SMEFiT 3.0 and beyond:
Future colliders, UV models, and RGE effects

SMEFT-Tools 2025

Mainz, Germany

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On behalf of the SMEFiT Collaboration

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Instituto Nazionale di Fisica Nucleare INFN Sezione di Padova

UNIVERSITÀ DEGLI STUDI DI PADOVA

Based on:

[2309.04523] JHEP 01 (2024) 179 (w/ J. ter Hoeve, G. Magni, J. Rojo, and E. Vryonidou)

[2404.12809] JHEP 09 (2024) 091 (w/ E. Celada, T. Giani, J. ter Hoeve, L. Mantani, J. Rojo, M. Thomas and E. Vryonidou)

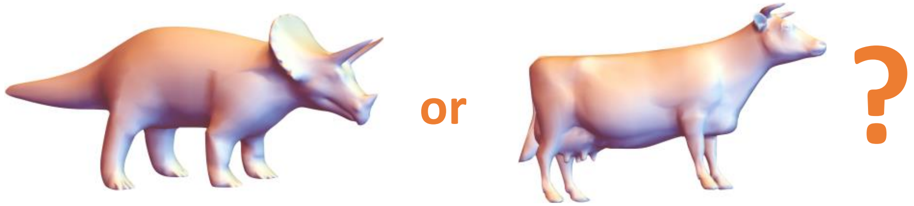
[2502.xxyyzz] Connecting Scales: RGE Effects in the SMEFT from LHC to Future Colliders (w/ J. ter Hoeve, L. Mantani, J. Rojo, and E. Vryonidou)

[2503.xxyyzz] From Coupling Modifiers and the SMEFT to UV-Physics at Future Colliders (w/ T. Armadillo, E. Celada, J. ter Hoeve, F. Maltoni, L. Mantani, J. Rojo, S. Tentori, M. Thomas, and E. Vryonidou)

The Standard Model EFT (SMEFT)

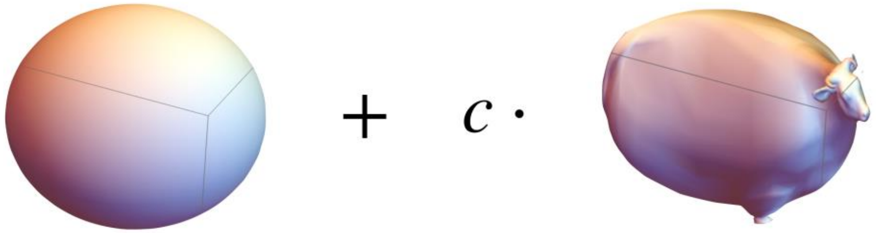
E

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



Λ

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \ldots$$



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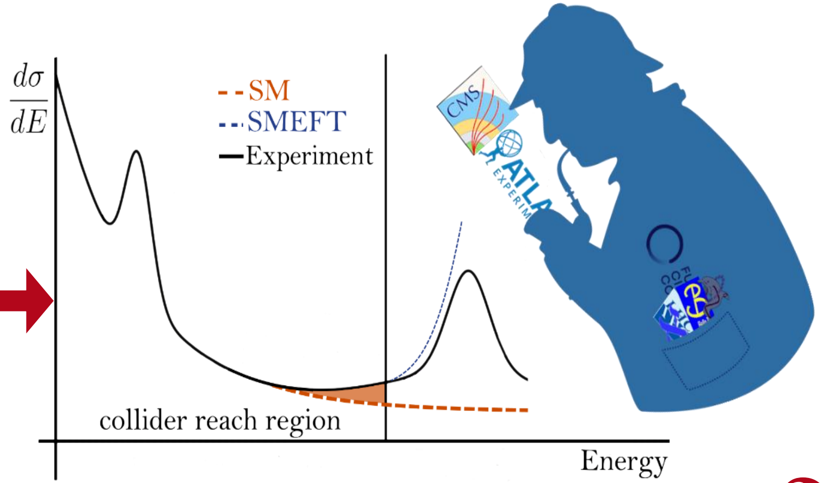
(Mostly) Model-independent phenomenology

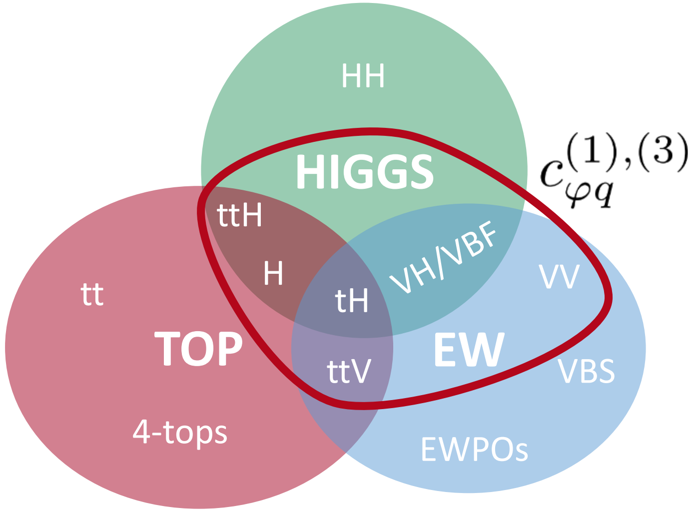
v

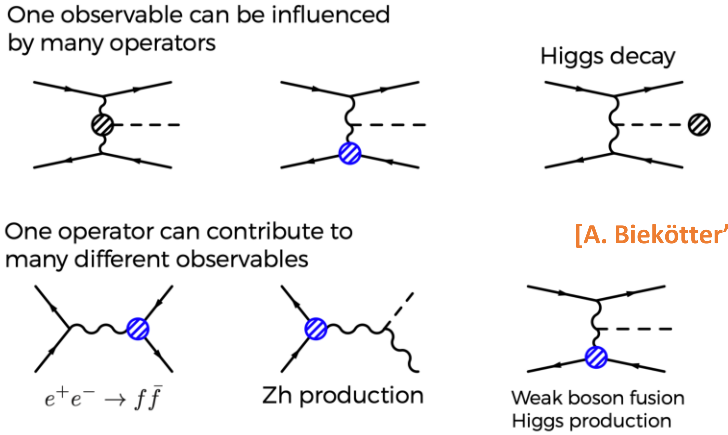
How we look for BSM with SMEFT process by process



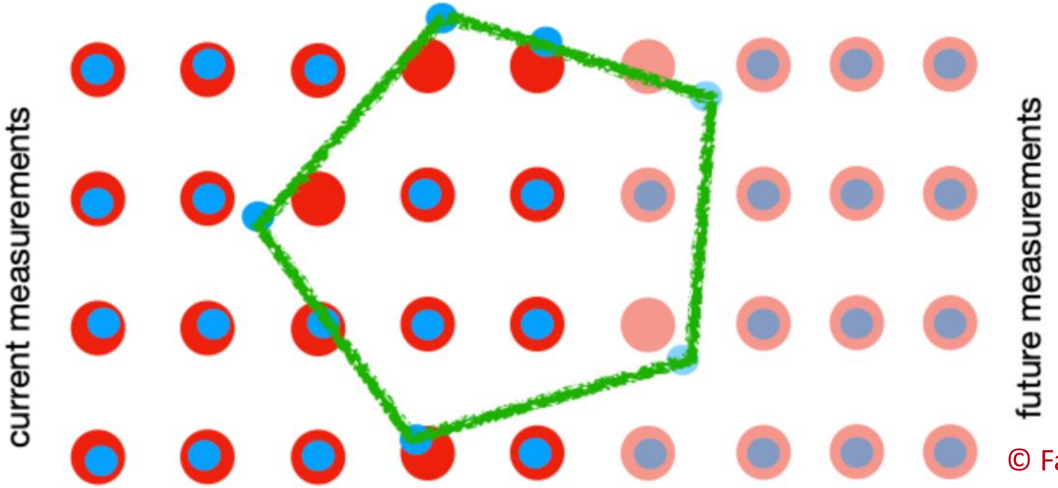
Why Global fits of SMEFT

Correlations, correlations everywhere…





[A. Biekötter's seminar]



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An overview of SMEFiT

SMEFiT In a nutshell

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

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

THEORY

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

DATA

LEP+SLD: EWPOs, WW, BrW…
LHC: Higgs, top, VV... Mostly Run-2
445 (+1) data points!

METHOD

Bayesian **Nested Sampling**
Analytic **Linear fit**
MC replicas

SMEFiT

TOOLS

PCA, Fisher, closure tests, documentation.

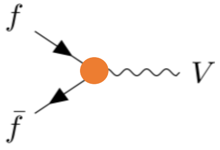
$$p\left(c_i \middle| D\right)$$

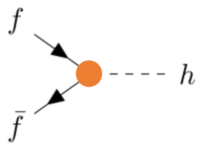
Posterior on WCs

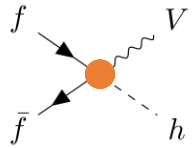
Operator basis

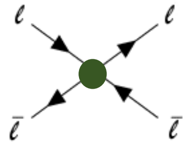
Slide concept from E. Celada

- Warsaw basis with rotations.
- Flavour sym.: $U(2)_q \times U(3)_d \times U(2)_u \times (U(1)_l \times U(1)_e)^3 + y^{SM}_{b,c,\tau} + c_{\varphi(b,c,\tau)}$



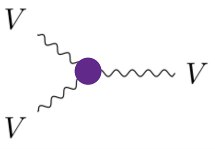


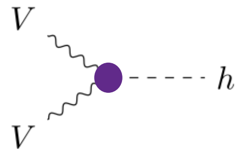


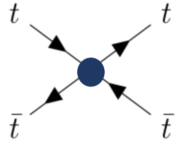


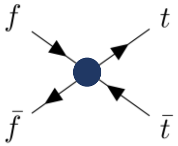
Operator	Coefficient	Definition	Operator	Coefficient	Definition
		3rd generation quarks			
$\mathcal{O}^{(1)}_{\varphi Q}$	$c^{(1)}_{\varphi Q}$ (*)	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{Q}\gamma^\mu Q)$	$\mathcal{O}_{tW}$	c_{tW}	$i(\bar{Q}\tau^{\mu\nu}\tau_I t)\tilde{\varphi}W^I_{\mu\nu} + \text{h.c.}$
$\mathcal{O}^{(3)}_{\varphi Q}$	$c^{(3)}_{\varphi Q}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \tau_I \varphi)(\bar{Q}\gamma^\mu \tau^I Q)$	$\mathcal{O}_{tB}$	c_{tB} (*)	$i(\bar{Q}\tau^{\mu\nu} t)\tilde{\varphi}B_{\mu\nu} + \text{h.c.}$
$\mathcal{O}_{\varphi t}$	$c_{\varphi t}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{t}\gamma^\mu t)$	$\mathcal{O}_{tG}$	c_{tG}	$ig_S(\bar{Q}\tau^{\mu\nu}T_A t)\tilde{\varphi}G^A_{\mu\nu} + \text{h.c.}$
$\mathcal{O}_{t\varphi}$	$c_{t\varphi}$	$(\varphi^\dagger\varphi)\bar{Q}t\tilde{\varphi} + \text{h.c.}$	$\mathcal{O}_{b\varphi}$	$c_{b\varphi}$	$(\varphi^\dagger\varphi)\bar{Q}b\varphi + \text{h.c.}$
		1st, 2nd generation quarks			
$\mathcal{O}^{(1)}_{\varphi q}$	$c^{(1)}_{\varphi q}$ (*)	$\sum_{i=1,2} i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{q}_i\gamma^\mu q_i)$	$\mathcal{O}_{\varphi d}$	$c_{\varphi d}$	$\sum_{i=1,2,3} i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{d}_i\gamma^\mu d_i)$
$\mathcal{O}^{(3)}_{\varphi q}$	$c^{(3)}_{\varphi q}$	$\sum_{i=1,2} i(\varphi^\dagger \overleftrightarrow{D}_\mu \tau_I\varphi)(\bar{q}_i\gamma^\mu\tau^I q_i)$	$\mathcal{O}_{c\varphi}$	$c_{c\varphi}$	$(\varphi^\dagger\varphi)\bar{q}_2 c\tilde{\varphi} + \text{h.c.}$
$\mathcal{O}_{\varphi u}$	$c_{\varphi u}$	$\sum_{i=1,2} i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{u}_i\gamma^\mu u_i)$			
		two-leptons			
$\mathcal{O}_{\varphi\ell_i}$	$c_{\varphi\ell_i}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{\ell}_i\gamma^\mu \ell_i)$	$\mathcal{O}_{\varphi\mu}$	$c_{\varphi\mu}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{\mu}\gamma^\mu \mu)$
$\mathcal{O}^{(3)}_{\varphi\ell_i}$	$c^{(3)}_{\varphi\ell_i}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \tau_I\varphi)(\bar{\ell}_i\gamma^\mu\tau^I \ell_i)$	$\mathcal{O}_{\varphi\tau}$	$c_{\varphi\tau}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{\tau}\gamma^\mu \tau)$
$\mathcal{O}_{\varphi e}$	$c_{\varphi e}$	$i(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{e}\gamma^\mu e)$	$\mathcal{O}_{\tau\varphi}$	$c_{\tau\varphi}$	$(\varphi^\dagger\varphi)\bar{\ell}_3\tau\varphi + \text{h.c.}$
		four-leptons			
$\mathcal{O}_{\ell\ell}$	$c_{\ell\ell}$	$(\bar{\ell}_1\gamma_\mu\ell_2)(\bar{\ell}_2\gamma^\mu\ell_1)$			

Operator	Coefficient	Definition	Operator	Coefficient	Definition
$\mathcal{O}_{\varphi G}$	$c_{\varphi G}$	$(\varphi^\dagger\varphi)G^{\mu\nu}_A G^A_{\mu\nu}$	$\mathcal{O}_{\varphi\Box}$	$c_{\varphi\Box}$	$\partial_\mu(\varphi^\dagger\varphi)\partial^\mu(\varphi^\dagger\varphi)$
$\mathcal{O}_{\varphi B}$	$c_{\varphi B}$	$(\varphi^\dagger\varphi)B^{\mu\nu}B_{\mu\nu}$	$\mathcal{O}_{\varphi D}$	$c_{\varphi D}$	$(\varphi^\dagger D^\mu\varphi)^\dagger(\varphi^\dagger D_\mu\varphi)$
$\mathcal{O}_{\varphi W}$	$c_{\varphi W}$	$(\varphi^\dagger\varphi)W^{\mu\nu}_I W^I_{\mu\nu}$	$\mathcal{O}_W$	c_{WWW}	$\epsilon_{IJK}W^I_{\mu\nu}W^{J,\nu\rho}W^{K,\mu}_\rho$
$\mathcal{O}_{\varphi WB}$	$c_{\varphi WB}$	$(\varphi^\dagger\tau_I\varphi)B^{\mu\nu}W^I_{\mu\nu}$			









DoF	Definition (in Warsaw basis notation)	DoF	Definition (in Warsaw basis notation)
c^1_{QQ}	$2c^{1(3333)}_{qq} - \frac{2}{3}c^{3(3333)}_{qq}$	c^8_{QQ}	$8c^{3(3333)}_{qq}$
c^1_{Qt}	$c^{1(3333)}_{qu}$	c^8_{Qt}	$c^{8(3333)}_{qu}$
$c^{1,8}_{Qq}$	$c^{1(i33i)}_{qq} + 3c^{3(i33i)}_{qq}$	$c^{1,1}_{Qq}$	$c^{1(ii33)}_{qq} + \frac{1}{6}c^{1(i33i)}_{qq} + \frac{1}{2}c^{3(i33i)}_{qq}$
$c^{3,8}_{Qq}$	$c^{1(i33i)}_{qq} - c^{3(i33i)}_{qq}$	$c^{3,1}_{Qq}$	$c^{3(ii33)}_{qq} + \frac{1}{6}(c^{1(i33i)}_{qq} - c^{3(i33i)}_{qq})$
c^8_{tq}	$c^{8(ii33)}_{qu}$	c^1_{tq}	$c^{1(ii33)}_{qu}$
c^8_{tu}	$2c^{(i33i)}_{uu}$	c^1_{tu}	$c^{(ii33)}_{uu} + \frac{1}{3}c^{(i33i)}_{uu}$
c^8_{Qu}	$c^{8(33ii)}_{qu}$	c^1_{Qu}	$c^{1(33ii)}_{qu}$
c^8_{td}	$c^{8(33jj)}_{ud}$	c^1_{td}	$c^{1(33jj)}_{ud}$
c^8_{Qd}	$c^{8(33jj)}_{qd}$	c^1_{Qd}	$c^{1(33jj)}_{qd}$

Fit of 45 (50) WCs at the linear (quadratic) level

Università degli Studi di Padova

The likelihood

Slide concept from L. Mantani

Gaussian approximation

$$\mathrm{cov} = \mathrm{cov}_{\mathrm{th}} + \mathrm{cov}_{\mathrm{exp}}$$

$$-2\log\mathcal{L} = \frac{1}{n_{\mathrm{dat}}}\sum_{i,j=1}^{n_{\mathrm{dat}}}\left(\sigma_{i,\mathrm{SMEFT}}(c) - \sigma_{i,\mathrm{exp}}\right)\left(\mathrm{cov}^{-1}\right)_{ij}\left(\sigma_{j,\mathrm{SMEFT}}(c) - \sigma_{j,\mathrm{exp}}\right)$$

$\mathcal{O}(1/\Lambda^2)$ or $\mathcal{O}(1/\Lambda^4)$

Two recommended fit routines

Analytic linear fit

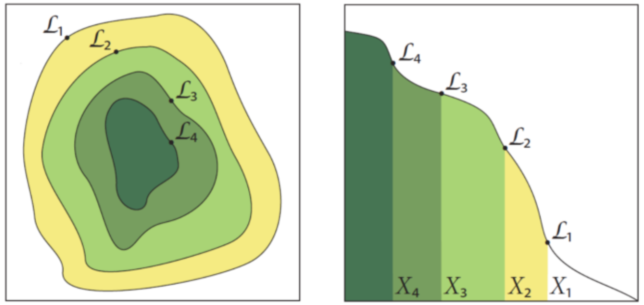
Bayesian Nested Sampling

$$\Sigma_C = (T_{eft} \cdot \Sigma_{exp}^{-1} \cdot T_{eft}^T)^{-1}$$

$$C_{MLE} = \Sigma_C \cdot T_{eft} \cdot \Sigma_{exp}^{-1} \cdot (y_{dat} - y_{SM})$$

Quick
Precise

Flexible
Versatile



Feroz, Hobson, Cameron, Pettitt [1306.2144]

Open-source code

Fitting code and database in 2 Github repositories

github.com/LHCfitNikhef/smefit_release

smefit_release Public

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main · 20 Branches · 4 Tags · Go to file · Add file · Code

jacoterh Merge pull request #115 from LHCfitNikhef/ordering_coeff_plots · 4de7005 · 2 days ago · 893 Commits

.github · reformatting all existing code · 2 months ago

About

SMEFiT a Standard Model Effective Field Theory fitter

Readme

SMEFiT

tests passing · codecov 42% · codefactor A

SMEFiT is a python program for Standard Model Effective Field Theory fits

Installation

To install smefit you can do:

```
pip install smefit
```

Installation from source using conda

You can install smefit from source using a conda environement. To install it you need a conda installation and run:

```
./install.sh -n <env_name='smefit_installation'>
```

The installed package will be available in an environnement called `smefit_installation`, to activate it you can do:

```
conda activate <env_name='smefit_installation'>
smefit -h
```

Running

The fitting code provide two equivalent fitting strategies. To run the code with `Nested Sampling` you can do:

```
smefit NS <path_to_runcard>
```

github.com/LHCfitNikhef/smefit_database

smefit_database Public

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main · 8 Branches · 0 Tags · Go to file · Add file · Code

LucaMantani Merge pull request #35 from LHCfitNikhef/move-opt-L0 · 89a4bb4 · last month · 185 Commits

.github · Merge branch 'main' into NLO-EW-ZH · last month

Documentation and results repo

lhcfitnikhef.github.io/smefit_release/

SMEFiT

Search docs

THEORY:
- Standard Model Effective Field Theory
- Fitting assumptions
- Nested Sampling
- Analytic solution
- The Monte Carlo replica method

DATA AND THEORY TABLES:
- Experimental data format
- Theory tables
- Construction of the fit covariance matrix
- Basis rotation
- Projections

FITTING CODE:
- Code structure
- How to run the code
- SMEFiT Tutorial

REPORTS:
- Report functions
- Produce a report
- Link to reports

Project description · View page source

Project description

SMEFiT is a Python package for global analyses of particle physics data in the framework of the Standard Model Effective Field Theory (SMEFT). The SMEFT represents a powerful model-independent framework to constrain, identify, and parametrize potential deviations with respect to the predictions of the Standard Model (SM). A particularly attractive feature of the SMEFT is its capability to systematically correlate deviations from the SM between different processes. The full exploitation of the SMEFT potential for indirect New Physics searches from precision measurements requires combining the information provided by the broadest possible dataset, namely carrying out extensive global analysis which is the main purpose of SMEFiT.

