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The Automation of SMEFT-Assisted constraints on UV-complete models

Planck 2024
Lisbon, Portugal
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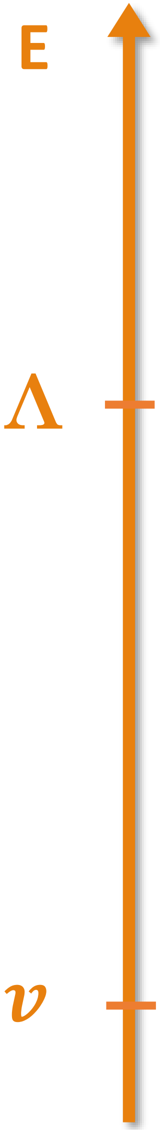
Alejo N. Rossia

On behalf of the SMEFiT Collaboration
Department of Physics and Astronomy
The University of Manchester

Based on:

[2309.04523] JHEP 01 (2024) 179 (w/ J. ter Hoeve, G. Magni, J. Rojo, and E. Vryonidou)
[2404.12809] (w/ E. Celada, T. Giani, J. ter Hoeve, L. Mantani, J. Rojo, M. Thomas and E. Vryonidou)

The Standard Model EFT (SMEFT)



$$\psi_{UV} = ? \quad \mathcal{L}_{UV} = ? \quad G_{UV} = ?$$

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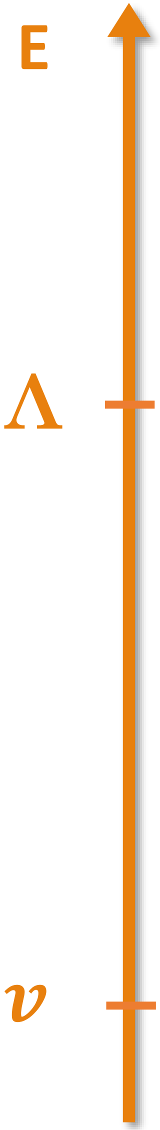

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$$G_{\mathrm{SMEFT}} = \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)$$
$$\psi_{\mathrm{SMEFT}} = \psi_{\mathrm{SM}}$$

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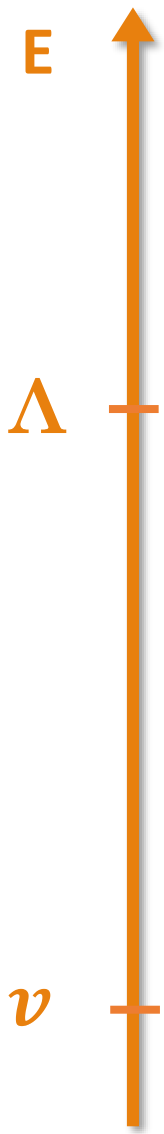

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(Fairly) Model-independent phenomenology

$$\mathrm{d}\sigma = \mathrm{d}\sigma_{\rm SM} + \frac{c_i^{(6)}}{\Lambda^2} d\sigma^i_{\rm int.} + \frac{c_i^{(6)} c_j^{(6)}}{\Lambda^4} d\sigma^{i,j}_{\rm EFT}$$

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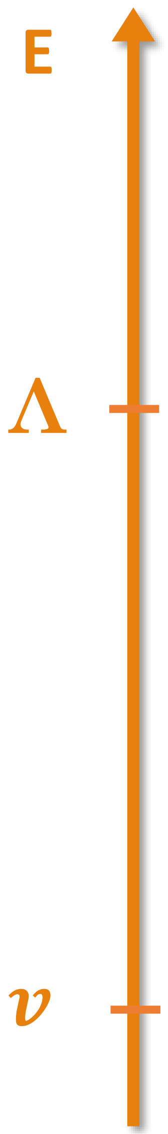

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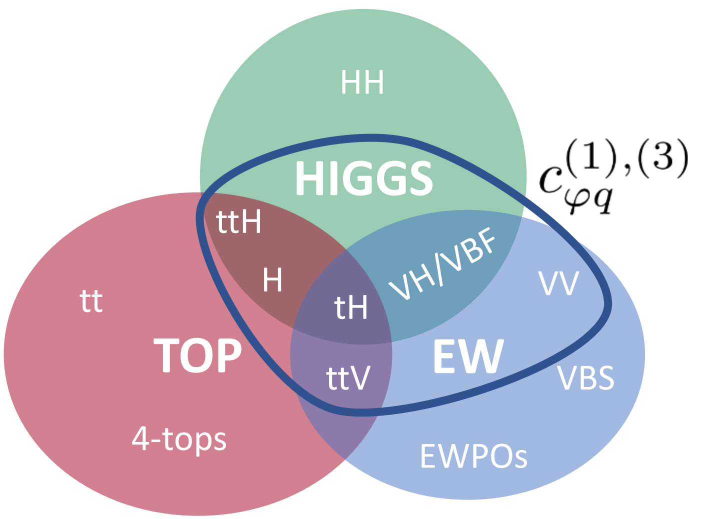
Interpretation of correlated data



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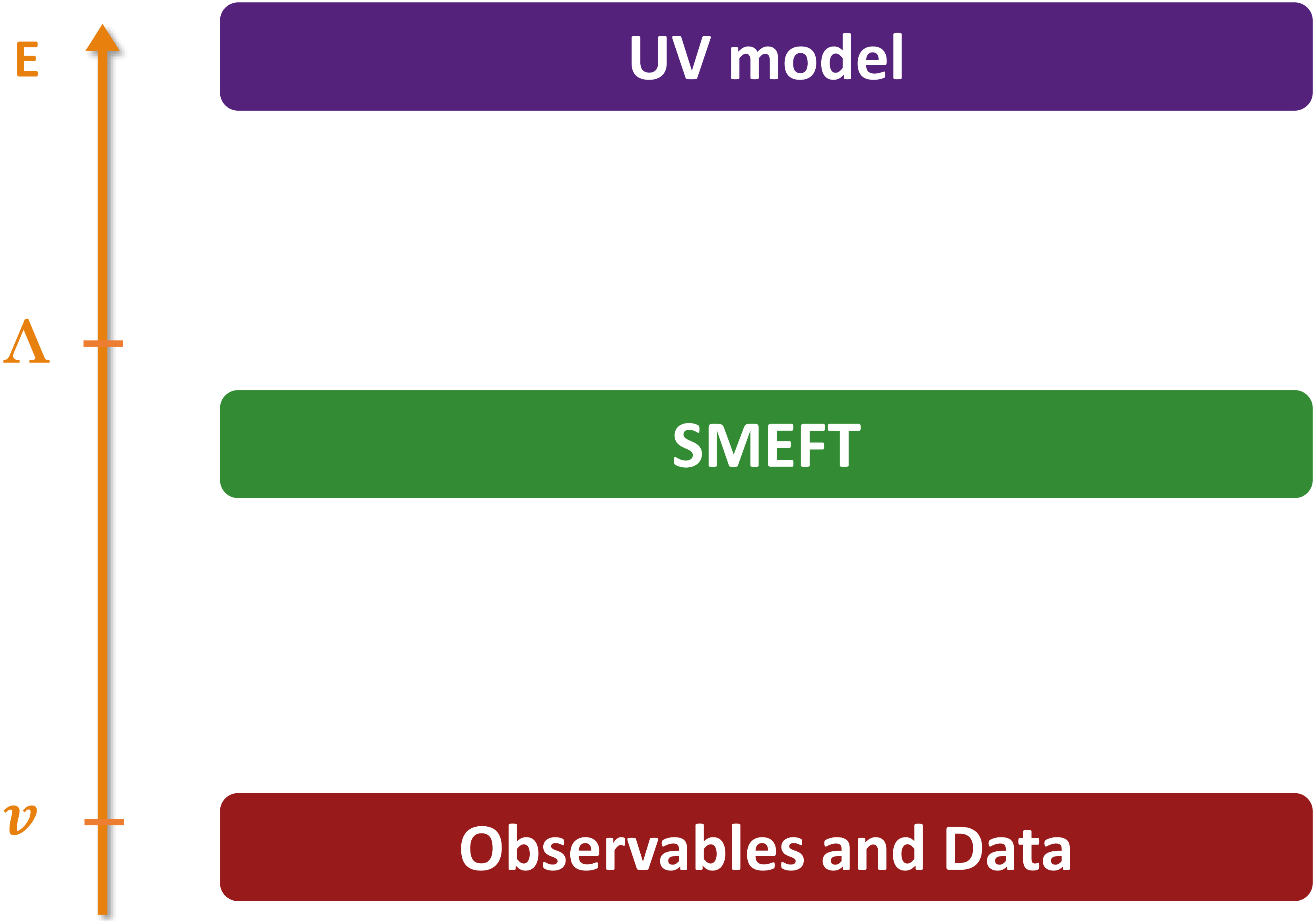
Automation across scales



Apologies for not including all tools/codes due to space-time restrictions.

Automation across scales

E

UV model

MATCHETE [2212. 04510]

MEFT [2112.10787]

CO [1808. 04403]

Λ

SMEFT

v

Observables and Data

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SMEFTsim [2012. 11343]

SMEFT@NLO [2008. 11743]

MADGRAPH 5 [1405.0301]

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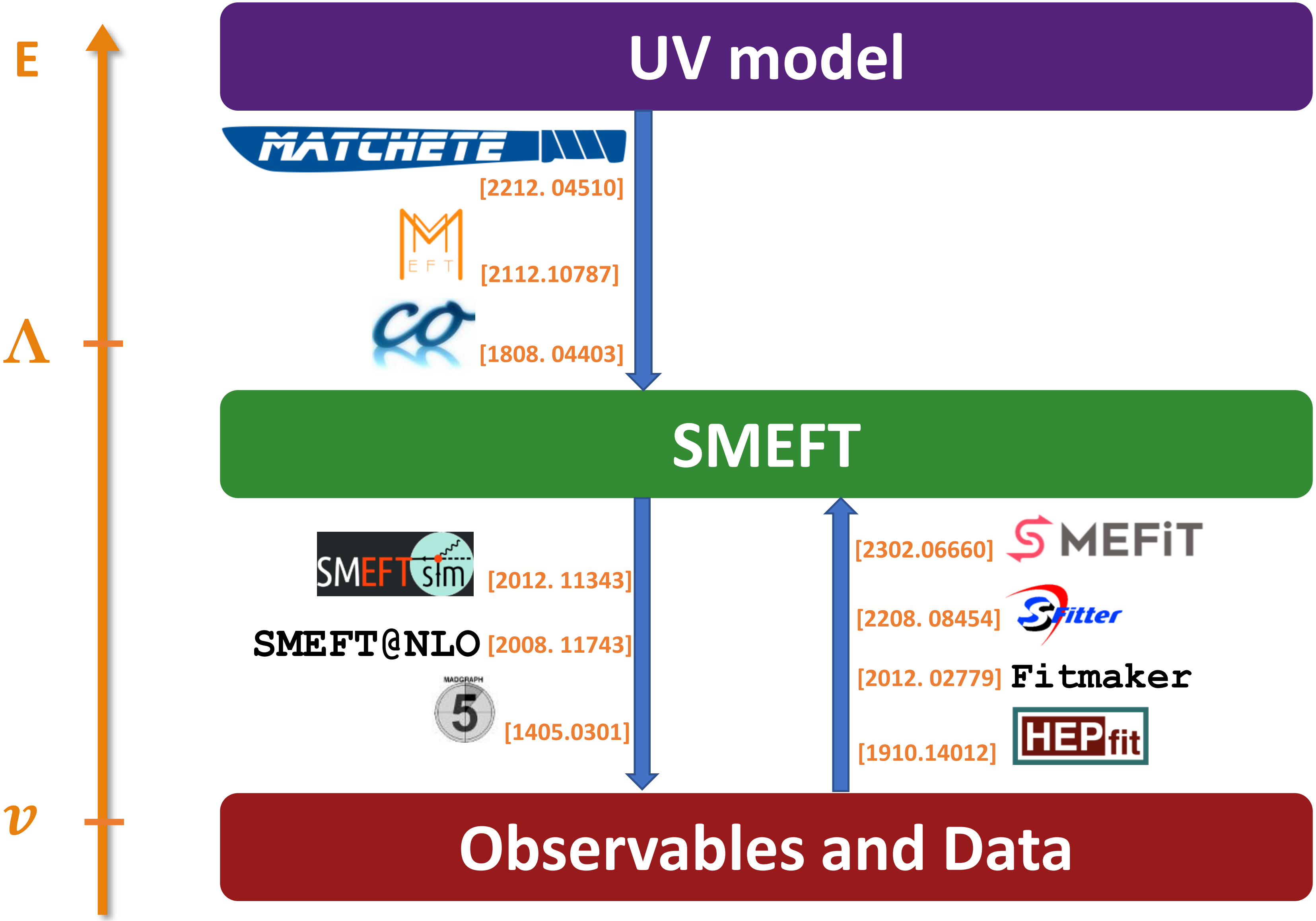

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Generated with AI – Bing.

