EFTs at Future Colliders

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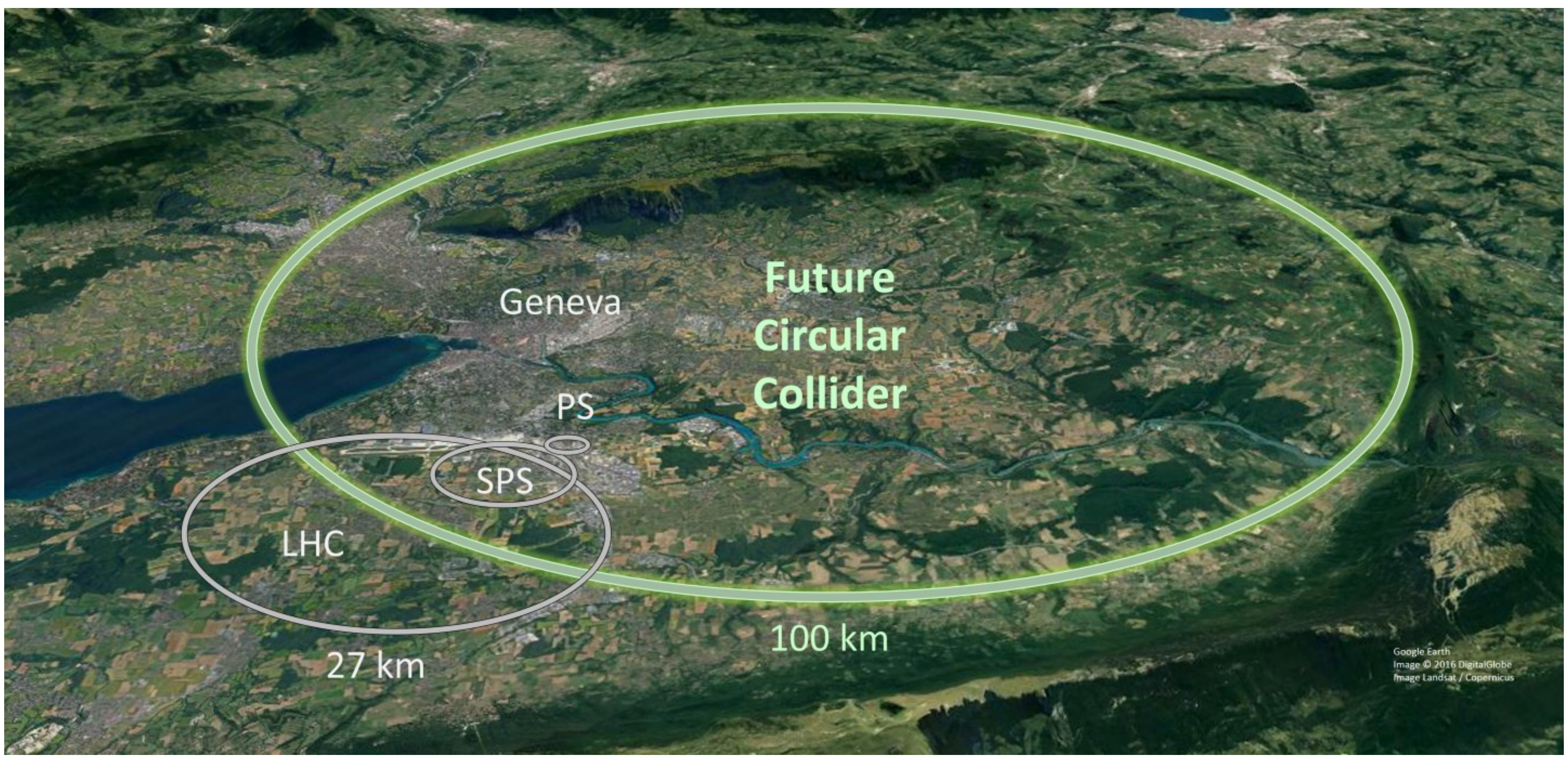


Nikhef Strategy Day, 15th October 2024

The Standard Model from the bottom up

- Specify the **particle (matter) content**: three generations of quarks and leptons
- Indicate **gauge** (local) symmetries and their eventual breaking mechanisms
- Impose **Lorentz** invariance and other global symmetries
- Ensure that predictions are valid **up to a cutoff scale Λ** (say Λ=10 TeV)