The SMEFiT framework has been used in the following **scientific publications**:

- *A Monte Carlo global analysis of the Standard Model Effective Field Theory: the top quark sector*, N. P. Hartland, F. Maltoni, E. R. Nocera, J. Rojo, E. Slade, E. Vryonidou, C. Zhang [HMN+19].
- *Constraining the SMEFT with Bayesian reweighting*, S. van Beek, E. R. Nocera, J. Rojo, and E. Slade [vBNRS19].
- *SMEFT analysis of vector boson scattering and diboson data from the LHC Run II* , J. Ethier, R. Gomez-Ambrosio, G. Magni, J. Rojo [EGAMR21].
- *Combined SMEFT interpretation of Higgs, diboson, and top quark data from the LHC*, J. Ethier, G.Magni, F. Maltoni, L. Mantani, E. R. Nocera, J. Rojo, E. Slade, E. Vryonidou, C. Zhang [EMM+21].
- *The automation of SMEFT-assisted constraints on UV-complete models*, J. ter Hoeve, G. Magni, J. Rojo, A. N. Rossia, E. Vryonidou [tHMR+23].
- *Mapping the SMEFT at High-Energy Colliders: from LEP and the (HL-)LHC to the FCC-ee*, E.Celada, T. Giani, J. ter Hoeve, L. Mantani, J. Rojo, A. N. Rossia, M. O. A. Thomas, E. Vryonidou [CGtH+24].

Results from these publications, including driver and analysis scripts, are available in the *Previous studies* section.

User-friendly input format

Slide concept from L. Mantani

$$\mathcal{O} = \mathcal{O}_{SM} + \frac{C_i}{\Lambda^2}\,\mathcal{O}_i^{INT} + \frac{C_i\,C_j}{\Lambda^4}\,\mathcal{O}_{ij}^{SQ}$$

THEORY

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

dataset_X.json


```json
{
    "best_sm": [3.0],
    "scales": [91.0],
    "theory_cov": [[1.0]],
    "LO": {"SM": 1.0, "Op1": -0.2, "Op1*Op1": 0.4},
    "NLO_QCD": {"SM": 2.0, "Op1": -0.3, "Op1*Op1": 0.6},
}
```


DATA

LEP+SLD: EWPOs, WW, BrW…
LHC: Higgs, top, VV... Mostly Run-2

dataset_X.yaml


```yaml
dataset_name: dataset_X
num_data: 1
num_sys: 1
data_central: 3.0
statistical_error: 1.0
systematics:
  - 1.5
sys_names: CORR
sys_type: ADD
```

User-friendly interface

```
alejorossia@vittiTCM75t:~$
alejorossia@vittiTCM75t:~$
alejorossia@vittiTCM75t:~$ smefit NS ./my_runcard.yaml
```

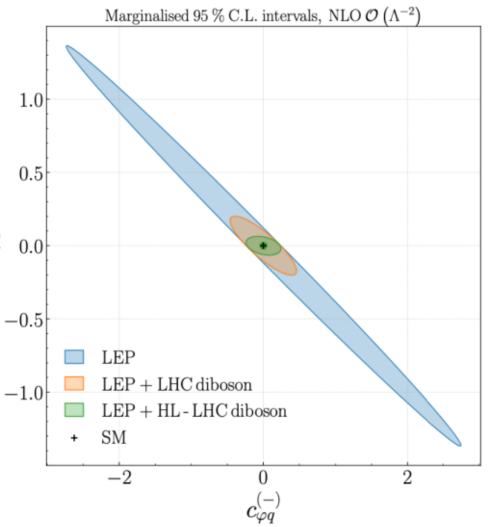
```
Commands:
  A        Get the analytic solution of the linear problem.
  MC       Run a fit with |MC|.
  NS       Run a fit with |NS| (Ultra Nest).
  POSTFIT  Run postfit selection over |MC| replicas.
  PREFIT   Run prefit: computes the SM chi2 as a check before fitting.
  PROJ     Compute projection for specified dataset
  R        Run a fit report.
  SCAN     Plot individual :math:`\chi^2` profiles for all the free...
```

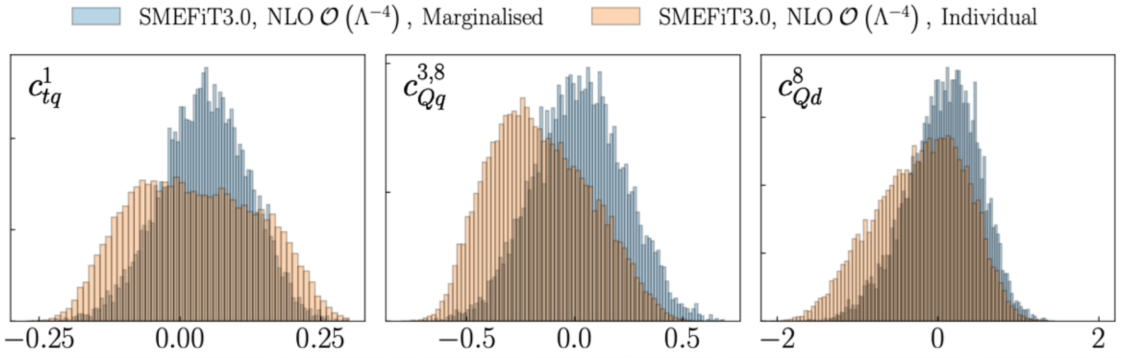
We also provide a tutorial!

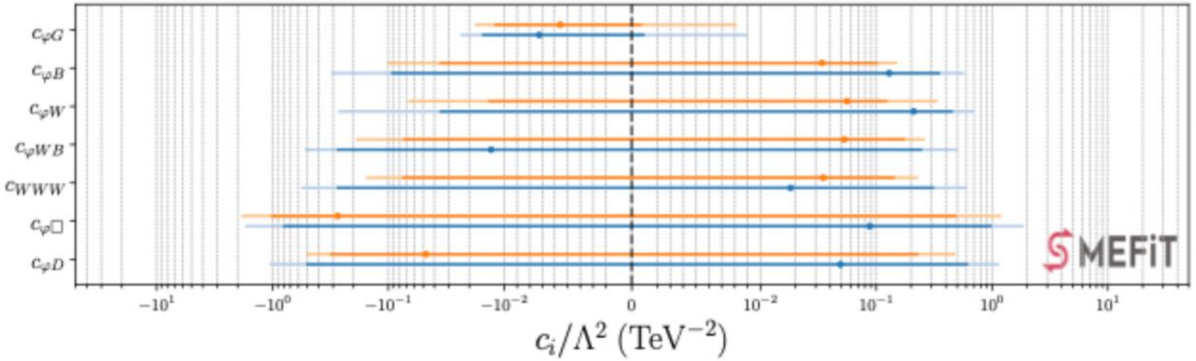
H: > My Drive > smefit > Talks > SMEFTools_2025 > ! my_runcard.yaml

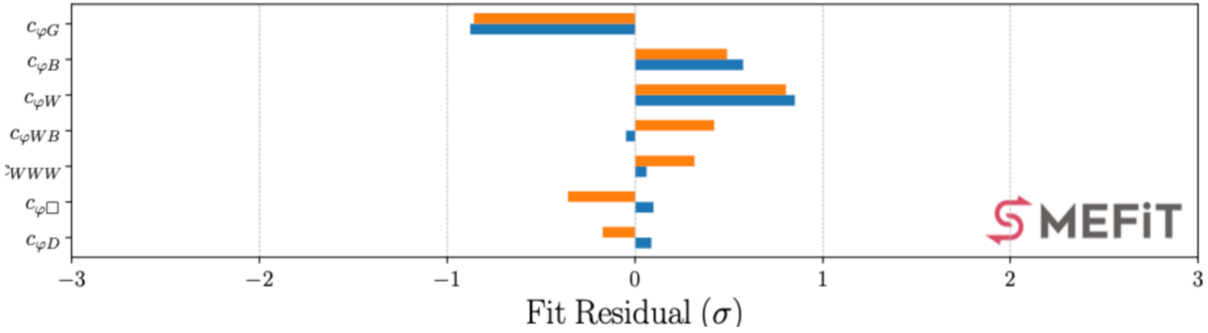
```yaml
# Input YAML configurations for SMEFiT code
result_ID: 241209_FCC_NLO_QUAD_GLOB_L0
# paths for results, data and predictions
result_path: /home/user/smefit_results
data_path: /home/user/smefit_database/commondata_projections_L0
theory_path: /home/user/smefit_database/theory
# Options
use_theory_covmat: True # Theory errors
use_t0: True # T0 prescription for systematic errors
float64: True # Higher-precision
use_quad: True # Whether to include the quadratic dependence on WCs
uv_couplings: False # True if we're fitting a UV model.
single_parameter_fits: False # True for fitting one coefficient at the time.
# NS settings
nlive: 200
#nsamples: 2000 # Replacement of nlive for single_parameter_fits
lepsilon: 0.0001
target_evidence_unc: 0.1
target_post_unc: 0.001
frac_remain: 0.01
# Datasets to include
datasets:
  - {name: dataset_1, order: NLO_QCD }
  - {name: dataset_2, order: NLO_EW }
  - {name: dataset_3, order: LO }
# Coefficients to fit and prior setting
coefficients:
  Op1: { 'min': -2, 'max': 2 }
  Op2: { 'min': -0.1, 'max': 0.1 }
# External likelihood
external_chi2:
  OptimalWW161:
    path: /home/user/smefit_database/external_chi2/optimal_observables/interface_oos.py
    scale: 161.0
# Basis rotation
rot_to_fit_basis: null
```

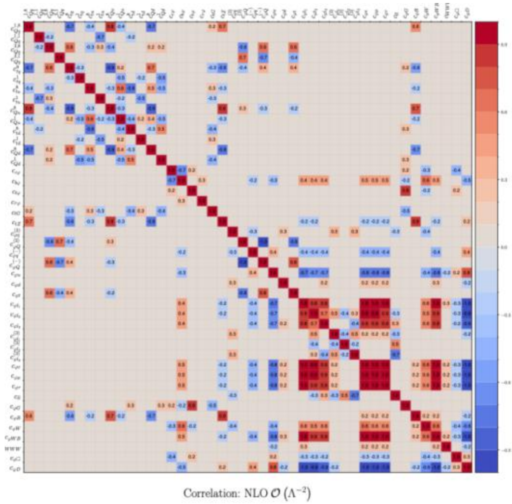
Automated analysis tools

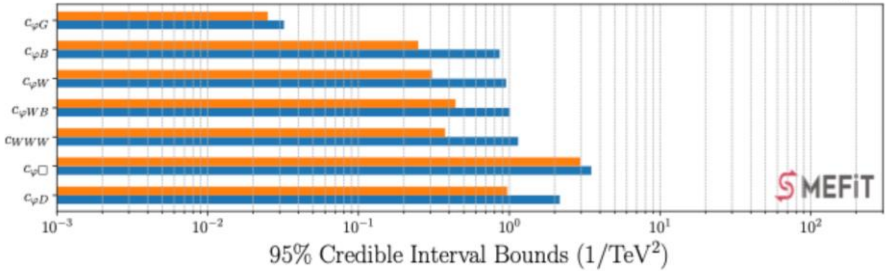


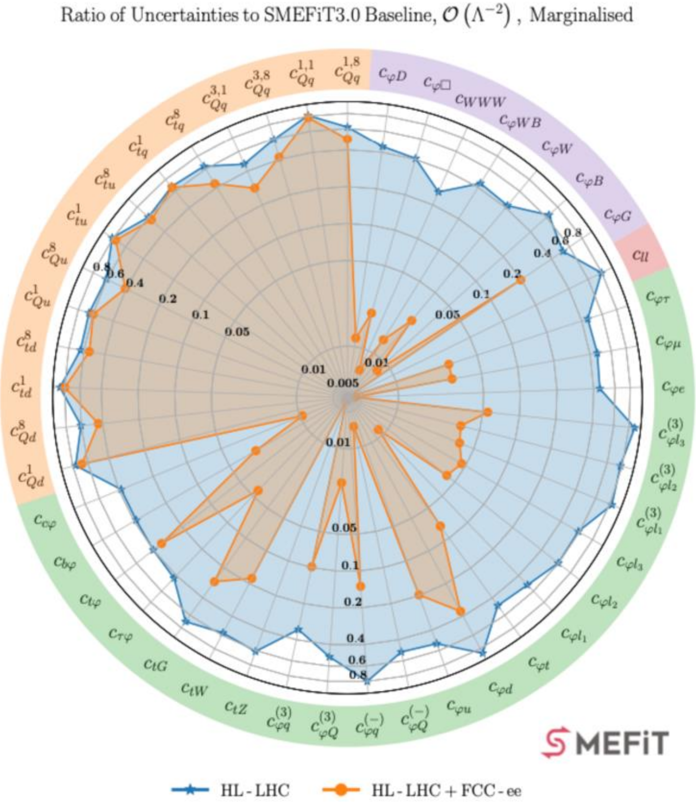












Recent updates (2023-now)

SMEFiT 3.0

[2404.12809]

- UV models: 1 or more heavy particles, tree or 1-loop matched.

SMEFiT + UV: Match2fit

[2309.04523]

- Full LEP dataset + Most recent LHC Run 2 data.
- Projections module to get HL-LHC projections + FCC-ee/CEPC predictions.
- External likelihoods interface:
  - Beyond Gaussian approximation.
  - Easy interface with other tools.

SMEFiT + RGE

[2502.xxyyy]

- RGE running: interface to wilson with Matrix Evolution Approximation. [1804.05033]
- Double Higgs (HL-)LHC measurements/projections + $e^+e^- \to Zh$ @NLO EW.
  - One more operator to fit: $\mathcal{O}_\varphi = |\varphi|^6$.
- JAX-enhanced: fast matrix calculations and GPU acceleration.

SMEFiT 3.0: more data, present and future

Celada, Giani, ter Hoeve, Mantani, Rojo, ANR, Thomas, Vryonidou
[2404.12809] [JHEP 09 (2024) 091]

Extended dataset

Category	Processes	$n_{\rm dat}$ SMEFiT2.0	$n_{\rm dat}$ SMEFiT3.0	
Top quark production	$t\bar{t}+X$	94	115	+21
	$t\bar{t}Z$, $t\bar{t}W$	14	21	+7
	$t\bar{t}\gamma$	—	2	+2
	single top (inclusive)	27	28	+1
	tZ, tW	9	13	+4
	$t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$	6	12	+6
	Total	**150**	**191**	**+41**
Higgs production and decay	Run I signal strengths	22	22	
	Run II signal strengths	40	36 (*)	
	Run II, differential distributions & STXS	35	71	+36
	Total	**97**	**129**	**+32**
Diboson production	LEP-2	40	40	
	LHC	30	41	+11
	Total	**70**	**81**	**+11**
EWPOs	LEP-2	—	44	**+44**
Baseline dataset	**Total**	**317**	**445**	

+128

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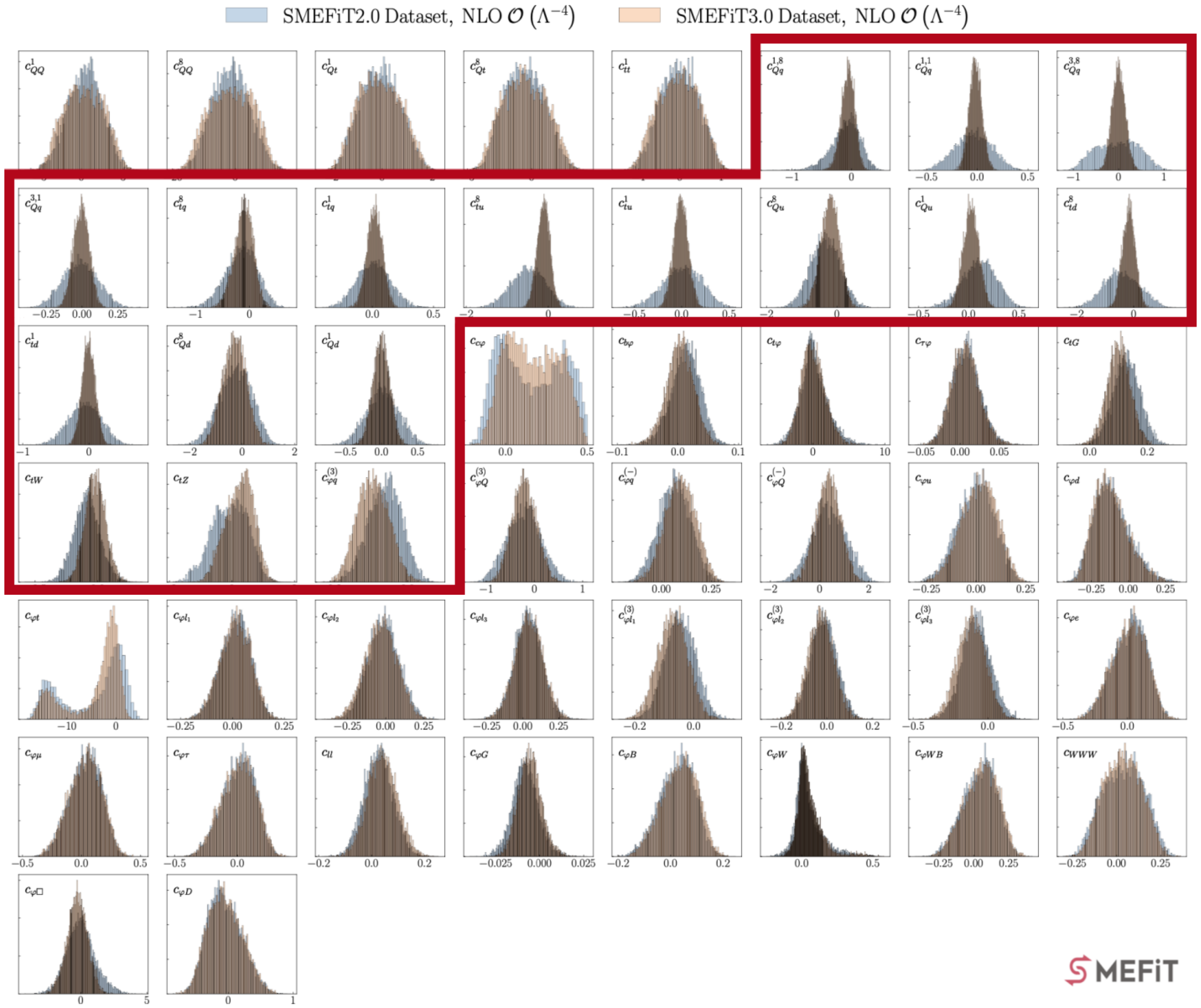
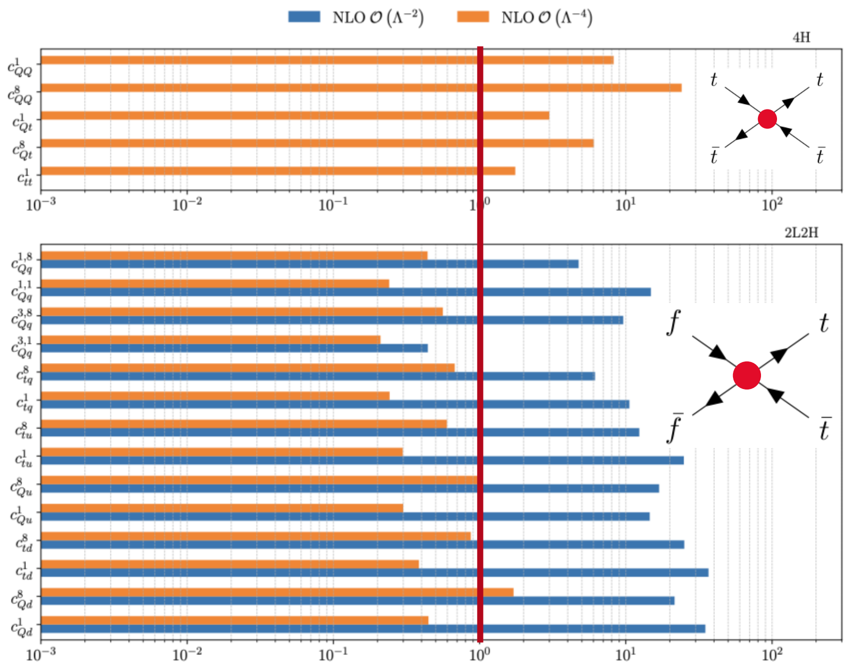
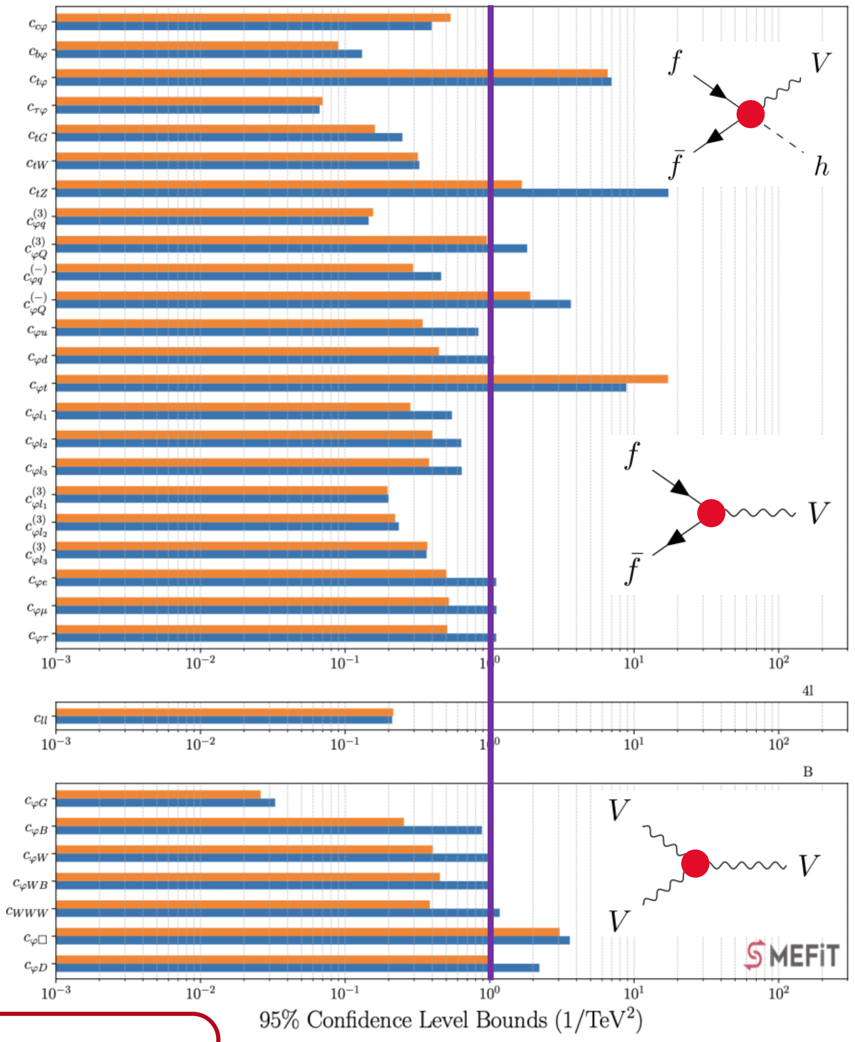
Impact of new LHC Run 2 data