SMEFT

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MADGRAPH 5 [1405.0301]

[2302.06660] SMEFiT

[2208. 08454] SFitter

[2012. 02779] Fitmaker

[1910.14012] HEPfit

Observables and Data

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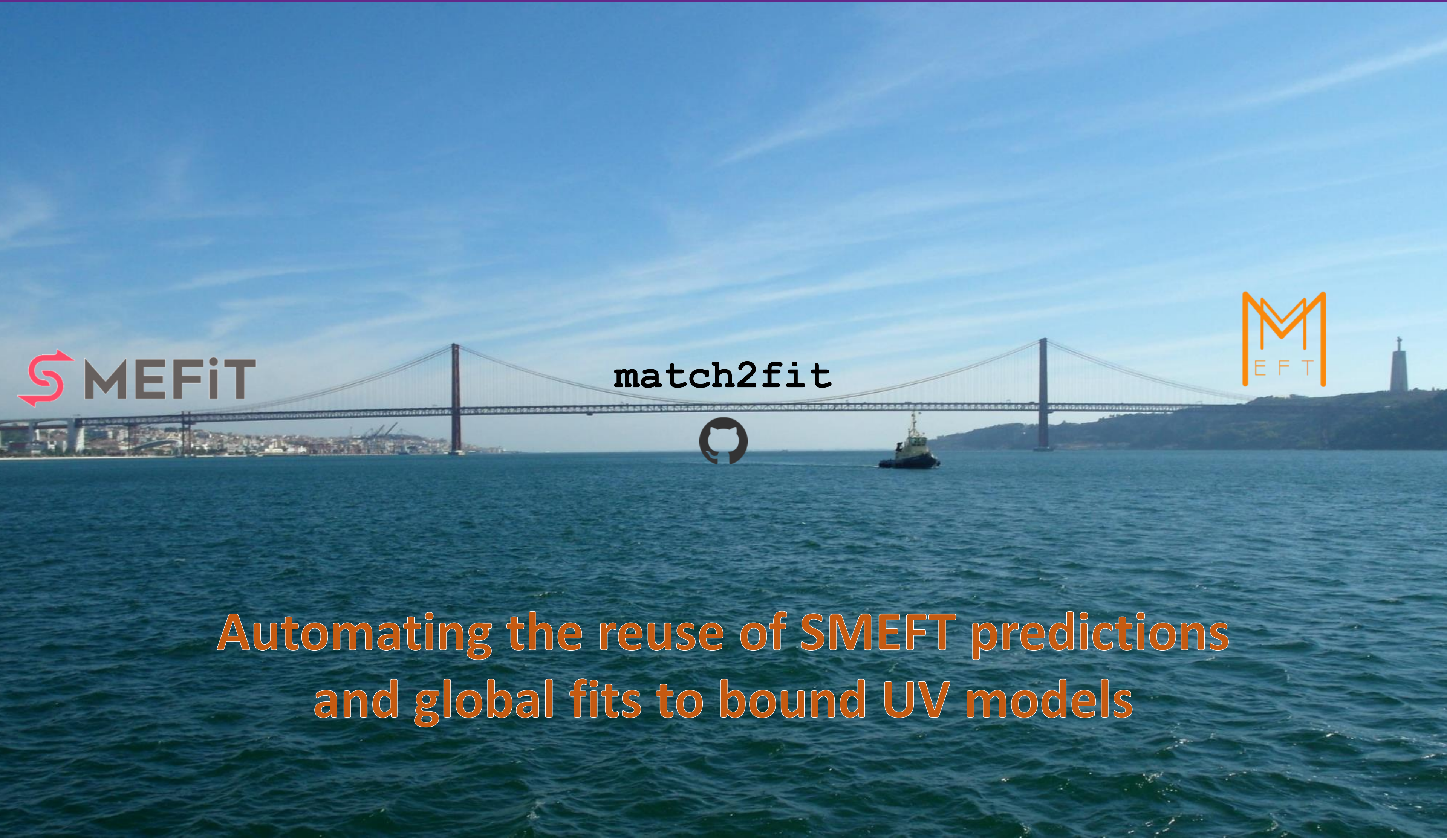
Bridging the gap



SMEFiT In a nutshell

v. 2.0: [2302.06660]
v. 3.0: [2404.12809]

A Python software for global interpretations of particle physics data in SMEFT

SMEFiT

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THEORY

SM: (N)NLO QCD + NLO EW
SMEFT: NLO QCD, quadratic in WCs

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METHOD

Bayesian **Nested Sampling**

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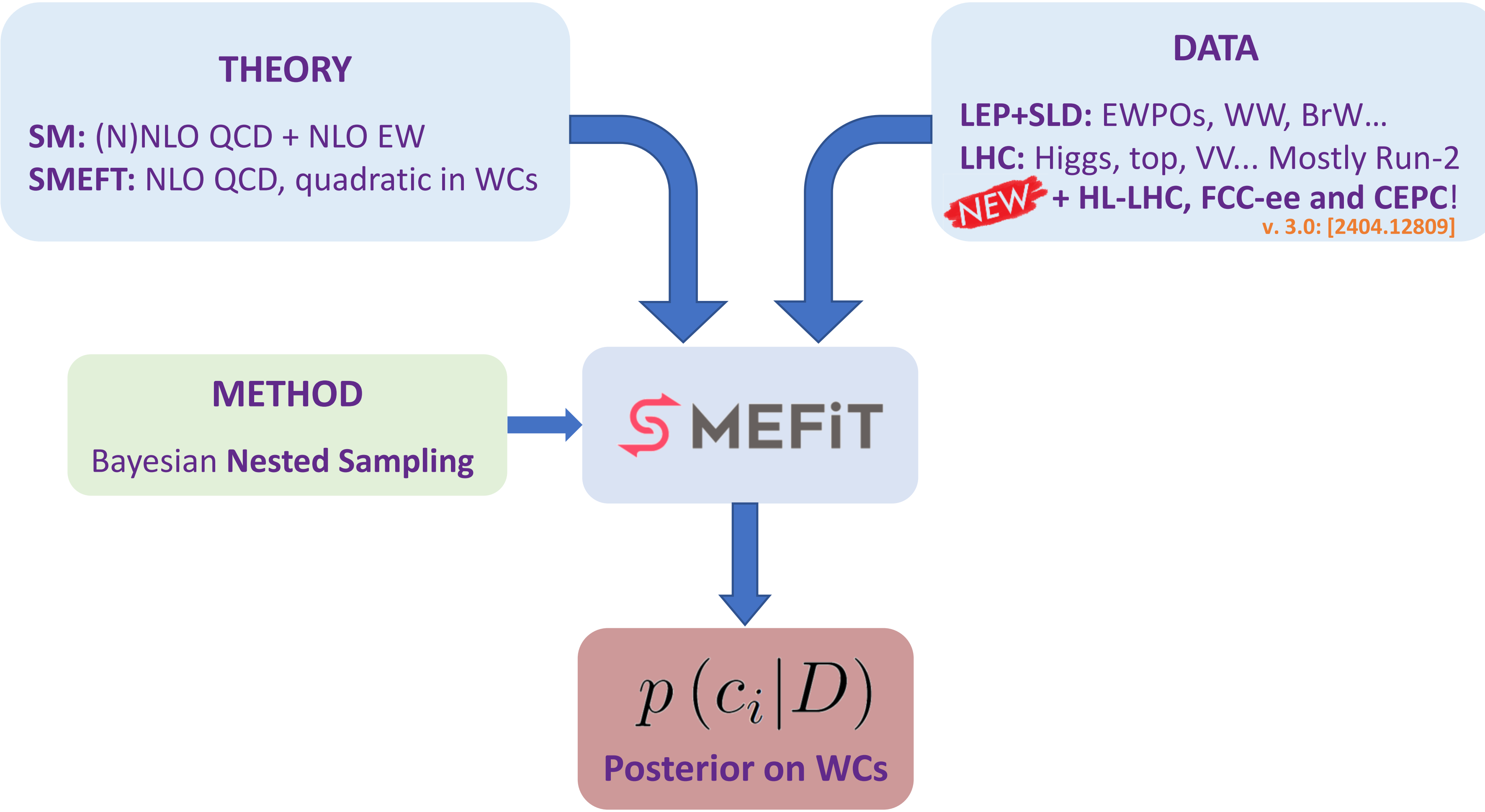

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v. 3.0: [2404.12809]

METHOD

Bayesian **Nested Sampling**

TOOLS

PCA, Fisher, closure tests, documentation.

SMEFiT

$$p\left(c_i|D\right)$$

Posterior on WCs

Non-linear UV constrains on WCs from matching

Tree-level matching

$$\frac{\left(c_{qd}^{(1)}\right)_{3333}}{\Lambda^2} = -\frac{\left(y_\phi^d\right)_{33}^2}{6\, m_\phi^2}, \quad \frac{\left(c_{qd}^{(8)}\right)_{3333}}{\Lambda^2} = -\frac{\left(y_\phi^d\right)_{33}^2}{m_\phi^2}, \qquad \frac{(c_{d\varphi})_{33}}{\Lambda^2} = \frac{\lambda_\phi \left(y_\phi^d\right)_{33}}{m_\phi^2}, \quad \frac{c_\varphi}{\Lambda^2} = \frac{\lambda_\phi^2}{m_\phi^2}$$

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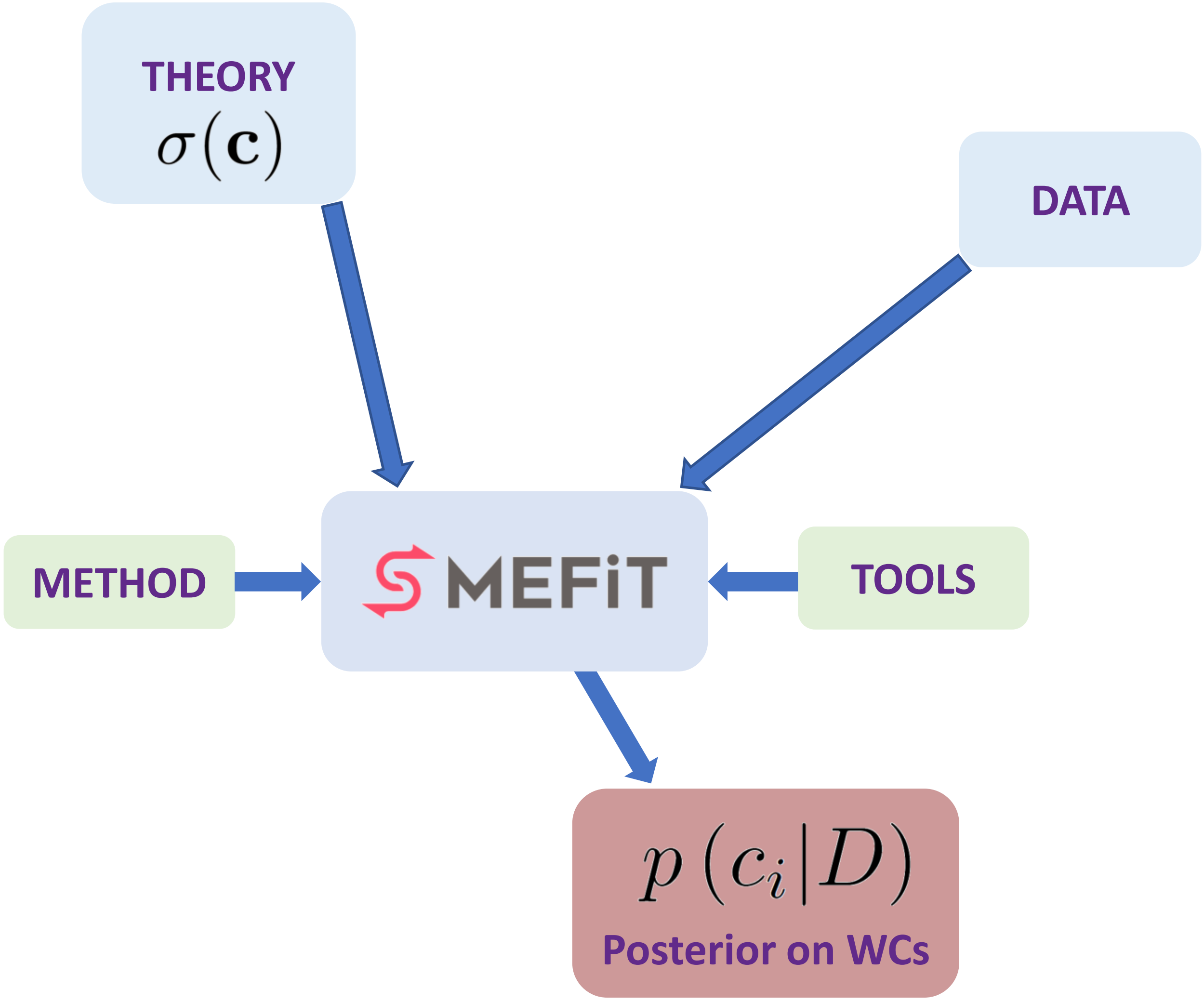
One-loop level matching

