Towards a systematic UV interpretation of global fits

HEFT Workshop 2022

FTAE, Universidad de Granada

16 June 2022

Granada, Spain

Alejo N. Rossia

Department of Physics and Astronomy
University of Manchester

With Giacomo Magni, Juan Rojo and Eleni Vryonidou.

arXiv 22XX.ZZZYY

MANCHESTER 1824

The University of Manchester

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

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.

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	SMEFiT	SFitter
arXiv: 2012.02779	arXiv: 2105.00006	arXiv: 2108.01094

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.

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: $\varphi \sim (1,2)_{1/2}$ $\quad \langle \varphi \rangle = 0$

General UV Lagrangian:

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

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:

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

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

Tree-level matching

Flavour symmetry:

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

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

For the example model we're using:

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

Tree-level matching

Flavour symmetry:

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

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?

$$y^d_{\varphi,33}$$

$$y^e_{\varphi,33}$$

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 at the level of WCs, 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?

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

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

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

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:

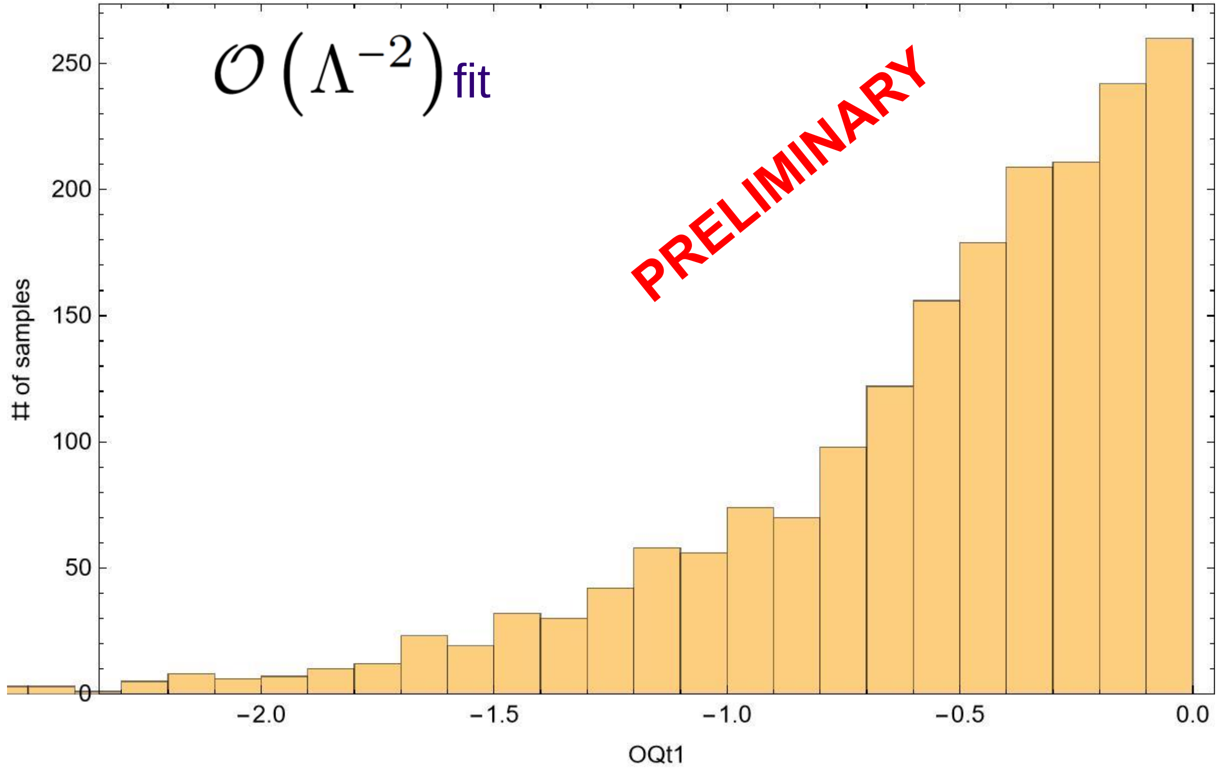
$$c_{qd}^{(1)} = -\frac{\left(\left(y_\varphi^d\right)_{33}\right)^2}{6\, m_\varphi^2} \quad c_{Qt}^{(1)} = -\frac{\left(y_{\varphi,33}^u\right)^2}{6\, m_\varphi^2} \quad c_{bH} = \frac{\lambda_\varphi \left(y_\varphi^d\right)_{33}}{m_\varphi^2} \quad c_{tH} = -\frac{\lambda_\varphi y_{\varphi,33}^u}{m_\varphi^2}$$

