

Global fits of the Standard Model and beyond

Constraining new physics via improved global fits of the
Standard Model Effective Field Theory



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Based on work in collaboration with:

J. de Blas, A. Goncalves, V. Miralles, M. Pierini, L. Silvestrini, M. Valli, and members of



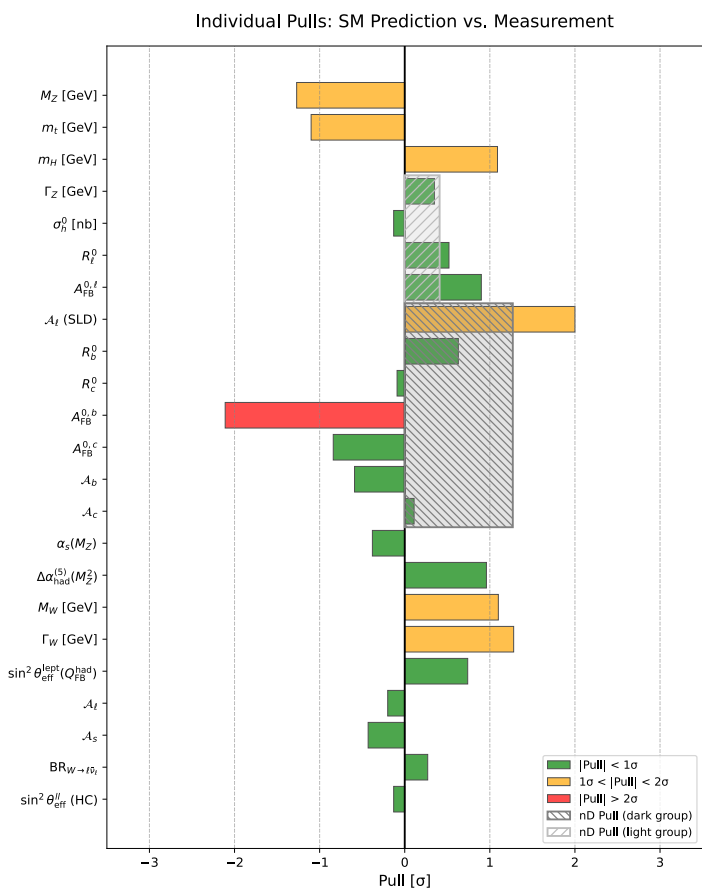
Stress-testing the Standard Model and beyond

Searching for indirect evidence of new physics through precision

- **EW precision fits:** testing the **quantum consistency** of the SM to the highest precision.
- **More observables** are and will be measured with high precision: evolving towards **global fits** that will allow to **test models beyond the SM** with more and more accuracy.

This will be a major component of the LHC legacy

Status of SM precision fit



α input scheme:

$$\{\alpha, G_F, M_Z, m_H, m_t, \alpha_s\}$$

All parameters and observables floating except α and G_F

Posterior:

the full fit result

Individual prediction:

remove one observable (set of),
fit predict the removed observable.

1D/nD pull: single (set of)
observable(s) pull

	Global SM EW fit				
	Measurement	Posterior	Individual Prediction	1D Pull	nD Pull
$\alpha_s(M_Z)$	0.11873 ± 0.00056	0.11878 ± 0.00055 [0.11769, 0.11986]	0.1199 ± 0.0028 [0.1144, 0.1253]	-0.38	
$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2)$	0.02766 ± 0.00010	0.027631 ± 0.000096 [0.027443, 0.027819]	0.02734 ± 0.00032 [0.02670, 0.02797]	0.96	
M_Z [GeV]	91.1875 ± 0.0021	91.1885 ± 0.0019 [91.1847, 91.1923]	91.1964 ± 0.0068 [91.1832, 91.2097]	-1.27	
m_t [GeV]	172.31 ± 0.32	172.38 ± 0.31 [171.77, 173.00]	174.0 ± 1.5 [171.1, 177.0]	-1.10	
m_H [GeV]	125.100 ± 0.090	125.101 ± 0.090 [124.925, 125.278]	106.2 ± 16.3 [76.2, 141.4]	1.09	
M_W [GeV]	80.3635 ± 0.0080	80.3562 ± 0.0045 [80.3475, 80.3650]	80.3529 ± 0.0054 [80.3423, 80.3635]	1.10	
Γ_W [GeV]	2.151 ± 0.049	2.08844 ± 0.00041 [2.08762, 2.08925]	2.08843 ± 0.00042 [2.08761, 2.08923]	1.28	
$\sin^2 \theta_{\text{eff}}^{\text{lept}}(Q_{\text{FB}}^{\text{had}})$	0.2324 ± 0.0012	0.231523 ± 0.000055 [0.231415, 0.231631]	0.231523 ± 0.000057 [0.231412, 0.231634]	0.74	
$-P_{\tau}^{\text{pol}} = \mathcal{A}_{\ell}$	0.1465 ± 0.0033	0.14701 ± 0.00043 [0.14616, 0.14785]	0.14702 ± 0.00043 [0.14616, 0.14788]	-0.20	
Γ_Z [GeV]	2.4955 ± 0.0023	2.49474 ± 0.00052 [2.49372, 2.49577]	2.49466 ± 0.00054 [2.49361, 2.49573]	0.35	
σ_h^0 [nb]	41.480 ± 0.033	41.4862 ± 0.0067 [41.4731, 41.4995]	41.4871 ± 0.0068 [41.4735, 41.5005]	-0.13	0.41
R_{ℓ}^0	20.767 ± 0.025	20.7545 ± 0.0067 [20.7413, 20.7676]	20.7529 ± 0.0069 [20.7394, 20.7668]	0.52	
$A_{\text{FB}}^{0,\ell}$	0.0171 ± 0.0010	0.016208 ± 0.000095 [0.016023, 0.016397]	0.016197 ± 0.000096 [0.016011, 0.016386]	0.90	
$\mathcal{A}_{\ell}$ (SLD)	0.1513 ± 0.0021	0.14701 ± 0.00043 [0.14616, 0.14785]	0.14700 ± 0.00045 [0.14613, 0.14789]	2.00	
R_b^0	0.21629 ± 0.00066	0.215881 ± 0.0000100 [0.215684, 0.216074]	0.21588 ± 0.00010 [0.21567, 0.21607]	0.63	
R_c^0	0.1721 ± 0.0030	0.172218 ± 0.000052 [0.172117, 0.172320]	0.172218 ± 0.000051 [0.172116, 0.172319]	-0.09	
$A_{\text{FB}}^{0,b}$	0.0996 ± 0.0016	0.10306 ± 0.00031 [0.10247, 0.10366]	0.10305 ± 0.00031 [0.10244, 0.10368]	-2.11	1.27
$A_{\text{FB}}^{0,c}$	0.0707 ± 0.0035	0.07363 ± 0.00022 [0.07318, 0.07407]	0.07362 ± 0.00023 [0.07316, 0.07409]	-0.84	
$\mathcal{A}_b$	0.923 ± 0.020	0.934735 ± 0.000039 [0.934658, 0.934812]	0.934735 ± 0.000039 [0.934658, 0.934813]	-0.59	
$\mathcal{A}_c$	0.670 ± 0.027	0.66777 ± 0.00021 [0.66735, 0.66819]	0.66777 ± 0.00022 [0.66735, 0.66820]	0.11	
$\mathcal{A}_s$	0.895 ± 0.091	0.935642 ± 0.000040 [0.935564, 0.935719]	0.935642 ± 0.000039 [0.935565, 0.935719]	-0.43	
$\text{BR}_{W\ell\nu_{\ell}}$	0.10860 ± 0.00090	0.108361 ± 0.000013 [0.108336, 0.108386]	0.108361 ± 0.000013 [0.108336, 0.108386]	0.27	
$\sin^2 \theta_{\text{eff}}^{\text{ll}}(\text{HC})$	0.23150 ± 0.00023	0.231523 ± 0.000055 [0.231415, 0.231631]	0.231523 ± 0.000057 [0.231412, 0.231634]	-0.13	

