Going global

Combining electroweak precision, diboson, Higgs, and top data to search for new physics

[J. Ellis, M. Madigan, KM, V. Sanz & T. You; JHEP 04 (2021) 279]

fitmaker

https://gitlab.com/kenmimasu/fitrepo

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ILC Workshop on Potential Experiments (ILCX)

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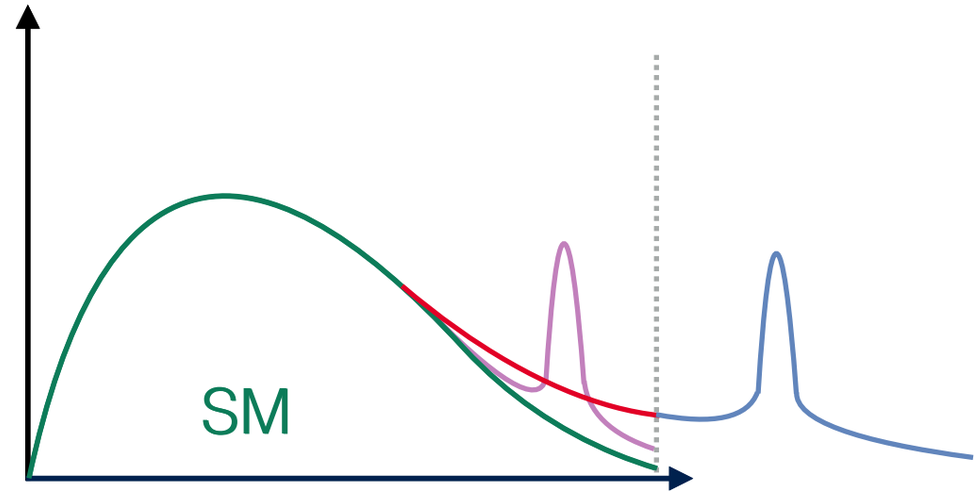
Energy & precision

Paradigm shift at the energy frontier for BSM searches

Direct (bumps)

Indirect (tails)

⇒ New physics is heavy



Heavy new physics
Precision measurements
High energy

Standard Model Effective Field Theory (SMEFT)

A parameter space for BSM interactions between SM particles

SMEFT is…

$$\mathcal{L}_{\text{eff}} = \sum_i \frac{c_i \mathcal{O}_i^D}{\Lambda^{D-4}}$$

Model independent

- Underlying assumptions

Heavy new physics: M > E_{exp}
SM field content & gauge symmetries
Linear EWSB: Higgs = doublet

Systematically improvable

- Double expansion *higher dim.* $\frac{E^2}{\Lambda^2}$ & $\{g_S, g, g'\}$ *more loops*

Global

- Model independence: we don't know what operators NP will generate
- Patterns & correlations among observables are key
- Ultimate goal: complete SMEFT likelihood confronted with HEP data

EWPO, Higgs, multiboson, top, DY, flavor,…

Established part of HEP programme

Status in a nutshell

Global new physics searches via high precision/energy

- Z & W-pole data: handle on the EW gauge sector
- LHC: thriving Higgs & top programmes
- Probing gauge interactions at high energy (VV, VBS, VVV, …)

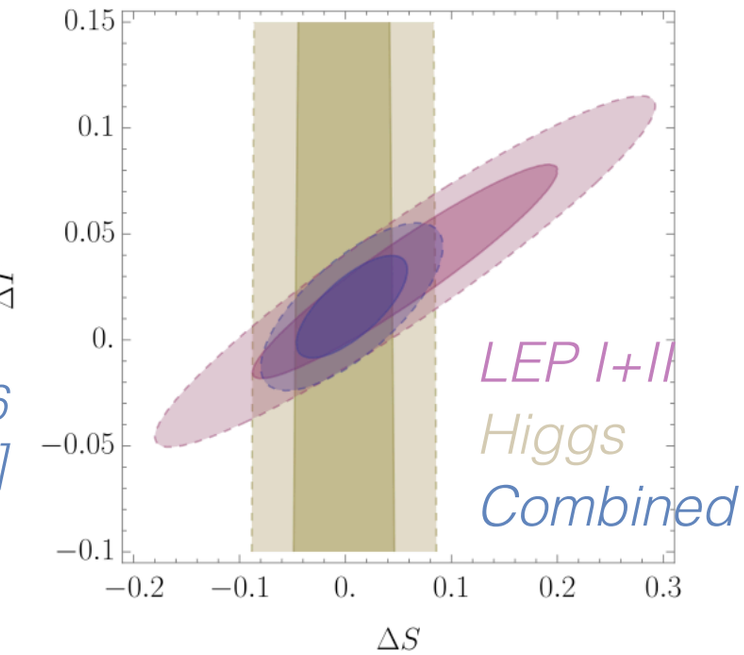
[Han & Skiba; PRD 71 (2005) 075009]
[Falkowski & Riva; JHEP 02 (2015) 039]

How much cross-talk? Where does being global matter?

We know that Higgs physics greatly complements LEP data

- Access to parameter directions not probed at LEP
- Allows for a closed fit to flavor-universal SMEFT
- Crucial to combine EWPO, Diboson & Higgs data

[Corbett et al.; PRD 87 (2013) 015022]
[Pomarol & Riva; JHEP 01 (2014) 151]
[Ellis, Sanz & You; JHEP 03 (2015) 157]
[Biekötter Corbett & Plehn; SciPost Phys 6 (2019) 6, 064]…
[Ellis et al.; JHEP 06 (2018) 146]



Top & Higgs

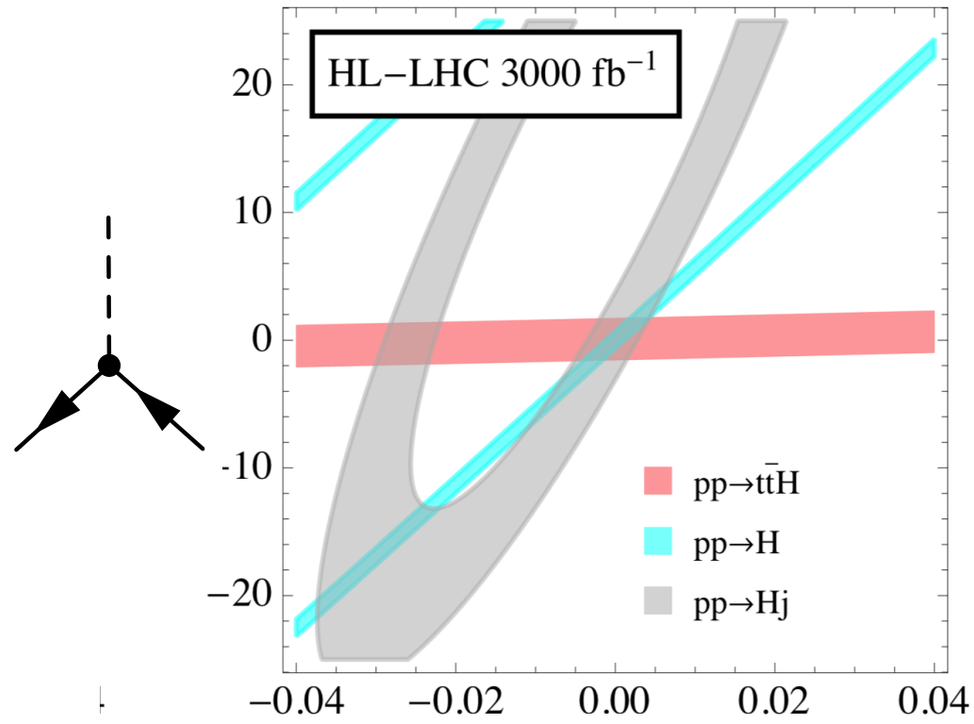
Inextricably linked in the SM

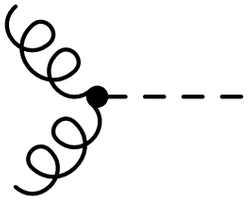
- Yukawa interaction controls ggF
- Strong BSM motivation to study tops

ggF is well measured now

- Does not exclude top partners, anomalous Yukawa!

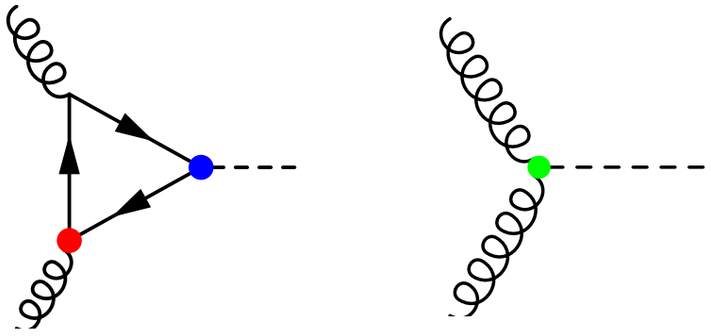
[Maltoni, Vryonidou & Zhang; JHEP 1610 (2016) 123]





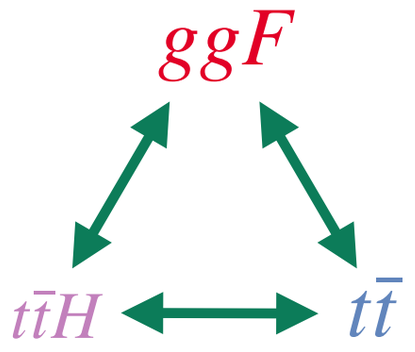
Blind direction in BSM scenarios
=
Effective coupling degeneracy

C_{HG} *Point-like*
C_{tH} *Yukawa*
C_{tG} *Dipole*



Need more data to break degeneracy

- $t\bar{t}H$ production for direct Yukawa measurement
- $t\bar{t}$ data to constrain dipole



The fit

Top, Higgs, Diboson and Electroweak Fit to the Standard Model Effective Field Theory

John Ellis,[a,b,c] Maeve Madigan,[d] Ken Mimasu,[a] Veronica Sanz[e,f] and Tevong You[b,d,g]

[JHEP 04 (2021) 279]

Global SMEFT interpretation of 4 categories of data

Based on [Ellis et al.; JHEP 06 (2018) 146]

14 • Electroweak Precision Observables (EWPO): Z-pole & W-mass

118 • LEP2 & LHC diboson production: differential WW, WZ, Zjj

72 • Higgs measurements: signal strengths & STXS

137 • Top data: single-top, ttbar & asymmetries, ttV, tZ, tW

Big thanks to authors of SMEFiT analysis [JHEP 04 (2019) 100] for sharing some of their top predictions

341 measurements across categories

- Chosen to be statistically independent & maximise reach
- Correlations included when publicly available (mostly are)

Linear EFT approximation: $\mu_X \equiv \frac{X}{X_{SM}} = 1 + \sum_i a_i^X \frac{C_i}{\Lambda^2} + \mathcal{O}\left(\frac{1}{\Lambda^4}\right)$

Theory

[Grzadkowski et al.; JHEP 10 (2010) 085]

