Mapping the SMEFT at High-Energy colliders

Based on SMEFiT3.0 [arXiv:2404.12809] with T. Giani, J. ter Hoeve, L. Mantani, J. Rojo, A. N. Rossia, M. Thomas, E. Vryonidou

> Top 2024, Saint-Malo, Brittany, France 24/09/24

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The University of Manchester

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The special role of top

- Lots of top measurements, but no deviation with the SM detected so far
- New physics searches require a general approach



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Standard Model Total Production Cross Section Measurements Status: June 2024 <u>අ</u> 10¹¹ ATLAS Preliminary Theor Ь $\sqrt{s} = 5,7,8,13,13.6$ TeV LHC pp $\sqrt{s} = 13.6$ TeV 106 Data 29.0 - 31.4 fb 10⁵ * + 0 40 ata 20.2 - 20.3 fb 10⁴ $\sqrt{s} = 7 \text{ TeV}$ Data 4.5 - 4.6 fb 10³ $\sqrt{s} = 5 \text{ TeV}$ Data 0.255 - 0.3 fb 10² 10¹ 1 10^{-1} 10-2 tī zz

- Top plays a special role in the SM
 - largest fermion mass
 - largest Yukawa coupling
 - top-loop effects are crucial in Higgs and EW processes
- Cross-talk between different sectors (Higgs, top, EW) requires a global analysis



[arXiv: 1804.09766]

SMEFT global fits

• The SMEFT reveals high energy physics effects through precise measurements at low energy

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_{i} \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \mathcal{O}(\Lambda^{-3})$$
$$\sigma = |\mathcal{M}_{\rm SM}|^2 + \frac{1}{\Lambda^2} \left(\sum c^{(6)} 2 \text{Re}[\mathcal{M}_{\rm SM}^* \mathcal{M}_{\rm EFT}^{(6)}] \right) + \frac{1}{\Lambda^4} \left(\sum c^{(6)} \mathcal{M}_{\rm EFT}^{(6)} \right)^2$$



- Ideal framework to look for overall pattern in global fits
- Large number of operator coefficients, many datasets needed to break degeneracies



Fitmaker Collaboration [arXiv:2012.02779]



Anke Biekötter - HET seminar Brookhaven

SMEFiT3.0: a summary



- Extension of SMEFTZ.0 with recent LnC Run-il datasets on top, diboson and higgs production
 [arXiv:2105.00006]
- Exact treatment of LEP and SLD Electroweak Precision Observables (EWPOs)
- Projections for HL-LHC pseudodata extrapolated from Run-II data
- FCC-ee and CEPC pseudodata from Snowmass predictions updated with FCC midterm Feasibility Report
 [arXiv:2206.08326]
 [CERN/3789/RA]
- Results for LHC Run-II and future colliders in terms of Wilson coefficients and UV-complete models
 [arXiv:2309.04523]



Experimental data

445 data points from Higgs, top, diboson (LHC) & EWPOs (LEP)

Experimental **uncertainties + correlations** as provided by experiments



Theory

SM: (N)NLO QCD + NLO EW

EFT: NLO QCD, linear and quadratics, with SMEFT@NLO

NNPDF4.0 no top

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SMEFit

Methodology

Linear fit: **Analytical solution** Quadratic fit: **Nested sampling** (Bayesian inference)

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Methodology

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Output

Automatised fit report with **bounds** on coefficients, **posterior** distributions, **PCA**, **Fisher information**...

