Dreaming about the SMEFT at future colliders

Nikhef Jamboree

Jaco ter Hoeve - Theory Group

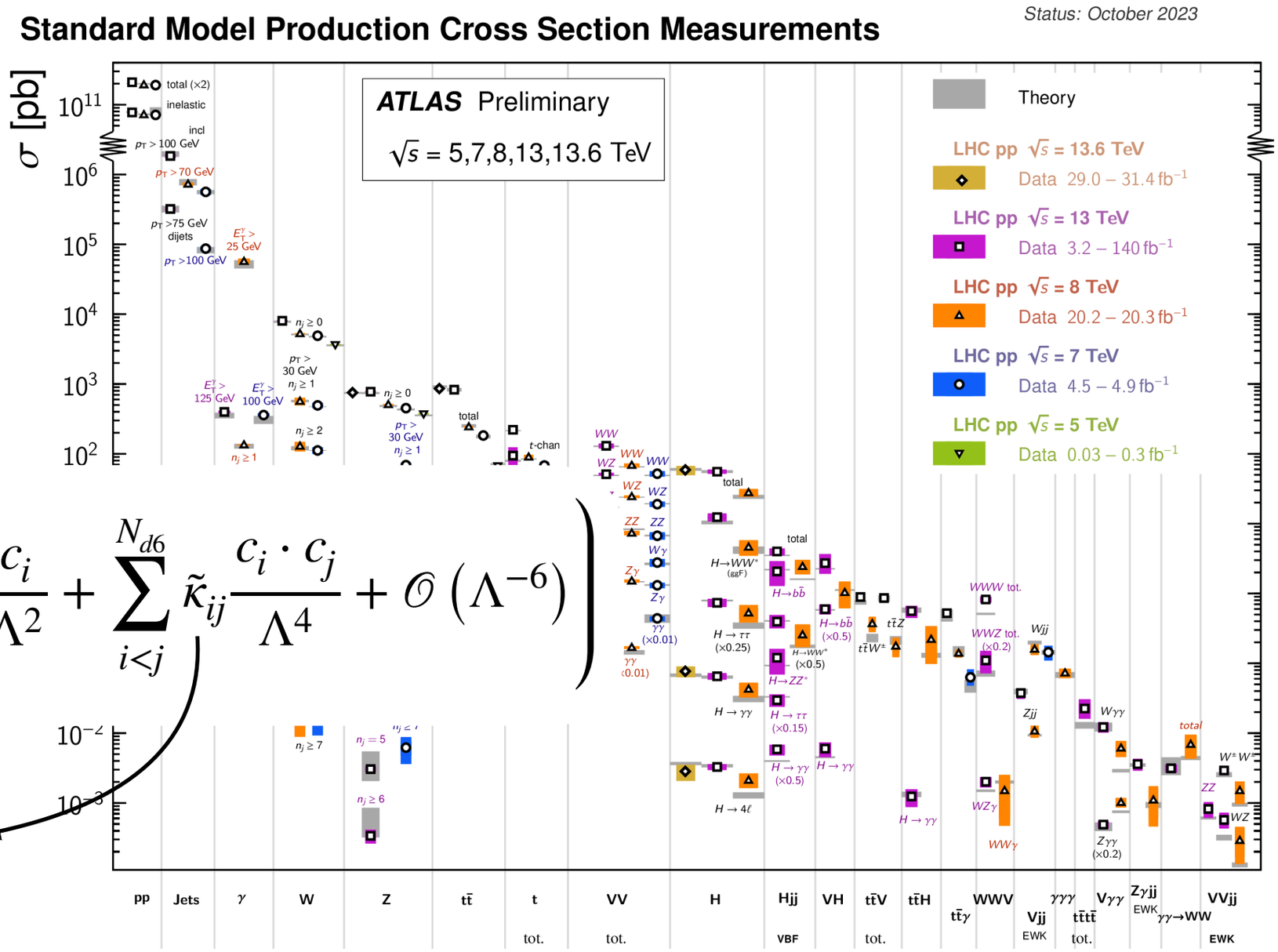
14/05

The high energy landscape

Lots of impressive cross-section measurements, but no clear deviation from the SM (yet) …

… so we study their overall pattern!

[ATL-PHYS-PUB-2023-039]



Linear EFT corrections:
interference SM-EFT$_{d6}$
@NLO QCD

Quadratic EFT
corrections:
EFT$_{d6}$-EFT$_{d6}$
@NLO QCD

$$\sigma(c,\Lambda) = \sigma_{\mathrm{SM}} \times \left(1 + \sum_{i}^{N_{d6}} \kappa_i \frac{c_i}{\Lambda^2} + \sum_{i<j}^{N_{d6}} \tilde{\kappa}_{ij} \frac{c_i \cdot c_j}{\Lambda^4} + \mathcal{O}\left(\Lambda^{-6}\right)\right)$$