X^3		H^6 and H^4D^2		ψ^2H^3	
$\mathcal{O}_G$	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	$\mathcal{O}_H$	$(H^\dagger H)^3$	$\mathcal{O}_{eH}$	$(H^\dagger H)(\bar{l}_p e_r H)$
$\mathcal{O}_{\tilde{G}}$	$f^{ABC}\widetilde{G}^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	$\mathcal{O}_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	$\mathcal{O}_{uH}$	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
$\mathcal{O}_W$	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$\mathcal{O}_{HD}$	$\left(H^\dagger D^\mu H\right)^\star \left(H^\dagger D_\mu H\right)$	$\mathcal{O}_{dH}$	$(H^\dagger H)(\bar{q}_p d_r H)$
$\mathcal{O}_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				

X^2H^2		ψ^2XH		ψ^2H^2D	
$\mathcal{O}_{HG}$	$H^\dagger H\, G^A_{\mu\nu}G^{A\mu\nu}$	$\mathcal{O}_{eW}$	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I H W^I_{\mu\nu}$	$\mathcal{O}^{(1)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p\gamma^\mu l_r)$
$\mathcal{O}_{H\tilde{G}}$	$H^\dagger H\, \widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	$\mathcal{O}_{eB}$	$(\bar{l}_p\sigma^{\mu\nu}e_r)H B_{\mu\nu}$	$\mathcal{O}^{(3)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$\mathcal{O}_{HW}$	$H^\dagger H\, W^I_{\mu\nu}W^{I\mu\nu}$	$\mathcal{O}_{uG}$	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{H}\, G^A_{\mu\nu}$	$\mathcal{O}_{He}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$
$\mathcal{O}_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	$\mathcal{O}_{uW}$	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{H}\, W^I_{\mu\nu}$	$\mathcal{O}^{(1)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$
$\mathcal{O}_{HB}$	$H^\dagger H\, B_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{uB}$	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{H}\, B_{\mu\nu}$	$\mathcal{O}^{(3)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$\mathcal{O}_{H\tilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{dG}$	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)H\, G^A_{\mu\nu}$	$\mathcal{O}_{Hu}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$
$\mathcal{O}_{HWB}$	$H^\dagger\tau^I H\, W^I_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{dW}$	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I H\, W^I_{\mu\nu}$	$\mathcal{O}_{Hd}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$
$\mathcal{O}_{H\widetilde{W}B}$	$H^\dagger\tau^I H\, \widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{dB}$	$(\bar{q}_p\sigma^{\mu\nu}d_r)H\, B_{\mu\nu}$	$\mathcal{O}_{Hud}$	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p\gamma^\mu d_r)$

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
$\mathcal{O}_{ll}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	$\mathcal{O}_{ee}$	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	$\mathcal{O}_{le}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$\mathcal{O}^{(1)}_{qq}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	$\mathcal{O}_{uu}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	$\mathcal{O}_{lu}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$\mathcal{O}^{(3)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	$\mathcal{O}_{dd}$	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	$\mathcal{O}_{ld}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$\mathcal{O}^{(1)}_{lq}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	$\mathcal{O}_{eu}$	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	$\mathcal{O}_{qe}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$\mathcal{O}^{(3)}_{lq}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	$\mathcal{O}_{ed}$	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$\mathcal{O}^{(1)}_{qu}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$\mathcal{O}^{(1)}_{ud}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$\mathcal{O}^{(8)}_{qu}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$\mathcal{O}^{(8)}_{ud}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$\mathcal{O}^{(1)}_{qd}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$\mathcal{O}^{(8)}_{qd}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
$\mathcal{O}_{ledq}$	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	$\mathcal{O}_{duq}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(q^{\gamma j}_s)^T C l^k_t\right]$
$\mathcal{O}^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$	$\mathcal{O}_{qqu}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$\mathcal{O}^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$	$\mathcal{O}_{qqq}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(q^{\gamma m}_s)^T C l^n_t\right]$
$\mathcal{O}^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$	$\mathcal{O}_{duu}$	$\varepsilon^{\alpha\beta\gamma}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$\mathcal{O}^{(3)}_{lequ}$	$(\bar{l}^j_p\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)$		

Warsaw basis with CP & B conservation

- Full ‘bosonic’ sector: Higgs, triple-gauge & gauge-Higgs
- Scenario 1: Flavor-**universal** degrees of freedom

  $U(3)_L \times U(3)_e \times U(3)_Q \times U(3)_u \times U(3)_d$ + Yukawas: $\mathcal{O}_{tH}, \mathcal{O}_{bH}, \mathcal{O}_{\tau H}, \mathcal{O}_{\mu H}$

- Scenario 2: **top**-centric flavor symmetry

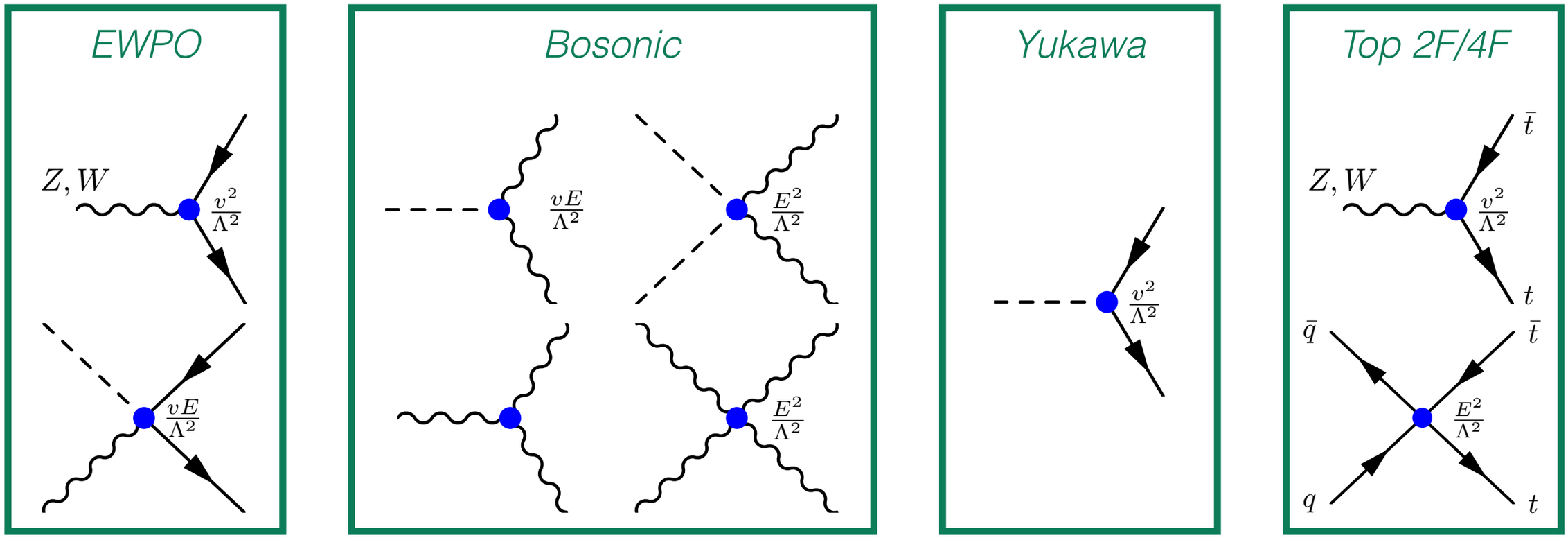
  $U(3)_L \times U(3)_e \times U(2)_Q \times U(2)_u \times U(3)_d$

cf. Minimal flavor violation
[Buras et al.; PLB 500 (2001) 161]
[D’Ambrosio et al.; NPB 645 (2002) 155]
[Aguilar-Saavedra et al.; arXiv:1802.07237]

