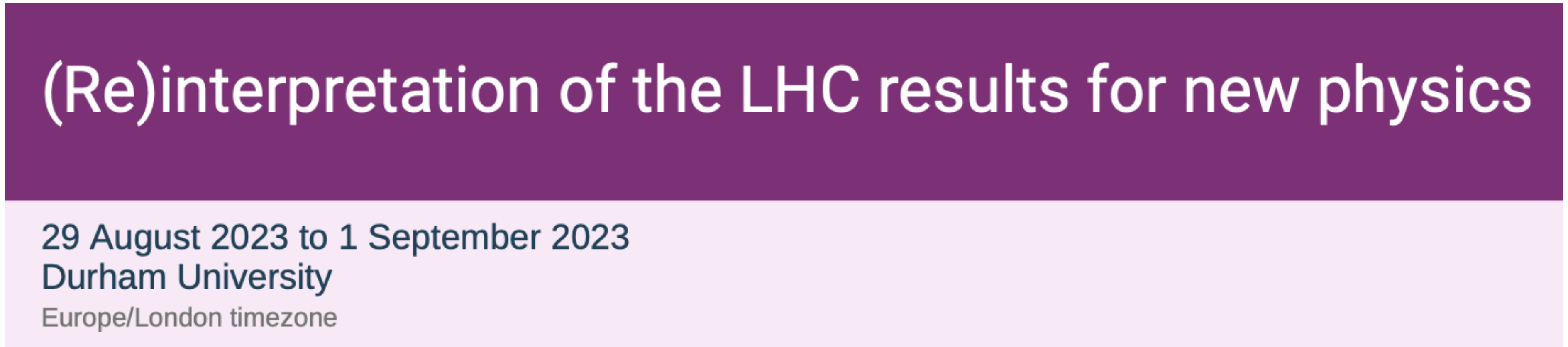
Interpreting HEP data in SMEFiT

An update from the SMEFiT* collaboration

Jaco ter Hoeve


(Re)interpretation of the LHC results for new physics

29 August 2023 to 1 September 2023
Durham University
Europe/London timezone

LHC RIF 2023 - 31/08

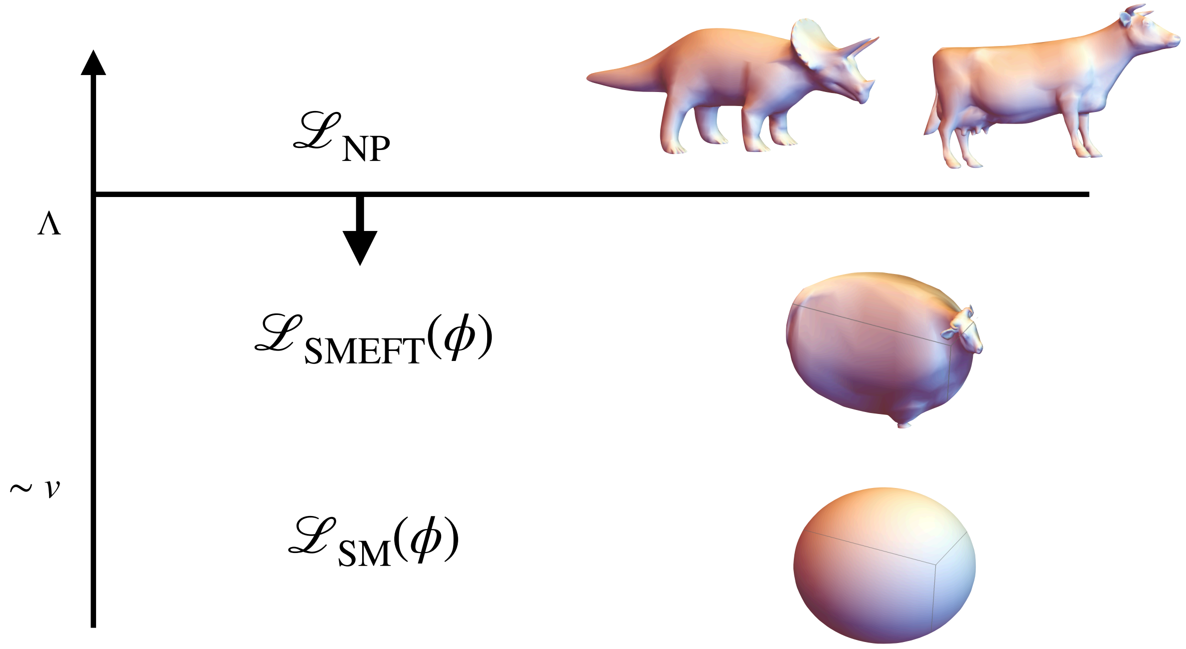
* E. Celada, H. El Faham, T. Giani, JtH, F. Maltoni, L. Mantani, G. Magni, J. Rojo, A. Rossia, C. Severi, M. Thomas, E. Vryonidou

The Standard Model as an EFT

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \sum_{i}^{N_{d5}} \frac{c_i}{\Lambda} \mathcal{O}_i^{(5)} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_{i}^{N_{d7}} \frac{c_i}{\Lambda^3} \mathcal{O}_i^{(7)} + \sum_{i}^{N_{d8}} \frac{b_i}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots$$

Wilson Coefficients (WC)

- **Systematic parameterisation** of the theory space in the vicinity of the SM
- **Low energy limit** of generic UV-complete theories at high energies
- Assumes the **SM fields and symmetries**
- Can be **matched** to any BSM model that reduces to the SM at low energies



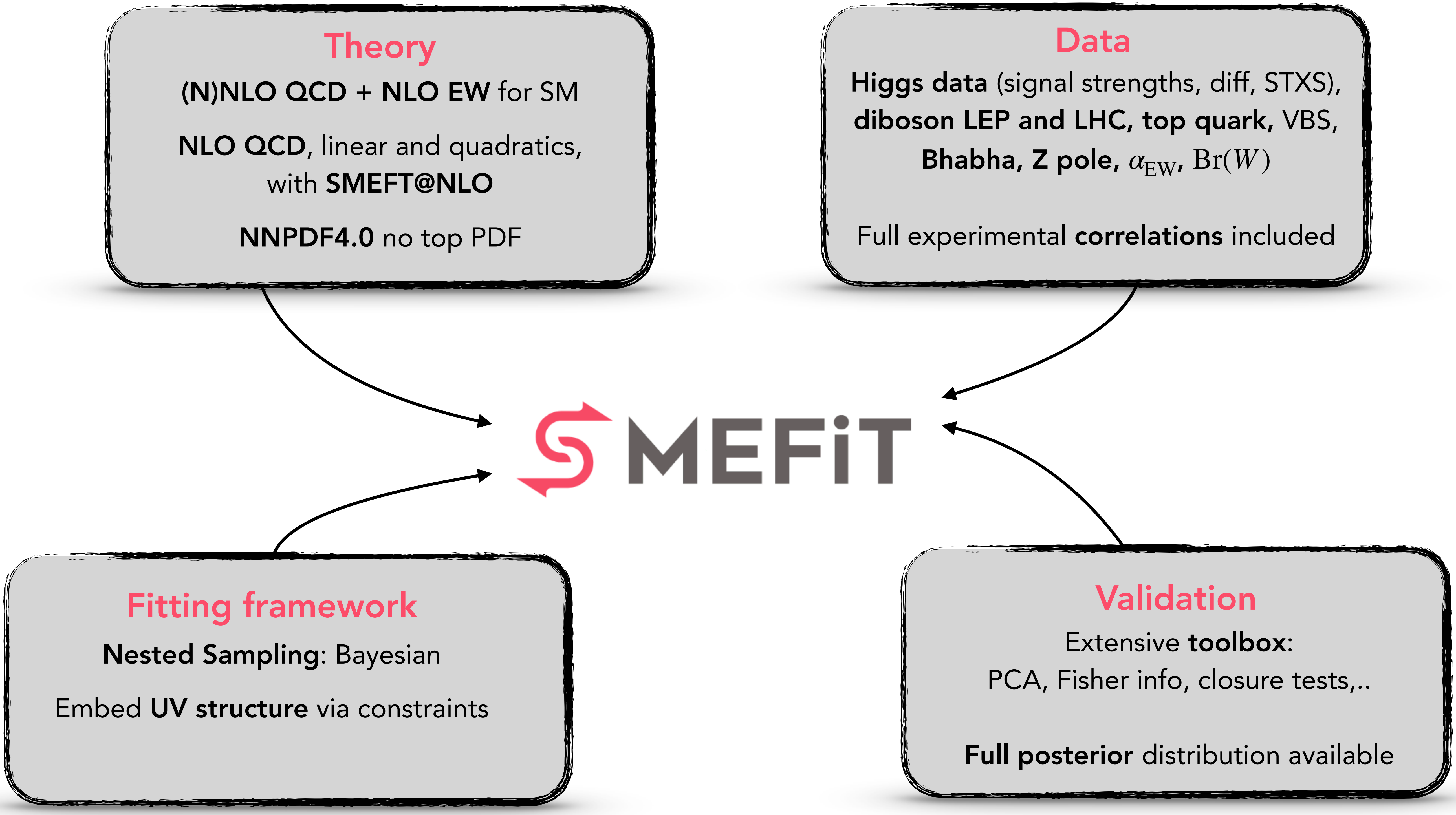
What is SMEFiT?