Experimental input

Extension of SMEFiT2.0 with recent LHC Run-II datasets on top, diboson and Higgs production

SMEFiT3.0: EC, Giani, ter Hoeve, Mantani, Rojo, Rossia, Thomas, Vryonidou [arXiv:2404.12809] SMEFiT2.0: Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, Vryonidou, Zhang [arXiv:2105.00006]

Catagory	Dro constant	$n_{ m dat}$					
Category	riocesses	SMEF1T2.0	SMEFIT3.0				
	$t\bar{t} + X$	94	115				
	$tar{t}Z,tar{t}W$	14	21				
	$tar{t}\gamma$	-	2				
Top quark production	single top (inclusive)	27	28				
	tZ, tW	9	13				
	$tar{t}tar{t}$, $tar{t}bar{b}$	6	12				
	Total	150	191				
	Run I signal strengths	22	22				
Higgs production	Run II signal strengths	40	36 (*)				
and decay	Run II, differential distributions & STXS	35	71				
	Total	97	129				
	LEP-2	40	40				
Diboson production	LHC	30	41				
	Total	70	81				
EWPOs	LEP-2	-	44				
Baseline dataset	Total	317	445				

+118 data points

Theory input: operators

- Warsaw basis of dim-6 SMEFT operators
- Flavour symmetry: $U(2)_q \times U(3)_d \times U(2)_u \times (U(1)_l \times U(1)_e)^3$ + Yukawa of bottom, charm and tau

Operator	Coefficien	t Definition	Operator	Coefficient	
		3rd genera	tion quarks		
${\cal O}^{(1)}_{_{arphi Q}}$	$c^{(1)}_{arphi Q}$ (*)	$i \bigl(\varphi^\dagger \overset{\leftrightarrow}{D}_\mu \varphi \bigr) \bigl(ar{Q} \gamma^\mu Q \bigr)$	\mathcal{O}_{tW}	c_{tW}	$i(\bar{Q}\tau^{\mu u} au_{I}t)\tilde{\varphi}W^{I}_{\mu u}+ ext{h.c.}$
${\cal O}^{(3)}_{_{arphi Q}}$	$c^{(3)}_{arphi Q}$	$iig(arphi^\dagger \! \stackrel{\leftrightarrow}{D}_\mu au_{\scriptscriptstyle I} arphiig)ig(ar{Q} \gamma^\mu au^{\scriptscriptstyle I} Qig)$	\mathcal{O}_{tB}	c_{tB} (*)	$i(\bar{Q}\tau^{\mu\nu}t)\tilde{\varphi}B_{\mu\nu}$ + h.c.
${\cal O}_{arphi t}$	$c_{arphi t}$	$i \left(\varphi^{\dagger} \stackrel{\leftrightarrow}{D}_{\mu} \varphi \right) \left(\bar{t} \gamma^{\mu} t \right)$	\mathcal{O}_{tG}	c_{tG}	$ig_{S}\left(ar{Q} au^{\mu u}T_{{}_{A}}t ight) ilde{arphi}G^{A}_{\cdot\cdot u}\!+\! ext{h.c.}$