$$\frac{c_{\varphi\Box}}{\Lambda^2} = -\frac{g_1^4}{7680\pi^2}\frac{1}{m_\phi^2} - \frac{g_2^4}{2560\pi^2}\frac{1}{m_\phi^2} - \frac{3}{32\pi^2}\frac{\lambda_\phi^2}{m_\phi^2},$$

$$\frac{c_{t\varphi}}{\Lambda^2} = -\frac{\lambda_\phi \left(y_\phi^u\right)_{33}}{m_\phi^2} - \frac{g_2^4 y_t^{\mathrm{SM}}}{3840\pi^2}\frac{1}{m_\phi^2} + \frac{y_t^{\mathrm{SM}}}{16\pi^2}\frac{\lambda_\phi^2}{m_\phi^2} + \frac{\left(4\left(y_b^{\mathrm{SM}}\right)^2 - 13\left(y_t^{\mathrm{SM}}\right)^2\right)}{64\pi^2}\frac{\lambda_\phi \left(y_\phi^u\right)_{33}}{m_\phi^2}$$

$$-\left(12\lambda_\varphi^{\mathrm{SM}} + \left(y_b^{\mathrm{SM}}\right)^2 - 11\left(y_t^{\mathrm{SM}}\right)^2\right)\frac{y_t^{\mathrm{SM}}}{64\pi^2}\frac{\left(y_\phi^u\right)_{33}^2}{m_\phi^2} + \frac{3}{128\pi^2}\frac{\lambda_\phi \left(y_\phi^u\right)_{33}^3}{m_\phi^2},$$

Reusing EFT global fits for the UV



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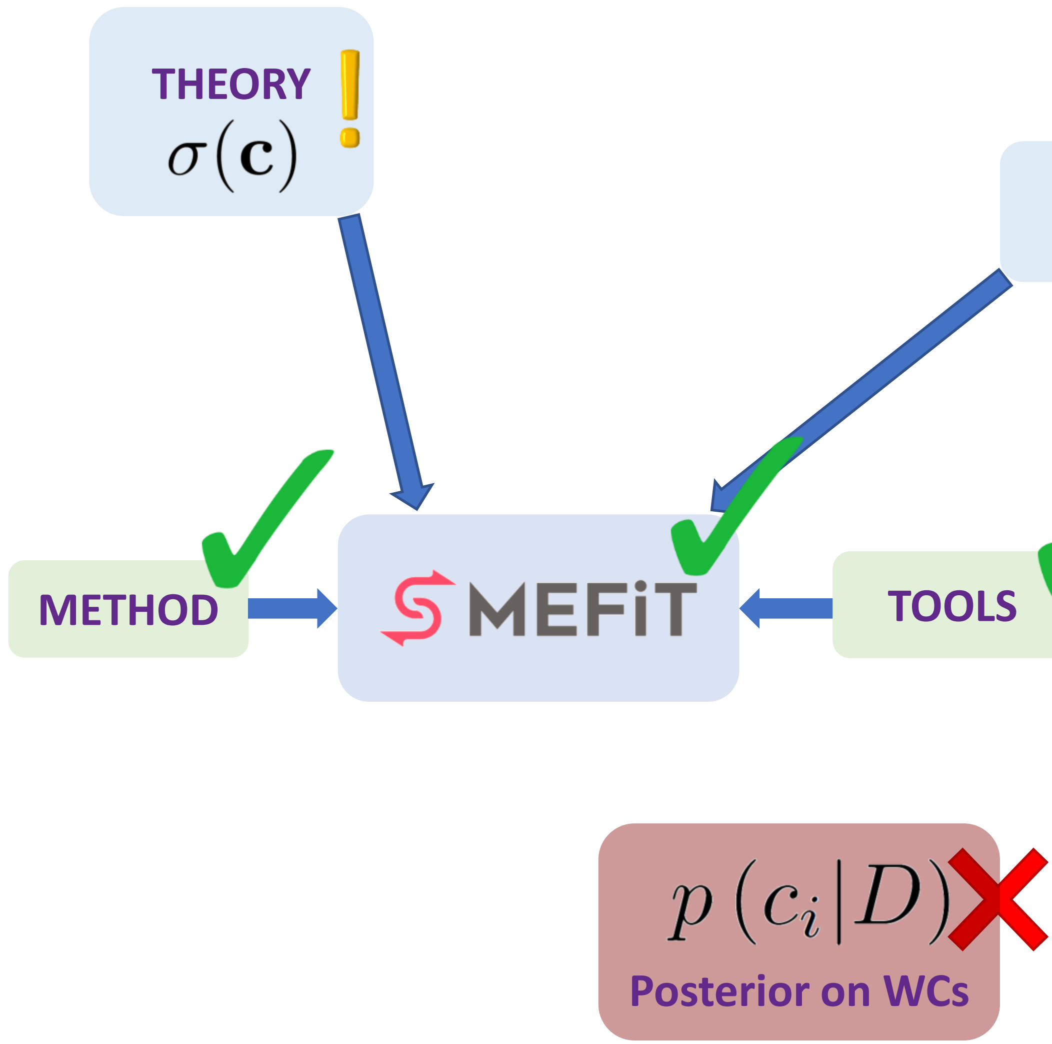

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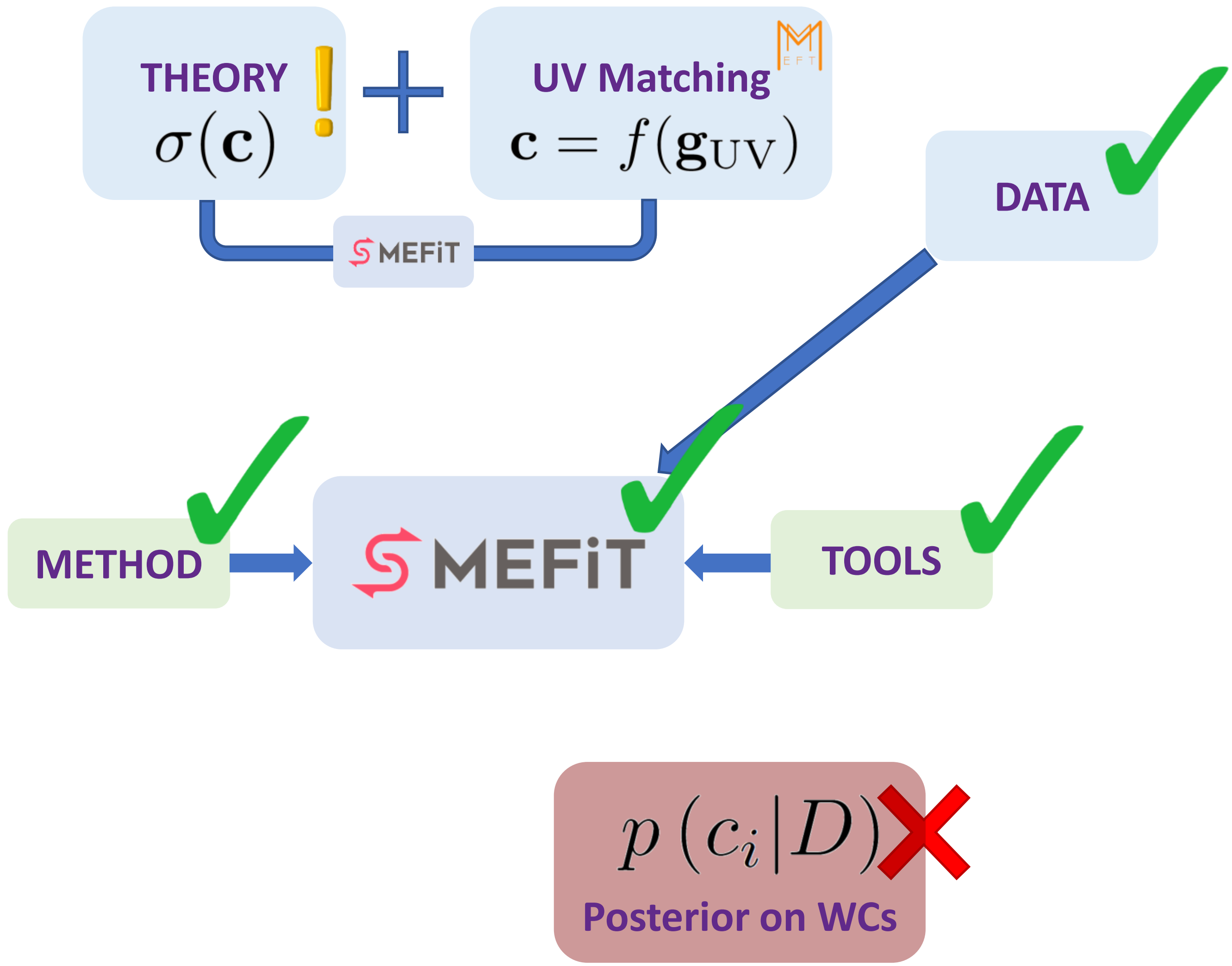