"A flexible toolbox for **global** interpretations of particle physics data with **EFTs**" [2302.06660]

SMEFiT

- *A Monte Carlo global analysis of the Standard Model Effective Field Theory: the* ***top quark sector*** *(2019)* [1901.05965]
- *Constraining the SMEFT with Bayesian reweighting (2019)* [1906.05296]
- *SMEFT analysis of VBS and diboson data from LHC Run II* [2101.03180]
- *Combined SMEFT interpretation of* ***Higgs, diboson, and top quark*** *data from the LHC (2021)* [2105.00006]
- *Automation of SMEFT-Assisted Constraints on UV complete Models (in preparation)*

The SMEFiT framework



Theory

(N)NLO QCD + NLO EW for SM

NLO QCD, linear and quadratics, with **SMEFT@NLO**

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Data

Higgs data (signal strengths, diff, STXS), **diboson LEP and LHC, top quark,** VBS, **Bhabha, Z pole,** α_{EW}, $\mathrm{Br}(W)$

Full experimental **correlations** included

SMEFiT

Fitting framework

Nested Sampling: Bayesian

Embed **UV structure** via constraints

Validation

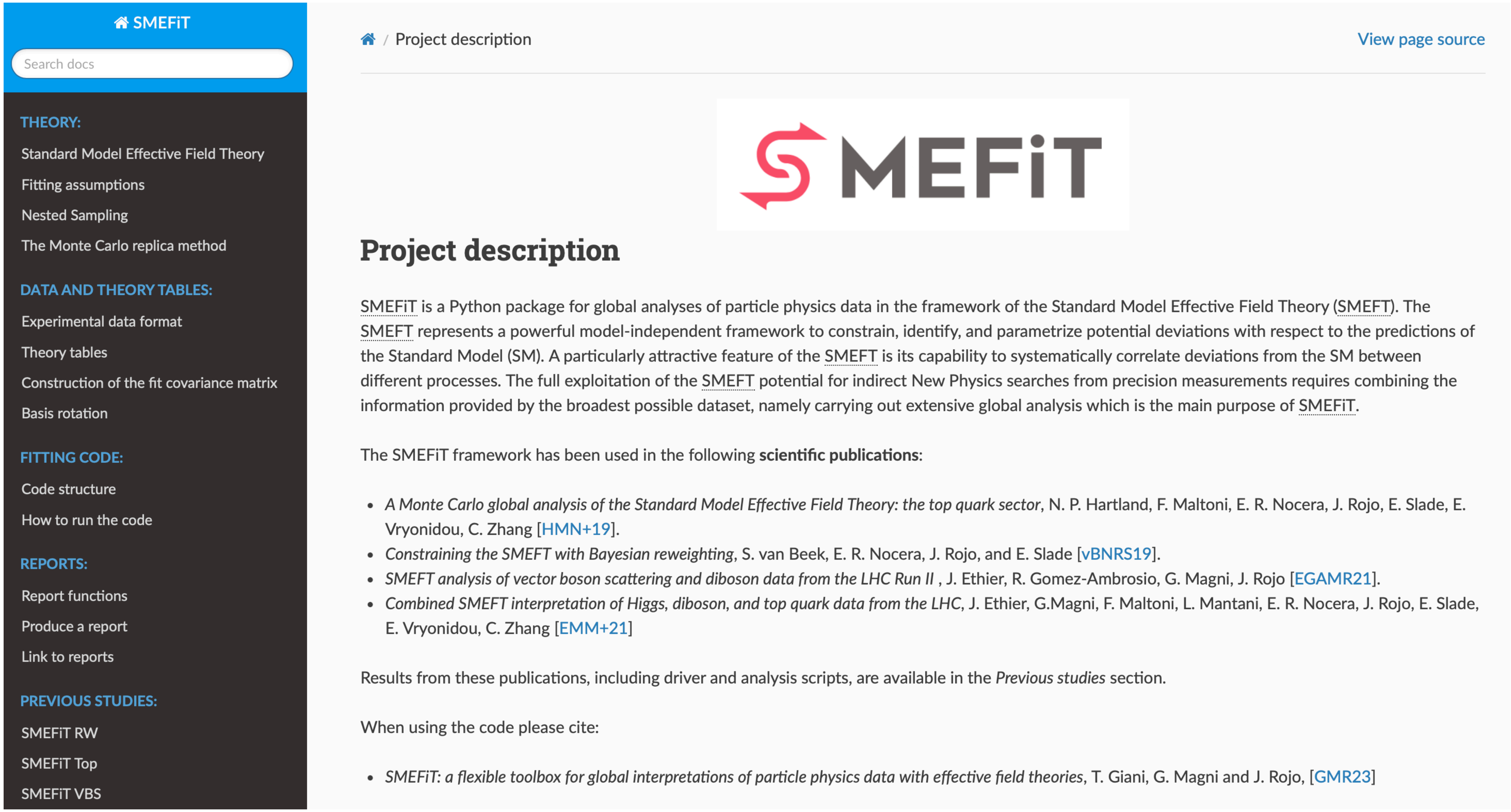
Extensive **toolbox**:
PCA, Fisher info, closure tests,..

Full posterior distribution available

The SMEFiT framework

Public code with tutorials and documentation available at

lhcfitnikhef.github.io/smefit_release/



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]

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

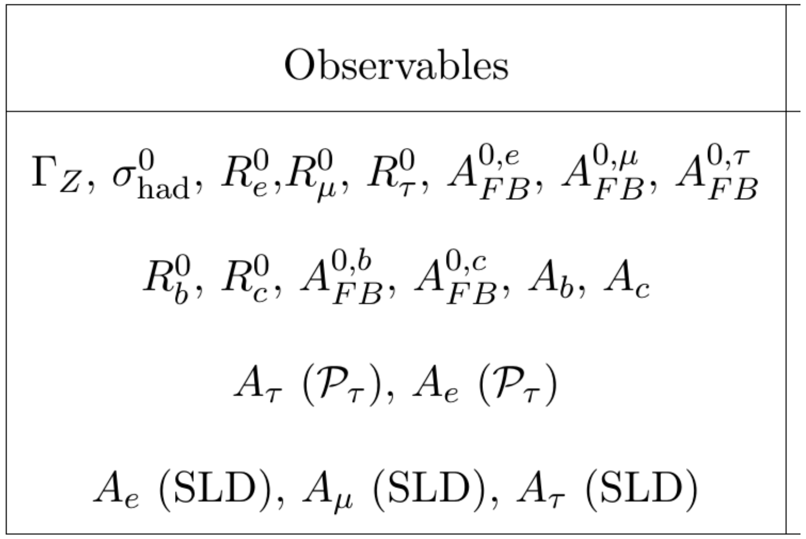
When using the code please cite:

- *SMEFiT: a flexible toolbox for global interpretations of particle physics data with effective field theories*, T. Giani, G. Magni and J. Rojo, [GMR23]

Major SMEFiT updates

First half of the talk

1. **Exact** implementation of the Electroweak Precision Observables (EWPOs) from LEP and SLC up to $\mathcal{O}\left(\Lambda^{-4}\right)$
   - Recomputed all EFT xsecs for processes sensitive to EWPO operators
   - Now 50 independent d.o.f. (36 before)



Observables
Γ_Z, σ^0_{had}, R^0_e,R^0_μ, R^0_τ, $A^{0,e}_{FB}$, $A^{0,\mu}_{FB}$, $A^{0,\tau}_{FB}$
R^0_b, R^0_c, $A^{0,b}_{FB}$, $A^{0,c}_{FB}$, A_b, A_c
A_τ $(\mathcal{P}_\tau)$, A_e $(\mathcal{P}_\tau)$
A_e (SLD), A_μ (SLD), A_τ (SLD)

2. Automatised constraints from **UV matching**

Second half of the talk

Both will come as dedicated publications, UV matching will be released soon!

Approximate EWPOs

- In the SMEFT, the SM couplings receive corrections from dim-6 operators

$$\begin{aligned}
\delta g_V^{l_i} &= \delta\bar{g}_Z \bar{g}_V^{l_i} + Q^{l_i}\delta s_\theta^2 + \Delta_V^{l_i} = 0\,, \quad i = 1,2,3\,,\\
\delta g_A^{l_i} &= \delta\bar{g}_Z \bar{g}_A^{l_i} + \Delta_A^{l_i} = 0\,, \quad i = 1,2,3\,,\\
\delta g_V^{u} &= \delta\bar{g}_Z \bar{g}_V^{u} + Q^{u}\delta s_\theta^2 + \Delta_V^{u} = 0\,,\\
\delta g_A^{u} &= \delta\bar{g}_Z \bar{g}_A^{u} + \Delta_A^{u} = 0\,,\\
\delta g_V^{d} &= \delta\bar{g}_Z \bar{g}_V^{d} + Q^{d}\delta s_\theta^2 + \Delta_V^{d} = 0\,,\\
\delta g_A^{d} &= \delta\bar{g}_Z \bar{g}_A^{d} + \Delta_A^{d} = 0\,,\\
\delta g_V^{W,l_i} &= \frac{c_{ll} + 2c_{\varphi\ell_i}^{(3)} - c_{\varphi\ell_1}^{(3)} - c_{\varphi\ell_2}^{(3)}}{4\sqrt{2}G_F} = 0\,, \quad i = 1,2,3\,,\\
\delta g_V^{W,q} &= \frac{c_{ll} + c_{\varphi q}^{(3)} - c_{\varphi\ell_1}^{(3)} - c_{\varphi\ell_2}^{(3)}}{4\sqrt{2}G_F} = 0\,,
\end{aligned}$$

$$\begin{pmatrix} c_{\varphi\ell_i}^{(3)} \\ c_{\varphi\ell_i}^{(1)} \\ c_{\varphi e/\mu/\tau} \\ c_{\varphi q}^{(-)} \\ c_{\varphi q}^{(3)} \\ c_{\varphi u} \\ c_{\varphi d} \\ c_{\ell\ell} \end{pmatrix} = \begin{pmatrix} -\frac{1}{t_W} & -\frac{1}{4t_W^2} \\ 0 & -\frac{1}{4} \\ 0 & -\frac{1}{2} \\ \frac{1}{t_W} & \frac{1}{4s_W^2} - \frac{1}{6} \\ -\frac{1}{t_W} & -\frac{1}{4t_W^2} \\ 0 & \frac{1}{3} \\ 0 & -\frac{1}{6} \\ 0 & 0 \end{pmatrix} \begin{pmatrix} c_{\varphi WB} \\ c_{\varphi D} \end{pmatrix}$$

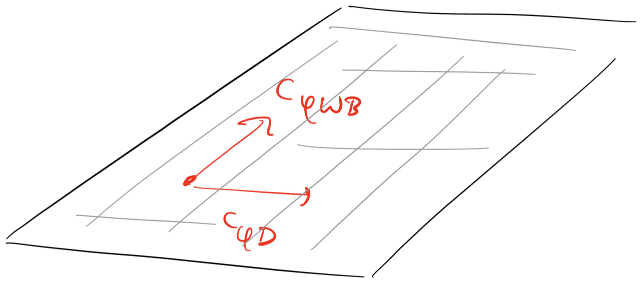
- Assume measurements at LEP are **precise** enough to set the linear combinations to zero: 14 constraints, 16 DoF

- Flavour assumption is **MFV**, with $U(2)_q \times U(2)_u \times U(3)_d$ in the quark sector and $\left(U(1)_\ell \times U(1)_e\right)^3$ in the lepton sector

