8th FCC Physics Workshop
January 16, 2025

Updates on Global SMEFT fits for the FCC feasibility study

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Introduction

- The purpose of any future collider is to improve our knowledge of what new physics explains the issues of the Standard Model

The best Future Collider is that which allows to explore many directions

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The best Future Collider is that which allows to explore many directions

- Because <u>we do not know what the form of new physics</u> may be or where it could be hidding…

Explore the search of BSM in a general way, not attached to any particular scenario

Model independence → Many posible BSM deformations
→ Need many observables and a global interpretation

Introduction

- The purpose of any future collider is to improve our knowledge of what new physics explains the issues of the Standard Model

The best Future Collider is that which allows to explore many directions

- Plus, at the end of the day, any reasonable new physics is unlikely to show exclusively in one single observable…

Global interpretations to maximize the sensitivity to new physics

Particularly important for model characterization

Introduction

- The purpose of any future collider is to improve our knowledge of what new physics explains the issues of the Standard Model

Naturalness

In this talk:

- **Summary of the global interpretation studies of the EW/Higgs sector prepared for FCC feasibility report**
- **Emphasis on updates wrt. last studies from CDR & Snowmass**
- **Focused on the *"agnostic"* global SMEFT fits**
- **Conclusions: Ongoing work for ESPP 2026**

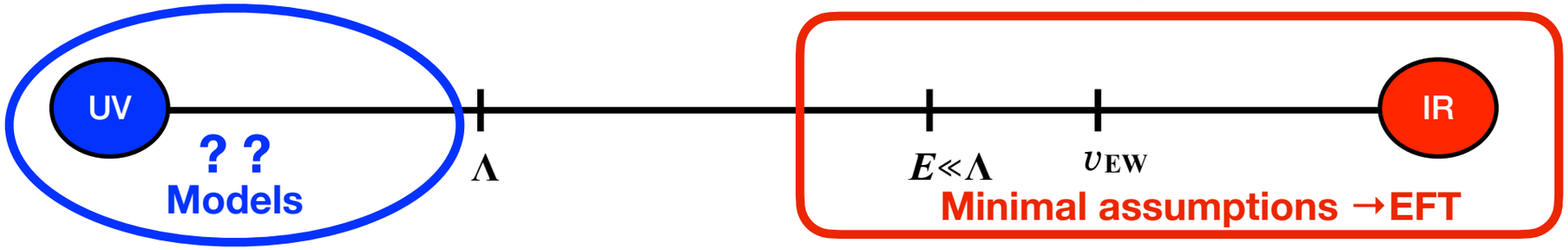
See talks by: L. Allwicher & J. ter Hove (Tue.)
H. Vuong (today)
for BSM interpretations of SMEFT fits

Global interpretations to maximize the sensitivity to new physics

Particularly important for model characterization

Effective Field Theories for BSM physics

- EFT to describe indirect effects of BSM at low energies:



- Global fits performed within the dimension-6 SMEFT framework:

$$\mathcal{L}_{\rm UV}(?) \longrightarrow_{E \ll \Lambda}$$

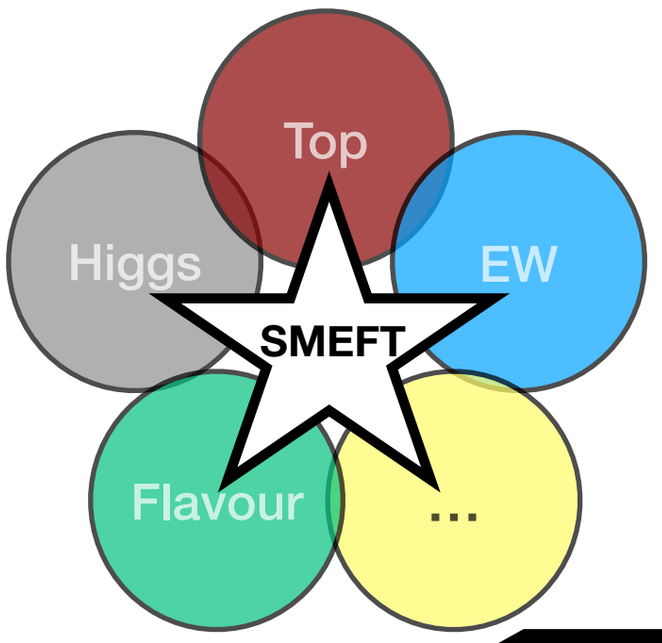
$$\mathcal{L}_{\rm Eff} = \sum_{d=4}^{\infty} \frac{1}{\Lambda^{d-4}} \mathcal{L}_d = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots$$

$$\mathcal{L}_d = \sum_i C_i^d \mathcal{O}_i \qquad [\mathcal{O}_i] = d \longrightarrow \left(\frac{q}{\Lambda}\right)^{d-4}$$

$$q = v, E < \Lambda$$

IR: SM Symmetries & Fields (H in 2~SU(2)$_L$) + Decoupling for Λ→∞

- Model independent <u>only within the assumptions</u>
- Not the only possibility (HEFT, EFTs with extra light d.o.f.) but:
  - ✓ Well motivated phenomenologically
  - ✓ SMEFT TH correlations connects sectors
  - ✓ More mature tools and techniques



