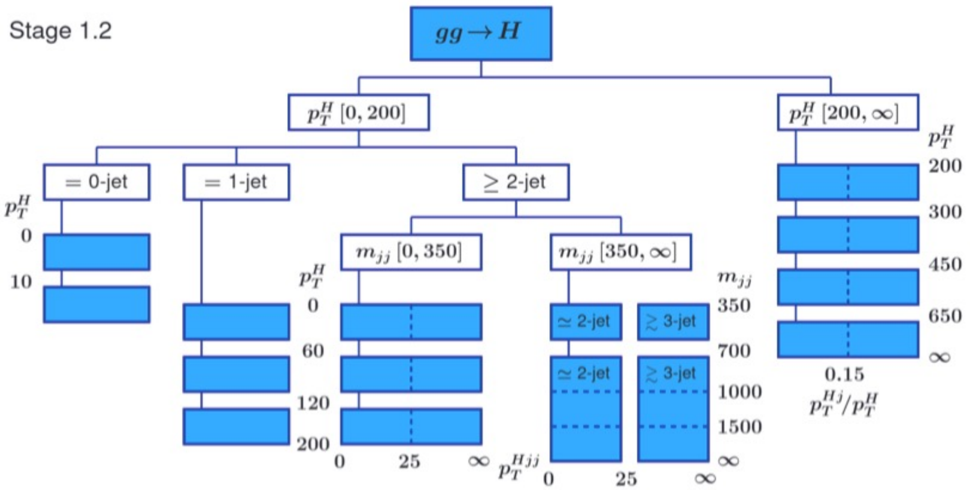
C_{eH}

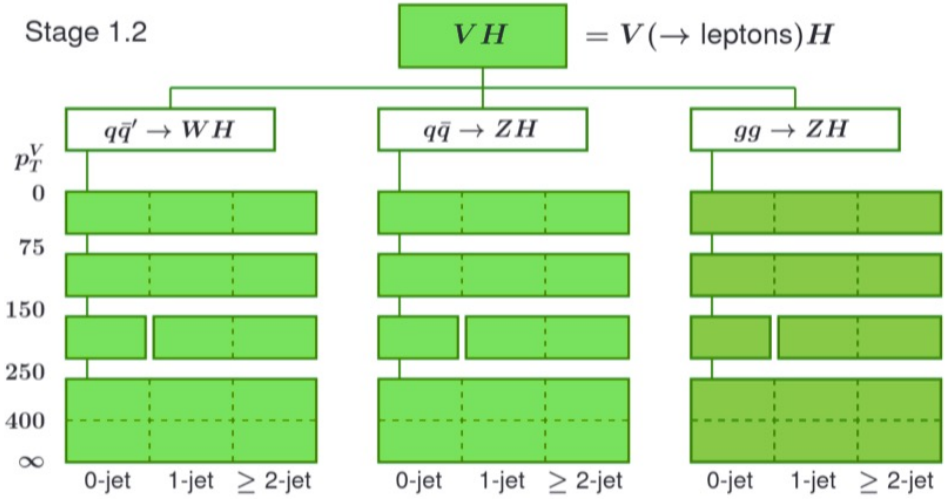


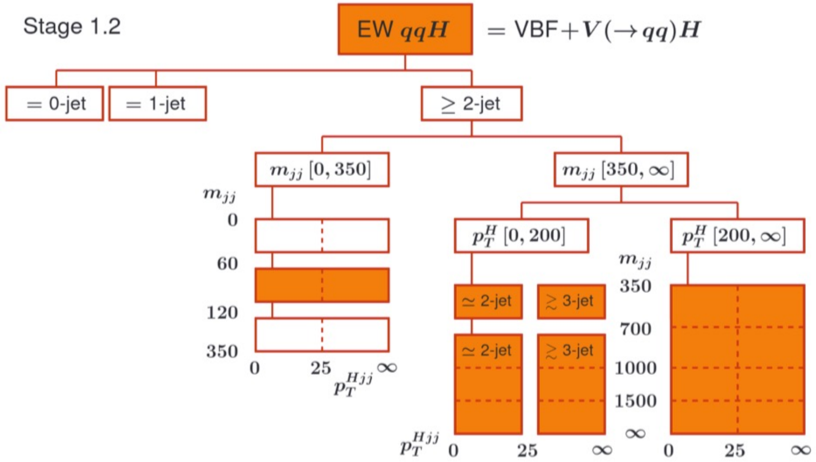
~50 related to Higgs measurements considered

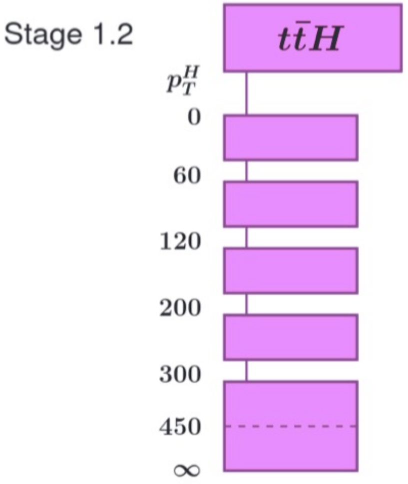
Higgs Combination and STXS

- How to constrain EFT parameters? What measurements are powerful?
  ➔ Simplified template cross-section (STXS)









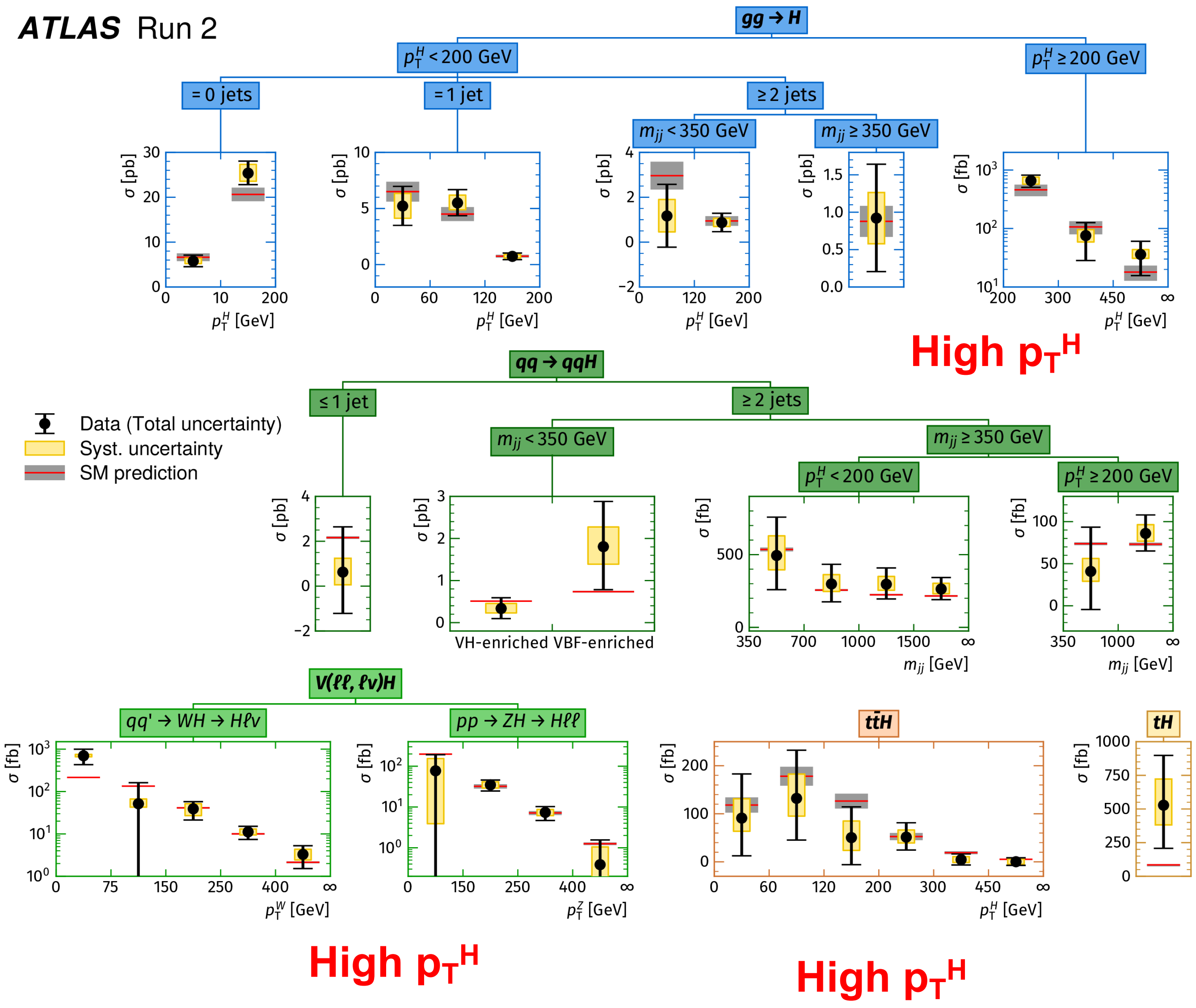
- STXS defines "bins" which are sensitive to the physics
- Bin definitions are tunable to maximize sensitivity based on the experimental precision
- Minimize theory dependences

➔ STXS measurements are sensitive to the EFT parameters

Combined STXS measurement in LHC

Decay channel	ggF	VBF	VH	ttH/tH
H→γγ	✔	✔	✔	✔
H→ZZ	✔	✔	✔	✔
H→WW	✔	✔	✔*	✔*
H→ττ	✔	✔	✔	✔
H→bb	✔	✔	✔	✔
H→Zγ	Inclusive			
H→μμ	✔	✔	✔	✔

Most of channels use full Run2 dataset (~140fb^{-1})