J. de Blas et al. 2204.04204

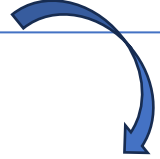
Update: LR+L.Silvestrini 2511.16534



SM precision fits: EW precision observables

- Γ_W : EW 1-loop + 2-loop EW-QCD corrections
 - D.Y. Bardin, P.K. Khristova, O. Fedorenko, Nucl. Phys B197 (1982) 1
 - D.Y. Bardin, S. Riemann, T. Riemann, Z. Phys C32 (1986) 121
- M_W : Full EW 2-loop corr. + leading 3-loop & some 4-loop
 - M. Awramik, M. Czakon, A. Freitas, G. Weiglein, Phys. Rev. D69 (2004) 053006
- $\sin^2\theta_{eff}^f$: (light fermions): Full EW 2-loop corr. + leading higher order
 - M. Awramik, M. Czakon, A. Freitas, JHEP 11 (2006) 048
 - M. Awramik, M. Czakon, A. Freitas, B.A. Kniehl, Nucl. Phys. B 813 (2009) 174
- Γ_Z^f : Full EW 2-loop corr. + leading higher order
 - I. Dubovyk, A. Freitas, J. Gluza, T. Riemann, J. Usovitsch, Phys. Lett. B 783 (2018) 86
- $\sin^2\theta_{eff}^b$: Full EW 2-loop corr. + leading higher order
 - I. Dubovyk, A. Freitas, J. Gluza, T. Riemann, J. Usovitsch, Phys. Lett. B 762 (2016) 184
- Leading 3-loop EW-QCD fermionic corr. ($M_W, \sin^2\theta_{eff}^f, \Gamma_Z^f$)
 - L. Cheng, A. Freitas, JHEP 07 (2020) 210, JHEP 03 (2021) 215

In fit: used **2-loop parametrizations** from:
Dubovyk, Freitas, Gluza, Riemann, Usovitsch
JHEP 08 (2019) 113



From same reference:
estimate of residual
theoretical uncertainties

Consolidating the SM consistency at the quantum level

For M_W we combine:

- ❑ All LEP 2 measurements
- ❑ Previous Tevatron average
- ❑ ATLAS and LHCb early measurements
- ❑ CDF [$M_W=(80.4335\pm0.0094)$ GeV]
- ❑ ATLAS [$M_W=(80.3665\pm0.016)$ GeV]
- ❑ CMS [$M_W=(80.3602\pm0.010)$ GeV]

$$M_W = 80.363 \pm 0.0080 \text{ GeV (without CDF)}$$

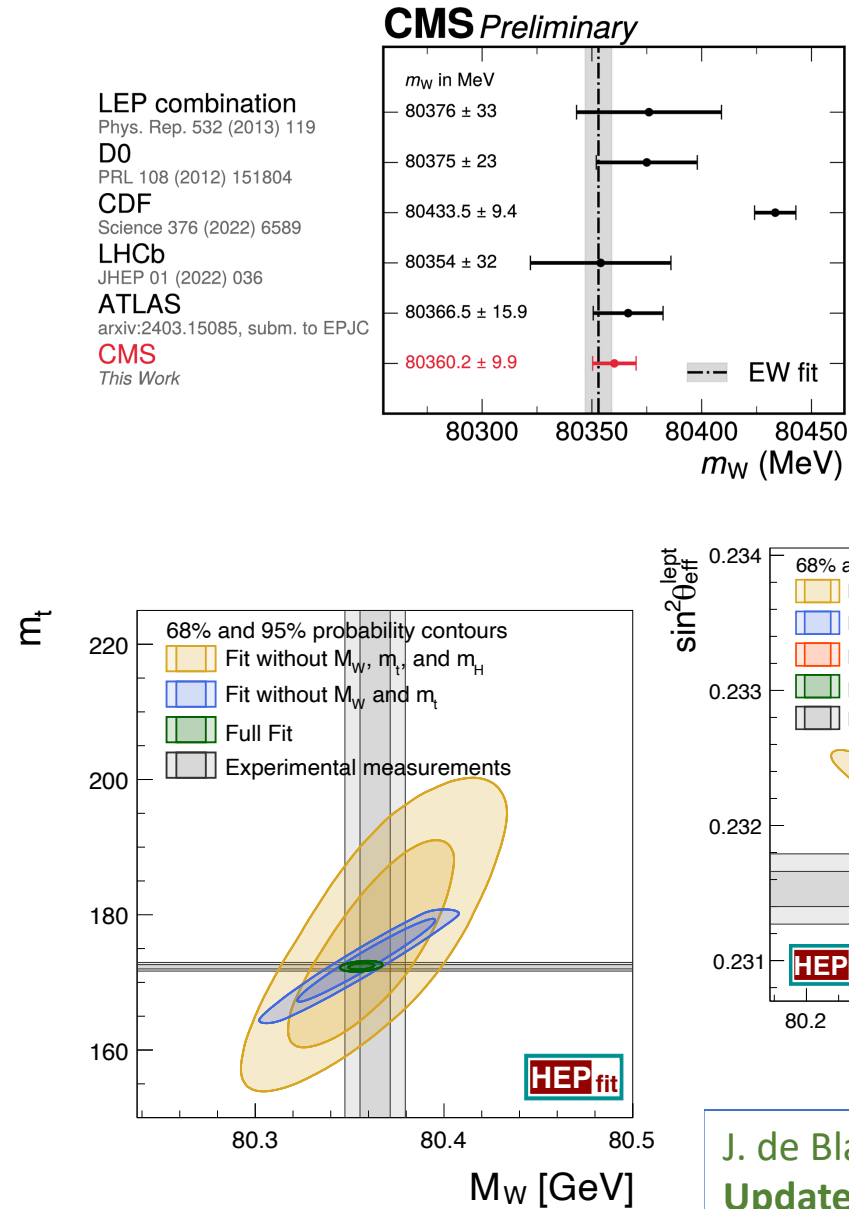
$$80.356 \pm 0.0045 \text{ GeV (from fit)}$$

For m_t we combine:

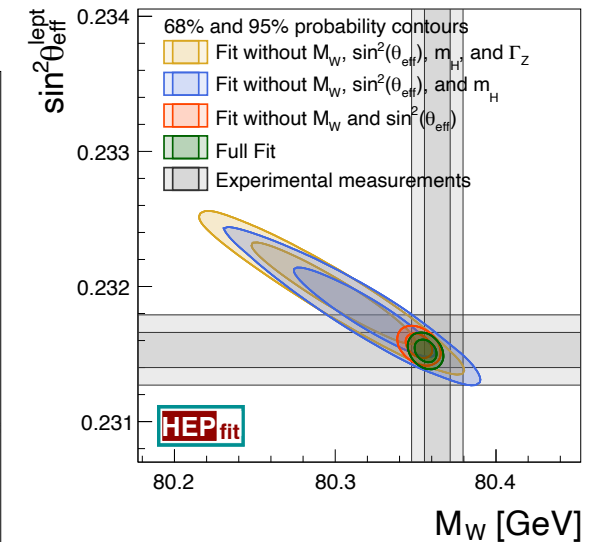
- ❑ 2016 Tevatron combination
- ❑ ATLAS Run 1 and early Run2 results
- ❑ CMS Run 1 and early Run 2 results
- ❑ CMS $l+j$ [$m_t=(171.77\pm0.38)$ GeV]
- ❑ CMS $l+j$ boosted [$m_t=(173.06\pm0.83)$ GeV]
- ❑ ATLAS $l+j$ boosted [$m_t=172.95\pm0.53$ GeV]