Global SMEFT studies

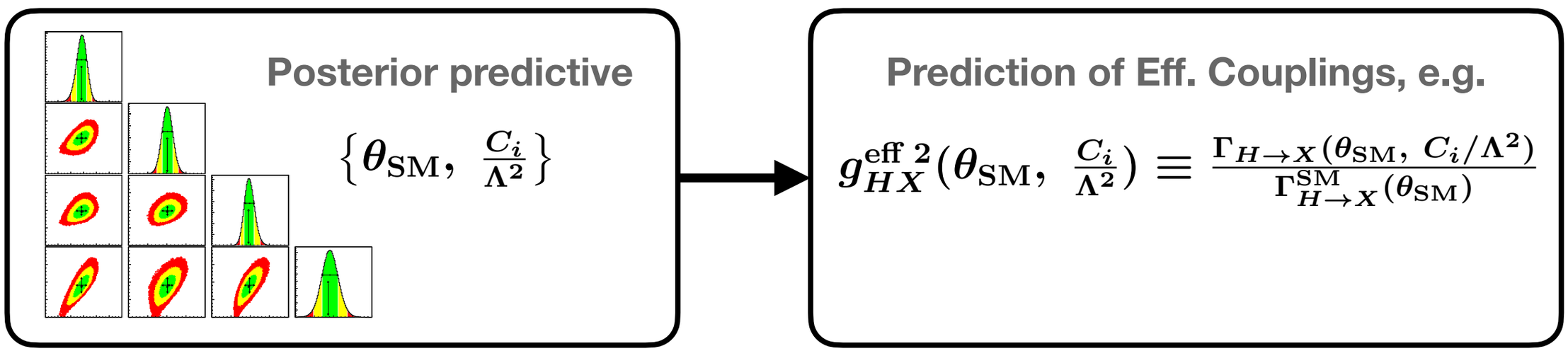
Updates for FCC feasibility study

Global SMEFT fit results in FCC feasibility report

- **Starting point:** setup prepared for the FCC CDR → previous European Strategy Update → later updated in the Snowmass 2021

  Designed with focus on the characterization of Higgs boson & role of EW

  - LO dimension-6 SMEFT fit to EW + Higgs + (very minimal) Top
    - Limited by input available at the time of CDR/2020 ESU. Improved during Snowmass (WW) and afterwards (Top)
  - Flavor assumptions: maximize exploration of deformations in Higgs and EW observables w/o FCNC
    - Non-universal Diagonal NC → SMEFT_{ND} (Cumbersome from BSM point of view)
  - Bayesian fit including 5 SM + 30 SMEFT free physics parameters using HEPfit
  - Performed in Warsaw basis ⇒ projected in terms of sensitivity to NP in "effective" SM couplings



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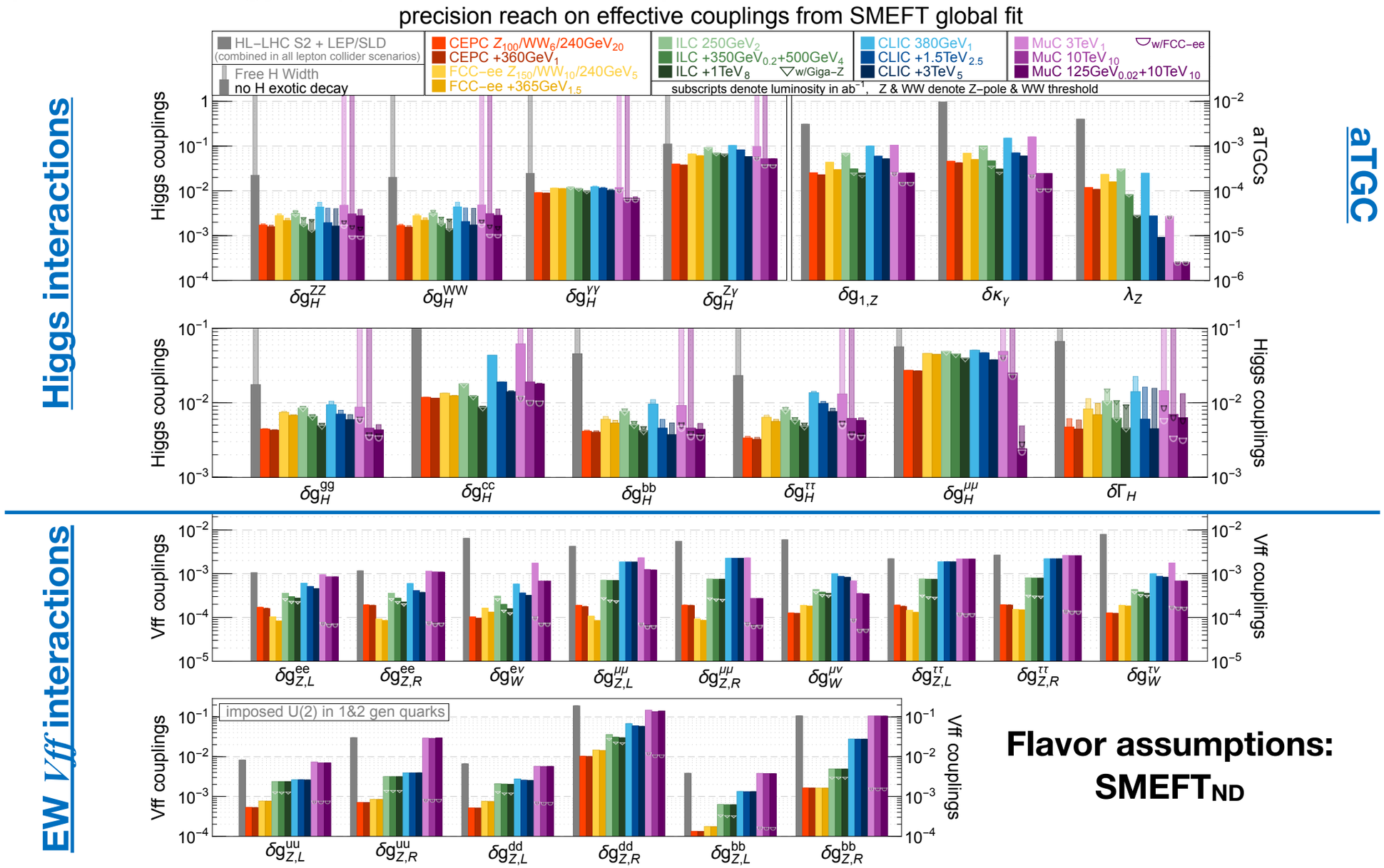