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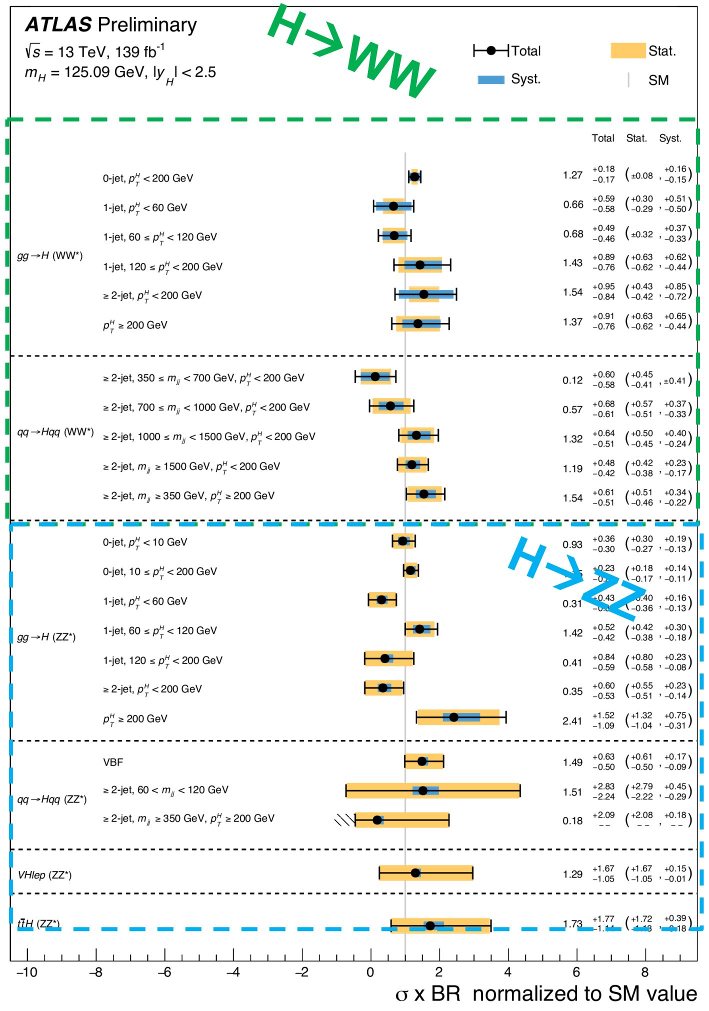
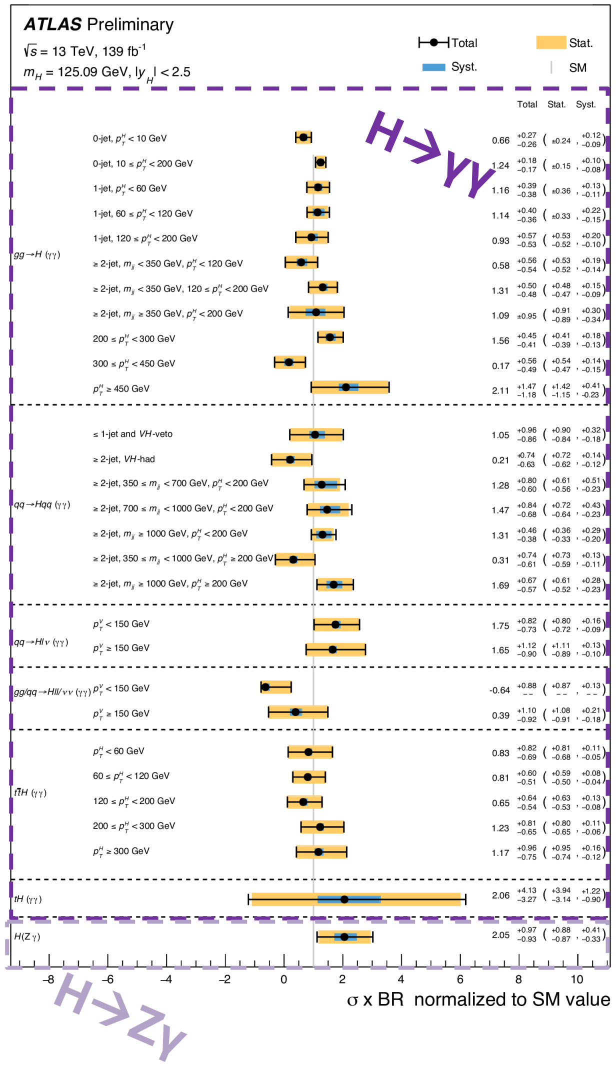
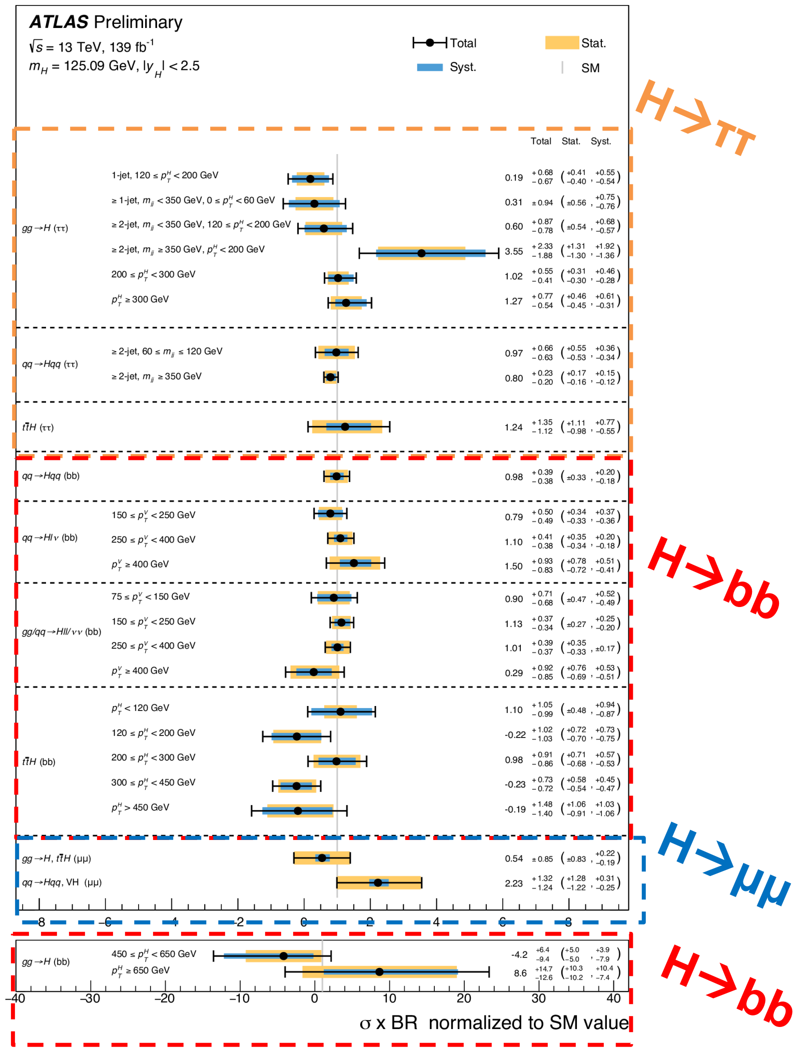
STXS measurements

- Decay branching ratios are also considered in EFT interpretation







2023/12/20

ILC meeting

Relative impact of EFT operators

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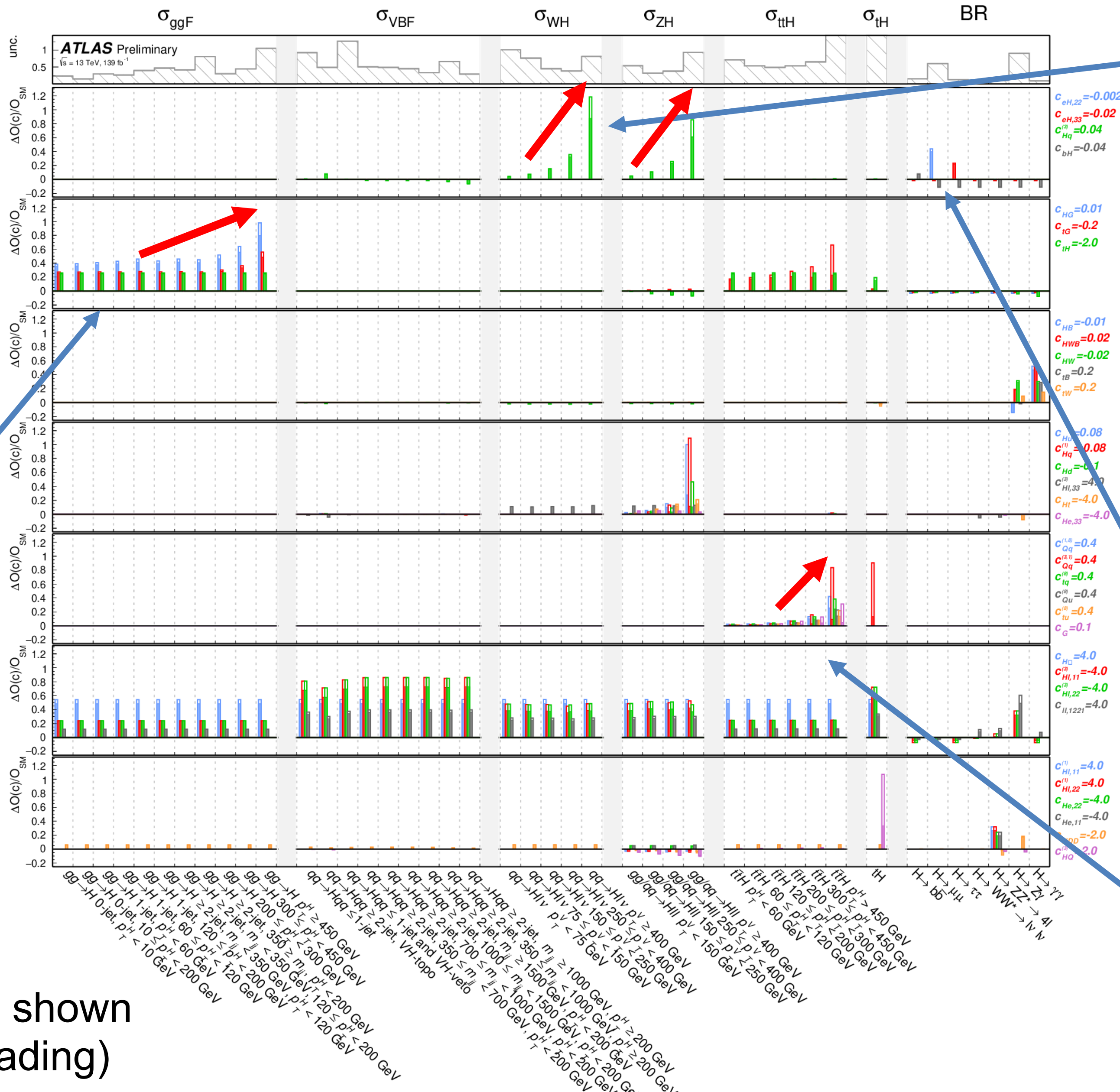
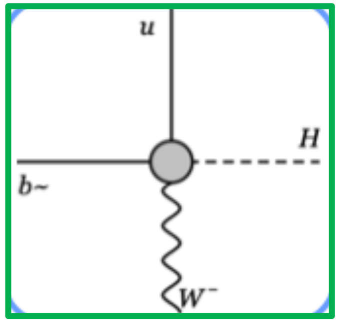
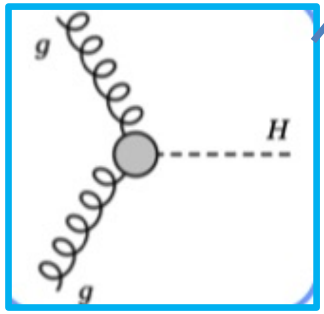




c_{HG}: Large BSM effects on cross-section in high p_T^H



c^3_{Hq}: Large BSM effects on cross-section in high p_T^V (p_T^H)