$$m_t = 172.31 \pm 0.32 \text{ GeV}$$

$$172.38 \pm 0.31 \text{ GeV (from fit)}$$

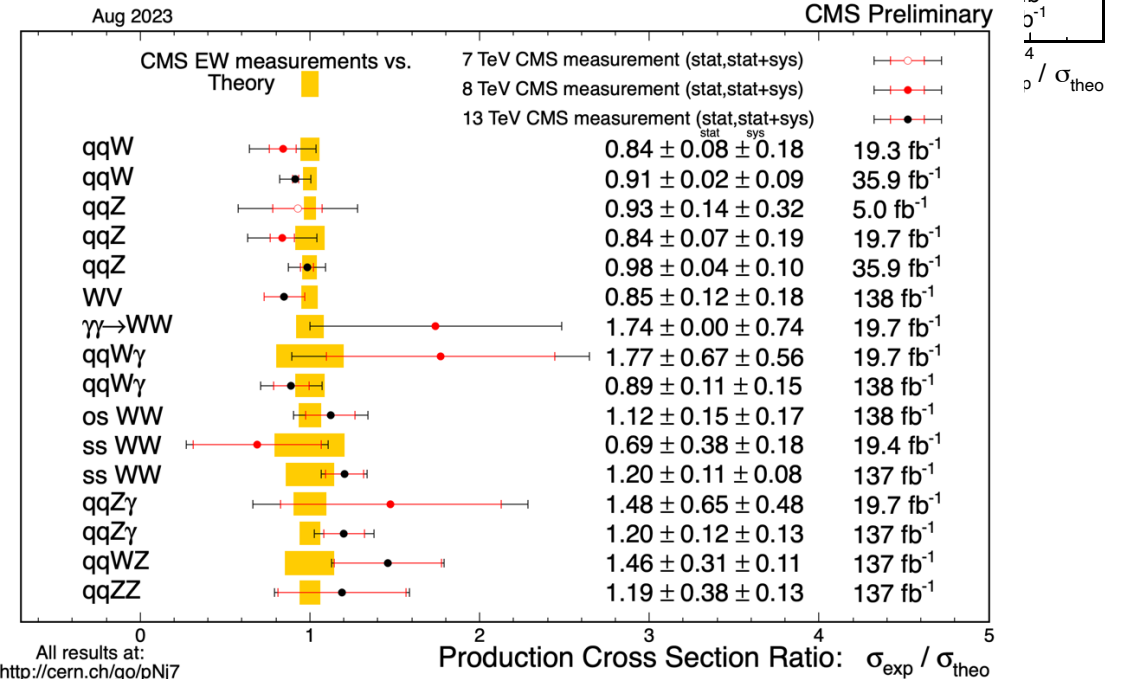
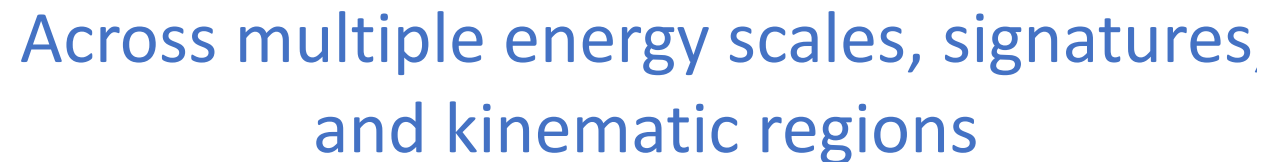


The LHC has started to play a major role



J. de Blas et al. 2204.04204,
Update: L.R., L. Silvestrini 2511.16534

Measured and predicted with increasing precision



Extending the reach of SM precision fits

Exploring new physics effects via EFT global fits

- Ideal to describe a **variety of physics observables across multiple energy scales** in a consistent unique (QFT) framework.
- Ideal to **explore new structures** beyond a simple rescaling of SM properties.
- Largely **model independent**, as we need not have evidence of specific BSM physics.
- The SM Effective Field Theory (SMEFT) approach as a well-motivated testing ground.

Reaching beyond the SM within very general assumptions

The SM Effective Field Theory (SMEFT) as testing ground

Consider the **SM** as an **effective low-energy realization of some UV completion**.

Extend the Lagrangian of the SM by effective interactions of dim>4

Since the UV completion is unknown, it is necessarily a **bottom-up approach**

$$\mathcal{L}_{SMEFT}(\psi, \phi, A) = \mathcal{L}_{SM}(\psi, \phi, A) + \sum_{d=5}^{\infty} \sum_{i=1}^{n_d} \frac{C_i^{(d)}}{\Lambda^{(d-4)}} Q_i^{(d)}(\psi, \phi, A)$$

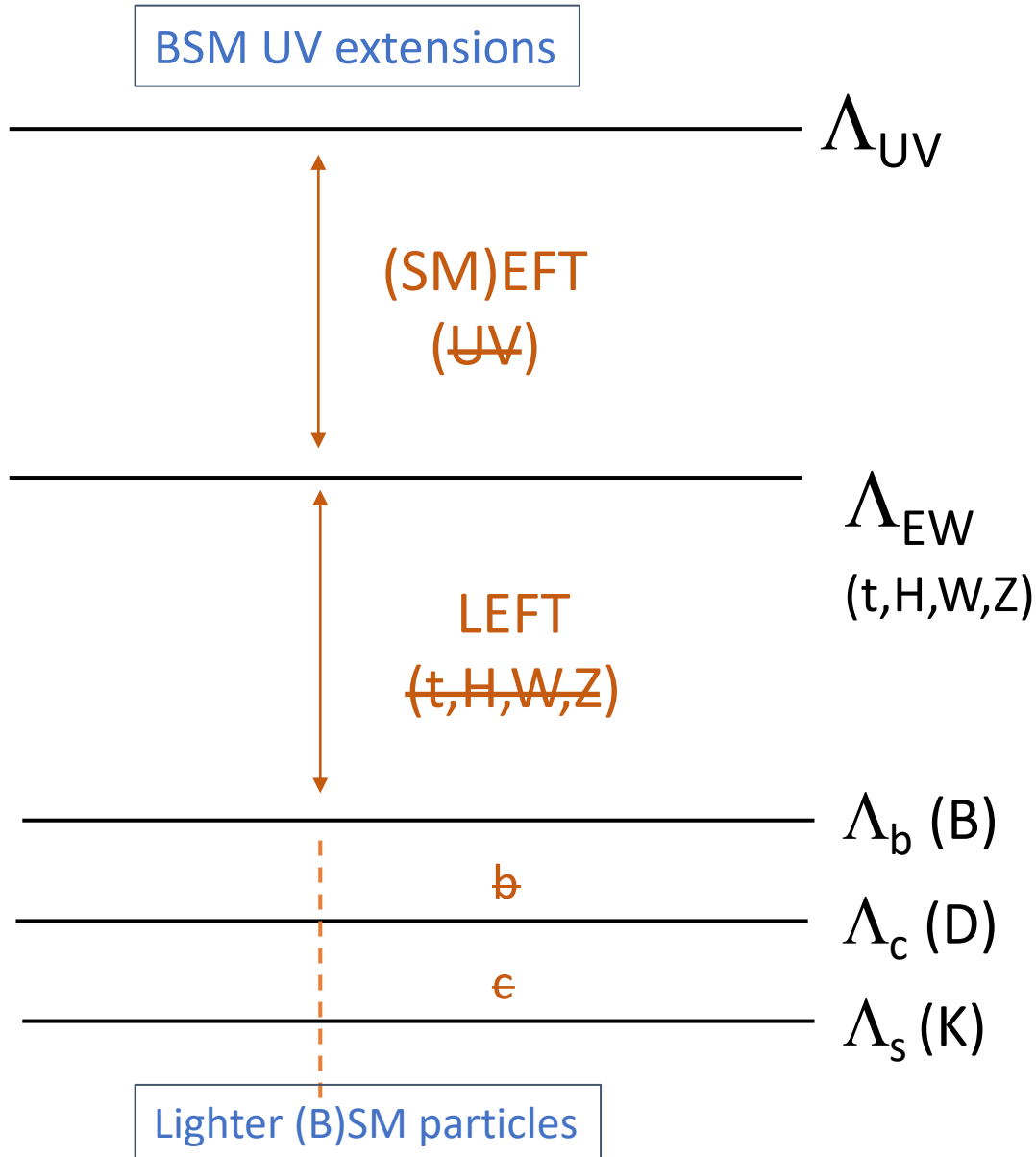
$\psi \rightarrow$ fermions
 $\phi \rightarrow$ scalars
 $A \rightarrow$ gauge bosons

where the $Q_i^{(d)}$ are functions of the fields of the SM (ψ, ϕ, A) and respect

- Lorentz invariance
- $SU(3)_c \times SU(2)_L \times U(1)_Y$ SM gauge symmetry
- Global symmetry such as lepton (L) and baryon (B) number conservation

We will analyze in detail the case of dim=6 operators and discuss how to further connect the SMEFT to the low-energy EFT (LEFT) describing flavor dynamics of B, D, and K mesons.