${\cal O}_{tarphi}$	c_{tarphi}	$\left(\varphi^{\dagger} \varphi \right) ar{Q} t \widetilde{\varphi} + {\rm h.c.}$	\mathcal{O}_{barphi}	$c_{b\varphi}$	
		1st, 2nd gene	ration quar	ks	
$\mathcal{O}^{(1)}_{_{arphi q}}$	$c^{(1)}_{arphi q}$ (*)	$\sum\limits_{i=1,2} i ig(arphi^{\dagger} \stackrel{\leftrightarrow}{D}_{\mu} arphi ig) ig(ar{q}_i \gamma^{\mu} q_i ig)$	$\mathcal{O}_{arphi d}$	$c_{arphi d}$	$\sum_{i=1,2,3} i (arphi^\dagger \overset{\leftrightarrow}{D}_\mu arphi) (ar{d}_i \gamma^\mu d_i)$
${\cal O}^{(3)}_{_{arphi q}}$	$c^{(3)}_{arphi q}$	$\sum\limits_{i=1,2} iig(arphi^\dagger \stackrel{\leftrightarrow}{D}_\mu au_I arphi ig) ig(ar q_i \gamma^\mu au^I q_i ig)$	\mathcal{O}_{carphi}	$c_{c\varphi}$	$\left(arphi^{\dagger}arphi ight)ar{q}_{2}c ilde{arphi}+ ext{h.c.}$
${\cal O}_{arphi u}$	$c_{arphi u}$	$\sum_{i=1,2}^{\infty} i \left(\varphi^{\dagger} \stackrel{\leftrightarrow}{D}_{\mu} \varphi \right) \left(ar{u}_i \gamma^{\mu} u_i ight)$			<i>J</i>
		two-le	eptons		\bar{f}
$\mathcal{O}_{_{arphi \ell_i}}$	$c_{arphi \ell_i}$	$i (\varphi^{\dagger} \stackrel{\leftrightarrow}{D}_{\mu} \varphi) (\bar{\ell}_i \gamma^{\mu} \ell_i)$	$\mathcal{O}_{arphi\mu}$	$c_{arphi\mu}$	$i \left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi ight) \left(ar \mu \gamma^\mu \mu ight)$
${\cal O}^{(3)}_{_{arphi\ell_i}}$	$c^{(3)}_{\varphi \ell_i}$	$iig(arphi^\dagger \stackrel{\leftrightarrow}{D}_\mu au_{\scriptscriptstyle I} arphiig)ig(ar{\ell}_i\gamma^\mu au^{\scriptscriptstyle I}\ell_iig)$	$\mathcal{O}_{arphi au}$	$c_{arphi au}$	$i\left(\varphi^{\dagger}\overset{\leftrightarrow}{D}_{\mu}\varphi\right)\left(\bar{\tau}\gamma^{\mu}\tau\right)$
$\mathcal{O}_{arphi e}$	$c_{arphi e}$	$i \bigl(\varphi^\dagger \overset{\leftrightarrow}{D}_\mu \varphi \bigr) \bigl(\bar{e} \gamma^\mu e \bigr)$	$\mathcal{O}_{ auarphi}$	$c_{ au arphi}$	$\left(\varphi^{\dagger} \varphi \right) \bar{\ell_3} \tau \varphi + {\rm h.c.}$
		four-le	eptons		
$\mathcal{O}_{\ell\ell}$	$c_{\ell\ell}$	$\left(ar{\ell}_1\gamma_\mu\ell_2 ight)\left(ar{\ell}_2\gamma^\mu\ell_1 ight)$			