Exact EWPOs

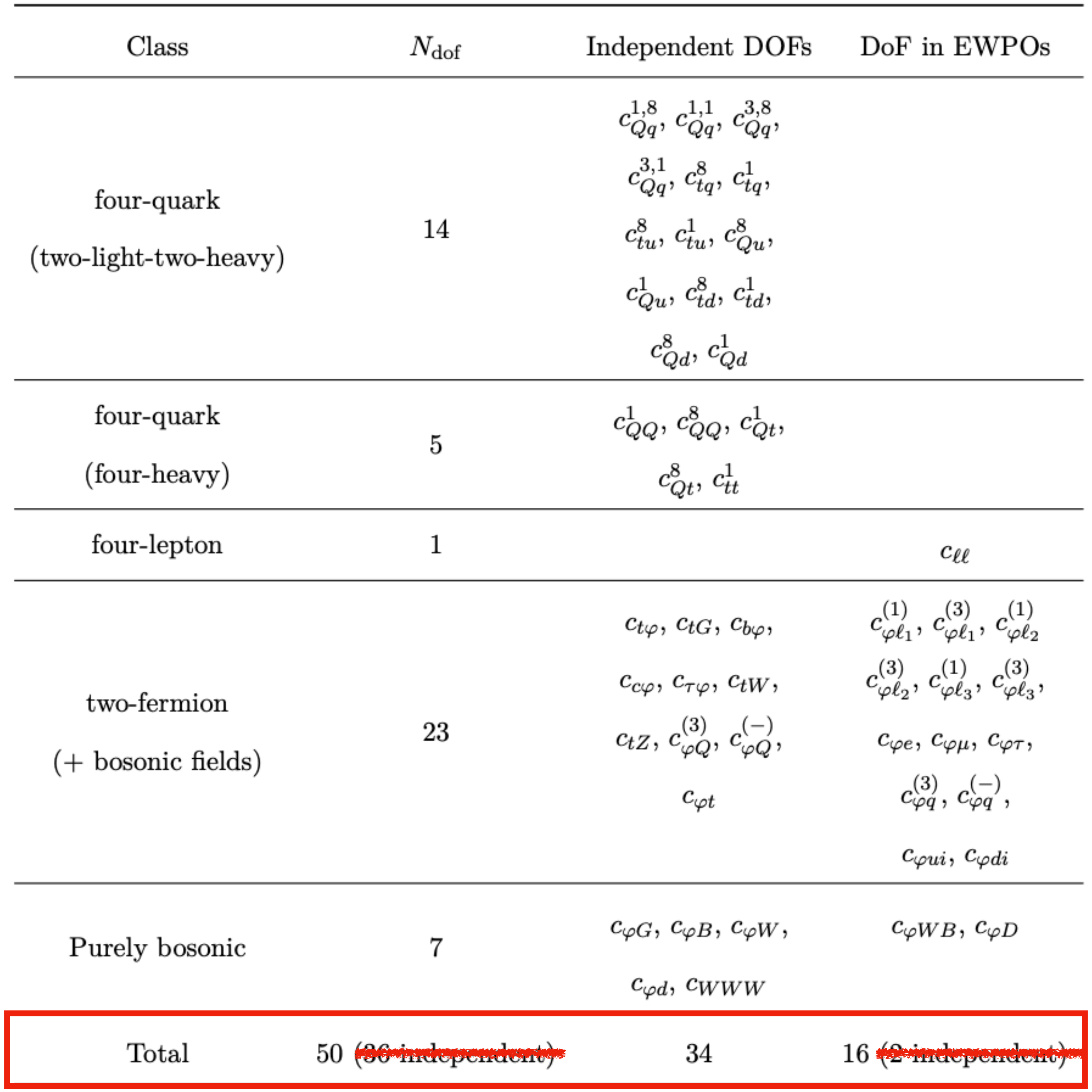
Class	N_{dof}	Independent DOFs	DoF in EWPOs
four-quark (two-light-two-heavy)	14	$c_{Qq}^{1,8}$, $c_{Qq}^{1,1}$, $c_{Qq}^{3,8}$, $c_{Qq}^{3,1}$, c_{tq}^{8}, c_{tq}^{1}, c_{tu}^{8}, c_{tu}^{1}, c_{Qu}^{8}, c_{Qu}^{1}, c_{td}^{8}, c_{td}^{1}, c_{Qd}^{8}, c_{Qd}^{1}	
four-quark (four-heavy)	5	c_{QQ}^{1}, c_{QQ}^{8}, c_{Qt}^{1}, c_{Qt}^{8}, c_{tt}^{1}	
four-lepton	1		$c_{\ell\ell}$
two-fermion (+ bosonic fields)	23	$c_{t\varphi}$, c_{tG}, $c_{b\varphi}$, $c_{c\varphi}$, $c_{\tau\varphi}$, c_{tW}, c_{tZ}, $c_{\varphi Q}^{(3)}$, $c_{\varphi Q}^{(-)}$, $c_{\varphi t}$	$c_{\varphi\ell_1}^{(1)}$, $c_{\varphi\ell_1}^{(3)}$, $c_{\varphi\ell_2}^{(1)}$, $c_{\varphi\ell_2}^{(3)}$, $c_{\varphi\ell_3}^{(1)}$, $c_{\varphi\ell_3}^{(3)}$, $c_{\varphi e}$, $c_{\varphi\mu}$, $c_{\varphi\tau}$, $c_{\varphi q}^{(3)}$, $c_{\varphi q}^{(-)}$, $c_{\varphi ui}$, $c_{\varphi di}$
Purely bosonic	7	$c_{\varphi G}$, $c_{\varphi B}$, $c_{\varphi W}$, $c_{\varphi d}$, c_{WWW}	$c_{\varphi WB}$, $c_{\varphi D}$
Total	50 (36 independent)	34	16 (2 independent)

- No longer impose constraints from LEP EWPOs via restrictions in parameter space



- Include 14 additional WCs as parameters in the fit
- 50 independent DoF

Exact EWPOs



Class	N_{dof}	Independent DOFs	DoF in EWPOs
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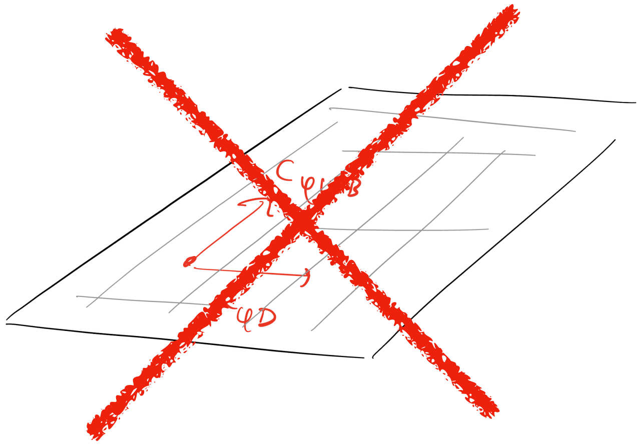
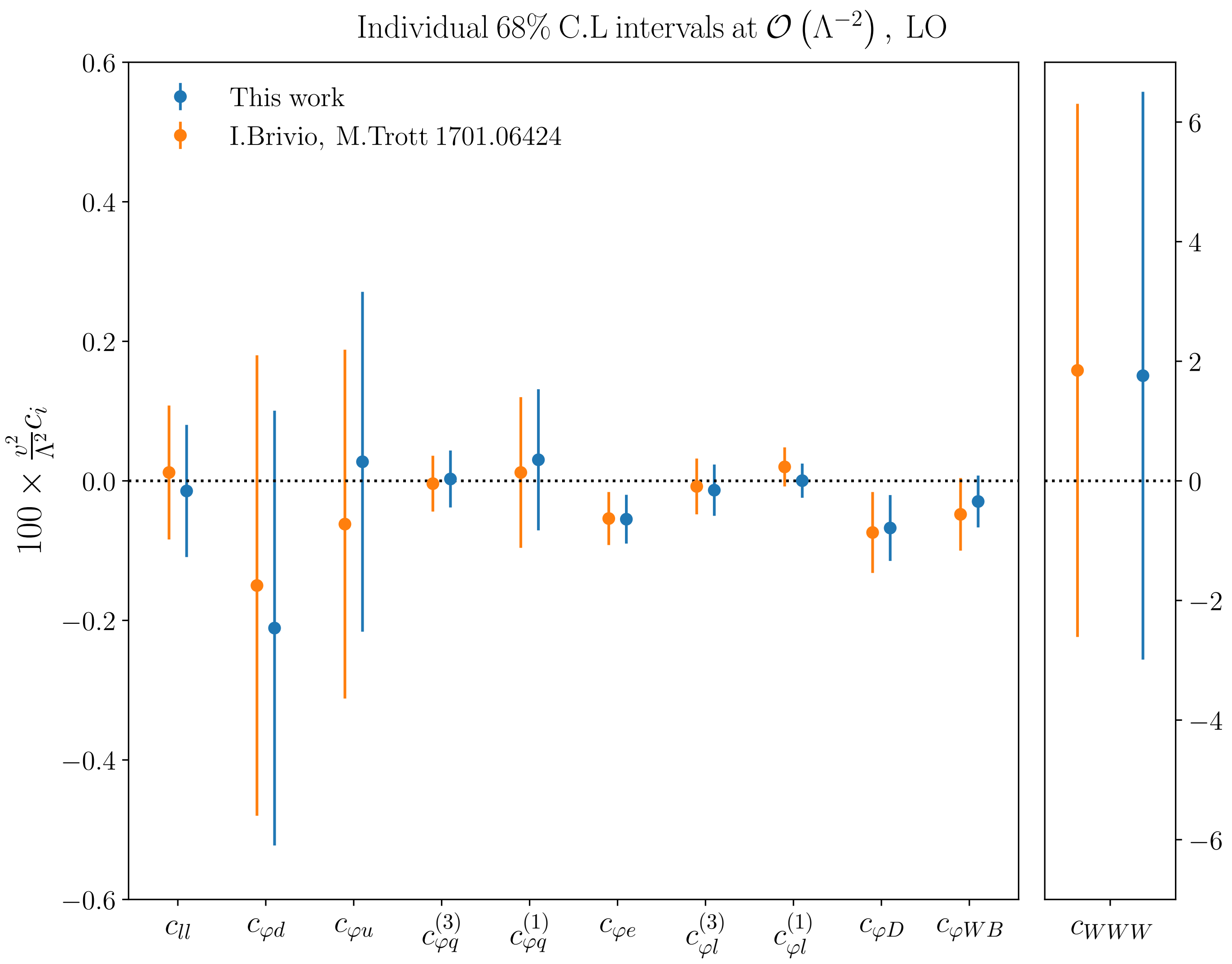
four-quark (four-heavy)	5	c_{QQ}^{1}, c_{QQ}^{8}, c_{Qt}^{1}, c_{Qt}^{8}, c_{tt}^{1}	
four-lepton	1		$c_{\ell\ell}$
two-fermion (+ bosonic fields)	23	$c_{t\varphi}$, c_{tG}, $c_{b\varphi}$, $c_{c\varphi}$, $c_{\tau\varphi}$, c_{tW}, c_{tZ}, $c_{\varphi Q}^{(3)}$, $c_{\varphi Q}^{(-)}$, $c_{\varphi t}$	$c_{\varphi\ell_1}^{(1)}$, $c_{\varphi\ell_1}^{(3)}$, $c_{\varphi\ell_2}^{(1)}$ $c_{\varphi\ell_2}^{(3)}$, $c_{\varphi\ell_3}^{(1)}$, $c_{\varphi\ell_3}^{(3)}$, $c_{\varphi e}$, $c_{\varphi\mu}$, $c_{\varphi\tau}$, $c_{\varphi q}^{(3)}$, $c_{\varphi q}^{(-)}$, $c_{\varphi ui}$, $c_{\varphi di}$
Purely bosonic	7	$c_{\varphi G}$, $c_{\varphi B}$, $c_{\varphi W}$, $c_{\varphi d}$, c_{WWW}	$c_{\varphi WB}$, $c_{\varphi D}$
Total	50 ~~(36 independent)~~	34	16 ~~(2 independent)~~