Connecting far apart scales: the EFT picture



Heavy physics decouples and leaves effective contact interactions of $\dim > 4$



RGE

EFT operators in terms of SM fields

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_{i,d} \frac{C_{i,d}^{SMEFT}}{\Lambda^{d-4}} O_{i,d}^{SMEFT}$$



RGE

WC depend on $m_t, M_W, M_Z, M_H, \dots M_X$

$$\mathcal{L}_{LEFT} = \mathcal{L}_{QED+QCD} + \sum_{i,d} \frac{C_{i,d}^{LEFT}}{\Lambda_{EW}^{d-4}} O_{i,d}^{LEFT}$$

Calculate physical processes at each scale and derive constraints on the UV theory

The SMEFT framework for this study

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM}^{(4)} + \sum_i \frac{C_i}{\Lambda^2} Q_i + \dots$$

Grzadkowski, Iskrzynski,
Misiak, Rosiek, 1008.4884

“Warsaw” basis

$$\begin{aligned} \mathcal{L}_{SM}^{(4)} = & -\frac{1}{4}G_{\mu\nu}^A G^{A,\mu\nu} - \frac{1}{4}W_{\mu\nu}^I W^{I,\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} \\ & + (D_\mu\varphi)^\dagger(D^\mu\varphi) + m^2\varphi^\dagger\varphi - \frac{1}{2}\lambda(\varphi^\dagger\varphi)^2 \\ & + i(\bar{l}'_L \not{D} l'_L + \bar{e}'_R \not{D} e'_R + \bar{q}'_L \not{D} q'_L + \bar{d}'_R \not{D} d'_R) \\ & - (\bar{l}'_L \Gamma_e e'_R \varphi + \bar{q}'_L \Gamma_u u'_R \tilde{\varphi} + \bar{q}'_L \Gamma_d d'_R \varphi) + h.c. \end{aligned}$$

- Dim-6 operators only, including linear (and quadratic effects)
- Obeying SM gauge symmetry
- One Higgs doublet of SU(2)_L, SSB linearly realized.
- Assuming different flavor symmetries: U(3)⁵, U(2)⁵ ...; no CPV

gauge fields
and masses,
HVV, VVV

Higgs field and Mh

Yukawa couplings

Vff, Hff

X ³		ϕ ⁶ and ϕ ⁴ D ²		ψ ² ϕ ³	
ℳ _G	f ^{ABC} G _{μν} ^A G _{νρ} ^B G _{ρμ} ^C	ℳ _ϕ	(ϕ [†] ϕ) ³	ℳ _{eϕ}	(ϕ [†] ϕ)($\bar{l}_p\varphi e_r$)
ℳ _W	ε ^{IJK} W _{μν} ^I W _{νρ} ^J W _{ρμ} ^K	ℳ _{ϕ□}	(ϕ [†] ϕ)□(ϕ [†] ϕ)	ℳ _{uϕ}	(ϕ [†] ϕ)($\bar{q}_p\tilde{\varphi}u_r$)
		ℳ _{ϕD}	(ϕ [†] D ^μ ϕ) [*] (ϕ [†] D _μ ϕ)	ℳ _{dϕ}	(ϕ [†] ϕ)($\bar{q}_p\varphi d_r$)
X ² ϕ ²		ψ ² Xϕ		ψ ² ϕ ² D	
ℳ _{ϕG}	ϕ [†] ϕ G _{μν} ^A G ^{Aμν}	ℳ _{eW}	($\bar{l}_p\sigma^{\mu\nu}e_r$)τ ^I ϕW _{μν} ^I	ℳ _{ϕl} ⁽¹⁾	(ϕ [†] i $\overleftrightarrow{D}_\mu$ ϕ)($\bar{l}_p\gamma^\mu l_r$)
ℳ _{ϕW}	ϕ [†] ϕ W _{μν} ^I W ^{Iμν}	ℳ _{eB}	($\bar{l}_p\sigma^{\mu\nu}e_r$)ϕB _{μν}	ℳ _{ϕl} ⁽³⁾	(ϕ [†] i $\overleftrightarrow{D}_\mu^I$ ϕ)($\bar{l}_p\tau^I\gamma^\mu l_r$)
ℳ _{ϕB}	ϕ [†] ϕ B _{μν} B ^{μν}	ℳ _{uG}	($\bar{q}_p\sigma^{\mu\nu}T^A u_r$) $\tilde{\varphi}$ G _{μν} ^A	ℳ _{ϕe}	(ϕ [†] i $\overleftrightarrow{D}_\mu$ ϕ)($\bar{e}_p\gamma^\mu e_r$)
ℳ _{ϕWB}	ϕ [†] τ ^I ϕ W _{μν} ^I B ^{μν}	ℳ _{uW}	($\bar{q}_p\sigma^{\mu\nu}u_r$)τ ^I $\tilde{\varphi}$ W _{μν} ^I	ℳ _{ϕq} ⁽¹⁾	(ϕ [†] i $\overleftrightarrow{D}_\mu$ ϕ)($\bar{q}_p\gamma^\mu q_r$)
		ℳ _{uB}	($\bar{q}_p\sigma^{\mu\nu}u_r$) $\tilde{\varphi}$ B _{μν}	ℳ _{ϕq} ⁽³⁾	(ϕ [†] i $\overleftrightarrow{D}_\mu^I$ ϕ)($\bar{q}_p\tau^I\gamma^\mu q_r$)
		ℳ _{dG}	($\bar{q}_p\sigma^{\mu\nu}T^A d_r$)ϕG _{μν} ^A	ℳ _{ϕu}	(ϕ [†] i $\overleftrightarrow{D}_\mu$ ϕ)($\bar{u}_p\gamma^\mu u_r$)
		ℳ _{dW}	($\bar{q}_p\sigma^{\mu\nu}d_r$)τ ^I ϕW _{μν} ^I	ℳ _{ϕd}	(ϕ [†] i $\overleftrightarrow{D}_\mu$ ϕ)($\bar{d}_p\gamma^\mu d_r$)
		ℳ _{dB}	($\bar{q}_p\sigma^{\mu\nu}d_r$)ϕB _{μν}	ℳ _{ϕud}	(ϕ [†] i $\overleftrightarrow{D}_\mu$ ϕ)($\bar{u}_p\gamma^\mu d_r$)
(LL)(LL)		(RR)(RR)		(LL)(RR)	
ℳ _{ll}	($\bar{l}_p\gamma_\mu l_r$)($\bar{l}_s\gamma^\mu l_t$)	ℳ _{ee}	($\bar{e}_p\gamma_\mu e_r$)($\bar{e}_s\gamma^\mu e_t$)	ℳ _{le}	($\bar{l}_p\gamma_\mu l_r$)($\bar{e}_s\gamma^\mu e_t$)
ℳ _{qq} ⁽¹⁾	($\bar{q}_p\gamma_\mu q_r$)($\bar{q}_s\gamma^\mu q_t$)	ℳ _{uu}	($\bar{u}_p\gamma_\mu u_r$)($\bar{u}_s\gamma^\mu u_t$)	ℳ _{lu}	($\bar{l}_p\gamma_\mu l_r$)($\bar{u}_s\gamma^\mu u_t$)
ℳ _{qq} ⁽³⁾	($\bar{q}_p\gamma_\mu\tau^I q_r$)($\bar{q}_s\gamma^\mu\tau^I q_t$)	ℳ _{dd}	($\bar{d}_p\gamma_\mu d_r$)($\bar{d}_s\gamma^\mu d_t$)	ℳ _{ld}	($\bar{l}_p\gamma_\mu l_r$)($\bar{d}_s\gamma^\mu d_t$)
ℳ _{lq} ⁽¹⁾	($\bar{l}_p\gamma_\mu l_r$)($\bar{q}_s\gamma^\mu q_t$)	ℳ _{eu}	($\bar{e}_p\gamma_\mu e_r$)($\bar{u}_s\gamma^\mu u_t$)	ℳ _{qe}	($\bar{q}_p\gamma_\mu q_r$)($\bar{e}_s\gamma^\mu e_t$)
ℳ _{lq} ⁽³⁾	($\bar{l}_p\gamma_\mu\tau^I l_r$)($\bar{q}_s\gamma^\mu\tau^I q_t$)	ℳ _{ed}	($\bar{e}_p\gamma_\mu e_r$)($\bar{d}_s\gamma^\mu d_t$)	ℳ _{qu} ⁽¹⁾	($\bar{q}_p\gamma_\mu q_r$)($\bar{u}_s\gamma^\mu u_t$)
		ℳ _{ud} ⁽¹⁾	($\bar{u}_p\gamma_\mu u_r$)($\bar{d}_s\gamma^\mu d_t$)	ℳ _{qu} ⁽⁸⁾	($\bar{q}_p\gamma_\mu T^A q_r$)($\bar{u}_s\gamma^\mu T^A u_t$)
		ℳ _{ud} ⁽⁸⁾	($\bar{u}_p\gamma_\mu T^A u_r$)($\bar{d}_s\gamma^\mu T^A d_t$)	ℳ _{qd} ⁽¹⁾	($\bar{q}_p\gamma_\mu q_r$)($\bar{d}_s\gamma^\mu d_t$)
				ℳ _{qd} ⁽⁸⁾	($\bar{q}_p\gamma_\mu T^A q_r$)($\bar{d}_s\gamma^\mu T^A d_t$)
(LR)(LR)		(LR)(RL)			
ℳ _{quqd} ^{(1)[prst]}	($\bar{q}_p^i u_r$)ε _{ij} ($\bar{q}_s^j d_t$)	ℳ _{ledq} ^[prst]	($\bar{l}_p^i e_r$)($\bar{d}_s q_{ti}$)	4-fermion interactions: tt, ttH, DY, flavour	
ℳ _{quqd} ^{(8)[prst]}	($\bar{q}_p^i T^A u_r$)ε _{ij} ($\bar{q}_s^j T^A d_t$)				
ℳ _{lequ} ^{(1)[prst]}	($\bar{l}_p^i e_r$)ε _{ij} ($\bar{q}_s^j u_t$)				
ℳ _{lequ} ^{(3)[prst]}	($\bar{l}_p^i \sigma_{\mu\nu} e_r$)ε _{ij} ($\bar{q}_s^j \sigma^{\mu\nu} u_t$)				