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Linear EFT cor
interference S
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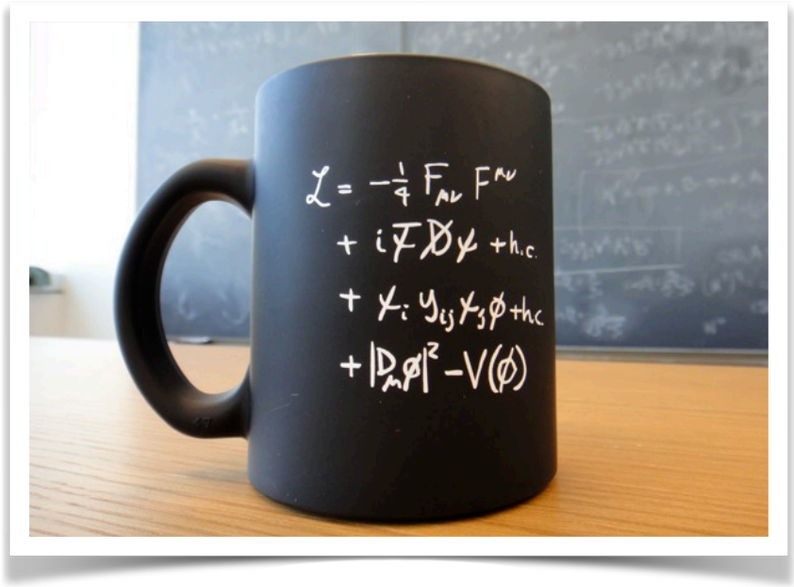
$$\sigma(c,\Lambda) = \sigma_{\mathrm{SM}} \times$$

$$\left(\qquad i \qquad\qquad i<j \right)$$

Quadratic EFT corrections: EFTd6-EFTd6 @NLO QCD

A theorists' view of the Standard Model

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



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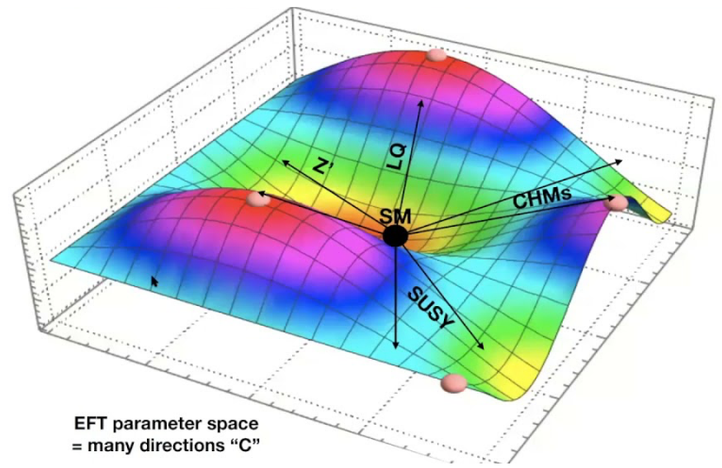
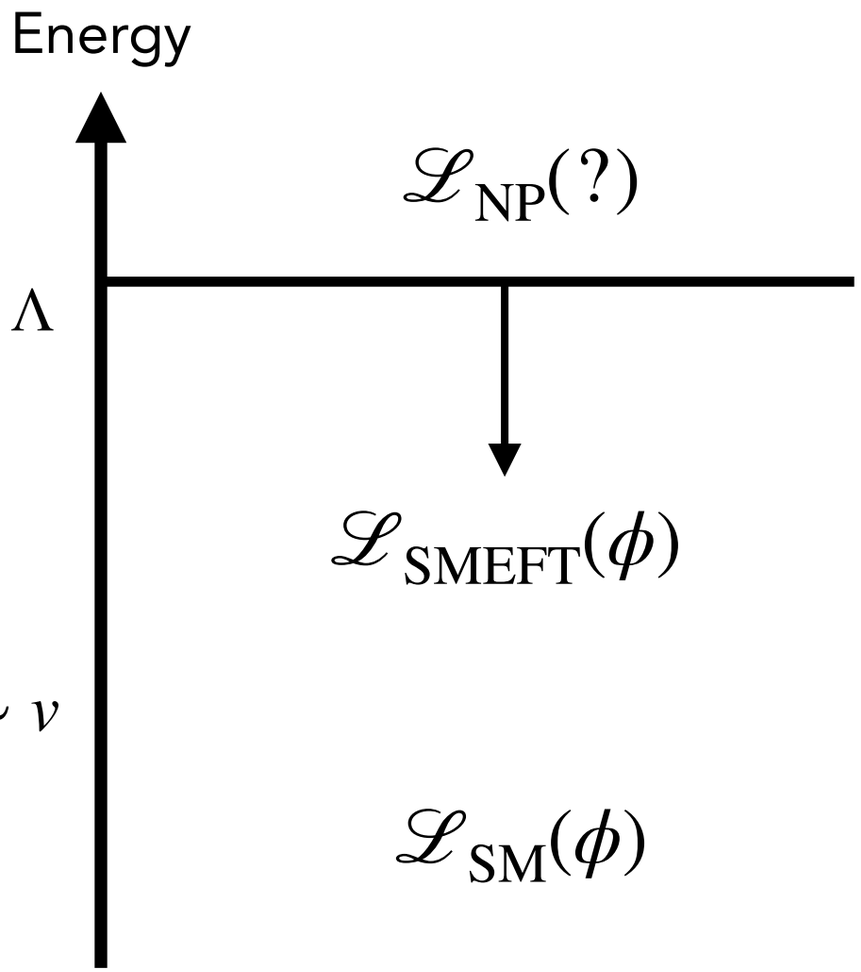
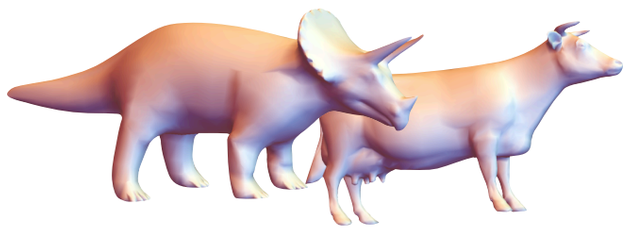