- No longer impose constraints from LEP EWPOs via restrictions in parameter space



- Include 14 additional WCs as parameters in the fit
- 50 independent DoF

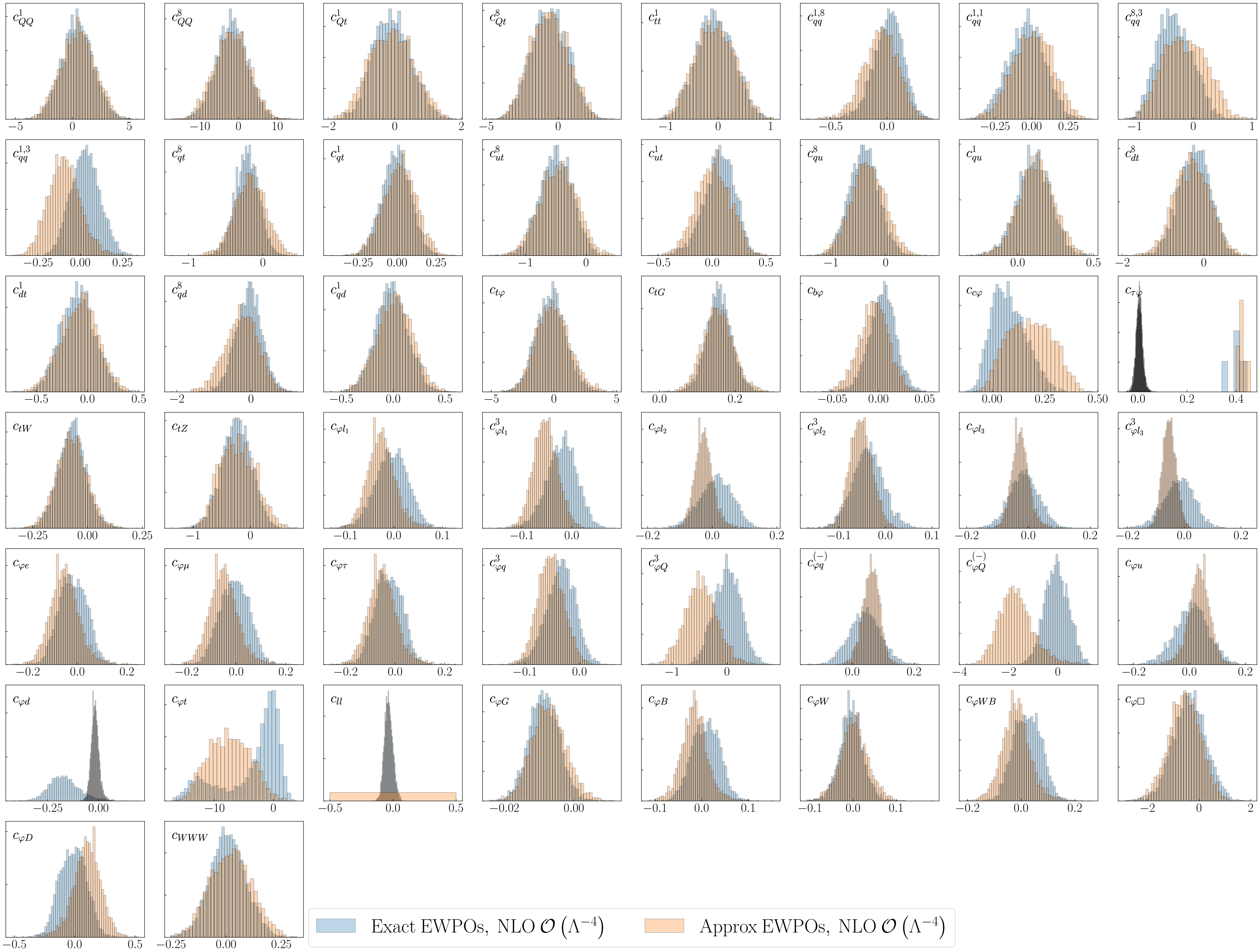
EWPOs benchmark



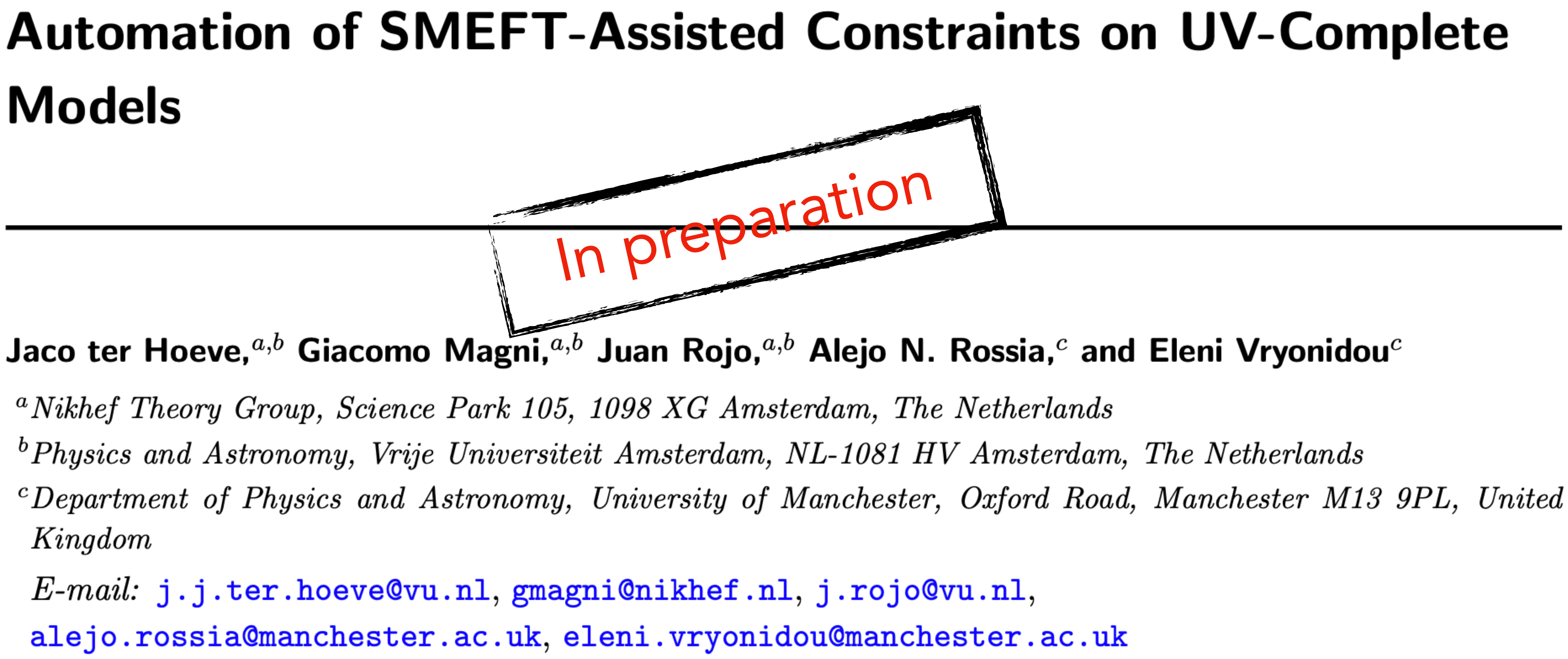
- Adopt $\{m_W, m_Z, G_F\}$ scheme
- We include Bhabha scattering, Z pole, $\mathrm{Br}(W)$ and α_{EW} (optional)
- 15/18 constrained directions with SMEFiT flavour assumptions
- 8/10 constrained directions in flavour universal scenario

$$w_1^{mW} = \frac{\bar{v}_T^2}{\Lambda^2}\left(\frac{1}{3}C_{Hd} - 2C_{HD} + C_{He} + \frac{1}{2}C_{Hl}^{(1)} - \frac{1}{6}C_{Hq}^{(1)} - \frac{2}{3}C_{Hu} - 1.24(C_{Hq}^{(3)} + C_{Hl}^{(3)}) + 1.60C_{HWB}\right) \tag{3.40}$$

$$w_2^{mW} = \frac{\bar{v}_T^2}{\Lambda^2}\left(\frac{1}{3}C_{Hd} - 2C_{HD} + C_{He} + \frac{1}{2}C_{Hl}^{(1)} - \frac{1}{6}C_{Hq}^{(1)} - \frac{2}{3}C_{Hu} + 2.20(C_{Hq}^{(3)} + C_{Hl}^{(3)}) - 0.24C_{HWB}\right)$$

c^1_{QQ} −5 0 5
c^8_{QQ} −10 0 10
c^1_{Qt} −2 0 2
c^8_{Qt} −5 0
c^1_{tt} −1 0 1
$c^{1,8}_{qq}$ −0.5 0.0
$c^{1,1}_{qq}$ −0.25 0.00 0.25
$c^{8,3}_{qq}$ −1 0 1
$c^{1,3}_{qq}$ −0.25 0.00 0.25
c^8_{qt} −1 0
c^1_{qt} −0.25 0.00 0.25
c^8_{ut} −1 0
c^1_{ut} −0.5 0.0 0.5
c^8_{qu} −1 0
c^1_{qu} 0.0 0.5
c^8_{dt} −2 0
c^1_{dt} −0.5 0.0 0.5
c^8_{qd} −2 0
c^1_{qd} −0.5 0.0 0.5
$c_{t\varphi}$ −5 0 5
c_{tG} 0.0 0.2
$c_{b\varphi}$ −0.05 0.00 0.05
$c_{c\varphi}$ 0.00 0.25 0.50
$c_{\tau\varphi}$ 0.0 0.2 0.4
c_{tW} −0.25 0.00 0.25
c_{tZ} −1 0
$c_{\varphi l_1}$ −0.1 0.0 0.1
$c^3_{\varphi l_1}$ −0.1 0.0
$c_{\varphi l_2}$ −0.2 0.0 0.2
$c^3_{\varphi l_2}$ −0.1 0.0 0.1
$c_{\varphi l_3}$ −0.2 0.0 0.2
$c^3_{\varphi l_3}$ −0.2 0.0 0.2
$c_{\varphi e}$ −0.2 0.0 0.2
$c_{\varphi \mu}$ −0.2 0.0 0.2
$c_{\varphi \tau}$ −0.2 0.0 0.2
$c^3_{\varphi q}$ −0.1 0.0
$c^3_{\varphi Q}$ −1 0
$c^{(-)}_{\varphi q}$ 0.0 0.2
$c^{(-)}_{\varphi Q}$ −4 −2 0
$c_{\varphi u}$ −0.2 0.0 0.2
$c_{\varphi d}$ −0.25 0.00
$c_{\varphi t}$ −10 0
c_{ll} −0.5 0.0 0.5
$c_{\varphi G}$ −0.02 0.00
$c_{\varphi B}$ −0.1 0.0 0.1
$c_{\varphi W}$ −0.1 0.0 0.1
$c_{\varphi WB}$ −0.2 0.0 0.2
$c_{\varphi \Box}$ −2 0 2
$c_{\varphi D}$ −0.5 0.0 0.5
c_{WWW} −0.25 0.00 0.25
Exact EWPOs, NLO $\mathcal{O}\left(\Lambda^{-4}\right)$
Approx EWPOs, NLO $\mathcal{O}\left(\Lambda^{-4}\right)$