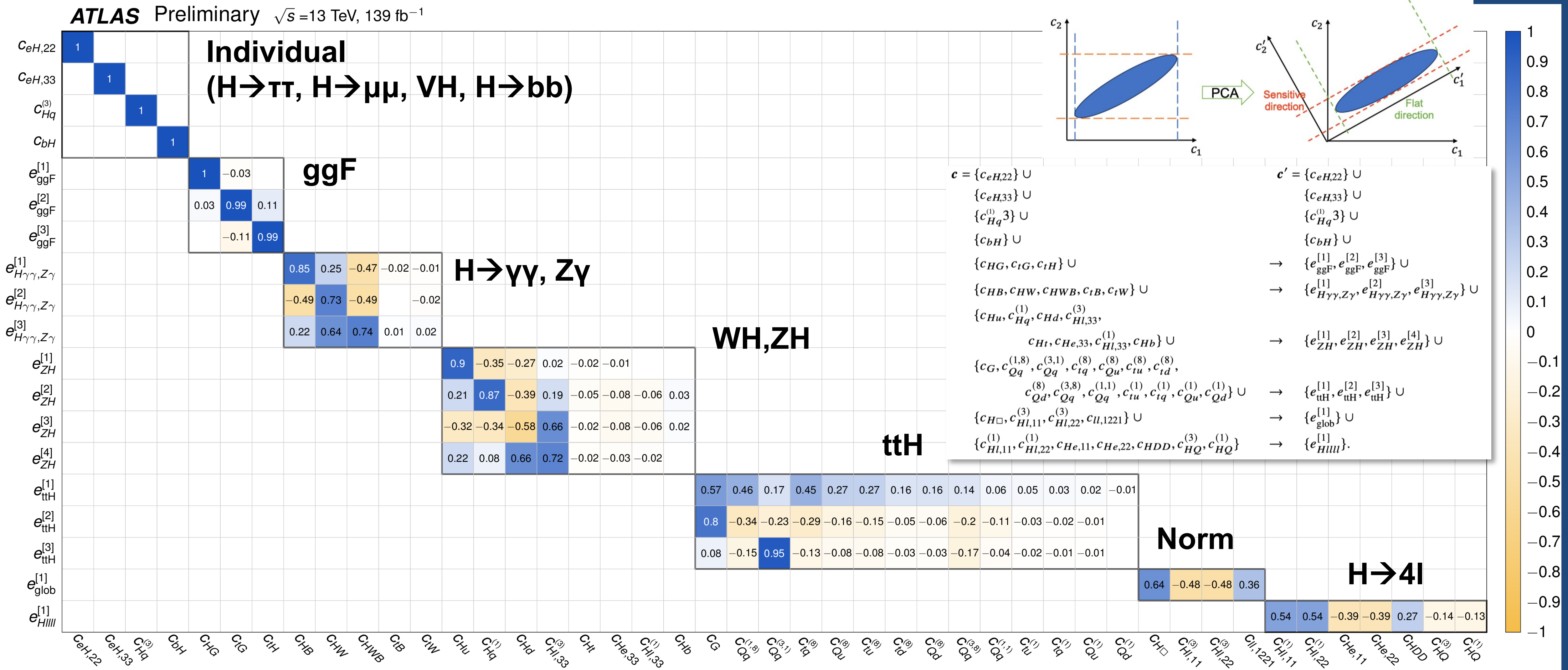
$C_{eH,22}$, $C_{eH,33}$ Unique impact on $H \rightarrow \tau\tau/\mu\mu$

c_{Qq}: Large BSM effects on cross-section in high p_T^H (Huge effect in quadratic term)

33 Wilson coefficients shown
(Remaining are subleading)

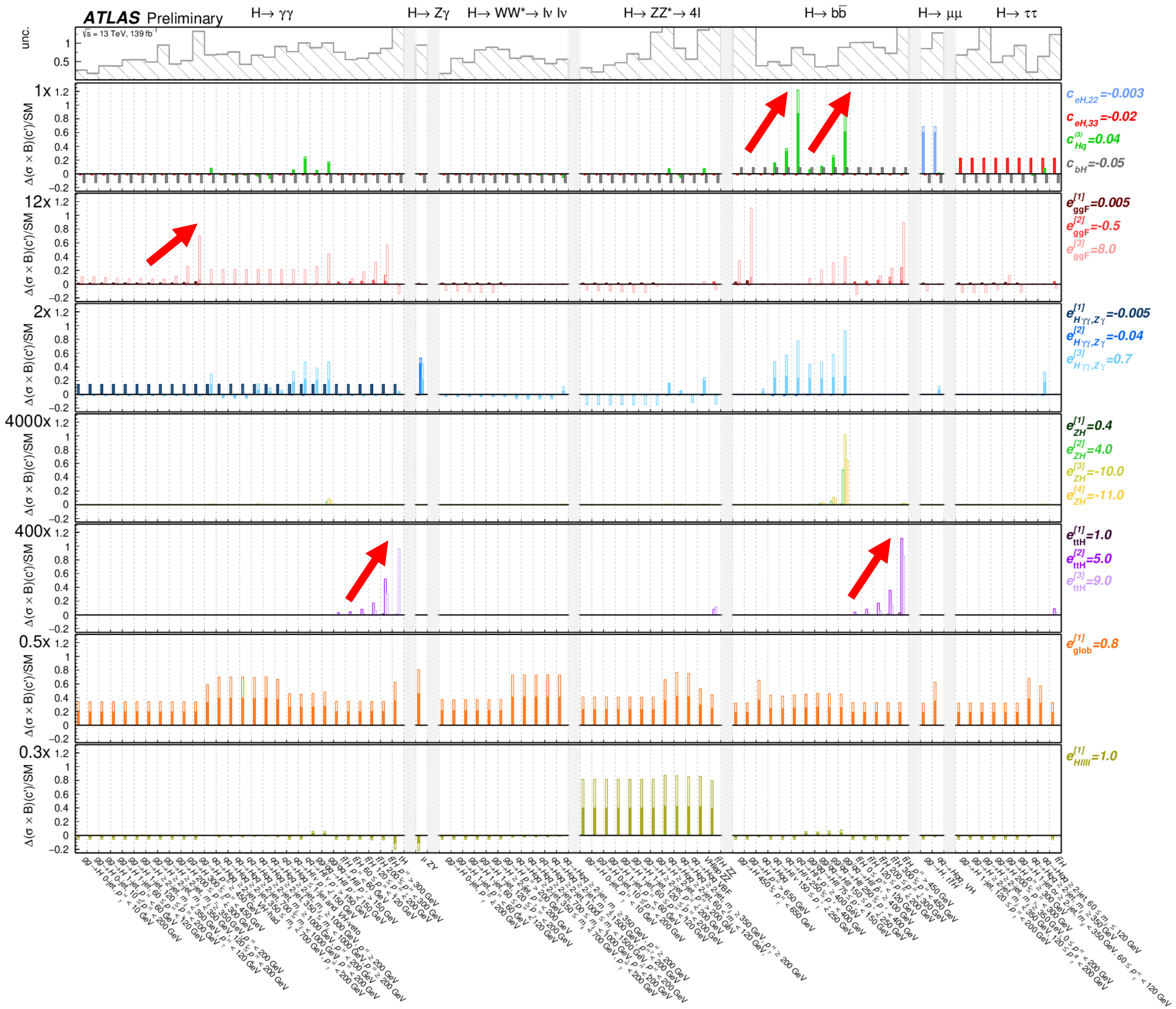
Modified basis with linear combinations

- Not able to constrain all Wilson coefficients in current sensitivity
  - ➔ Huge correlation among measurements
  - ➔ 19 parameters are reparametrized by the linear combinations



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

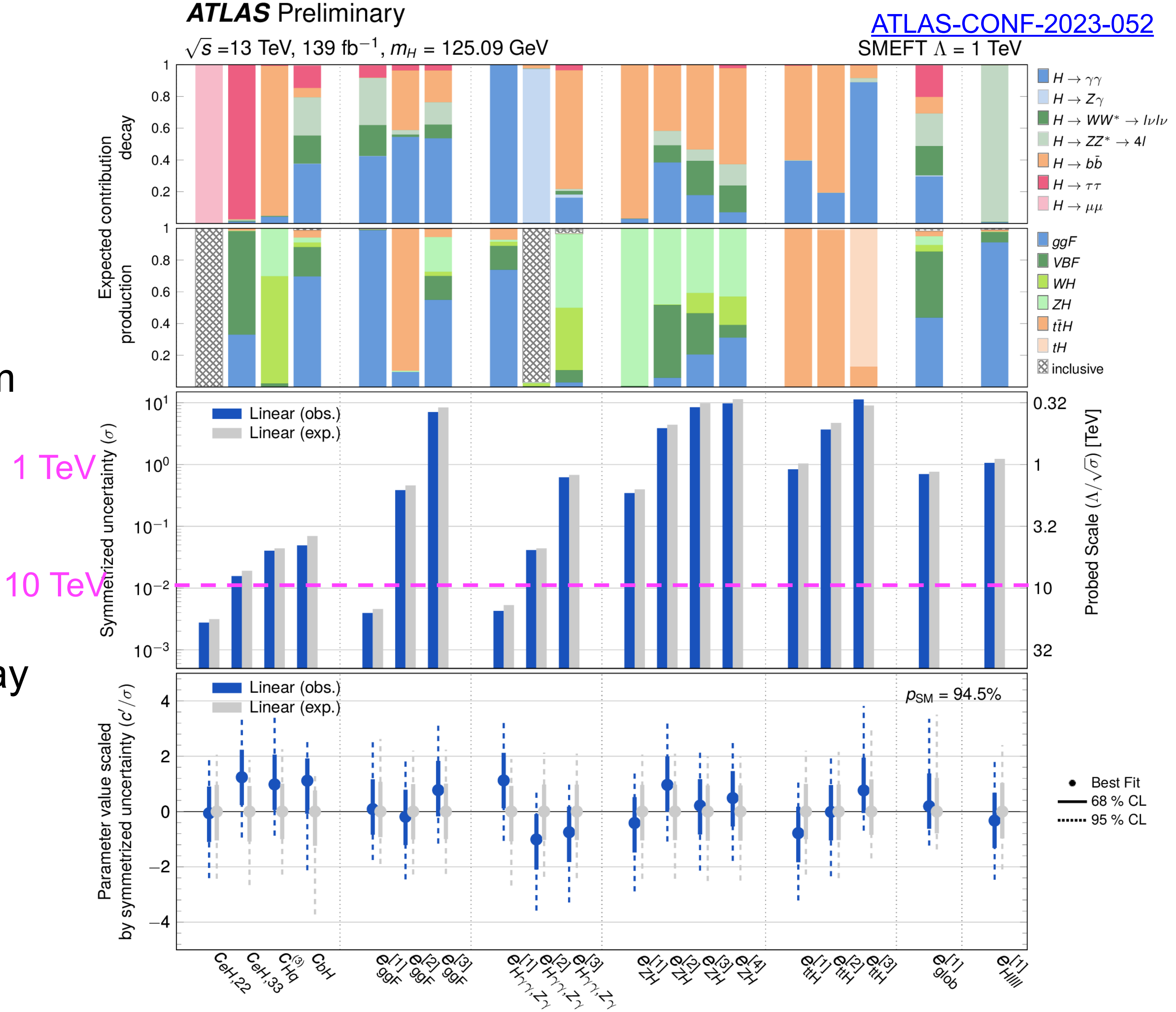
Impact on reparametrized coefficients



- Extract the feature of each coefficient more clearly
- Mitigated correlations among coefficients

