

Updated Global SMEFT Fit

Tevong You



J. Ellis, C. W. Murphy, V. Sanz, TY [1803.03252]

Introduction

- Motivation
- SM EFT framework
- EWPT and TGCs
- Updated Run 2 SM EFT fit
- Conclusion


Why SM EFT?

Assuming a SM Higgs and decoupled new physics at higher energies, the SM EFT is the next phenomenological framework

The TeV Scale

What effective theory captures everything we know experimentally about weak interactions?

1933–1982 4-fermion interactions



$$\sim G_F E^2 \quad \Rightarrow \Lambda \sim \text{TeV}$$

1982–2011 SM without Higgs



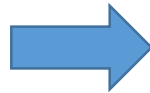
$$\sim \frac{g^2 E^2}{m_W^2} \quad \Rightarrow \Lambda \sim \text{TeV}$$

2012–now SM + higher-dimension operators?
 $\Rightarrow \Lambda \lesssim M_P?$

SMEFT framework

- New physics appear to be decoupled at higher energies
- Given particle content, write down *all* terms allowed by symmetries...

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
Q_L	3	2	$\frac{1}{6}$
q_R^u	3	1	$\frac{2}{3}$
q_R^d	3	1	$-\frac{1}{3}$
L_L	1	2	$-\frac{1}{2}$
l_R	1	1	-1
ϕ	1	2	$\frac{1}{2}$



$$\mathcal{L}_{SM} = \mathcal{L}_m + \mathcal{L}_g + \mathcal{L}_h + \mathcal{L}_y \quad ,$$

$$\mathcal{L}_m = \bar{Q}_L i \gamma^\mu D_\mu^L Q_L + \bar{q}_R i \gamma^\mu D_\mu^R q_R + \bar{L}_L i \gamma^\mu D_\mu^L L_L + \bar{l}_R i \gamma^\mu D_\mu^R l_R$$

$$\mathcal{L}_G = -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W_{\mu\nu}^a W^{a\mu\nu}$$

$$\mathcal{L}_H = (D_\mu^L \phi)^\dagger (D^{L\mu} \phi) - V(\phi)$$

$$\mathcal{L}_Y = y_d \bar{Q}_L \phi q_R^d + y_u \bar{Q}_L \phi^c q_R^u + y_L \bar{L}_L \phi l_R + \text{h.c.} \quad ,$$

- ...Including **higher-dimensional** operators!

$$+ \quad \boxed{\mathcal{L}_{SM}^{\text{dim-6}} = \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i}$$

- Generated by new physics at scale $\Lambda \gg v$

SMEFT framework

- Unique dim-5 Weinberg operator, violates lepton number, predicts neutrino masses
- Modulo flavour structure, there are **59** dim-6 (CP-even) operators in a **non-redundant** basis

Buchmuller and Wyler (Nucl. Phys. B 268 (1986) 621)
 Gradkowski et al [arXiv:1008.4884]

- **~19** operators relevant for EWPT, TGC, and Higgs physics

EWPTs	Higgs Physics	TGCs
$\mathcal{O}_W = \frac{ig}{2} \left(H^\dagger \overset{\leftrightarrow}{D}^\mu H \right) D^\nu W_{\mu\nu}^a$		
$\mathcal{O}_B = \frac{ig'}{2} \left(H^\dagger \overset{\leftrightarrow}{D}^\mu H \right) \partial^\nu B_{\mu\nu}$		$\mathcal{O}_{3W} = g \frac{\epsilon_{abc}}{3!} W_\mu^{a\nu} W_{\nu\rho}^b W^{c\rho\mu}$
$\mathcal{O}_T = \frac{1}{2} \left(H^\dagger \overset{\leftrightarrow}{D}_\mu H \right)^2$	$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W_{\mu\nu}^a$	
$\mathcal{O}_{LL}^{(3)l} = (\bar{L}_L \sigma^a \gamma^\mu L_L) (\bar{L}_L \sigma^a \gamma_\mu L_L)$	$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$	
$\mathcal{O}_R^e = (iH^\dagger \overset{\leftrightarrow}{D}_\mu H) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_g = g_s^2 H ^2 G_{\mu\nu}^A G^{A\mu\nu}$	
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$\mathcal{O}_L^{(3)q} = (iH^\dagger \overset{\leftrightarrow}{D}_\mu H) (\bar{Q}_L \sigma^a \gamma^\mu Q_L)$	$\mathcal{O}_f = y_f H ^2 \bar{F}_L H^{(c)} f_R + \text{h.c.}$	
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In SILH basis (Giudice et al. hep-ph/0703164), adopted from Pomarol and Riva (1308.1426)

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Combinations of operators constrained in EWPT more easily set to zero in Higgs and TGCs

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Operators
 constrained by
 measurements at
 per cent level or
 worse

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Operators benefit from per mille precision at LEP

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LEP EWPT Example

- (Pseudo-)Observables

$$\Gamma_Z^L = \Gamma_{had}^L + 3\Gamma_e^L + 3\Gamma_\nu^L \quad R_l = \frac{\Gamma_{had}^L}{\Gamma_Z^L} \quad \sigma_{had} = 12\pi \frac{\Gamma_e^L \Gamma_{had}^L}{\hat{m}_Z^2 \Gamma_Z^2} \quad A_{FB}^f = \frac{3}{4} A_e A_f \quad M_W = c_W M_Z$$

$$R_q = \frac{\Gamma_q}{\Gamma_{had}^L}$$

- Depends on

$$\Gamma_f = \frac{\sqrt{2} G_F M_Z^2 \hat{M}_Z}{G\pi} \left[(g_L^f)^2 + (g_R^f)^2 \right] \quad A_f = \frac{(g_L^f)^2 - (g_R^f)^2}{(g_L^f)^2 + (g_R^f)^2}$$

$$g^f = T_f^3 - Q_f s_W^2$$

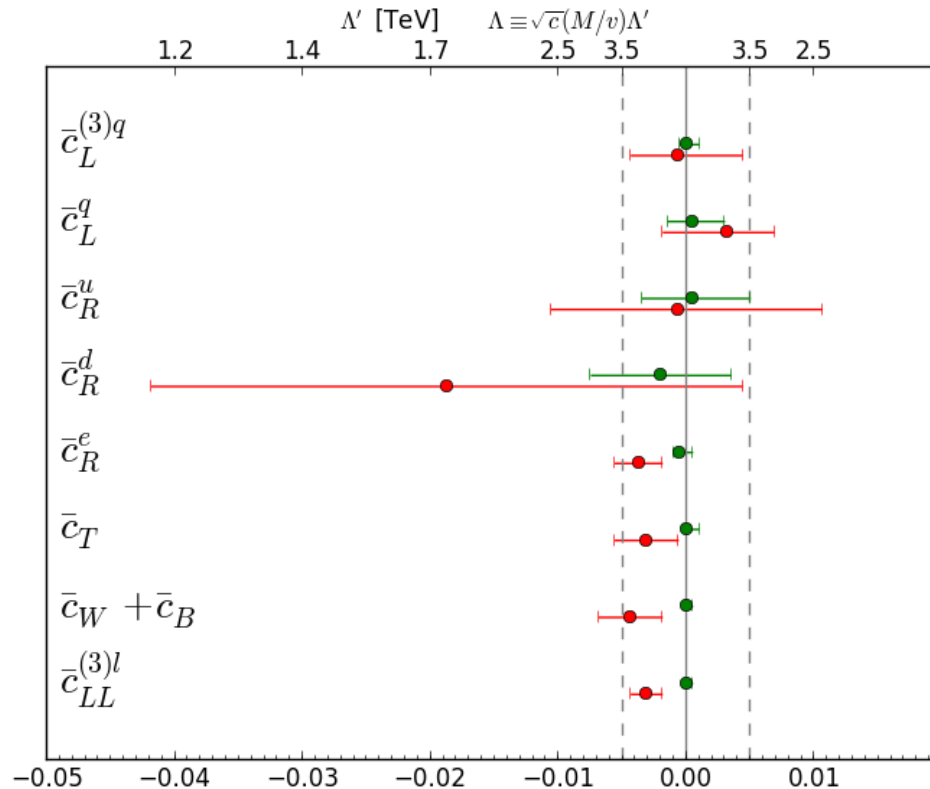
$$s_W^2 \equiv \frac{1}{2} - \frac{1}{2} \sqrt{1 - \frac{4\pi\alpha}{\sqrt{2}G_F M_Z^2}}$$

- Dim-6 operators can modify observables directly through Zff couplings contributions or indirectly through redefinitions of input observables

$$m_Z^2 = (m_Z^2)^0 (1 + \pi_{ZZ}^0) \quad G_F = G_F^0 (1 - \pi_{uw}^0) \quad \alpha(m_Z) = \alpha^0(m_Z) (1 + \pi_{\gamma\gamma}^0)$$

LEP EWPT Example

- Individual (green) and marginalised (red) 95% CL limits



Ellis, Sanz and T.Y. 1410.7703

- 8 (combinations of) operators probed by EWPT

Triple-Gauge-Couplings in Diboson

- Assume SM Z and W couplings to fermions in diboson measurements
- Interpret in anomalous TGC framework:

$$\mathcal{L}_{\text{TGC}} =$$

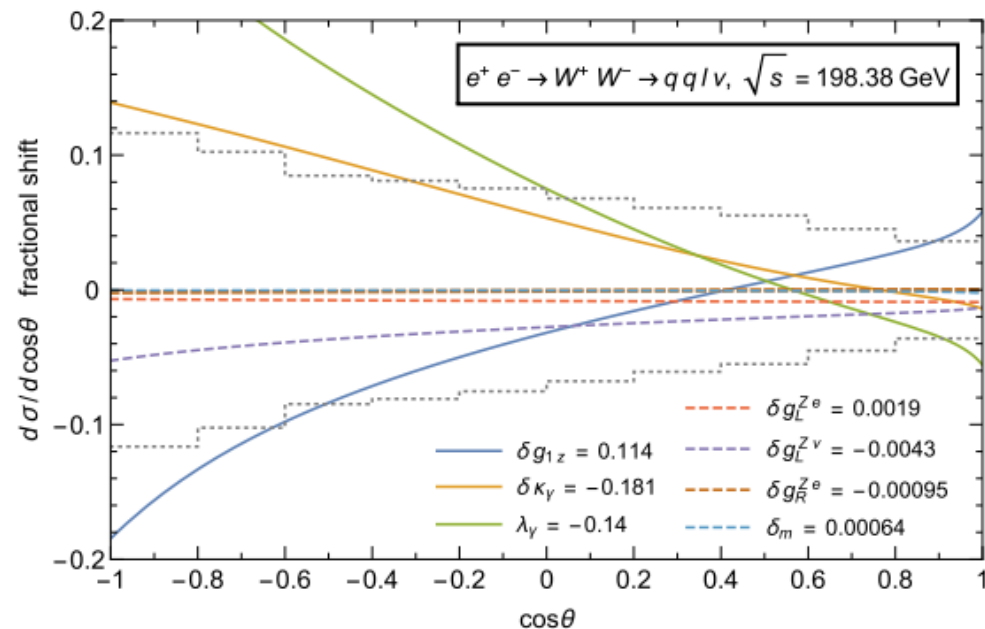
$$ig \left\{ (W_{\mu\nu}^+ W^{-\mu} - W_{\mu\nu}^- W^{+\mu}) [(1 + \delta g_{1z}) c_\theta Z^\nu + s_\theta A^\nu] \right.$$

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$$\left. + \frac{1}{m_W^2} W_\mu^{+\nu} W_\nu^{-\rho} (\lambda_z c_\theta Z_\rho^\mu + \lambda_\gamma s_\theta A_\rho^\mu) \right\},$$