SMEFiT 3.0 results





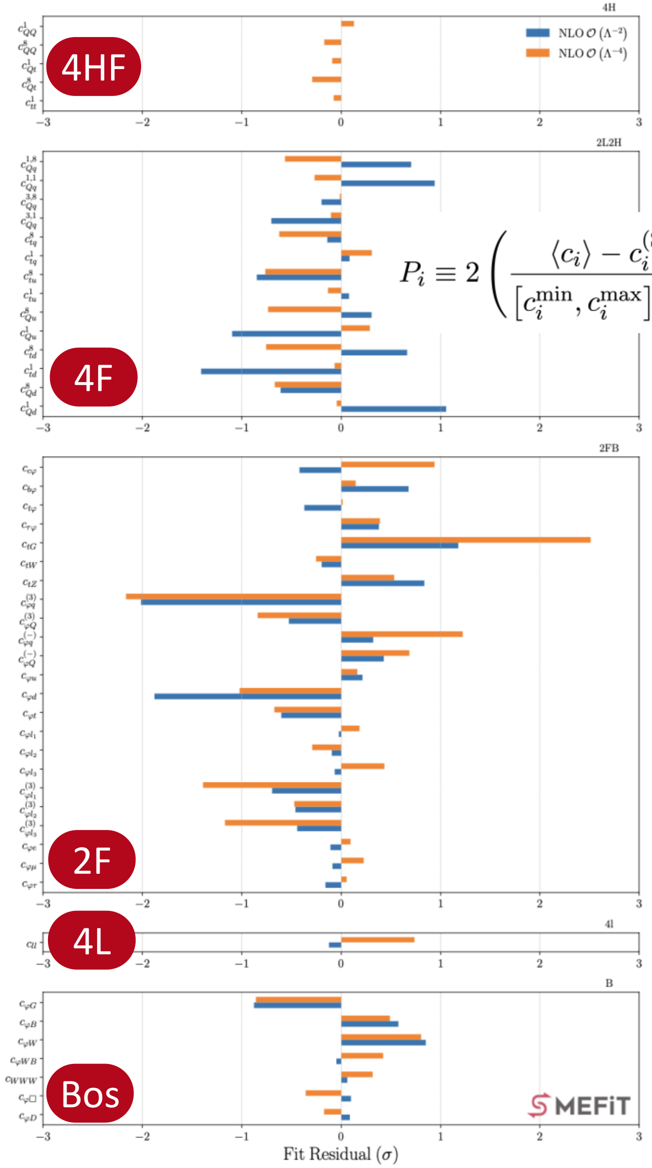
- Marginalised fit
- LEP + LHC

Linear in EFT

Quadratic in EFT

Many bounds dominated by quadratic contributions

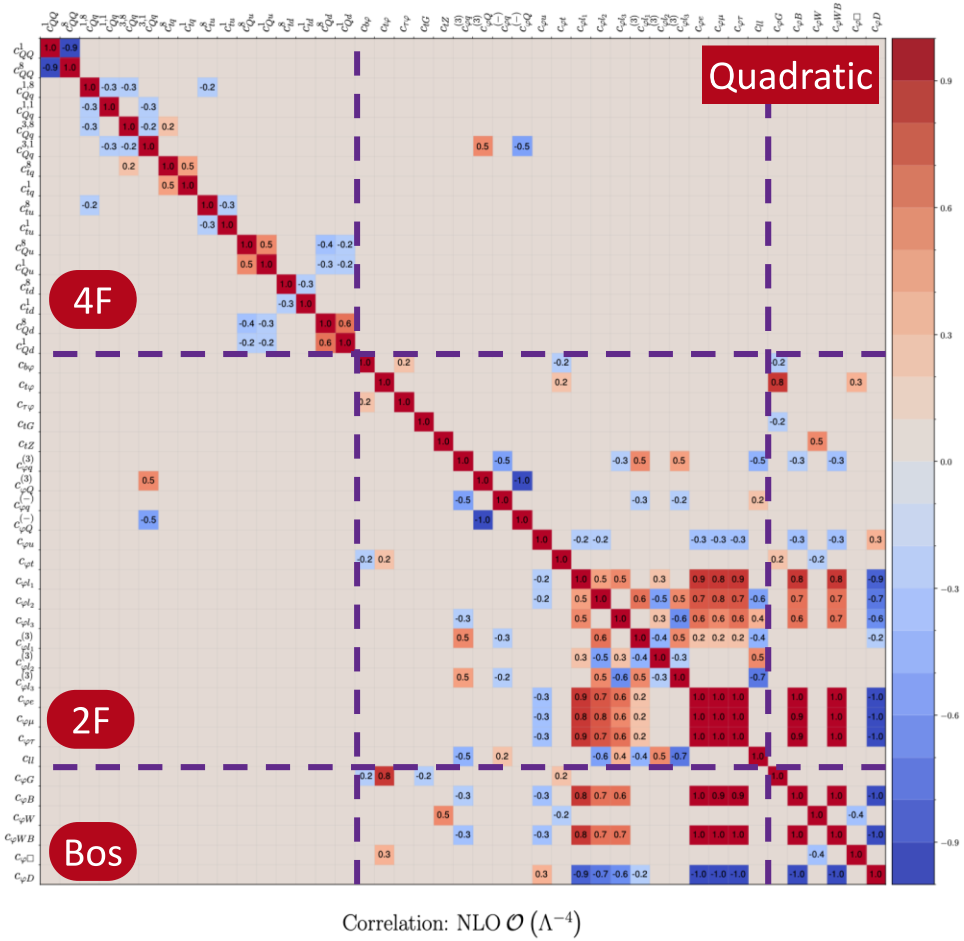
Pulls and correlations



$$P_i \equiv 2\left(\frac{\langle c_i\rangle - c_i^{(\mathrm{SM})}}{\left[c_i^{\min}, c_i^{\max}\right]_{68\%\ \mathrm{CI}}}\right)$$

Fit residuals (pulls) largely SM compatible

No large correlations



An eye on the future

HiLumi HL-LHC PROJECT | FCC hh ee | CEPC

Already implemented Celada et al [2404.12809]

CLIC | ilc international linear collider | International MUON Collider Collaboration

Work in Progress Armadillo et al [2503.xxyyy]

How to forecast

HiLumi HL-LHC PROJECT

(3 ab^{-1})

FCC ee CEPC CLIC ilc international linear collider International MUON Collider Collaboration

- Take SMEFiT 3.0 **LHC datasets with highest int. luminosity**
- Pseudodata fluctuated around SM
- **Rescale uncertainties:**
  - Statistical $\longrightarrow \mathcal{L}$
  - Systematics $\longrightarrow \frac{1}{2}$
- **No HL-LHC optimization**

- **Snowmass + FCC midterm Feas. Rep.**

Automated since SMEFiT 3.0

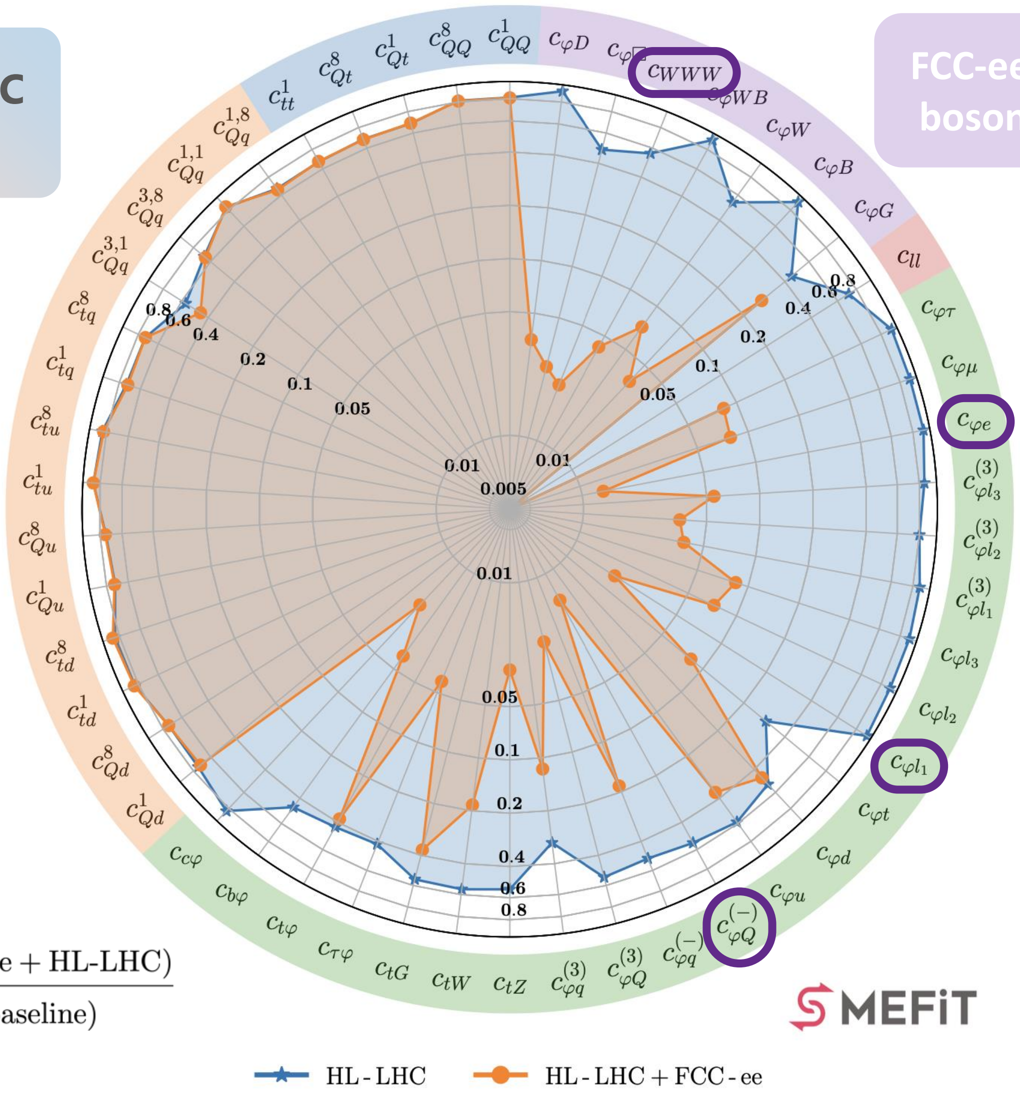
Improvements at HL-LHC and FCC-ee

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

4-quark: HL-LHC improvement

FCC-ee probes well bosonic operators

And several 2-fermion operators!



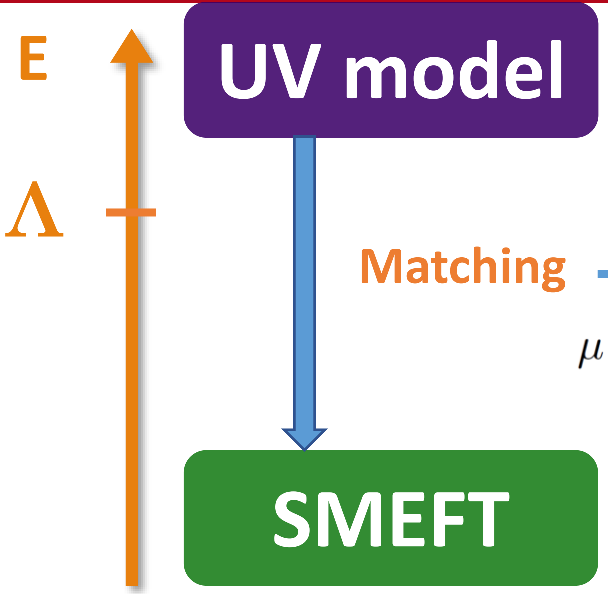
$$R_{\delta c_i} = \frac{[c_i^{\min}, c_i^{\max}]^{95\%\ \mathrm{CL}}\ (\text{baseline} + \text{HL-LHC})}{[c_i^{\min}, c_i^{\max}]^{95\%\ \mathrm{CL}}\ (\text{baseline})}$$

SMEFiT + UV: connecting to Matchmakereft via Match2fit

Ter Hoeve, Magni, Rojo, ANR, Vryonidou

[2309.04523] [JHEP 01 (2024) 179]

UV perspective



$$\mu \leqslant \Lambda \simeq \min\{\mathbf{m}_{\mathrm{UV}}\}$$

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

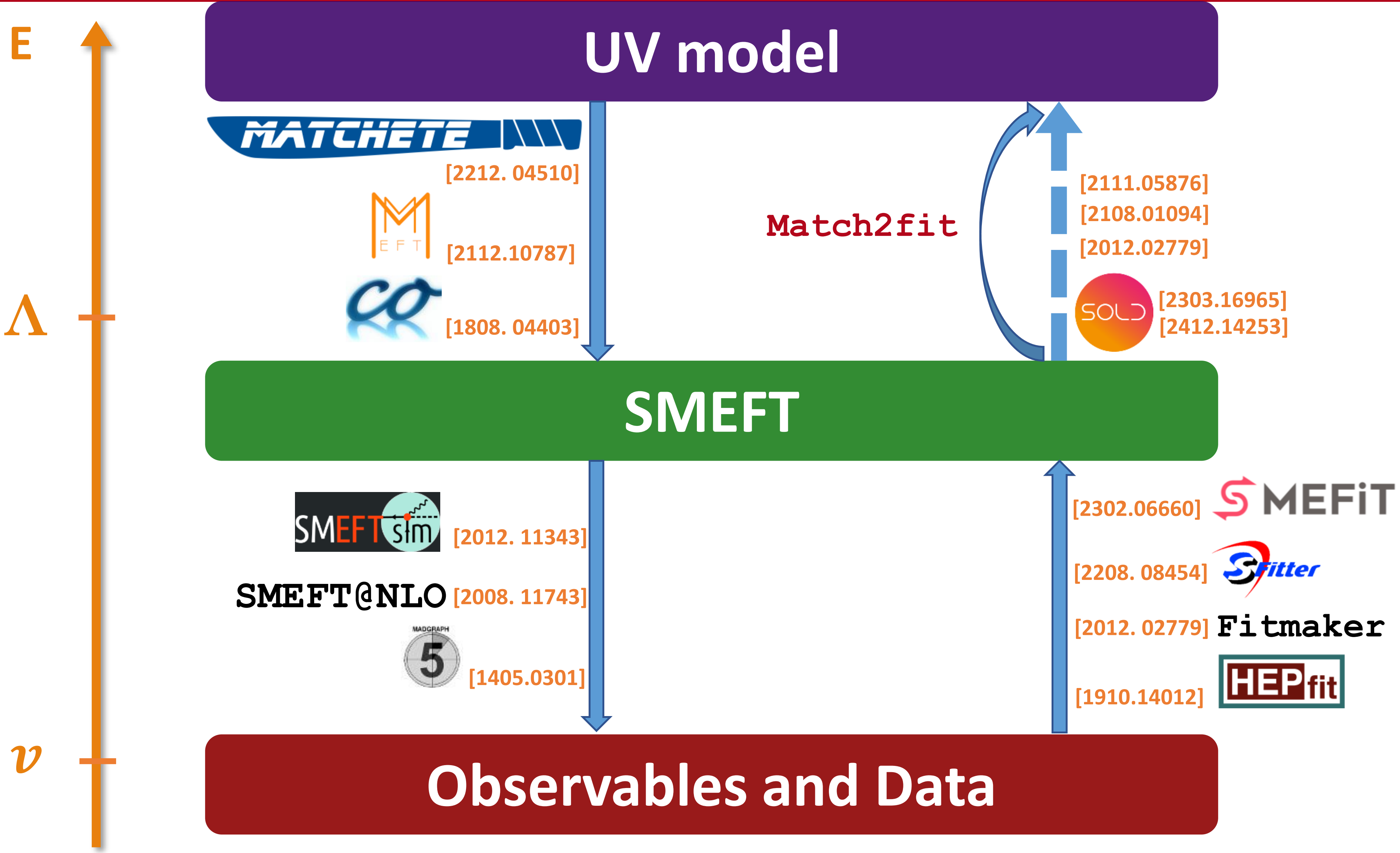
$$\frac{c_{t\varphi}}{\Lambda^2} = -\frac{\lambda_\phi\,(y_\phi^u)_{33}}{m_\phi^2} - \frac{g_2^4 y_t^{\mathrm{SM}}}{3840\pi^2}\frac{1}{m_\phi^2} + \frac{y_t^{\mathrm{SM}}}{16\pi^2}\frac{\lambda_\phi^2}{m_\phi^2} + \frac{\left(4\left(y_b^{\mathrm{SM}}\right)^2 - 13\left(y_t^{\mathrm{SM}}\right)^2\right)}{64\pi^2}\frac{\lambda_\phi\,(y_\phi^u)_{33}}{m_\phi^2}$$
$$- \left(12\lambda_\varphi^{\mathrm{SM}} + \left(y_b^{\mathrm{SM}}\right)^2 - 11\left(y_t^{\mathrm{SM}}\right)^2\right)\frac{y_t^{\mathrm{SM}}}{64\pi^2}\frac{(y_\phi^u)_{33}^2}{m_\phi^2} + \frac{3}{128\pi^2}\frac{\lambda_\phi\,(y_\phi^u)_{33}^3}{m_\phi^2},$$