Results

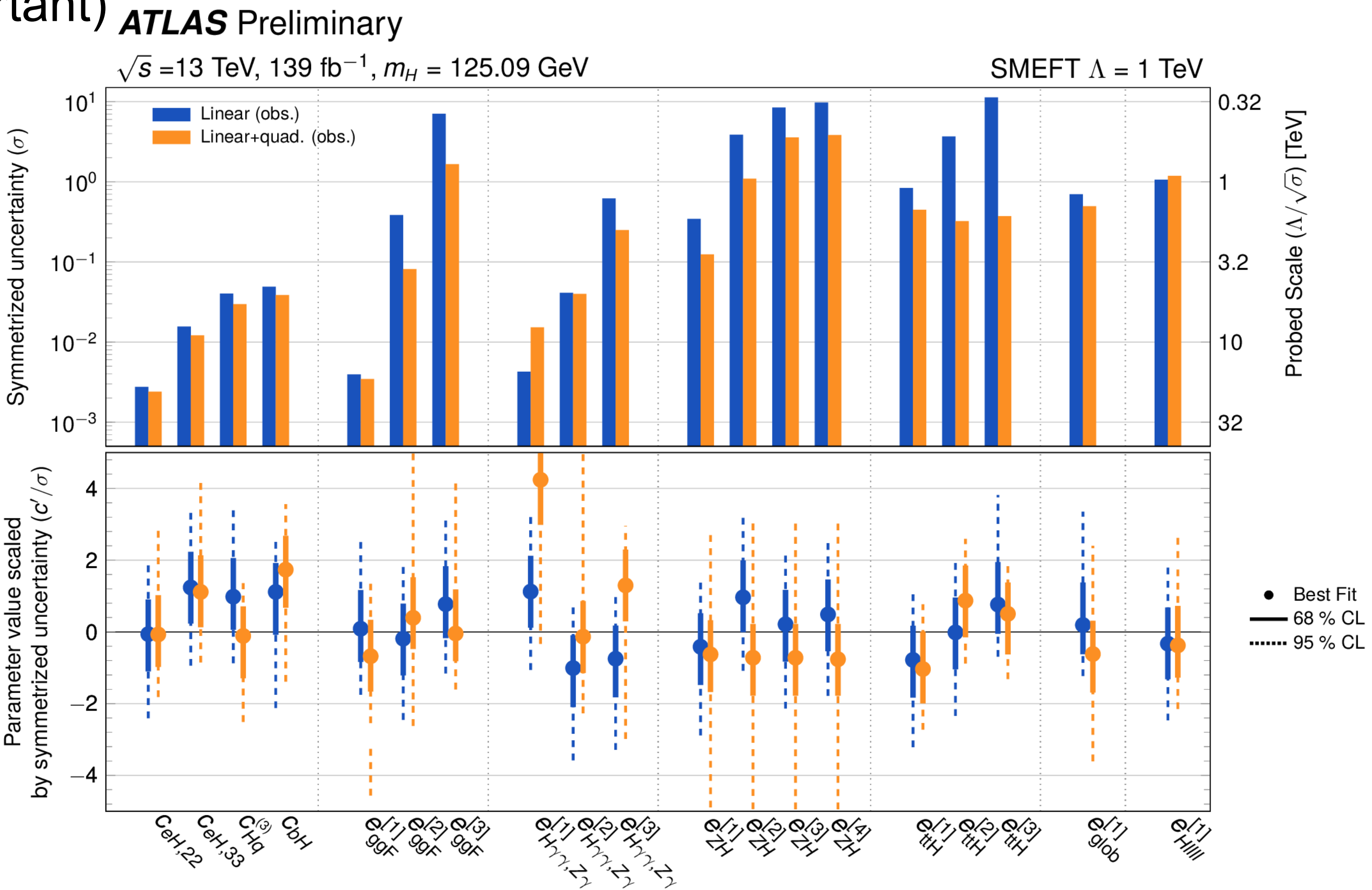
- Only linear term considered
- No strong deviation from SM (p-value 94.5%)
- *O*(1 TeV)-*O*(10 TeV) scale can be probed in the current sensitivity
- Various production/decay modes contributes EFT parameter constraint



Linear vs Linear+Quad

[ATLAS-CONF-2023-052](https://cds.cern.ch/record/2870161)

- In general, linear+quad provides stronger constraint (dim8 terms are important)



Constrain UV complete BSM models

EFT to 2HDM constraints

Phy. Rev. D 102, 055012 (2020)
S.Dawson, S.Homiller, & S.D. Lane

- EFT measurement can be mapped to the UV-complete models
- SMEFT constraints are interpretated 2HDM using theory paper

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

- $\Lambda \gg v$ in EFT ➔ cos(β-α) → 0 (valid near alignment limit)
- Constrain in tanβ vs cos(β-α)
- use only single Higgs for c_H constraint (no HH direct measurement included)

$Y_{b,t,\mu,\tau} = \frac{\sqrt{2}m_i}{v}$ (~SM)

2HDM constraints

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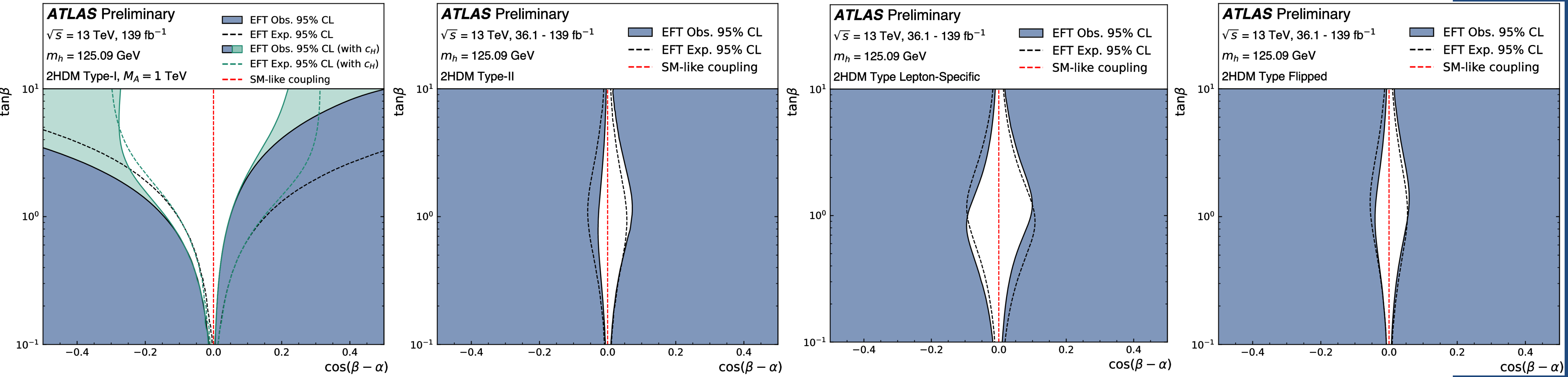
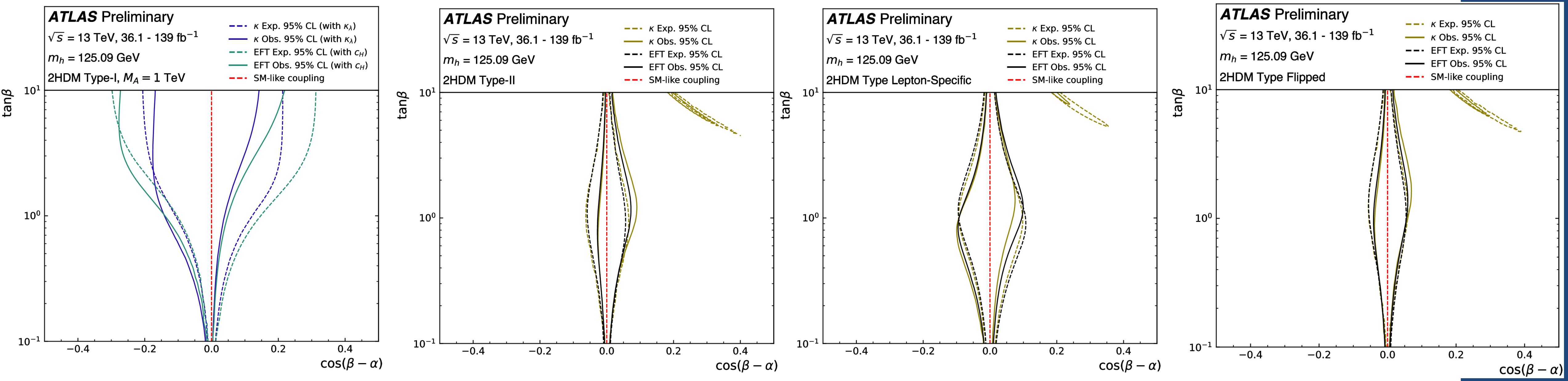
- Only linear expansion for EFT



- No surprise and large 2HDM parameter spaces are excluded
- c_H constraint is included in Type-I

2HDM constraint

- Compare with interpretation with coupling measurement(k-framework)



- Coupling measurement gives similar (slightly better) constraint
  - Missing dim-8 operators
  - No petal structure in EFT (no 2nd minimum)

Constraints on MSSM

Eur. Phys. J. C 79 (2019) 617, 279
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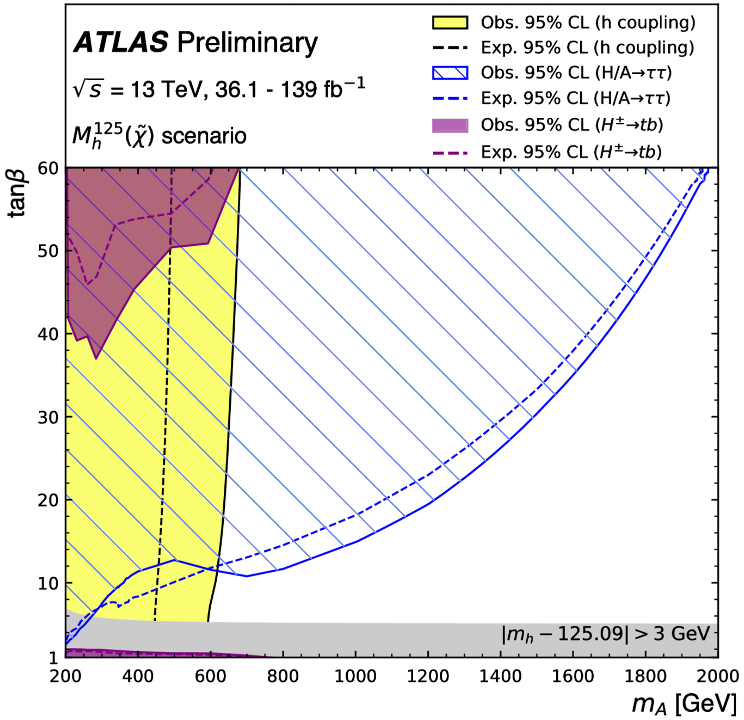
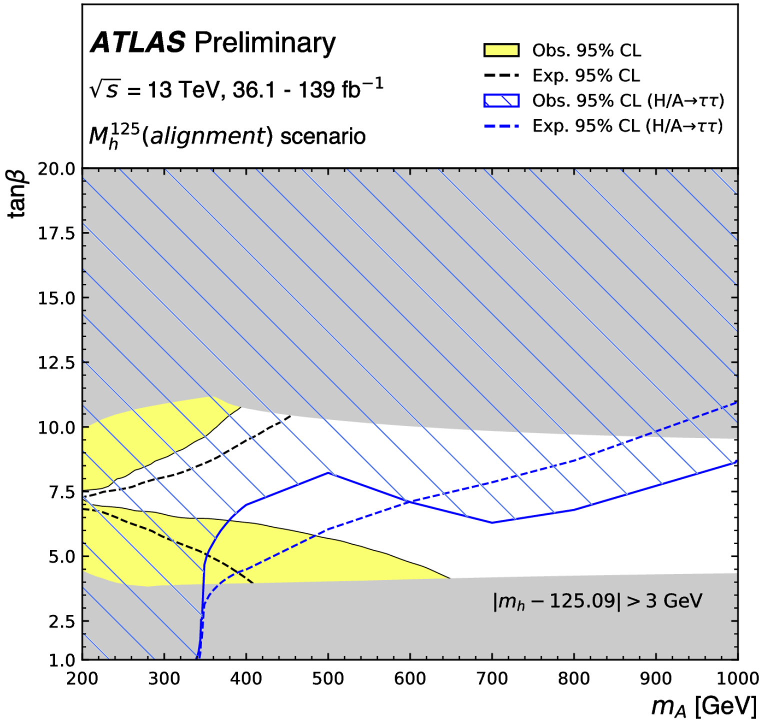
- Not use EFT interpretation results but Constraint from STXS measurements
- Several MSSM benchmark scenarios are considered (more in backup)

