Towards a systematic UV interpretation of global fits

HEFT Workshop 2022

FTAE, Universidad de Granada

16 June 2022

Granada, Spain

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arXiv 22XX.ZZZYY

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Why global fits?

- Need to assess deviations in several observables.
- SMEFT offers a common interpretation to them in a more model-independent way.
- Large number of parameters require broad dataset.
- A truly global fit would be a key piece in the legacy of (HL-)LHC
- However, simple UV models allow us to interpret more easily the results.

Fitmaker — arXiv: 2012.02779

SMEFiT — arXiv: 2105.00006

SFitter — arXiv: 2108.01094

No interpretation in terms of UV models yet!

The SMEFiT framework

- SMEFT at dimension 6, Warsaw-like basis.
- Datasets: Top quark production, Higgs production and decay, Run II diboson production, LEP WW production, EWPO (approx.).
- State-of-the-art theoretical predictions:
  - SM at NNLO QCD with NLO EW where available.
  - SMEFT predictions with NLO QCD corrections (based on SMEFTatNLO), with interference and quadratic terms.
- Two complementary fitting strategies:
  - MCFit: MonteCarlo replica method, inspired by NNPDF analysis.
  - Nested Sampling: reconstructs the posterior by means of Bayesian inference.

UV assumptions

Any UV model boils down to a restriction of the EFT space.

Applying them to a general fit will fail in general, they must be considered from the beginning.

A simple example

Let's add to the SM another scalar: $\varphi \sim (1,2)_{1/2} \qquad \langle\varphi\rangle = 0$

General UV Lagrangian:

$$\mathcal{L}_{UV} = \mathcal{L}_{SM} + |D_\mu \varphi|^2 - m_\varphi^2 \varphi^\dagger \varphi$$
$$- \left((y_\varphi^e)_{ij} \varphi^\dagger \bar{e}_R^i \ell_L^j + (y_\varphi^d)_{ij} \varphi^\dagger \bar{d}_R^i q_L^j + (y_\varphi^u)_{ij} \varphi^\dagger i\sigma_2 \bar{q}_L^{T,j} u_R^j + \lambda_\varphi \varphi^\dagger H |H|^2 + h.c. \right)$$

At tree-level, use Granada dictionary! (arXiv: 1711.10391)

We can perform the fit with any one-particle SM extension in there.

Tree-level matching

Flavour symmetry:

$$\mathrm{U}(2)_q \times \mathrm{U}(2)_u \times \mathrm{U}(3)_d \times \left(\mathrm{U}(1)_\ell \times \mathrm{U}(1)_e\right)^3 \; + \; \delta y_{b,c,\tau}$$

Enforced <u>at the level of WCs</u>, work out its meaning in terms of UV couplings.

For the example model we're using:

$$\frac{c_{Qt}^{(1)}}{\Lambda^2} = -\frac{\left(y^u_{\varphi,33}\right)^2}{6\,m_\varphi^2}, \qquad \frac{c_{Qt}^{(8)}}{\Lambda^2} = -\frac{\left(y^u_{\varphi,33}\right)^2}{m_\varphi^2}, \qquad \frac{c_{tH}}{\Lambda^2} = -\frac{y^u_{\varphi,33}\lambda_\varphi}{m_\varphi^2}$$

Why aren't more couplings allowed?

$$0 = \left(c^1_{quqd}\right)_{3333} \sim y^u_{\varphi,33}\, y^d_{\varphi,33}$$

$$0 = \left(c^1_{lequ}\right)_{3333} \sim y^u_{\varphi,33}\, y^e_{\varphi,33}$$

$$\rightarrow \quad y^d_{\varphi,33} = y^e_{\varphi,33} = 0$$

Simple constraints on WCs

$$\frac{c_{Qt}^{(1)}}{\Lambda^2} = -\frac{\left(y_{\varphi,33}^{u}\right)^2}{6\,m_\varphi^2}, \qquad \frac{c_{Qt}^{(8)}}{\Lambda^2} = -\frac{\left(y_{\varphi,33}^{u}\right)^2}{m_\varphi^2}, \qquad \frac{c_{tH}}{\Lambda^2} = -\frac{y_{\varphi,33}^{u}\lambda_\varphi}{m_\varphi^2}$$