$$\frac{\mathbf{c}}{\Lambda^n} = f(\mathbf{g}_{\mathrm{UV}}, \mathbf{m}_{\mathrm{UV}})$$

$$\sigma(\mathbf{c}) \longrightarrow \sigma(\mathbf{g}_{\mathrm{UV}})$$

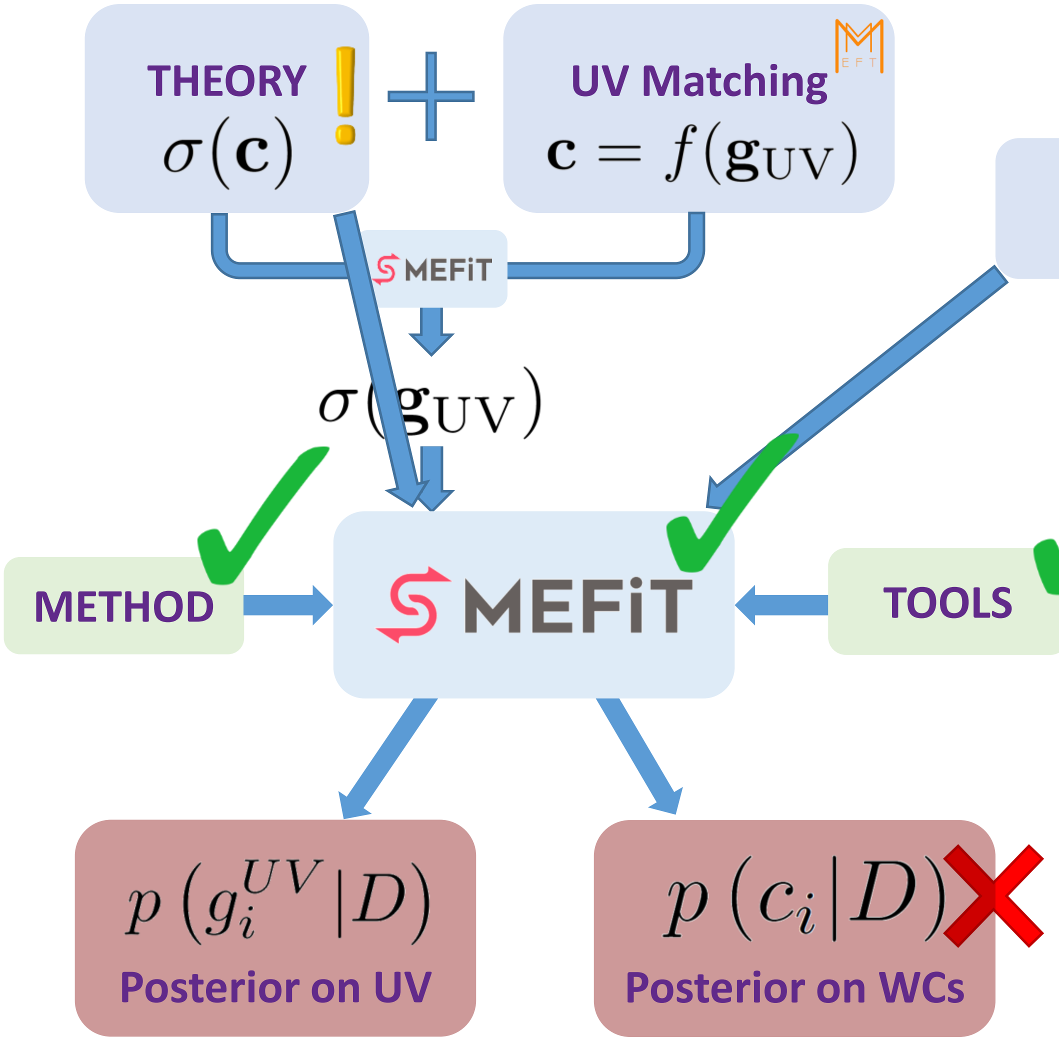
- Less parameters
- Stronger correlations
- Model dependent
- Sharper interpretation

Automation across scales



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

Reusing EFT global fits for the UV



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.

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

- It can impose UV flavor assumptions and evaluates the masses.
- It can run Matchmakereft to do all at once.

It supports 1-loop matching results.

- Improved v2.0 to be released soon: better handling of multi-particle models, better interface to SMEFiT, mass scans…
- Many ideas for v3.0: interface to SOLD, Matchete, WCxf, additional WC bases, ability to run SMEFiT…

Match2fit v2.0 preview

```
<< match2fit`

match2fit: an interface between matching and fitting codes.

Version: 2.0
Date: yy/zz/2025
Author: Alejo N. Rossia
Affiliations: The University of Manchester

matchResToUVscanCard[NotebookDirectory[] <> "/sample_results/MatchingResult_Varphi_oneloop.dat",
8, 1,
 {"UVFlavourAssumption" ->
   Join[realDiagSMYukas, {yVarphiD[i_, j_] :> 0, yVarphiE[i_, j_] :> 0,
     yVarphiU[i_, j_] :> KroneckerDelta[i, 3] * KroneckerDelta[j, 3] * yVarphiuf33, lamvarphi -> lamvarphi}],
  "Collection" -> "1LoopMatching", "Model" -> "Varphi", "OutputFormat" -> "SMEFiT"}]

matchResToUVscanCard[NotebookDirectory[] <> "/sample_results/MatchingResult_Varphi_oneloop.dat",
8, 0,
 {"UVFlavourAssumption" ->
   Join[realDiagSMYukas, {yVarphiD[i_, j_] :> 0, yVarphiE[i_, j_] :> 0,
     yVarphiU[i_, j_] :> KroneckerDelta[i, 3] * KroneckerDelta[j, 3] * yVarphiuf33, lamvarphi -> lamvarphi}],
  "Collection" -> "1LoopMatching", "Model" -> "Varphi"}]

modelToUVscanCard[NotebookDirectory[] <> "sample_model/", "T1", 1, "loop",
 {"UVFlavourAssumption" → {lambdaT1[a_] ⧴ lambdaT1[3]}, "Collection" -> "1Loop"}]

The matching results are available in:
/home/alejo/Documents/match2fit-1loop_update/sample_model/T1_MM/MatchingResult.dat
```

Mass value [TeV]

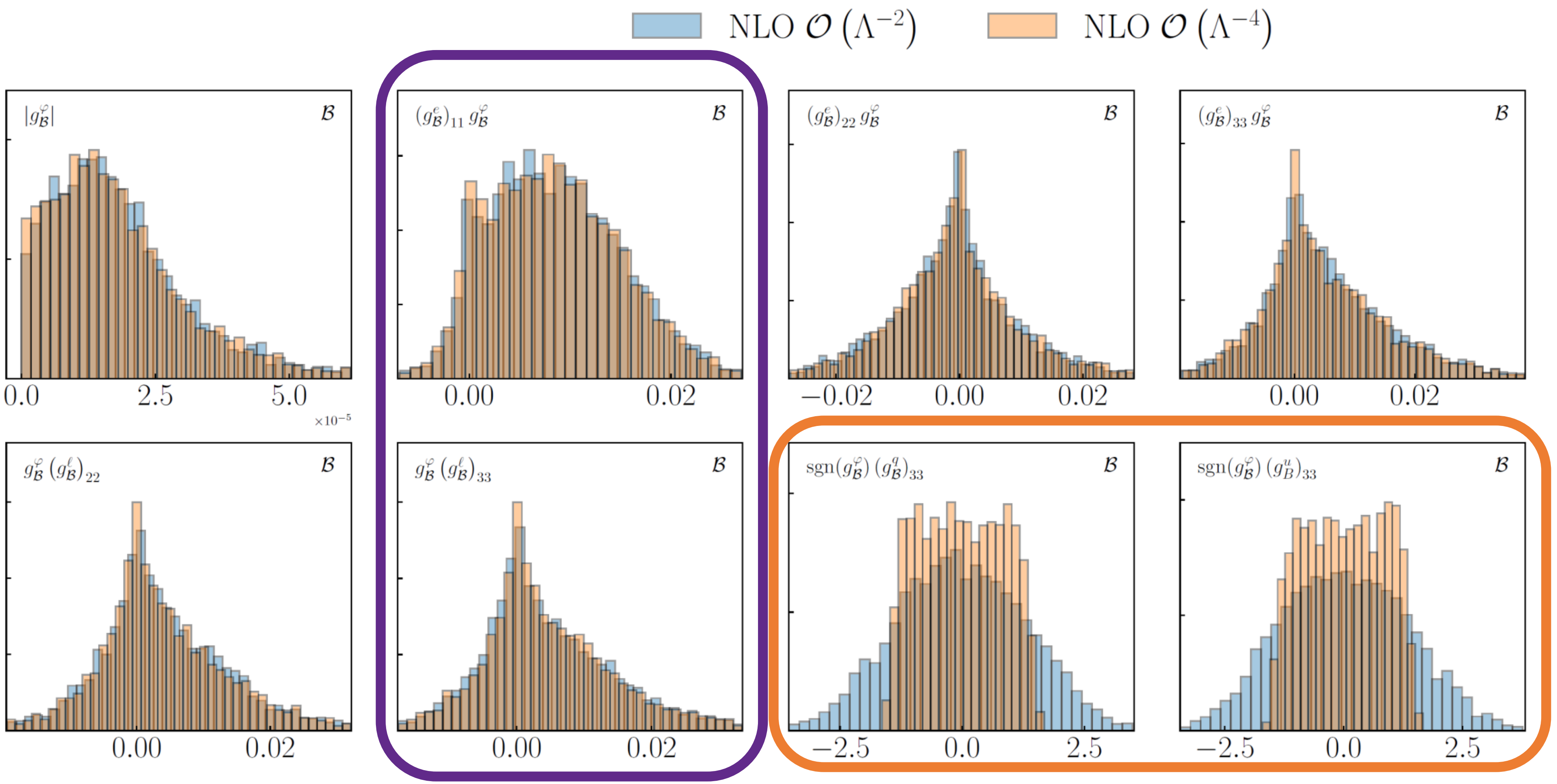
Matching Loop level

Output format

```
# UV dictionary with WCs in terms of UV variables
# ~~~~~~~~~~~~~~~~~~~~~~~~
UV Collection : 1LoopMatching
UV model : Varphi
Model name : Varphi
# ~~~~~~~~~~~~~~~~~~~~~~~~
UV couplings : [lamvarphi, yVarphiuf33]
UV masses : [Mvarphi]
# ~~~~~~~~~~~~~~~~~~~~~~~~
# Loop level of the results : Tree
# ~~~~~~~~~~~~~~~~~~~~~~~~
# Setting of the UV mass in TeV:
m : 8 # TeV
# ~~~~~~~~~~~~~~~~~~~~~~~~
# Expressions for all the WCs in SMEFiT basis
cpG : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpB : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpW : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpWB : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpd : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpD : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cWWW : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpqMi : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
cpQM : [{lamvarphi: [0.,0],yVarphiuf33: [1,0]}]
```


```
Model name: Varphi
UV Collection: 1LoopMatching
UV model: Varphi
coefficients:
  Opd:
    constrain:
    - lamvarphi:
      - -1.157657260831957e-7
      - 0
    - lamvarphi:
      - -0.0001484197026010873
      - 2
    max: 100
    min: -100
  OpD:
    constrain:
    - lamvarphi:
      - -1.3552404694322209e-8
      - 0
    max: 100
    min: -100
  OWWW:
    constrain:
    - lamvarphi:
      - 7.649753615115059e-8
      - 0
    max: 100
    min: -100
  OpqMi:
    constrain:
    - lamvarphi:
      - 7.265968249068972e-8
      - 0
    max: 100
    min: -100
```

One-part. models at tree level



Spin 1

$$\mathcal{B} \sim (1,1)_0$$

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

$$m_{\mathcal{B}} = 1 \text{ TeV}$$

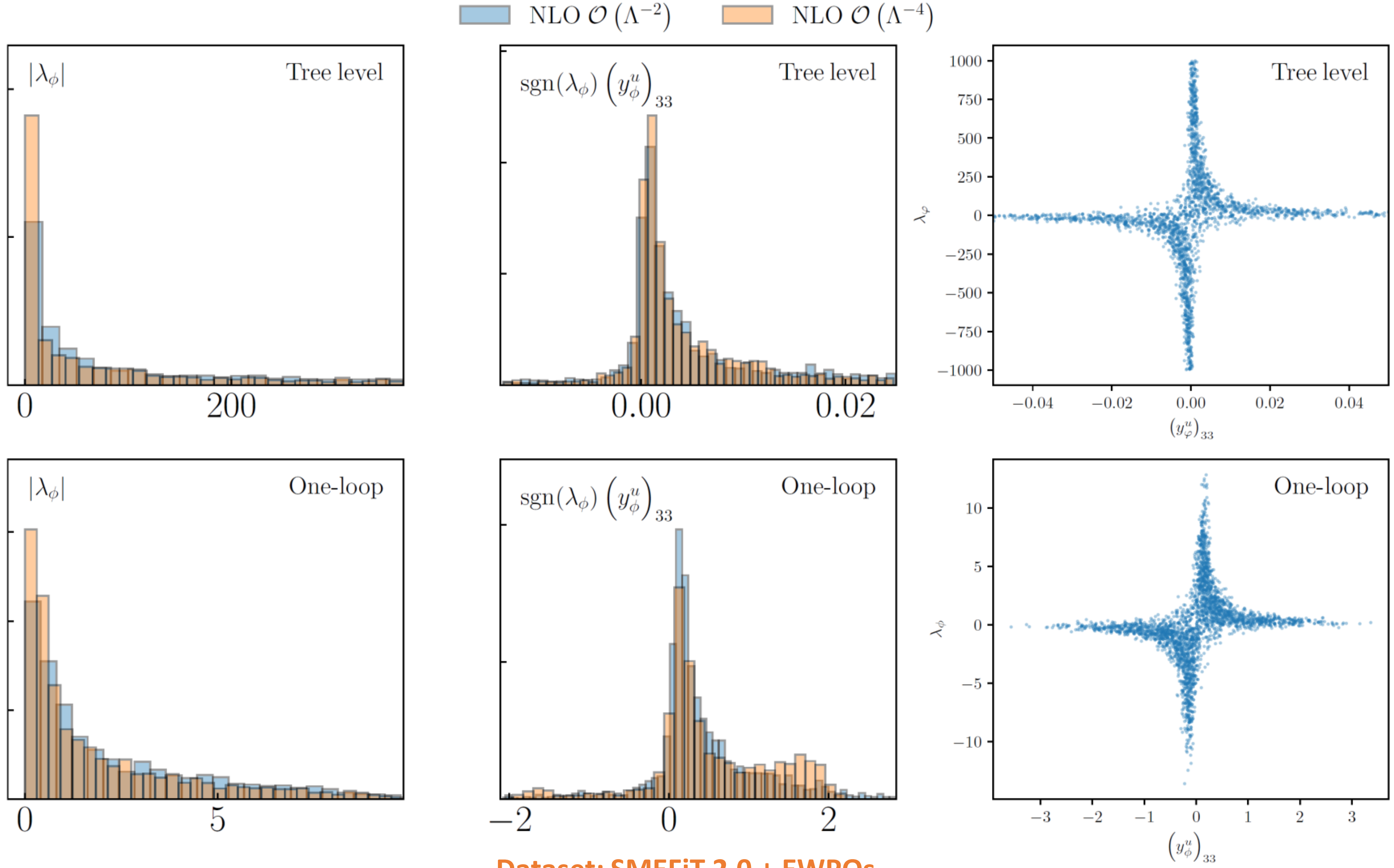
Sensitivity to the sign of UV couplings

Top couplings sensitive to quadratic-in-WCs pieces

Dataset: SMEFiT 2.0 + EWPOs

One-loop matching makes a difference

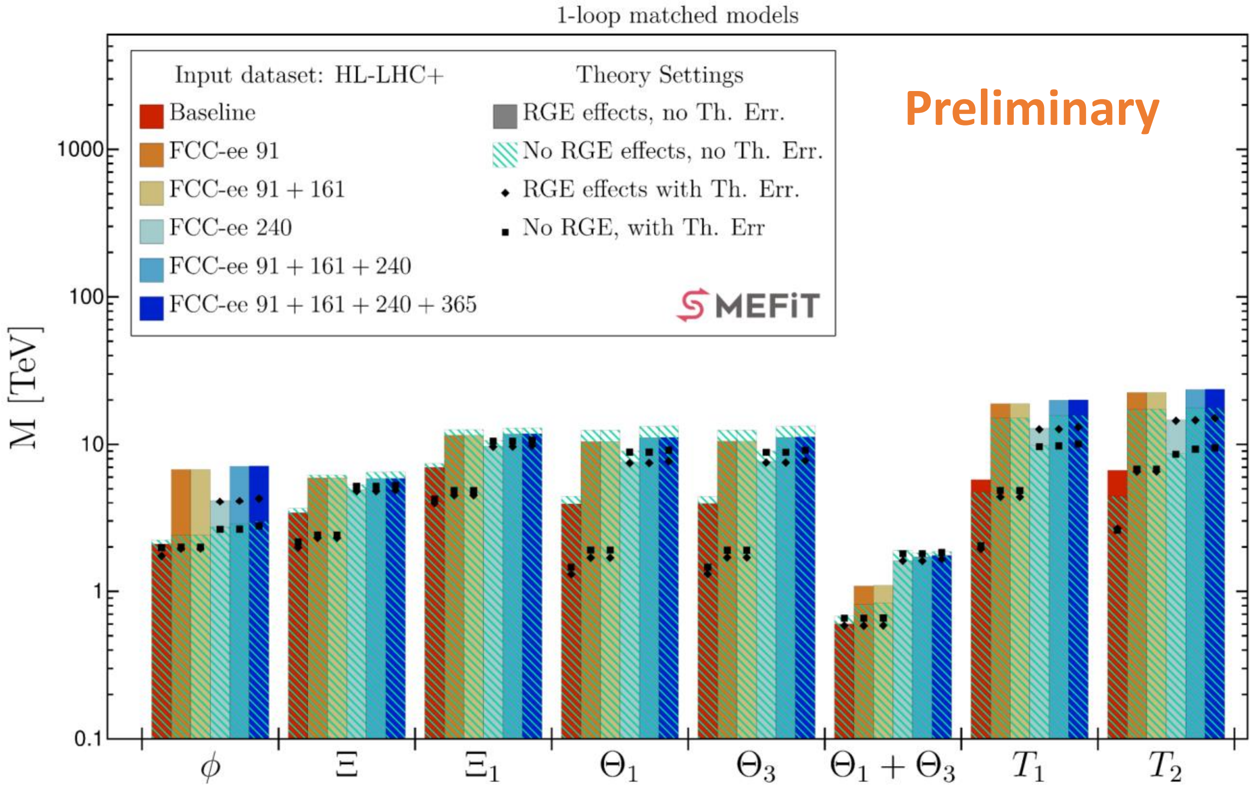
$\phi \sim (1,2)_{1/2}$ $\mathcal{L}_{\mathrm{UV}} \supset -\left(y_\phi^u\right)_{33} \phi^\dagger i\sigma_2 \bar{q}_L^{T,3} u_R^3 - \lambda_\phi \phi^\dagger H |H|^2 + \mathrm{h.c.}$ $m_\phi = 1$ TeV