Matching to UV complete models



Automation of SMEFT-Assisted Constraints on UV-Complete Models

In preparation

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UV matching

- The ultimate goal of the EFT framework is to **bridge the energy gap** to UV complete models

- In the EFT approach, there is no need to constrain models on a case-by-case basis provided **matching relations** are known

- Example: extend the SM with a complex scalar $\phi \sim (1{,}2)_{1/2}$

$$\begin{aligned}\mathcal{L}_{\mathrm{UV}} =& \mathcal{L}_{\mathrm{SM}} + |D_\mu \phi|^2 - m_\phi^2 \phi^\dagger \phi - \Big(y^e_{\phi,ij}\, \phi^\dagger \bar{e}^i_R \ell^j_L + y^d_{\phi,ij}\, \phi^\dagger \bar{d}^i_R q^j_L \\ & + y^u_{\phi,ij}\, \phi^\dagger i\sigma_2 \bar{q}^{T,i}_L u^j_R + \lambda_\phi\, \phi^\dagger \varphi |\varphi|^2 + \mathrm{h.c.} \Big) .\end{aligned}$$

Integrate out ϕ to find

$$\frac{\left(c_{qu}^{(1)}\right)_{3333}}{\Lambda^2} = -\frac{\left(y^u_{\phi,33}\right)^2}{6\, m_\phi^2}, \quad \frac{\left(c_{qu}^{(8)}\right)_{3333}}{\Lambda^2} = -\frac{\left(y^u_{\phi,33}\right)^2}{m_\phi^2}, \quad \frac{(c_{u\varphi})_{33}}{\Lambda^2} = -\frac{\lambda_\phi\, y^u_{\phi,33}}{m_\phi^2}, \quad \frac{c_\varphi}{\Lambda^2} = 0$$

UV matching

- What do we learn from this?

$$\frac{\left(c_{qu}^{(1)}\right)_{3333}}{\Lambda^2} = -\frac{\left(y^u_{\phi,33}\right)^2}{6\,m_\phi^2}, \quad \frac{\left(c_{qu}^{(8)}\right)_{3333}}{\Lambda^2} = -\frac{\left(y^u_{\phi,33}\right)^2}{m_\phi^2}, \quad \frac{(c_{u\varphi})_{33}}{\Lambda^2} = -\frac{\lambda_\phi\, y^u_{\phi,33}}{m_\phi^2}, \quad \frac{c_\varphi}{\Lambda^2} = 0$$

- The UV model gives **additional structure** on the EFT parameter space
  - **Positivity** constraints
  - Some UV parameters appear only as a **product**
- **Natural question:** How do we **embed** this structure in EFT fits?

UV matching in SMEFiT

1. Assume a matching relation between the Wilson coefficients $\mathbf{c}$ and the UV parameters $\mathbf{g}$ at a scale μ

$$\mathbf{c} = f(\mathbf{g}, \mu)$$

`Matchmakereft`

[2122.10787]

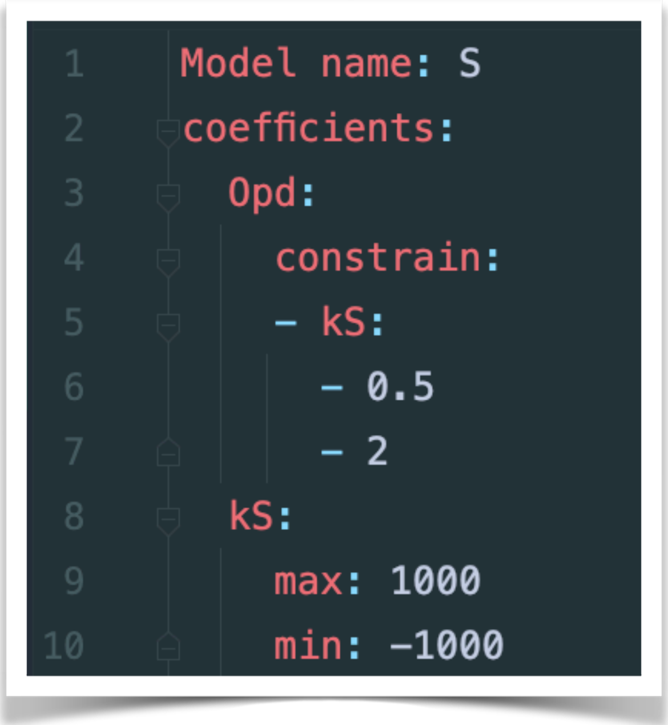
2. Reparameterise the EFT cross-section σ in terms of the UV parameters

$$\sigma(\mathbf{c}) = \sigma(f(\mathbf{g}, \mu))$$

3. Assume a flat prior $\pi(\mathbf{g})$, and repeat **global SMEFT analysis** with matching relation f **built in**

NEW

The interface between `Matchmakereft` and SMEFiT is provided by a **new** Mathematica package `Match2Fit`

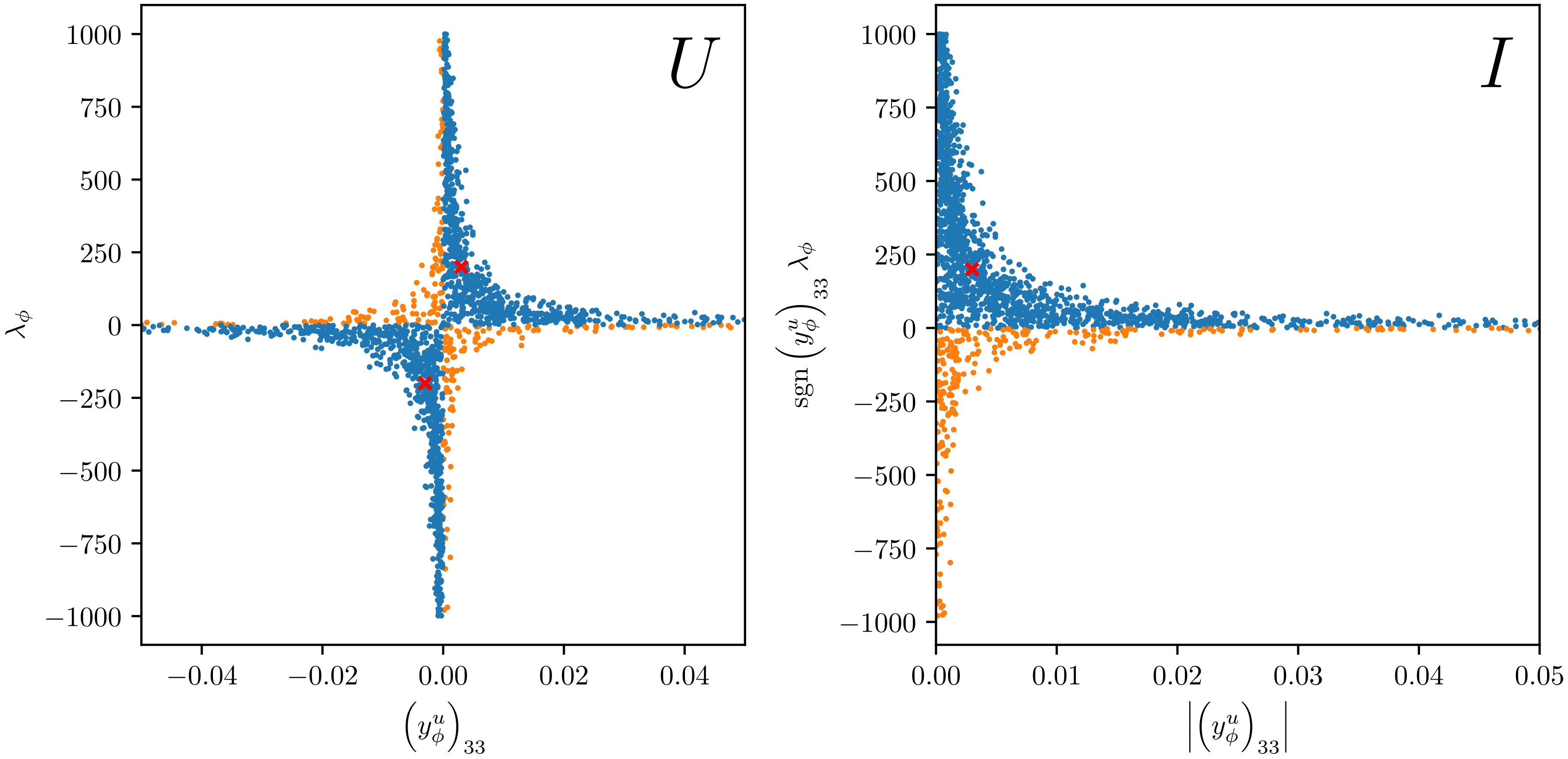


```
Model name: S
coefficients:
  Opd:
    constrain:
    - kS:
      - 0.5
      - 2
  kS:
    max: 1000
    min: -1000
```

$$c_{\varphi\Box} = \frac{1}{2} k_S^2$$

UV invariants

- In the fit, we can only discriminate UV parameters $\mathbf{g}$ that map to **different** Wilson coefficients $\mathbf{c} = f(\mathbf{g}, \mu)$
- Introduce *UV invariants* $h : U \to I$