Z. Zhang, 1610.01618

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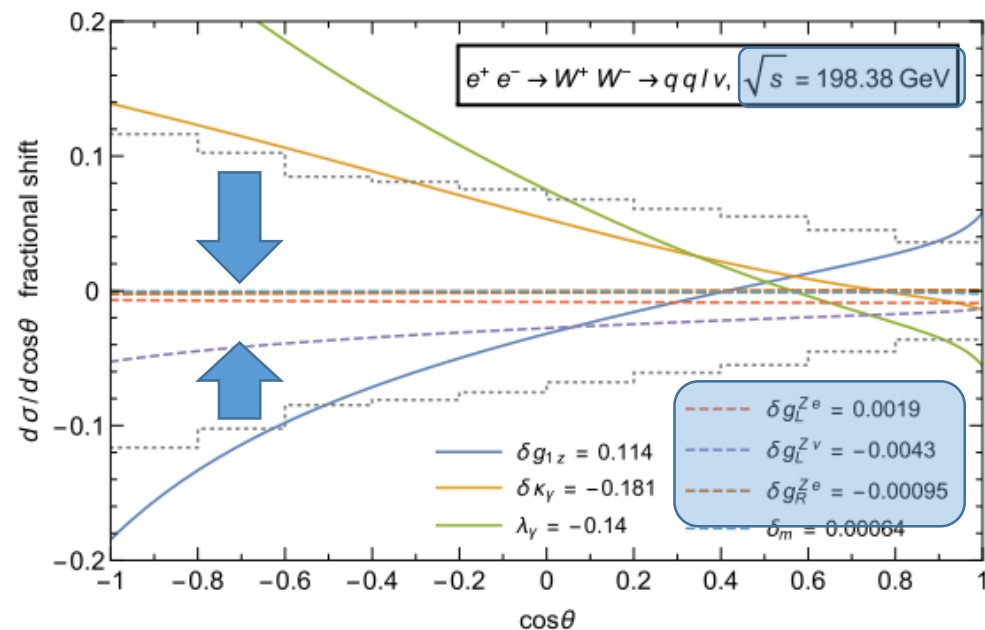
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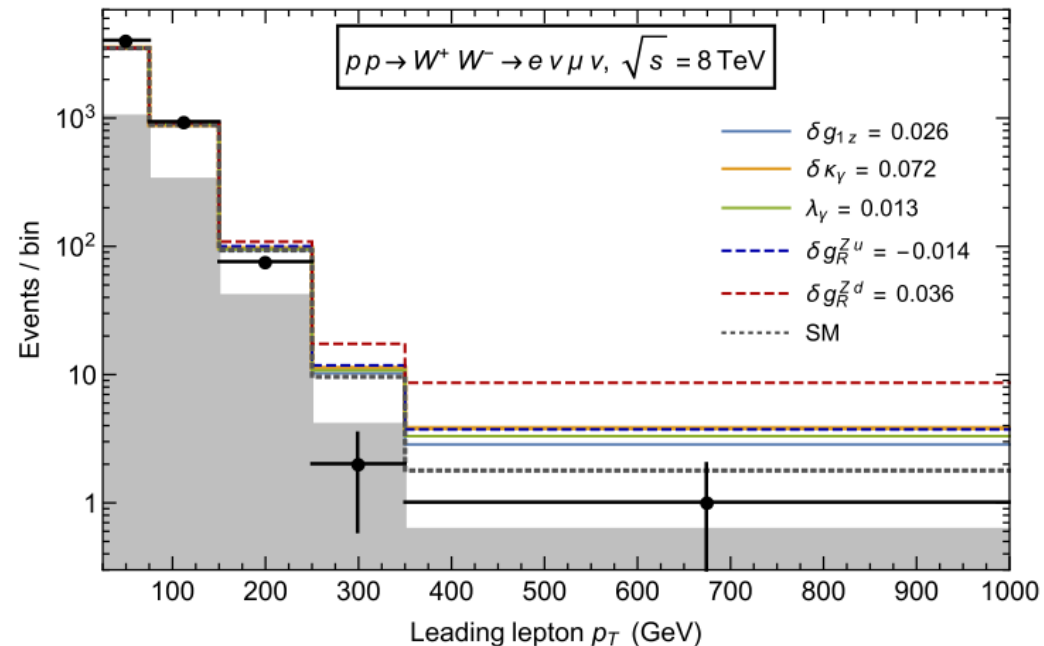
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- But not at high p_T :



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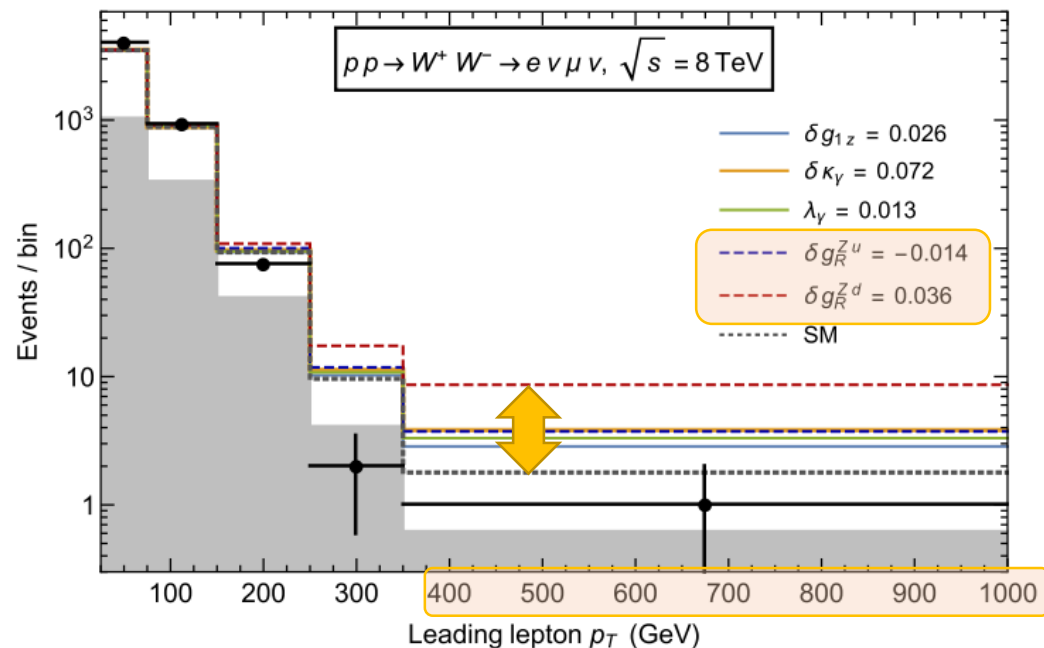
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- But not at high p_T :



Updated Global SMEFT Fit

- Combine **EWPT, diboson, Higgs** data
- Fit to 20 dim-6 CP-even operators **simultaneously**
- Present results in **Warsaw** and **SILH** basis
- Match to **simplified models**

Updated Global SMEFT Fit

- SILH basis

$$\begin{aligned}
\mathcal{L}_{\text{SMEFT}}^{\text{SILH}} \supset & \frac{\bar{c}_W}{m_W^2} \frac{ig}{2} \left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H \right) D^\nu W_{\mu\nu}^a + \frac{\bar{c}_B}{m_W^2} \frac{ig'}{2} \left(H^\dagger \overleftrightarrow{D}^\mu H \right) \partial^\nu B_{\mu\nu} + \frac{\bar{c}_T}{v^2} \frac{1}{2} \left(H^\dagger \overleftrightarrow{D}_\mu H \right)^2 \\
& + \frac{\bar{c}_{ll}}{v^2} 2(\bar{L}\gamma_\mu L)(\bar{L}\gamma^\mu L) + \frac{\bar{c}_{He}}{v^2} (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R\gamma^\mu e_R) + \frac{\bar{c}_{Hu}}{v^2} (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R\gamma^\mu u_R) \\
& + \frac{\bar{c}_{Hd}}{v^2} (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R\gamma^\mu d_R) + \frac{\bar{c}'_{Hq}}{v^2} (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L\sigma^a\gamma^\mu Q_L) \\
& + \frac{\bar{c}_{Hq}}{v^2} (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L\gamma^\mu Q_L) + \frac{\bar{c}_{HW}}{m_W^2} ig(D^\mu H)^\dagger \sigma^a (D^\nu H)W_{\mu\nu}^a + \frac{\bar{c}_{HB}}{m_W^2} ig'(D^\mu H)^\dagger (D^\nu H)B_{\mu\nu} \\
& + \frac{\bar{c}_{3W}}{m_W^2} g^3 \epsilon_{abc} W_\mu^{a\nu} W_{\nu\rho}^b W^{c\rho\mu} + \frac{\bar{c}_g}{m_W^2} g_s^2 |H|^2 G_{\mu\nu}^A G^{A\mu\nu} + \frac{\bar{c}_\gamma}{m_W^2} g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu} \\
& + \frac{\bar{c}_H}{v^2} \frac{1}{2} (\partial^\mu |H|^2)^2 - \sum_{f=e,u,d} \frac{\bar{c}_f}{v^2} y_f |H|^2 \bar{F}_L H^{(c)} f_R \\
& + \frac{\bar{c}_{3G}}{m_W^2} g_s^3 f_{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu} - \frac{\bar{c}_{uG}}{m_W^2} 4g_s y_u H^\dagger \cdot \bar{Q}_L \gamma^{\mu\nu} T_a u_R G_{\mu\nu}^A.
\end{aligned} \tag{6}$$

Updated Global SMEFT Fit

- Warsaw basis

$$\begin{aligned}
 \mathcal{L}_{\text{SMEFT}}^{\text{Warsaw}} \supset & \frac{\bar{C}_{Hl}^{(3)}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu^I H) (\bar{l} \tau^I \gamma^\mu l) + \frac{\bar{C}_{Hl}^{(1)}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu H) (\bar{l} \gamma^\mu l) + \frac{\bar{C}_{ll}}{v^2} (\bar{l} \gamma_\mu l) (\bar{l} \gamma^\mu l) \\
 & + \frac{\bar{C}_{HD}}{v^2} |H^\dagger D_\mu H|^2 + \frac{\bar{C}_{HWB}}{v^2} H^\dagger \tau^I H W_{\mu\nu}^I B^{\mu\nu} \\
 & + \frac{\bar{C}_{He}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu H) (\bar{e} \gamma^\mu e) + \frac{\bar{C}_{Hu}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu H) (\bar{u} \gamma^\mu u) + \frac{\bar{C}_{Hd}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu H) (\bar{d} \gamma^\mu d) \\
 & + \frac{\bar{C}_{Hq}^{(3)}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu^I H) (\bar{q} \tau^I \gamma^\mu q) + \frac{\bar{C}_{Hq}^{(1)}}{v^2} (H^\dagger i \overleftrightarrow{D}_\mu H) (\bar{q} \gamma^\mu q) + \frac{\bar{C}_W}{v^2} \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}
 \end{aligned}$$

$$\begin{aligned}
 \mathcal{L}_{\text{SMEFT}}^{\text{Warsaw}} \supset & \frac{\bar{C}_{eH}}{v^2} (H^\dagger H) (\bar{l} e H) + \frac{\bar{C}_{dH}}{v^2} (H^\dagger H) (\bar{q} d H) + \frac{\bar{C}_{uH}}{v^2} (H^\dagger H) (\bar{q} u \tilde{H}) \\
 & + \frac{\bar{C}_G}{v^2} f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu} + \frac{\bar{C}_{H\Box}}{v^2} (H^\dagger H) \Box (H^\dagger H) + \frac{\bar{C}_{uG}}{v^2} (\bar{q} \sigma^{\mu\nu} T^A u) \tilde{H} G_{\mu\nu}^A \\
 & + \frac{\bar{C}_{HW}}{v^2} H^\dagger H W_{\mu\nu}^I W^{I\mu\nu} + \frac{\bar{C}_{HB}}{v^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{C}_{HG}}{v^2} H^\dagger H G_{\mu\nu}^A G^{A\mu\nu}.
 \end{aligned}$$

Observables

- LEP and SLC EWPTs

Observable	Measurement	Ref.	SM Prediction	Ref.
Γ_Z [GeV]	2.4952 ± 0.0023	[39]	2.4943 ± 0.0005	[38]
σ_{had}^0 [nb]	41.540 ± 0.037	[39]	41.488 ± 0.006	[38]
R_ℓ^0	20.767 ± 0.025	[39]	20.752 ± 0.005	[38]
$A_{\text{FB}}^{0,\ell}$	0.0171 ± 0.0010	[39]	0.01622 ± 0.00009	[114]
$\mathcal{A}_\ell(P_\tau)$	0.1465 ± 0.0033	[39]	0.1470 ± 0.0004	[114]
$\mathcal{A}_\ell(\text{SLD})$	0.1513 ± 0.0021	[39]	0.1470 ± 0.0004	[114]
R_b^0	0.021629 ± 0.00066	[39]	0.2158 ± 0.00015	[38]
R_c^0	0.1721 ± 0.0030	[39]	0.17223 ± 0.00005	[38]
$A_{\text{FB}}^{0,b}$	0.0992 ± 0.0016	[39]	0.1031 ± 0.0003	[114]
$A_{\text{FB}}^{0,c}$	0.0707 ± 0.0035	[39]	0.0736 ± 0.0002	[114]
\mathcal{A}_b	0.923 ± 0.020	[39]	0.9347	[114]
\mathcal{A}_c	0.670 ± 0.027	[39]	0.6678 ± 0.0002	[114]
M_W [GeV]	80.387 ± 0.016	[40]	80.361 ± 0.006	[114]
M_W [GeV]	80.370 ± 0.019	[94]	80.361 ± 0.006	[114]