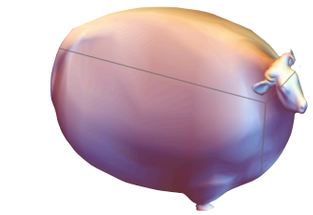
- **Low energy limit** of generic UV-complete theories at high energies
- Assumes the **SM field content and symmetries**
- **Complete basis** at any given mass dimension

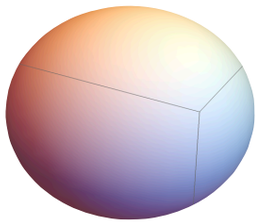
The Standard Model as an EFT

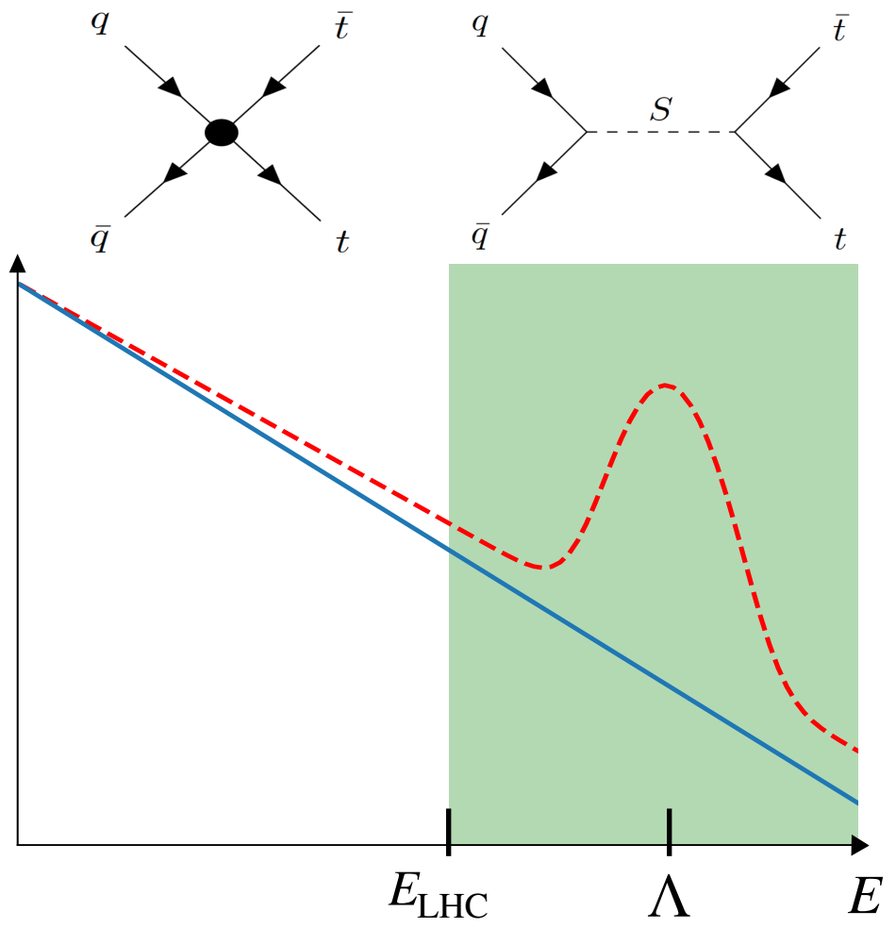
$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \sum_i^{N_{d5}} \frac{c_i}{\Lambda} \mathcal{O}_i^{(5)} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i^{N_{d7}} \frac{c_i}{\Lambda^3} \mathcal{O}_i^{(7)} + \sum_i^{N_{d8}} \frac{b_i}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots$$