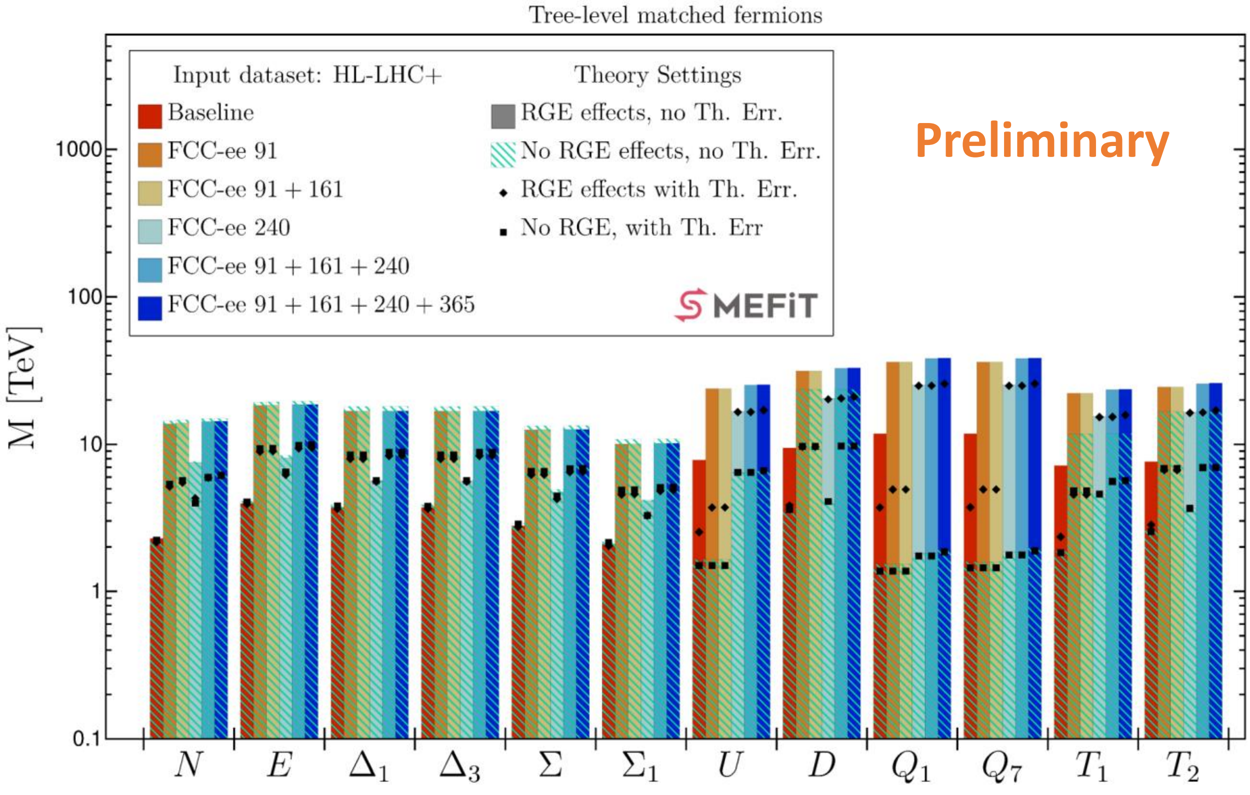
Dataset: SMEFiT 2.0 + EWPOs

Projections for the future: 1-part. models

95% CL reach in mass for unit UV couplings

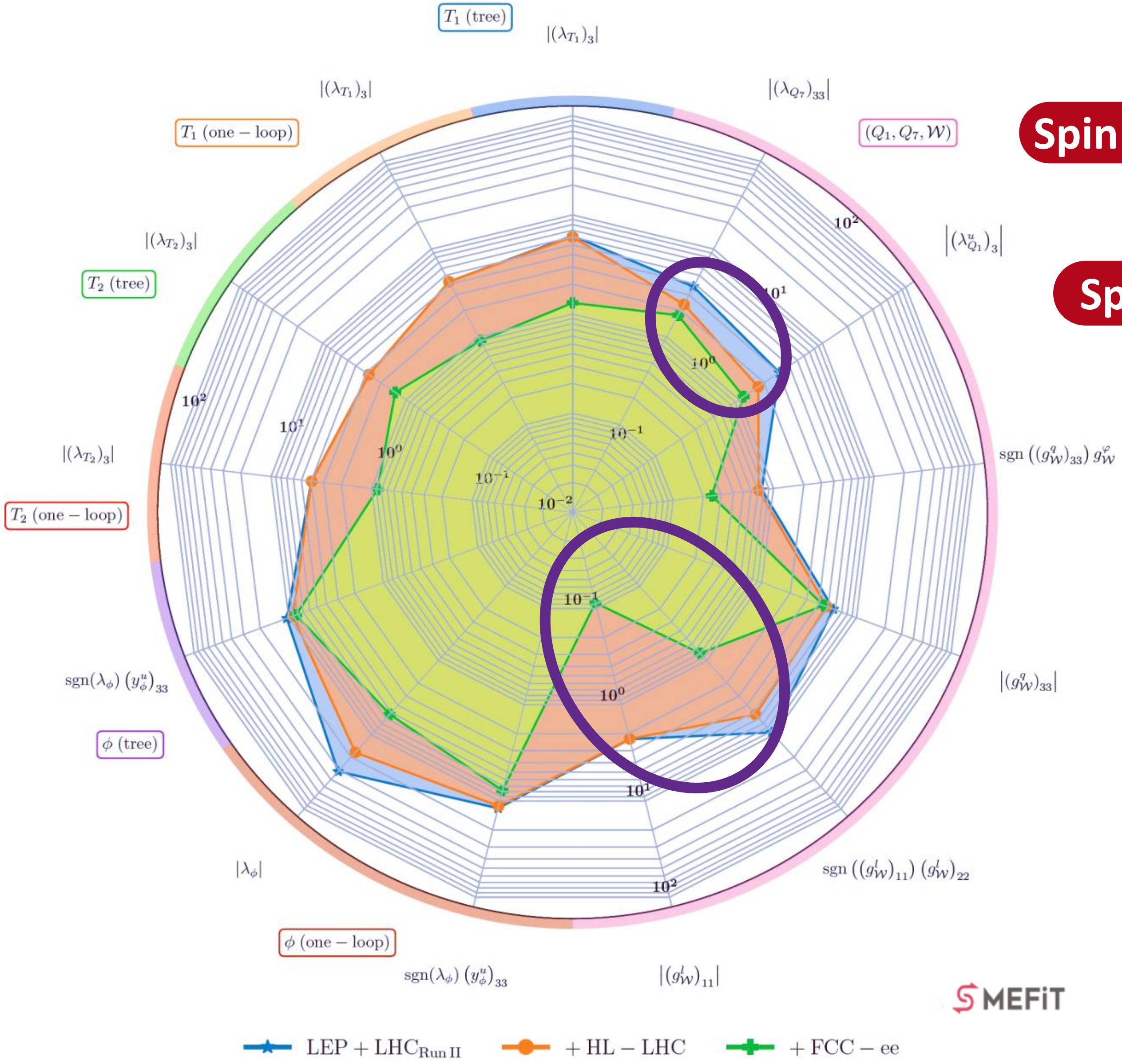


$g_{\mathrm{UV}} = 1$



Ter Hoeve, Mantani, Rojo, ANR, Vryonidou [2502.xxyyy]
FCC Feasibility Report

Projections for the future: UV couplings



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

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

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

$m_{Q_1} = 3$ TeV

$m_{Q_7} = 4.5$ TeV

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

Connecting Scales: RGE effects in the SMEFiT Global Fit from LHC to FCC-ee

Ter Hoeve, Mantani, Rojo, ANR, Vryonidou
[2502.xxyyy]

How we solve the RG Equations

$$\frac{dc_i(\mu)}{d\ln\mu} = \sum_{j=1}^{n_{\rm op}} \gamma_{ij}^{(6)}\,(\bar{g})\,c_j(\mu)$$

$$\bar{g} = \bar{g}(\cancel{c})$$

$$\frac{d\bar{g}_i(\mu)}{d\ln\mu} = \sum_{j=1}^{n_{\rm op}} \gamma_{ij}^{(4)}\,(\bar{g},\cancel{c})\,\bar{g}_j(\mu)$$

Matrix Evolution Approximation: decouples and linearizes the equations.

$$c_i(\mu) = \sum_{j=1}^{n_{\rm op}} \Gamma_{ij}(\mu,\mu_0;\bar{g})c_j(\mu_0)\,, \qquad i = 1,\ldots,n_{\rm op}$$

$$\Gamma_{ij}(\mu,\mu_0;\bar{g}) = \exp\left(\int_{\mu_0}^{\mu} d\log(\mu')\gamma_{ij}^{(6)}(\bar{g}(\mu'))\right)$$

RGE implementation in the code

SMEFiT ⊃ wilson

[1804.05033]

SMEFiT is interfaced to and includes wilson

```
rge:
  init_scale: 5000.0 # The reference scale $\mu_0$ for the Wilson coefficients
  obs_scale: dynamic # "float" or "dynamic"
  scale_variation: 0.5  # Apply a scale factor to the dynamic observable scale
  smeft_accuracy: integrate # Options: integrate, leadinglog
  yukawa: top # Options: top, full, or none
  adm_QCD: False # If true, the EW couplings are set to zero
```

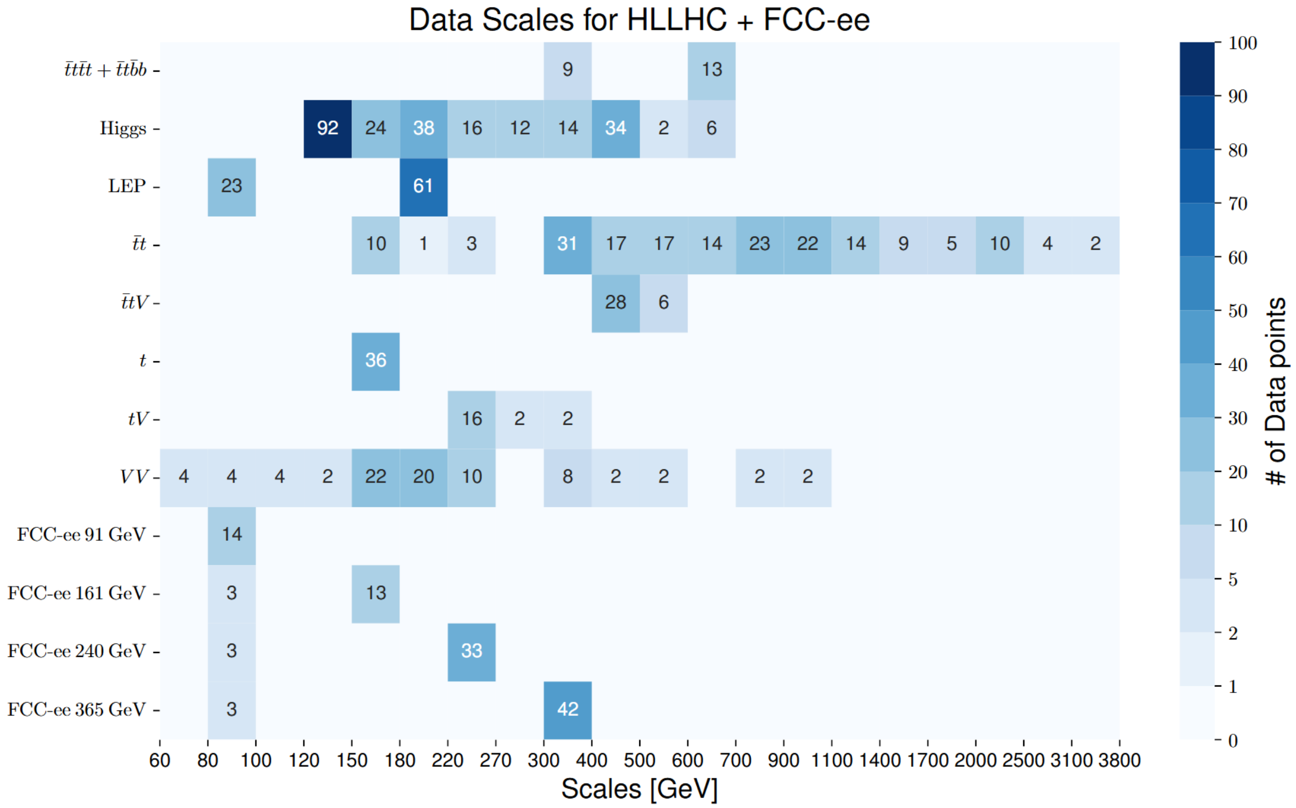
$$\bar{g} = \{g_s, g, g', y_t, \mu_h^2, \lambda\}$$

Plenty of options on how to run

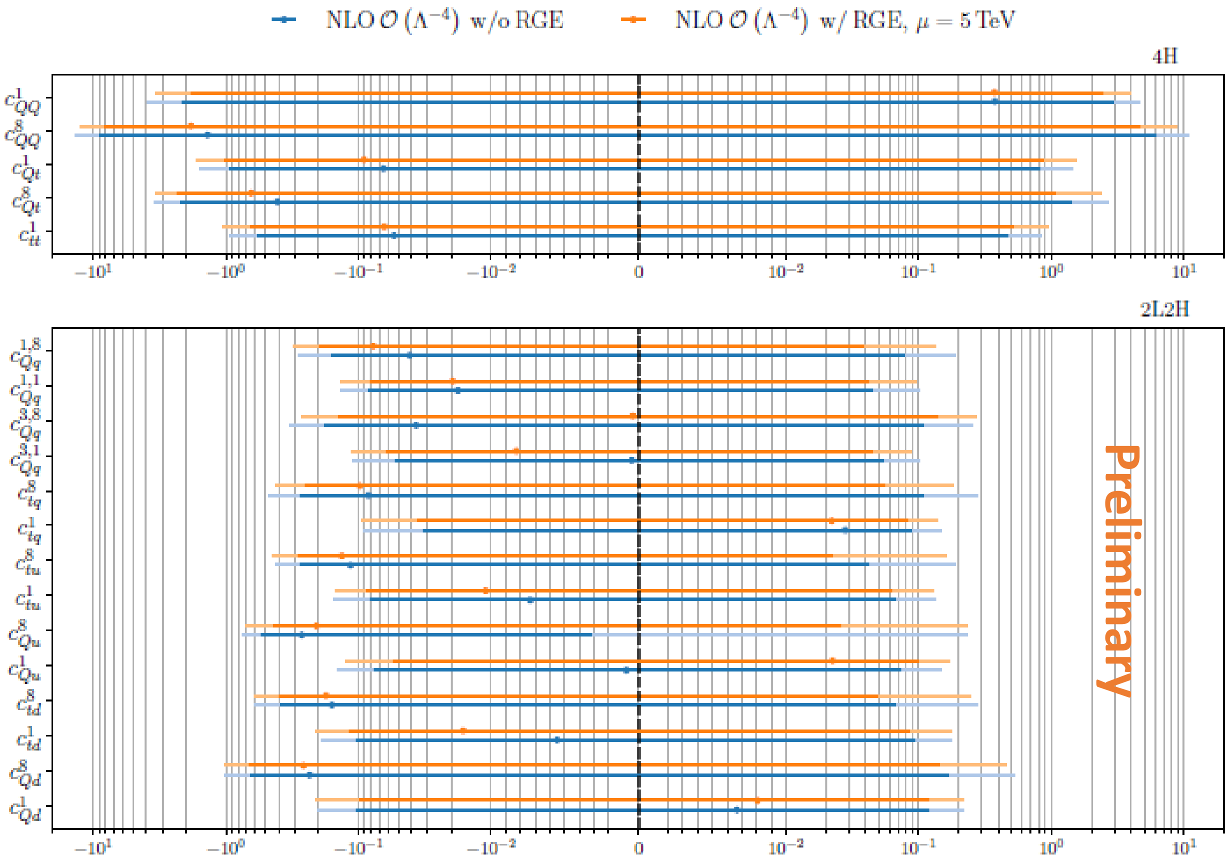
RGE implies scale choices

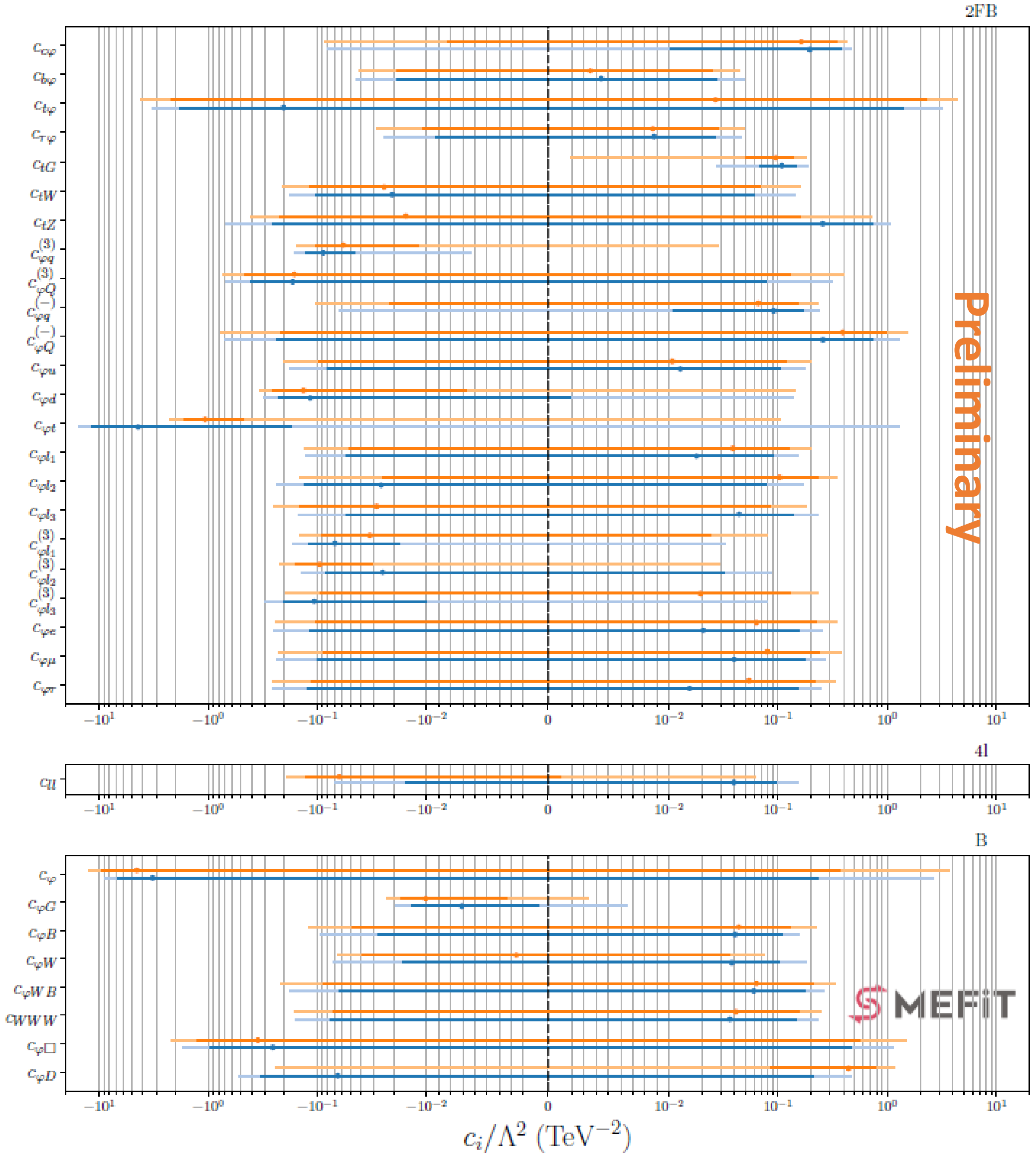
Each datapoint is assigned a scale for the dynamic mode