- LEP WW measurements
- ATLAS WW high p_T overflow bin

Observables

- ATLAS+CMS Higgs Run 1

Production	Decay	Signal Strength	Production	Decay	Signal Strength
ggF	$\gamma\gamma$	$1.10^{+0.23}_{-0.22}$	Wh	$\tau\tau$	-1.4 ± 1.4
ggF	ZZ	$1.13^{+0.34}_{-0.31}$	Wh	bb	1.0 ± 0.5
ggF	WW	0.84 ± 0.17	Zh	$\gamma\gamma$	$0.5^{+3.0}_{-2.5}$
ggF	$\tau\tau$	1.0 ± 0.6	Zh	WW	$5.9^{+2.6}_{-2.2}$
VBF	$\gamma\gamma$	1.3 ± 0.5	Zh	$\tau\tau$	$2.2^{+2.2}_{-1.8}$
VBF	ZZ	$0.1^{+1.1}_{-0.6}$	Zh	bb	0.4 ± 0.4
VBF	WW	1.2 ± 0.4	tth	$\gamma\gamma$	$2.2^{+1.6}_{-1.3}$
VBF	$\tau\tau$	1.3 ± 0.4	tth	WW	$5.0^{+1.8}_{-1.7}$
Wh	$\gamma\gamma$	$0.5^{+1.3}_{-1.2}$	tth	$\tau\tau$	$-1.9^{+3.7}_{-3.3}$
Wh	WW	$1.6^{+1.2}_{-1.0}$	tth	bb	1.1 ± 1.0
pp	$Z\gamma$	$2.7^{+4.6}_{-4.5}$	pp	$\mu\mu$	0.1 ± 2.5

Observables

- ATLAS+CMS Higgs Run 2

	Production	Decay	Sig. Stren.		Production	Decay	Sig. Stren.
[96]	1-jet, $p_T > 450$	$b\bar{b}$	$2.3^{+1.8}_{-1.6}$	[105]	pp	$\mu\mu$	-0.1 ± 1.4
[97]	Zh	$b\bar{b}$	0.9 ± 0.5	[106]	Zh	$b\bar{b}$	$0.69^{+0.35}_{-0.31}$
[97]	Wh	$b\bar{b}$	1.7 ± 0.7	[106]	Wh	$b\bar{b}$	$1.21^{+0.45}_{-0.42}$
[98]	$t\bar{t}h$	$b\bar{b}$	$-0.19^{+0.80}_{-0.81}$	[107]	$t\bar{t}h$	$b\bar{b}$	$0.84^{+0.64}_{-0.61}$
[99]	$t\bar{t}h$	$1\ell + 2\tau_h$	$-1.20^{+1.50}_{-1.47}$	[108]	$t\bar{t}h$	$2\ell os + 1\tau_h$	$1.7^{+2.1}_{-1.9}$
[99]	$t\bar{t}h$	$2\ell ss + 1\tau_h$	$0.86^{+0.79}_{-0.66}$	[108]	$t\bar{t}h$	$1\ell + 2\tau_h$	$-0.6^{+1.6}_{-1.5}$
[99]	$t\bar{t}h$	$3\ell + 1\tau_h$	$1.22^{+1.34}_{-1.00}$	[108]	$t\bar{t}h$	$3\ell + 1\tau_h$	$1.6^{+1.8}_{-1.3}$
[100]	$t\bar{t}h$	$2\ell ss$	$1.7^{+0.6}_{-0.5}$	[108]	$t\bar{t}h$	$2\ell ss + 1\tau_h$	$3.5^{+1.7}_{-1.3}$
[100]	$t\bar{t}h$	3ℓ	$1.0^{+0.8}_{-0.7}$	[108]	$t\bar{t}h$	3ℓ	$1.8^{+0.9}_{-0.7}$
[100]	$t\bar{t}h$	4ℓ	$0.9^{+2.3}_{-1.6}$	[108]	$t\bar{t}h$	$2\ell ss$	$1.5^{+0.7}_{-0.6}$
[101]	0-jet	WW	$0.9^{+0.4}_{-0.3}$	[109]	VBF	WW	$1.7^{+1.1}_{-0.9}$
[101]	1-jet	WW	1.1 ± 0.4	[109]	Wh	WW	$3.2^{+4.4}_{-4.2}$
[101]	2-jet	WW	1.3 ± 1.0	[110]	$B(h \rightarrow \gamma\gamma) / B(h \rightarrow 4\ell)$		$0.69^{+0.15}_{-0.13}$
[101]	VBF 2-jet	WW	1.4 ± 0.8	[110]	0-jet	4ℓ	$1.07^{+0.27}_{-0.25}$
[101]	Vh 2-jet	WW	$2.1^{+2.3}_{-2.2}$	[110]	1-jet, $p_T < 60$	4ℓ	$0.67^{+0.72}_{-0.68}$
[101]	Wh 3-lep	WW	-1.4 ± 1.5	[110]	1-jet, $p_T \in (60, 120)$	4ℓ	$1.00^{+0.63}_{-0.55}$
[102]	ggF	$\gamma\gamma$	$1.11^{+0.19}_{-0.18}$	[110]	1-jet, $p_T \in (120, 200)$	4ℓ	$2.1^{+1.5}_{-1.3}$
[102]	VBF	$\gamma\gamma$	$0.5^{+0.6}_{-0.5}$	[110]	2-jet	4ℓ	$2.2^{+1.1}_{-1.0}$
[102]	$t\bar{t}h$	$\gamma\gamma$	2.2 ± 0.9	[110]	“BSM-like”	4ℓ	$2.3^{+1.2}_{-1.0}$
[102]	Vh	$\gamma\gamma$	$2.3^{+1.1}_{-1.0}$	[110]	VBF, $p_T < 200$	4ℓ	$2.14^{+0.94}_{-0.77}$
[103]	ggF	4ℓ	$1.20^{+0.22}_{-0.21}$	[110]	Vh lep	4ℓ	$0.3^{+1.3}_{-1.2}$
[104]	0-jet	$\tau\tau$	0.84 ± 0.89	[110]	$t\bar{t}h$	4ℓ	$0.51^{+0.86}_{-0.70}$
[104]	boosted	$\tau\tau$	$1.17^{+0.47}_{-0.40}$				
[104]	VBF	$\tau\tau$	$1.11^{+0.34}_{-0.35}$				

Observables

Including kinematical information facilitated by **STXS**

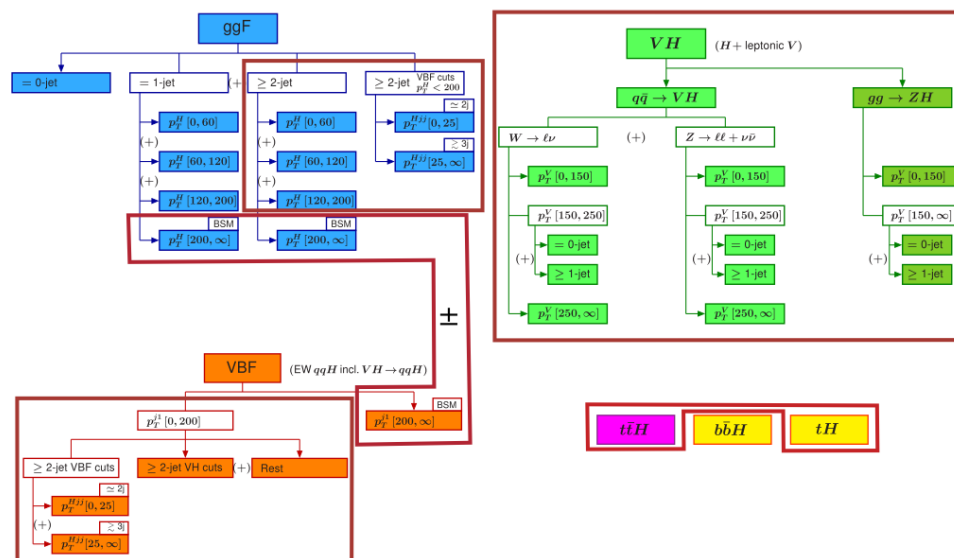
- ATLAS+CMS Higgs Run 2

	Production	Decay	Sig. Stren.		Production	Decay	Sig. Stren.
[96]	1-jet, $p_T > 450$	$b\bar{b}$	$2.3^{+1.8}_{-1.6}$	[105]	pp	$\mu\mu$	-0.1 ± 1.4
[97]	Zh	$b\bar{b}$	0.9 ± 0.5	[106]	Zh	$b\bar{b}$	$0.69^{+0.35}_{-0.31}$
[97]	Wh	$b\bar{b}$	1.7 ± 0.7	[106]	Wh	$b\bar{b}$	$1.21^{+0.45}_{-0.42}$
[98]	$t\bar{t}h$	$b\bar{b}$	$-0.19^{+0.80}_{-0.81}$	[107]	$t\bar{t}h$	$b\bar{b}$	$0.84^{+0.64}_{-0.61}$
[99]	$t\bar{t}h$	$1\ell + 2\tau_h$	$-1.20^{+1.50}_{-1.47}$	[108]	$t\bar{t}h$	$2\ell os + 1\tau_h$	$1.7^{+2.1}_{-1.9}$
[99]	$t\bar{t}h$	$2\ell ss + 1\tau_h$	$0.86^{+0.79}_{-0.66}$	[108]	$t\bar{t}h$	$1\ell + 2\tau_h$	$-0.6^{+1.6}_{-1.5}$
[99]	$t\bar{t}h$	$3\ell + 1\tau_h$	$1.22^{+1.34}_{-1.00}$	[108]	$t\bar{t}h$	$3\ell + 1\tau_h$	$1.6^{+1.8}_{-1.3}$
[100]	$t\bar{t}h$	$2\ell ss$	$1.7^{+0.6}_{-0.5}$	[108]	$t\bar{t}h$	$2\ell ss + 1\tau_h$	$3.5^{+1.7}_{-1.3}$
[100]	$t\bar{t}h$	3ℓ	$1.0^{+0.8}_{-0.7}$	[108]	$t\bar{t}h$	3ℓ	$1.8^{+0.9}_{-0.7}$
[100]	$t\bar{t}h$	4ℓ	$0.9^{+2.3}_{-1.6}$	[108]	$t\bar{t}h$	$2\ell ss$	$1.5^{+0.7}_{-0.6}$
[101]	0-jet	WW	$0.9^{+0.4}_{-0.3}$	[109]	VBF	WW	$1.7^{+1.1}_{-0.9}$
[101]	1-jet	WW	1.1 ± 0.4	[109]	Wh	WW	$3.2^{+4.4}_{-4.2}$
[101]	2-jet	WW	1.3 ± 1.0	[110]	B($h \rightarrow \gamma\gamma$)/ B($h \rightarrow 4\ell$)		$0.69^{+0.15}_{-0.13}$
[101]	VBF 2-jet	WW	1.4 ± 0.8	[110]	0-jet	4ℓ	$1.07^{+0.27}_{-0.25}$
[101]	Vh 2-jet	WW	$2.1^{+2.3}_{-2.2}$	[110]	1-jet, $p_T < 60$	4ℓ	$0.67^{+0.72}_{-0.68}$
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[102]	ggF	$\gamma\gamma$	$1.11^{+0.19}_{-0.18}$	[110]	1-jet, $p_T \in (120, 200)$	4ℓ	$2.1^{+1.5}_{-1.3}$
[102]	VBF	$\gamma\gamma$	$0.5^{+0.6}_{-0.5}$	[110]	2-jet	4ℓ	$2.2^{+1.1}_{-1.0}$
[102]	$t\bar{t}h$	$\gamma\gamma$	2.2 ± 0.9	[110]	“BSM-like”	4ℓ	$2.3^{+1.2}_{-1.0}$
[102]	Vh	$\gamma\gamma$	$2.3^{+1.1}_{-1.0}$	[110]	VBF, $p_T < 200$	4ℓ	$2.14^{+0.94}_{-0.77}$
[103]	ggF	4ℓ	$1.20^{+0.22}_{-0.21}$	[110]	Vh lep	4ℓ	$0.3^{+1.3}_{-1.2}$
[104]	0-jet	$\tau\tau$	0.84 ± 0.89	[110]	$t\bar{t}h$	4ℓ	$0.51^{+0.86}_{-0.70}$
[104]	boosted	$\tau\tau$	$1.17^{+0.47}_{-0.40}$				
[104]	VBF	$\tau\tau$	$1.11^{+0.34}_{-0.35}$				