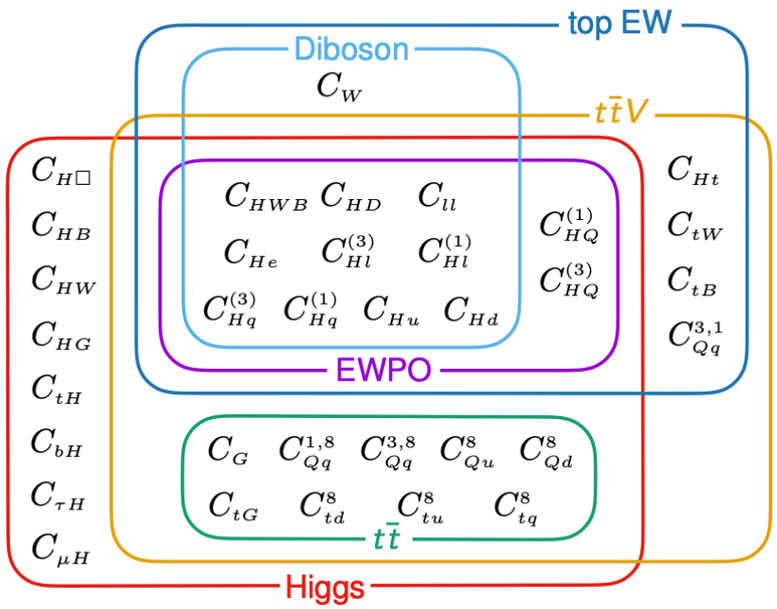






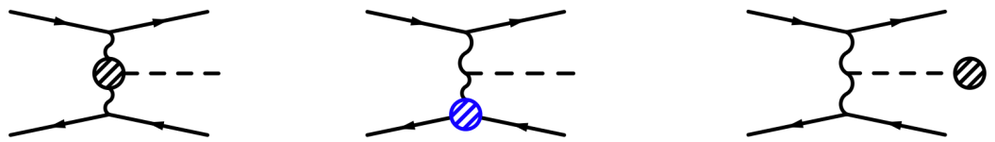
Why global fits?

- The SMEFT is a **universal** tool to search for BSM physics above the EW scale, with **minimal assumptions** on what it may look like
- Given the **cross-talk** between the various processes, a simultaneous fit is our only way forward
- **Challenge**: a large number of operators, with many datasets needed!



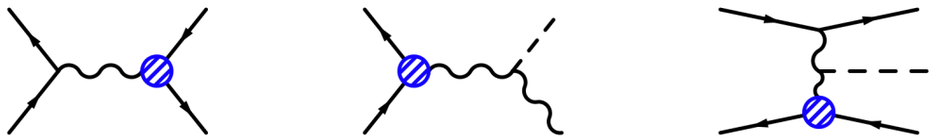
[2012.02779] Fitmaker collaboration

One observable can be influenced by many operators



Higgs decay

One operator can contribute to many different observables



Anke Biekötter - HET seminar Brookhaven

The SMEFT at work

From (differential) cross sections …

$$\sigma_{\text{SMEFT}}(c,\Lambda) = \sigma_{\text{SM}} \times \left(1 + \sum_{i}^{N_{d6}} \kappa_i \frac{c_i}{\Lambda^2} + \sum_{i<j}^{N_{d6}} \tilde{\kappa}_{ij} \frac{c_i \cdot c_j}{\Lambda^4} + \mathcal{O}\left(\Lambda^{-6}\right)\right)$$

Linear EFT corrections: interference SM-EFT$_{d6}$ @NLO QCD

Quadratic EFT corrections: EFT$_{d6}$-EFT$_{d6}$ @NLO QCD

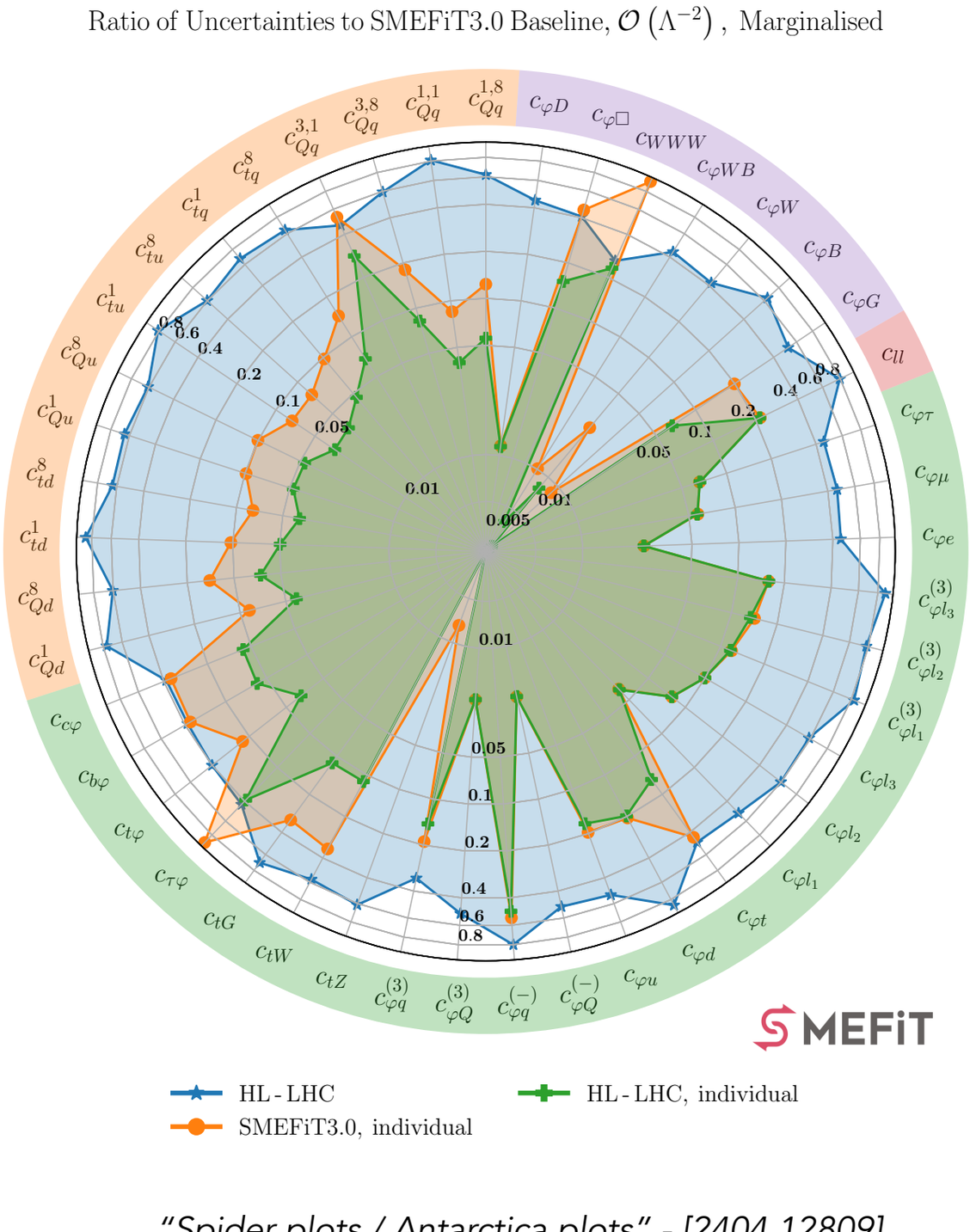
To a combined likelihood ready for optimisation …