Wilson coefficients

$$\mathscr{L}_{\rm SMEFT} = \mathscr{L}_{\rm SM} + \sum_i \frac{c_i^{(5)}}{\Lambda}\mathcal{O}_i^{(d=5)} + \sum_j \frac{c_j^{(6)}}{\Lambda^2}\mathcal{O}_j^{(d=6)} + \sum_k \frac{c_j^{(7)}}{\Lambda^3}\mathcal{O}_k^{(d=7)} \ldots$$

cutoff (BSM) scale

all possible operators consistent with these requirements

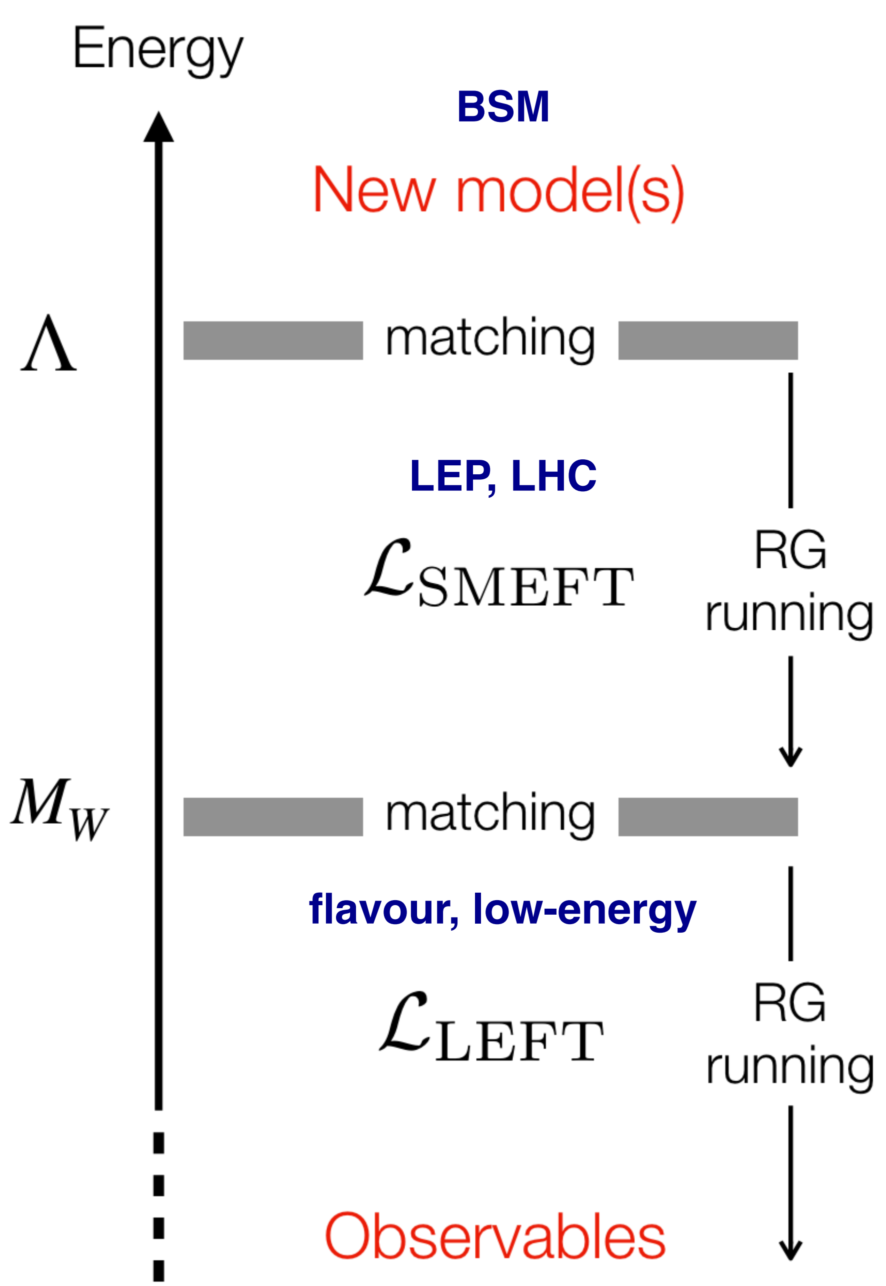
The SM Effective Field Theory (SMEFT) is the general low-energy limit of BSM theories with new heavy degrees of freedom and SM-like EWSB