Higgs interactions | **aTGC** | **EW *Vff* interactions**

Flavor assumptions: SMEFT$_{ND}$

Effective couplings

$$g_{HX}^{\text{eff}\ 2} \equiv \frac{\Gamma_{H\to X}}{\Gamma_{H\to X}^{\text{SM}}}. \qquad \Gamma_{Z\to e^+e^-} = \frac{\alpha\, M_Z}{6\sin^2\theta_w\cos^2\theta_w}(|g_{Zee,L}^{\text{eff}}|^2 + |g_{Zee,R}^{\text{eff}}|^2), \qquad A_e = \frac{|g_{Zee,L}^{\text{eff}}|^2 - |g_{Zee,R}^{\text{eff}}|^2}{|g_{Zee,L}^{\text{eff}}|^2 + |g_{Zee,R}^{\text{eff}}|^2}.$$

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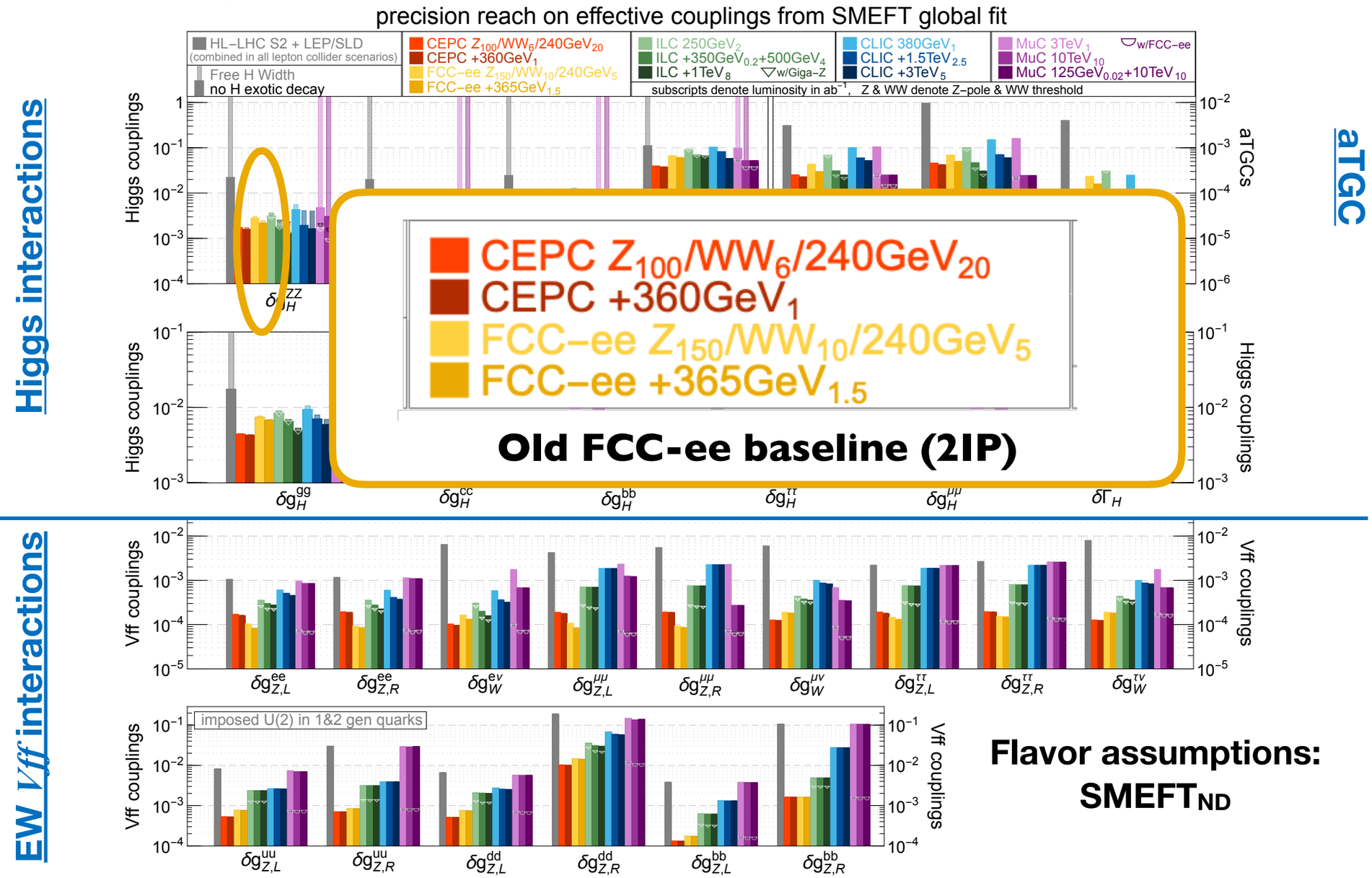