STXS

- Simplified Template Cross-Sections
- Sub-division into kinematic regions for production processes

ATLAS preliminary

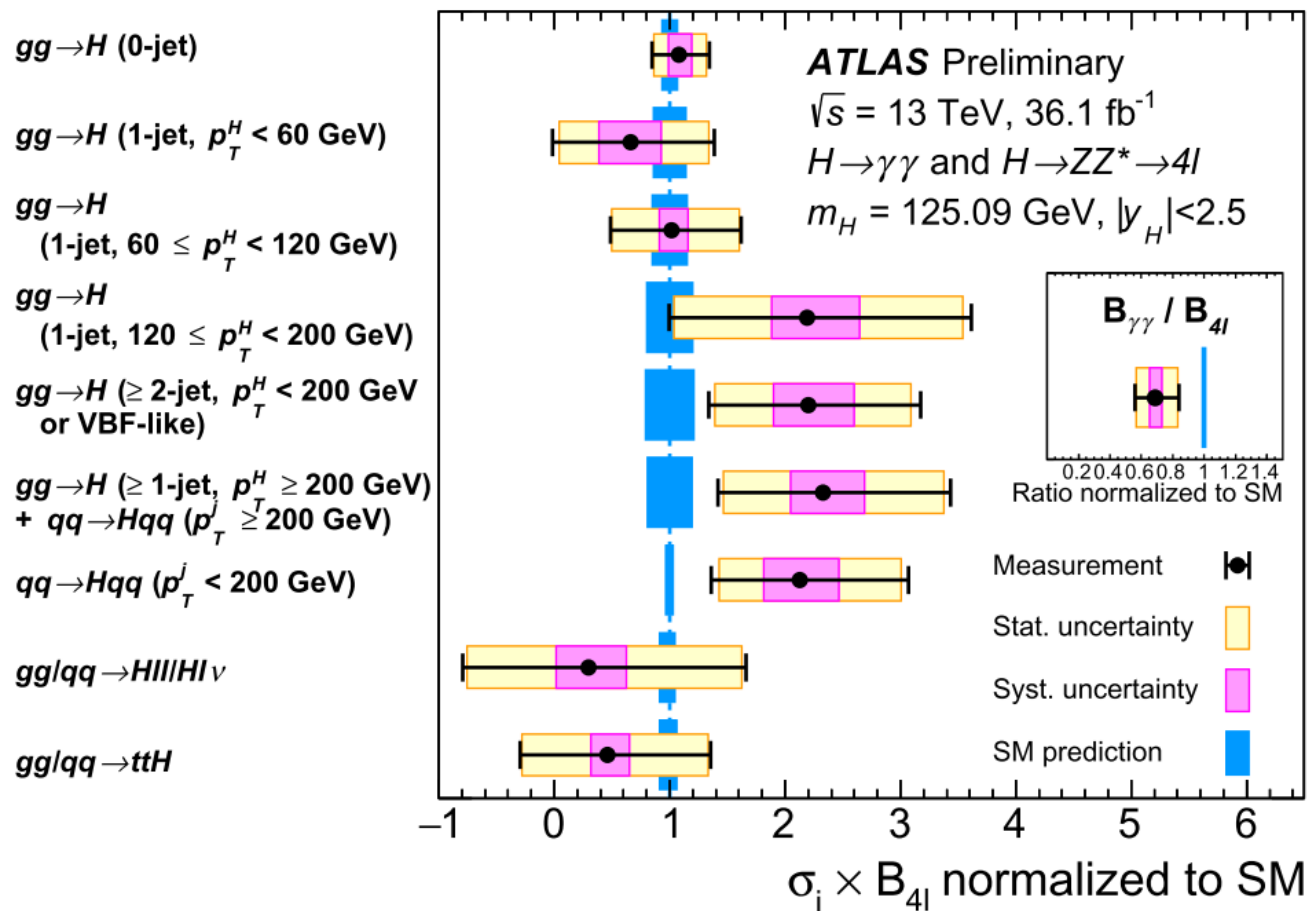


ATLAS-CONF-2017-047

- Facilitates combination and interpretation

STXS

- STXS measurements



STXS

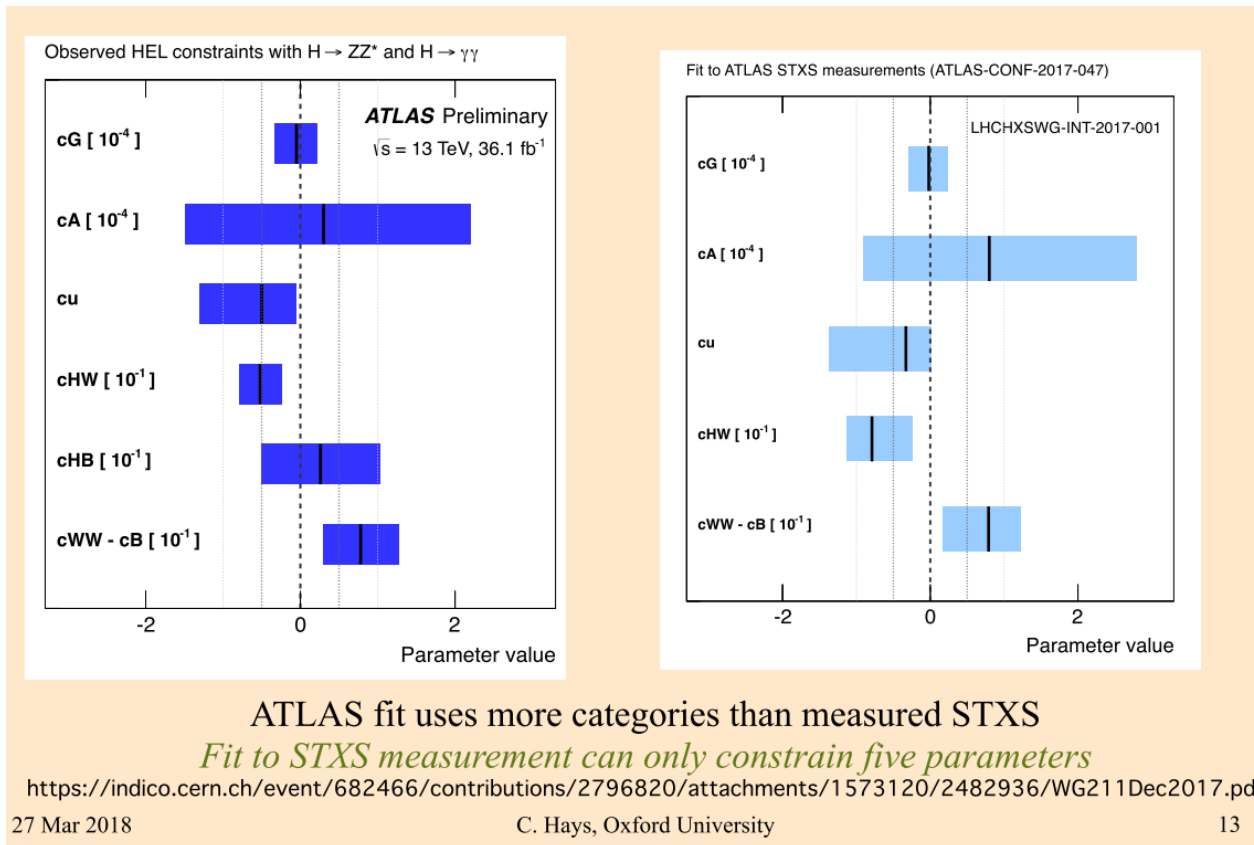
- STXS dim-6 predictions

Cross-section region	$\sum_i A_i c_i$
$gg \rightarrow H$ (0-jet)	
$gg \rightarrow H$ (1-jet, $p_T^H < 60$ GeV)	$56c'_g$
$gg \rightarrow H$ (1-jet, $60 \leq p_T^H < 120$ GeV)	
$gg \rightarrow H$ (1-jet, $120 \leq p_T^H < 200$ GeV)	$56c'_g + 18c3G + 11c2G$
$gg \rightarrow H$ (1-jet, $p_T^H \geq 200$ GeV)	$56c'_g + 52c3G + 34c2G$
$gg \rightarrow H$ (\geq 2-jet, $p_T^H < 60$ GeV)	$56c'_g$
$gg \rightarrow H$ (\geq 2-jet, $60 \leq p_T^H < 120$ GeV)	$56c'_g + 8c3G + 7c2G$
$gg \rightarrow H$ (\geq 2-jet, $120 \leq p_T^H < 200$ GeV)	$56c'_g + 23c3G + 18c2G$
$gg \rightarrow H$ (\geq 2-jet, $p_T^H \geq 200$ GeV)	$56c'_g + 90c3G + 68c2G$
$gg \rightarrow H$ (\geq 2-jet VBF-like, $p_T^{j3} < 25$ GeV)	$56c'_g$
$gg \rightarrow H$ (\geq 2-jet VBF-like, $p_T^{j3} \geq 25$ GeV)	$56c'_g + 9c3G + 8c2G$
$qq \rightarrow Hqq$ (VBF-like, $p_T^{j3} < 25$ GeV)	$-1.0cH - 1.0cT + 1.3cWW - 0.023cB - 4.3cHW$ $-0.29cHB + 0.092cHQ - 5.3cPHQ - 0.33cHu + 0.12cHd$
$qq \rightarrow Hqq$ (VBF-like, $p_T^{j3} \geq 25$ GeV)	$-1.0cH - 1.1cT + 1.2cWW - 0.027cB - 5.8cHW$ $-0.41cHB + 0.13cHQ - 6.9cPHQ - 0.45cHu + 0.15cHd$
$qq \rightarrow Hqq$ ($p_T^j \geq 200$ GeV)	$-1.0cH - 0.95cT + 1.5cWW - 0.025cB - 3.6cHW$ $-0.24cHB + 0.084cHQ - 4.5cPHQ - 0.25cHu + 0.1cHd$
$qq \rightarrow Hqq$ ($60 \leq m_{jj} < 120$ GeV)	$-0.99cH - 1.2cT + 7.8cWW - 0.19cB - 31cHW$ $-2.4cHB + 0.9cHQ - 38cPHQ - 2.8cHu + 0.9cHd$
$qq \rightarrow Hqq$ (rest)	$-1.0cH - 1.0cT + 1.4cWW - 0.028cB - 6.2cHW$ $-0.42cHB + 0.14cHQ - 6.9cPHQ - 0.42cHu + 0.16cHd$
$gg/q\bar{q} \rightarrow t\bar{t}H$	$-0.98cH + 2.9cu + 0.93cG + 310cuG$ $+27c3G - 13c2G$

Hays, Sanz, Zemaityte
[LHCHXSWG-INT-2017-01]