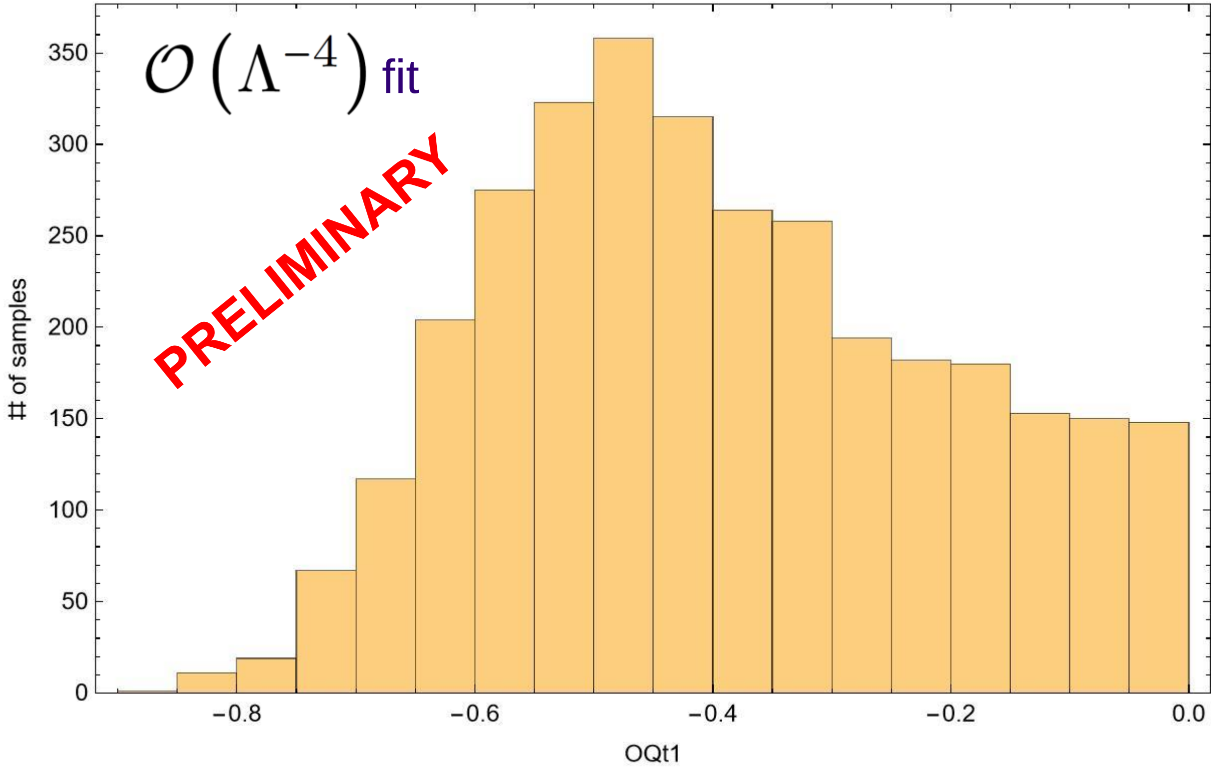
$$\frac{c_{Qt}^{(1)}}{c_{qd}^{(1)}} = \left(\frac{c_{t\varphi}}{c_{b\varphi}}\right)^2$$