Linear relations

$$\frac{c_{Qt}^{(8)}}{\Lambda^2} = 6\,\frac{c_{Qt}^{(1)}}{\Lambda^2}$$

Sign-definiteness

$$\frac{c_{Qt}^{(8)}}{\Lambda^2} = -\frac{\left(y_{\varphi,33}^{u}\right)^2}{m_\varphi^2} \leqslant 0$$

The fit is performed assuming all these constraints

Automatized computation for all models

Not so simple constraints on WCs

Relaxed flavour assumptions for the same model give:

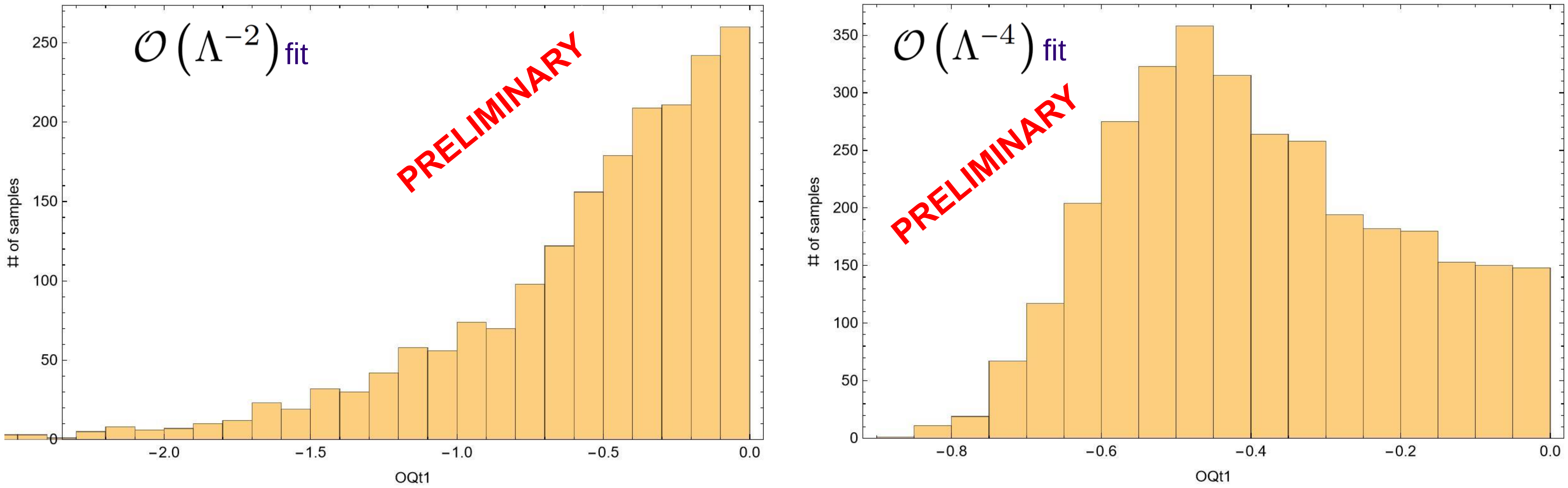
$$c_{qd}^{(1)} = -\frac{\left(\left(y_\varphi^d\right)_{33}\right)^2}{6\,m_\varphi^2} \qquad c_{Qt}^{(1)} = -\frac{\left(y_{\varphi,33}^u\right)^2}{6\,m_\varphi^2} \qquad c_{bH} = \frac{\lambda_\varphi \left(y_\varphi^d\right)_{33}}{m_\varphi^2} \qquad c_{tH} = -\frac{\lambda_\varphi y_{\varphi,33}^u}{m_\varphi^2}$$

$$\frac{c_{Qt}^{(1)}}{c_{qd}^{(1)}} = \left(\frac{c_{t\varphi}}{c_{b\varphi}}\right)^2$$

Relations like this are common when using 1-loop matching results.

Their computation is also automatized.

Sign-definite posteriors.



How to correctly compute the bounds with this distribution?