Simultaneous fit of 50 Wilson coefficients

DoF	Definition (in Wa	rsaw basis notation)	DoF	Definition (in V	Warsaw basis notation)
c_{QQ}^1	$2c_{qq}^{1(3333)} - \frac{2}{3}c_{qq}^{3(333)}$		c_{QQ}^8	$8c_{qq}^{3(3333)}$	
c_{Qt}^1	$c_{qu}^{1(3333)}$		c_{Qt}^8	$c_{qu}^{8(3333)}$	
$c_{Qq}^{1,8}$	$c_{qq}^{1(i33i)} + 3c_{qq}^{3(i33i)}$	t	$c_{Qq}^{1,1}$	$c_{qq}^{1(ii33)} + \frac{1}{6}c_{qq}^{1(i3)}$	$a^{3i)} + \frac{1}{2}c^{3(i33i)}_{qq}$
$c_{Qq}^{3,8}$	$c_{qq}^{1(i33i)} - c_{qq}^{3(i33i)}$		$c_{Qq}^{3,1}$	$c_{qq}^{3(ii33)} + \frac{1}{6}(c_{qq}^{1(i)})$	$^{33i)} - c_{qq}^{3(i33i)})$
c_{tq}^8	$c_{qu}^{8(ii33)}$	f	t c_{tq}^1	$c_{qu}^{1(ii33)}$	
c_{tu}^8	$2c_{uu}^{(i33i)}$		c_{tu}^1	$c_{uu}^{(ii33)} + \frac{1}{3}c_{uu}^{(i33i)}$)
c_{Qu}^8	$c_{qu}^{8(33ii)}$	\overline{f}	$\overline{t} c^1_{Qu}$	$c_{qu}^{1(33ii)}$	
c_{td}^8	$c_{ud}^{8(33jj)}$	J	c_{td}^1	$c_{ud}^{1(33jj)}$	
c_{Qd}^8	$c_{qd}^{8(33jj)}$		c_{Qd}^1	$c_{qd}^{1(33jj)}$	
Operator	Coefficient	Definition	Operator	Coefficient	Definition
$\mathcal{O}_{arphi G}$	$c_{\varphi G}$	$\left(arphi^{\dagger} arphi ight) G^{\mu u}_{\scriptscriptstyle A} G^{\scriptscriptstyle A}_{\mu u}$	$\mathcal{O}_{arphi\square}$	$c_{arphi\square}$	$\partial_\mu (arphi^\dagger arphi) \partial^\mu (arphi^\dagger arphi)$
${\cal O}_{arphi B}$	$c_{arphi B}$	$\left(\varphi^{\dagger}\varphi\right)B^{\mu\nu}B_{\mu\nu}$	$\mathcal{O}_{arphi D}$	$c_{arphi D}$	$(\varphi^{\dagger}D^{\mu}\varphi)^{\dagger}(\varphi^{\dagger}D_{\mu}\varphi)$
${\cal O}_{arphi W}$	$c_{arphi W}$	$\left(\varphi^{\dagger} \varphi \right) W^{\mu \nu}_{\scriptscriptstyle I} W^{\scriptscriptstyle I}_{\mu \nu}$	\mathcal{O}_W	c_{WWW}	$\epsilon_{IJK}W^{I}_{\mu\nu}W^{J,\nu\rho}W^{K,\mu}_{\rho}$
${\cal O}_{arphi WB}$	$c_{arphi WB}$	$(\varphi^{\dagger} au_{\scriptscriptstyle I} \varphi) B^{\mu u} W^{\scriptscriptstyle I}_{\mu u}$		_	
		~ V		V	h







- Most bounds below 1 for $\Lambda=1~{\rm TeV}$
- Quadratic terms important (mostly 2light-2-heavy)
- Least constrained are 4-heavy operators



• Fit residuals (pulls) largely consistent with the SM

$$P_{i} \equiv 2 \left(\frac{\langle c_{i} \rangle - c_{i}^{(\text{SM})}}{\left[c_{i}^{\min}, c_{i}^{\max} \right]^{68\% \text{ CI}}} \right)$$



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• Large correlations in the linear fit are lifted in the quadratic fit





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Impact of new datasets



Prospects at future colliders









MInternational UON Collider Collaboration

HL-LHC results

<i>P</i> . —	$\left[c_i^{\min}, c_i^{\max}\right]^{95\% \text{ CL}}$	(baseline + HL-LHC)
$m_{\delta c_i}$ —	$\left[c_{i}^{\min},c_{i}^{\max} ight]^{95}$	5% CL (baseline)

Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}\left(\Lambda^{-4}\right)$, Marginalised



HL-LHC results

$$R_{\delta c_i} = \frac{\left[c_i^{\min}, c_i^{\max}\right]^{95\% \text{ CL}} \text{ (baseline + HL-LHC)}}{\left[c_i^{\min}, c_i^{\max}\right]^{95\% \text{ CL}} \text{ (baseline)}}$$

- L1 projections of Run II datasets
 - pseudodata fluctuated around SM theory
 - statistics rescaled by luminosity
 - systematics reduced by a factor 2



Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}\left(\Lambda^{-4}\right)$, Marginalised

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- L1 projections of Run II datasets
 - pseudodata fluctuated around SM theory
 - statistics rescaled by luminosity
 - systematics reduced by a factor 2
- marginalised bounds improve by a factor 1.2-3
- individual bounds are overly optimistic
- 2-light-2-heavy improved by 30% (further improvement of a factor 2 expected with a dedicated binning)

[arXiv:2206.08326] [arXiv:2205.02140] Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}(\Lambda^{-4})$, Marginalised