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

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

E.T.I.: Equal-tailed interval

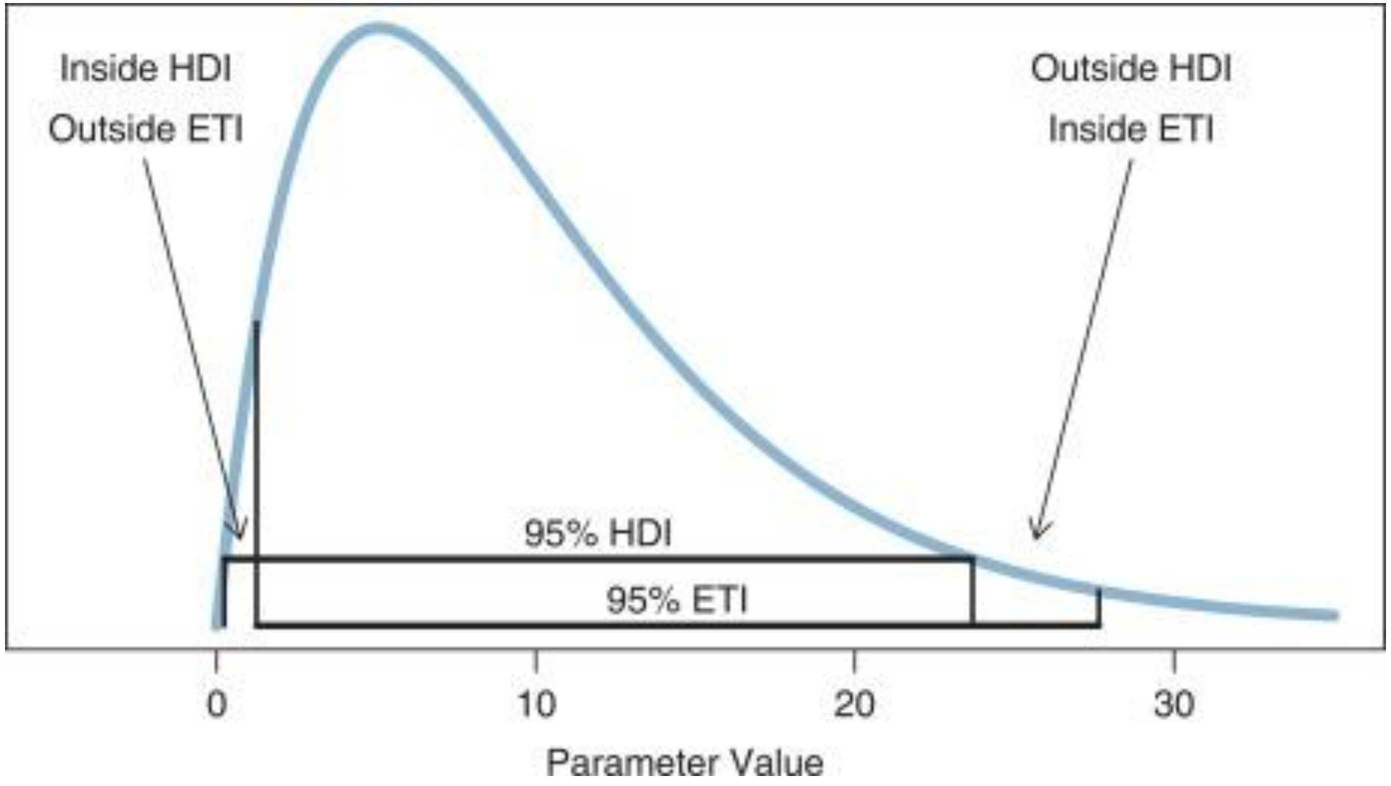
H.D.I.: Highest-density interval

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

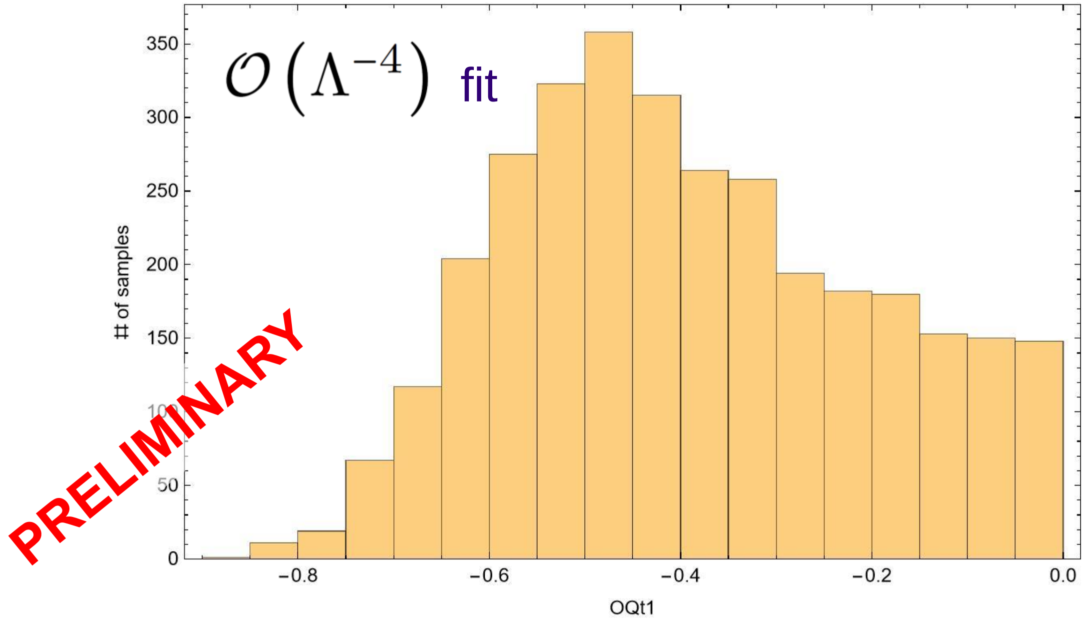


α% C.I.