Credible Intervals for bounded distributions

α% C.I. $\begin{cases} \text{E.T.I.: } [\frac{100-\alpha}{2}^{\text{th}} \text{ percentile}, \frac{100+\alpha}{2}^{\text{th}} \text{ percentile}] \\ \text{H.D.I.: } \int_{x:p(x)>W} p(x)\,dx = \frac{\alpha}{100} \end{cases}$

E.T.I.: Equal-tailed interval

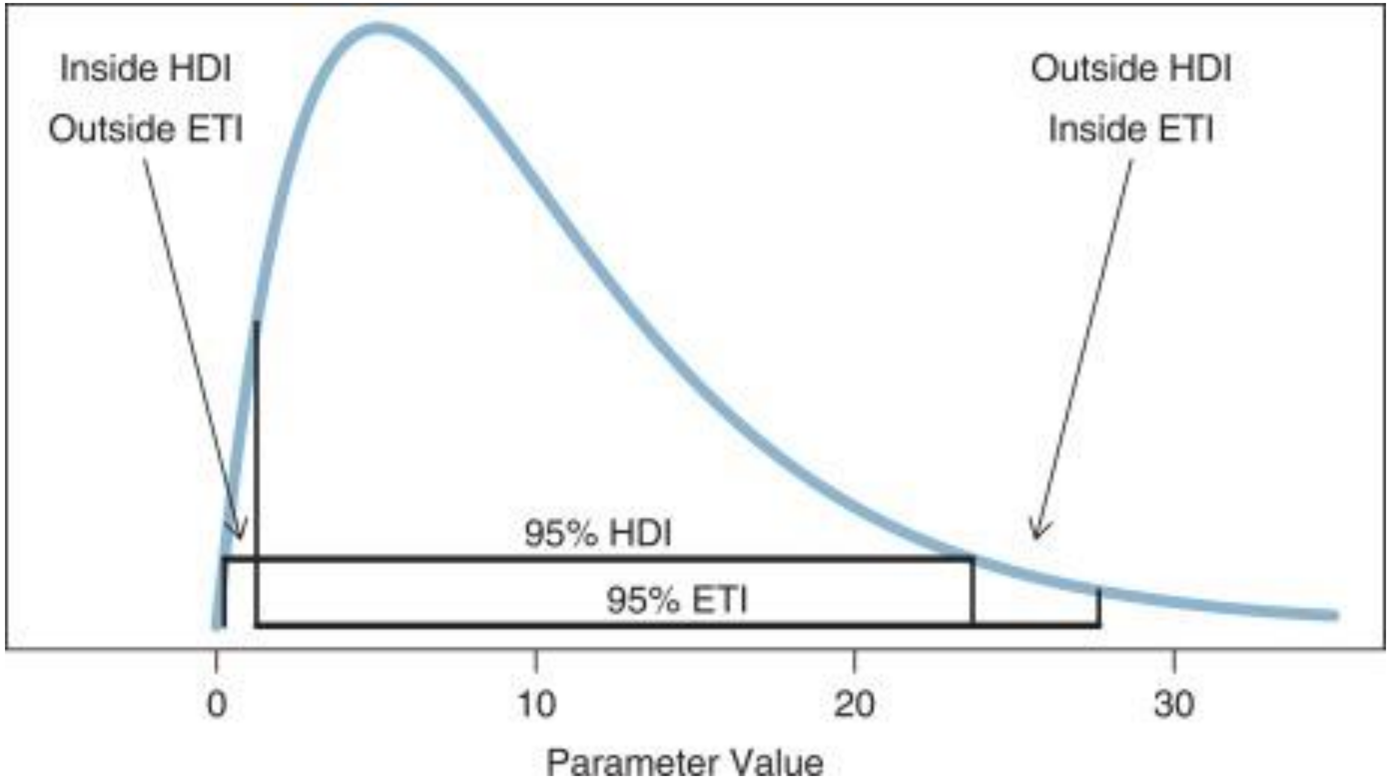
H.D.I.: Highest-density interval

Adapting the ETIs to bounded distributions

WC sign property	95% C.I. definition
Unrestricted	(2.5th percentile, 97.5th percentile)
Positive defined	[0, 95th percentile)
Negative defined	(5th percentile, 0]

Reference: J. K. Kruschke, *Doing Bayesian Data Analysis*, Second Ed., Academic Press (2015) Ch. 12, Pages 335-358.