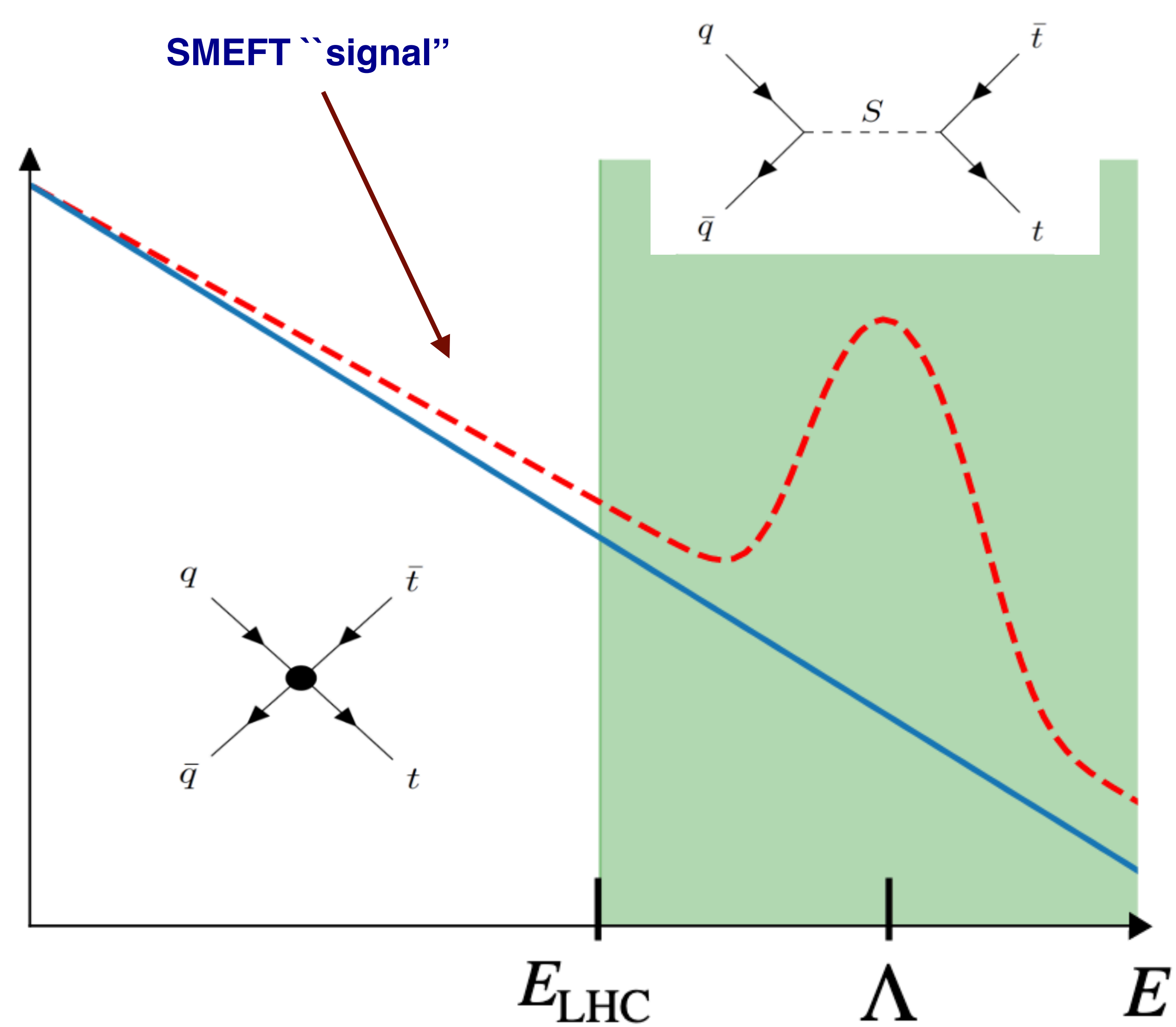
nb$_1$: accidental symmetries of the SM (e.g. baryon number conservation) may not be satisfied by the SMEFT

nb$_2$: not all BSM models reduce to SMEFT e.g. those with light DoF, or with non-SM EWSB

Why the SMEFT?