Beyond EW precision fits: global precision fits

Constraining new physics through a broad spectrum of collider and flavor observables

• EW precision observables

- Z-pole observables (LEP/SLD): Γ_Z , $\sin^2\theta_{\text{eff}}$, A_l , A_{FB} , ...
- W observables (LEP II, Tevatron, LHC): M_W , Γ_W
- m_t , M_H , $\sin^2\theta_{\text{eff}}$ (Tevatron/LHC)

Including recent LHC measurements of m_t and M_W

• Higgs boson observables

- Production and decay rates
- Simplified Template Cross Sections (STXS)

• Top quark observables

- $pp \rightarrow t\bar{t}, t\bar{t}Z, t\bar{t}W, t\bar{t}\gamma, tZq, t\gamma q, tW, \dots$

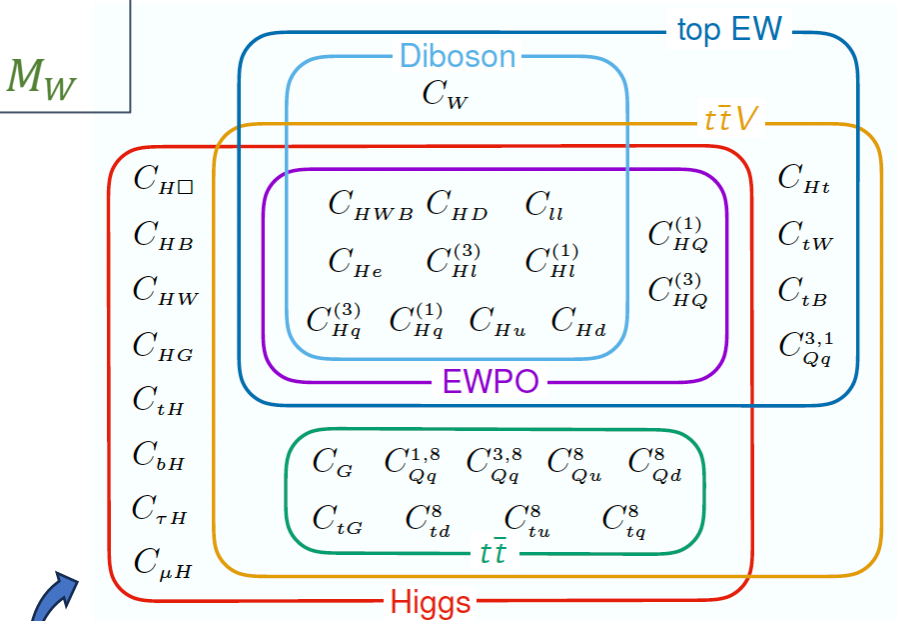
• Drell-Yan, Di-boson measurements

- $pp \rightarrow W, Z \rightarrow f_i \bar{f}_j$
- $pp \rightarrow WZ, WW, ZZ, Z\gamma$

• Flavor observables

- $\Delta F=2$: $\Delta m_{B_{d,s}}$, $A_{sl}^{s,d}$, $D^0 - \bar{D}^0(\phi_{12}^M)$, ε_K
- Leptonic decays: $B_s \rightarrow \mu^+ \mu^-$, $B \rightarrow \tau \nu$, $K \rightarrow \ell \nu$, $\pi \rightarrow \ell \nu$
- Semi-leptonic decays: $B \rightarrow D^{(*)} \ell \nu$, $B \rightarrow \pi \ell \nu$, $K \rightarrow \pi \ell \nu$
- Radiative B decays: $B \rightarrow X_{s,d} \gamma$

ATLAS and CMS Run 1+2 results



Flavour involves almost all of them either directly or through RGE

Exp: PDG, HFLAV

Th: best available predictions

The HEPfit framework

Open-source tool.

Statistical framework based on a Bayesian MCMC analysis as implemented in

BAT (Bayesian Analysis Toolkit)

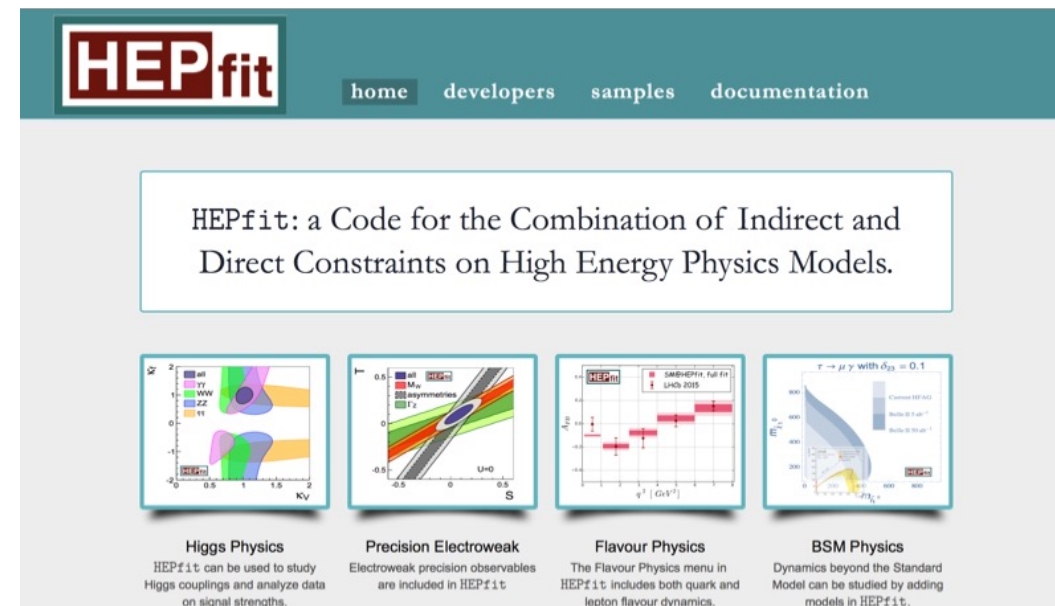
Caldwell et al., arXiv:0808.2552

Supports SM (fully implemented) and BSM models, in particular the dim-6 SMEFT.

Used for several global fits and future collider projections.

New release includes EW, Higgs, top, and flavour observables in the SM and the SMEFT with

- ☐ SM predictions at NLO or higher.
- ☐ SMEFT at tree level (dim-6 operators only).
- ☐ Linear (and quadratic) effects from dim-6 operators.
- ☐ RGE running of the SMEFT Wilson Coefficients.
- ☐ Fitting both SMEFT and SM parameters.