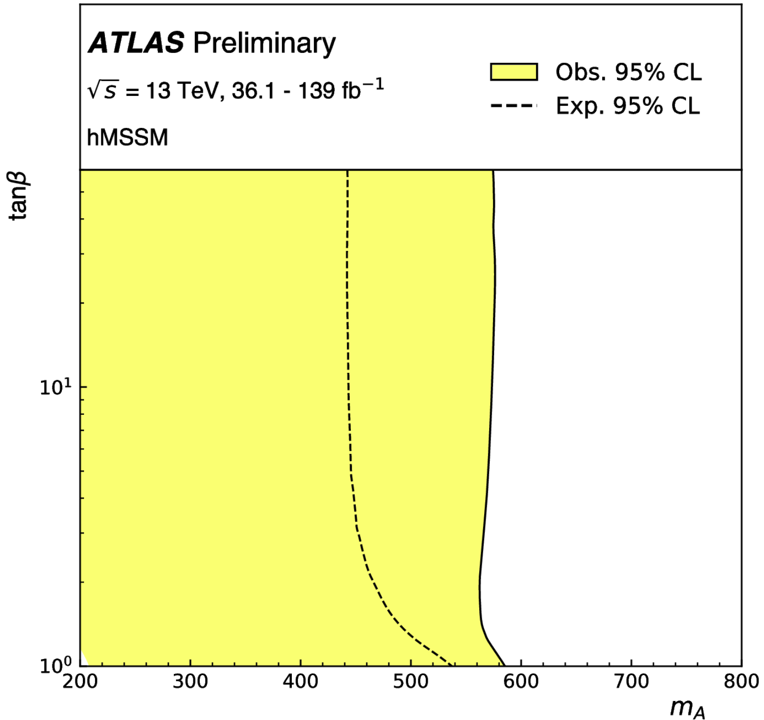
$M_H^{125}(\overline{\chi})$ scenario:
All charginos and neutralinos are relatively light with significant higgsino-gaugio mixing
H→bb, H→γγ decay enhanced (suppressed) at low(high) tanβ,



$M_H^{125}(alighment)$ scenario:
Alignment without decoupling scenario one of CP even scalars have SM-like couplings
tanβ ~7 → nearly SM-like



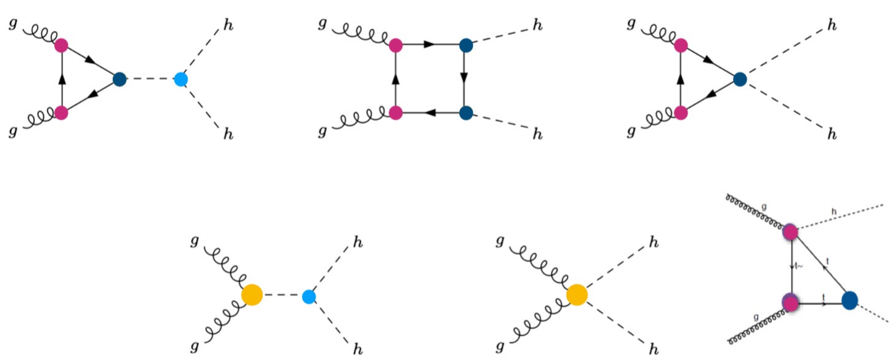
hMSSM scenario:
m_H is 125.09 GeV with radiative correction from stop-top sector, determine α, m_H, $m_{H\pm}$, couplings



EFT in DiHiggs

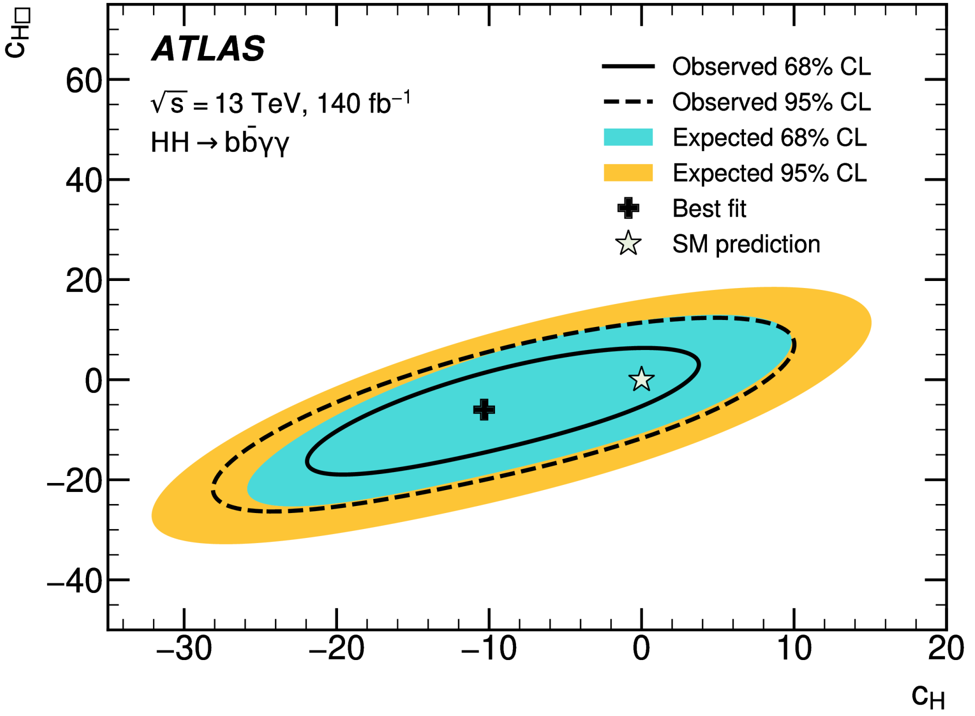
arXiv:2310.12301

- DiHiggs production is sensitive to the EFT parameters
  - Both interpretations for HEFT and SMEFT
  - 1D or 2D parameter scan (other parameters fixed to zero)



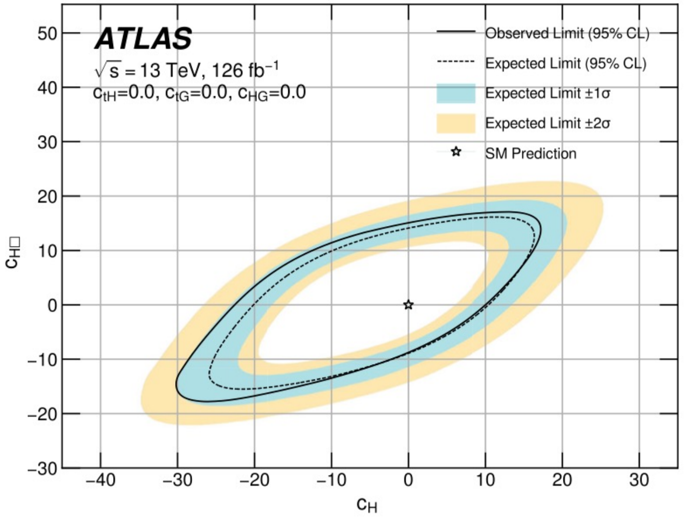
$C_{H\square}$
C_{HD}
C_{H}
C_{HG}
C_{tH}
C_{tG}

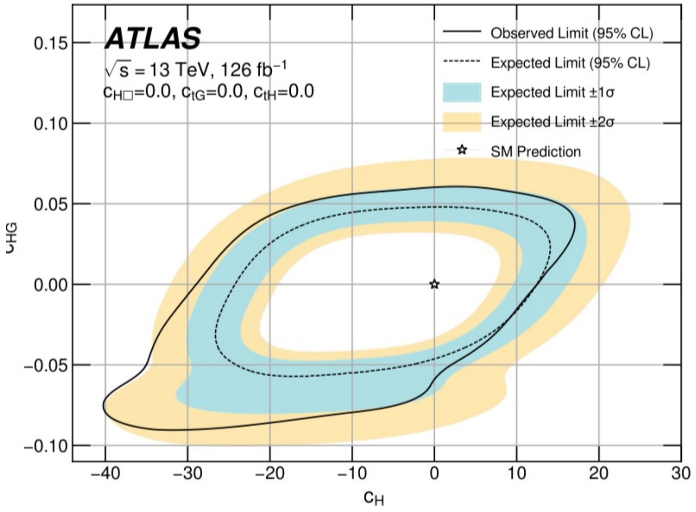
HH→bbγγ



Wilson coefficient	95% CL Observed	95% CL Expected
c_H	$[-14.4,\ 6.2]$	$[-16.8,\ 9.7]$
$c_{H\square}$	$[-\ 9.4, 10.2]$	$[-12.4, 13.7]$

HH→4b





Constraint on CP-odd operators

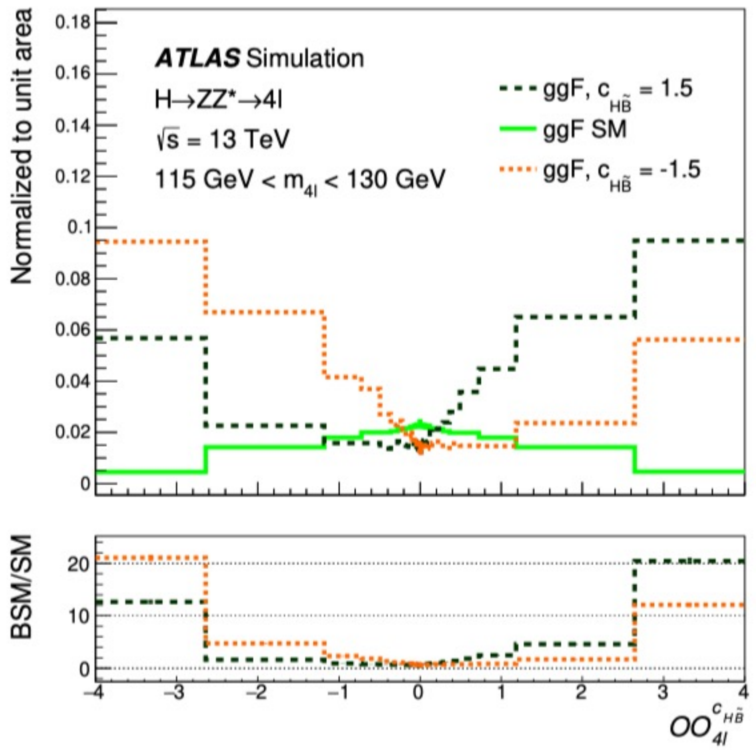
- H→ZZ→4l constraint with CP-odd EFT parameters
- "Optimal observable" using the interference term of SM and BSM