Future circular lepton colliders



- Dataset input
 - EWPOs at the Z pole
 - light fermion pair production
 - Higgs production (Higgstrahlung and VBF)
 - diboson (WW) production
 - top pair production
- Uncertainty projections from Snowmass study updated with FCC midterm Feasibility Report [arXiv:2206.08326]

[CERN/3789/RA]

Enormy ($\mathcal{L}_{\mathrm{int}}$ (Ru			
Energy $(\sqrt{3})$	FCC-ee (4 IPs)	CEPC (2 IPs)	\sim FCC $-ee/\sim$ CEPC	
91 GeV (Z-pole)	$300 \text{ ab}^{-1} (4 \text{ years})$	$100 \text{ ab}^{-1} (2 \text{ years})$	3	
161 GeV $(2 m_W)$	$20 \text{ ab}^{-1} (2 \text{ years})$	$6 \text{ ab}^{-1} (1 \text{ year})$	3.3	
$240 { m ~GeV}$	$10 \text{ ab}^{-1} (3 \text{ years})$	20 ab^{-1} (10 years)	0.5	
$350~{ m GeV}$	$0.4 \text{ ab}^{-1} (1 \text{ year})$	$0.2 \ {\rm ab}^{-1}$	2	
$\boxed{365~{\rm GeV}~(2m_t)}$	3 ab^{-1} (4 years)	1 ab^{-1} (5 years)	3	

FCC-ee results

$$R_{\delta c_i} = \frac{\left[c_i^{\min}, c_i^{\max}\right]^{95\% \text{ CL}} \text{ (baseline + HL-LHC)}}{\left[c_i^{\min}, c_i^{\max}\right]^{95\% \text{ CL}} \text{ (baseline)}}$$

- gauge operators improve of up to a factor 30
- 2-fermion operators improve of up to a factor 50
- no sensitivity to 4-quark operators: improvement only from marginalisation

further improvement expected from one loop corrections

[see for instance arXiv: 1809.03520, arXiv: 2409.11466] Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}(\Lambda^{-4})$, Marginalised



Fisher information

• The Fisher information matrix quantifies which dataset is most sensitive to a EFT parameter (each row is normalised by 100)

$$I_{ij} = \sum_{m=1}^{n_{\text{dat}}} \frac{\sigma_{m,i}^{(\text{eft})} \sigma_{m,j}^{(\text{eft})}}{\delta_{\exp,m}^2}, \qquad i, j = 1, \dots, n_{\text{eft}}$$

neglects correlations and quadratic effects

- HL-LHC dominates in the 2-light-2-heavy and 4-heavy sectors
- FCC-ee dominates in the bosonic and 2fermion sector
- FCC-ee run at 161 GeV is the less useful for SMEFT