STXS

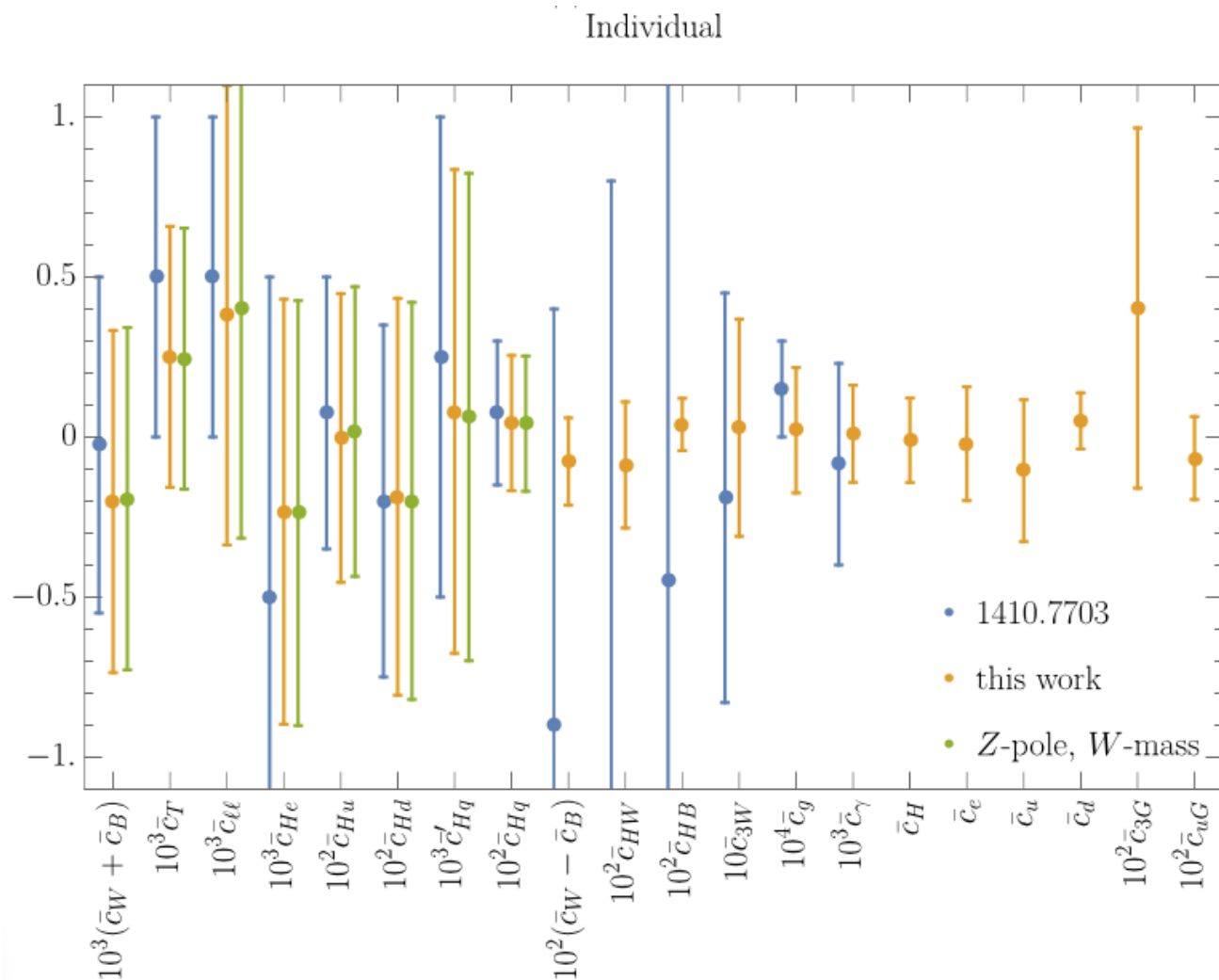
- Good agreement with optimised non-STXS fit