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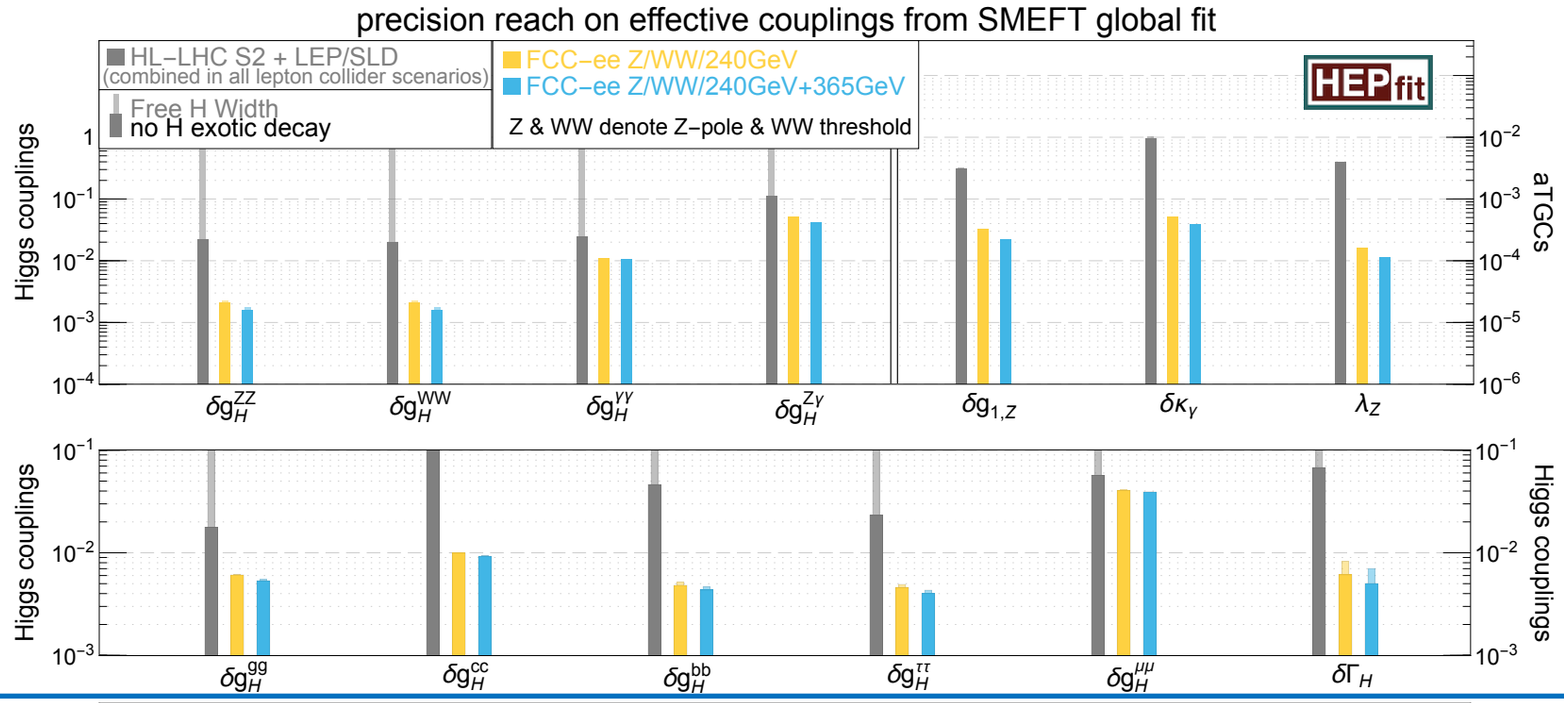
Global SMEFT fit results in FCC feasibility report

Characterization of Higgs boson & role of EW

- Updated to the current baseline (4IP) and luminosities

Higgs interactions



EW *Vff* interactions

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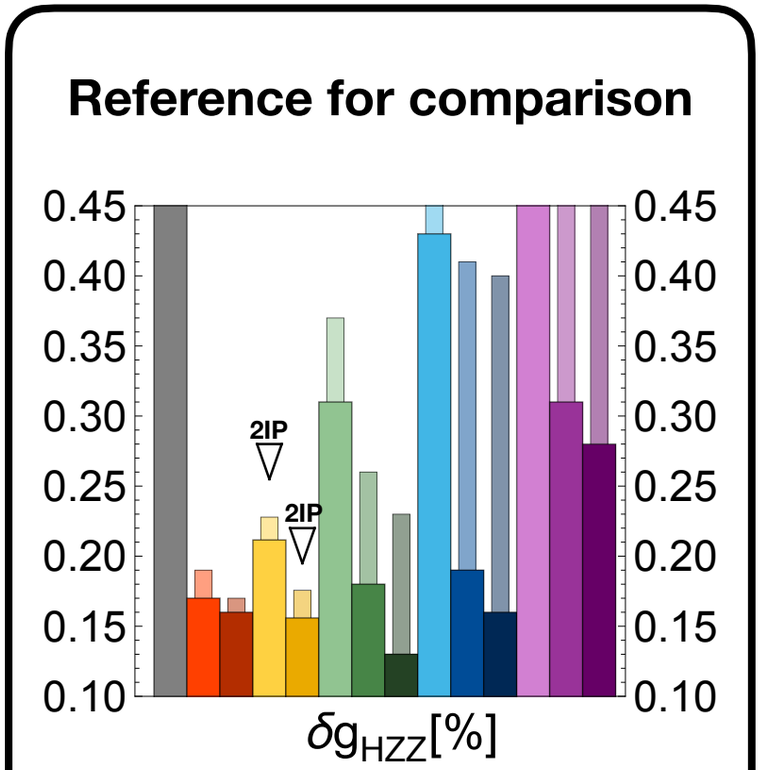