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

Likelihoods based on the full statistical model are also possible

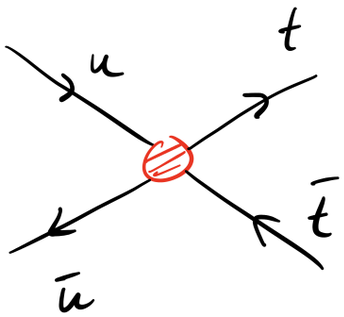
SMEFiT3.0 in a nutshell

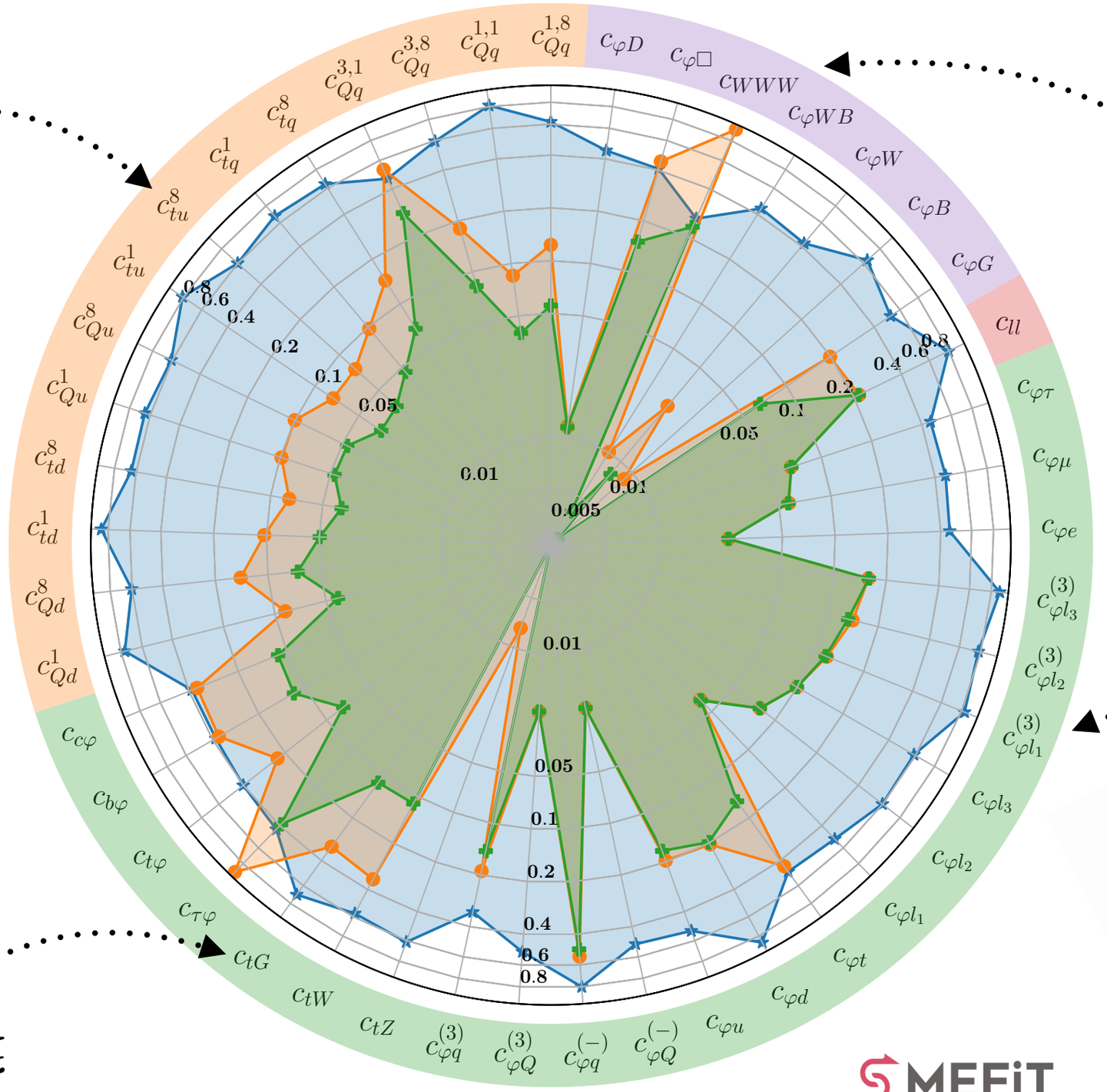
- SMEFiT2.0 extended with recent datasets in **top, diboson and Higgs production** based on the full Run II luminosity
- Full independent treatment of the EWPOs
- **HL-LHC projections** from Run II
- **FCC-ee and CEPC** pseudodata with 4IPs
- Both results in terms of Wilson coefficients and **UV-complete models**