$$U = \text{UV parameters}$$

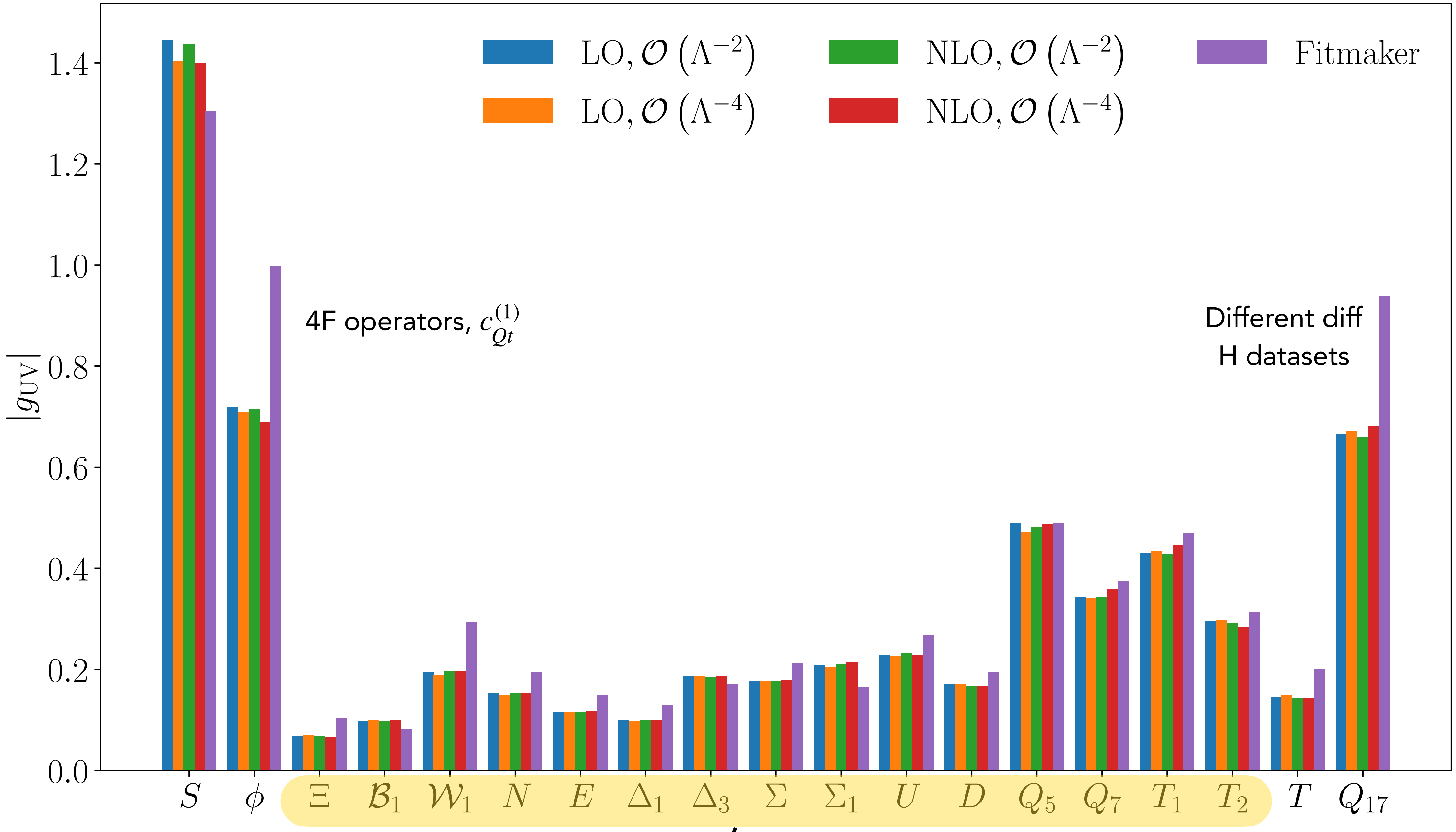
$$I = \text{UV invariants}$$

$$f(h(\mathbf{g})) = f(h(\mathbf{g}'))$$

UV matching in SMEFiT

Comparison to the Fitmaker group [2012.02779]

$m_{\mathrm{UV}} = 1$ TeV



4F operators, $c_{Qt}^{(1)}$

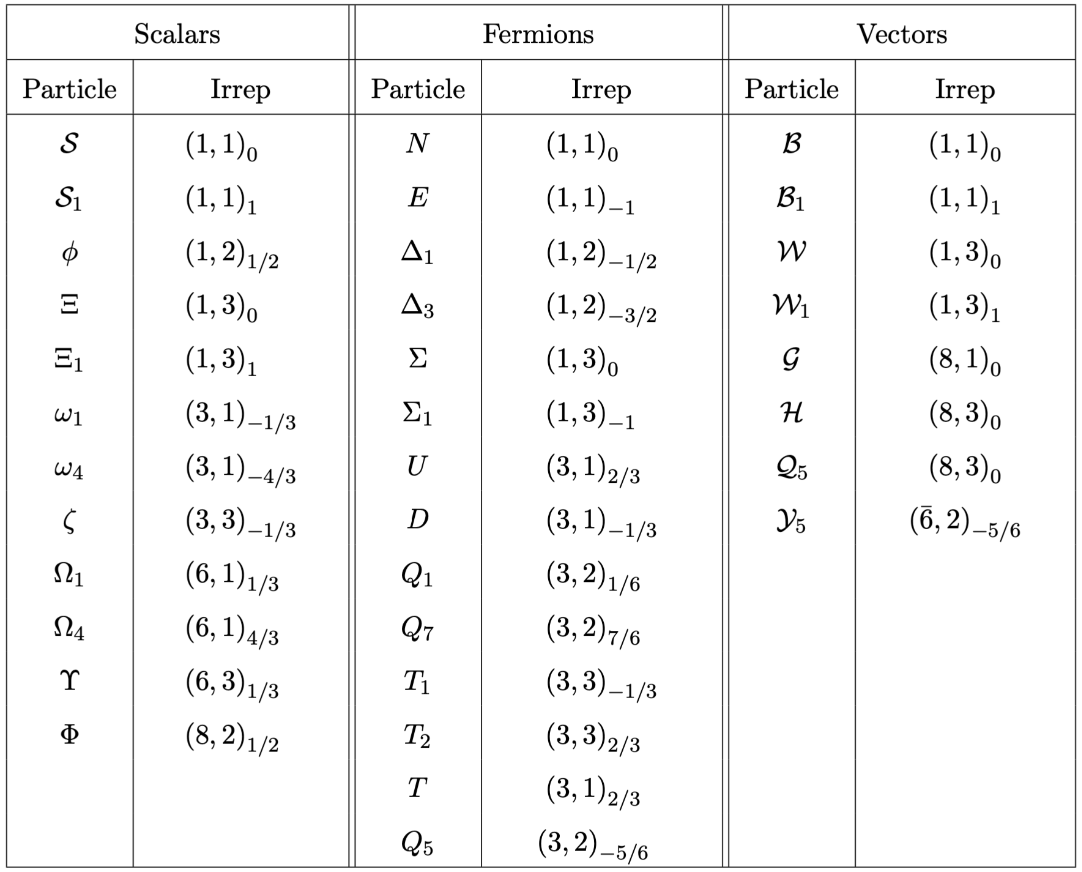
Different diff H datasets

Constrained by EWPO

UV matching in SMEFiT

- We include 1-particle models and **multi-particle** models at tree level, and 1-particle models at **1-loop**

- Classified by spin: heavy scalars, fermions and vectors



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	$(3,3)_{2/3}$		
		T	$(3,1)_{2/3}$		
		Q_5	$(3,2)_{-5/6}$		

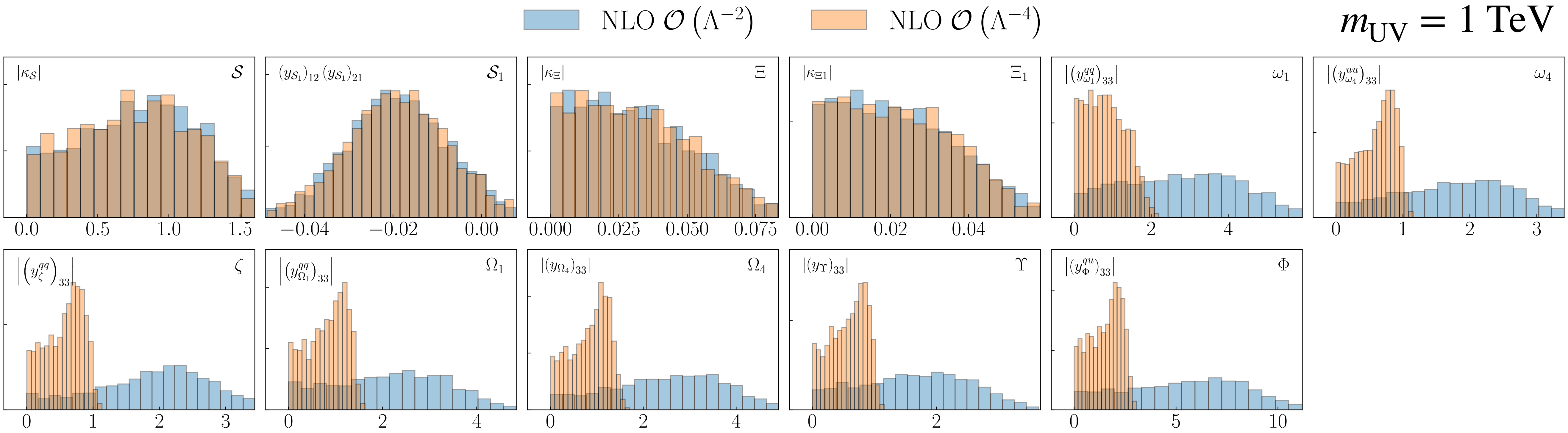
Based on [1711.10391] and [2012.02779]