FCCee/CEPC same final precision with different running setup

δg_{HZZ}~0.15%

Flavor assumptions: SMEFT$_{ND}$

Effective couplings

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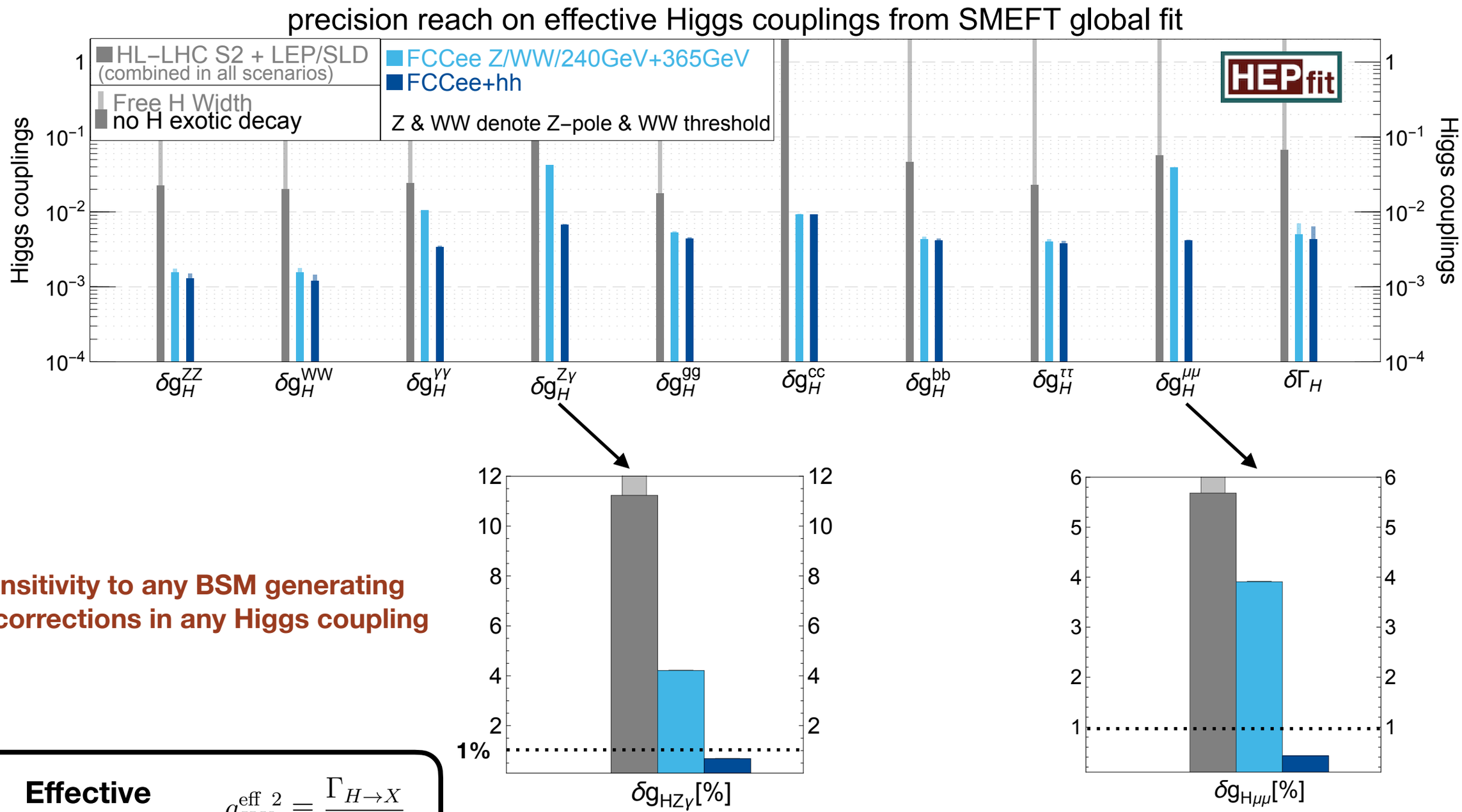
Global SMEFT fit results in FCC feasibility report

Characterization of Higgs boson & role of EW

- Updated to the current baseline (4IP) and luminosities and in combination with FCC-hh (Higgs)



Sensitivity to any BSM generating 1% corrections in any Higgs coupling

Effective couplings $g_{HX}^{\text{eff }2} \equiv \dfrac{\Gamma_{H\to X}}{\Gamma_{H\to X}^{\text{SM}}}.$

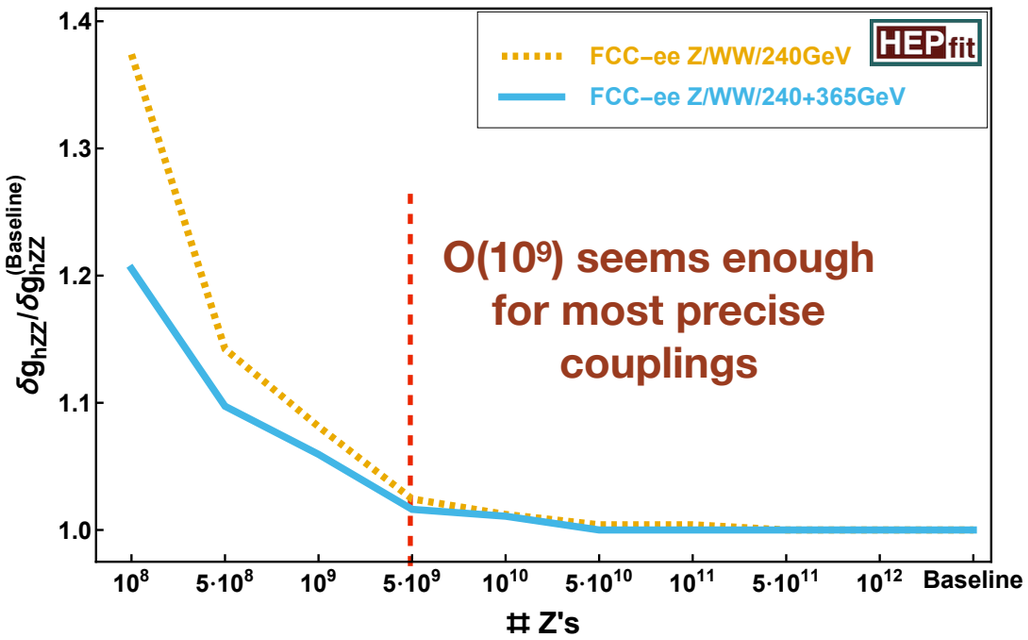
Global SMEFT fit results in FCC feasibility report

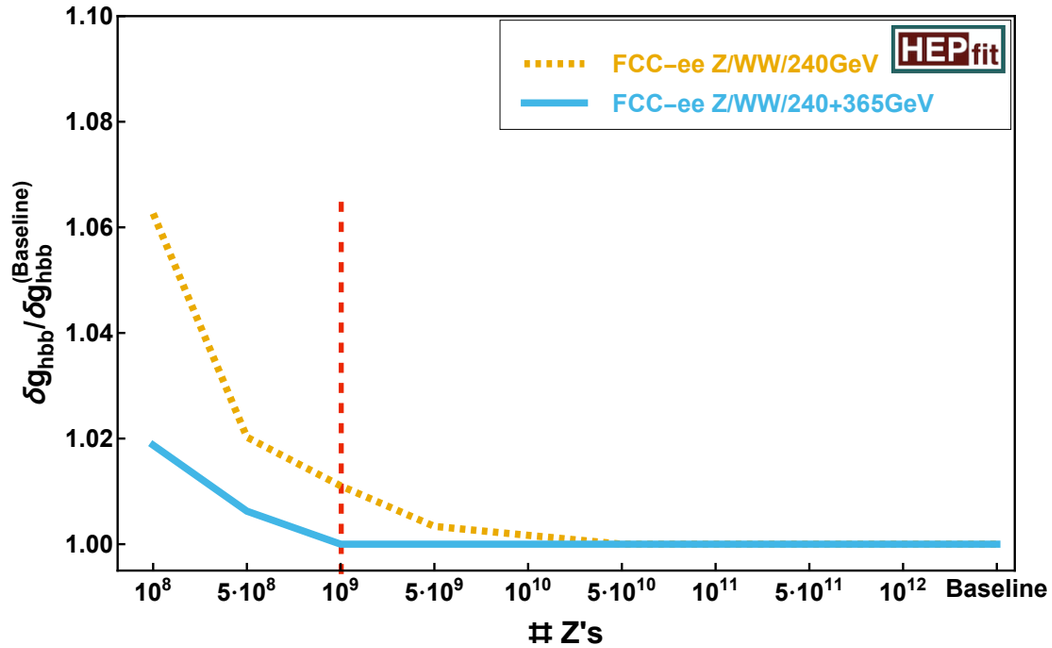
Characterization of Higgs boson & role of EW