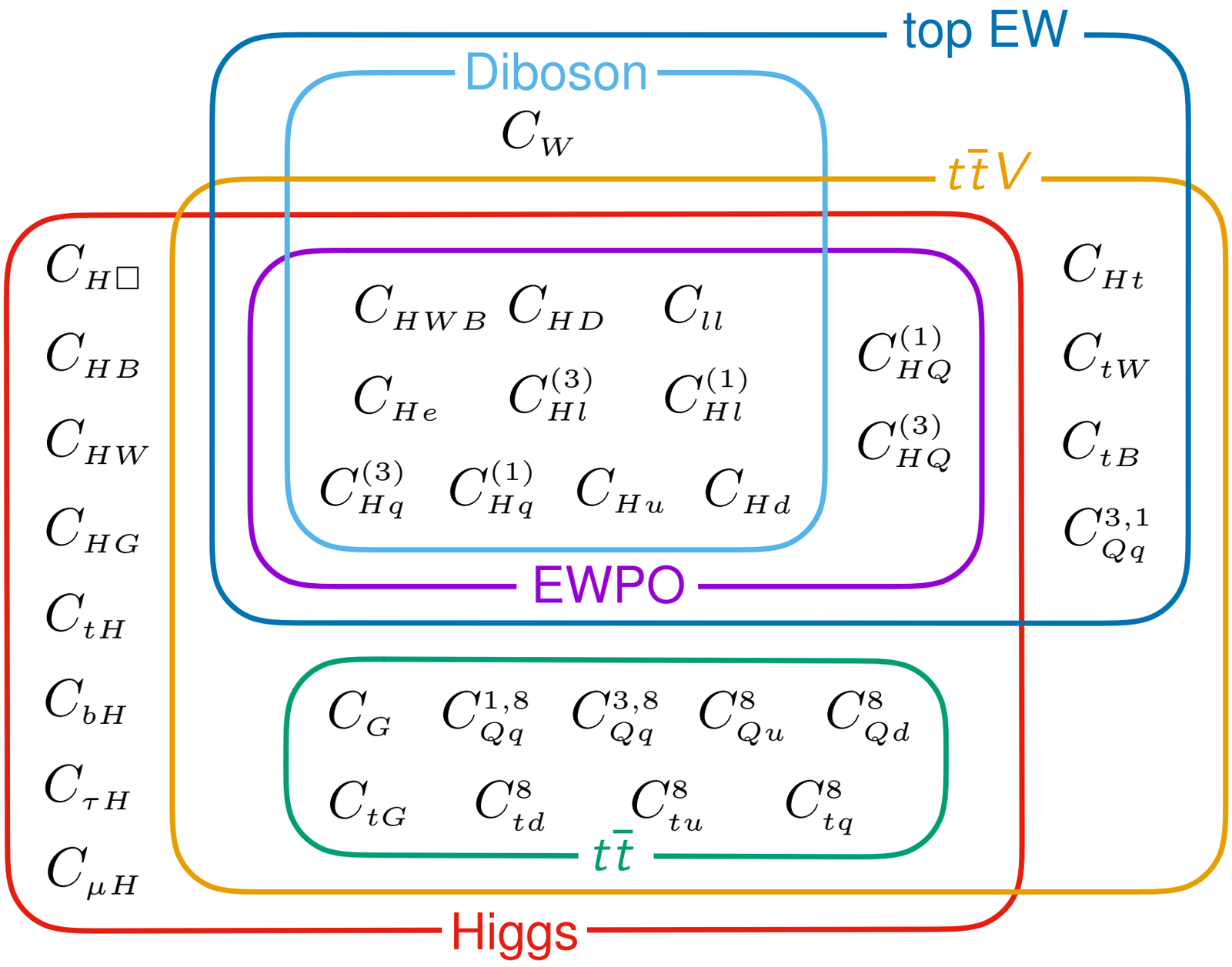
Degrees of freedom

EWPO:	$\mathcal{O}_{HWB}$, $\mathcal{O}_{HD}$, $\mathcal{O}_{ll}$, $\mathcal{O}_{Hl}^{(3)}$, $\mathcal{O}_{Hl}^{(1)}$, $\mathcal{O}_{He}$, $\mathcal{O}_{Hq}^{(3)}$, $\mathcal{O}_{Hq}^{(1)}$, $\mathcal{O}_{Hd}$, $\mathcal{O}_{Hu}$,	
Bosonic:	$\mathcal{O}_{H\Box}$, $\mathcal{O}_{HG}$, $\mathcal{O}_{HW}$, $\mathcal{O}_{HB}$, $\mathcal{O}_{W}$, $\mathcal{O}_{G}$,	
Yukawa:	$\mathcal{O}_{\tau H}$, $\mathcal{O}_{\mu H}$, $\mathcal{O}_{bH}$, $\mathcal{O}_{tH}$,	20
Top 2F:	$\mathcal{O}_{HQ}^{(3)}$, $\mathcal{O}_{HQ}^{(1)}$, $\mathcal{O}_{Ht}$, $\mathcal{O}_{tG}$, $\mathcal{O}_{tW}$, $\mathcal{O}_{tB}$,	
Top 4F:	$\mathcal{O}_{Qq}^{3,1}$, $\mathcal{O}_{Qq}^{3,8}$, $\mathcal{O}_{Qq}^{1,8}$, $\mathcal{O}_{Qu}^{8}$, $\mathcal{O}_{Qd}^{8}$, $\mathcal{O}_{tQ}^{8}$, $\mathcal{O}_{tu}^{8}$, $\mathcal{O}_{td}^{8}$.	+14

In total: 20(34) d.o.f. for the two flavor scenarios



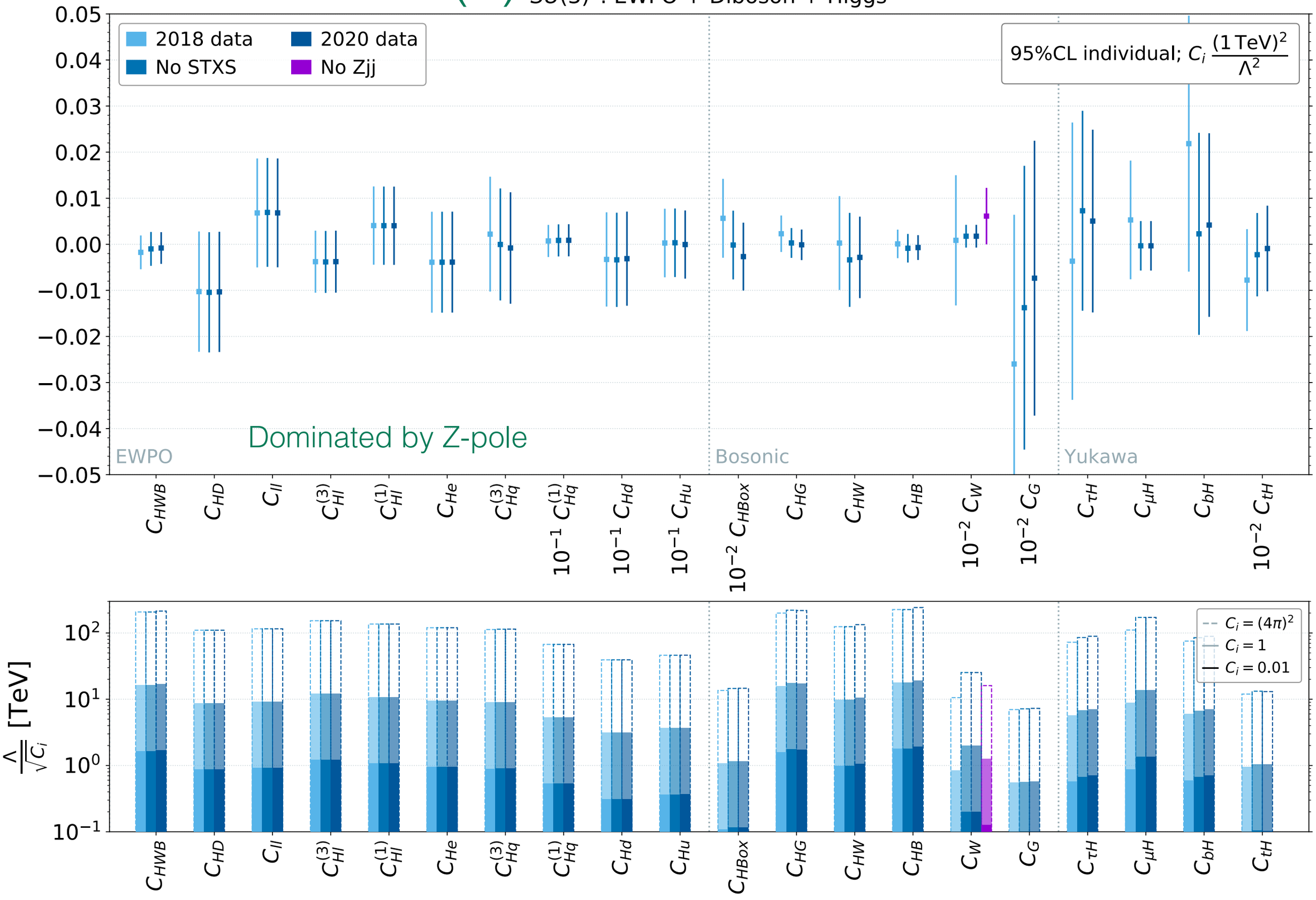
Interplay


top EW
Diboson
C_W
$t\bar{t}V$
$C_{H\Box}$
C_{HB}
C_{HW}
C_{HG}
C_{tH}
C_{bH}
$C_{\tau H}$
$C_{\mu H}$
C_{HWB} C_{HD} C_{ll}
C_{He} $C_{Hl}^{(3)}$ $C_{Hl}^{(1)}$
$C_{Hq}^{(3)}$ $C_{Hq}^{(1)}$ C_{Hu} C_{Hd}
$C_{HQ}^{(1)}$
$C_{HQ}^{(3)}$
EWPO
C_{Ht}
C_{tW}
C_{tB}
$C_{Qq}^{3,1}$
C_G $C_{Qq}^{1,8}$ $C_{Qq}^{3,8}$ C_{Qu}^8 C_{Qd}^8
C_{tG} C_{td}^8 C_{tu}^8 C_{tq}^8
$t\bar{t}$
Higgs

Individual limits: U(3)^5

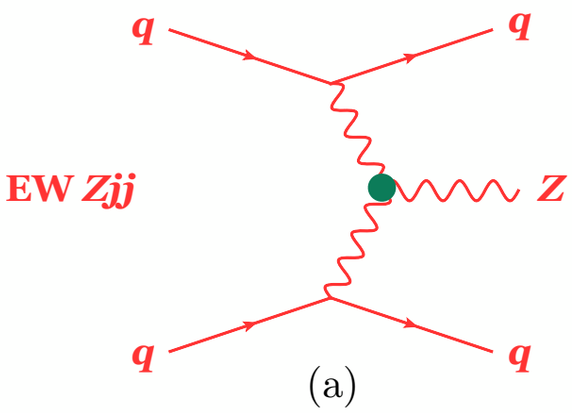
2018 data: [Ellis et al.; JHEP 06 (2018) 146]

$SU(3)^5$: EWPO + Diboson + Higgs

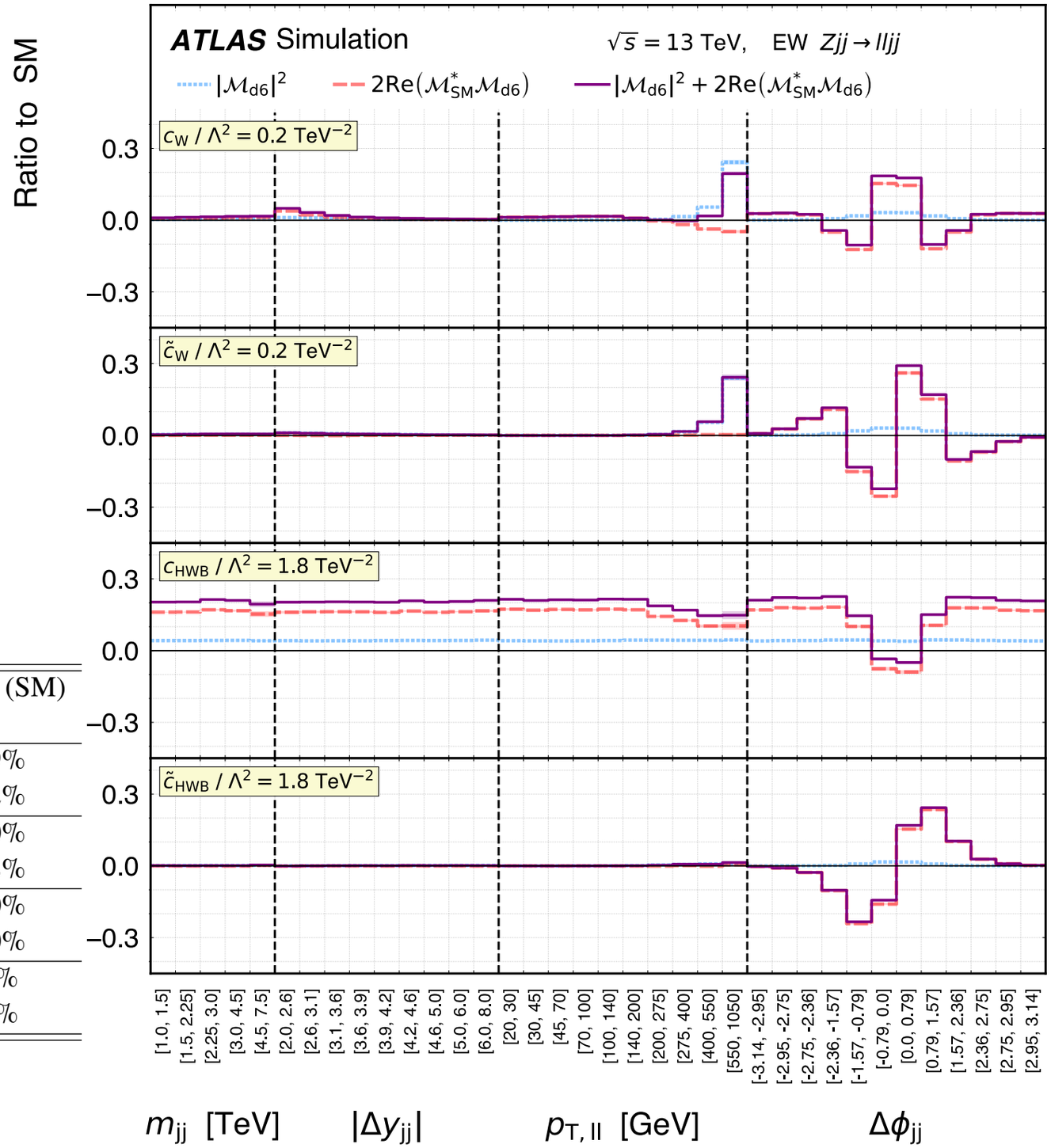


Zjj for triple gauge coupling

[ATLAS; CERN-EP-2020-045]