Credible Intervals for bounded distributions

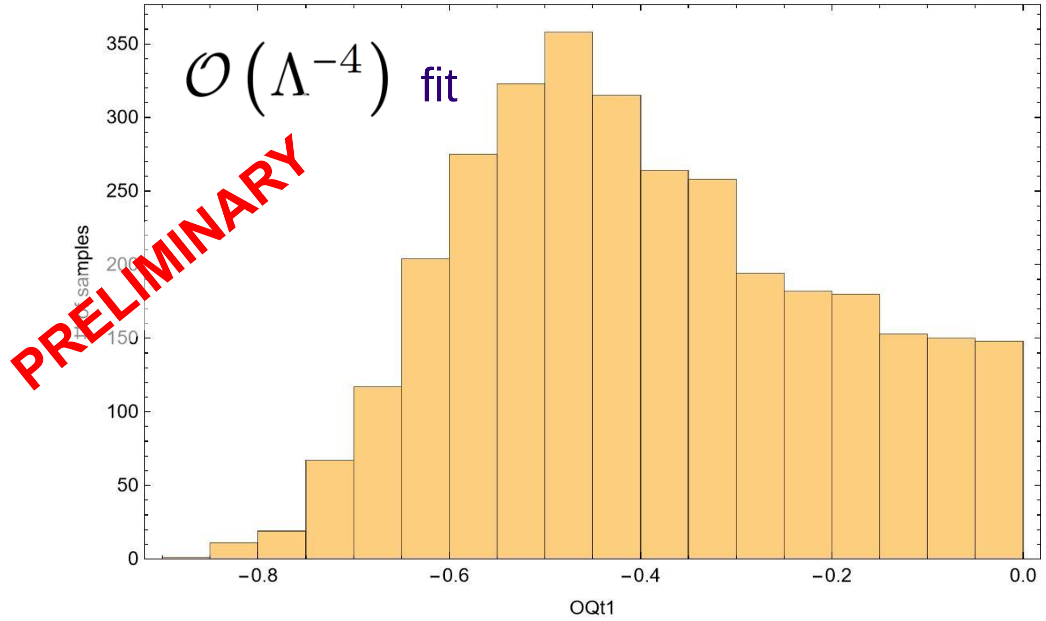


α% C.I.

- E.T.I.: $[\frac{100-\alpha}{2}^{\text{th}}$ percentile, $\frac{100+\alpha}{2}^{\text{th}}$ percentile$]$
- H.D.I.: $\int_{x:p(x)>W} p(x)\,dx = \frac{\alpha}{100}$

Image from: J. K. Kruschke, *Doing Bayesian Data Analysis*, Second Ed., Academic Press (2015) Ch. 12, Pages 335-358.

Credible Intervals for bounded distributions



Comparing results with ETIs and HDIs

PRELIMINARY

WC	68% C.I.	95% C.I.	68% HDI	95% HDI
$c_{Qt}^{(1)}$	$(-0.499, 0]$	$(-0.672, 0]$	$(-0.633, -0.238)$	$(-0.690, -0.017)$
$c_{Qt}^{(8)}$	$(-2.992, 0]$	$(-4.028, 0]$	$(-3.799, -1.43)$	$(-4.140, -0.100)$
$c_{t\varphi}$	$(-0.908, 0.063)$	$(-1.285, 0.352)$	$(-0.902, 0.042)$	$(-1.314, 0.352)$

What UV information can we extract?