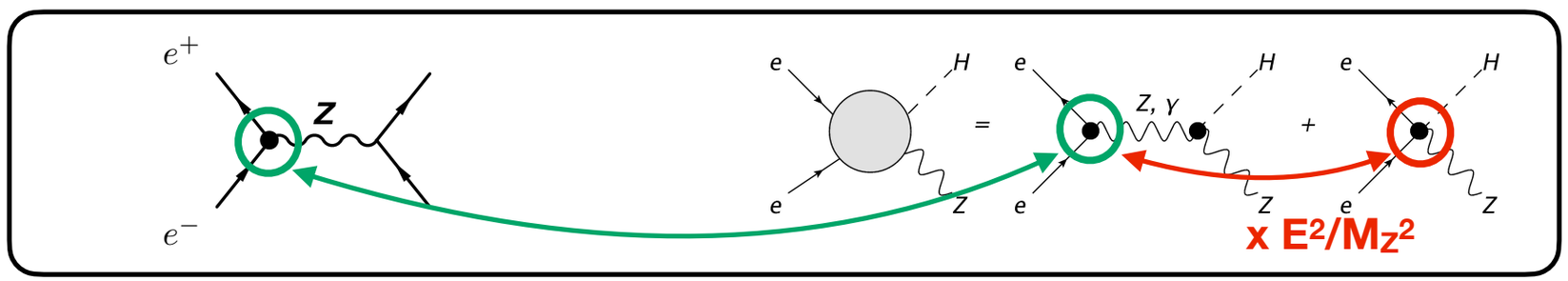
- Made more precise the interplay between Z-pole and Higgs measurements