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

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?

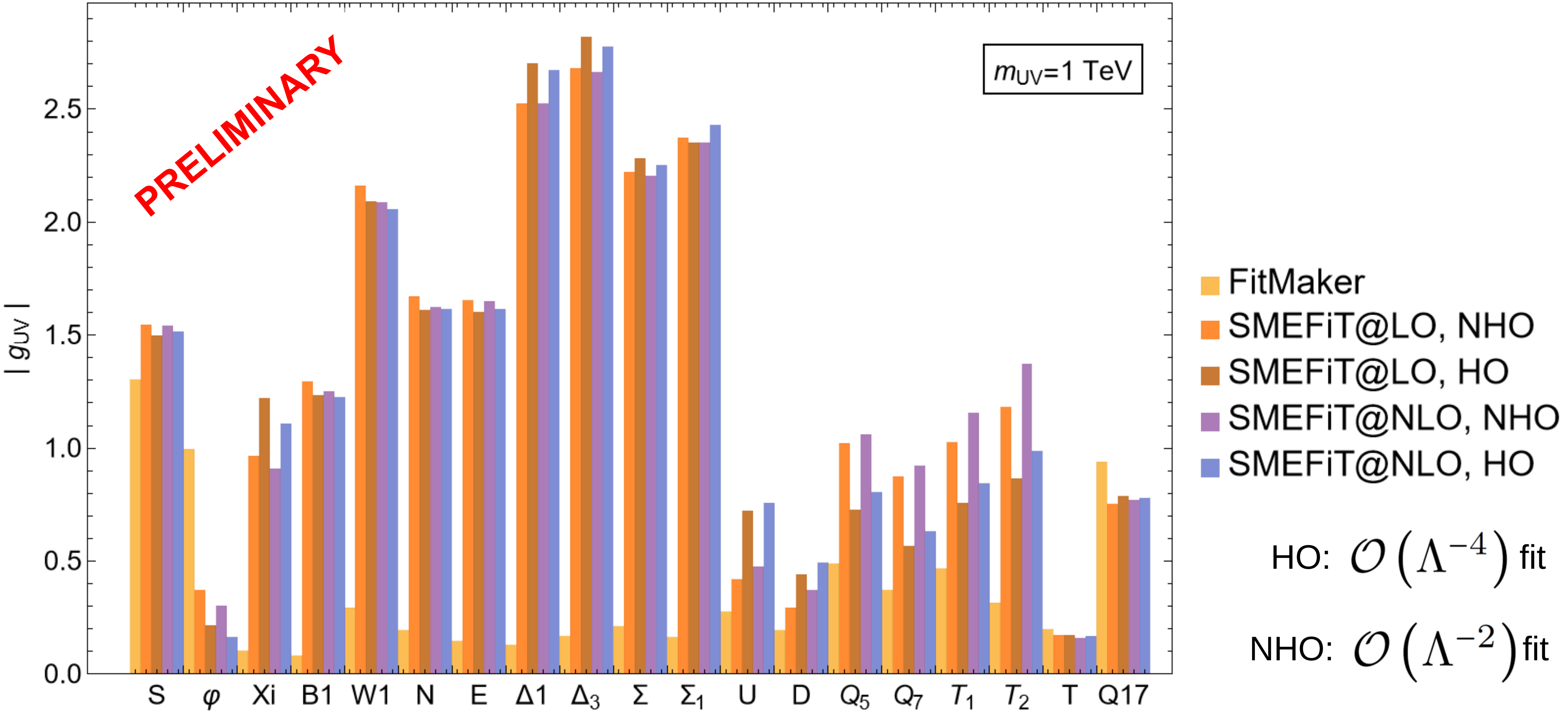
$$\frac{c_{Qt}^{(1)}}{\Lambda^2} = -\frac{\left(y_{\varphi,33}^{u}\right)^2}{6\,m_\varphi^2}, \qquad \frac{c_{Qt}^{(8)}}{\Lambda^2} = -\frac{\left(y_{\varphi,33}^{u}\right)^2}{m_\varphi^2}, \qquad \frac{c_{tH}}{\Lambda^2} = -\frac{y_{\varphi,33}^{u}\lambda_\varphi}{m_\varphi^2}$$

$$\left|y_{\varphi,33}^{u}\right|, \qquad \lambda_\varphi \frac{y_{\varphi,33}^{u}}{\left|y_{\varphi,33}^{u}\right|}$$

$$\operatorname{sgn}\left(\lambda_\varphi y_{\varphi,33}^{u}\right) \times |\lambda_\varphi|$$

Automatized computation.