al	LEP	$t\bar{t}$ 8 TeV	$t\overline{t}$ 13 TeV	$t\bar{t}\gamma$	$t\bar{t}W$	$t\bar{t}Z$	t 8 TeV	t 13 TeV	tW	tZ	$t\bar{t}A_c$	W helicities	$\begin{bmatrix} 1 & t\bar{t}t\bar{t} + t\bar{t}b\bar{b} \end{bmatrix}$	Higgs-run I	Higgs-run II	AA	$t\bar{t}$ 13 TeV HL-LHC	ttW HL-LHC	$t\bar{t}Z$ HL-LHC	t 13 TeV HL-LHC	tW HL-LHC	tZ HL-LHC	$t\bar{t}A_c$ HL-LHC	W helicities HL-LHC	$t\bar{t}t\bar{t} + t\bar{t}b\bar{b}$ HL-LHC	Higgs HL-LHC	VV HL-LHC	FCC-ee 91 GeV	FCC-ee 161 GeV	FCC-ee 240 GeV	FCC-ee 365 GeV	1			- 100	
c_{QQ}^{*} c_{QQ}^{8}													15.1												84.9											
c_{Qt}^1				ŀ	1()		D	a	S	e	Ir	16	Э)					F	١L	-	۰L	. -	+(81.9				F	()(5-	E	96	è	
c_{Qt}^{1} c_{tt}^{1}													14.0												86.0											
$c_{Qq}^{1,8}$		0.4	8.4	0.2	1.6	1.3					9.1		0.0	0.0	0.1		22.7	7.9	6.3				41.7		0.1	0.1										
$c_{Qq}^{1,1}$		0.3	10.4								11.6		0.0				31.2						46.4		0.2											
$c_{Qq}^{3,8}$		0.3	2.2	0.3	1.9	1.0	1.2	0.3			13.6		0.0	0.0	0.1		4.3	9.2	4.6	1.3			59.6		0.1	0.0										
$c_{Qq}^{3,1}$		0.0	0.0				15.2	7.7		4.8	0.1		0.0		0.0		0.1			40.0		31.6	0.4		0.0	0.0										
c_{tq}^8		0.5	6.9	1.0	4.1	2.3					8.1		0.1	0.0	0.3		7.0	20.1	10.4				38.6		0.5	0.1									- 80	
c_{tq}^1		0.2	10.1								12.3		0.0				29.1						48.2		0.1											
c_{tu}^8		0.4	8.9	0.3		0.1					13.5		0.0	0.0	0.1		14.9		0.8				60.7		0.2	0.1										
c_{tu}		0.2	8.9								12.7		0.0				26.9						51.1		0.2											
c_{Qu}^{0}		0.8	3.7	2.5		1.0					13.7		0.1	0.0	0.4		0.9		5.2				64.8		0.7	0.2										
C_{Qu}^{1}		0.3	14.4	0.2		0.4					9.7		0.0	0.0	0.2		20.1		2.0				40.0		0.1	0.1									ŀ	
c_{td}		0.7	13.8	0.3		0.4					9.7		0.0	0.0	0.2		38.8		2.0				37.1		0.2	0.1										
C_{td}^{-}		1.5	8.7	0.2		24					9.4		0.0	0.0	0.5		21.2		12.1				42.9		0.8	0.2										
Qd		0.4	13.8	0.2		2.1					10.2		0.0	0.0	0.0		35.6						40.0		0.0	0.2										
Qd														0.0	0.0											0.1				78.8	21.1					
-cφ														0.0	0.1		-									0.3				70.5	29.1				- 60	
$b\varphi$														0.5	3.9											16.9				53.6	25.1					7
$t\varphi$														0.0	0.1											0.0				78.7	21.2					lor