Influence of # Z's in Higgs precision

Degradation in Higgs precision wrt Tera Z







Effective couplings

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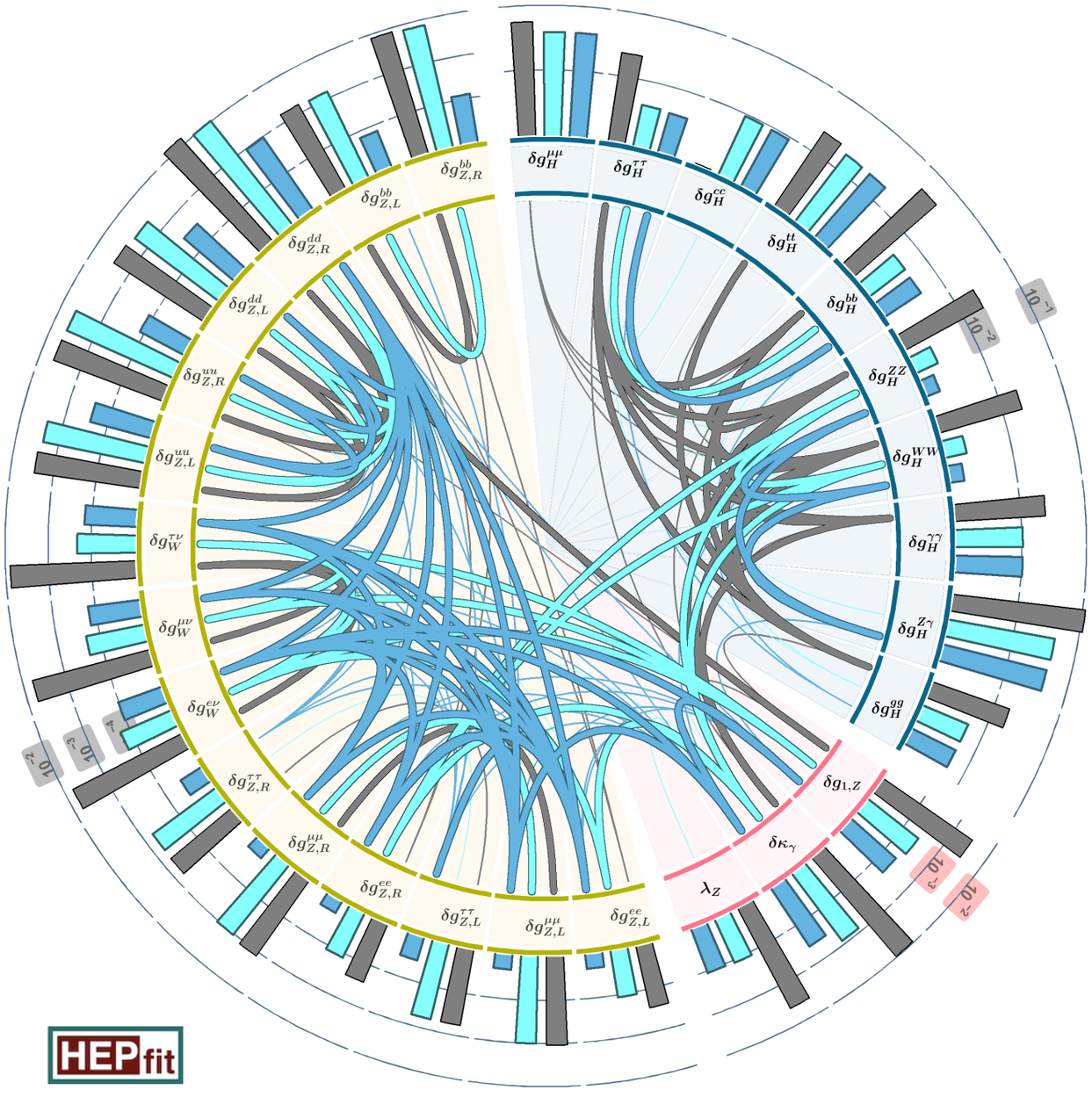
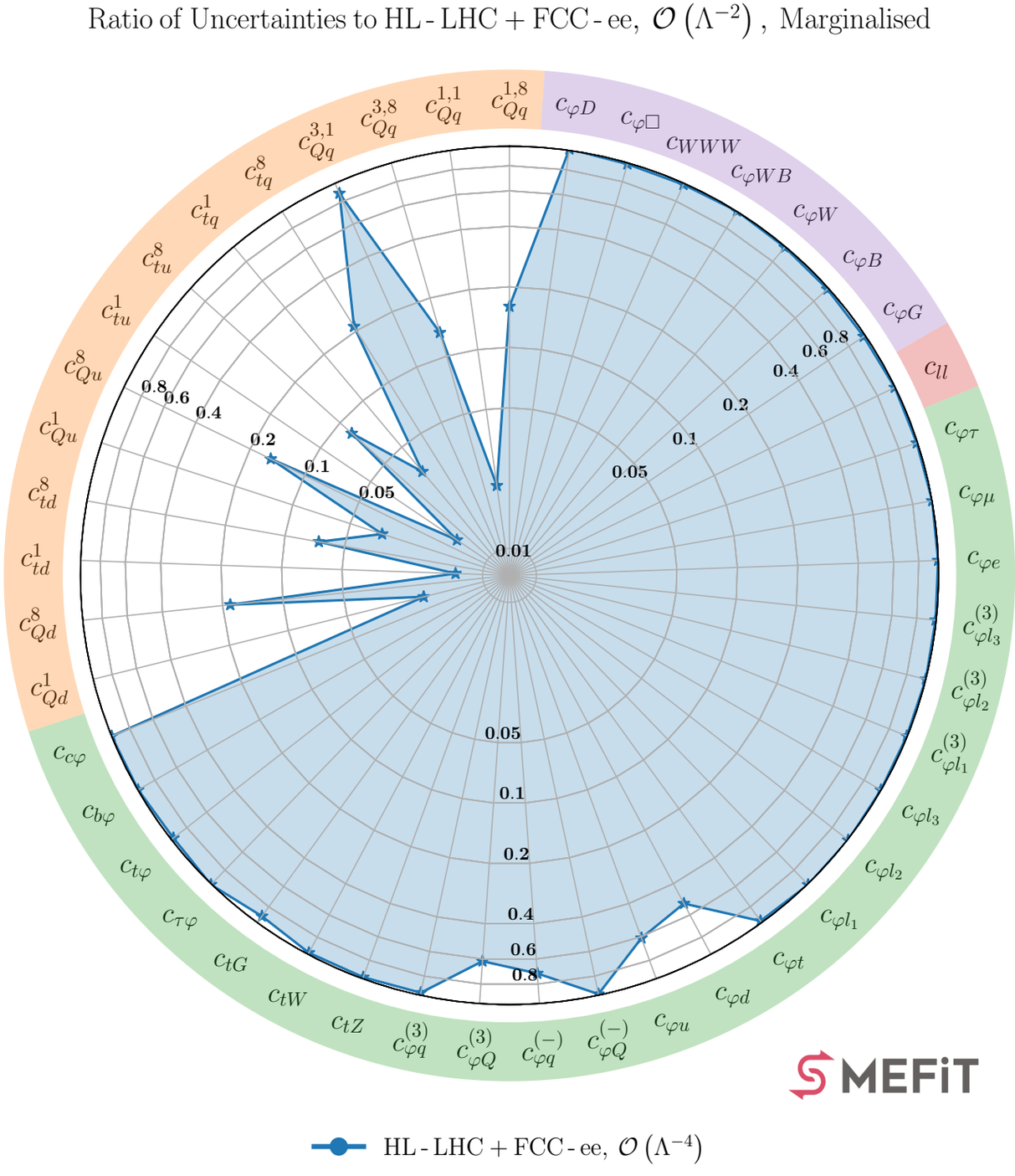
Global SMEFT fit results in FCC feasibility report