<http://hepfit.roma1.infn.it>

J. De Blas et al., 1910.14012

Other existing frameworks for SMEFT global fits:

SMEFiT, Celada et al. 2105.00006, 2302.06660, 2404.12809, 2604.596

Fitmaker, Ellis et al. 2012.02779

Smelli+Wilson+Flavio, Aebischer et al., 1810.07698

Allwicher et al, 2311.00020

Cirigliano et al. 2311.00021

Bartocci et al. 2311.04963, 2412.09674

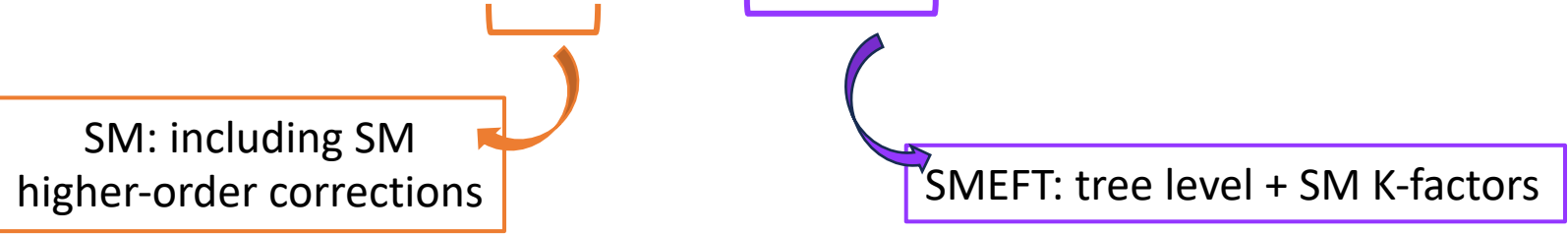
ATLAS (2604.21670) and CMS (2504.02958)

} Include flavour

SMEFT predictions

A given observable will be written as

$$O_{\text{SMEFT}} = O_{\text{SM}} + \Delta O^{(1)} + \Delta O^{(2)} + \dots$$



SM: including SM
higher-order corrections

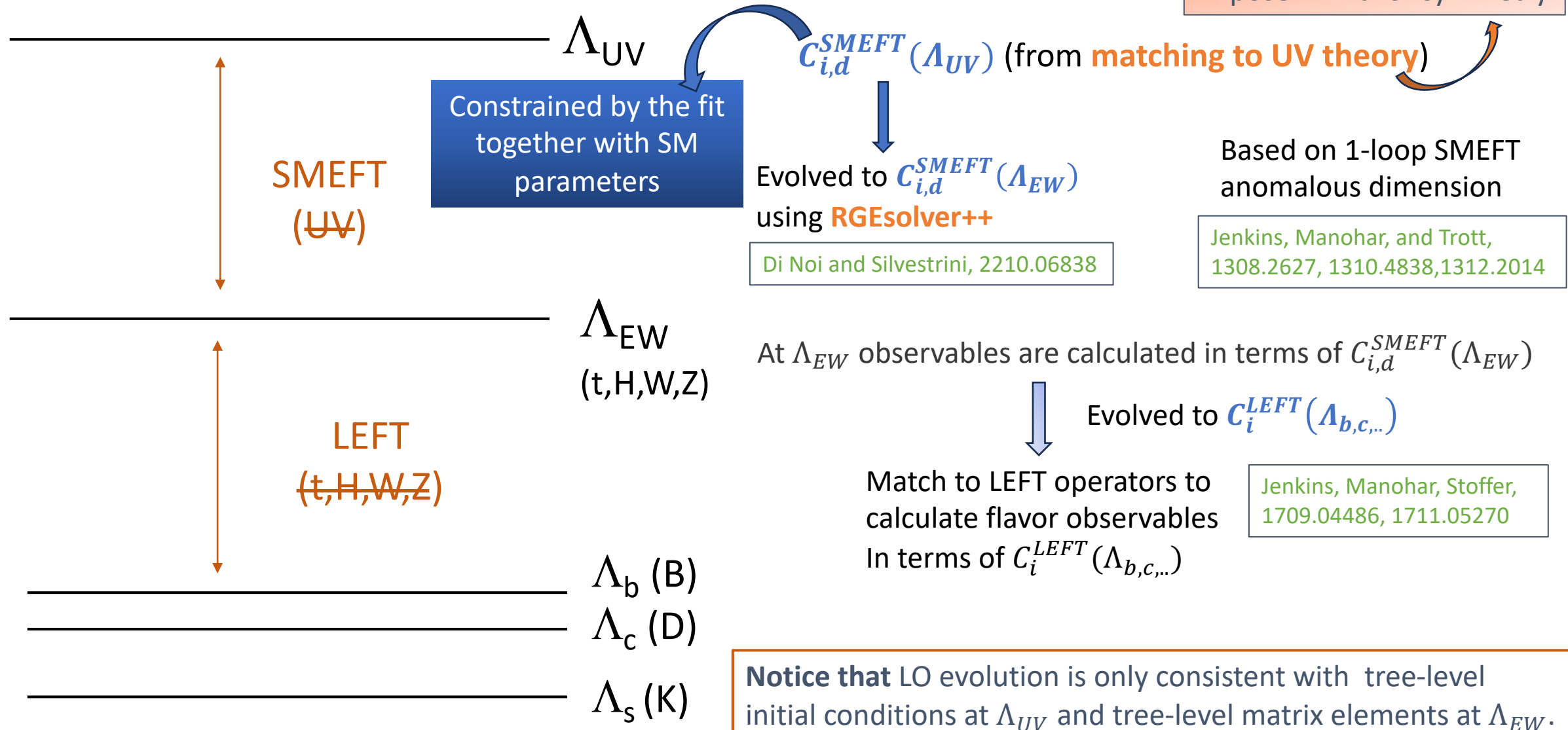
SMEFT: tree level + SM K-factors

Observables have been calculated either analytically and via parametrizations reported in the literature (e.g. EW observables) or obtained using various tools (analytic results, MG5_aMC@NLO or in-house codes with **SMEFTci2**, a new UFO file developed for this study, Feynart+Feyncalc, ...)

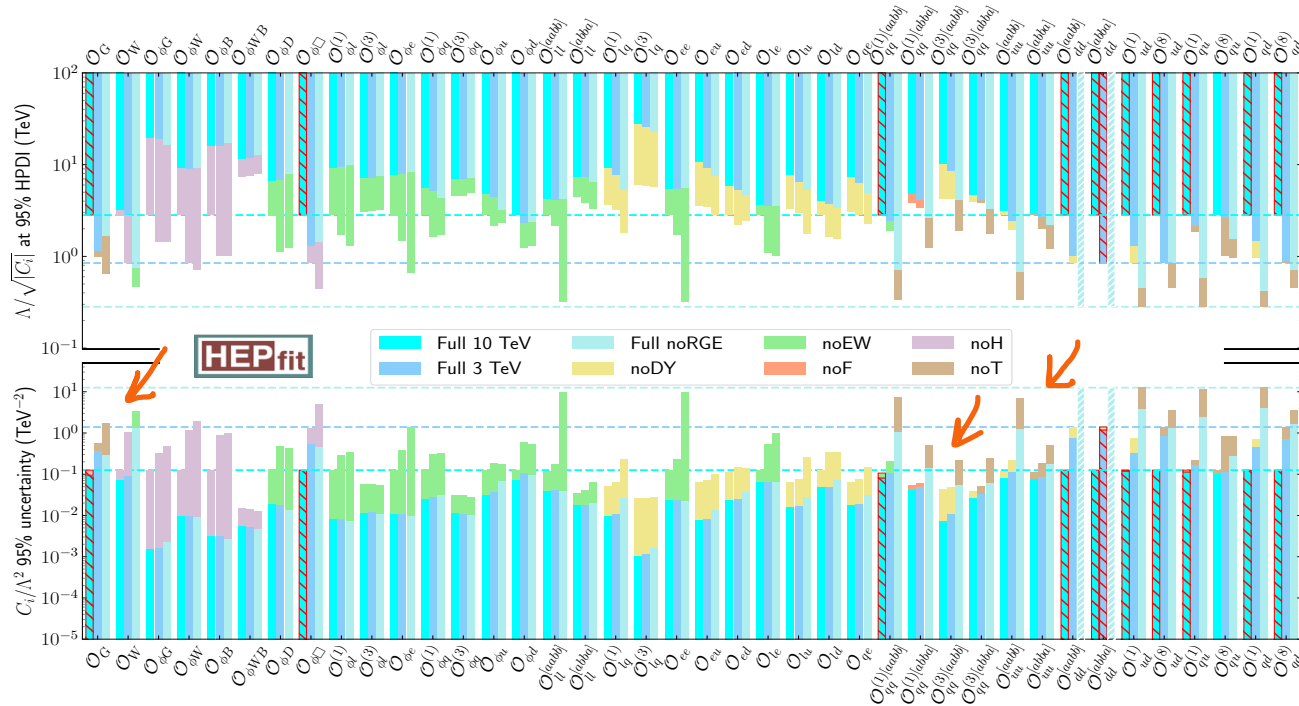
Including direct and indirect SMEFT effects from dim-6 operators up to $O(1/\Lambda^4)$, by **A. Goncalves**

Beyond EW fits – Higgs, top, EW, and flavor observables

Connecting far apart scales naturally lends itself to the EFT framework



De Blas, Goncalves, Miralles,
L.R., Silvestrini, Valli,
2507.06191, JHEP 03 (2026) 013