Process	Scale Choice μ	Process	Scale Choice μ
Higgs (ggF)	$\sqrt{m_H^2 + (p_T^H)^2}$	$t\bar{t}b\bar{b}$	$2m_t$
Higgs (VBF)	$\sqrt{m_H^2 + (p_T^H)^2}$	$t\bar{t}V$	$\sqrt{(2m_t + m_V)^2 + (p_T^V)^2}$
VH	$\sqrt{(m_V + m_H)^2 + (p_T^V)^2}$	tV	$m_t + m_V$ or $\sqrt{(m_t + m_V)^2 + (p_T^t)^2}$
$t\bar{t}H$	$\sqrt{(2m_t + m_H)^2 + (p_T^H)^2}$	W - helicities	m_t
tH	$m_t + m_H$	WZ	m_T^{WZ} or $\sqrt{(m_Z + m_W)^2 + (p_T^Z)^2}$
$t\bar{t}$	m_{tt}	WW	$m_{e\mu}$
Single-t	m_t	V pole (incl. EWPOs)	m_V
$t\bar{t}\gamma$	$2m_t$	Bhabha scattering	$\sqrt{s}$
$t\bar{t}t\bar{t}$	$4m_t$	$e^+e^- \to WW\,/\,t\bar{t}\,/\,f\bar{f}$	$\sqrt{s}$

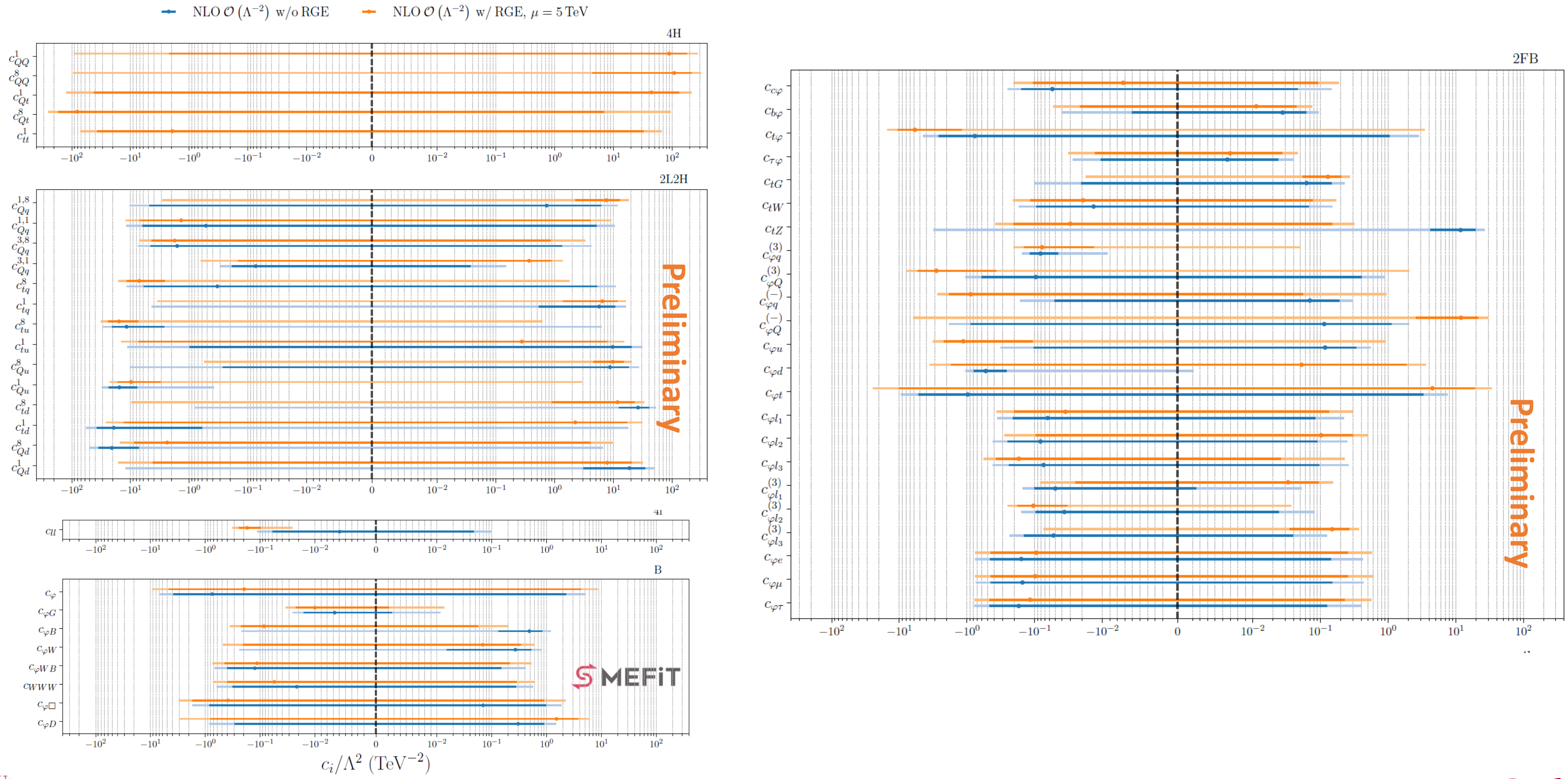


Effects in the global fit





Effects in linear the global fit



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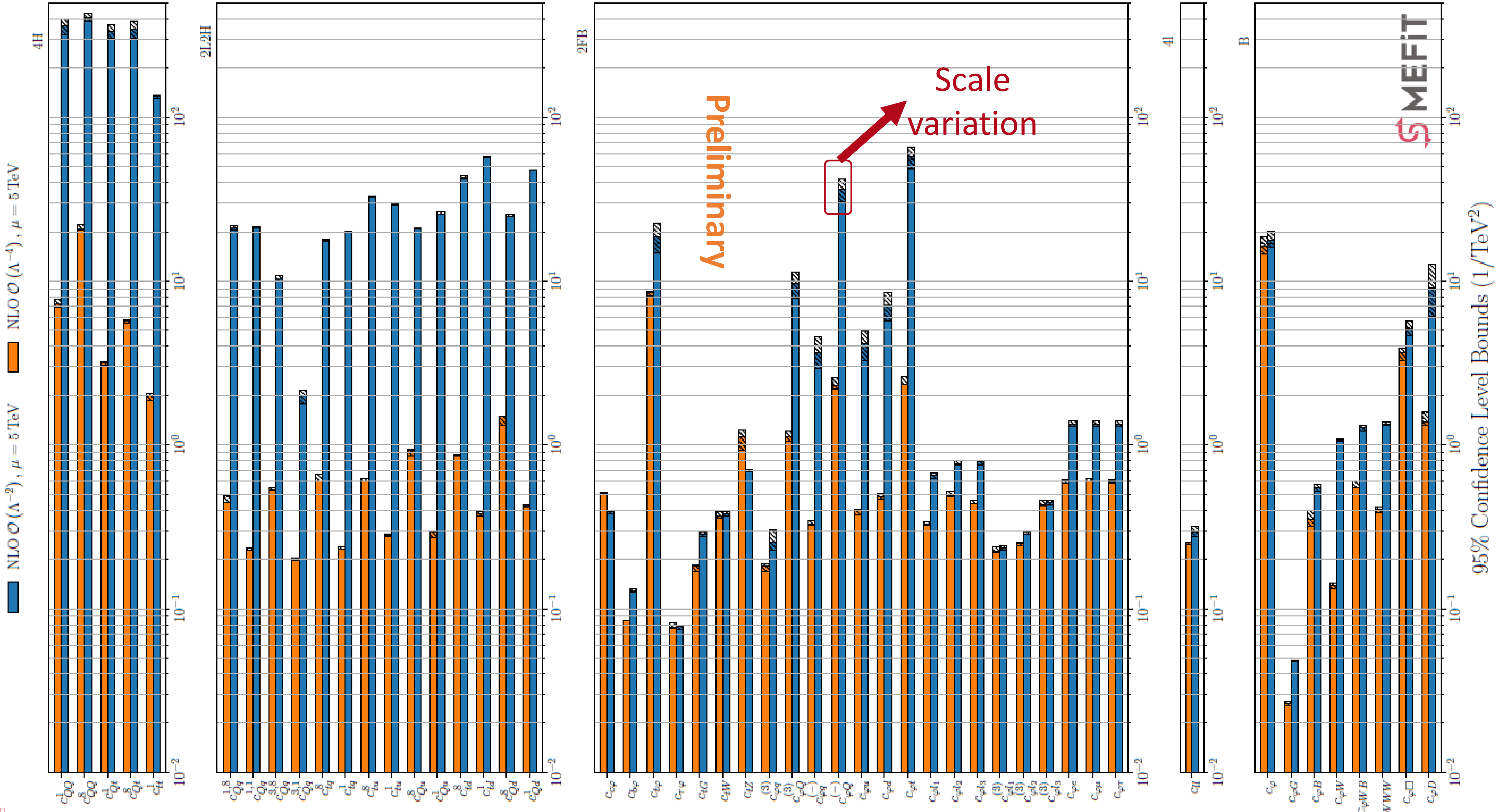
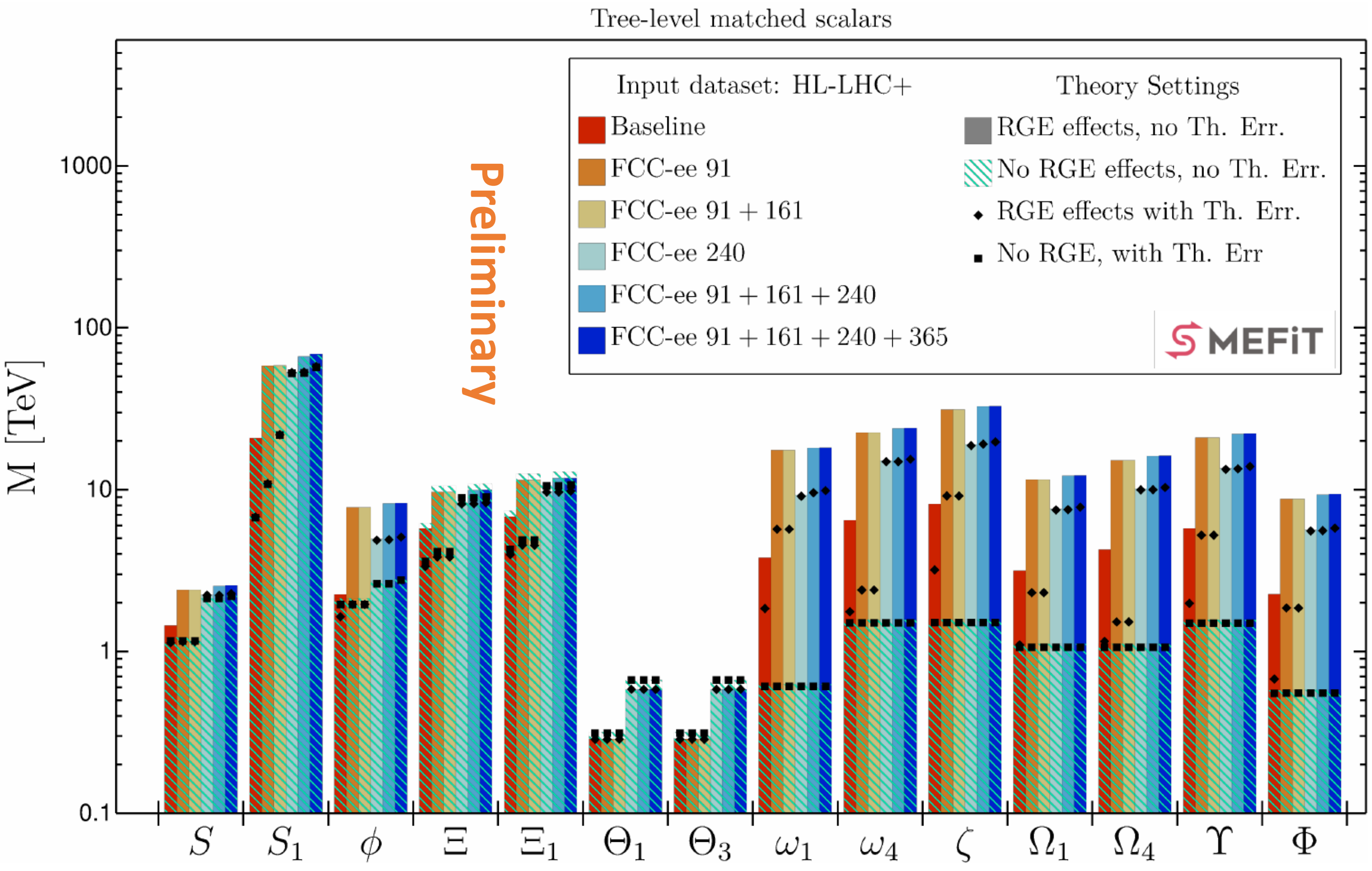
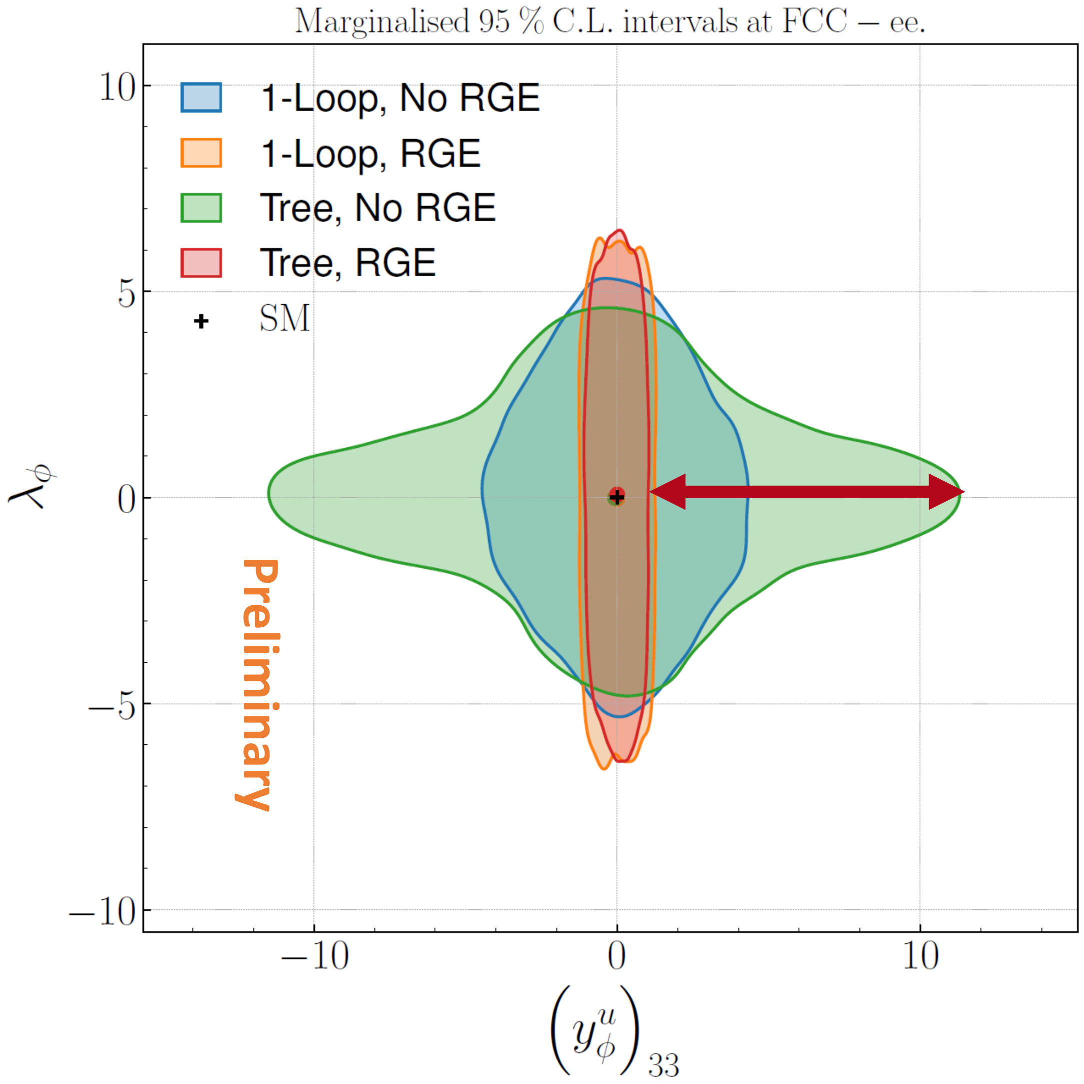
Effects in the global fit



RGE with UV models at future colliders





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.
- SMEFiT includes up-to-date LHC Run 2 data and future projections. And it's easy to add datasets!
- Match2fit provides a simple and flexible SMEFiT-MMEFT interface.
- We can account for RGE effects, which are particularly big for UV models and future colliders.
- SMEFiT is becoming more than just a fitting code, it's a hub for SMEFT phenomenology.
- Several exciting developments to come.

Thanks for your attention!

Contact:

Alejo N. Rossia

E-mail: alejonahuel dot rossia at unipd dot it

Appendix

Restrictions from EFT flavor symmetry for UV fits

- 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 for UV fits

SMEFiT supports relations among fit parameters like:

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

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

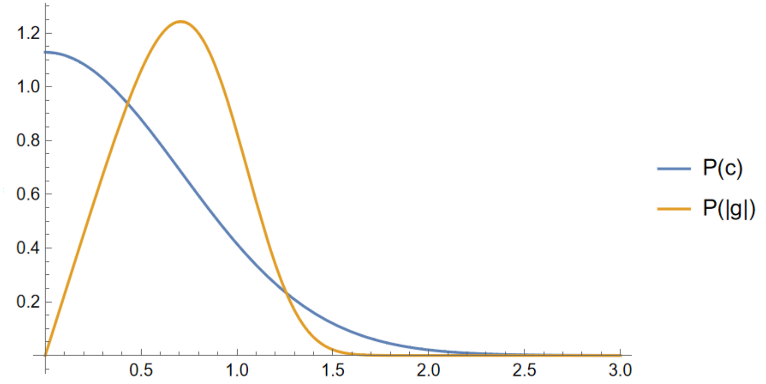
Probability in UV and WC spaces

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

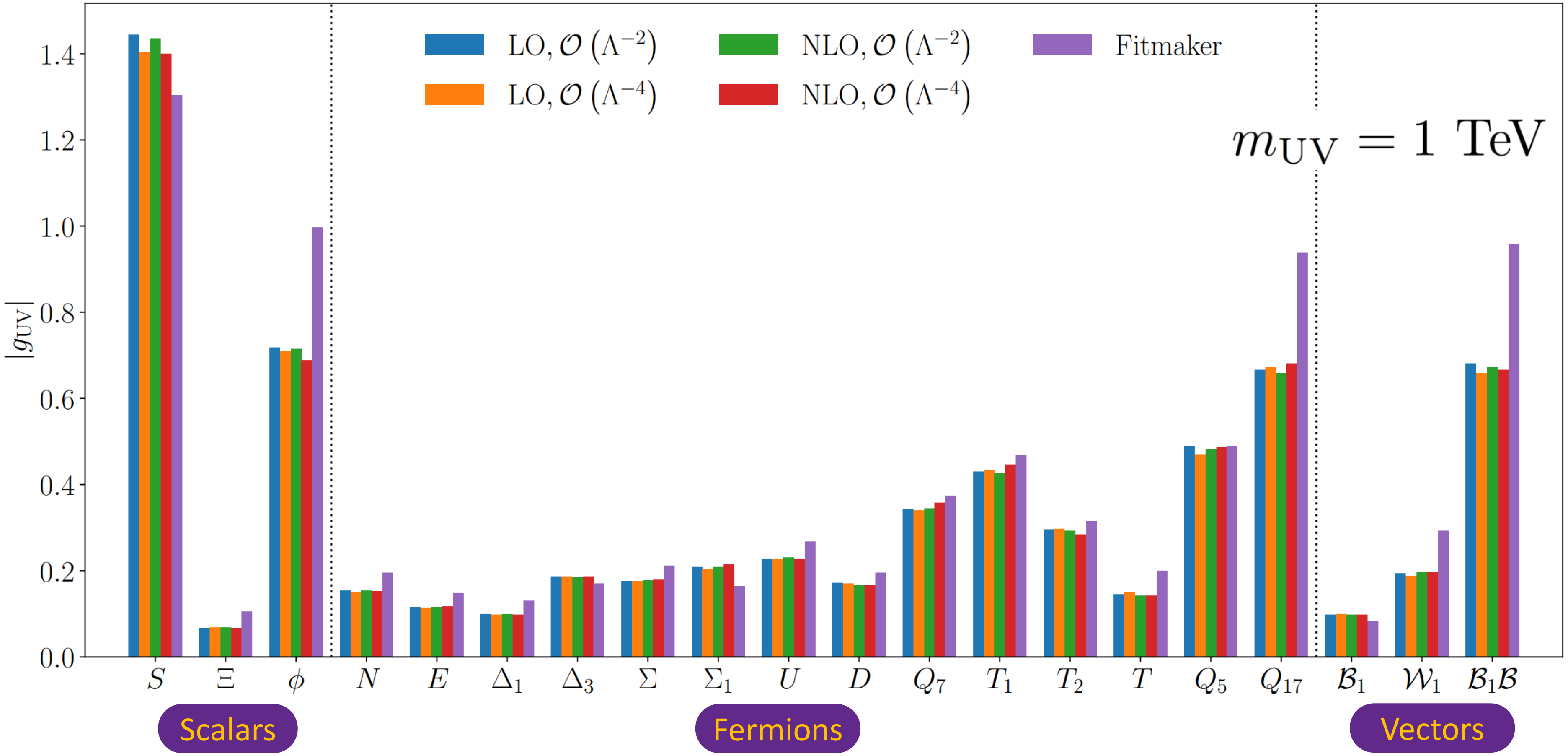
$$P(c)=\frac{2}{\sqrt{\pi}}e^{-c^2}\,,\qquad \int_0^\infty dc\,P(c)=1$$