- Model-agnostic strategy to **interpret constraints on** (heavy) **BSM dynamics** affecting (very) different sectors & energy regimes
- A single SMEFT analysis automatically **constrains all UV models matched to it**

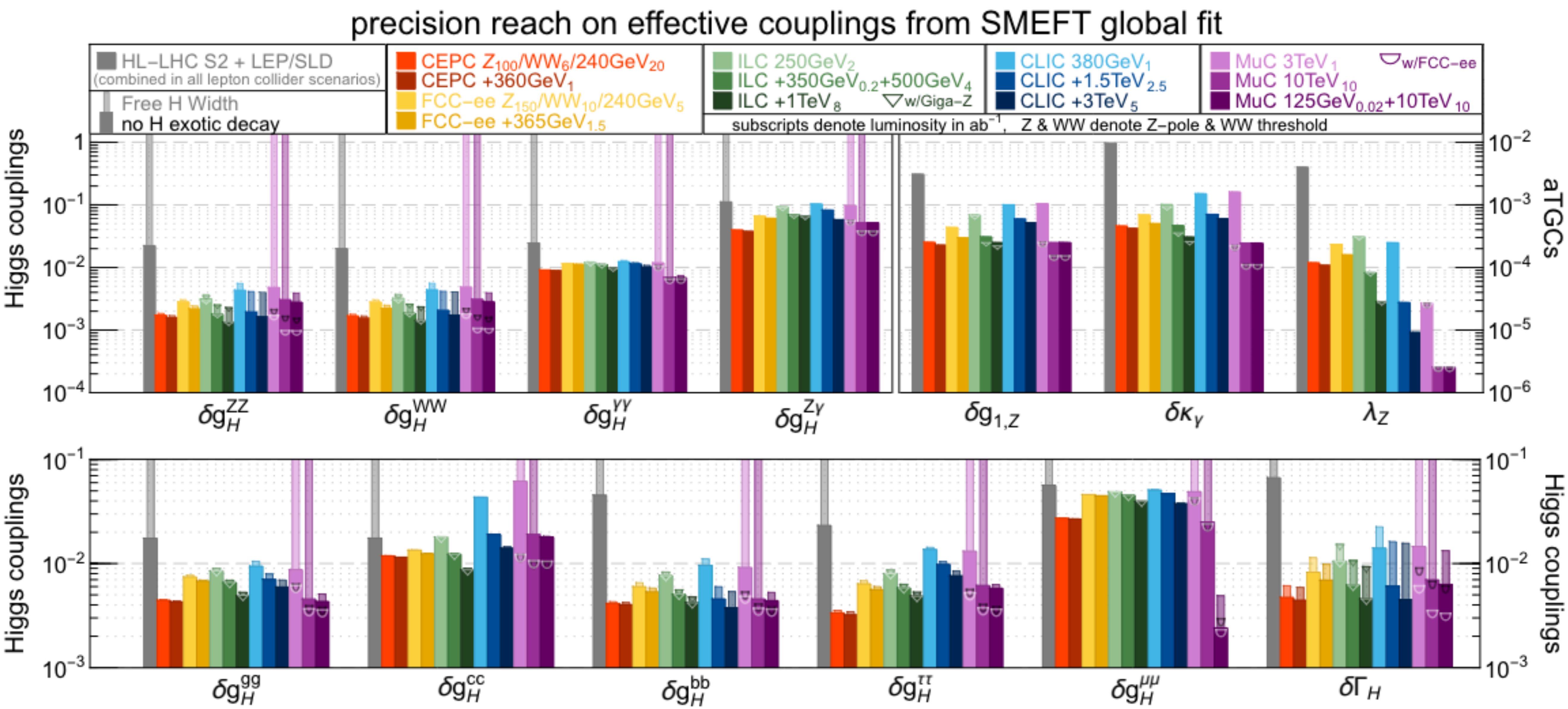




J. Fuentes-Martin, SM@LHC2024

The SMEFT at Future Colliders

- The SMEFT framework (combined with UV matching) is well suited to consistently **compare the reach of future particle colliders** on the parameter space of heavy BSM physics
- Several studies carried out for Snowmass and the FCC Feasibility Report, more ongoing for **ESPPU**