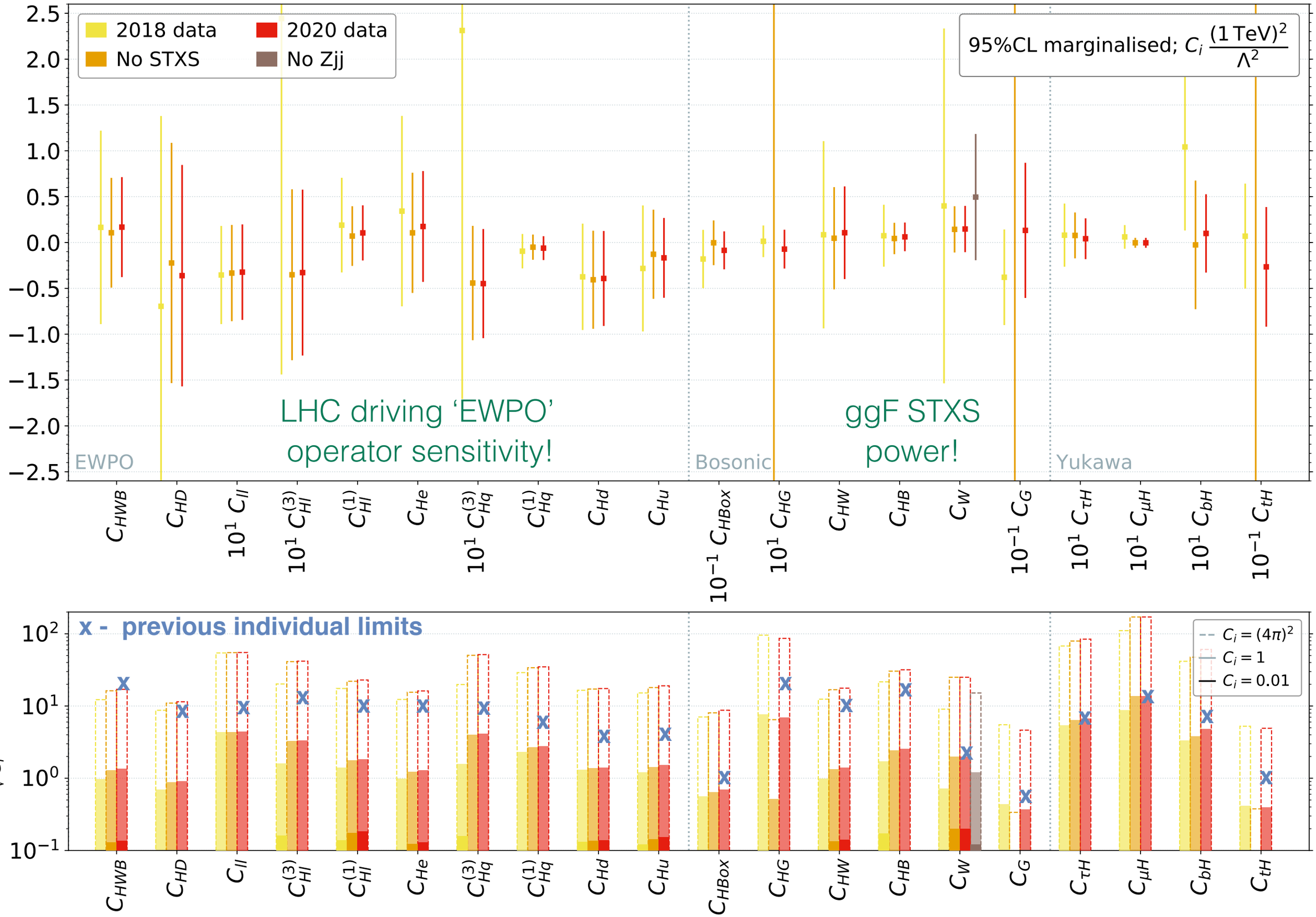
$\Delta\phi_{jj}$ *distribution sensitive to linear* C_W *contributions*



Wilson coefficient	Includes $\lvert\mathcal{M}_{d6}\rvert^2$	95% confidence interval [TeV^{-2}] Expected	Observed	p-value (SM)
c_W/Λ^2	no	[−0.30, 0.30]	[−0.19, 0.41]	45.9%
	yes	[−0.31, 0.29]	[−0.19, 0.41]	43.2%
$\tilde{c}_W/\Lambda^2$	no	[−0.12, 0.12]	[−0.11, 0.14]	82.0%
	yes	[−0.12, 0.12]	[−0.11, 0.14]	81.8%
c_{HWB}/Λ^2	no	[−2.45, 2.45]	[−3.78, 1.13]	29.0%
	yes	[−3.11, 2.10]	[−6.31, 1.01]	25.0%
$\tilde{c}_{HWB}/\Lambda^2$	no	[−1.06, 1.06]	[0.23, 2.34]	1.7%
	yes	[−1.06, 1.06]	[0.23, 2.35]	1.6%

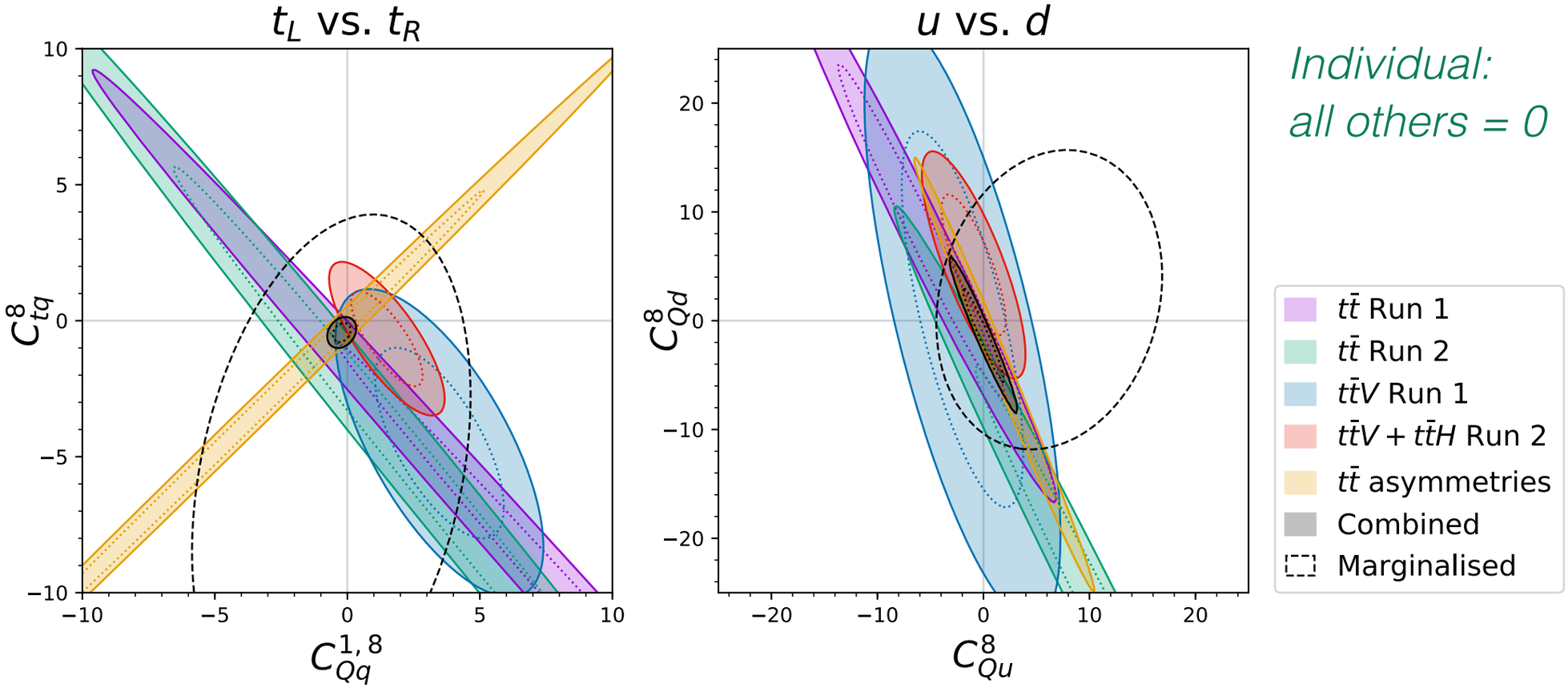
Marginalised limits: U(3)^5

2018 ⇒ 2020: only LHC data changed



See also dedicated top fits: *SMEFiT [Hartland et al.; JHEP 04 (2019) 100]*
SFitter [Brivio et al.; JHEP 02 (2020) 131]