- Though more information lost in VH case

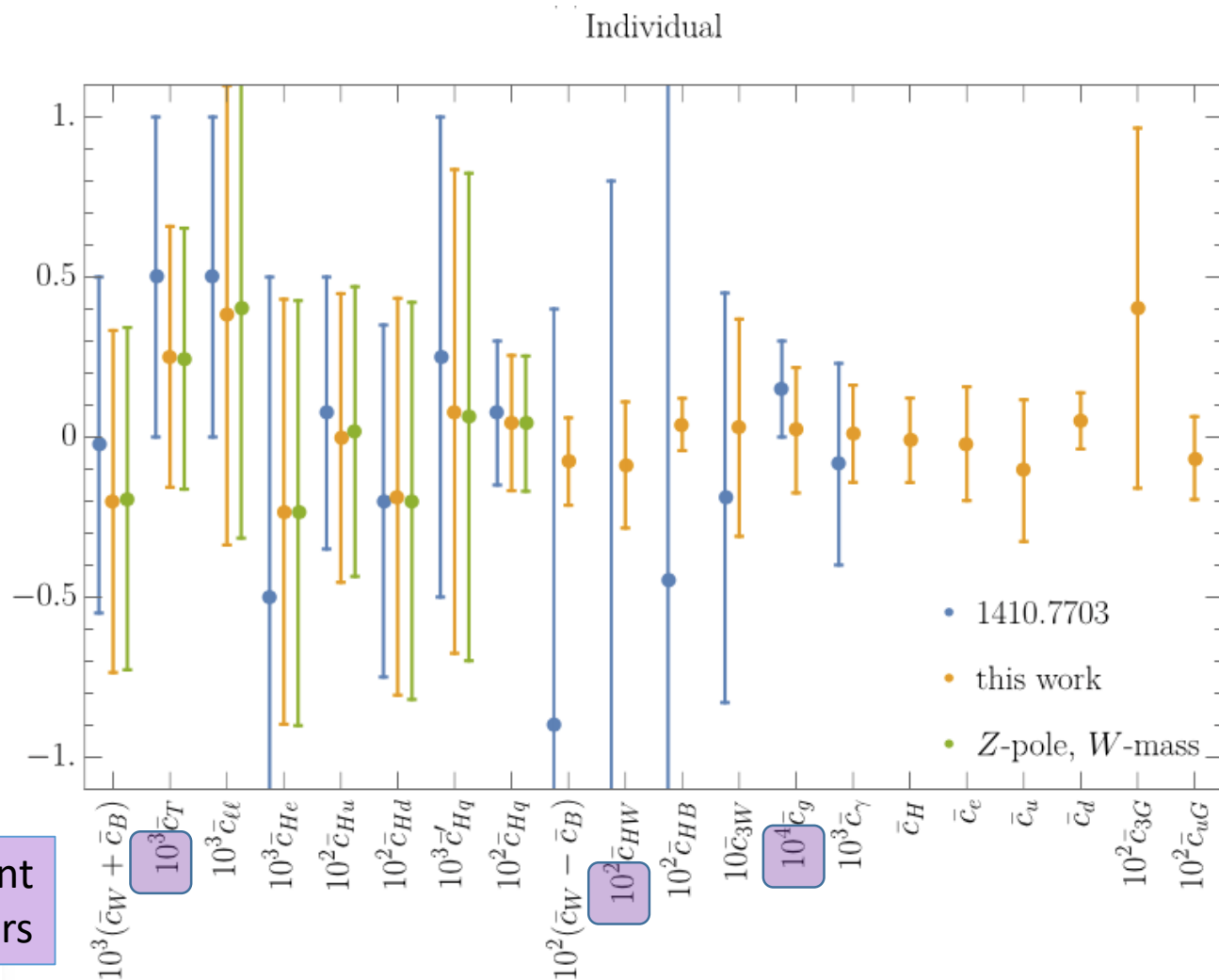
Results

- **SILH** basis, fit each operator **individually**



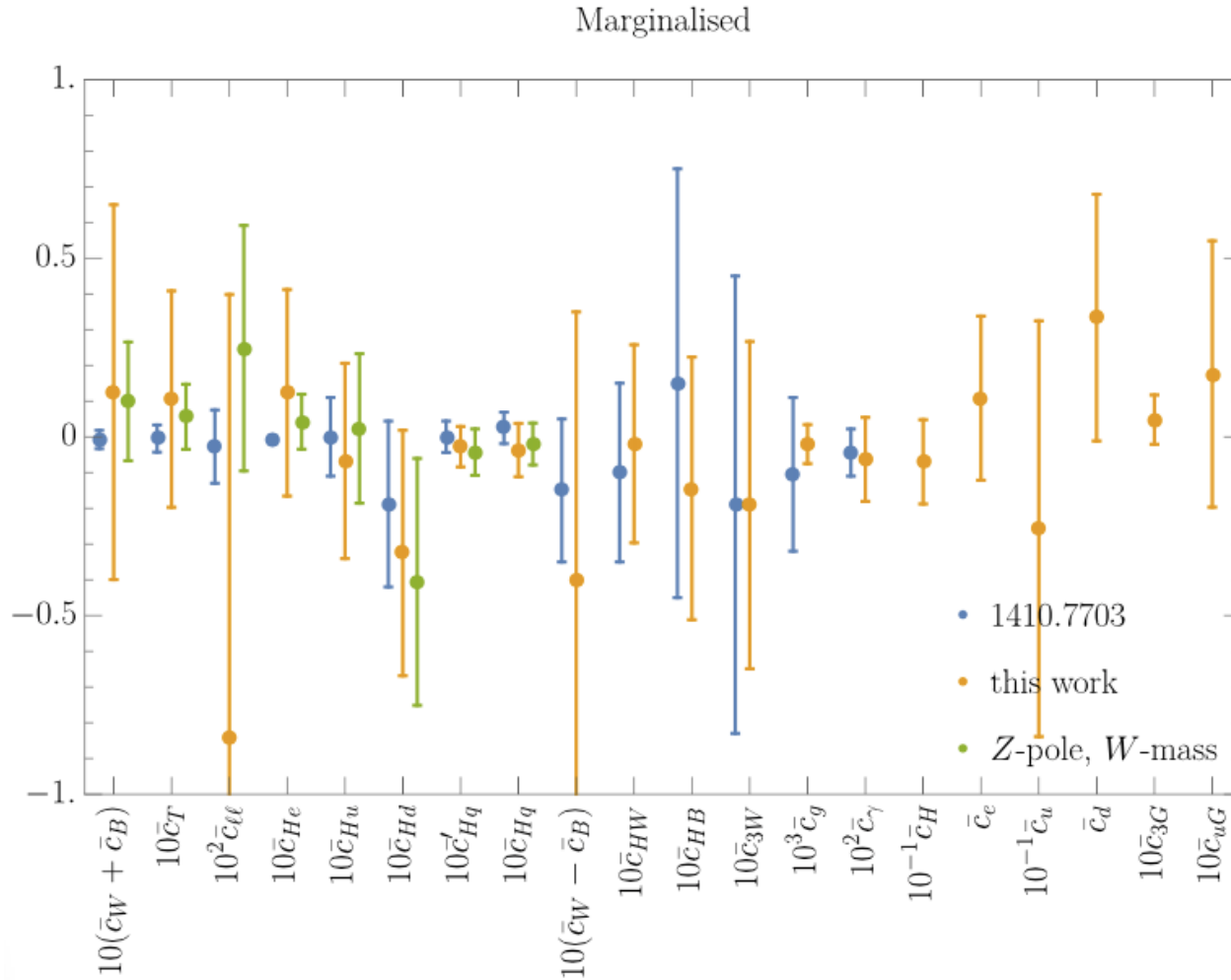
Results

- **SILH** basis, fit each operator **individually**



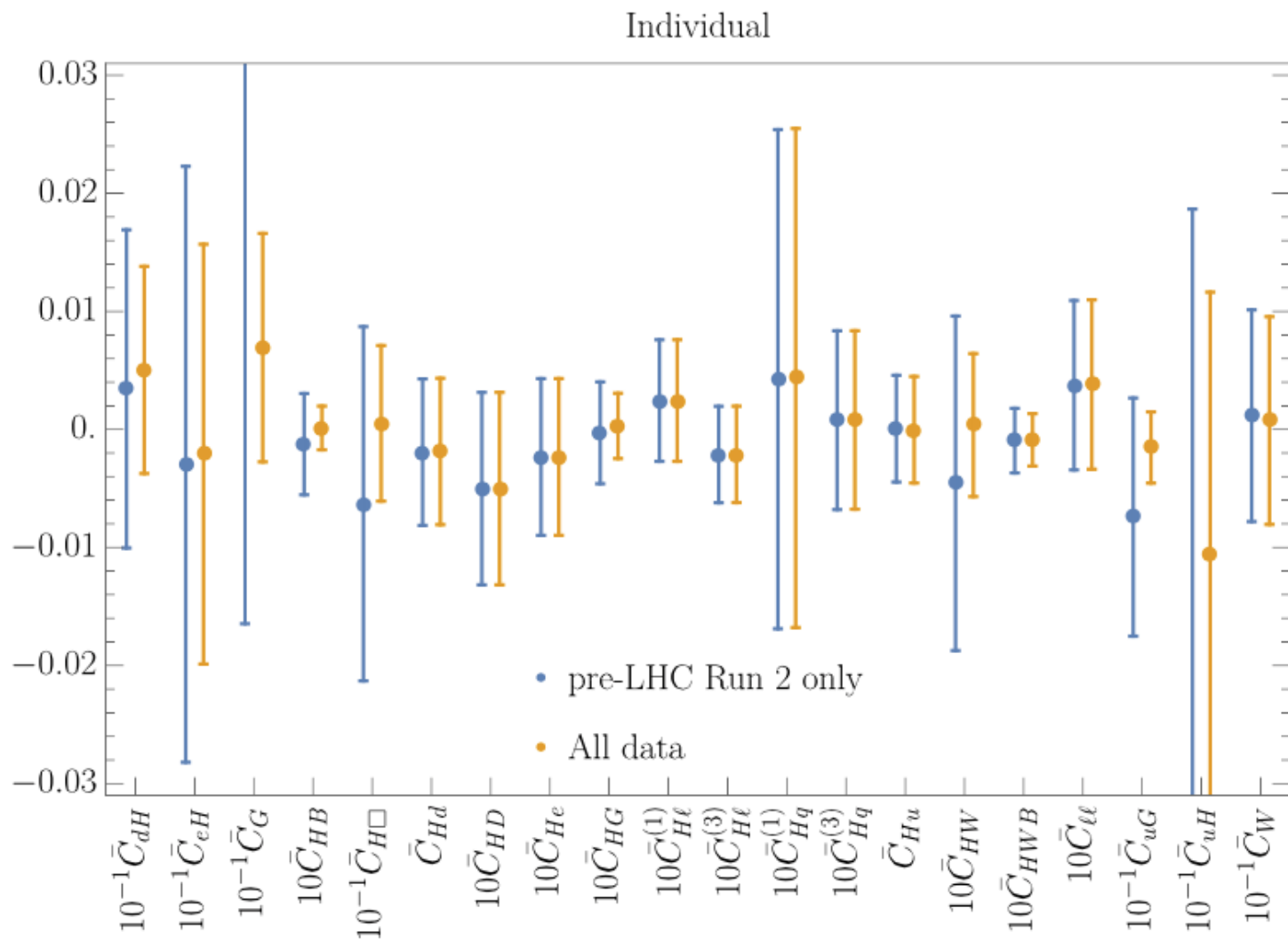
Results

- **SILH** basis, fit *all* operators **simultaneously**



Results

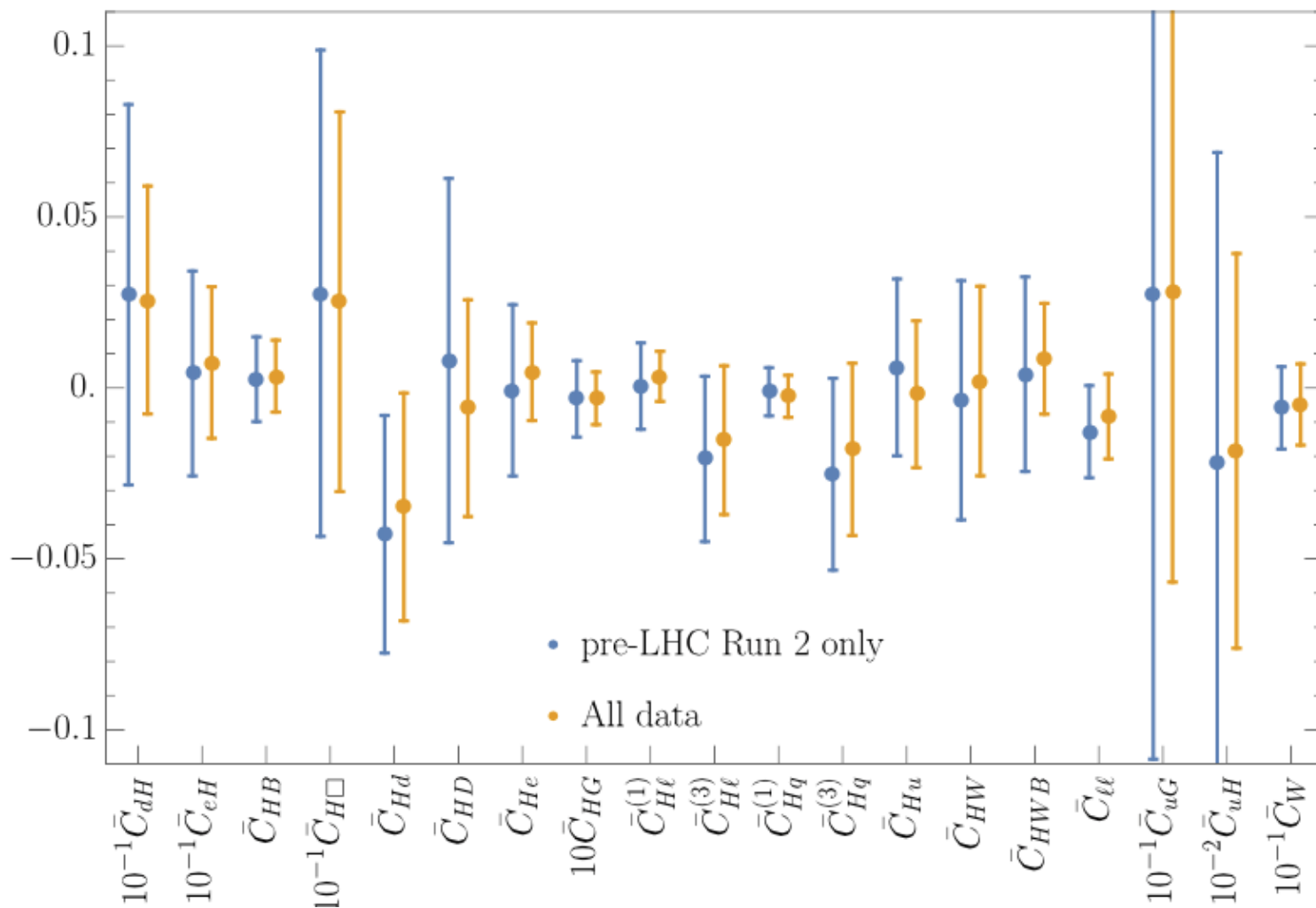
- **Warsaw** basis, fit each operator **individually**



Results

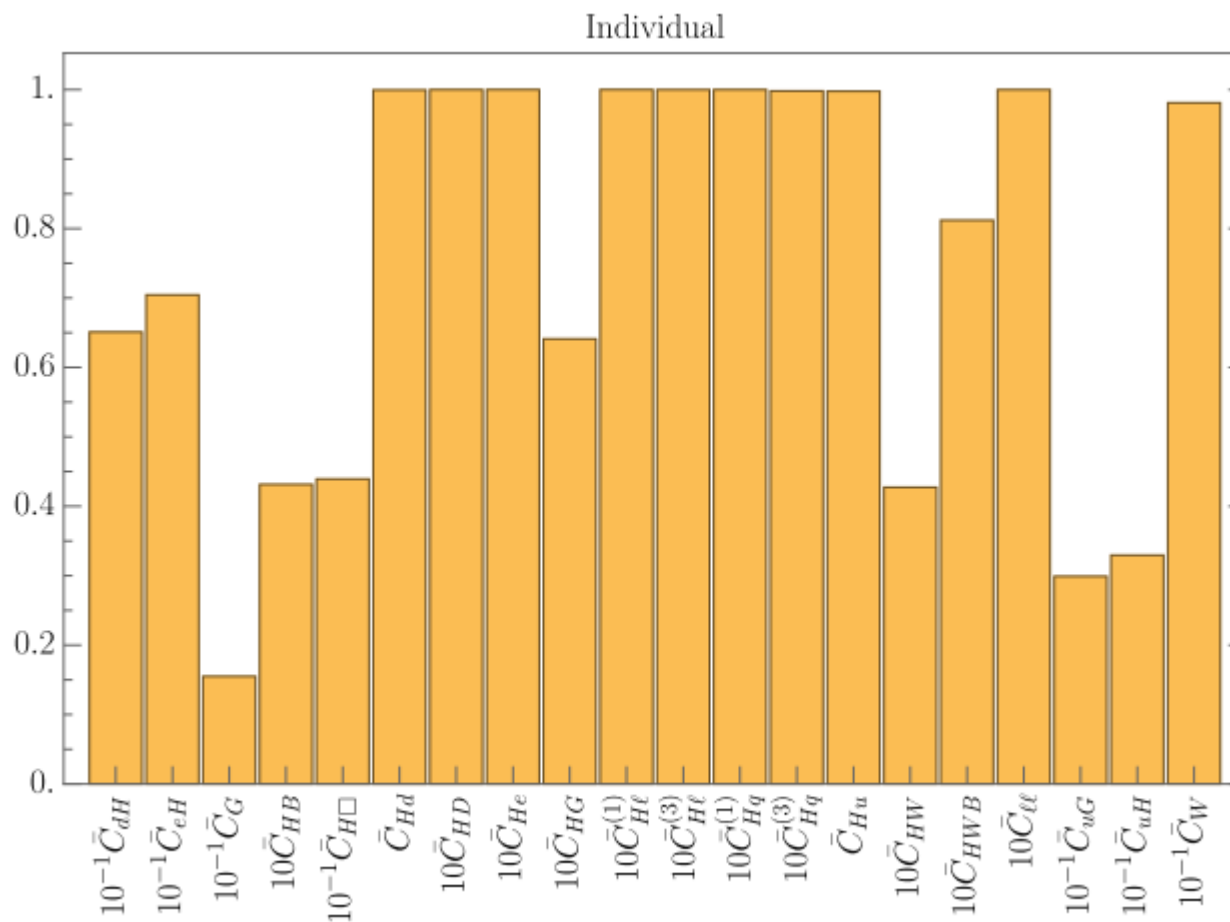
- **Warsaw basis, fit *all* operators simultaneously**

Marginalised



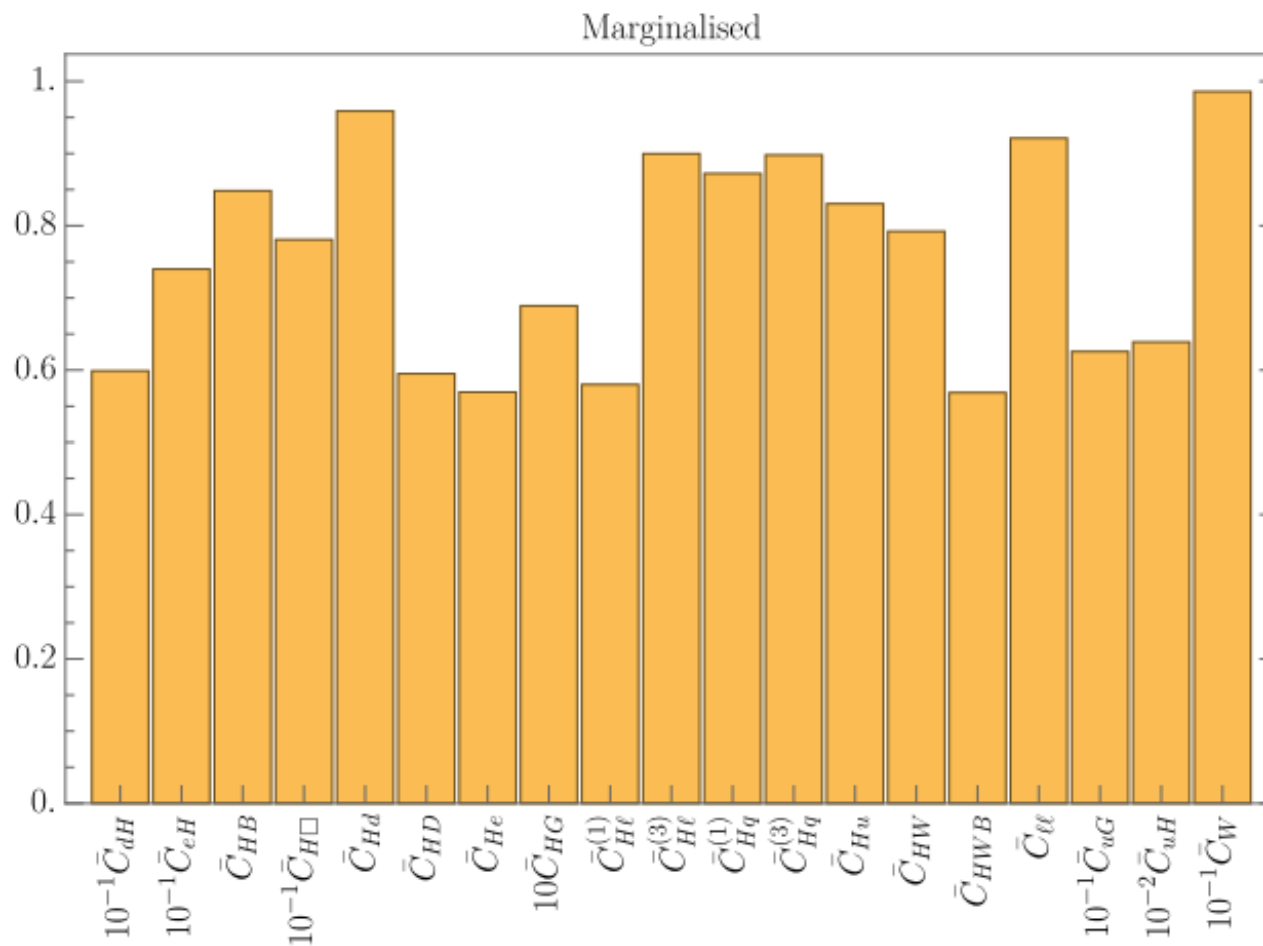
Results

- **Warsaw** basis, improvement from Run 1 to 2 (lower is better) for **individual** fit