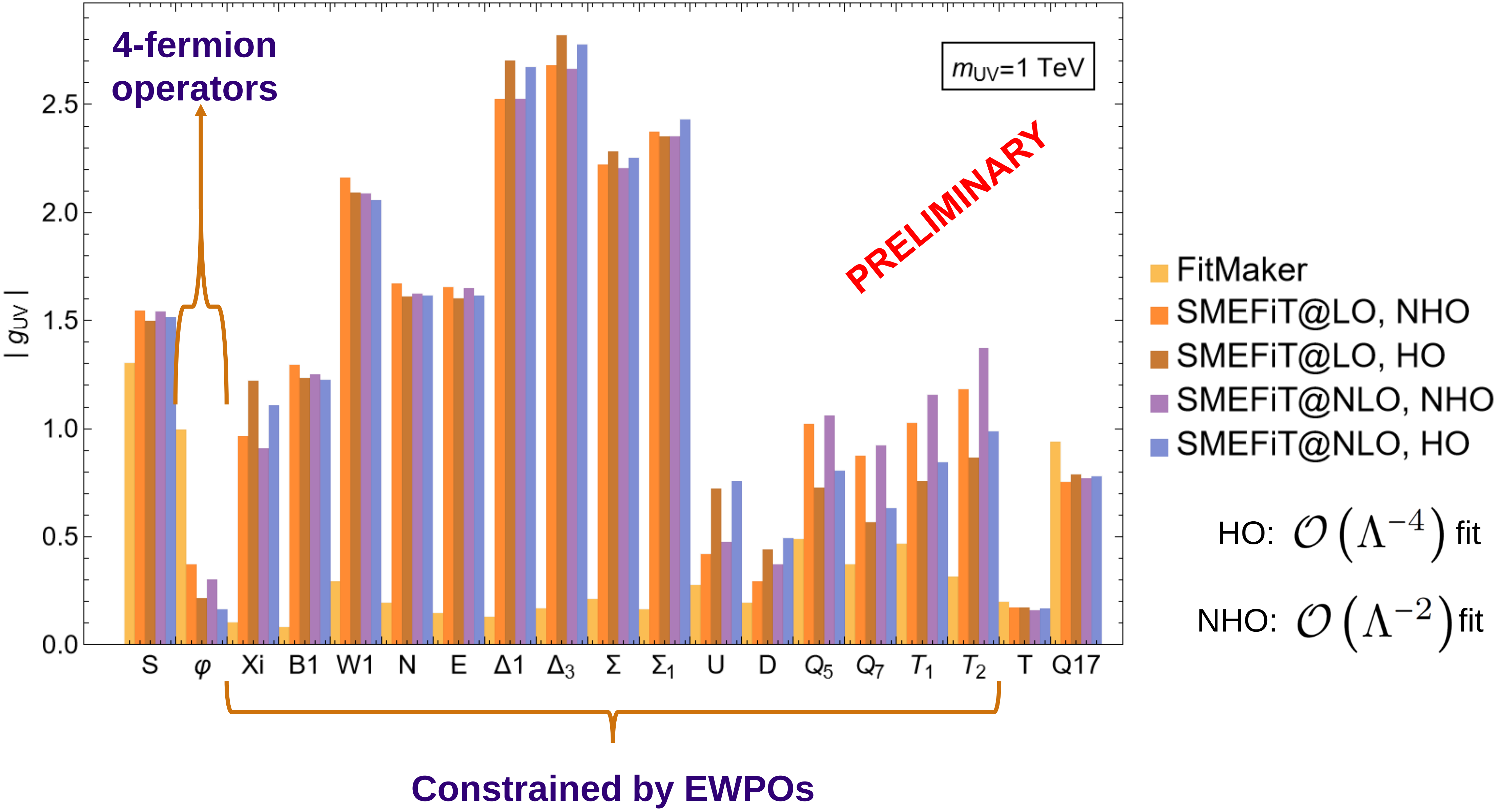
$$\frac{c_{Qt}^{(1)}}{\Lambda^2} = -\frac{\left(y^u_{\varphi,33}\right)^2}{6\, m_\varphi^2}, \qquad \frac{c_{Qt}^{(8)}}{\Lambda^2} = -\frac{\left(y^u_{\varphi,33}\right)^2}{m_\varphi^2}, \qquad \frac{c_{tH}}{\Lambda^2} = -\frac{y^u_{\varphi,33}\lambda_\varphi}{m_\varphi^2}$$

$$\left|y^u_{\varphi,33}\right|, \qquad \lambda_\varphi \frac{y^u_{\varphi,33}}{\left|y^u_{\varphi,33}\right|}$$

$$\mathrm{sgn}\left(\lambda_\varphi y^u_{\varphi,33}\right) \times \left|\lambda_\varphi\right|$$

Automatized computation.