- **Fit individual operators** (one $C_i(\Lambda) \neq 0$ at a time, multiple $C_i(\mu)$ induced by RGE)
- Choose scales such that LO RGE effects can be relevant ($\log(\mu_1^2/\mu_2^2) \geq 2$)
- $\Lambda = 1, 3, 10$ TeV $\rightarrow$ reach of current/future colliders
- **Between different Λ : not a simple rescaling** because of RGE effects

Lower half: uncertainty on C_i/Λ^2 reported as half of the 95% HPDI (high posterior density interval)

Upper half: lower bound on $\Lambda/\sqrt{|C_i|}$ from the maximum of the 95% HPDI of $|C_i|$
(since no interval is driven away from zero at 95% probability, we can only put a lower bound)

Dashed lines: perturbativity bounds ($|C_i| \sim 4\pi$)

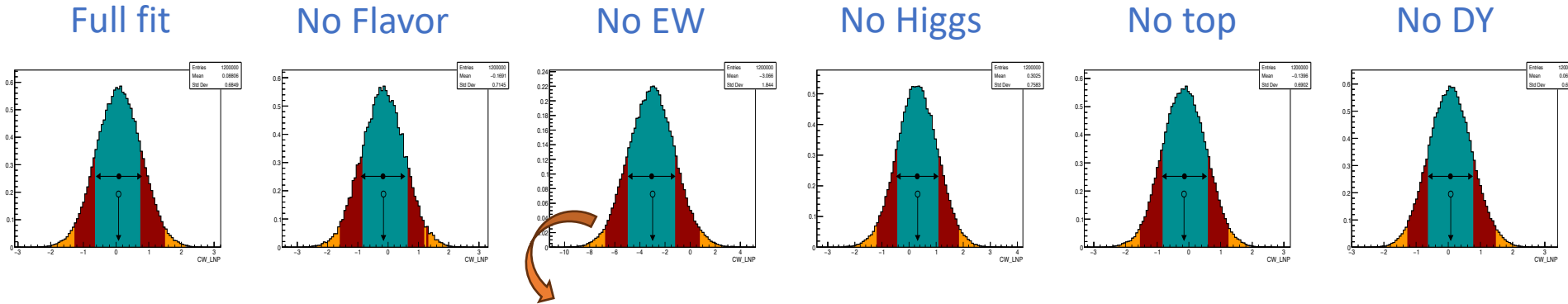
Red shades: posteriors touches the edges of the prior (truncated) → need better measurements

White shades: posterior completely flat $\rightarrow$ need more observables

For illustration (C_W)

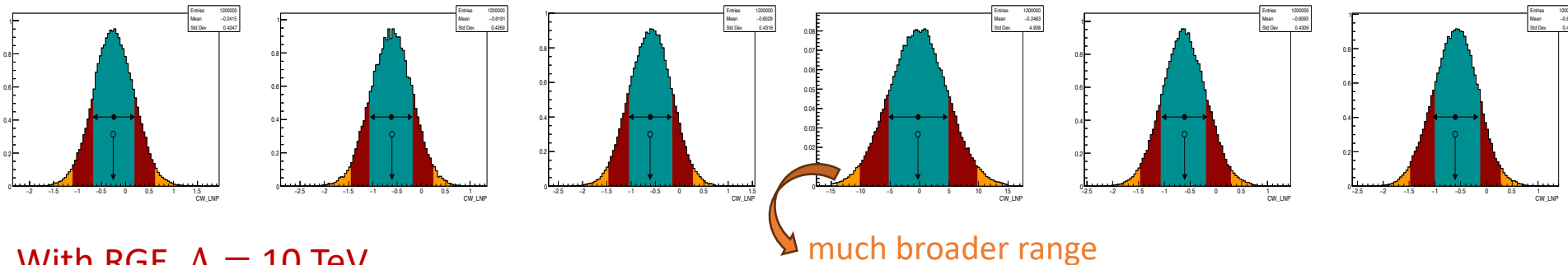
All 95% intervals compatible with $C_W=0$:
the bounds on C_W/Λ^2 can only establish a lower bound on Λ

No RGE ($\Lambda = 1$ TeV)



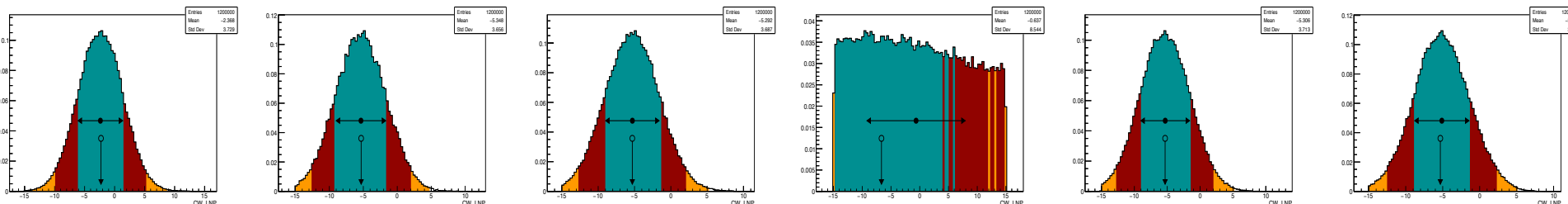
No RGE:
EW obs. are the
strongest constraint

With RGE, $\Lambda = 3$ TeV



With RGE, $\Lambda = 3$ TeV
Higgs obs. are the
strongest constraint

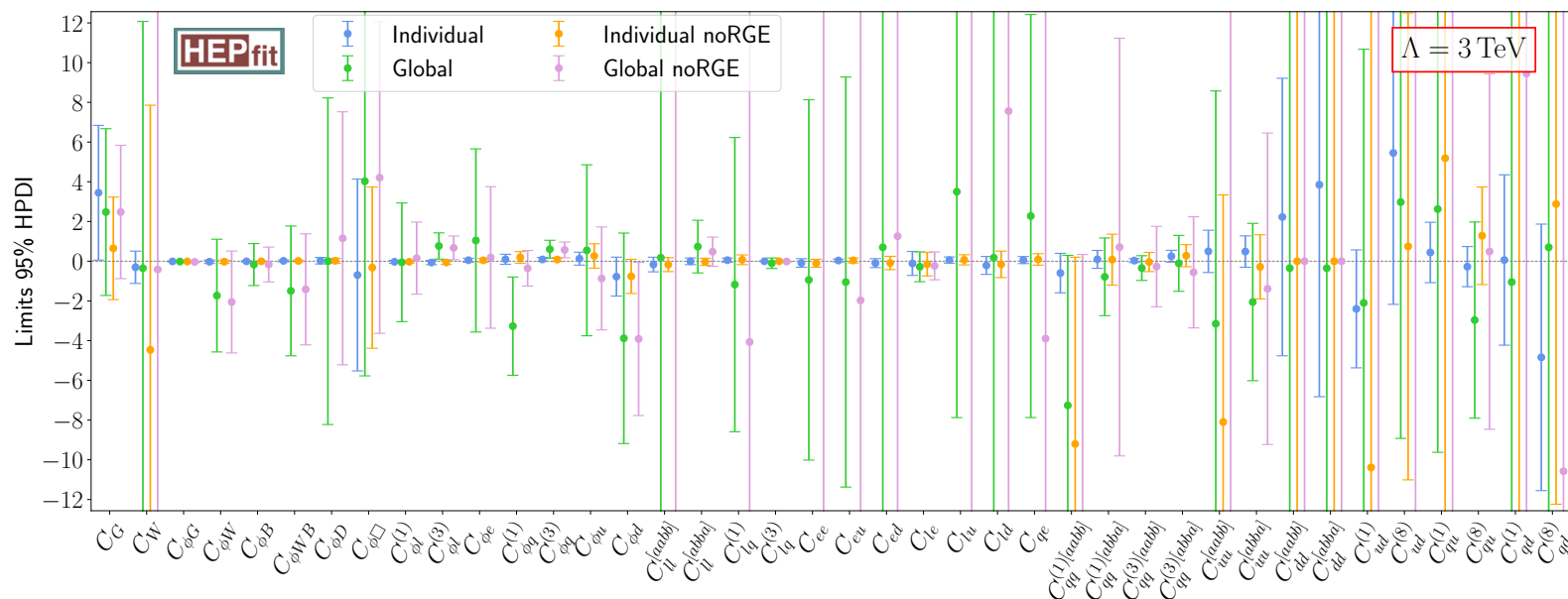
With RGE, $\Lambda = 10$ TeV



With RGE, $\Lambda = 10$ TeV
Higgs obs. are the
strongest constraint, but
overall less constrained.