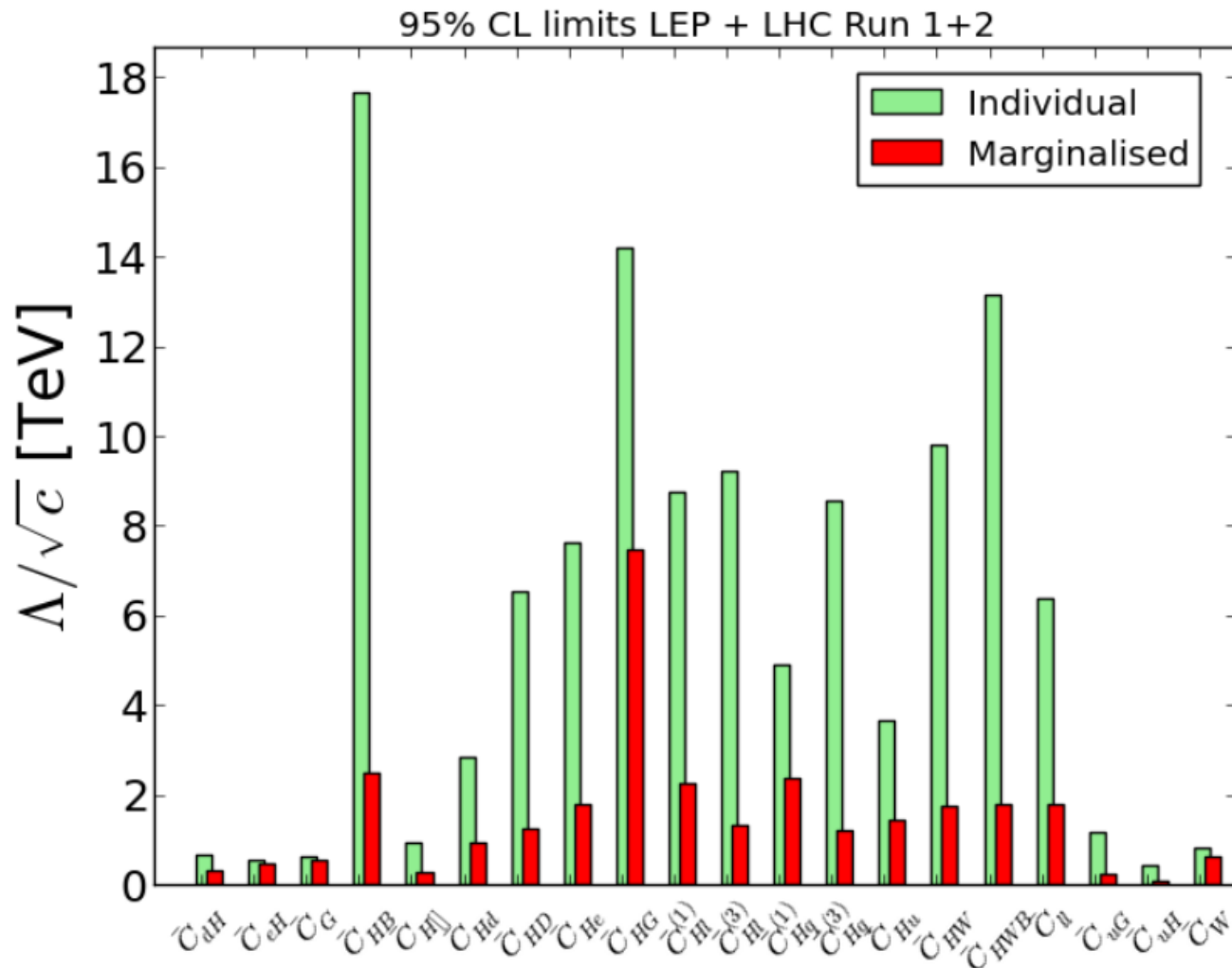
Results

- **Warsaw** basis, improvement from Run 1 to 2 (lower is better) for **marginalised** fit



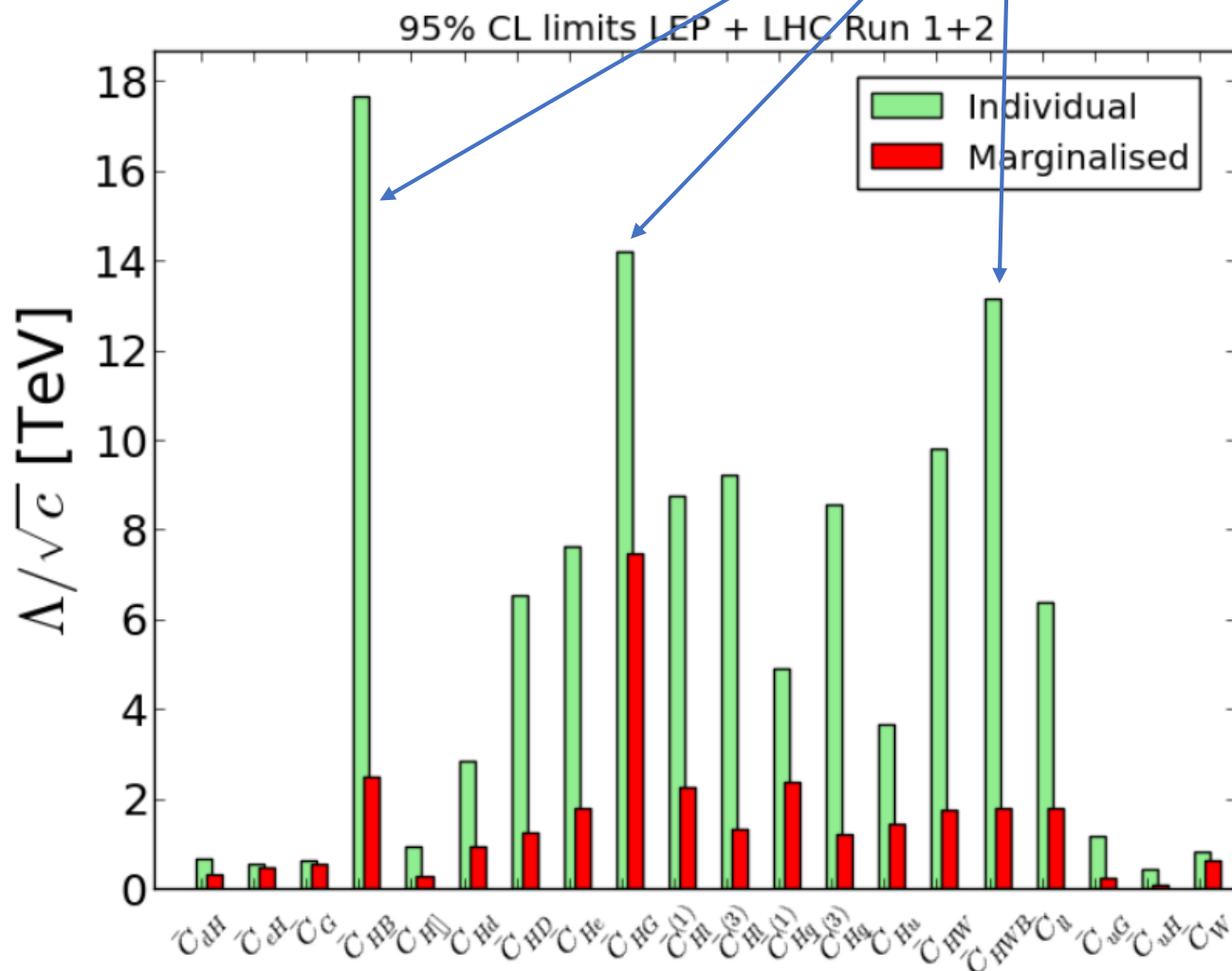
Results

- **Warsaw basis, summary**



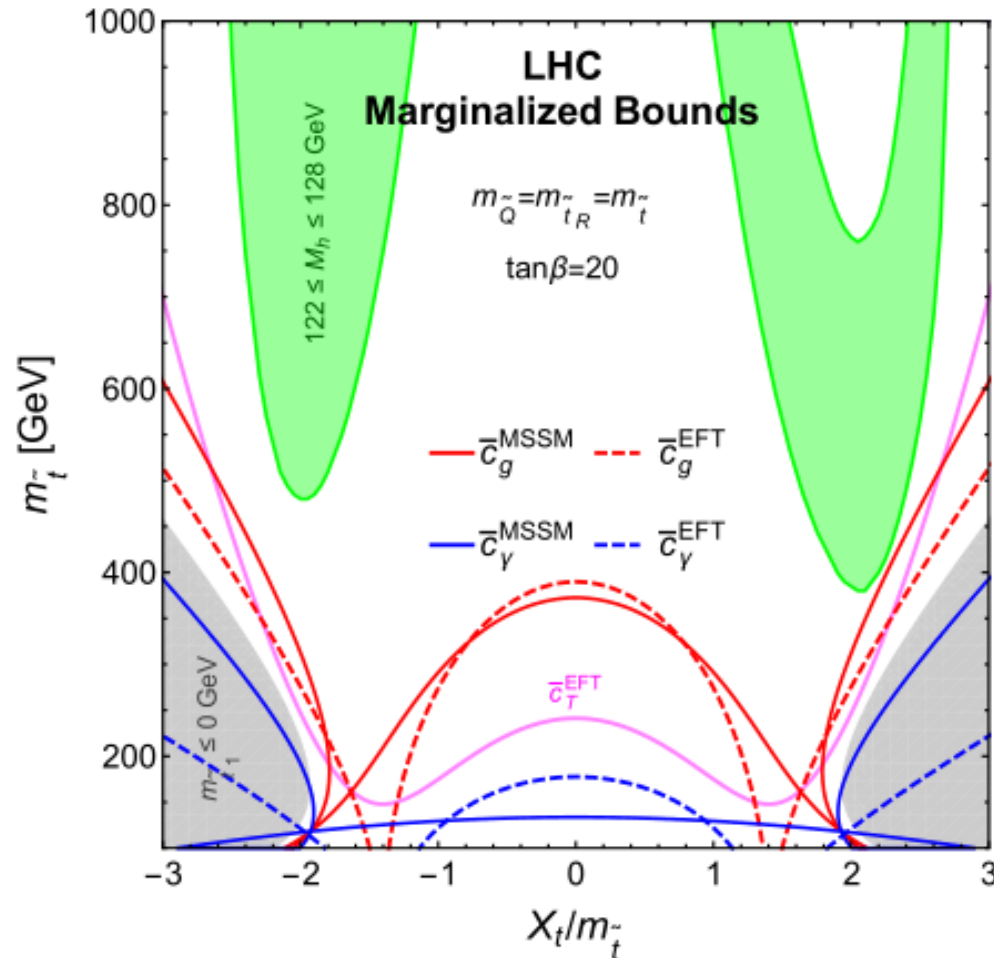
Results

- **Warsaw basis, summary**



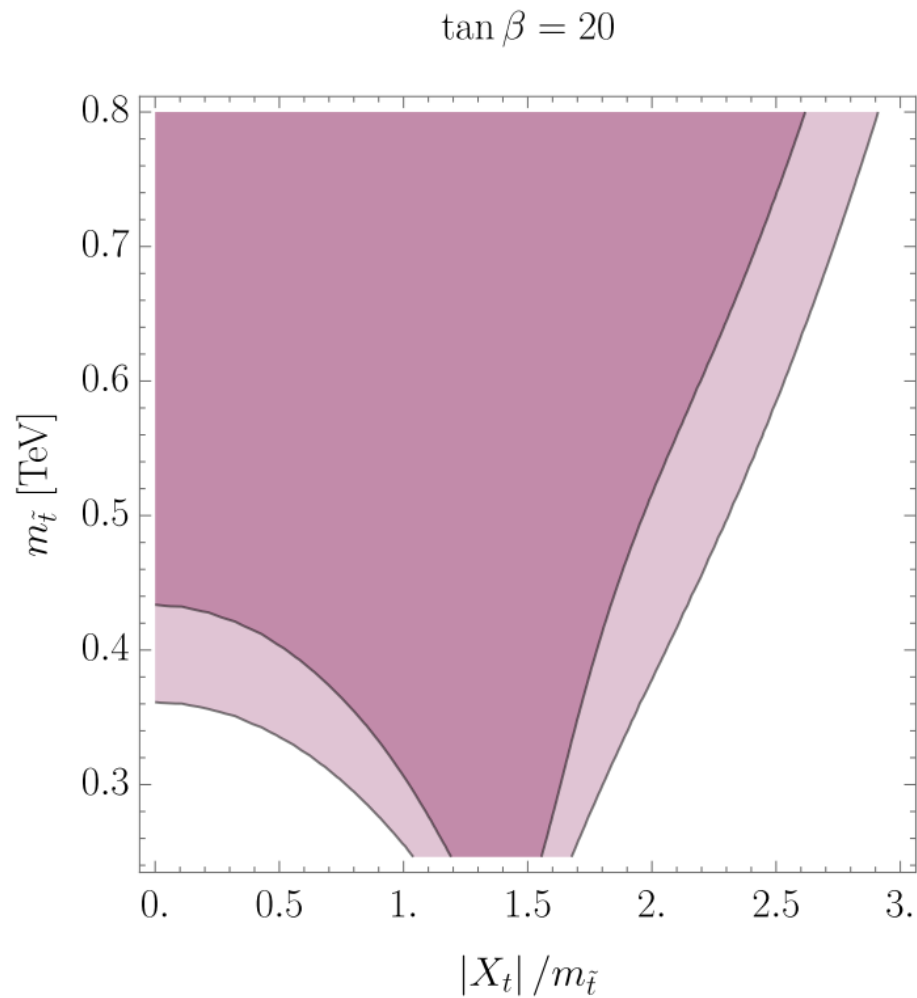
Results

- Simplified models: **stops** (Run 1)