J. de Blas at al., arXiv:2206.08326 (Snowmass)

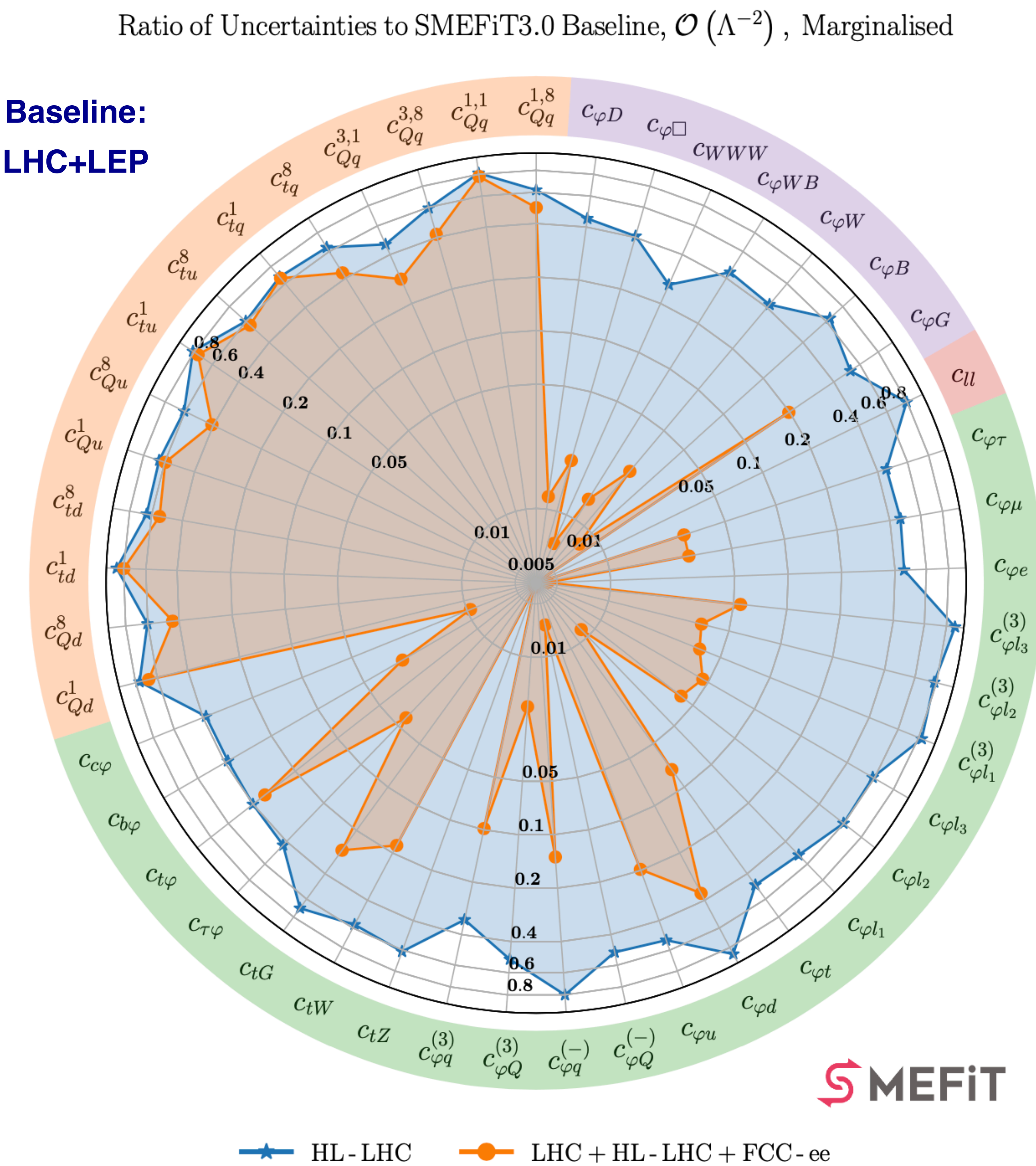
***nb*: Interpretation in terms of effective couplings only possible with a restrictive subset of SMEFT operators**

The SMEFT at Future Colliders

- Start from **state-of-the-art global SMEFT fit** of Higgs, top, diboson, and EWPO data (SMEFiT3.0)
- Account for the projected **HL-LHC** and **FCC-ee** constraints (pseudo-data, assume SM)
- Match to a broad range of **UV complete models**