Advantages

- **Flexible pipeline**: fit can be done for any user-defined model

- SMEFiT allows to study the **impact of NLO QCD** and **quadratic** corrections

Heavy scalars

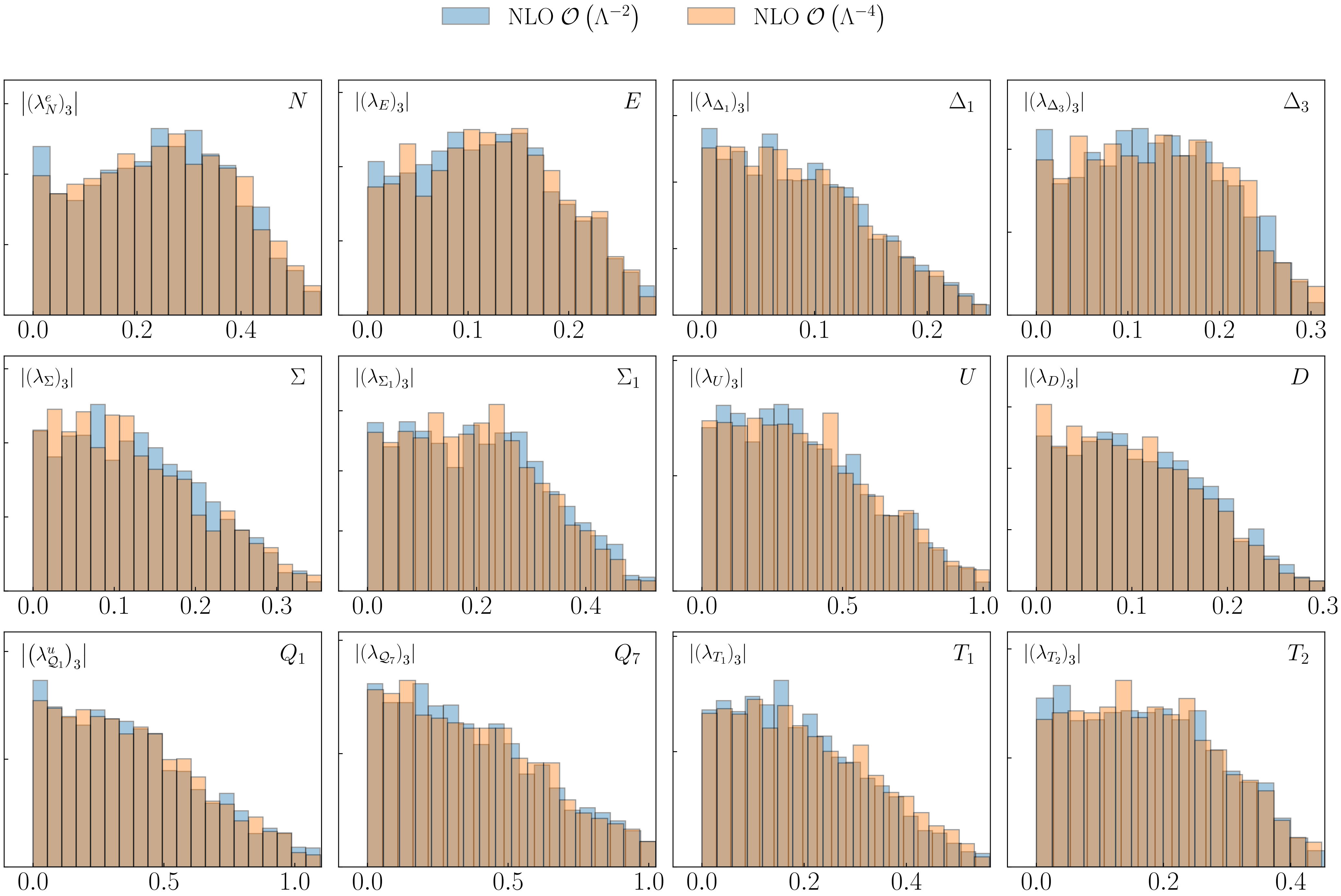


Model	UV invariants	NLO $\mathcal{O}(\Lambda^{-2})$	NLO $\mathcal{O}(\Lambda^{-4})$
$\mathcal{S}$	$\lvert\kappa_{\mathcal{S}}\rvert$	1.446	1.418
$\mathcal{S}_1$	$(y_{\mathcal{S}_1})_{12}(y_{\mathcal{S}_1})_{21}$	[-4.243e−2, 2.668e−3]	[-4.225e−2, 2.961e−3]
Ξ	$\lvert\kappa_{\Xi}\rvert$	6.862e−2	6.923e−2
Ξ_1	$\lvert\kappa_{\Xi 1}\rvert$	4.914e−2	4.783e−2
ω_1	$\lvert(y^{qq}_{\omega_1})_{33}\rvert$	5.186	1.704
ω_4	$\lvert(y^{uu}_{\omega_4})_{33}\rvert$	3.081	9.704e−1
ζ	$\lvert(y^{qq}_{\zeta})_{33}\rvert$	3.186	9.639e−1
Ω_1	$\lvert(y^{qq}_{\Omega_1})_{33}\rvert$	4.037	1.383
Ω_4	$\lvert(y_{\Omega_4})_{33}\rvert$	4.400	1.397
Υ	$\lvert(y_{\Upsilon})_{33}\rvert$	3.044	9.809e−1
Φ	$\lvert(y^{qu}_{\Phi})_{33}\rvert$	9.809	2.624

	Heavy Scalars											
	$\mathcal{S}$	$\mathcal{S}_1$	ϕ	Ξ	Ξ_1	ω_1	ω_4	ζ	Ω_1	Ω_4	Υ	Φ
$c_{\varphi\Box}$	✓			✓	✓							
$c_{\varphi D}$				✓	✓							
$c_{\tau\varphi}$			✓	✓	✓							
$c_{b\varphi}$			✓	✓	✓							
$c_{t\varphi}$			✓	✓	✓							
$c_{\ell\ell}$		✓										
c^{1}_{Qt}			✓									✓
c^{8}_{Qt}			✓									✓
c^{1}_{QQ}						✓		✓	✓		✓	
c^{8}_{QQ}						✓		✓	✓		✓	
c^{1}_{tt}							✓			✓		
$c^{(1)\dagger}_{qd}$			✓									
$c^{(8)\dagger}_{qd}$			✓									

4 fermion operators

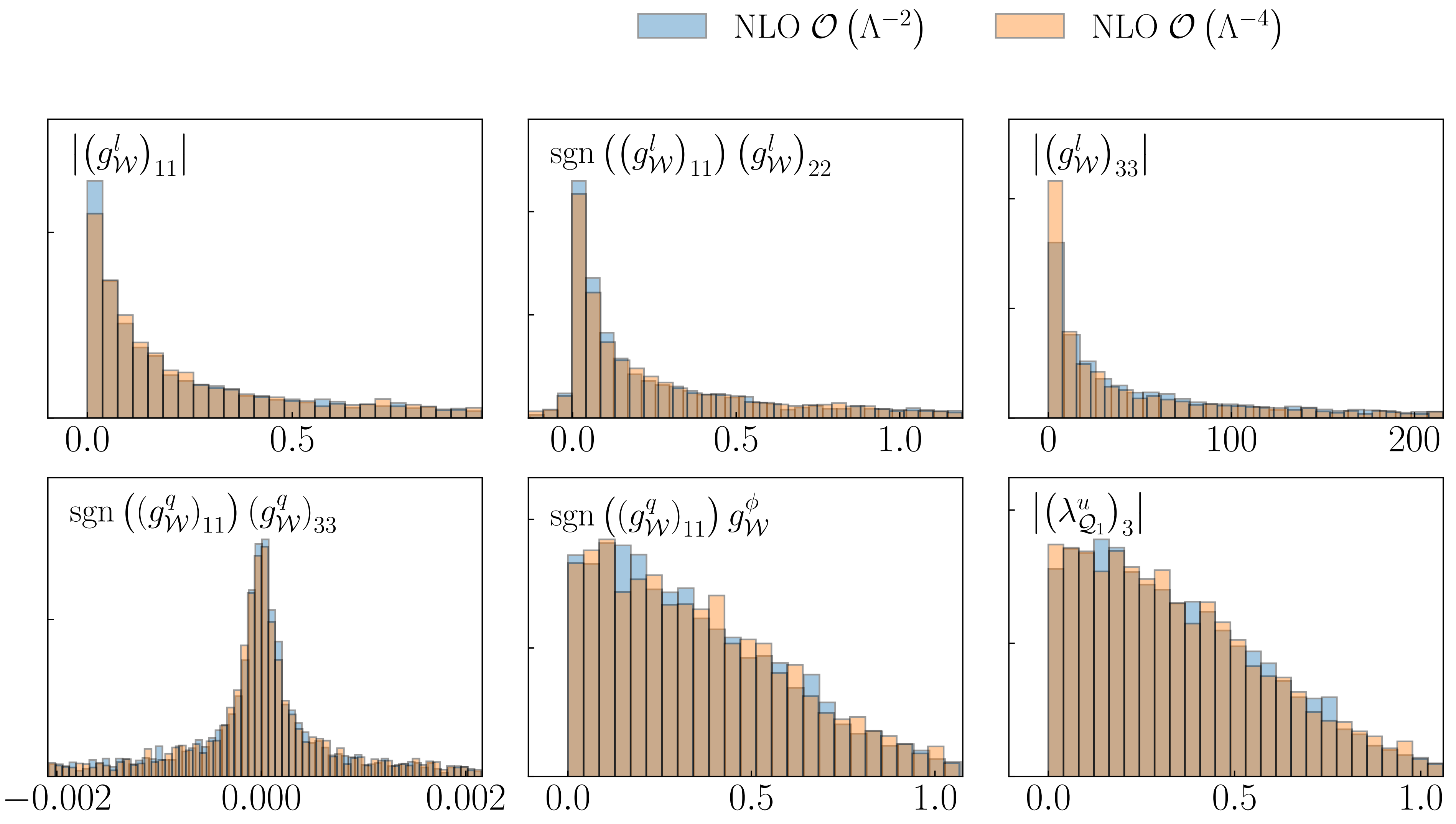
Heavy fermions



The heavy fermions get largely constrained by EWPO, hence negligible quadratic corrections

Multiparticle models

- Nothing stops us from adding multiple fields **simultaneously**!
- Example: 2 quark bidoublets $\mathcal{Q}_1$ and $\mathcal{Q}_7$ + neutral vector triplet $\mathscr{W}$
- Any other combination possible as long as number of UV parameters stays sufficiently small