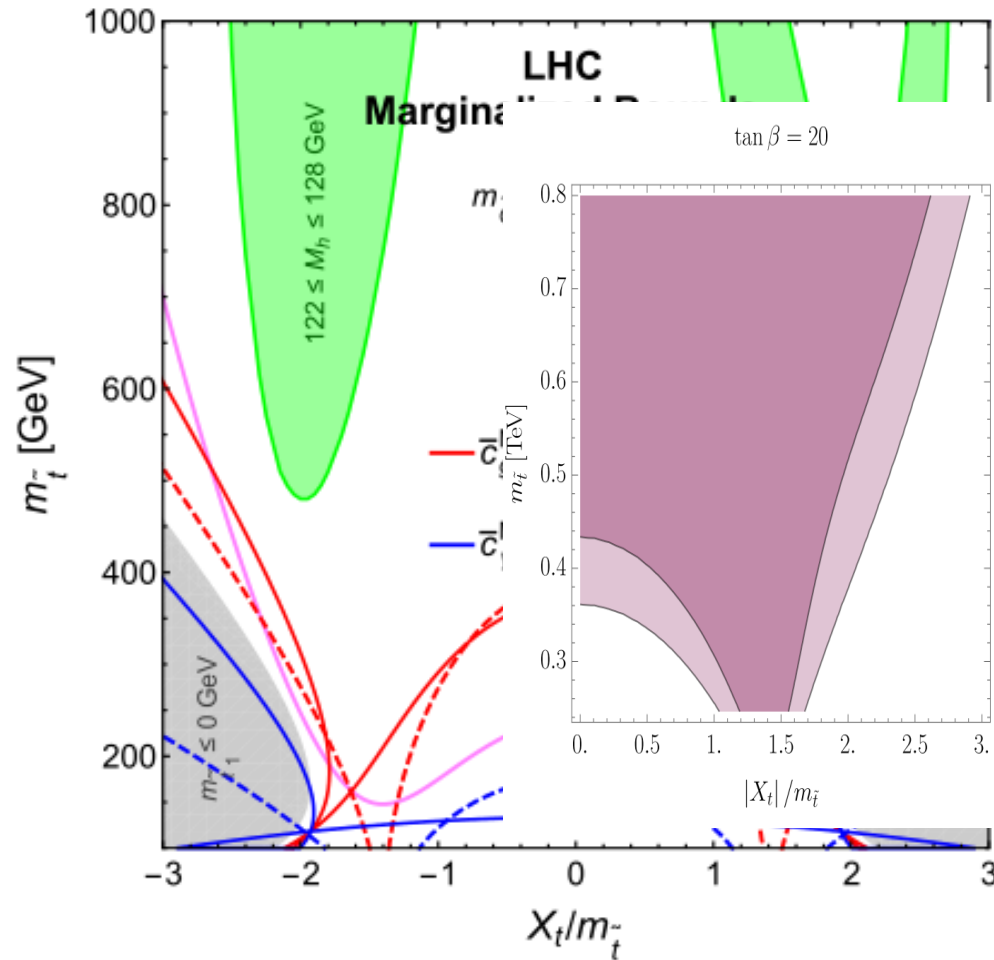
Results

- Simplified models: **stops** (Run 2)



Results

- Simplified models: **stops** (Run 2)



Results

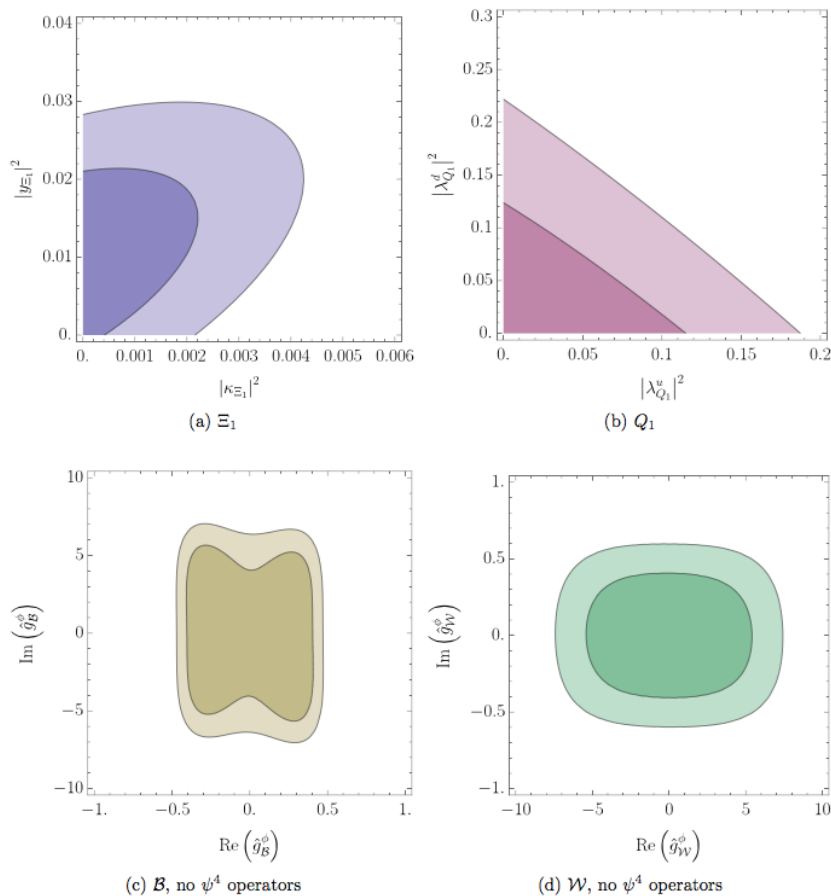
- Simplified models: **renormalisable SM extensions**

Name	Spin	$SU(3)$	$SU(2)$	$U(1)$	Name	Spin	$SU(3)$	$SU(2)$	$U(1)$
\mathcal{S}	0	1	1	0	Δ_1	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
\mathcal{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	$\frac{2}{3}$
\mathcal{B}	1	1	1	0	D	$\frac{1}{2}$	3	1	$-\frac{1}{3}$
\mathcal{B}_1	1	1	1	1	Q_1	$\frac{1}{2}$	3	2	$\frac{1}{6}$
\mathcal{W}	1	1	3	0	Q_5	$\frac{1}{2}$	3	2	$-\frac{5}{6}$
\mathcal{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	$\frac{2}{3}$

- Classification and tree-level matching dictionary

Results

- Simplified models: **renormalisable SM extensions**



Model	Pull [σ]	$\Delta \chi^2_{\text{dof}}$ [%]	Coupling	Mass / TeV
\mathcal{S}_1	1.1	0.1	$ y_{\mathcal{S}_1} ^2 = (6.3 \pm 5.9) \cdot 10^{-3}$	$M_{\mathcal{S}_1} = (9.1, 53)$
φ , Type I	0.6	-0.4	$Z_6 \cdot \cos \beta = -0.41 \pm 0.66$	$M_{\varphi} = (1.0, \infty)$
Ξ	1.2	0.4	$ \kappa_{\Xi} ^2 = (4.1 \pm 3.4) \cdot 10^{-3}$	$M_{\Xi} = (12, 36)$
N	1.5	0.9	$ \lambda_N ^2 = (1.8 \pm 1.2) \cdot 10^{-2}$	$M_N = (5.8, 13)$
E	0.2	-0.6	$ \lambda_E ^2 = (2.0 \pm 9.7) \cdot 10^{-3}$	$M_E = (9.2, \infty)$
Δ_3	0.7	-0.3	$ \lambda_{\Delta_3} ^2 = (0.8 \pm 1.1) \cdot 10^{-2}$	$M_{\Delta_3} = (7.3, \infty)$
Σ	0.4	-0.5	$ \lambda_{\Sigma} ^2 = (0.9 \pm 2.0) \cdot 10^{-2}$	$M_{\Sigma} = (5.9, \infty)$
Q_5	0.7	-0.3	$ \lambda_{Q_5} ^2 = 0.07 \pm 0.10$	$M_{Q_5} = (2.4, \infty)$
T_2	0.3	-0.5	$ \lambda_{T_2} ^2 = (1.8 \pm 5.1) \cdot 10^{-2}$	$M_{T_2} = (3.8, \infty)$
\mathcal{W}_1	1.2	0.3	$ \hat{g}_{\mathcal{W}_1}^{\phi} ^2 = (3.3 \pm 2.7) \cdot 10^{-3}$	$M_{\mathcal{W}_1} = (4.1, 13)$
\mathcal{S}	-	-	$ y_{\mathcal{S}} ^2 < 0.47$	$M_{\mathcal{S}} > 1.5$
Δ_1	-	-	$ \lambda_{\Delta_1} ^2 < 5.7 \cdot 10^{-3}$	$M_{\Delta_1} > 13$
Σ_1	-	-	$ \lambda_{\Sigma_1} ^2 < 7.3 \cdot 10^{-3}$	$M_{\Sigma_1} > 12$
U	-	-	$ \lambda_U ^2 < 3.1 \cdot 10^{-2}$	$M_U > 5.7$
D	-	-	$ \lambda_D ^2 < 1.5 \cdot 10^{-2}$	$M_D > 8.2$
Q_7	-	-	$ \lambda_{Q_7} ^2 < 7.2 \cdot 10^{-2}$	$M_{Q_7} > 3.7$
T_1	-	-	$ \lambda_{T_1} ^2 < 0.11$	$M_{T_1} > 3.0$
\mathcal{B}_1	-	-	$ \hat{g}_{\mathcal{B}_1}^{\phi} ^2 < 2.4 \cdot 10^{-3}$	$M_{\mathcal{B}_1} > 20$

- Streamlines process of interpreting limits on BSM parameter space

Conclusion

- SM EFT framework is the Fermi theory of the 21st century
- Systematic classification of decoupled new physics
- Correlates measurements and eases interpretation
- Finding patterns of deviations will give clues to the underlying fundamental theory at higher energies

Backup

Coefficient	Z-pole + m_W	WW at LEP2	Higgs Run1	Higgs Run2	LHC WW high- p_T
\bar{C}_{dH}	×	×	42.4	57.6	×
\bar{C}_{eH}	×	×	49.6	50.4	×
\bar{C}_G	×	×	2.4	97.6	×
\bar{C}_{HB}	×	×	18.6	81.4	×
$\bar{C}_{H\Box}$	×	×	19.3	80.7	0.01
\bar{C}_{Hd}	99.85	×	0.04	0.1	×
\bar{C}_{HD}	99.92	0.06	×	×	×
\bar{C}_{He}	99.99	0.01	×	×	×
\bar{C}_{HG}	×	×	41.1	58.9	0.03
$\bar{C}_{H\ell}^{(1)}$	99.97	0.03	×	×	×
$\bar{C}_{H\ell}^{(3)}$	99.56	0.41	×	×	0.01
$\bar{C}_{Hq}^{(1)}$	99.98	×	×	×	×
$\bar{C}_{Hq}^{(3)}$	98.5	0.96	0.19	0.31	0.07
\bar{C}_{Hu}	99.3	×	0.2	0.42	0.04
\bar{C}_{HW}	×	×	18.3	81.7	×
\bar{C}_{HWB}	57.7	0.02	8.2	34.1	×
$\bar{C}_{\ell\ell}$	99.66	0.3	×	0.01	×
\bar{C}_{uG}	×	×	8.9	91.1	×
\bar{C}_{uH}	×	×	10.9	89.1	×
\bar{C}_W	×	96.2	×	×	3.8

Backup