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

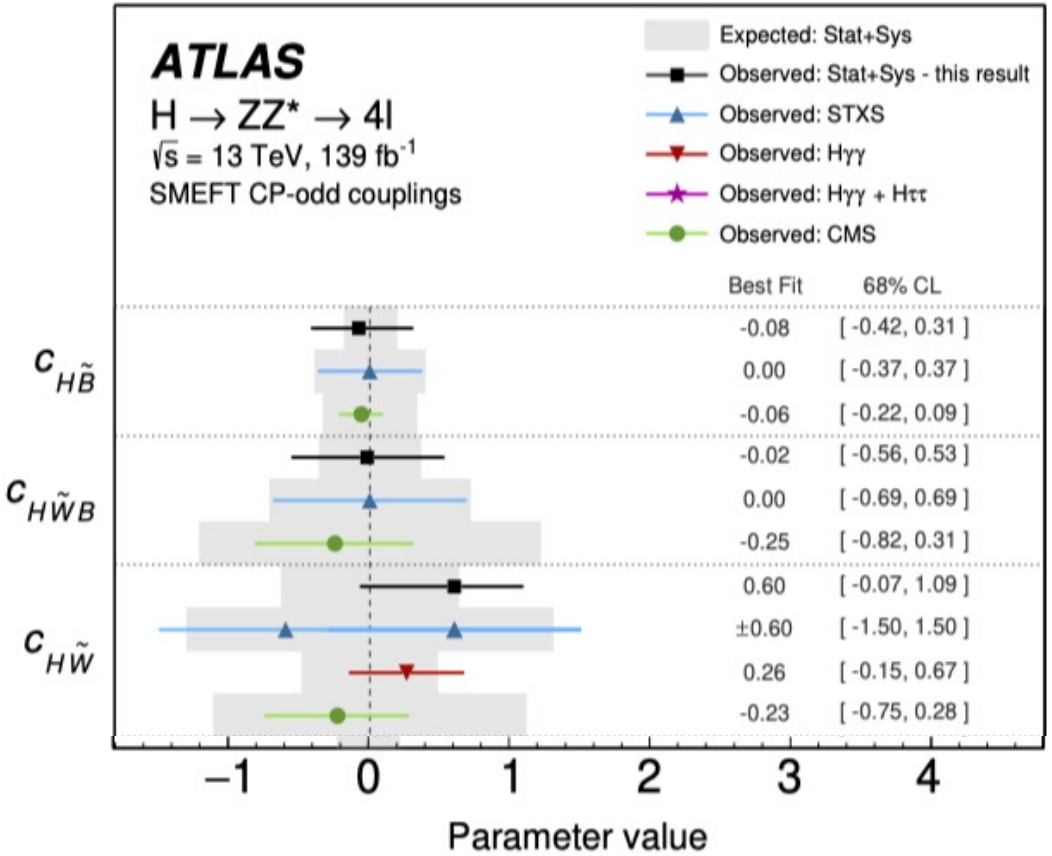
Operator	Structure	Coupling
Warsaw Basis		
$O_{\Phi\tilde{W}}$	$\Phi^\dagger\Phi\tilde{W}^I_{\mu\nu}W^{\mu\nu I}$	$c_{H\tilde{W}}$
$O_{\Phi\tilde{W}B}$	$\Phi^\dagger\tau^I\Phi\tilde{W}^I_{\mu\nu}B^{\mu\nu}$	$c_{H\tilde{W}B}$
$O_{\Phi\tilde{B}}$	$\Phi^\dagger\Phi\tilde{B}_{\mu\nu}B^{\mu\nu}$	$c_{H\tilde{B}}$

Asymmetric CP-odd

Symmetric CP-even



(b) $OO_{4\ell}^{c_{H\tilde{B}}}$



Other EFT interpretations

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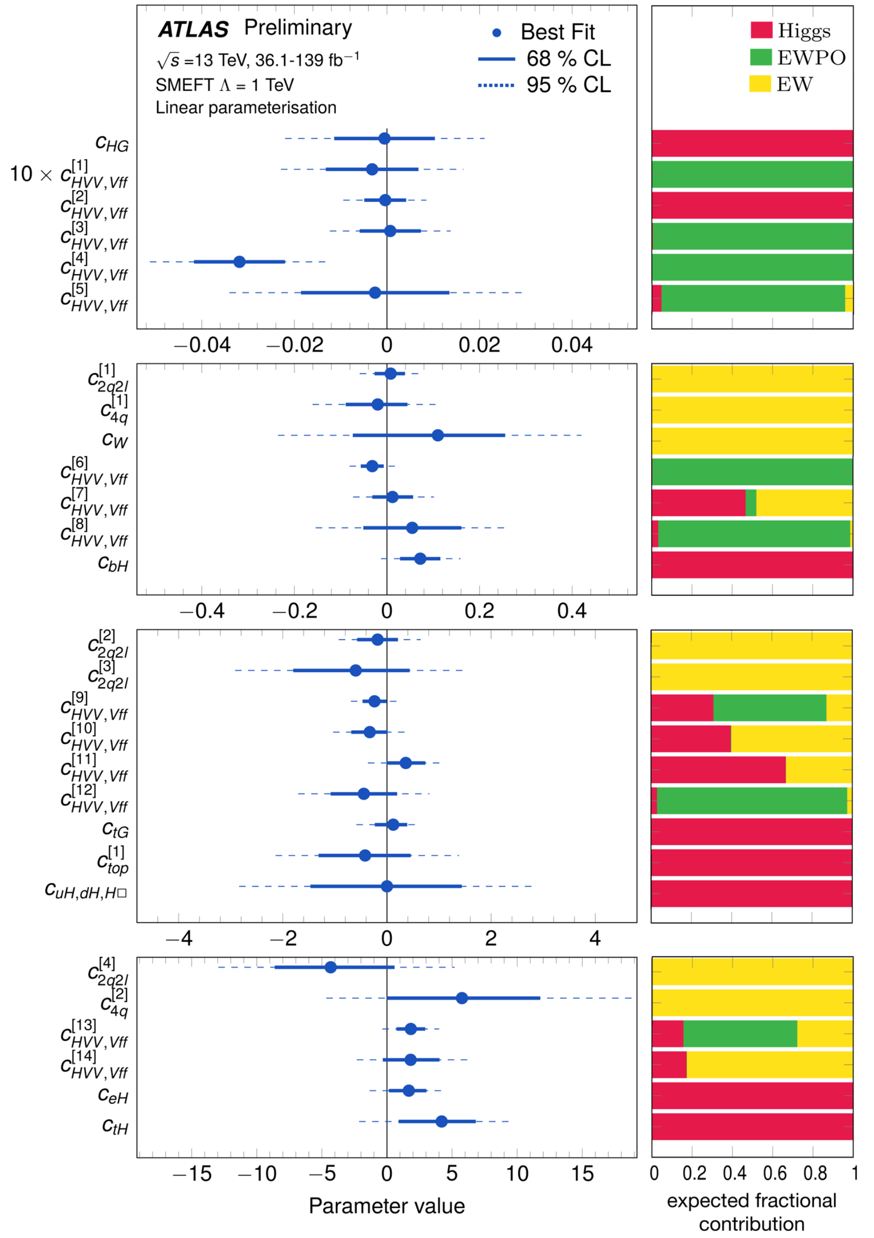
- Combined EFT interpretations with other EW measurements
  - Differential cross section measurements with diboson and VBF Z production

  (All EW measurements are not included yet)

Process	Important phase space requirements	Observable	$\mathcal{L}$ [fb^{-1}]	Ref.
$pp \to e^{\pm}\nu\mu^{\mp}\nu$	$m_{\ell\ell} > 55\,GeV$, $p_{\mathrm{T}}^{\mathrm{jet}} < 35\,GeV$	$p_{\mathrm{T}}^{\mathrm{lead.\ lep.}}$	36	[19]
$pp \to \ell^{\pm}\nu\ell^{+}\ell^{-}$	$m_{\ell\ell} \in (81, 101)\,GeV$	m_{T}^{WZ}	36	[20]
$pp \to \ell^{+}\ell^{-}\ell^{+}\ell^{-}$	$m_{4\ell} > 180\,GeV$	m_{Z2}	139	[21]
$pp \to \ell^{+}\ell^{-}jj$	$m_{jj} > 1000\,GeV$, $m_{\ell\ell} \in (81, 101)\,GeV$	$\Delta\phi_{jj}$	139	[22]

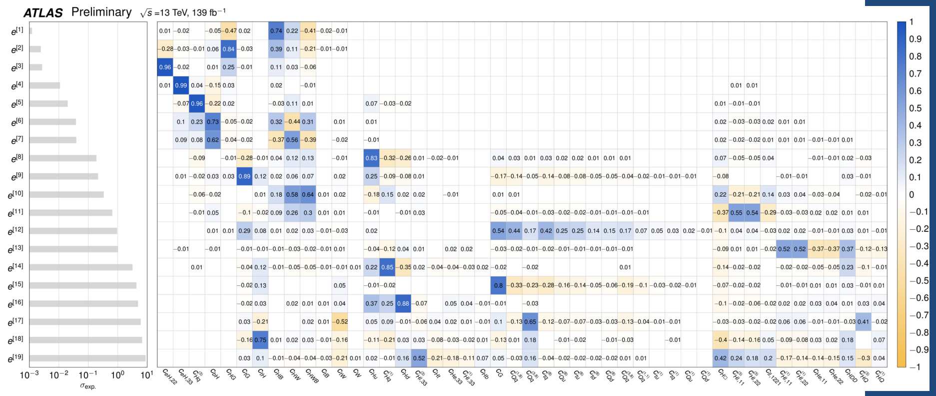
  - Electroweak precision observable (mainly from SLC and LEP)