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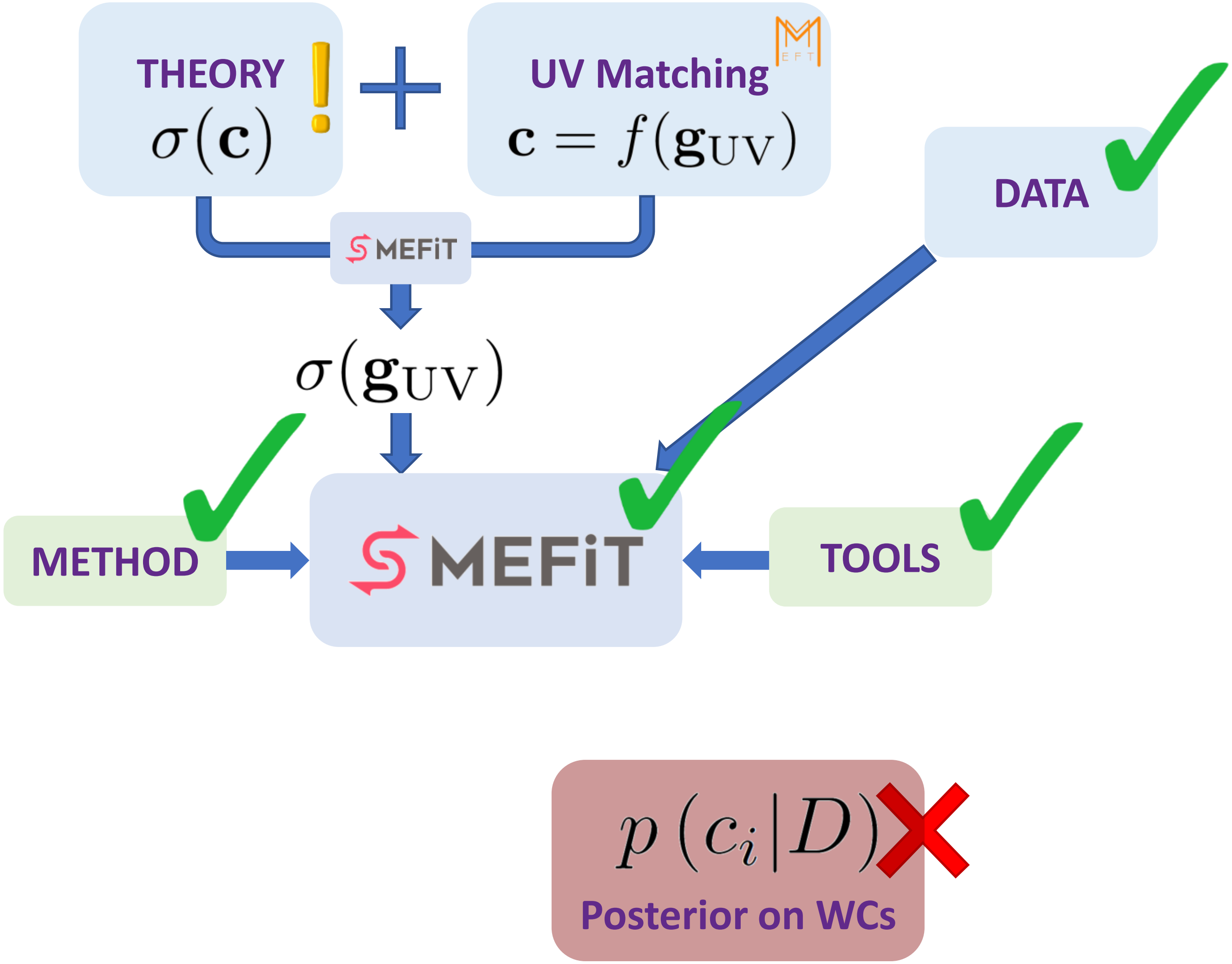

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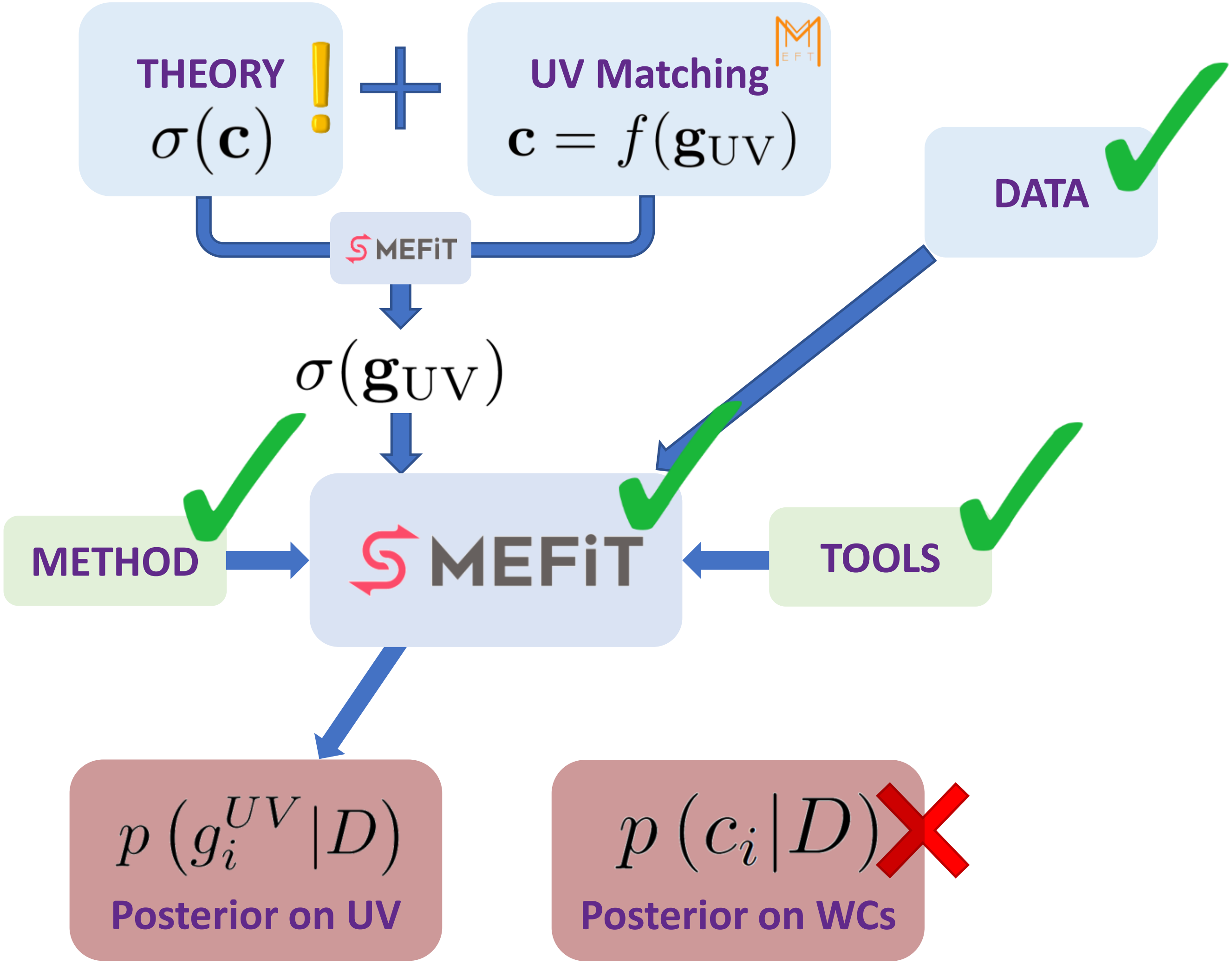


match2fit

- A Wolfram Mathematica™ package, fully documented.
- Reads results from `Matchmakereft` and produces run cards that can be fed into `smefit` to perform a fit .
- Uses the same WC basis than SMEFiT.

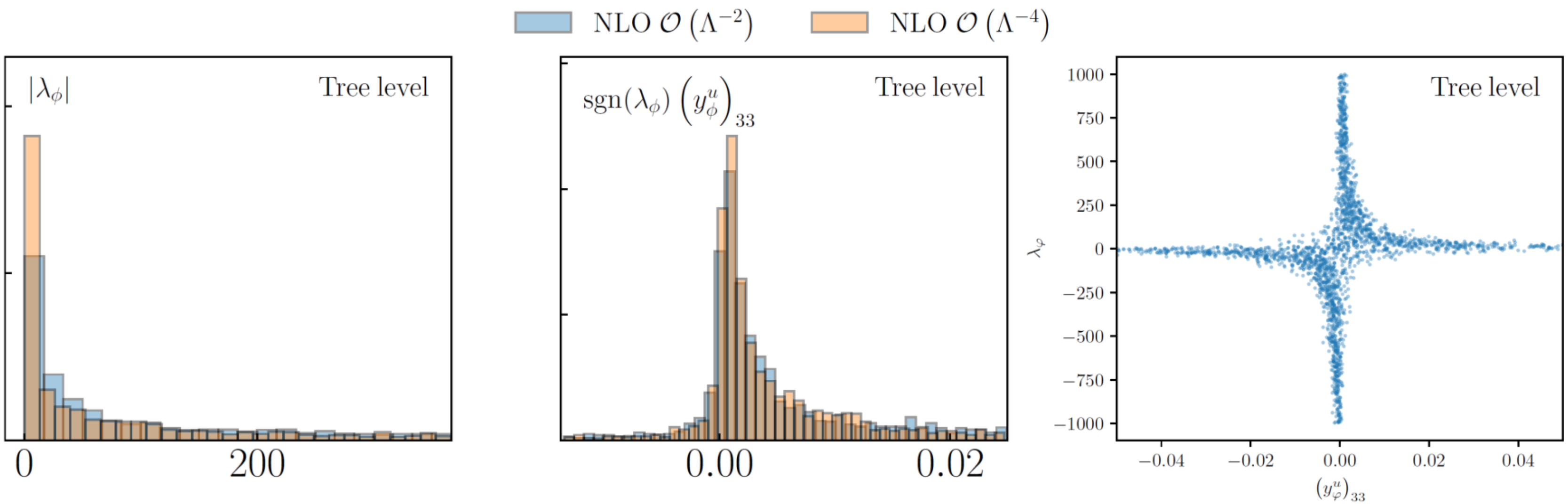
$$\mathrm{U}(2)_q \times \mathrm{U}(3)_d \times \mathrm{U}(2)_u \times (\mathrm{U}(1)_\ell \times \mathrm{U}(1)_e)^3 + c_{b\varphi},\ c_{\tau\varphi},\ c_{c\varphi}$$

- It can impose UV flavor assumptions and evaluates the masses.
- It can run Matchmakereft to perform the matching and translation at once.

It supports 1-loop matching results.

One-loop matching makes a difference

$\phi \sim (1,2)_{1/2}$ $\mathcal{L}_{\rm UV} \supset -\left(y_\phi^u\right)_{33} \phi^\dagger i\sigma_2 \bar{q}_L^{T,3} u_R^3 - \lambda_\phi \phi^\dagger H |H|^2 + \text{h.c.}$ $m_\phi = 1$ TeV



Dataset: SMEFiT 2.0 + EWPOs

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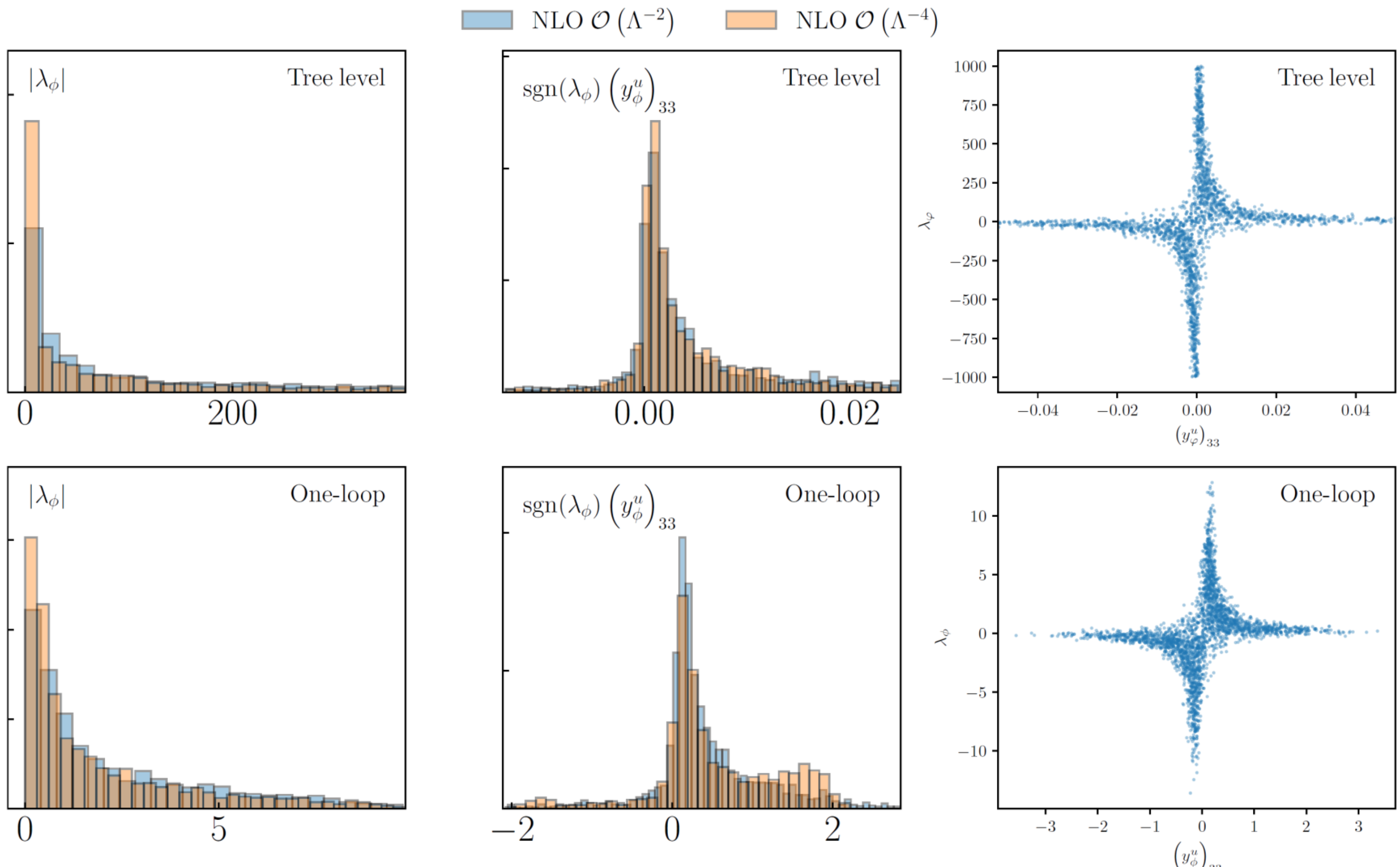