Top asymmetries



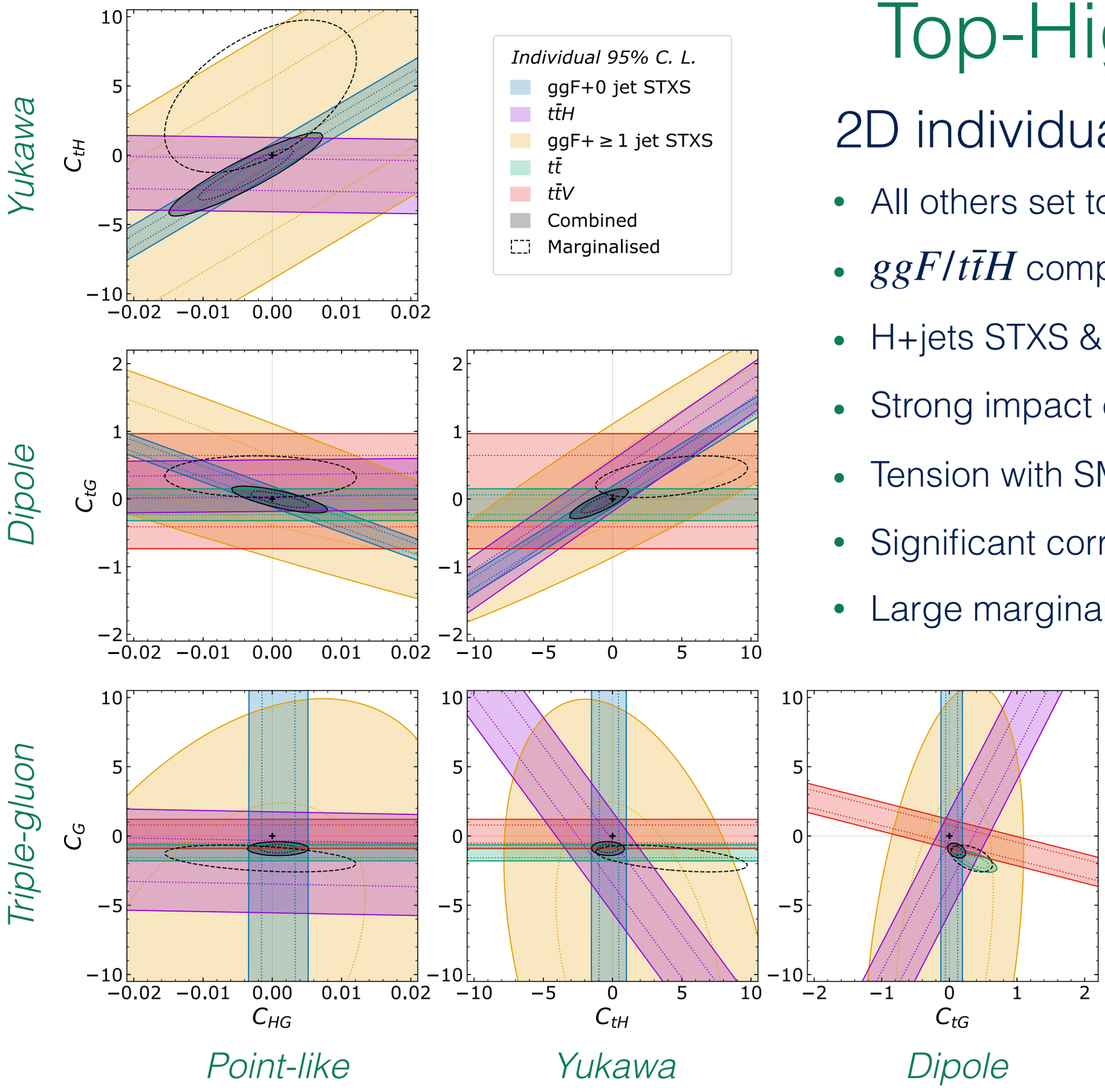
Individual:
all others = 0

- $t\bar{t}$ asymmetries constrain orthogonal direction to cross section
- Large marginalisation effects: many similar operators
- $t\bar{t}V$ & $t\bar{t}H$ help to close the space
- Marginalised linear sensitivity: $C_{4F}\left[\frac{1\,\mathrm{TeV}^2}{\Lambda^2}\right] \sim (5-15)$ *significant* $\frac{1}{\Lambda^4}$ *effects*

Top-Higgs interplay

2D individual constraints

- All others set to 0
- $ggF/t\bar{t}H$ complementarity for (C_{HG}, C_{tH})
- H+jets STXS & $t\bar{t}V$ not yet competitive
- Strong impact of $t\bar{t}$ evident for (C_{tG}, C_G)
- Tension with SM $> 2\sigma$
- Significant correlations remain
- Large marginalisation effects

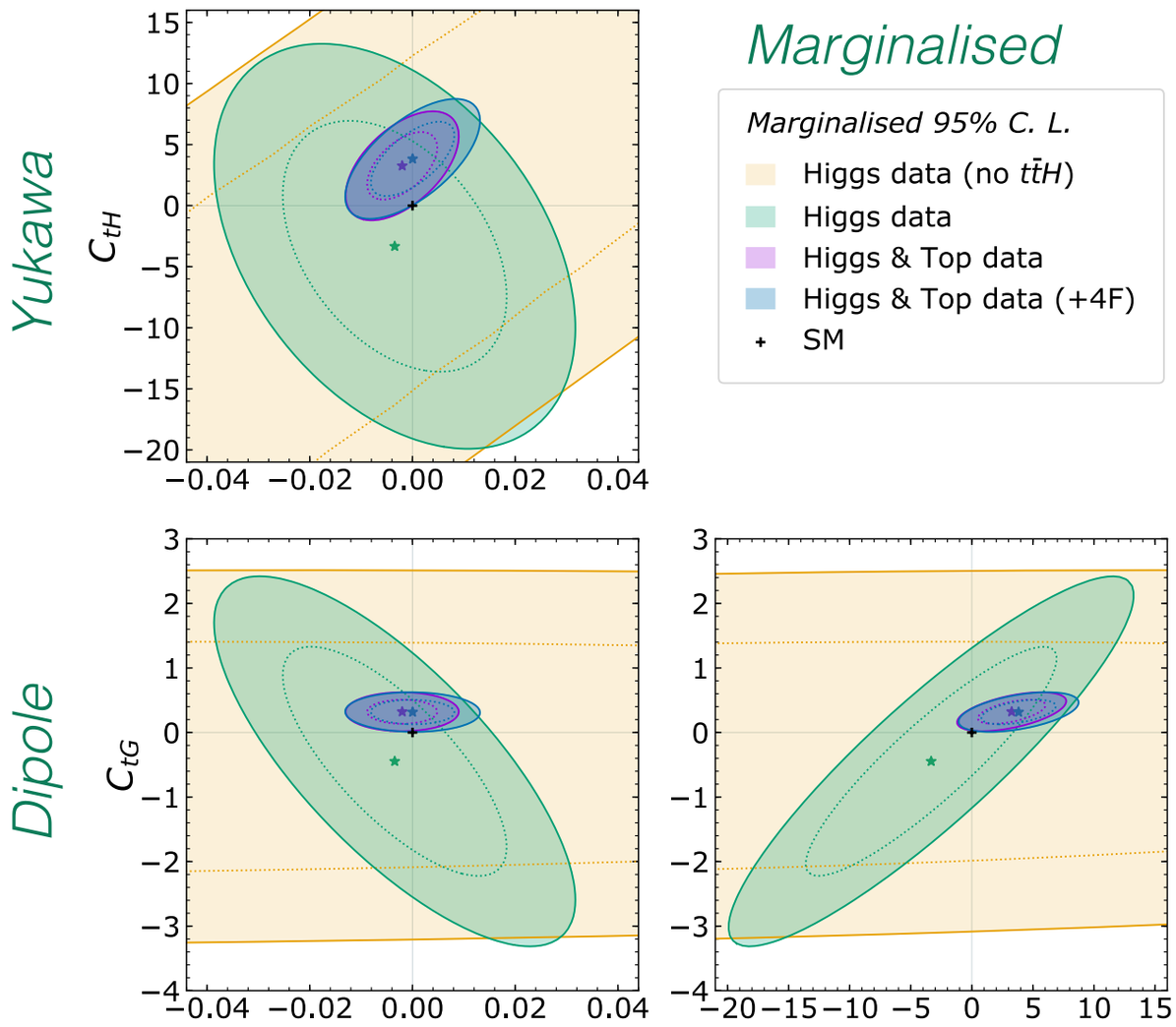


4F operators affect $t\bar{t}(X)$

Up to 14 in our flavor assumption

Do they spoil Higgs coupling sensitivity?

4F impact



Fit to 'Higgs-only' subspace

$$C_{H\Box}, C_{HG}, C_{HW}, C_{HB}, C_{tH}, C_{bH}, C_{\tau H}, C_{\mu H} + C_{tG} \,\&\, C_G$$

- Allow a closed fit to Higgs data only
- Emphasises impact of $t\bar{t}H$ & $t\bar{t}$

Now add in $t\bar{t}$ 4F operators

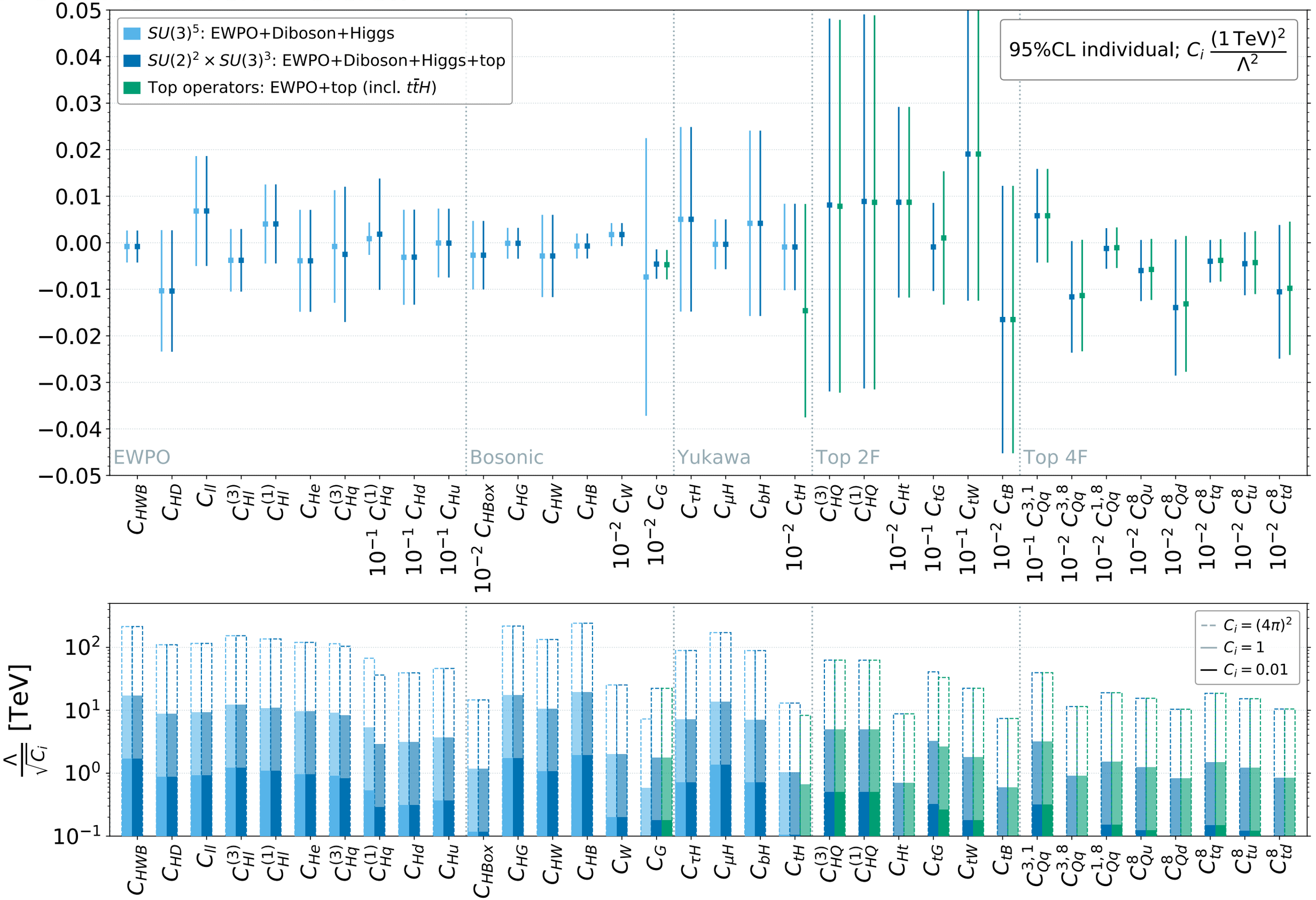
$$+ C_{Qq}^{3,8}, C_{Qq}^{1,8}, C_{Qu}^{8}, C_{Qd}^{8}, C_{tq}^{8}, C_{tu}^{8}, C_{td}^{8}$$