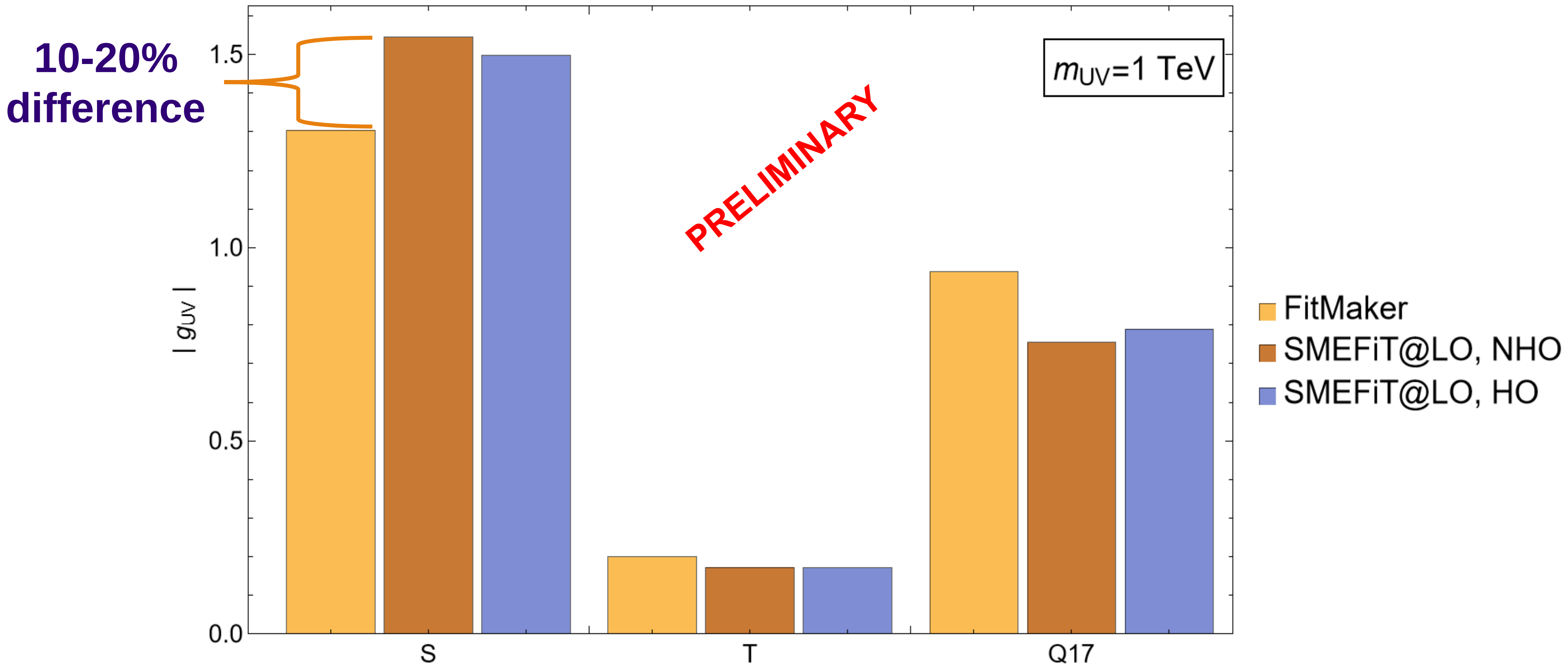
Comparison with FitMaker



HO: $\mathcal{O}\left(\Lambda^{-4}\right)$ fit

NHO: $\mathcal{O}\left(\Lambda^{-2}\right)$ fit

Comparison with FitMaker



Models for which the comparison is fair.

1-loop matching, our next milestone

- **Use of Matchmaker EFT to compute the 1-loop matching results.**
- **We have the matching results for a handful of models.**
- **A big difficulty could be imposing the relations among WCs…**

$$\left(y^u_{\varphi,33}\right)^2 = \frac{\left(\lambda_\varphi\, y^u_{\varphi,33}\right)^2}{\left(\lambda_\varphi\right)^2} \longrightarrow 0 = \left(-\frac{g_2^3}{320\, g_3^2}\frac{c_{tq}^{(8)}}{c_{WWW}}\right)\left(\frac{27}{64\, g_3^2}c_{tq}^{(8)} + \frac{720}{g_2^3}\frac{\left(18653761 + 93268136\pi^2\right)}{11658517}c_{WWW}\right)^2 + \frac{\left(c_{t\varphi} - \frac{725090343831}{1865864036231}\frac{1}{g_3^2\sqrt{2}}c_{tq}^{(8)} + \frac{4319\sqrt{2}}{12311}\frac{g_1^4+6g_2^4}{g_2^3}c_{WWW} + \frac{17276\sqrt{2}}{36933}c_{\varphi d}\right)^2}{192\left(\frac{g_1^4}{138240} + \frac{g_2^4}{46080}\right) + \frac{g_2^3}{540}\frac{c_{\varphi d}}{c_{WWW}}},$$

- **But we're woking on an alternative route!**

Conclusion and outlook

- Volume of data calls for general and automatized analysis/fitting frameworks.
- The inclusion of UV models helps to understand the meaning of the fits.
- SMEFiT is on the way towards a very general and automatized framework to do this.
- The implementation with tree-level matching is mostly ready.
- The 1-loop matching case will be ready soon.
- The inclusion of EWPOs in SMEFiT is a pressing issue.

Thank you for your attention

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