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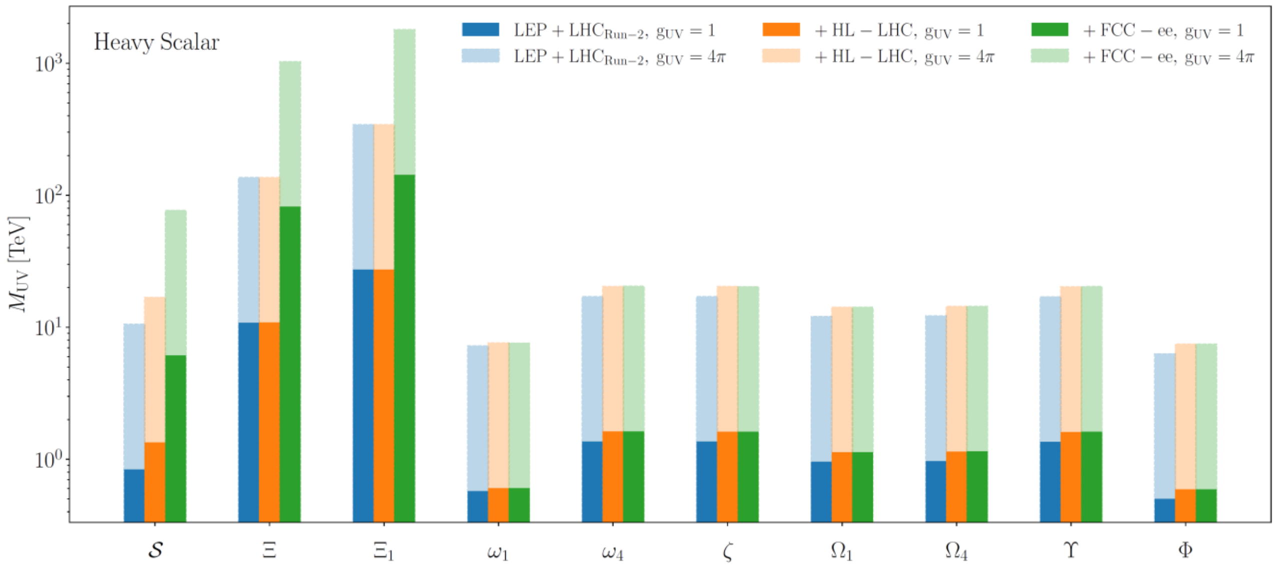
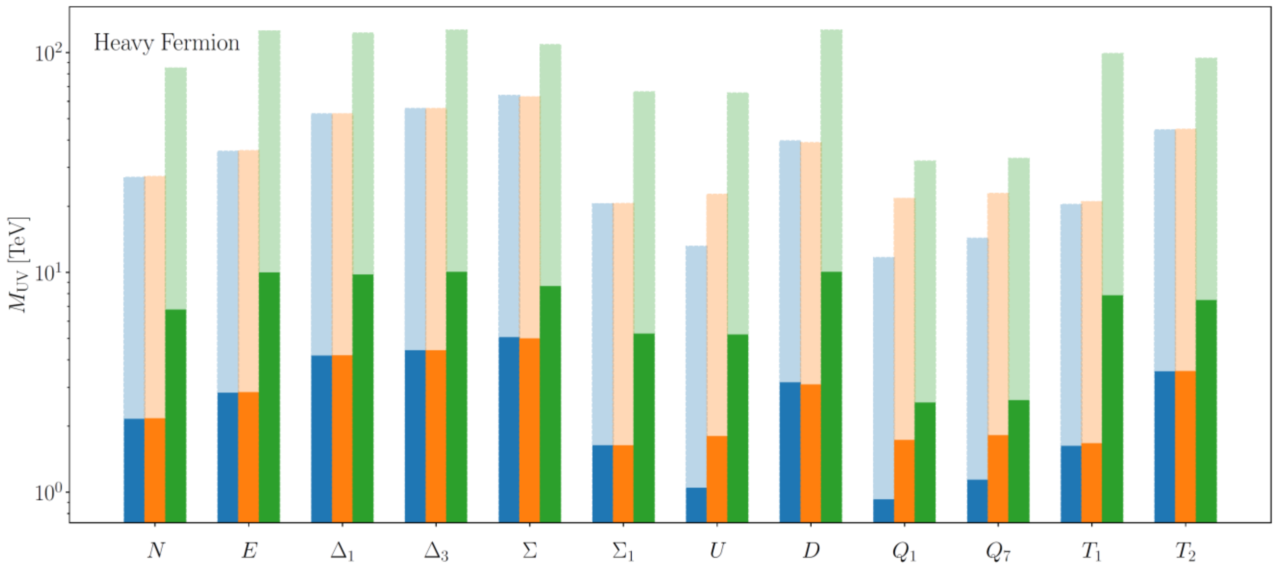
Projections for future colliders I