- Relatively mild impact
- Preferred $t\bar{t}$ phase space is different

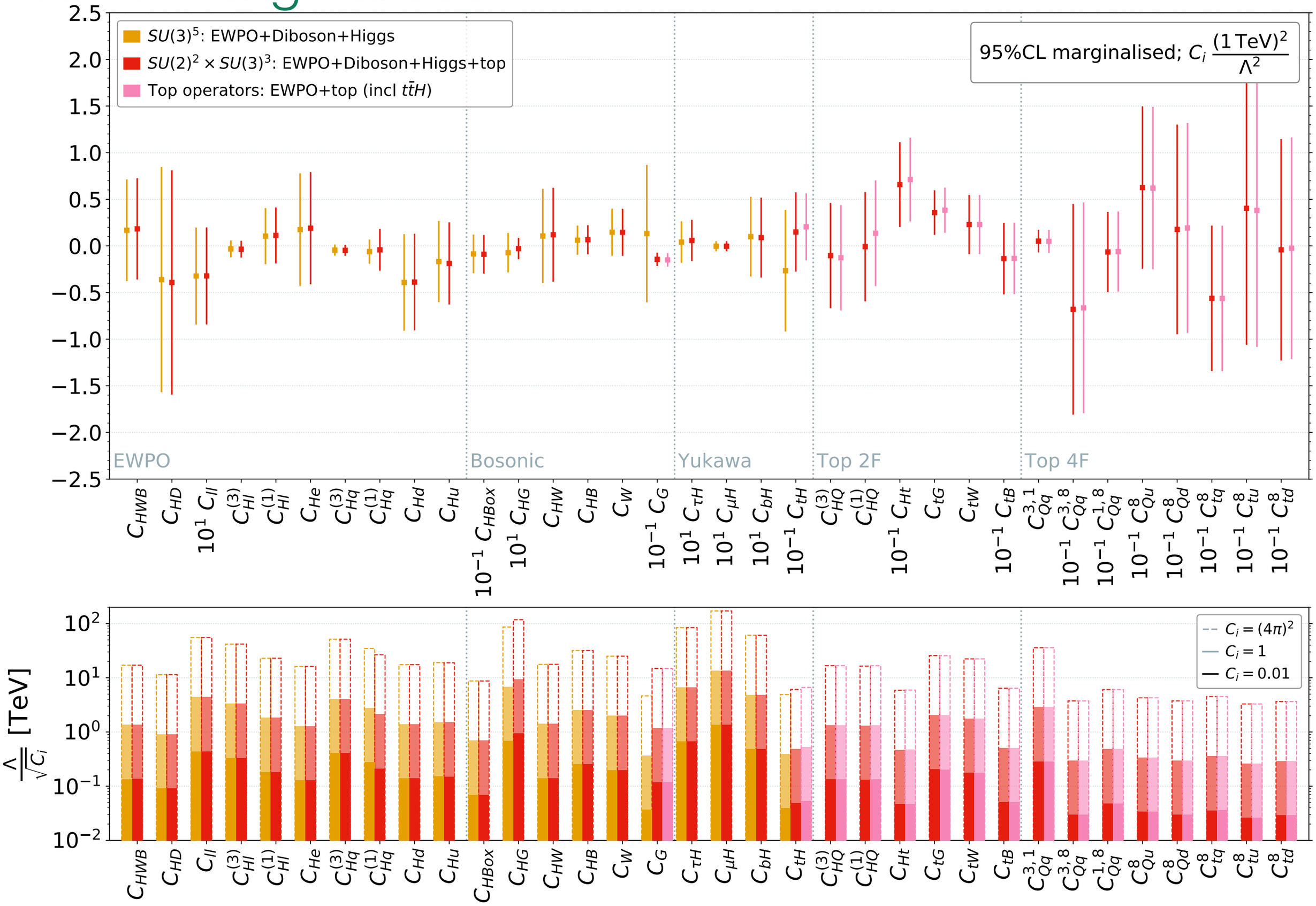
  C_{tG} : low $m_{t\bar{t}}$

  $4F$: high $m_{t\bar{t}}$
- Able to constrain them independently

Full fit: individual



Full fit: marginalised



Correlations

Block diagonal: correlations *within* ‘sector’

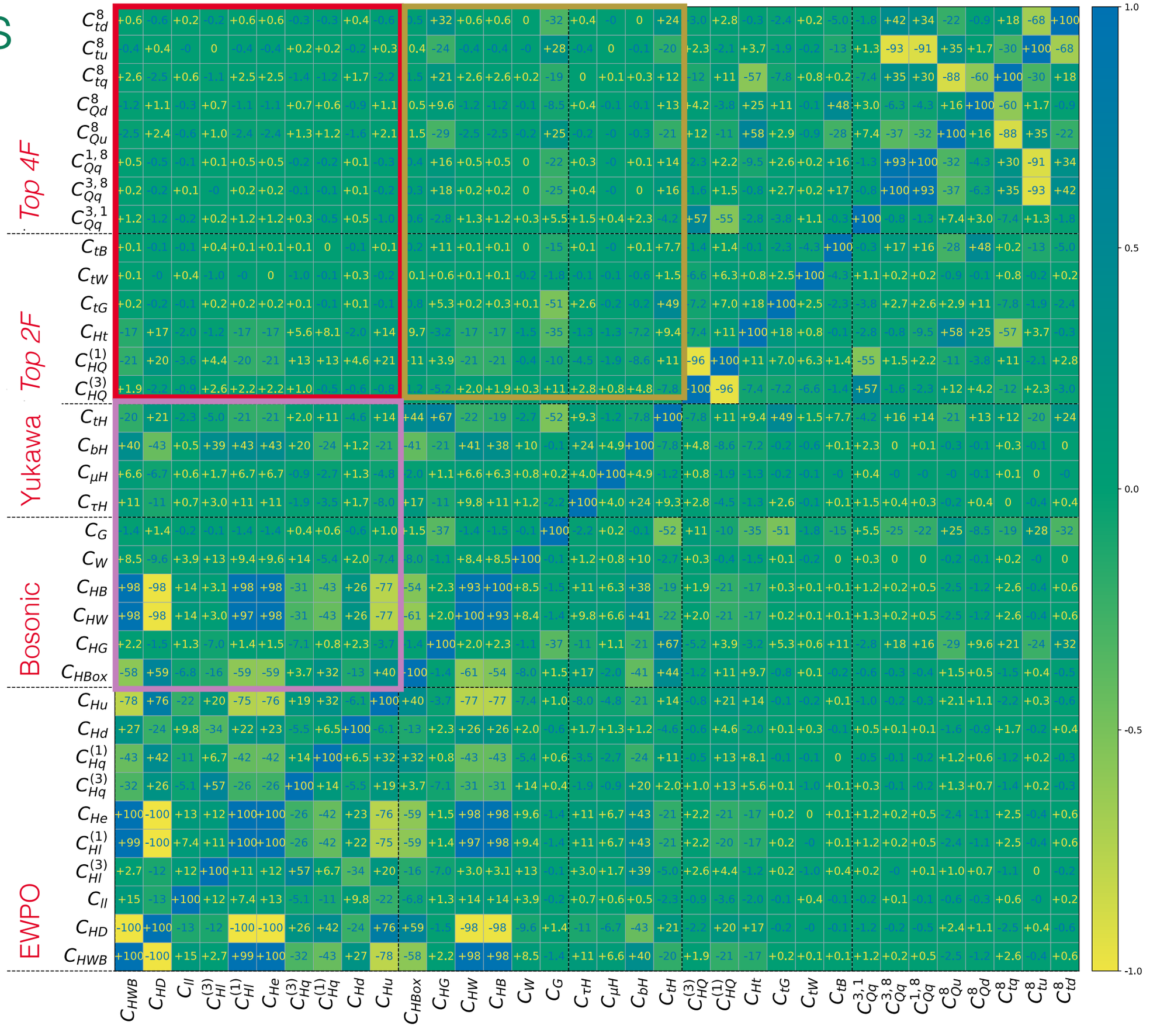
Block off-diagonal: correlations *among* ‘sectors’