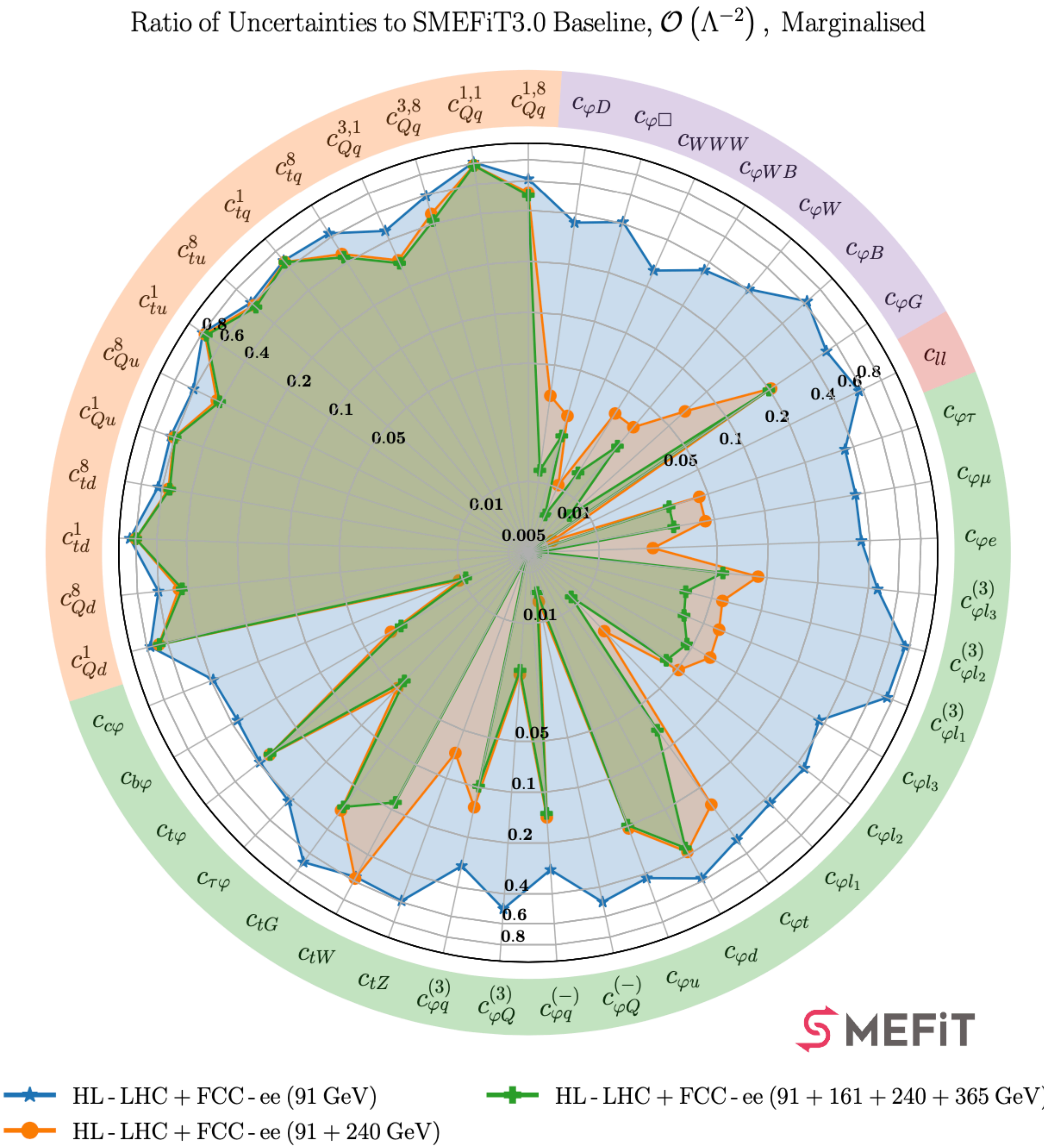
E. Celada *et al.* (smefit), JHEP 2024

Baseline: LHC+LEP



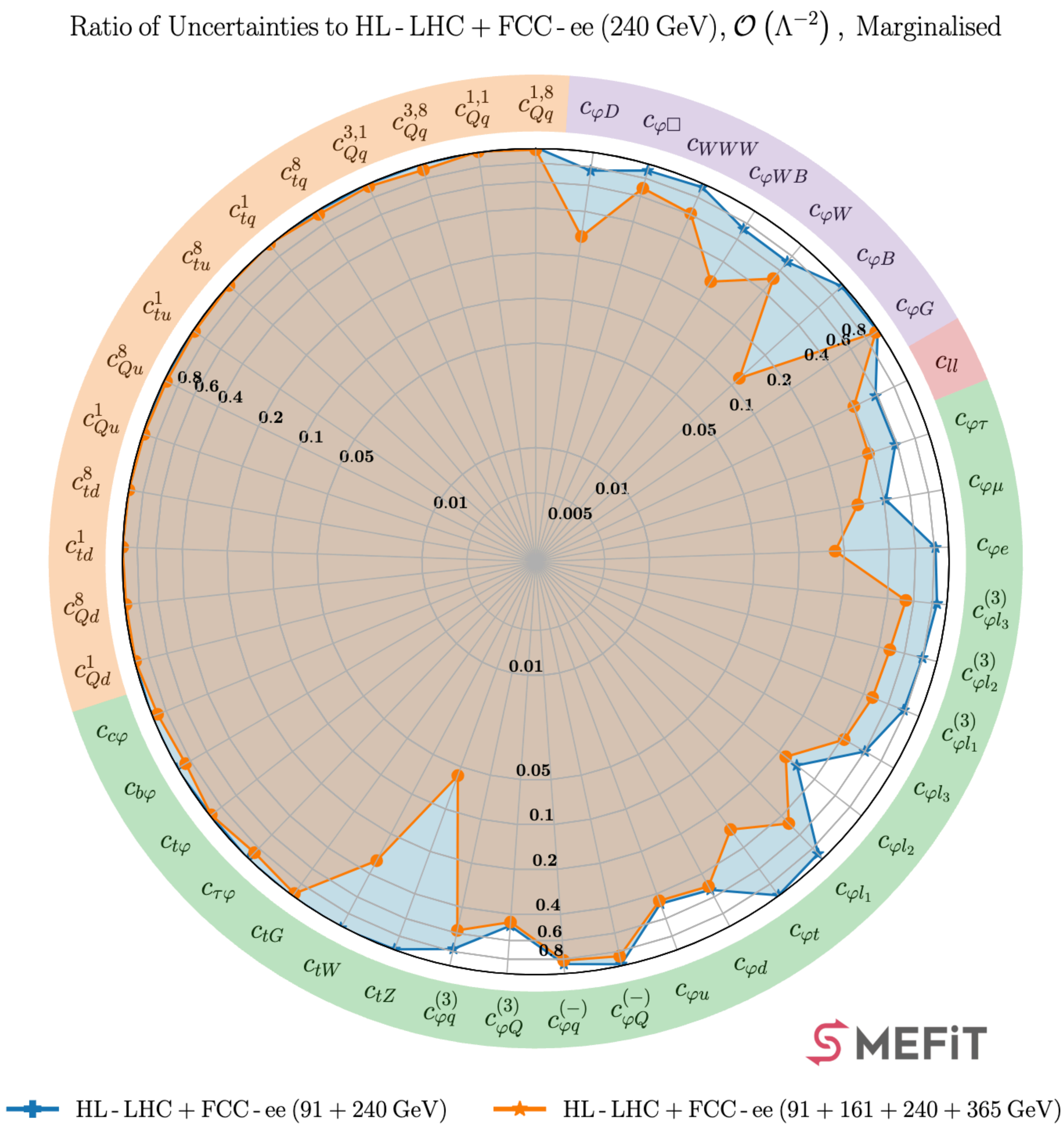
- FCC-ee: **huge improvements** (up to factor 100) for most EFT coefficients
- Most impact on **two-fermion**, **purely bosonic**, and **four-lepton operators**
- Four-fermion operators **involving top quarks** are unaffected by FCC-ee

The SMEFT at Future Colliders



- Study impact of **sequentially adding FCC-ee data** for different CoM energies
- Combining the ***Z*-pole run** with the **Higgs factory run at 240 GeV** provides the bulk of the final reach
- **Higgs factory run** dominates the overal SMEFT sensitivity