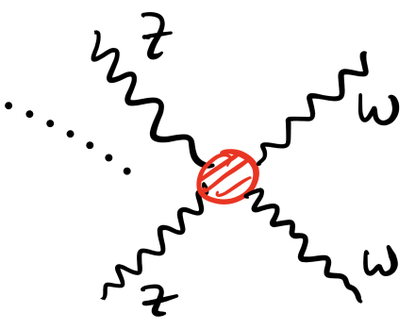


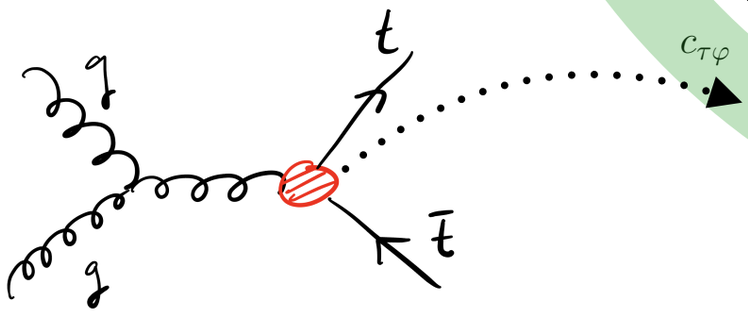
"Spider plots / Antarctica plots" - [2404.12809]

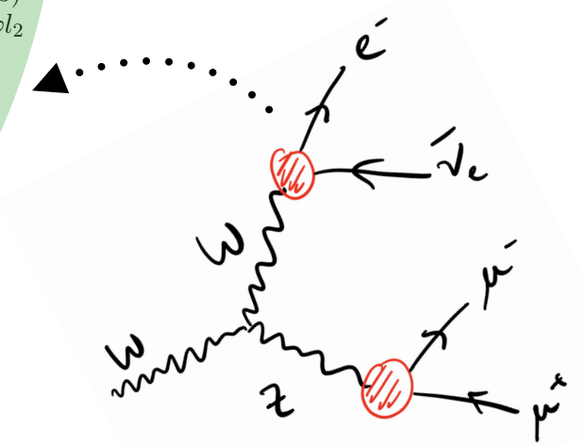
Ratio of Uncertainties to SMEFiT3.0 Baseline, $\mathcal{O}\left(\Lambda^{-2}\right)$, Marginalised











SMEFiT

HL - LHC
HL - LHC, individual
SMEFiT3.0, individual

What the FCC-ee can do for you!

- Study the **origin of EW symmetry breaking** (and the origin of the H boson itself)

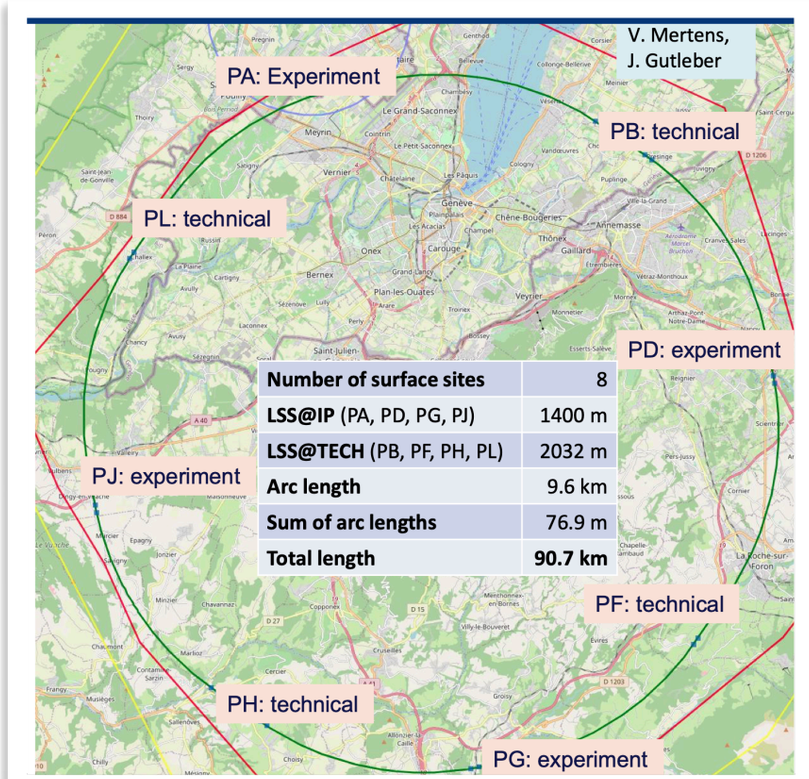
  Higgs self coupling / EW phase transition 1st or 2nd order / matter antimatter asymmetry