EWPO & top ~uncorrelated

EWPO-Higgs
$C_{HB}, C_{HW}, C_{H\Box}$
& Yukawa
with EWPO

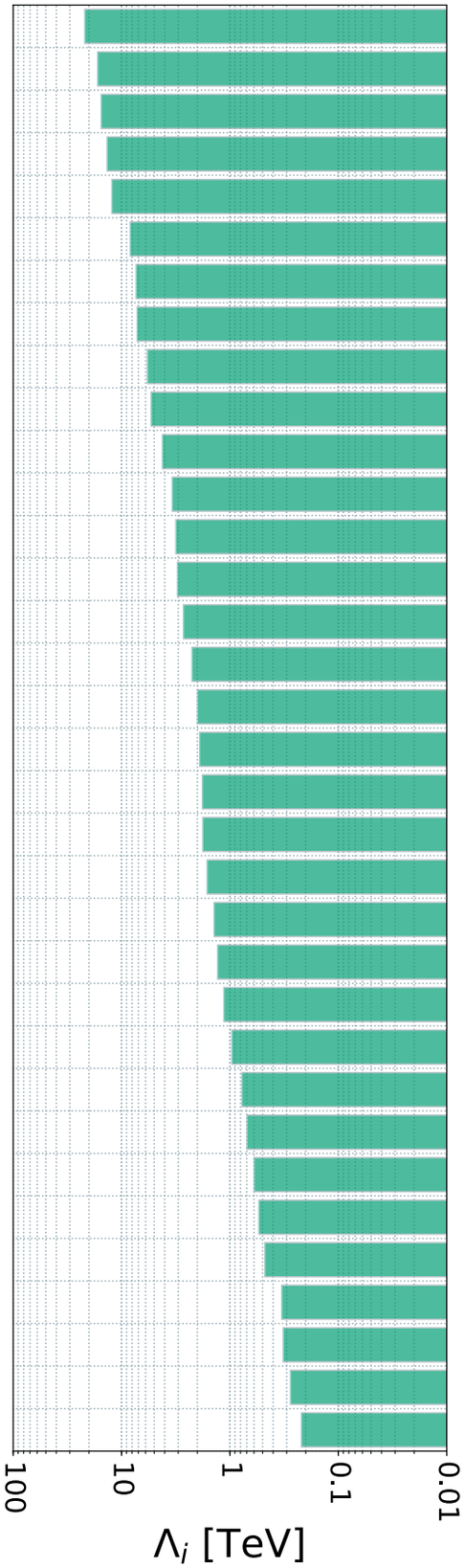
Higgs precision rivalling LEP

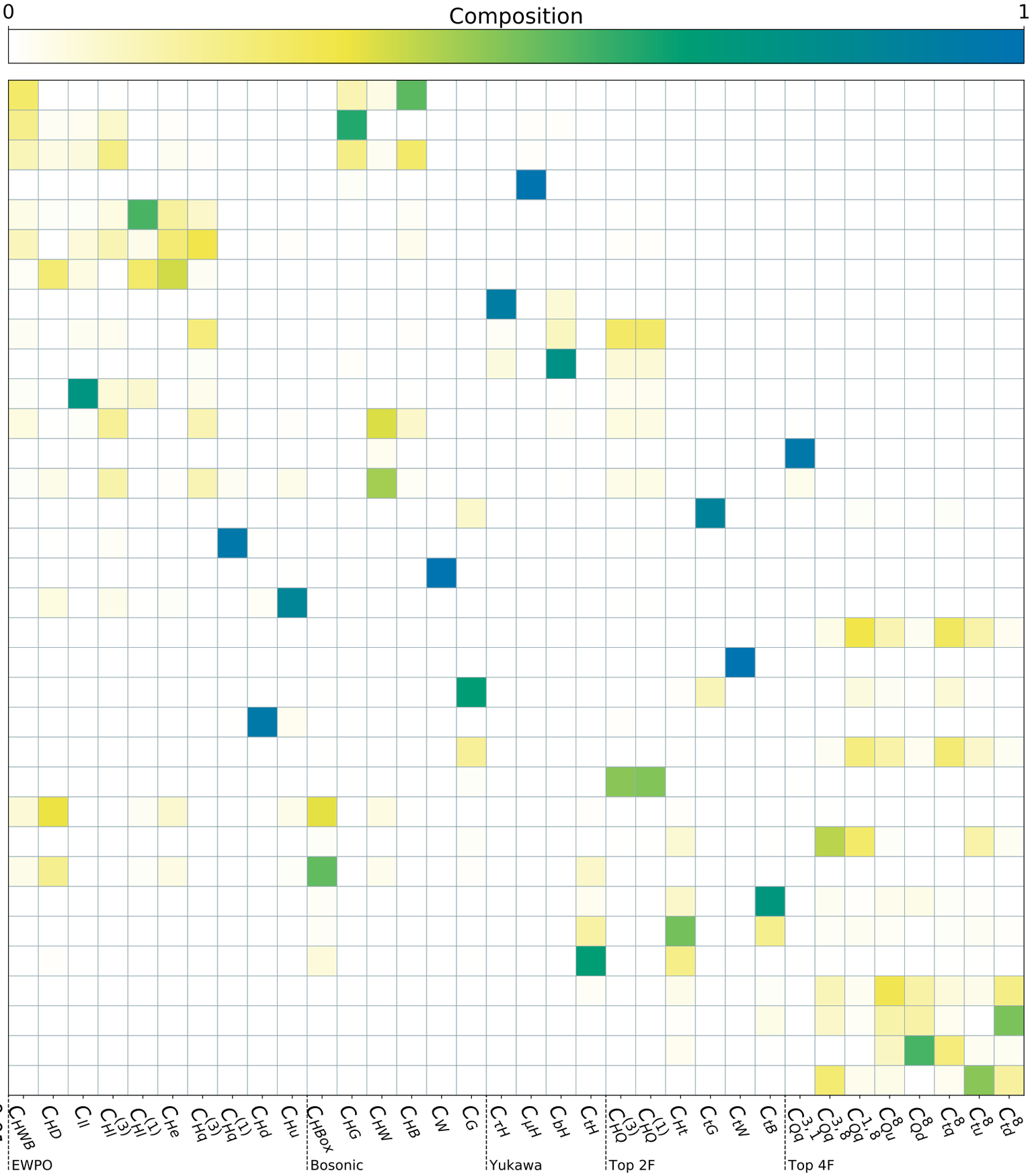
Top-Higgs
C_{HG}, C_G, C_{tH}
with 4F



PCA

2σ bound on Λ_i, $a_{ij}c_j = 1$



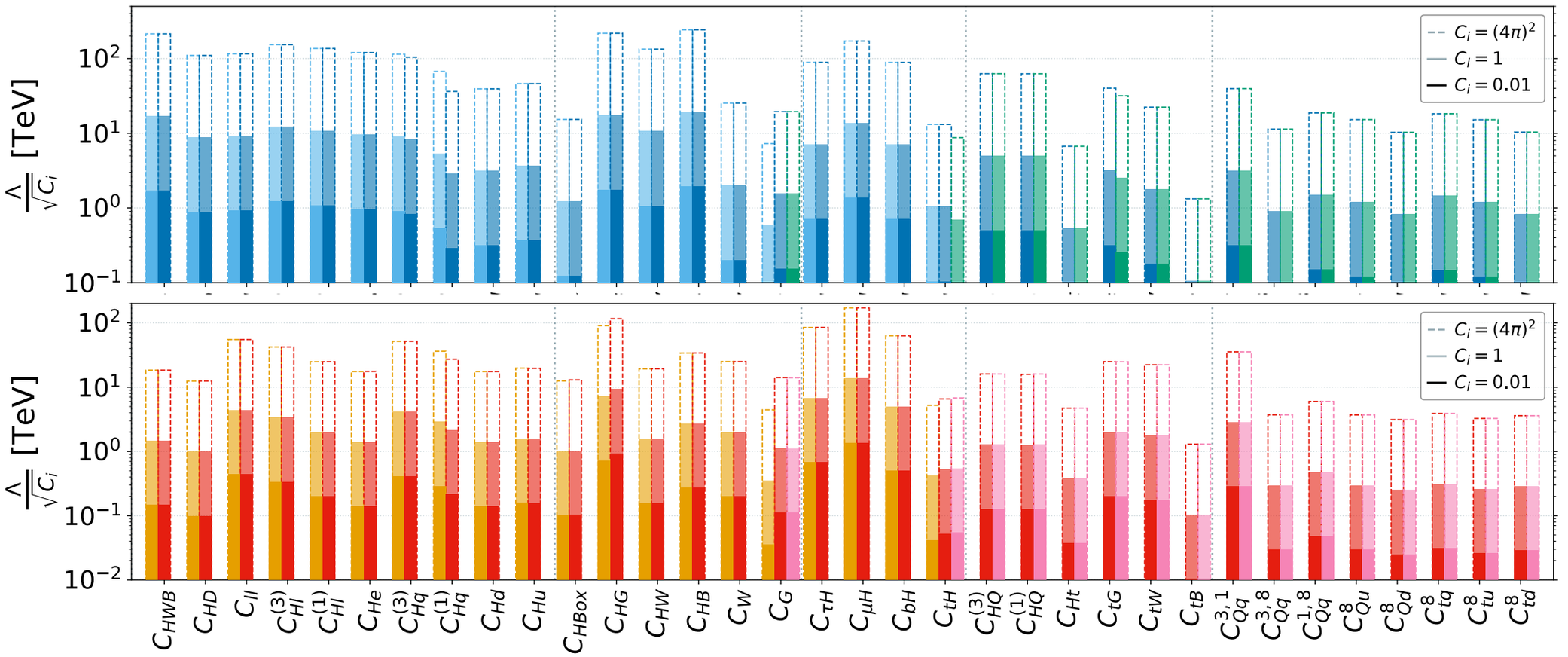


Relative constraining power (%)

6	–	15	29	50	–	–	–	–	–
35	–	13	28	23	–	–	–	–	–
59	–	7	16	18	–	–	–	–	–
–	–	5	94	1	–	–	–	–	–
99	–	–	–	–	–	–	–	–	–
95	–	–	–	–	3	–	–	–	–
99	–	–	–	–	–	–	–	–	–
–	–	21	45	33	–	–	–	–	–
74	–	2	4	14	6	–	–	–	–
18	–	8	19	55	–	–	–	–	–
73	22	–	–	–	3	–	–	–	–
7	2	5	53	4	29	–	–	–	–
–	–	–	3	–	–	–	–	96	–
7	–	2	39	2	46	–	–	3	–
–	–	–	10	4	–	–	57	–	28
94	2	–	–	–	2	–	–	–	–
–	2	–	–	–	11	86	–	–	–
65	14	2	4	10	4	1	–	–	–
–	–	–	–	–	–	–	99	–	–
–	–	–	–	–	–	–	84	15	–
–	–	–	13	6	–	–	48	–	32
90	5	–	–	1	2	–	–	–	–
–	–	–	5	2	–	–	79	–	13
–	–	–	–	–	–	–	3	78	18
2	3	27	40	12	6	–	4	–	4
–	–	1	2	–	–	–	15	4	77
4	4	14	33	23	7	1	12	–	2
–	–	1	3	1	–	–	4	–	89
–	–	3	10	4	–	–	28	2	53
1	–	8	27	16	2	–	32	–	12
–	–	–	–	–	–	–	58	–	41
–	–	–	–	–	–	–	90	–	10
–	–	–	–	–	–	–	61	–	38
–	–	–	–	–	–	–	95	–	5

EWPO
LEP WW
Run 1, μ_t
Run 2, μ_t
STXS
LHC WW$\ell\nu$
LHC Zjj
$t\bar{t}$
single top
$t\bar{t}V$

BSM implications



Individual/marginalised = optimistic/pessimistic

- Real models should lie somewhere in between
- Need to ‘re-run’ the fits to infer on underlying model parameters
- Advantage of fast, linear fit

Single field extensions

Name	Spin	SU(3)	SU(2)	U(1)	Name	Spin	SU(3)	SU(2)	U(1)
S	0	1	1	0	Δ_1	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
S_1	0	1	1	1	Δ_3	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
φ	0	1	2	$\frac{1}{2}$	Σ	$\frac{1}{2}$	1	3	0
Ξ	0	1	3	0	Σ_1	$\frac{1}{2}$	1	3	-1
Ξ_1	0	1	3	1	U	$\frac{1}{2}$	3	1	$\frac{2}{3}$
B	1	1	1	0	D	$\frac{1}{2}$	3	1	$-\frac{1}{3}$
B_1	1	1	1	1	Q_1	$\frac{1}{2}$	3	2	$\frac{1}{6}$
W	1	1	3	0	Q_5	$\frac{1}{2}$	3	2	$-\frac{5}{6}$
W_1	1	1	3	1	Q_7	$\frac{1}{2}$	3	2	$\frac{7}{6}$
N	$\frac{1}{2}$	1	1	0	T_1	$\frac{1}{2}$	3	3	$-\frac{1}{3}$
E	$\frac{1}{2}$	1	1	-1	T_2	$\frac{1}{2}$	3	3	$\frac{2}{3}$
T	$\frac{1}{2}$	3	1	$\frac{2}{3}$	TB	$\frac{1}{2}$	3	2	$\frac{1}{6}$

Considered single field extensions of the SM

- Complete tree-level matching dictionary is known *[de Blas et al.; JHEP 03 (2018) 109]*
- Interpret in terms of simplified 1 & 2 parameter versions of the models