Tree-level matching

Projections for future colliders I

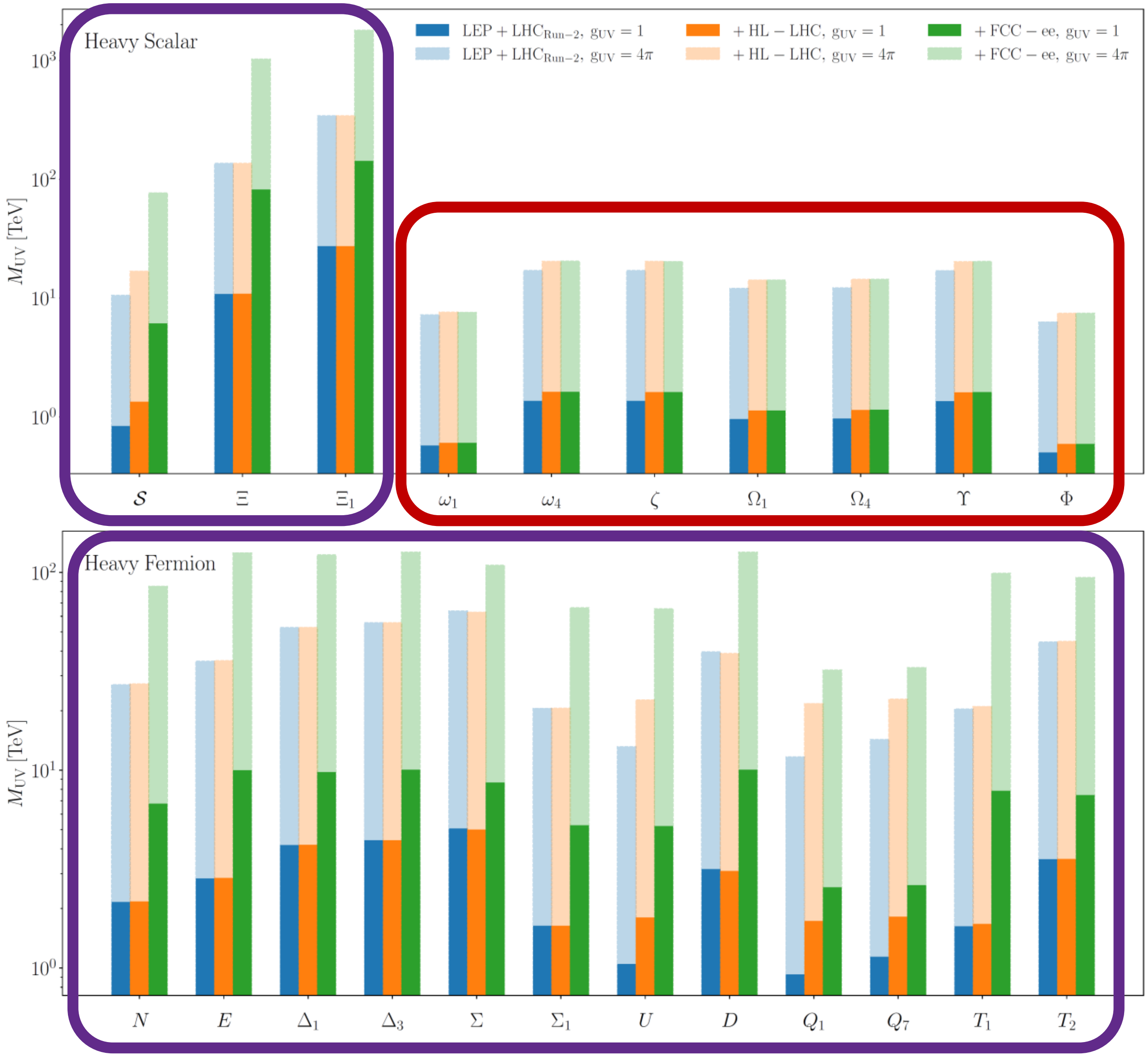
Driven by heavy 4-quark operators

Tree-level matching

Projections for future colliders I

Driven by heavy 4-quark operators

Driven by EWPOs



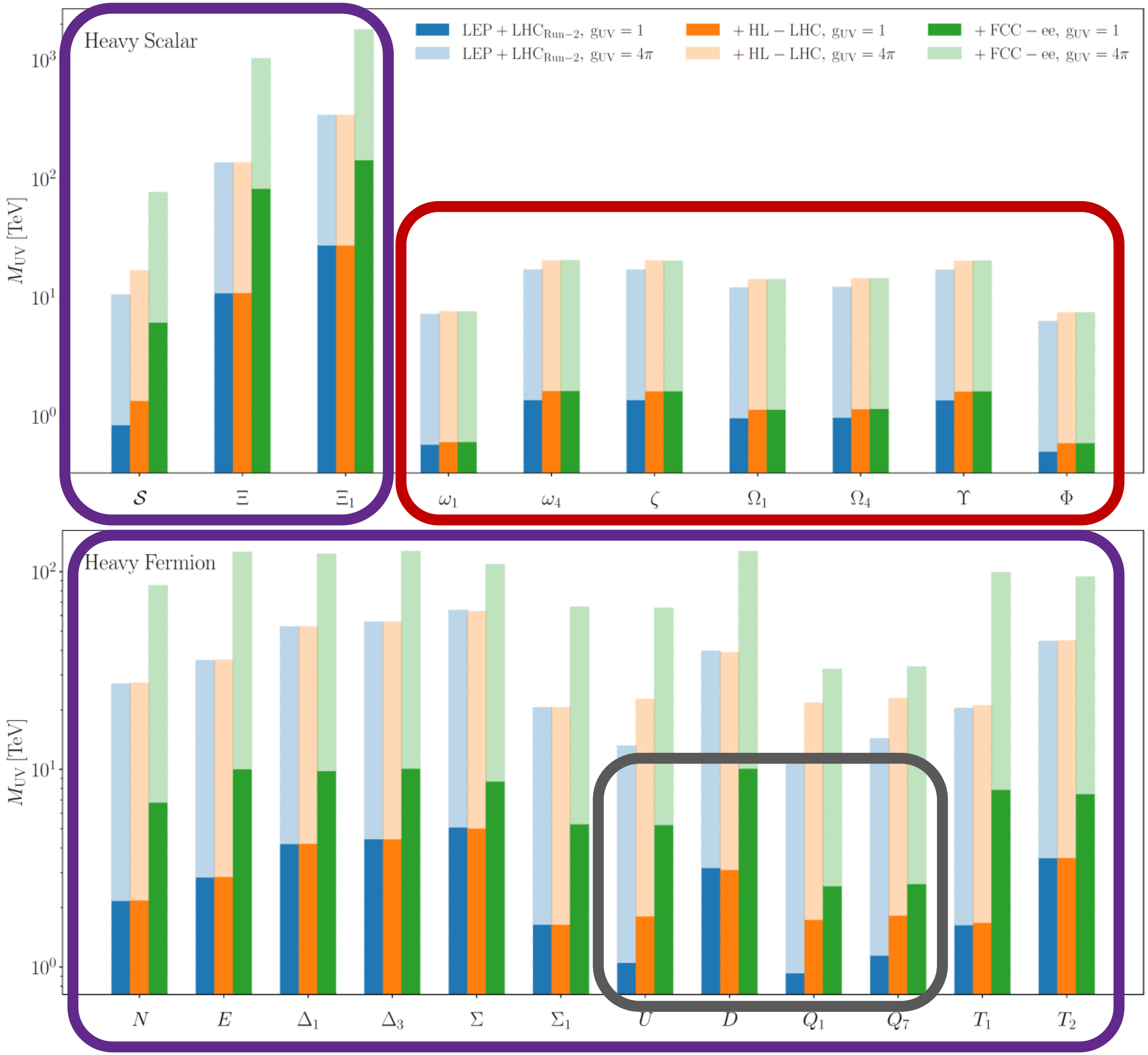
Tree-level matching

Projections for future colliders I

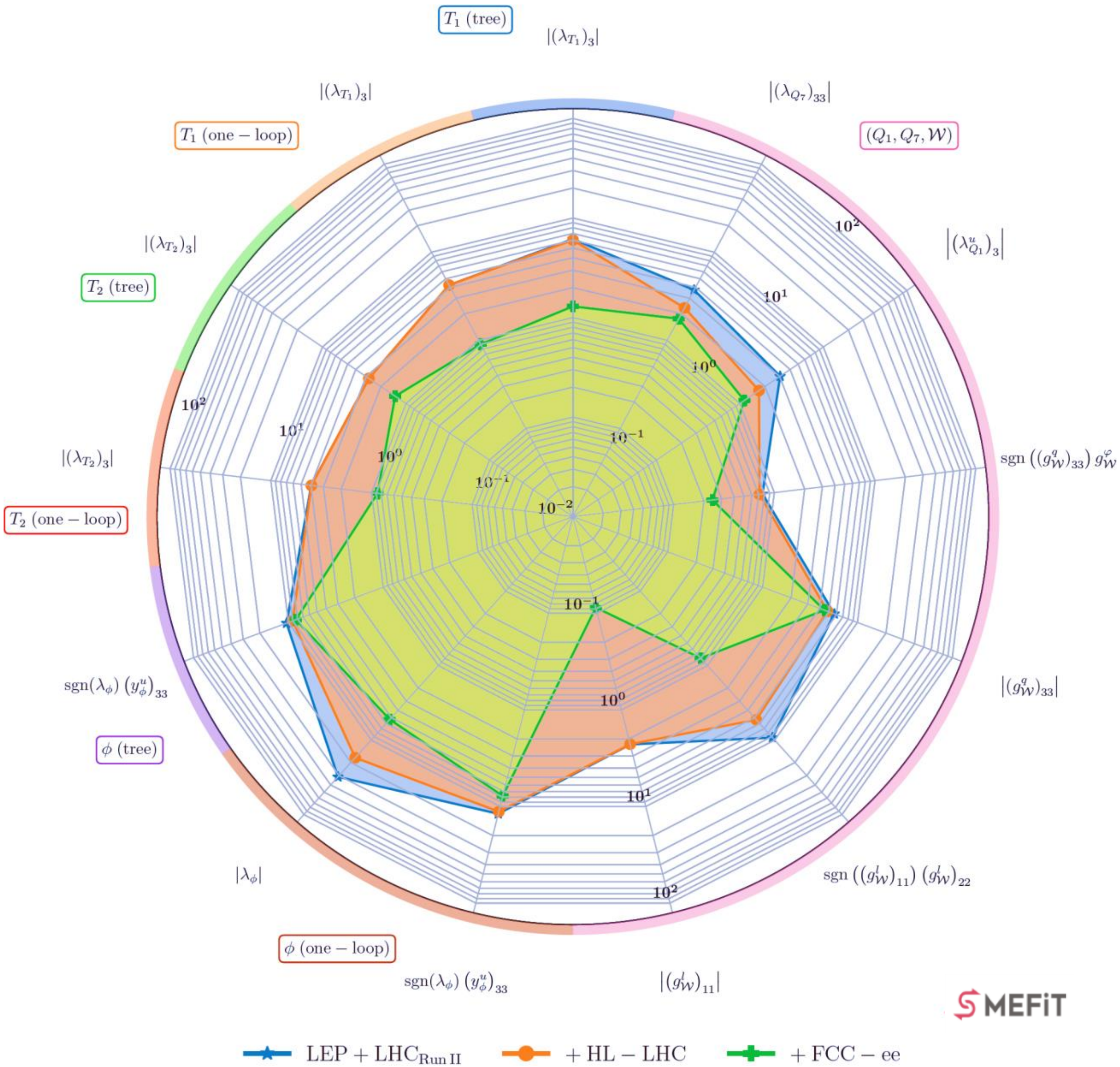
Driven by heavy 4-quark operators

Driven by EWPOs

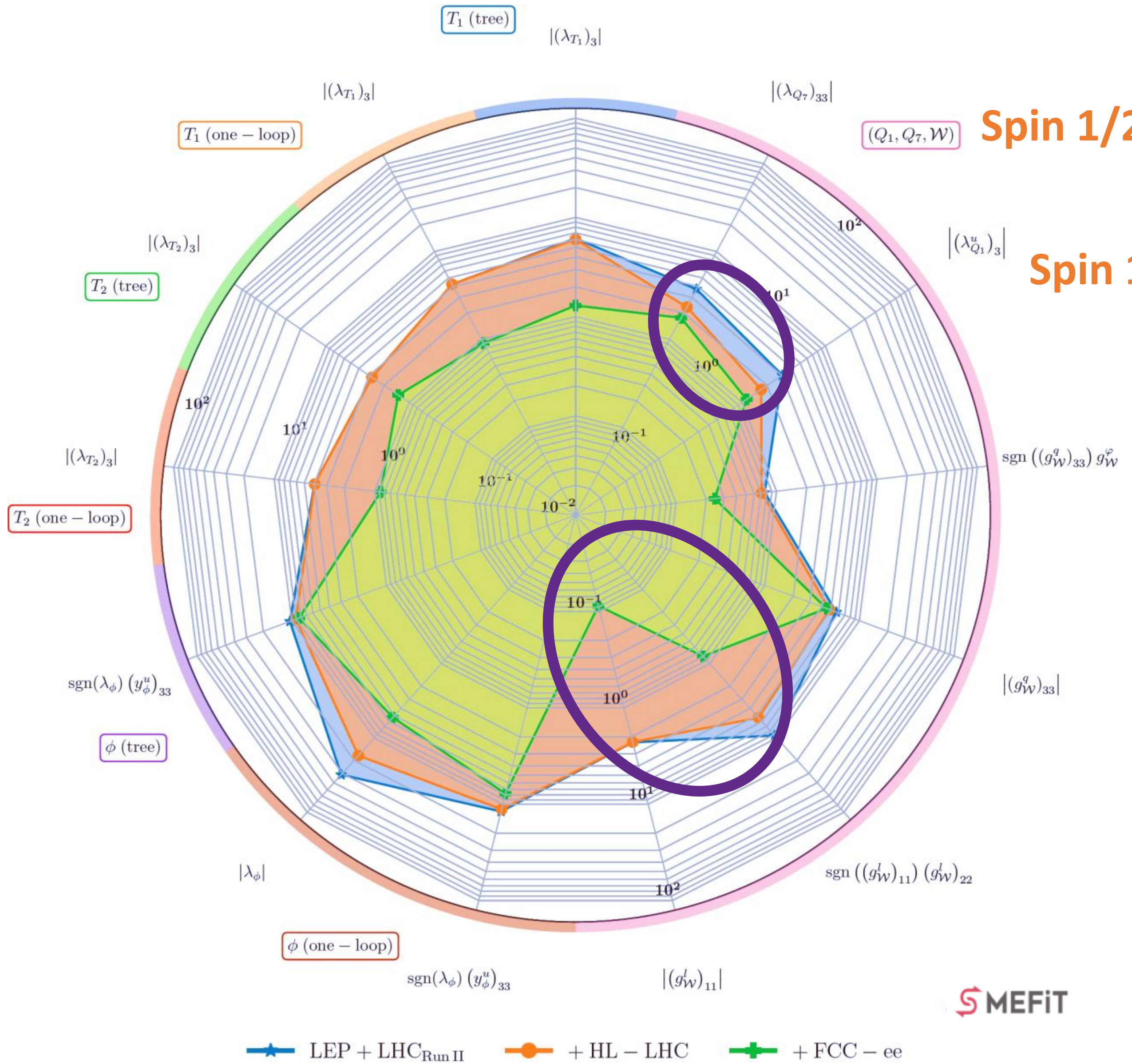
Top partners



Tree-level matching


T_1 (tree)
$|(\lambda_{T_1})_3|$
$|(\lambda_{Q_7})_{33}|$
$(Q_1, Q_7, \mathcal{W})$
$|(\lambda^u_{Q_1})_3|$
$\mathrm{sgn}\,((g^q_{\mathcal{W}})_{33})\, g^{\varphi}_{\mathcal{W}}$
$|(g^q_{\mathcal{W}})_{33}|$
$\mathrm{sgn}\,((g^l_{\mathcal{W}})_{11})\,(g^l_{\mathcal{W}})_{22}$
$|(g^l_{\mathcal{W}})_{11}|$
$\mathrm{sgn}(\lambda_\phi)\,(y^u_\phi)_{33}$
ϕ (one − loop)
$|\lambda_\phi|$
ϕ (tree)
$\mathrm{sgn}(\lambda_\phi)\,(y^u_\phi)_{33}$
T_2 (one − loop)
$|(\lambda_{T_2})_3|$
T_2 (tree)
$|(\lambda_{T_2})_3|$
T_1 (one − loop)
$|(\lambda_{T_1})_3|$
10^{-2}
10^{-1}
10^0
10^1
10^2
SMEFiT
LEP + LHC$_{\mathrm{Run\,II}}$
+ HL − LHC
+ FCC − ee

Projections for future colliders II



Spin 1/2 $\begin{cases} Q_1 \sim (3,2)_{1/6} \\ Q_7 \sim (3,2)_{7/6} \end{cases}$