All ranges broader than for $\Lambda = 3$ TeV

$U(3)^5$ case: individual vs global

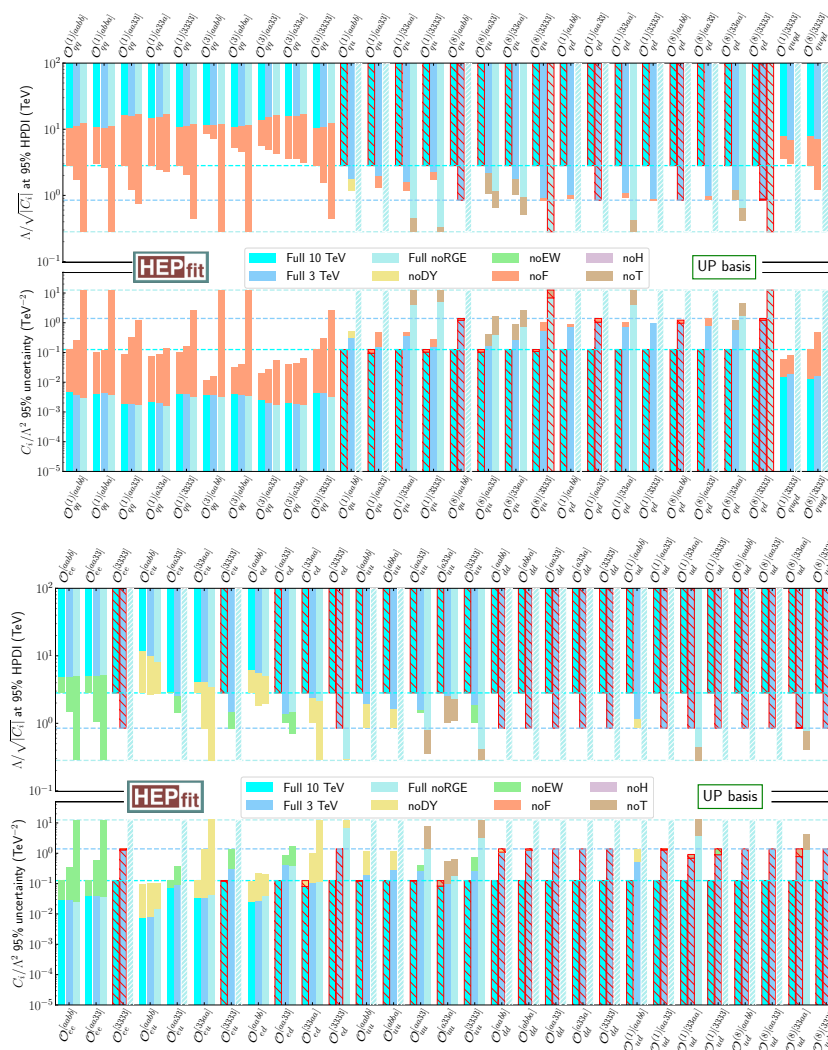
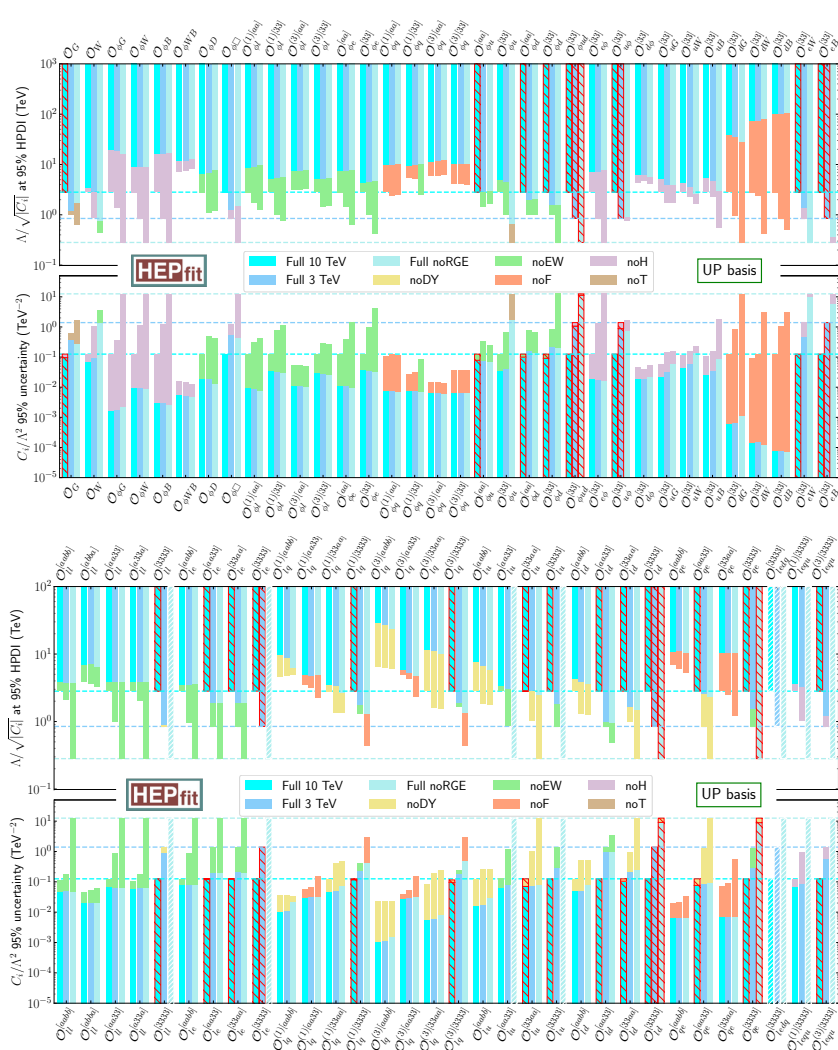


This is already relevant input to model building!

- In general (both individual and global): **adding more observables lift degeneracies and leaves strong correlations**
- Although bounds get diluted in the global fit, both with and without RGE, some cases still very well constrained, giving strong lower bounds. Higher precision will buy more constraining power.
- Global fits, if really global, are numerically massive. Adding all existing measurements may prevent the fit from converging: fine balance between higher information and better convergence.

UV theory flavour symmetry: $U(2)^5$, testing third family

The impact of a non flavour-blind choice. More scenarios can be explored.



124 operators (123 if not considering $O_\phi = (\phi^\dagger \phi)^3$)

Main flavour constraints coming from:

- $B \rightarrow X_s \gamma$ (O_{dG}, O_{dW}, O_{dB})
- $B_s \rightarrow \mu^+ \mu^-$ (O_{qe}^{ijkl})
- meson mixing ($O_{qq}^{(1,3)}$)

Where do we go from here?

To maximize the potential of EFTs in the HL-LHC era

- Improve accuracy and interpretation of EFT global fits

Improve accuracy and interpretation of EFT global fits

➤ SMEFT (+LEFT) NLO RGE evolution:

- ❑ implement 2-loop anomalous dimension, 1-loop matching, and 1-loop matrix elements (QCD+EW)

Dawson, Bellafronte, Giardino, ...

L. Born, J. Fuentes-Martín, A. Eller Thomsen, 2601.19974

- ❑ Check consistency, explore **new approaches**: unitarity methods?
- ❑ Improve theoretical precision on all observables.

➤ Extend framework to new EFT approaches (on-shell EFT, HEFT).

- ❑ Useful to estimate accuracy of EFT expansion?

➤ “**Model inspired fits**”: models generate only a handful of operators at the UV scale (top-down).

- ❑ Different UV flavour assumption already go in that direction, in very general terms.

➤ **Improve fitting tools and procedures**: refine statistical methods, explore new methods, AI/ML, ...

➤ **Remove SM biases** in the interpretation of experimental measurements (PDF, backgrounds, etc.)

Summary and Outlook

- After the Higgs discovery **collider physics** remains as a **unique and necessary test of BSM scenarios**, both via direct and indirect evidence.
- Extending **precision fits** beyond EW observables, allows to **connect Higgs, top, and flavour physics**, allowing to test the SM paradigm and its EFT extensions at an unprecedented level.
- The **EFT framework** (here illustrated by the SMEFT) can be used to connect unknown physics at the UV scale (> 1 TeV) to the EW scale and below within a **systematic framework that allows some model independence** and can be systematically improved as precision grows.
- Improving the **precision of theoretical predictions** can add crucial **constraining power to global fits** of the SM and beyond and **provide indications towards future explorations**.