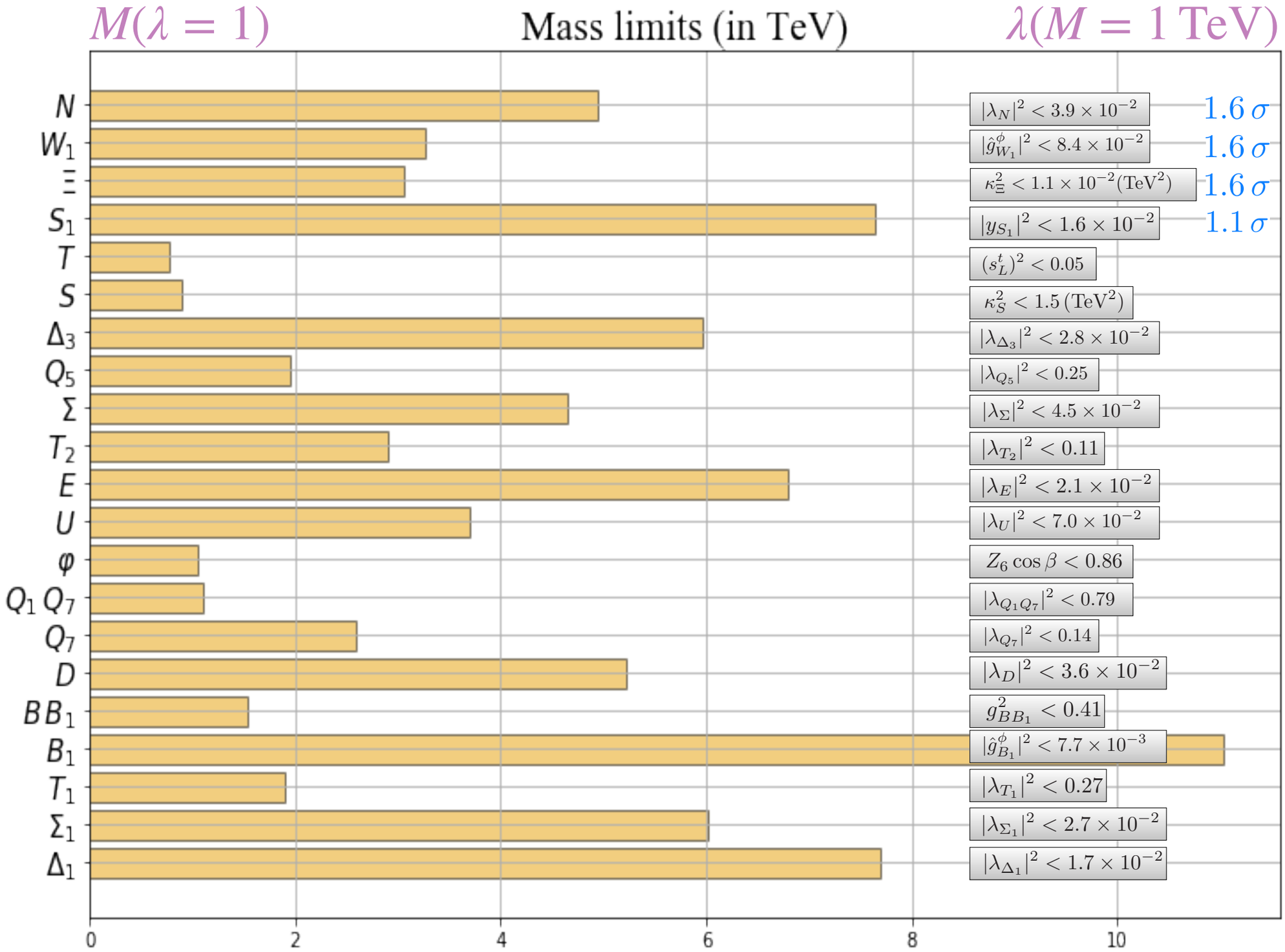
One parameter models

Model	C_{HD}	C_{ll}	C_{Hl}^3	C_{Hl}^1	C_{He}	$C_{H\Box}$	$C_{\tau H}$	C_{tH}	C_{bH}
S						-1			
S_1		1							
Σ			$\frac{5}{8}$	$\frac{3}{16}$			$\frac{y_\tau}{4}$		
Σ_1			$-\frac{5}{8}$	$-\frac{3}{16}$			$\frac{y_\tau}{8}$		
N			$-\frac{1}{4}$	$\frac{1}{4}$					
E			$-\frac{1}{4}$	$-\frac{1}{4}$			$\frac{y_\tau}{2}$		
Δ_1					$\frac{1}{2}$		$\frac{y_\tau}{2}$		
Δ_3					$-\frac{1}{2}$		$\frac{y_\tau}{2}$		
B_1	1					$-\frac{1}{2}$	$-\frac{y_\tau}{2}$	$-\frac{y_t}{2}$	$-\frac{y_b}{2}$
Ξ	-2					$\frac{1}{2}$	y_τ	y_t	y_b
W_1	$-\frac{1}{4}$					$-\frac{1}{8}$	$-\frac{y_\tau}{8}$	$-\frac{y_t}{8}$	$-\frac{y_b}{8}$
φ							$-y_\tau$	$-y_t$	$-y_b$
$\{B, B_1\}$						1	y_τ	y_t	y_b
$\{Q_1, Q_7\}$								y_t	

Model	C_{HG}	C_{Hq}^3	C_{Hq}^1	$(C_{Hq}^3)_{33}$	$(C_{Hq}^1)_{33}$	C_{Hu}	C_{Hd}	C_{tH}	C_{bH}
U		$-\frac{1}{4}$	$\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{4}$			$\frac{y_t}{2}$	
D		$-\frac{1}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$				$\frac{y_b}{2}$
Q_5							$-\frac{1}{2}$		$\frac{y_b}{2}$
Q_7						$\frac{1}{2}$		$\frac{y_t}{2}$	
T_1		$-\frac{5}{8}$	$-\frac{3}{16}$	$-\frac{5}{8}$	$-\frac{3}{16}$			$\frac{y_t}{4}$	$\frac{y_b}{8}$
T_2		$-\frac{5}{8}$	$\frac{3}{16}$	$-\frac{5}{8}$	$\frac{3}{16}$			$\frac{y_t}{8}$	$\frac{y_b}{4}$
T	$-\frac{M_T^2}{v^2}\frac{\alpha_s(0.02)}{8\pi}$			$-\frac{1}{2}\frac{M_T^2}{v^2}$	$\frac{1}{2}\frac{M_T^2}{v^2}$			$y_t\frac{M_T^2}{v^2}$	

$$\times \frac{\lambda^2}{M^2}$$

One parameter models

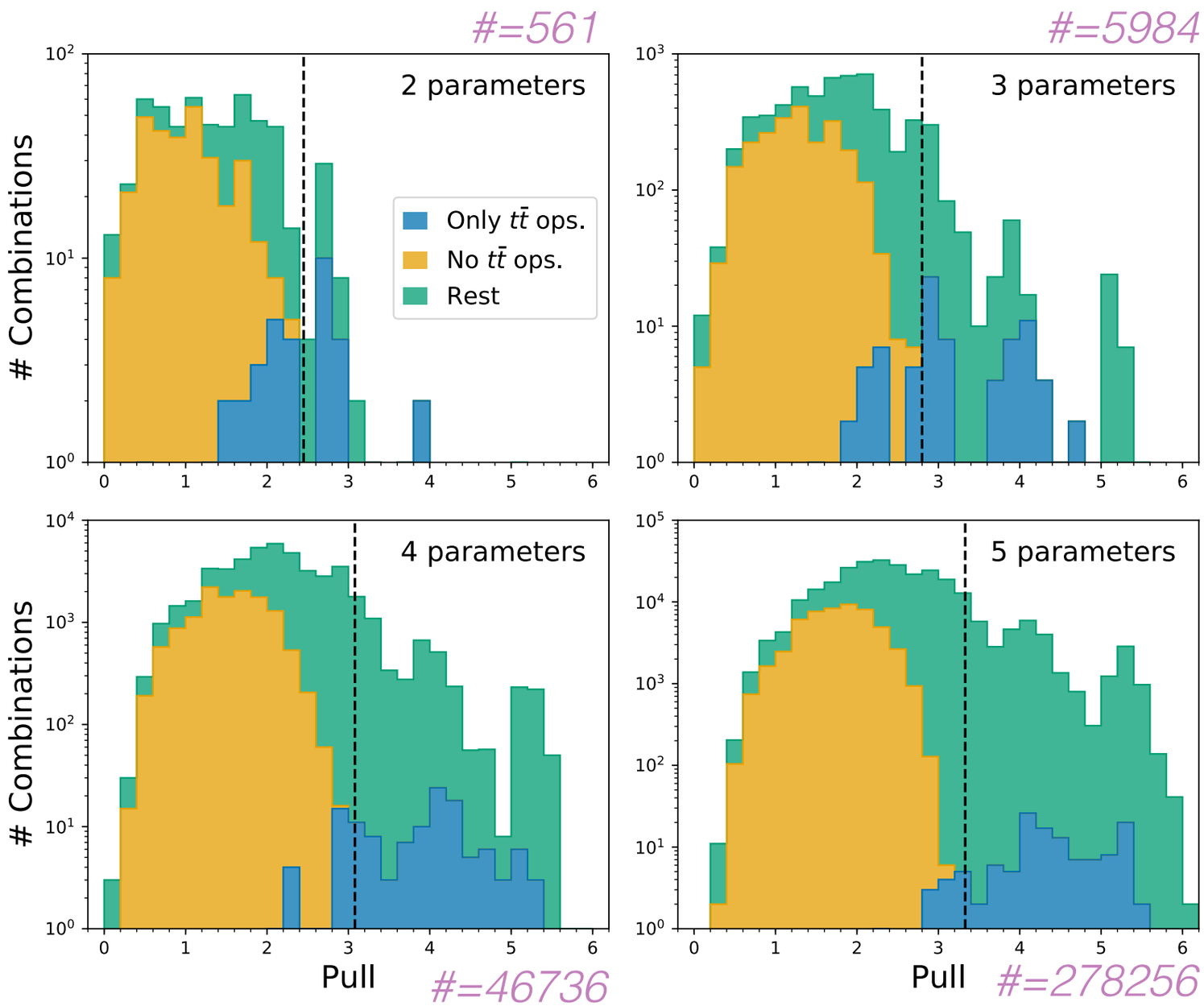


Pull-ology

Brute force: fit to all combinations of n-coefficients

$$P \equiv \sqrt{\chi^2_{SM} - \chi^2_{\text{fit}}}$$

- Agnostic search for improved fit w.r.t SM
- NP hints could show up in this way
- Advantage of fast, linear fit method
- Highlights tension in $t\bar{t}$ data
- No conclusive NP hints so far…



Conclusions

Presented first EWPO, Higgs, Diboson & Top fit in SMEFT

- Include leading contributions from top operators in ggF
- Top & Higgs sector are starting to talk to each other
- $t\bar{t}$ 4 fermion operators don't appear to spoil naive picture of interplay

Analytic, linear analysis has many benefits

- Easy to interpret/combine with other likelihoods
- Fast: repeat for subsets, BSM interpretations
- Enables a broad-band search for simple UV physics

& Drawbacks

- Potentially important quadratic effects, especially in top data
- Gaussian priors only, not really appropriate for th. errors

Outlook

Much more to be done

- Explore the likelihood further
- Compare results to a quadratic fit to test validity
- SMEFT theory errors?
- Explore impact of new observables: VBS, VVV, rare top modes

Impact of loops

- Top operators in loops: Higgs decays + EWPO
- NLO corrections

BSM implications

- Go beyond 1 particle benchmarks towards realistic models
- Are there compelling top/Higgs scenarios that admit a valid EFT interpretation with LHC data?