Spin 1 $\{\ \mathcal{W} \sim (1,3)_0$

$(\mathrm{SU(3)_c, SU(2)_L})_{\mathrm{U(1)_Y}}$

$m_{Q_1} = 3$ TeV

$m_{Q_7} = 4.5$ TeV

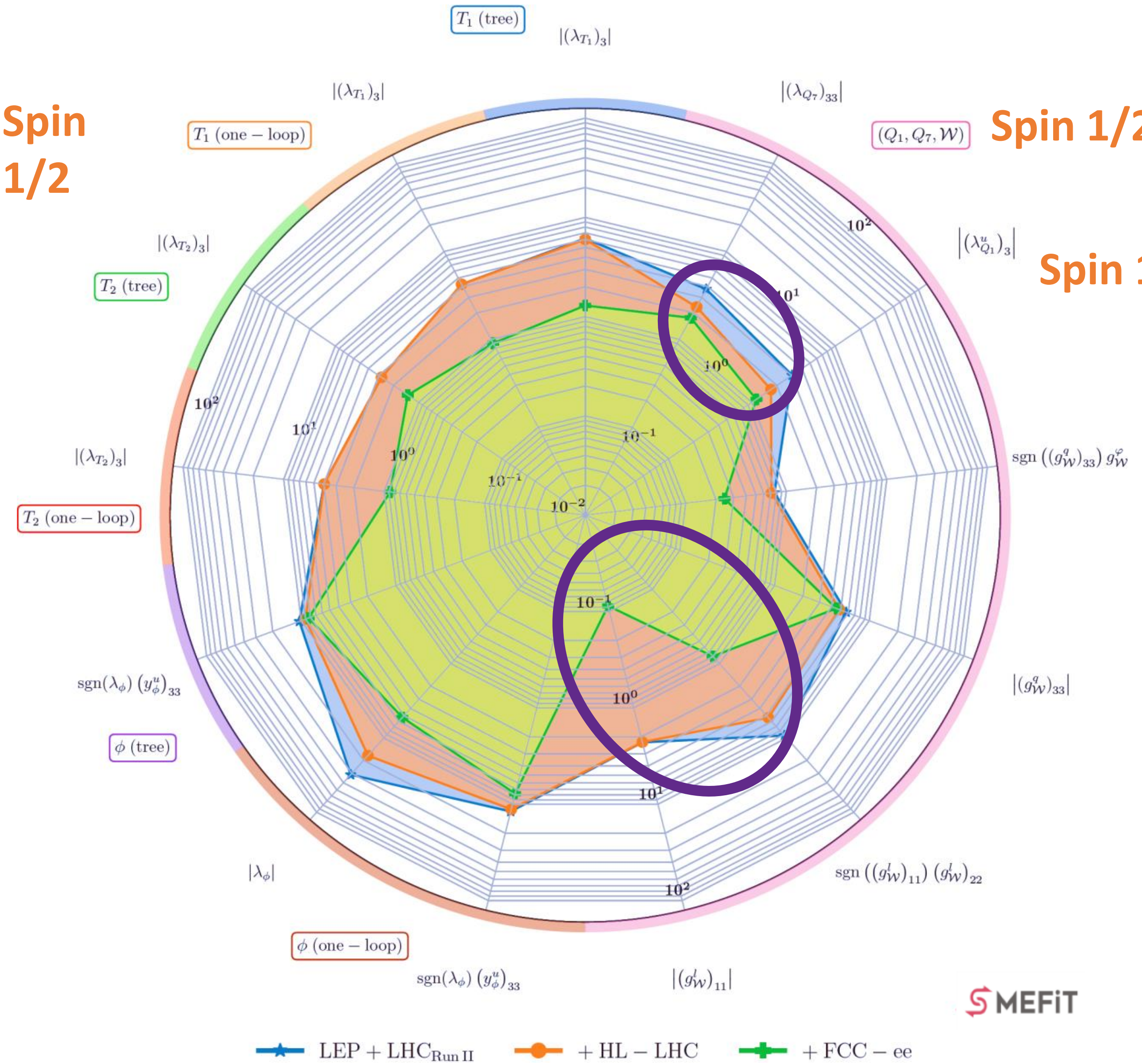
$m_{\mathcal{W}} = 2.5$TeV

Projections for future colliders II

$T_1 \sim (3,3)_{-1/2}$
$T_2 \sim (3,3)_{2/3}$
} **Spin 1/2**

$m_{T_1} = 10$ TeV

$m_{T_2} = 10$ TeV



Spin 1/2 {
$Q_1 \sim (3,2)_{1/6}$
$Q_7 \sim (3,2)_{7/6}$

Spin 1 { $\mathcal{W} \sim (1,3)_0$

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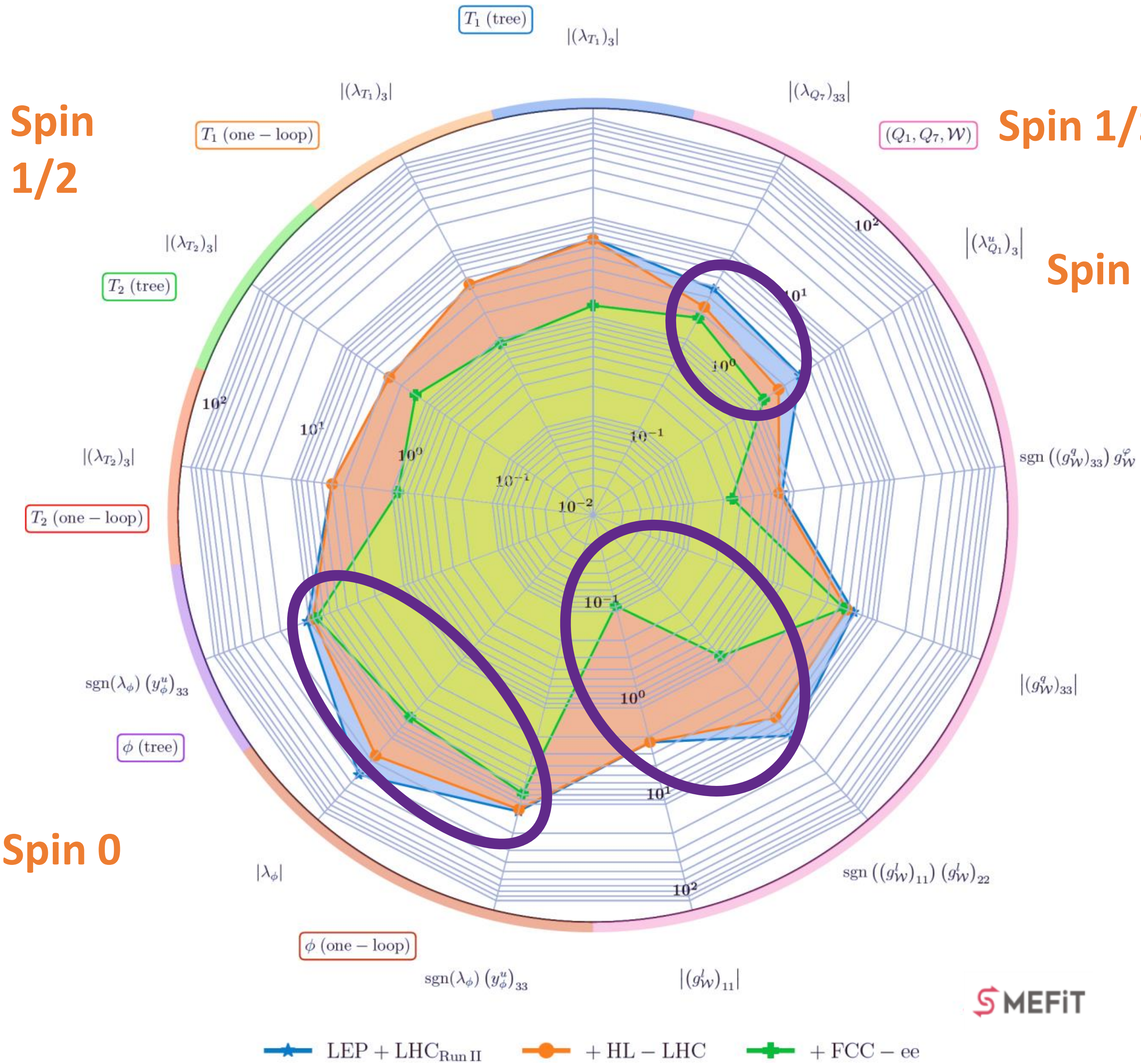

$Q_1 \sim (3,2)_{1/6}$
$Q_7 \sim (3,2)_{7/6}$ } **Spin 1/2**

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$m_{Q_1} = 3$ TeV

$m_{Q_7} = 4.5$ TeV

$m_{\mathcal{W}} = 2.5$TeV

$\phi \sim (1,2)_{1/2}$ } **Spin 0**

$m_\phi = 5$ TeV

Conclusions

- We have the tools for the full cycle of the EFT program for BSM Physics.
- SMEFiT allows to interpret LHC data at the EFT and UV model levels from one set of predictions.
- Match2fit provides a simple and flexible SMEFiT-MMEFT interface.
- Useful for pheno studies at current and future colliders.
- Several improvement possibilities: interfacing more codes, flavor data, RGE effects, more general flavor symmetries…

Thanks for your attention!

Contact:

Alejo N. Rossia

HEP Theory Group – Dept. Of Physics and Astronomy

E-mail: alejo dot rossia at manchester dot ac dot uk

Appendix

UV invariants

We are sensitive only to combinations of UV couplings that enter the WCs.

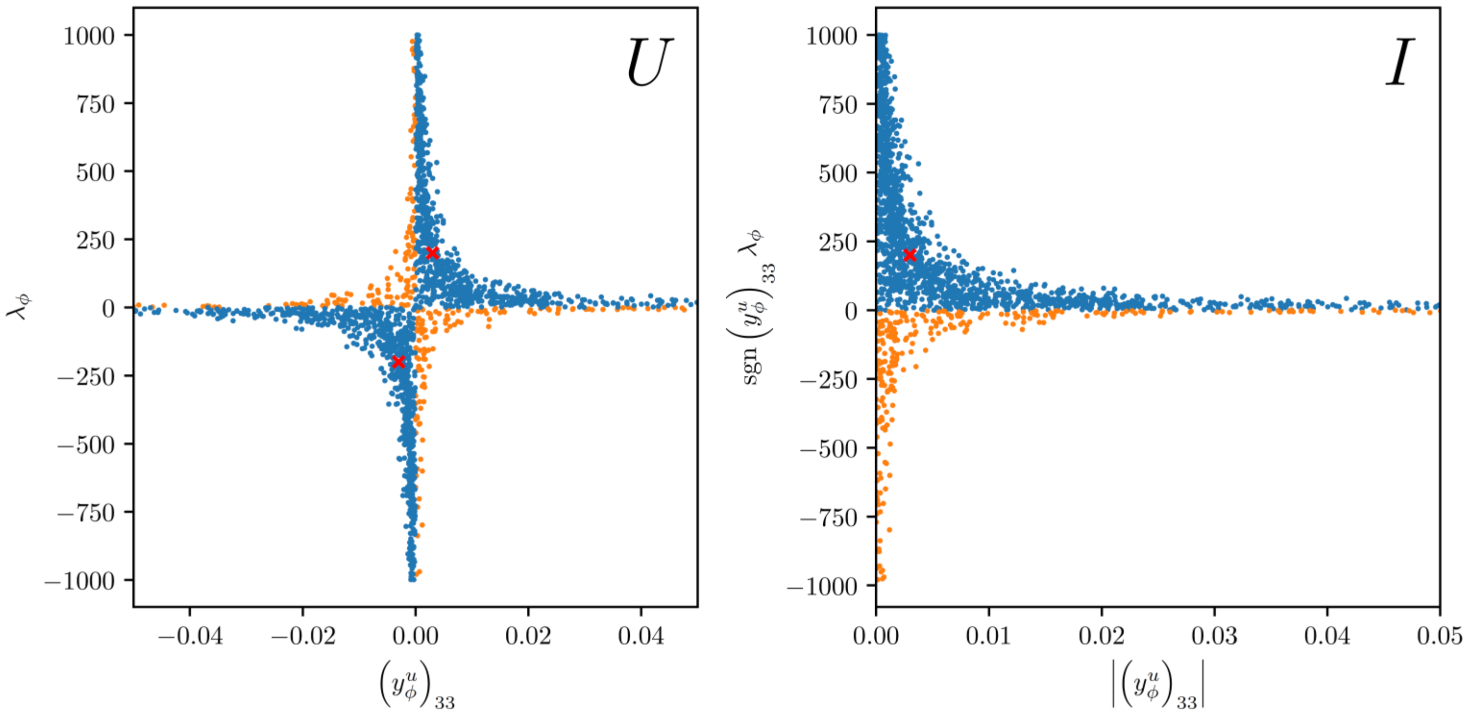
$$h : U \to I$$

"UV invariants"

$$\mathbf{c} = f(\mathbf{g}_{\mathrm{UV}})$$

$$f\left(h(g)\right) = f\left(h(g')\right) \iff h(g) = h(g')$$

$$\mathbf{c} = f(h(\mathbf{g}_{\mathrm{UV}}))$$



Not necessary to do the fit, but useful to understand the results.