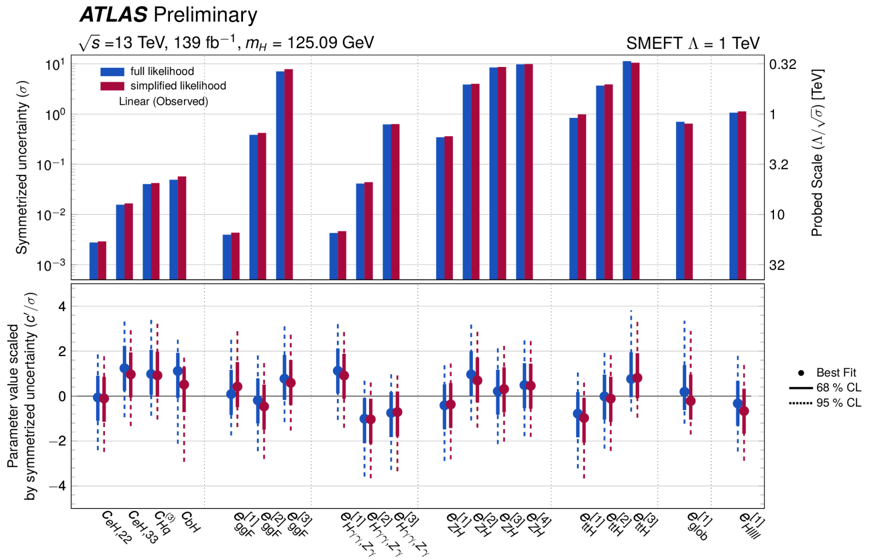
Observable	Measurement	Prediction	Ratio
Γ_Z [MeV]	2495.2 ± 2.3	2495.7 ± 1	0.9998 ± 0.0010
R^0_ℓ	20.767 ± 0.025	20.758 ± 0.008	1.0004 ± 0.0013
R^0_c	0.1721 ± 0.0030	0.17223 ± 0.00003	0.999 ± 0.017
R^0_b	0.21629 ± 0.00066	0.21586 ± 0.00003	1.0020 ± 0.0031
$A^{0,\ell}_{\mathrm{FB}}$	0.0171 ± 0.0010	0.01718 ± 0.00037	0.995 ± 0.062
$A^{0,c}_{\mathrm{FB}}$	0.0707 ± 0.0035	0.0758 ± 0.0012	0.932 ± 0.048
$A^{0,b}_{\mathrm{FB}}$	0.0992 ± 0.0016	0.1062 ± 0.0016	0.935 ± 0.021
σ^0_{had} [pb]	41488 ± 6	41489 ± 5	0.99998 ± 0.00019



Summary

- No BSM particle found (so far) at LHC 😢
- Higgs, EW, top precise measurements provide valuable EFT interpretations and stronger constraints
- Still can improve EFT formalism for both theory and experimental sides
  - Principal component analysis
  - Global EFT interpretation
  - Provide simplified likelihood in HEPdata
  - Dim-8 calculation
- Showed EFT interpretation is usable to constrain UV complete model
  ➔ Beyond 2HDM scenarios?





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Backup

EFT formulation

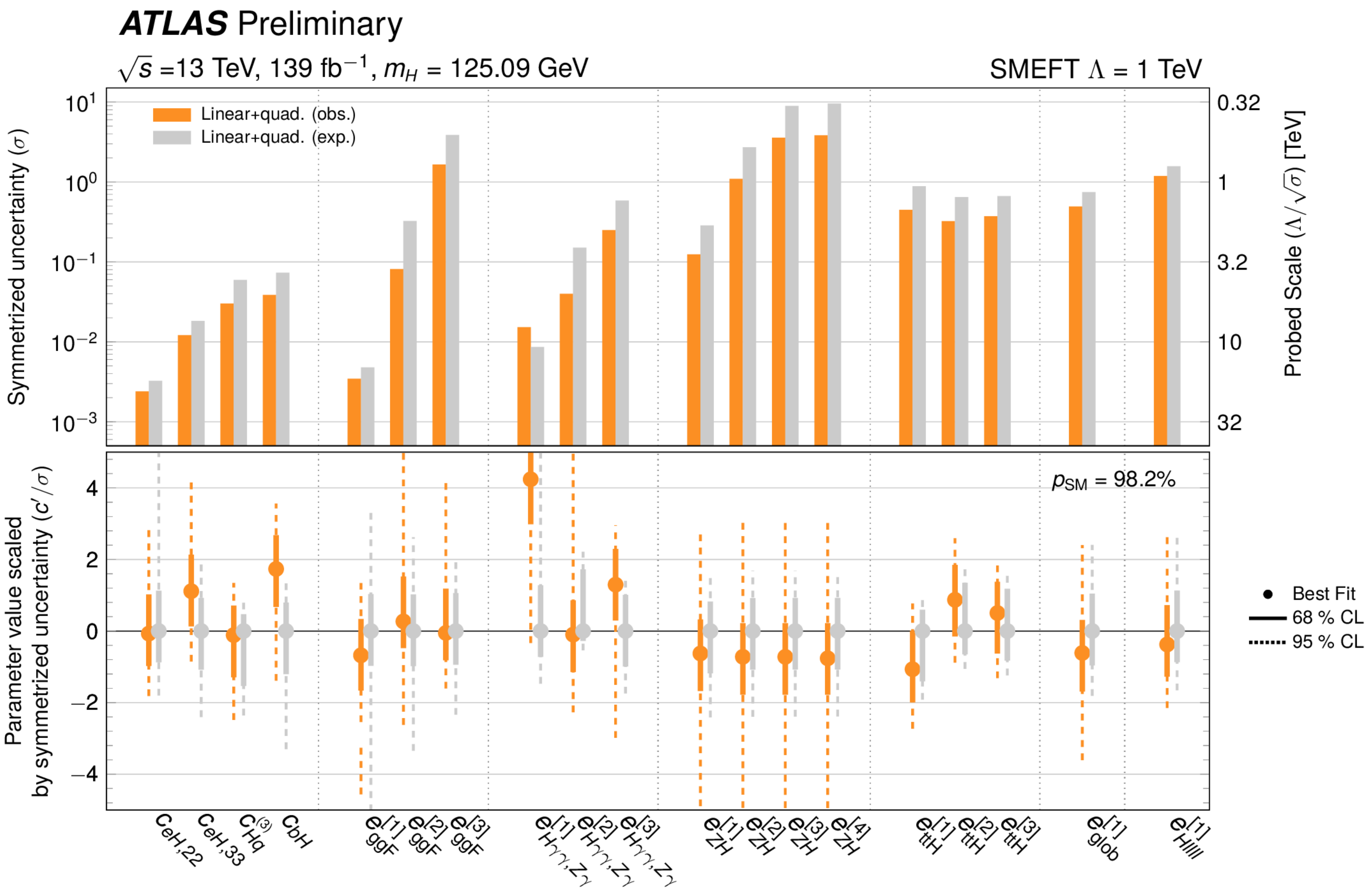
- SMEFT cross sections are calculated by LO diagrams (NLO QCD for loop, NLO QED for H→γγ, Zγ)
- Higher order calculation computed by scaling SM cross section assuming the same relative effect on σ_{int} and σ_{BSM} as on σ_{SM}

$$\sigma_{\mathrm{SMEFT}} = \sigma_{\mathrm{SM}}^{\mathrm{((N)N)NLO}} \times \left(1 + \frac{\sigma_{\mathrm{int}}^{\mathrm{(N)LO}}}{\sigma_{\mathrm{SM}}^{\mathrm{(N)LO}}} + \frac{\sigma_{\mathrm{BSM}}^{\mathrm{(N)LO}}}{\sigma_{\mathrm{SM}}^{\mathrm{(N)LO}}}\right)$$

- Branching ratio effects are taken into account

$$(\sigma\times B)_{\mathrm{SMEFT}}^{i,k',H\to X} = (\sigma\times B)_{\mathrm{SM,(N(N))NLO}}^{i,k',H\to X} \left(1 + \boxed{\frac{\sigma_{\mathrm{int,(N)LO}}^{i,k'}}{\sigma_{\mathrm{SM,(N)LO}}^{i,k'}}} + \boxed{\frac{\sigma_{\mathrm{BSM,(N)LO}}^{i,k'}}{\sigma_{\mathrm{SM,(N)LO}}^{i,k'}}}\right) \left(\frac{1 + \boxed{\frac{\Gamma_{\mathrm{int}}^{H\to X}}{\Gamma_{\mathrm{SM}}^{H\to X}}} + \boxed{\frac{\Gamma_{\mathrm{BSM}}^{H\to X}}{\Gamma_{\mathrm{SM}}^{H\to X}}}}{1 + \boxed{\frac{\Gamma_{\mathrm{int}}^{H}}{\Gamma_{\mathrm{SM}}^{H}}} + \boxed{\frac{\Gamma_{\mathrm{BSM}}^{H}}{\Gamma_{\mathrm{SM}}^{H}}}}\right)$$

Linear+Quad



ATLAS Preliminary
$\sqrt{s}$ =13 TeV, 139 fb^{-1}, m_H = 125.09 GeV
SMEFT Λ = 1 TeV
Linear+quad. (obs.)
Linear+quad. (exp.)
Symmetrized uncertainty (σ)
Probed Scale ($\Lambda/\sqrt{\sigma}$) [TeV]
Parameter value scaled by symmetrized uncertainty (c'/σ)
p_{SM} = 98.2%
Best Fit
68 % CL
95 % CL
$C_{eH,22}$ $C_{eH,33}$ $C_{Hq}^{(3)}$ C_{bH}
$e_{ggF}^{[1]}$ $e_{ggF}^{[2]}$ $e_{ggF}^{[3]}$
$e_{H\gamma\gamma,Z\gamma}^{[1]}$ $e_{H\gamma\gamma,Z\gamma}^{[2]}$ $e_{H\gamma\gamma,Z\gamma}^{[3]}$
$e_{ZH}^{[1]}$ $e_{ZH}^{[2]}$ $e_{ZH}^{[3]}$ $e_{ZH}^{[4]}$
$e_{ttH}^{[1]}$ $e_{ttH}^{[2]}$ $e_{ttH}^{[3]}$
$e_{glob}^{[1]}$
$e_{Hllll}^{[1]}$

Constraints on 2HDM

2HDM: one of natural extension of Higgs sector

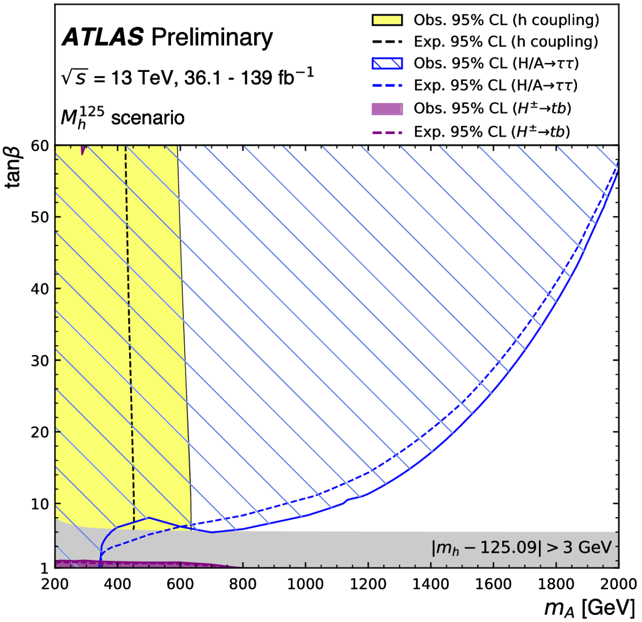
- parameter: h, H, A, $H^{\pm}$, CP-even mixing angle α, two doublet mixing β, m_{12}