- Determine the **1st and 2nd generation Yukawas**

- **More precise determination** of SM inputs: α_{EW} , α_S, m_t

- ...

Energy ($\sqrt{s}$)	$\mathcal{L}_{\text{int}}$ (Run time)	
	FCC-ee	CEPC
91 GeV (Z-pole)	300 ab^{-1} (4 years)	100 ab^{-1} (2 years)
161 GeV ($2\,m_W$)	20 ab^{-1} (2 years)	6 ab^{-1} (1 year)
240 GeV	10 ab^{-1} (3 years)	20 ab^{-1} (10 years)
350 GeV	0.4 ab^{-1} (1 years)	-
365 GeV ($2\,m_t$)	3 ab^{-1} (4 years)	1 ab^{-1} (5 years)

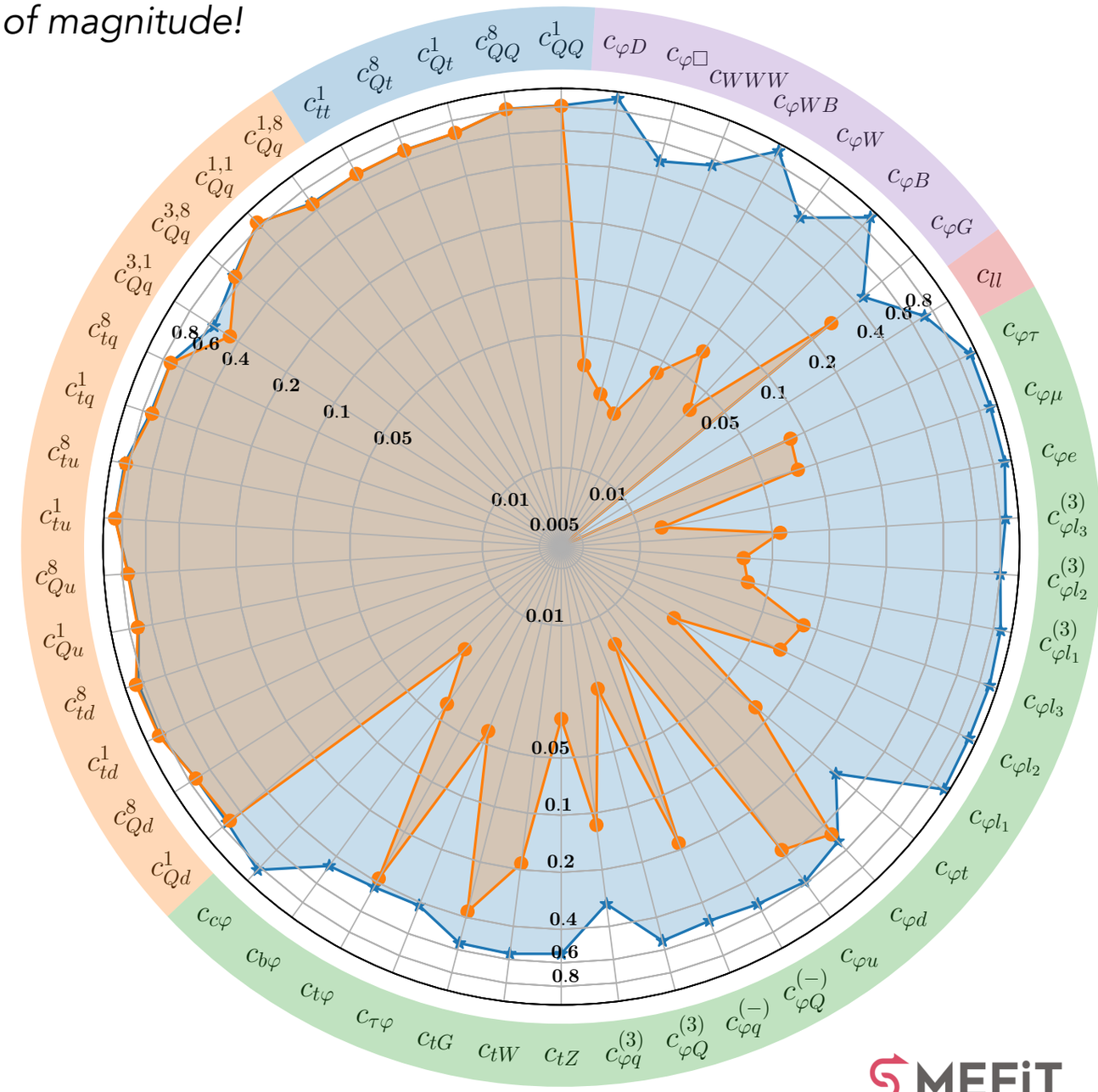


The FCC-ee on Antarctica

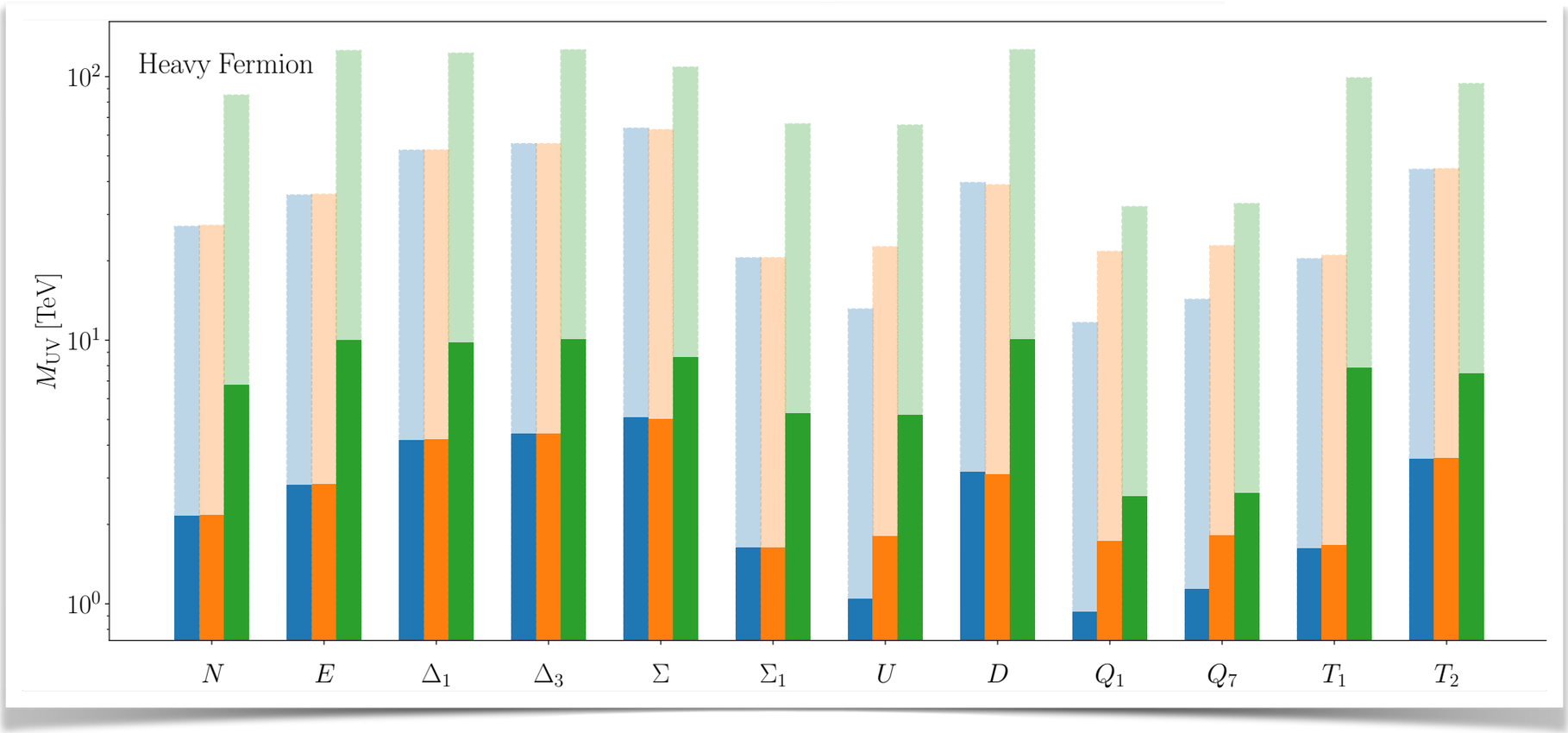
The FCC-ee improves the bounds by several orders of magnitude!

Dataset input

- EWPOs at the Z-pole
- Light fermion pair prediction
- Higgstrahlung and VBF
- Gauge boson pair production
- Top-quark pair production
- ....



How high can we reach?



- We quantify the mass reach of one-particle extensions of the SM
- Future colliders will give an unprecedented **indirect mass reach up to a 100 TeV**

Conclusion and outlook

- New physics might be just **around the corner**, and the SMEFT provides the ideal framework to capture its effects with a minimal set of assumptions
- SMEFiT3.0: a global SMEFT analysis with 50 WC to 449 datapoints
- Demonstrated the impact of HL-LHC and FCC-ee on the global SMEFT parameter space
- The FCC-ee predicts an **unprecedented mass reach** on new heavy particles

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Contact: jthoeve@nikhef.nl

Thanks for your attention!