$$\Big\downarrow\; c=g^2$$

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



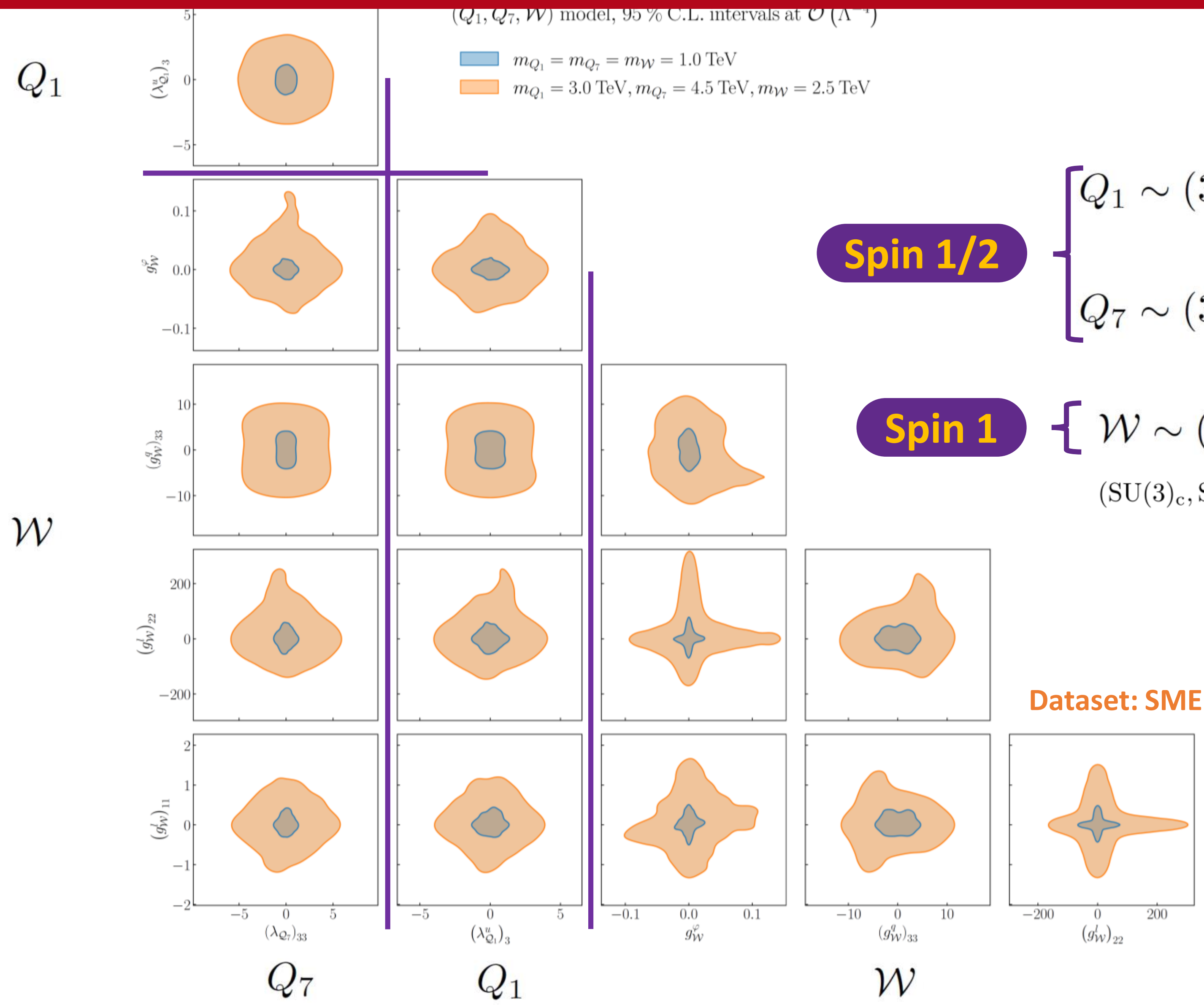
One-part. models at tree level



Good agreement with the Fitmaker results

Dataset: SMEFiT 2.0 + EWPOs

Multi-particle models at tree level



Spin 1/2

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

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

Spin 1

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

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

Dataset: SMEFiT 2.0 + EWPOs

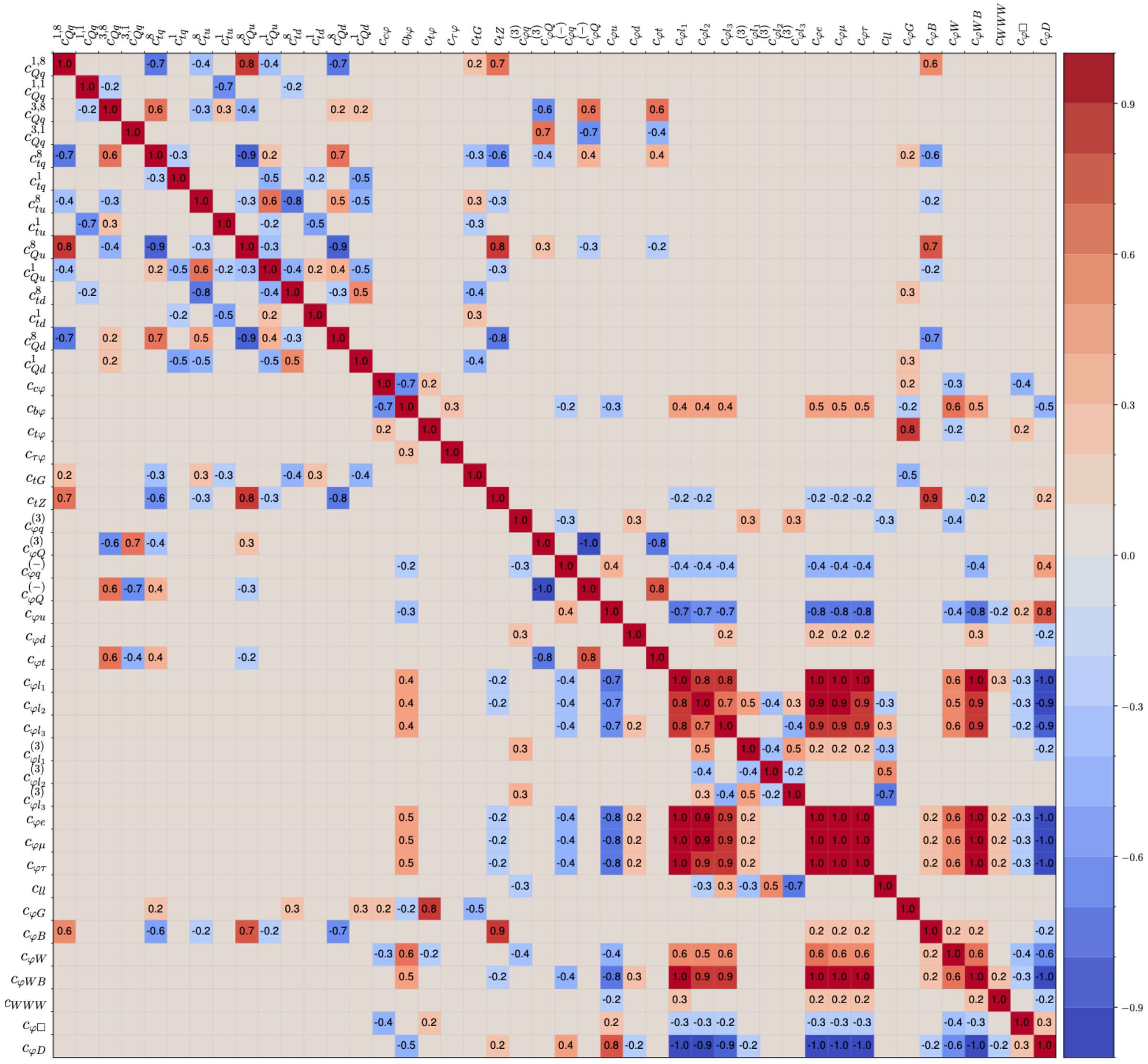
List of models

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	$(3,2)_{-5/6}$		

UV 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	$\left(\lambda_{Q_1}^u\right)_3$		
Υ	$(y_\Upsilon)_{33}$	Q_7	$(\lambda_{Q_7})_3$	$\mathcal{H}$	$(g_{\mathcal{H}})_{33}$
Φ	$(y_\Phi^{qu})_{33}$	T_1	$(\lambda_{T_1})_3$	$\mathcal{Q}_5$	$\left(g_{\mathcal{Q}_5}^{uq}\right)_{33}$
		T_2	$(\lambda_{T_2})_3$	$\mathcal{Y}_5$	$(g_{\mathcal{Y}_5})_{33}$

Correlations in linear fit

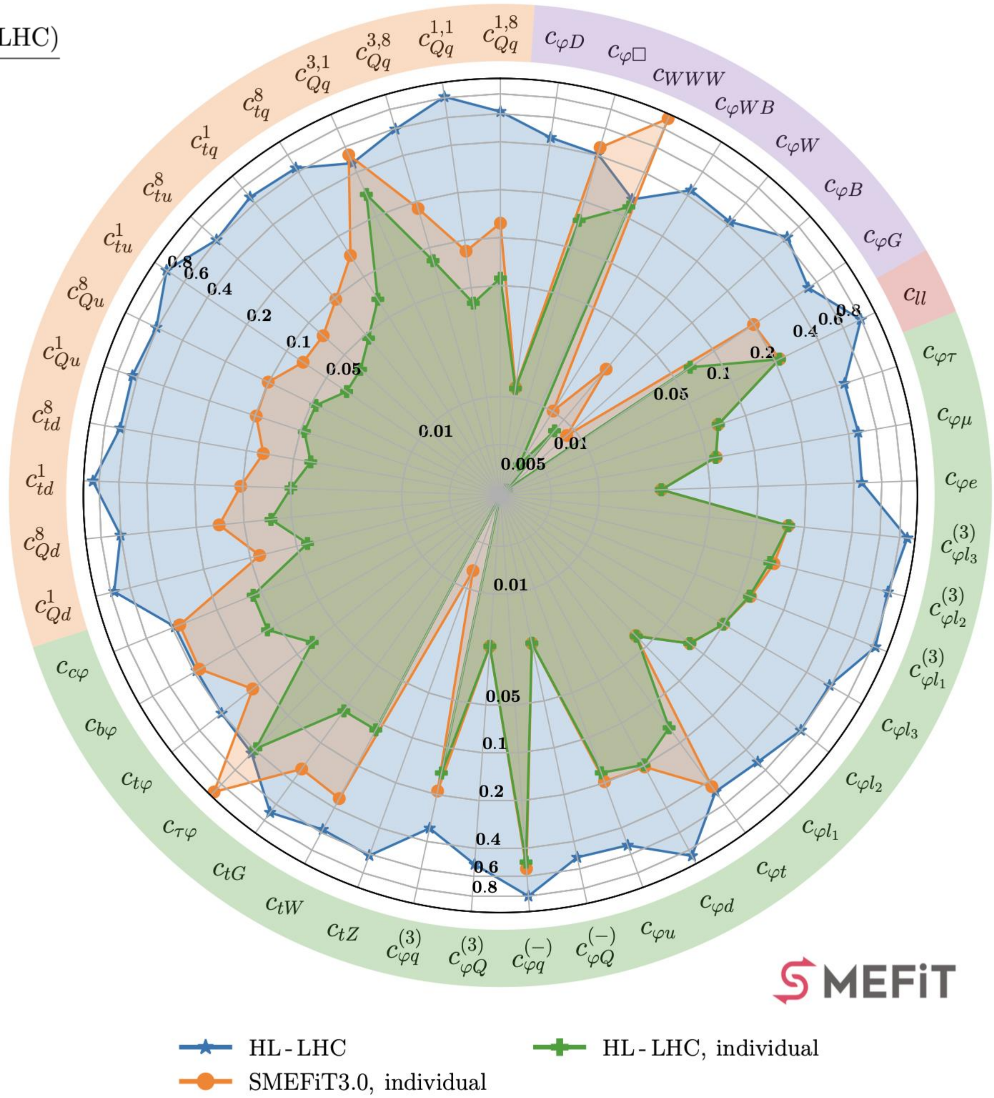


Correlation: NLO $\mathcal{O}\left(\Lambda^{-2}\right)$

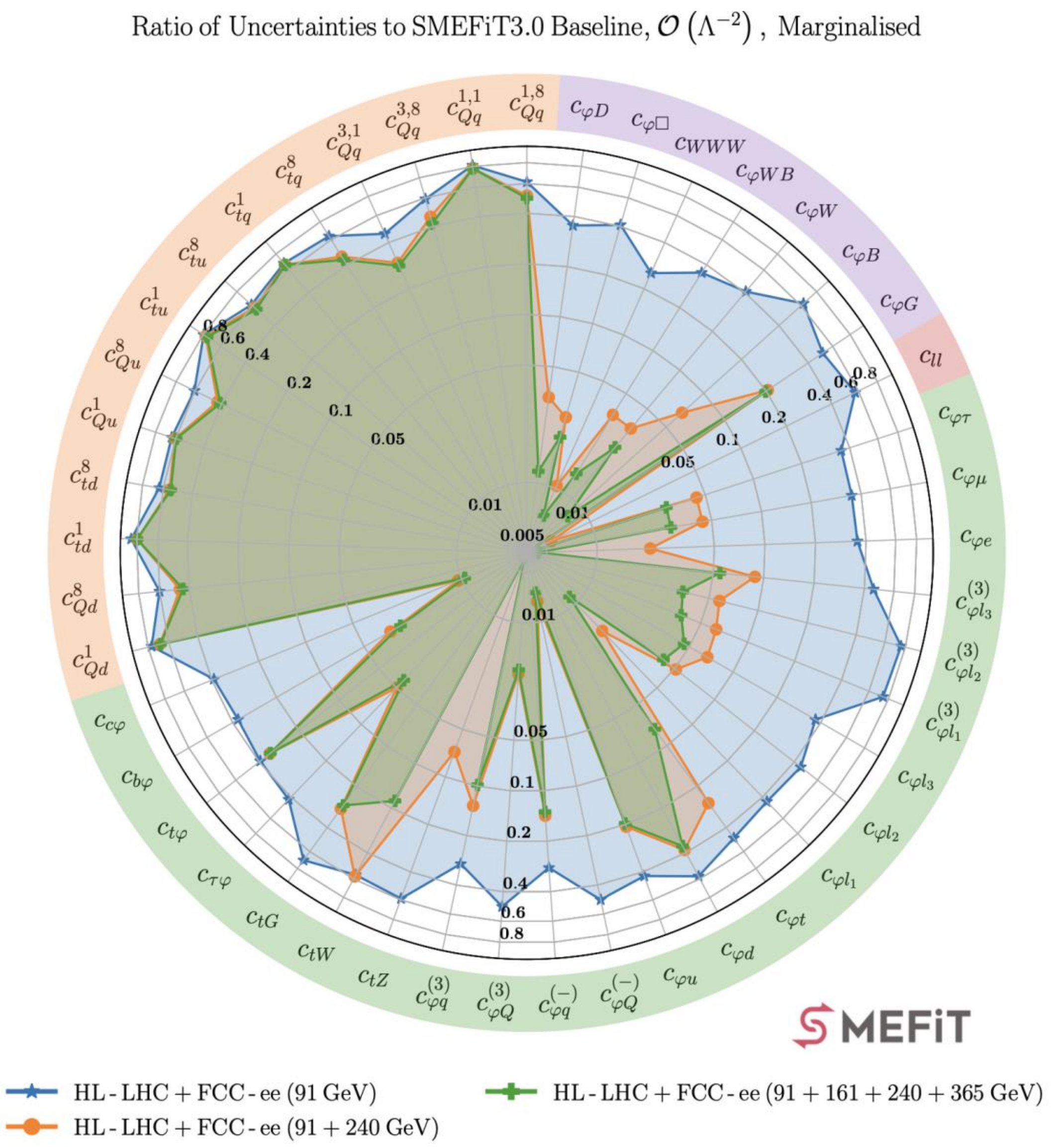
HL-LHC impact in detail

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

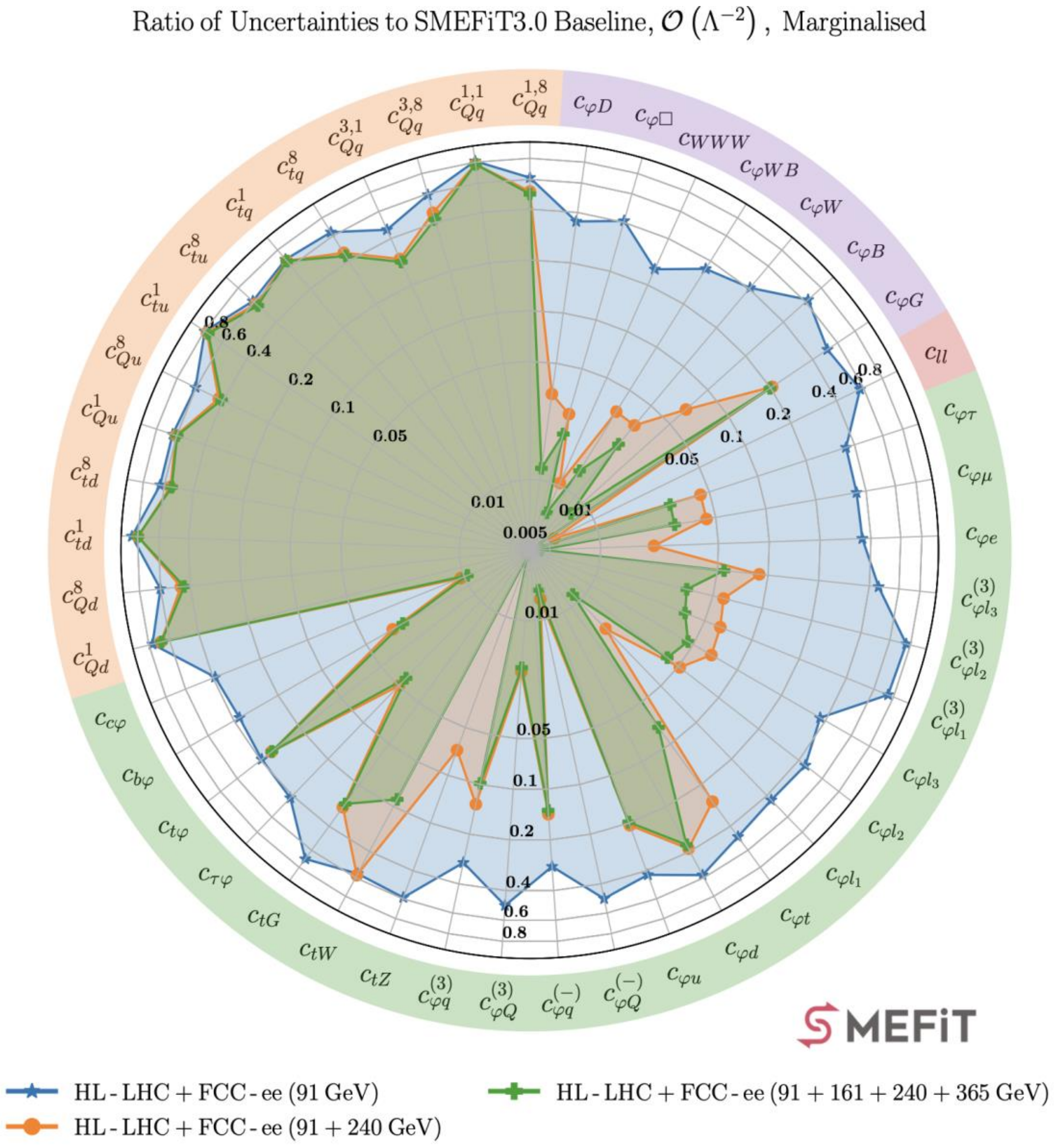
Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}\left(\Lambda^{-2}\right)$, Marginalised