Restrictions from EFT flavor symmetry

- Your model produces an operator that should vanish and does not enter in any fitted process.
  - The bounds from the fit might be suboptimal with respect to bounds from other processes.

- Your model produces an operator that should vanish and enters some processes in the dataset.
  - The bounds from the fit might not be trustworthy and suboptimal.

- The symmetry assumes two WCs to be equal but your model produces them with different values.
  - Match2fit will take only one of those values and ignore the other. Unless the difference is small, the bounds from the fit are not trustworthy.

Additional technicalities

SMEFiT supports relations among fit parameters like:

$$\sum_i a_i\,(c_1)^{n_{1,i}}\ldots(c_N)^{n_{N,i}}=0$$

The exponents can be rational numbers of any sign.
This imposes restrictions on the supported matching relations.

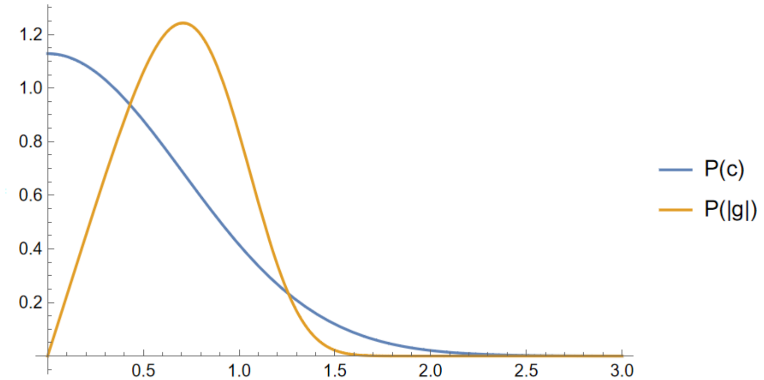
Probability in UV and WC spaces

The relation between PDFs in WC and UV space can be misleading.

$$P(c)=\frac{2}{\sqrt{\pi}}e^{-c^2}\,,\qquad \int_0^\infty dc\,P(c)=1$$

$$c=g^2$$

$$P(|g|)=\frac{4}{\sqrt{\pi}}|g|e^{-|g|^4}\,,\qquad \int_0^\infty d|g|\,P(|g|)=1$$



List of models

Scalars		Fermions		Vectors	
Particle	Irrep	Particle	Irrep	Particle	Irrep
$\mathcal{S}$	$(1,1)_0$	N	$(1,1)_0$	$\mathcal{B}$	$(1,1)_0$
$\mathcal{S}_1$	$(1,1)_1$	E	$(1,1)_{-1}$	$\mathcal{B}_1$	$(1,1)_1$
ϕ	$(1,2)_{1/2}$	Δ_1	$(1,2)_{-1/2}$	$\mathcal{W}$	$(1,3)_0$
Ξ	$(1,3)_0$	Δ_3	$(1,2)_{-3/2}$	$\mathcal{W}_1$	$(1,3)_1$
Ξ_1	$(1,3)_1$	Σ	$(1,3)_0$	$\mathcal{G}$	$(8,1)_0$
ω_1	$(3,1)_{-1/3}$	Σ_1	$(1,3)_{-1}$	$\mathcal{H}$	$(8,3)_0$
ω_4	$(3,1)_{-4/3}$	U	$(3,1)_{2/3}$	$\mathcal{Q}_5$	$(8,3)_0$
ζ	$(3,3)_{-1/3}$	D	$(3,1)_{-1/3}$	$\mathcal{Y}_5$	$(\bar{6},2)_{-5/6}$
Ω_1	$(6,1)_{1/3}$	Q_1	$(3,2)_{1/6}$		
Ω_4	$(6,1)_{4/3}$	Q_7	$(3,2)_{7/6}$		
Υ	$(6,3)_{1/3}$	T_1	$(3,3)_{-1/3}$		
Φ	$(8,2)_{1/2}$	T_2	$(3,3)_{2/3}$		
		Q_5	$(3,2)_{-5/6}$		

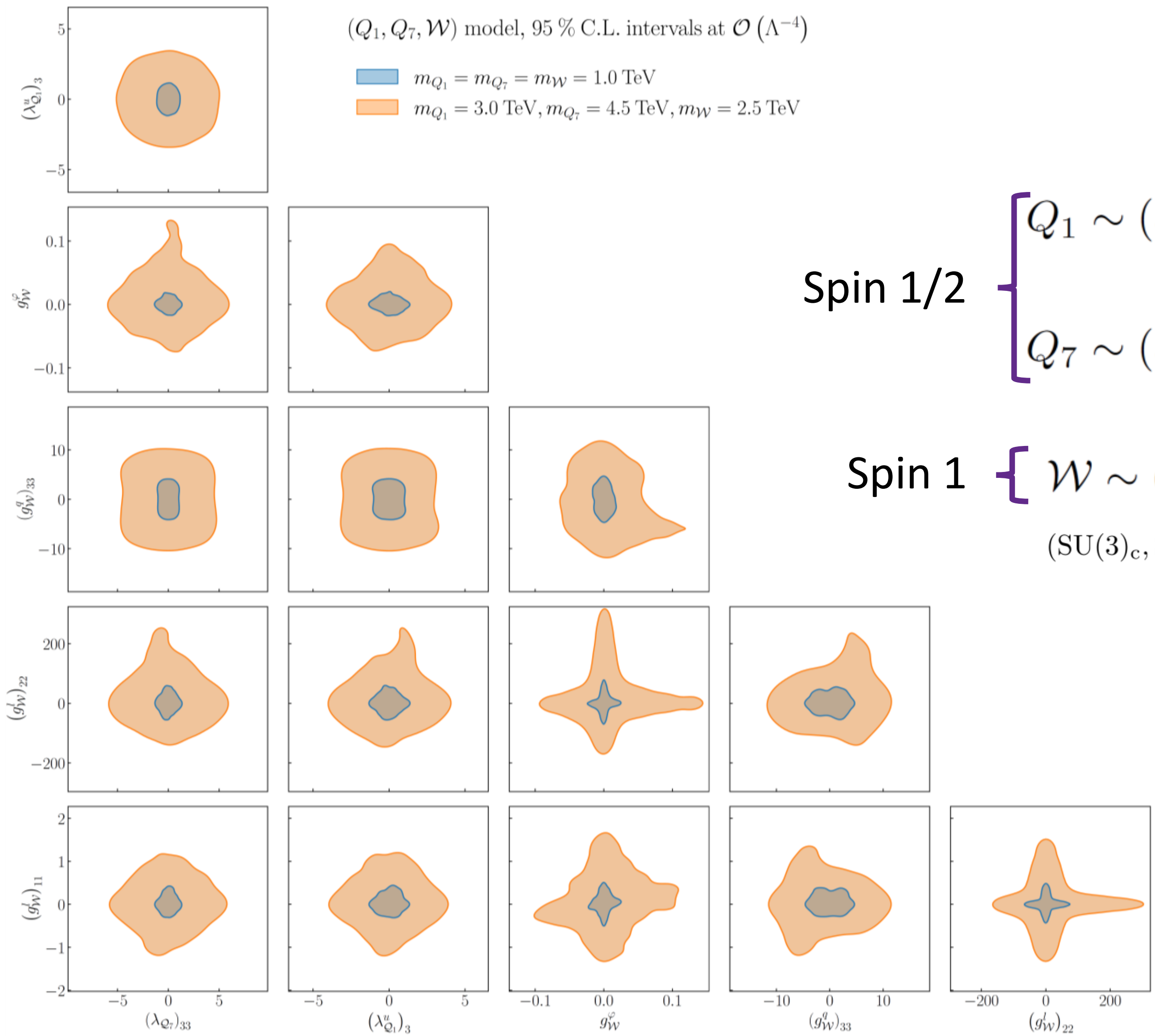
Couplings

Scalars		Fermions		Vectors	
Model	UV couplings	Model	UV couplings	Model	UV couplings
$\mathcal{S}$	$\kappa_{\mathcal{S}}$	N	$(\lambda_N^e)_3$	$\mathcal{B}$	$(g_B^u)_{33}$, $(g_B^q)_{33}$, g_B^{φ},
ϕ	λ_ϕ, $(y_\phi^u)_{33}$	E	$(\lambda_E)_3$		$(g_B^e)_{11}$, $(g_B^e)_{22}$, $(g_B^e)_{33}$,
Ξ	κ_Ξ	Δ_1	$(\lambda_{\Delta_1})_3$		$\left(g_B^\ell\right)_{22}$, $\left(g_B^\ell\right)_{33}$
Ξ_1	κ_{Ξ_1}	Δ_3	$(\lambda_{\Delta_3})_3$	$\mathcal{B}_1$	$g_{B_1}^{\varphi}$
ω_1	$(y_{\omega_1}^{qq})_{33}$	Σ	$(\lambda_\Sigma)_3$	$\mathcal{W}$	$\left(g_{\mathcal{W}}^l\right)_{11} = 2\left(g_{\mathcal{W}}^l\right)_{22}$, $\left(g_{\mathcal{W}}^l\right)_{33}$
ω_4	$(y_{\omega_4}^{uu})_{33}$	Σ_1	$(\lambda_{\Sigma_1})_3$		$g_{\mathcal{W}}^{\varphi}$, $(g_{\mathcal{W}}^q)_{33}$
ζ	$\left(y_\zeta^{qq}\right)_{33}$	U	$(\lambda_U)_3$	$\mathcal{W}_1$	$g_{\mathcal{W}_1}^{\varphi}$
Ω_1	$\left(y_{\Omega_1}^{qq}\right)_{33}$	D	$(\lambda_D)_3$	$\mathcal{G}$	$\left(g_{\mathcal{G}}^q\right)_{33}$, $(g_{\mathcal{G}}^u)_{33}$
Ω_4	$(y_{\Omega_4})_{33}$	Q_1	$\left(\lambda_{\mathcal{Q}_1}^u\right)_3$		
Υ	$(y_\Upsilon)_{33}$	Q_7	$(\lambda_{\mathcal{Q}_7})_3$	$\mathcal{H}$	$(g_{\mathcal{H}})_{33}$
Φ	$(y_\Phi^{qu})_{33}$	T_1	$(\lambda_{T_1})_3$	$\mathcal{Q}_5$	$\left(g_{\mathcal{Q}_5}^{uq}\right)_{33}$
		T_2	$(\lambda_{T_2})_3$	$\mathcal{Y}_5$	$(g_{\mathcal{Y}_5})_{33}$

Dataset

Category	Processes	$n_{\rm dat}$ SMEFiT2.0	SMEFiT3.0
Top quark production	$t\bar{t}+X$	94	115
	$t\bar{t}Z$, $t\bar{t}W$	14	21
	$t\bar{t}\gamma$	-	2
	single top (inclusive)	27	28
	tZ, tW	9	13
	$t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$	6	12
	Total	**150**	**191**
Higgs production and decay	Run I signal strengths	22	22
	Run II signal strengths	40	36 (*)
	Run II, differential distributions & STXS	35	71
	Total	**97**	**129**
Diboson production	LEP-2	40	40
	LHC	30	41
	Total	**70**	**81**
EWPOs	LEP-2	-	44
Baseline dataset	**Total**	**317**	**445**

Multi-particle models at tree level



Spin 1/2 $\begin{cases} \mathcal{Q}_1 \sim (3,2)_{1/6} \\ \mathcal{Q}_7 \sim (3,2)_{7/6} \end{cases}$

Spin 1 $\{ \mathcal{W} \sim (1,3)_0$

$(\mathrm{SU}(3)_c, \mathrm{SU}(2)_L)_{\mathrm{U}(1)_Y}$

Dataset: SMEFiT 2.0 + EWPOs