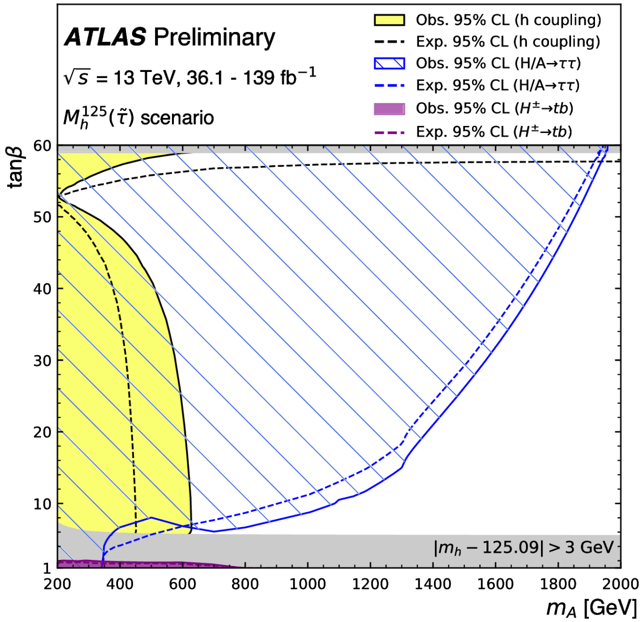
Coupling	Type I	Type II	Lepton-specific	Flipped
u, c, t	$s_{\beta-\alpha} + c_{\beta-\alpha}/\tan\beta$			
d, s, b	$s_{\beta-\alpha} + c_{\beta-\alpha}/\tan\beta$	$s_{\beta-\alpha} - c_{\beta-\alpha} \times \tan\beta$	$s_{\beta-\alpha} + c_{\beta-\alpha}/\tan\beta$	$s_{\beta-\alpha} - c_{\beta-\alpha}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

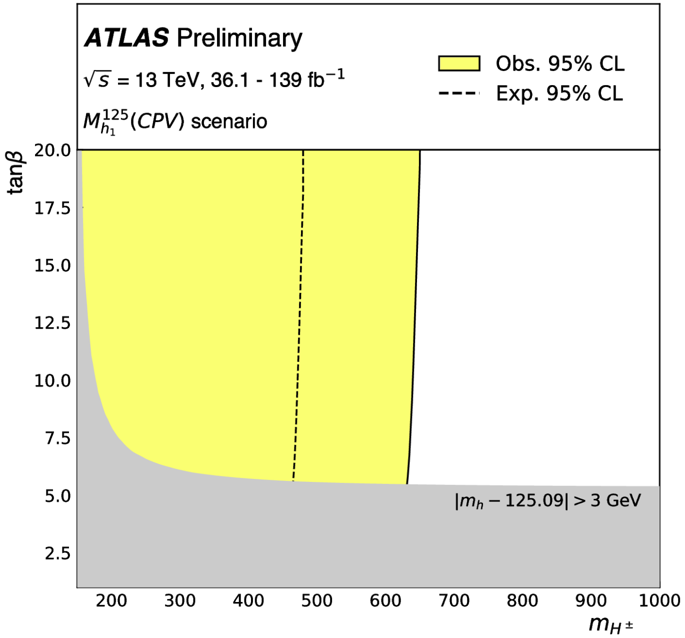
$$v_1^2 + v_2^2 = v^2\,, \tan\beta = \frac{v_2}{v_1}, \bar{m}^2 = \frac{m_{12}^2}{\sin\beta\cos\beta} = m_A^2 + \lambda_5 v^2$$

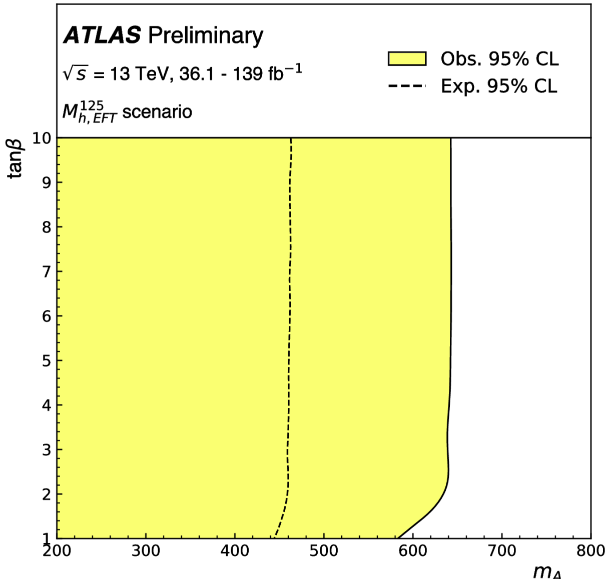
$$\text{Assuming, } \lambda_5 v^2 \ll m_A^2, \bar{m} = m_A = 1\text{TeV}\ (\lambda_5 = 0)$$

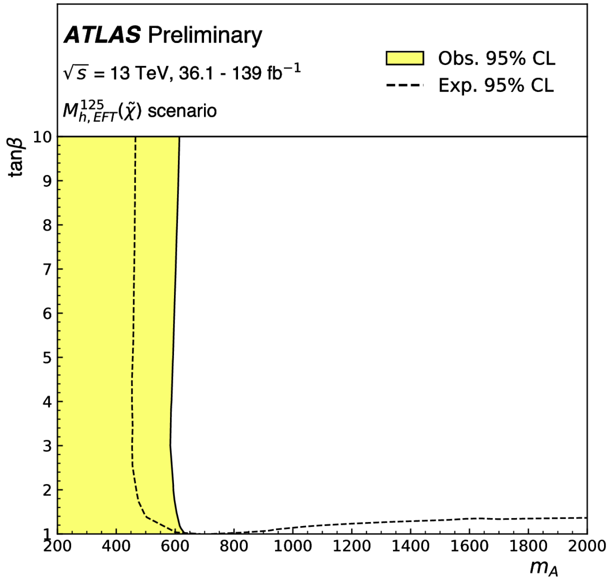
Constraints on MSSM



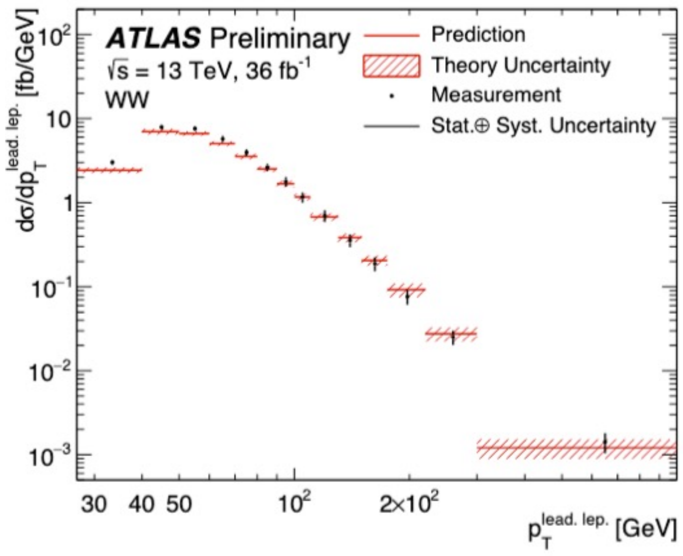


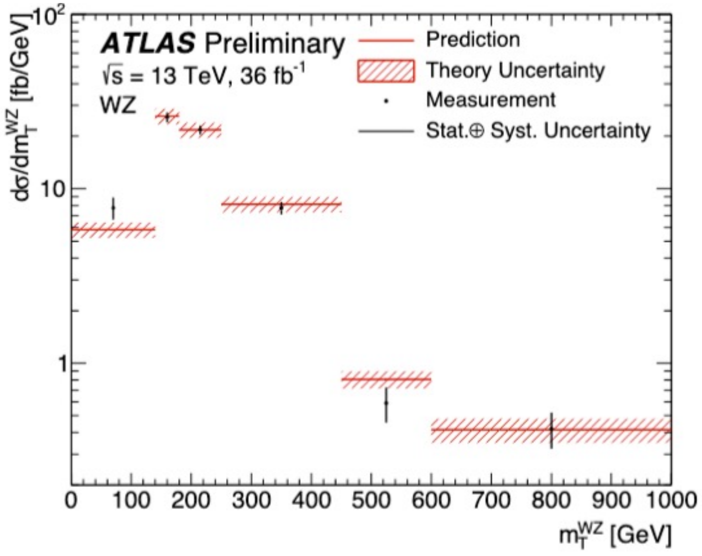


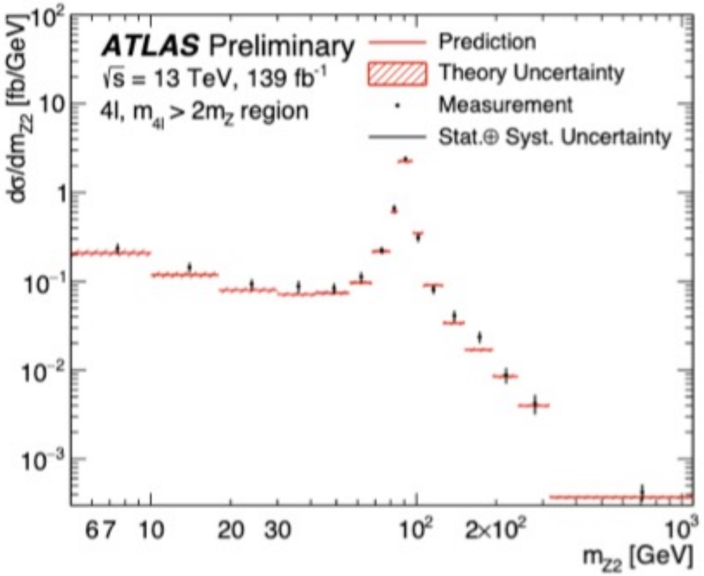


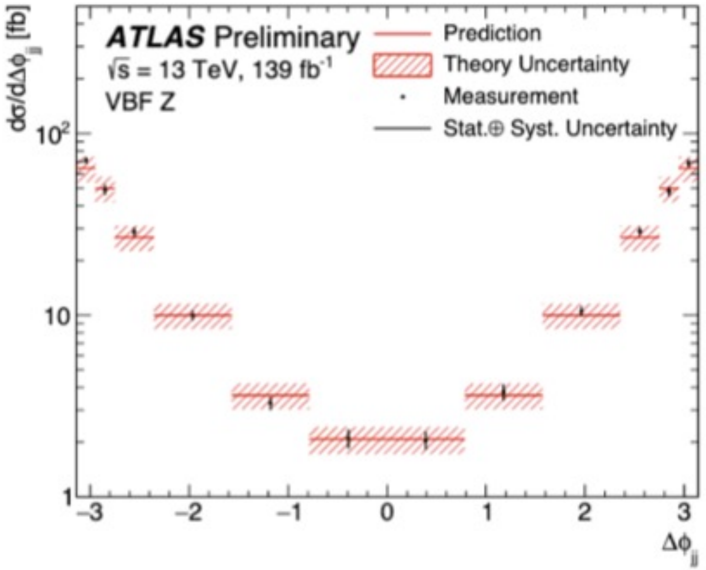


Global EFT EW inputs









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Ref

- https://indico.cern.ch/event/1296757/timetable/
- https://indico.cern.ch/event/1276727/timetable/?view=standard