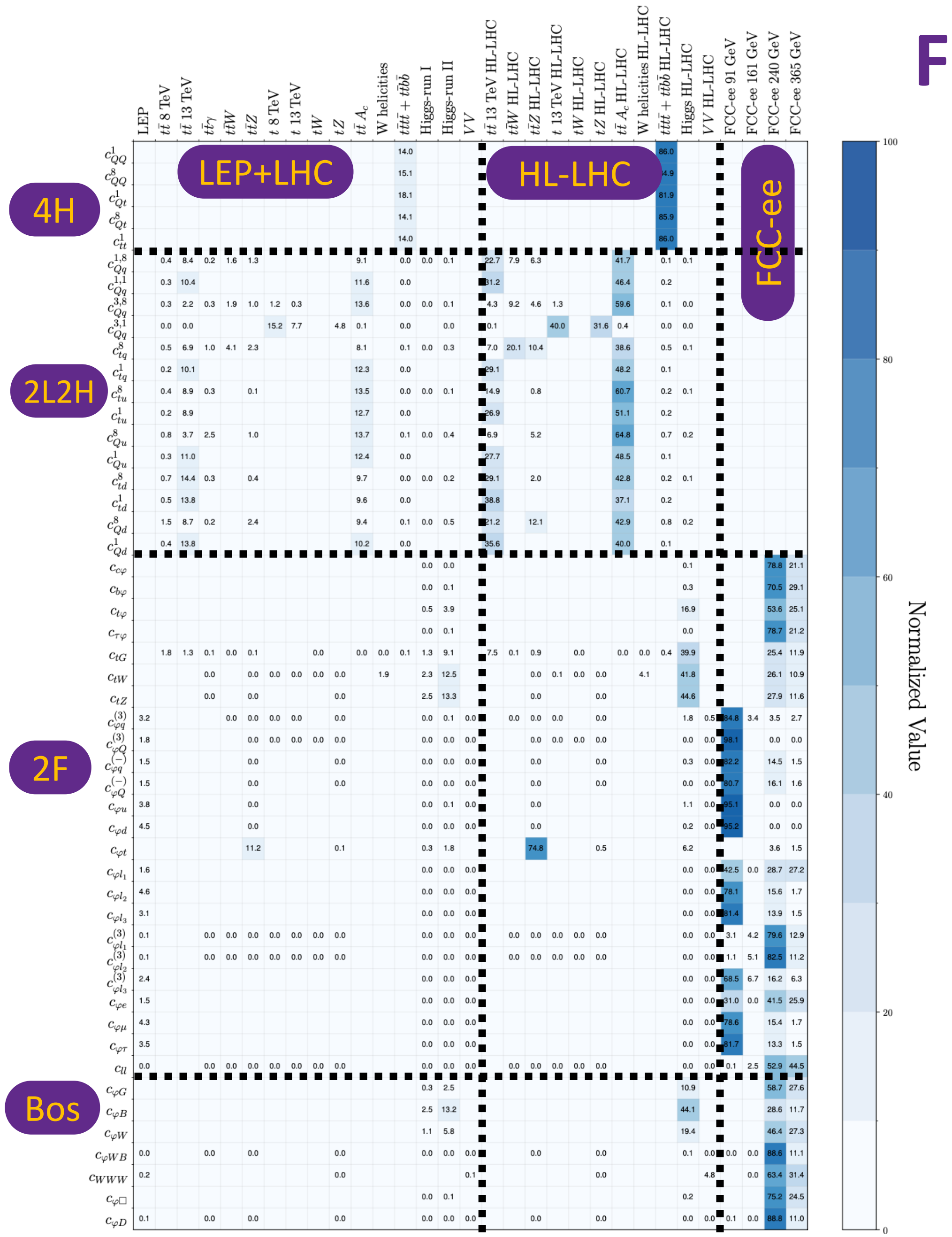
FCC-ee Energy runs



FCC-ee Energy runs



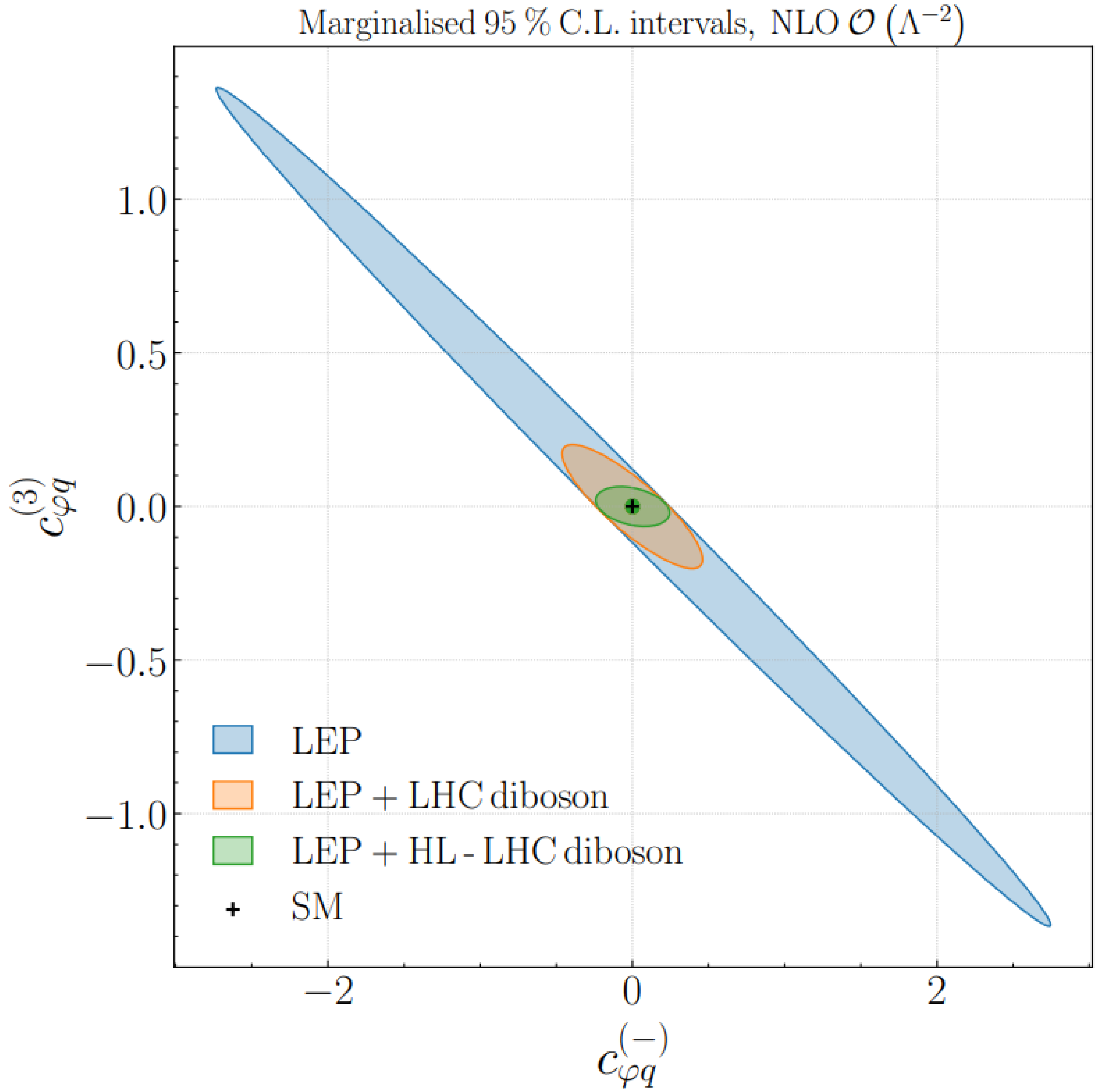
Fisher Information matrix



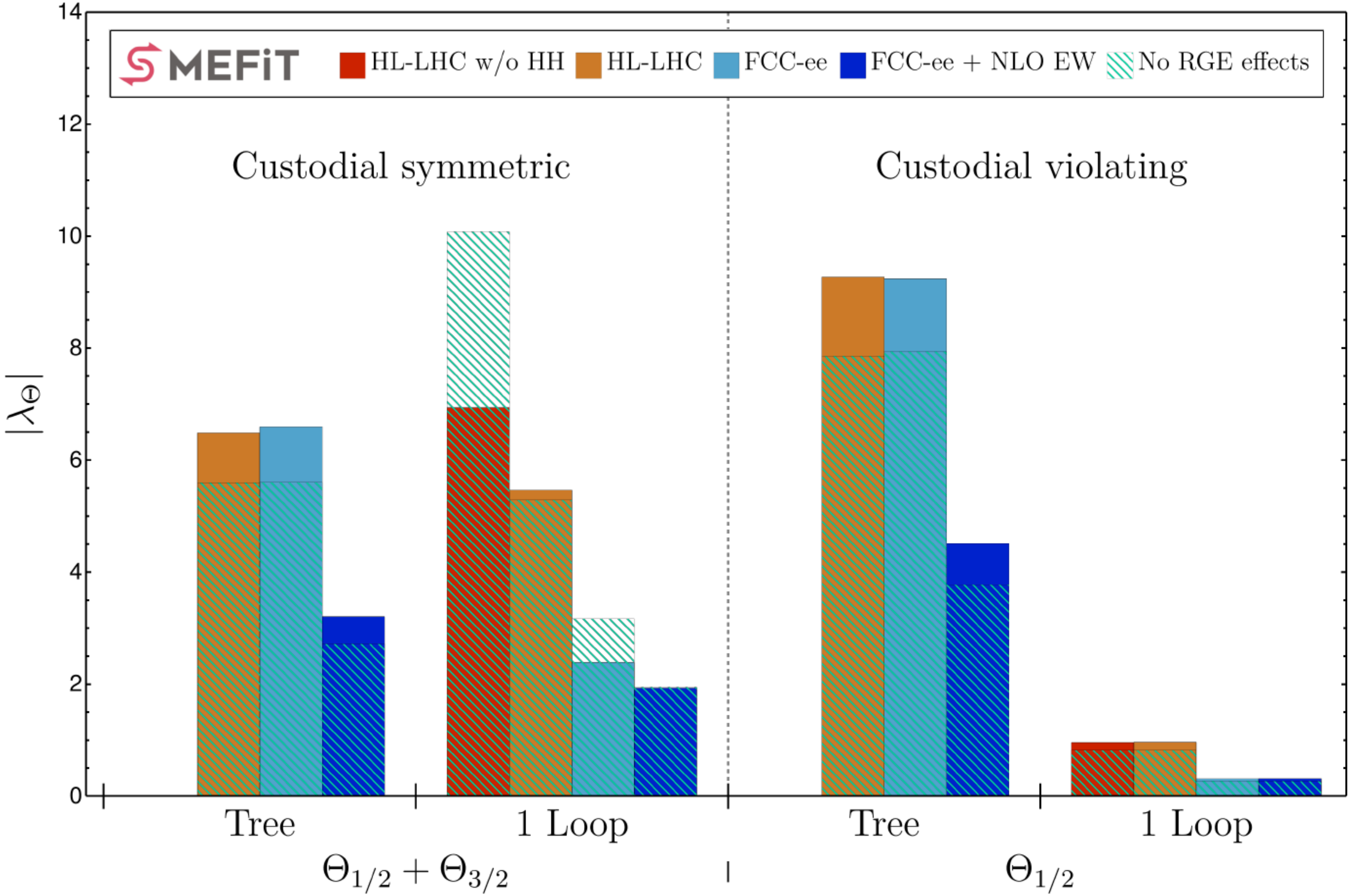
- Quantifies which datasets have more sensitivity to given operator
- Proxy for linear individual fit
- FCC-ee dominates nearly all operators except 4-quark operators, only accessible in pp collisions (tree level)
- Combination of 91 GeV and 240 GeV runs important to pin down 2-fermion and gauge operators
- FCC-ee run at 161 GeV is the least useful for the SMEFT

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

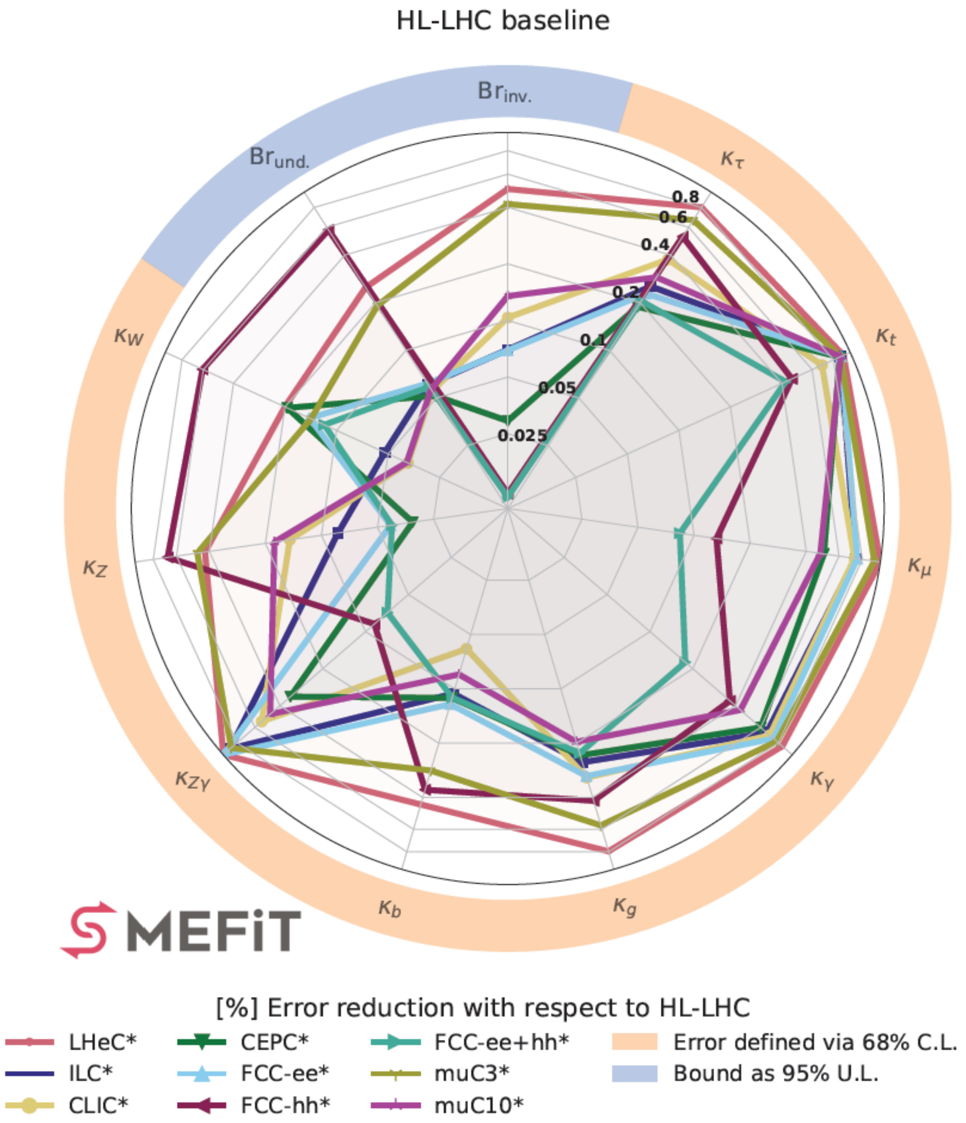
The power of multi(di)-boson

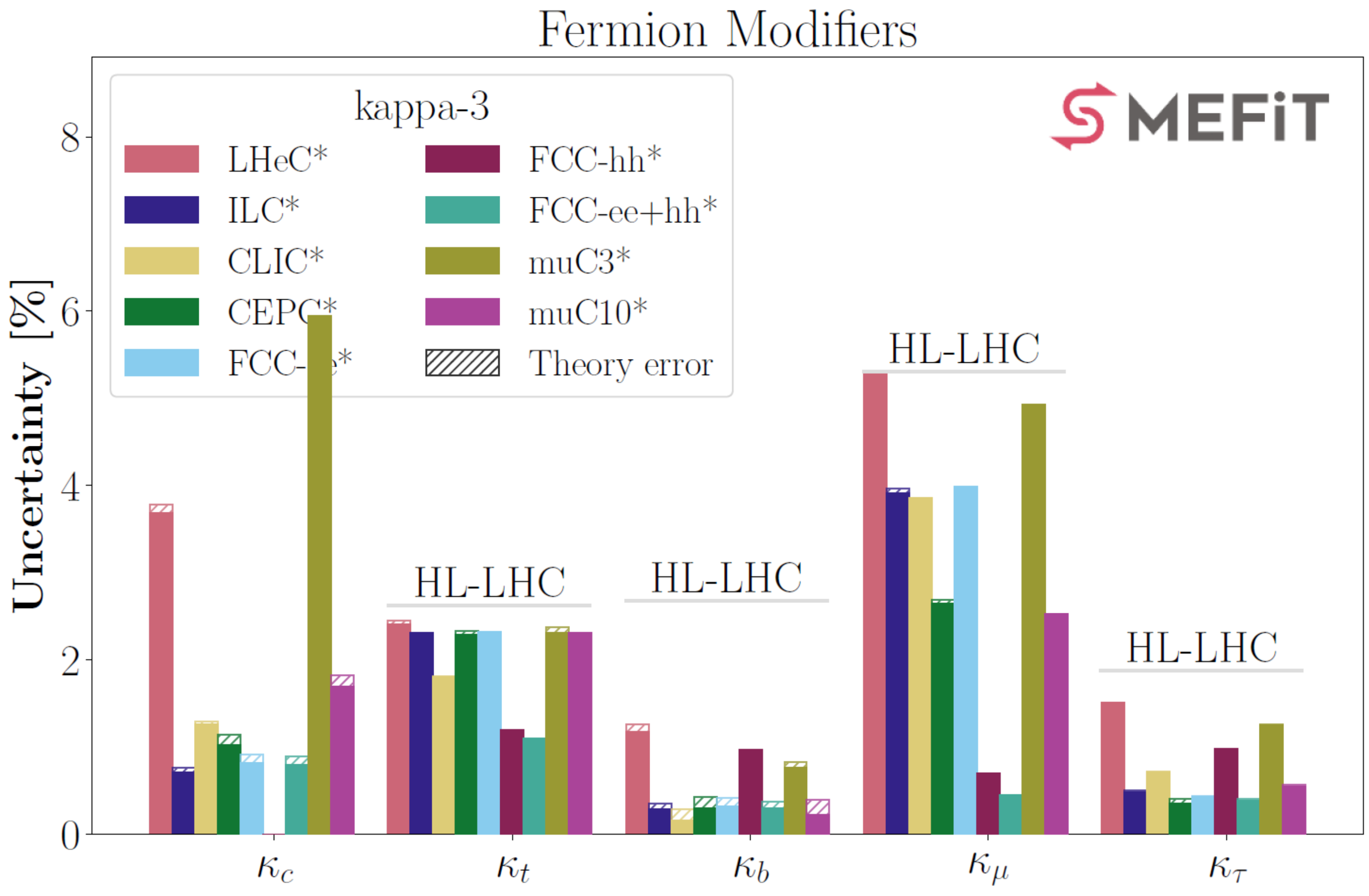


The special case of EW quadruplets



Kappa-Framework fit, a SMEFiT child





Armadillo et al [2503.xxyyy]