The SMEFT at Future Colliders



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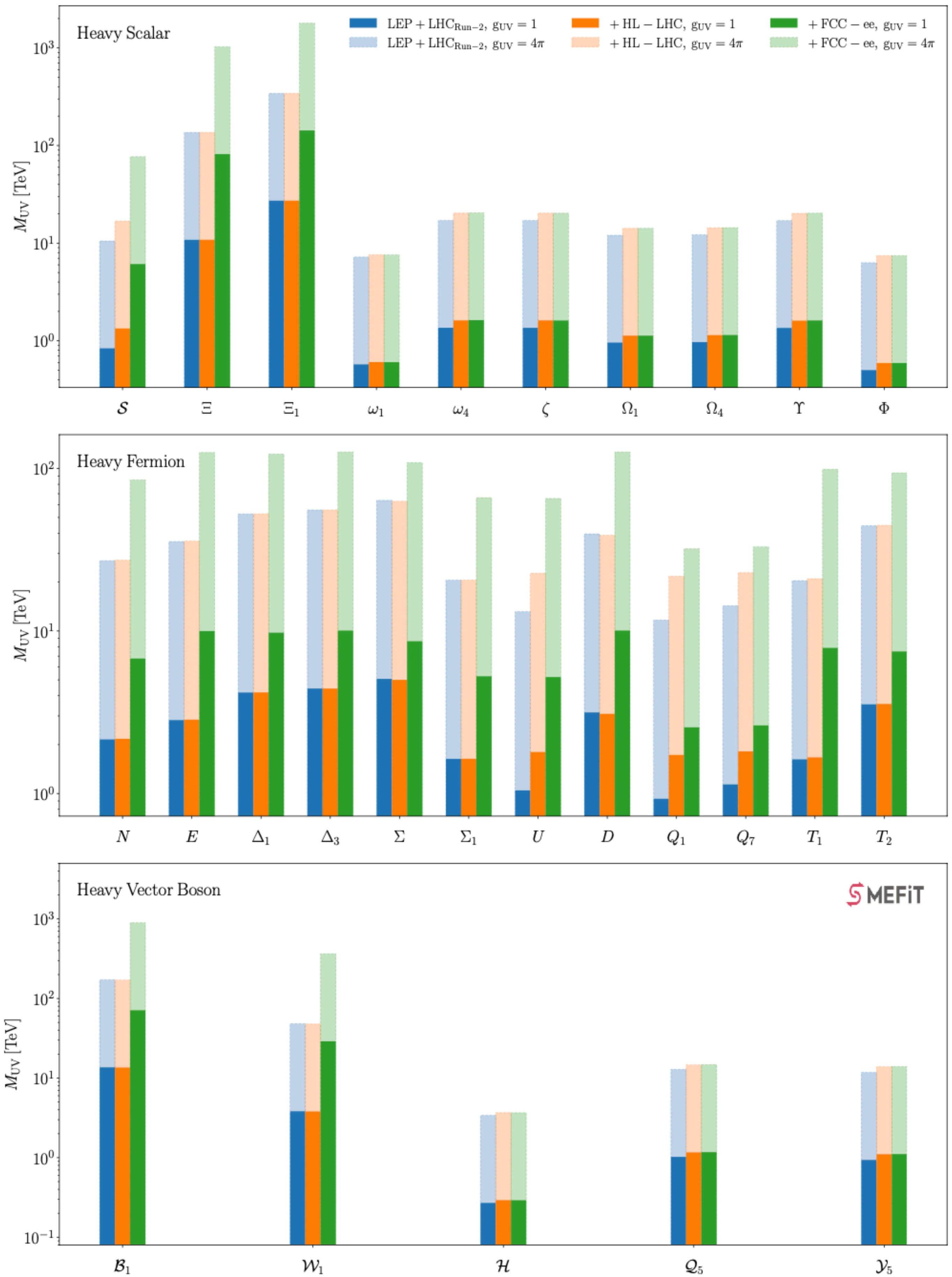
provides guidance to e.g. prioritise different CoM runs or their duration

The SMEFT at Future Colliders



- Lower bounds (95% CL) on different **one-particle extensions** of the SM matched to the SMEFT at tree level (results with one-loop matching & multi-particle models also available)
- FCC-ee has an (indirect) reach on **heavy particles** with masses between **a few TeV and up to around 100 TeV**, for O(1) UV couplings
- Strongest impact for UV models that induce the **purely bosonic and two-fermion operators**, which are tightly constrained by FCC-ee

Summary and outlook

- The SMEFT framework provides a robust strategy to **interpret particle physics data in terms of new BSM** phenomena while reducing model-specific assumptions

- A global SMEFT analysis constrains a **plethora of UV-complete scenarios** (matched to the SMEFT) at once: **bridge between data and BSM models**

- The SMEFT framework also beautifully illustrates the **unprecedented reach of future colliders** to probe new physics at **high scales through precision measurements**

Global SMEFT analyses provide an objective, quantitative ``metric" to gauge the relative performance of future colliders

WIP: extend to ILC/CLIC/MuCol & LHeC & FCC-hh/FCC-eh, RGE effects, kappa formalism…

contribution to various ESPPU documents ongoing