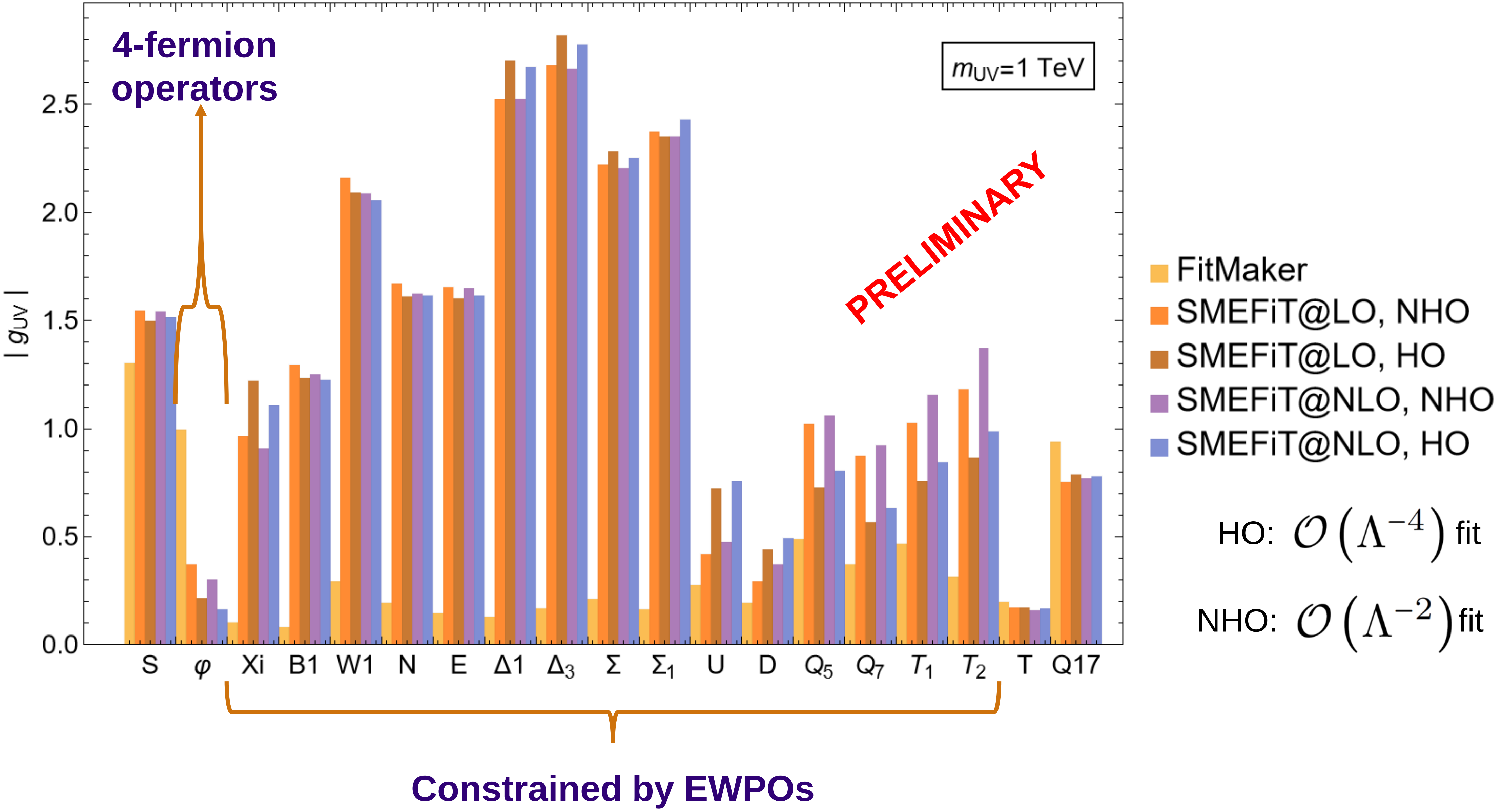
Comparison with FitMaker



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

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

Comparison with FitMaker

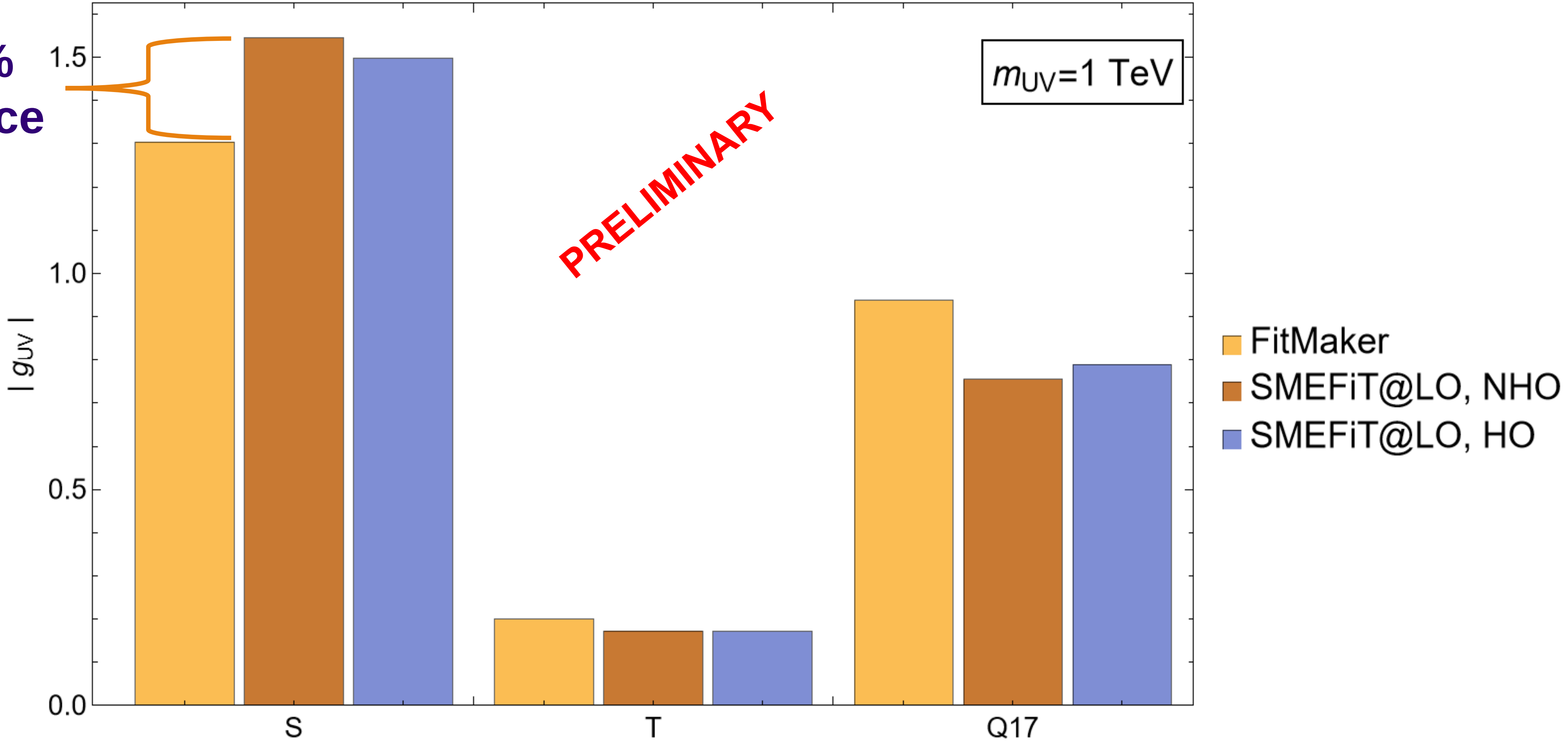


HO: $\mathcal{O}\left(\Lambda^{-4}\right)$ fit

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

Comparison with FitMaker

10-20% difference



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

Contact

The University of Manchester
Oxford Road
M13 9PL
Manchester, UK
www.manchester.ac.uk

Alejo N. Rossia
HEP Theory Group – Dept. Of Physics and Astronomy
E-mail: alejo dot rossia at manchester dot ac dot uk
http://www.hep.man.ac.uk/