τφ		1.8	1.3	0.1	0.0	0.1			0.0		0.0	0.0	0.1	1.3	9.1		7.5	0.1	0.9		0.0		0.0	0.0	0.4	39.9				25.4	11.9					m.
uG uuz				0.0		0.0	0.0	0.0	0.0	0.0		1.9		2.3	12.5				0.0	0.1	0.0	0.0		4.1		41.8				26.1	10.9					ali
47				0.0		0.0				0.0				2.5	13.3				0.0			0.0				44.6				27.9	11.6					Ze
(3)	3.2				0.0	0.0	0.0	0.0		0.0				0.0	0.1	0.0		0.0	0.0	0.0		0.0				1.8	0.5	84.8	3.4	3.5	2.7					
(3)	1.8					0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0			0.0	0.0	0.0	0.0				0.0	0.0	98.1		0.0	0.0					a
ρQ −)	1.5					0.0				0.0				0.0	0.0	0.0			0.0			0.0				0.3	0.0	82.2		14.5	1.5					lue
-)	1.5					0.0				0.0				0.0	0.0	0.0			0.0			0.0				0.0	0.0	80.7		16.1	1.6					
Q ou	3.8					0.0								0.0	0.1	0.0			0.0							1.1	0.0	95.1		0.0	0.0				- 40	
ρd	4.5					0.0								0.0	0.0	0.0			0.0							0.2	0.0	95.2		0.0	0.0					
φt						11.2				0.1				0.3	1.8				74.8			0.5				6.2				3.6	1.5					
ρl_1	1.6													0.0	0.0	0.0										0.0	0.0	42.5	0.0	28.7	27.2					
ρl_2	4.6													0.0	0.0	0.0										0.0	0.0	78.1		15.6	1.7					
ρl_3	3.1													0.0	0.0	0.0										0.0	0.0	81.4		13.9	1.5					
(3)	0.1			0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0				0.0	0.0	3.1	4.2	79.6	12.9					
(3)	0.1			0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0				0.0	0.0	1.1	5.1	82.5	11.2					
(3) (3)	2.4													0.0	0.0	0.0										0.0	0.0	68.5	6.7	16.2	6.3					
ς Cφe	1.5													0.0	0.0	0.0										0.0	0.0	31.0	0.0	41.5	25.9				- 20	
ζφμ	4.3													0.0	0.0	0.0										0.0	0.0	78.6		15.4	1.7				20	
$\varphi_{\varphi\tau}$	3.5													0.0	0.0	0.0										0.0	0.0	81.7		13.3	1.5					
c_{ll}	0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.1	2.5	52.9	44.5					
φG														0.3	2.5											10.9				58.7	27.6					
φB														2.5	13.2											44.1				28.6	11.7				ł	
ρW														1.1	5.8											19.4				46.4	27.3					
VΒ	0.0			0.0		0.0				0.0				0.0	0.0	0.0			0.0			0.0				0.1	0.0	0.0	0.0	88.6	11.1					
W	0.2									0.0						0.1						0.0					4.8		0.0	63.4	31.4					
$\varphi \Box$														0.0	0.1											0.2				75.2	24.5					
0 0	01			0.0		0.0				0.0				0.0	0.0	0.0	1		0.0			0.0				0.0	0.0	0.1	0.0	88.8	11.0					