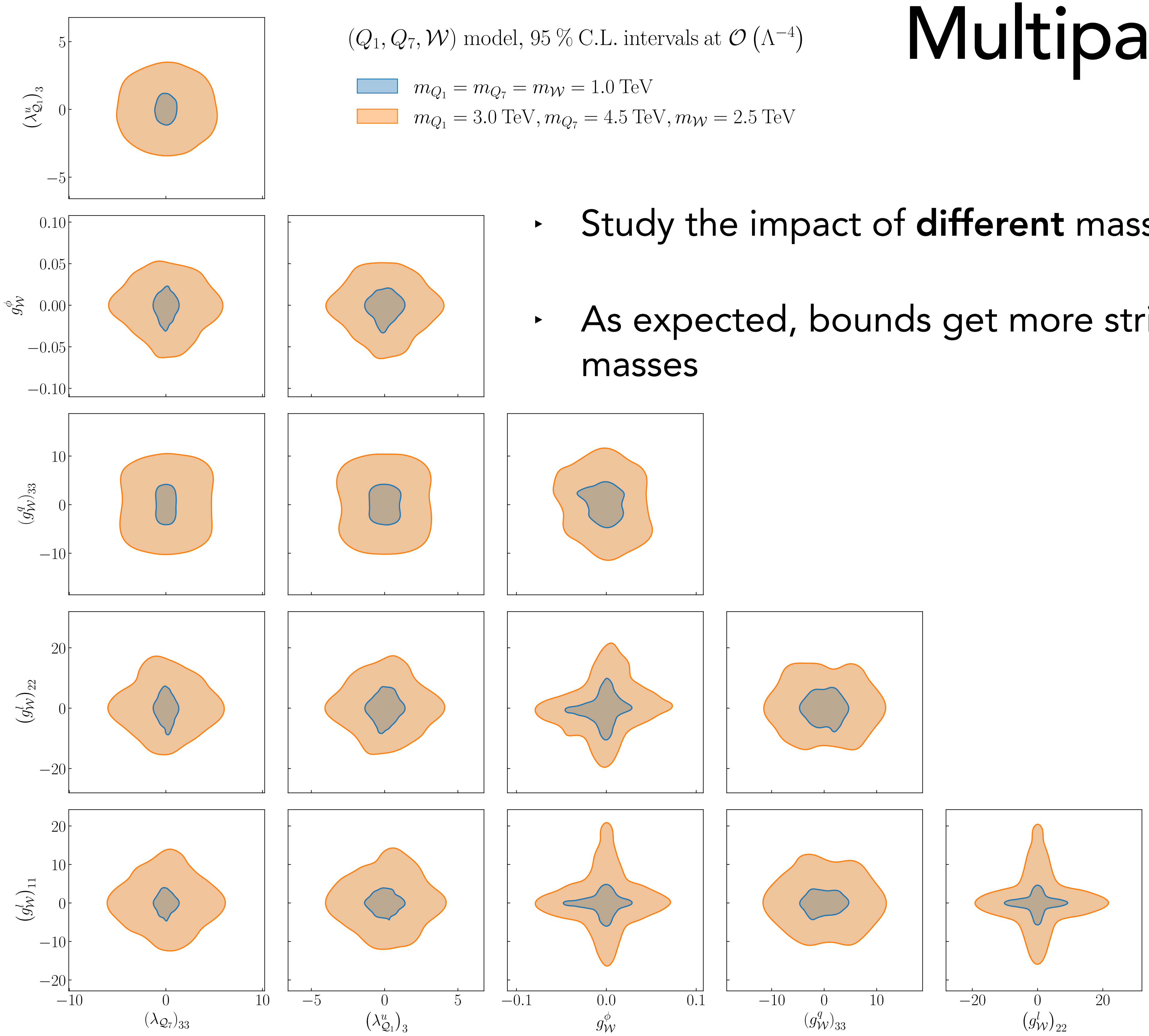
$\mathcal{Q}_1 \sim (3,2)_{1/6}$

$\mathcal{Q}_7 \sim (3,2)_{7/6}$

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

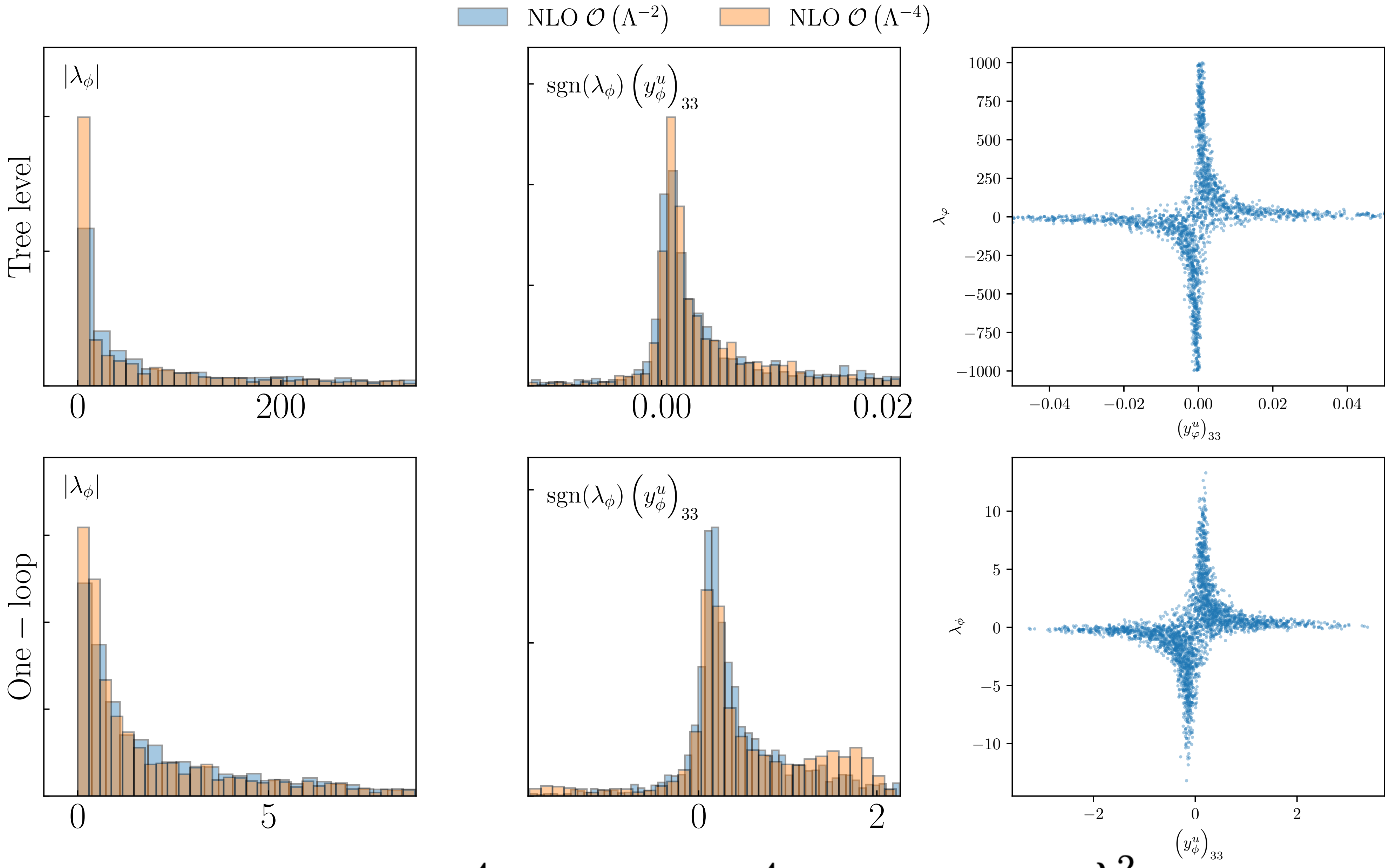
Multiparticle models

- Study the impact of **different** mass scenarios
- As expected, bounds get more stringent in case of lower masses



One-loop matching

- One-loop matching gives sensitivity to additional operators



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

Summary

- SMEFiT provides a flexible toolbox for global interpretations of particle physics data with EFTs
- The SMEFiT framework has been extended with an **exact EWPO implementation**, leading to an unprecedented 50 d.o.f.
- New state of the art EFT theory calculations have been adopted
- SMEFiT now supports UV fits for any user-defined UV model
- We have shown the impact of **NLO QCD and quadratic corrections** on UV fits

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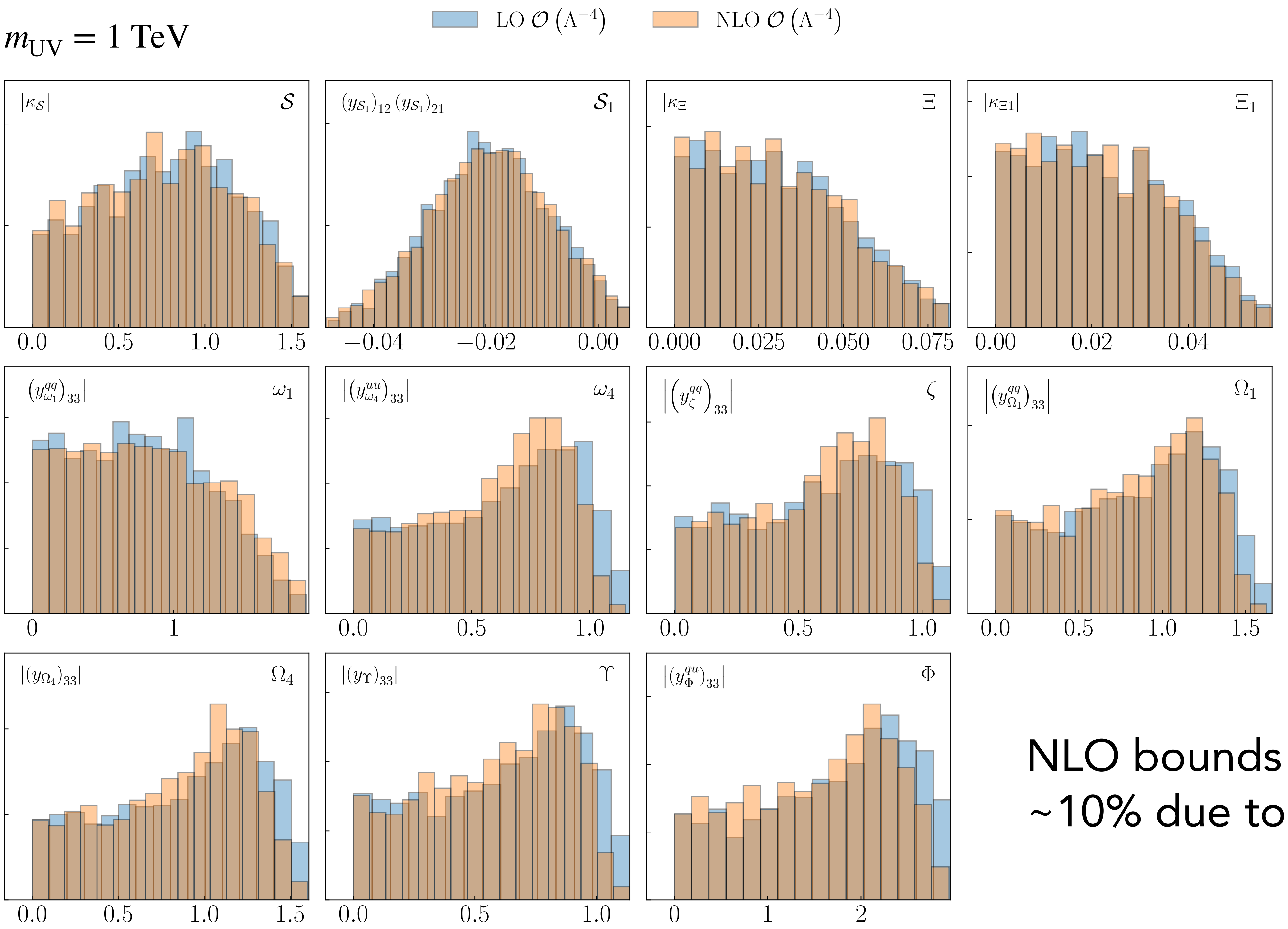
Thank you for listening!

Backup

Heavy scalars


$m_{\mathrm{UV}} = 1$ TeV

NLO bounds improve by ~10% due to 4F operators