Conclusions & outlook

- SMEFT is a consistent way to look for new interactions
- Global fits need to combine all the processes available at LHC
- SMEFiT3.0 in the biggest global SMEFT analysis to date: 50 Wilson coefficients and 445 datapoints
- Significant improvement in New Physics reach expected at HL-LHC and at future circular lepton colliders
- Extension to other future colliders (ILC, CLIC, muon collider) and RG running in progress
- Code, data and theory are public and available at C Incfitnikhef.github.io/smefit_release/

Backup

EWPOs exact implementation

- In the SMEFT, Z and W fermionic coupling receive contributions from dim-6 operators
- SMEFiT2.0: assume LEP/SLD measurements precise enough to set coupling shift to 0
 - only 2 independent Wilson coefficients



 SMEFiT3.0: EWPOs implemented like the rest of LHC data
 16 independent Wilson coefficients

no major difference, but the approximate implementation resulted in too stringent constraints on some EW operators



New LHC datasets

Dataset	\sqrt{s} (TeV)	\mathcal{L} (fb ⁻¹)	Info	Observables	$n_{ m dat}$	ref.	
ATLAS_STXS_RunII_13TeV_2022	13	139	gg F, VBF, Vh , $t\bar{t}h$, th	$d\sigma/dp_T^h \ d\sigma/dm_{jj} \ d\sigma/dm_{jj}$	36	[82]	
CMS_WZ_pTZ_13TeV_2022	13	137	WZ, fully leptonic	$1/\sigma d\sigma/dp_T^Z$	10	[83]	
CMS_tt_13TeV_ljets_inc	13	137	$\ell+\mathrm{jets}$	$\sigma(tar{t})$	1	[84]	
$CMS_{tt}_{13}TeV_{Mtt}$	13	137	$\ell + { m jets}$	$1/\sigma d\sigma/dm_{tar{t}}$	14	[84]	
CMS_tt_13TeV_asy	13	138	$\ell+\mathrm{jets}$	A_C	3	[85]	
ATLAS_tt_13TeV_asy_2022	13	139	$\ell + { m jets}$	A_C	5	[86]	
ATLAS_Whel_13TeV	13	139	W-helicity fraction	F_0,F_L	2	[87]	
$ATLAS_ttZ_13TeV_pTZ$	13	139	$t\bar{t}Z$	$d\sigma/dp_T^Z$	7	[88]	
ATLAS_tta_8TeV	8	20.2	Inclusive	$\sigma \left(t ar{t} \gamma ight)$	1	[89]	
CMS_tta_8TeV	8	19.7	Inclusive	$\sigma\left(tar{t}\gamma ight)$	1	[<mark>90</mark>]	
ATLAS_tttt_13TeV_slep_inc	13	139	single-lepton	$\sigma_{ m tot}\left(tar{t}tar{t} ight)$	1	[91]	
$CMS_tttt_13TeV_slep_inc$	13	35.8	single-lepton	$\sigma_{ m tot}\left(tar{t}tar{t} ight)$	1	[<mark>92</mark>]	
ATLAS_tttt_13TeV_2023	13	139	multi-lepton	$\sigma_{ m tot}(tar{t}tar{t})$	1	[<mark>93</mark>]	
CMS_tttt_13TeV_2023	13	139	same-sign or multi-lepton	$\sigma_{ m tot}(tar{t}tar{t})$	1	[94]	
CMS_ttbb_13TeV_dilepton_inc	13	35.9	dilepton	$\sigma_{ m tot}\left(tar{t}bar{b} ight)$	1	[95]	
CMS_ttbb_13TeV_ljets_inc	13	35.9	$\ell + { m jets}$	$\sigma_{ m tot}\left(tar{t}bar{b} ight)$	1	[95]	
ATLAS_t_sch_13TeV_inc	13	139	s-channel	$\sigma_{ m tot}\left(t+ar{t} ight)$	1	[96]	
$CMS_tZ_13TeV_pTt$	13	138	dilepton	$d\sigma_{ m fid}(tZj)/dp_T^t$	3	[97]	
CMS_tW_13TeV_slep_inc	13	36	single-lepton	$\sigma_{ m tot}(tW)$	1	[98]	

L0 vs L1 projections

• Level-0: no fluctuation of the pseudo-data

$${\cal O}_i^{(
m exp)} = {\cal O}_i^{(
m th)}\,, \qquad i=1,\ldots,n_{
m bin}$$

- Level-1:
 - pseudodata fluctuated around SM

$$\mathcal{O}_i^{(\mathrm{exp})} = \mathcal{O}_i^{(\mathrm{th})} \left(1 + r_i \delta_i^{(\mathrm{stat})} + \sum_{k=1}^{n_{\mathrm{sys}}} r_{k,i} \delta_{k,i}^{(\mathrm{sys})} \right), \qquad i = 1, \dots, n_{\mathrm{bin}}$$

statistics rescaled by luminosity

$$\delta_i^{(\mathrm{stat})} = ilde{\delta}_i^{(\mathrm{stat})} \sqrt{rac{\mathcal{L}_{\mathrm{Run2}}}{\mathcal{L}_{\mathrm{HLLHC}}}}$$

• systematics reduced by a factor $f_{\rm red}^{(k)} = 1/2$

$$\delta_{k,i}^{(\mathrm{sys})} = \tilde{\delta}_{k,i}^{(\mathrm{sys})} \times f_{\mathrm{red}}^{(k)}, \qquad i = 1, \dots, n_{\mathrm{bin}}, \quad k = 1, \dots, n_{\mathrm{sys}}$$

Good agreement found between the two approaches.

FCC-ee and CEPC



Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}\left(\Lambda^{-2}\right)$, Marginalised

FCC-ee energy breakdown

Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}(\Lambda^{-2})$, Marginalised

Study the impact of sequentially adding different runs

- largest impact from 91 + 240 GeV combination
- 365 GeV also relevant



→ HL - LHC + FCC - ee (91 GeV)
 → HL - LHC + FCC - ee (91 + 240 GeV)
 → HL - LHC + FCC - ee (91 + 161 + 240 + 365 GeV)