- Most of our plots are linear, but the nicest are circular…

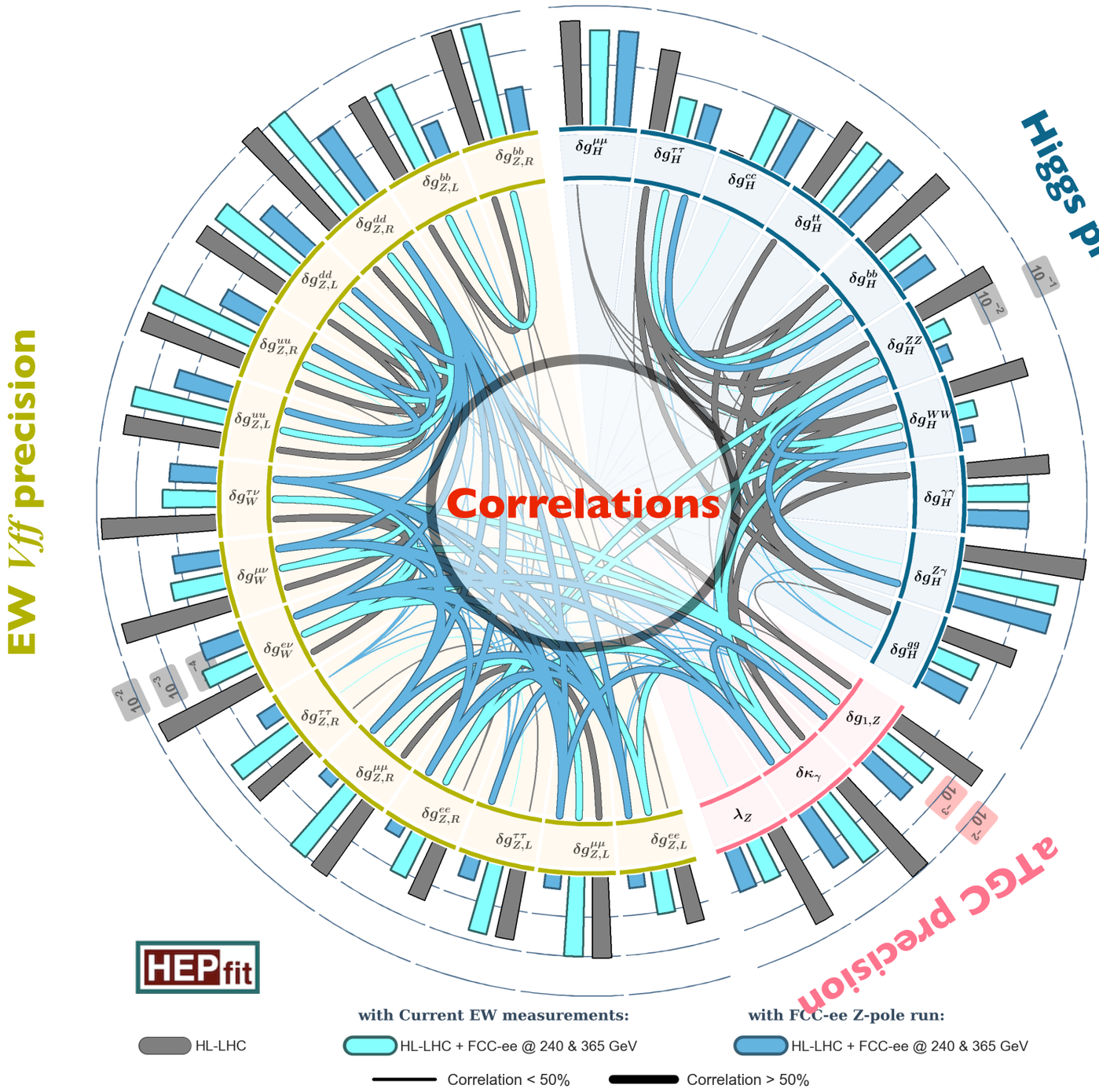




Global SMEFT fit results in FCC feasibility report

Characterization of Higgs boson & role of EW

- Made more precise the interplay between Z-pole and Higgs measurements



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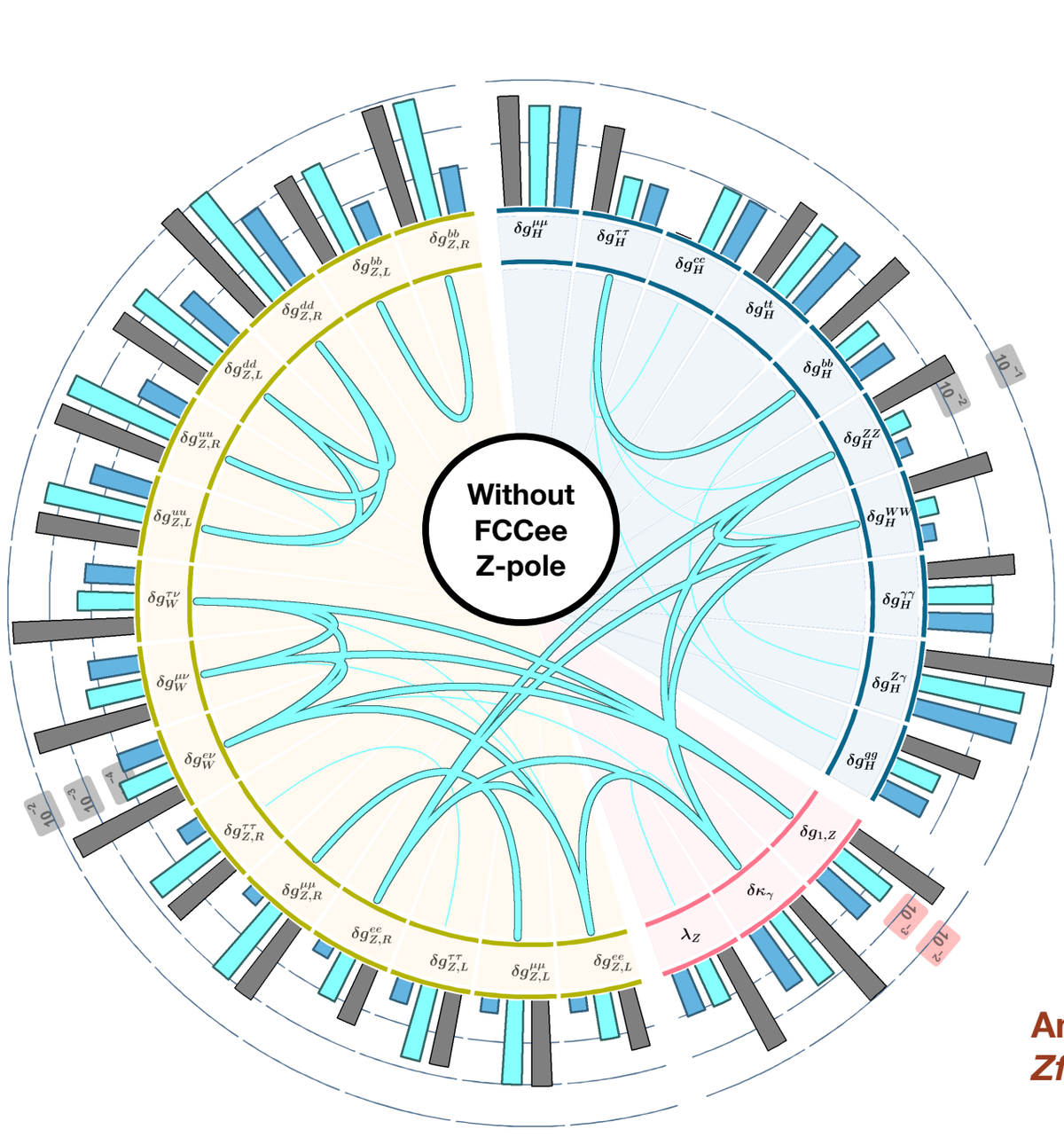
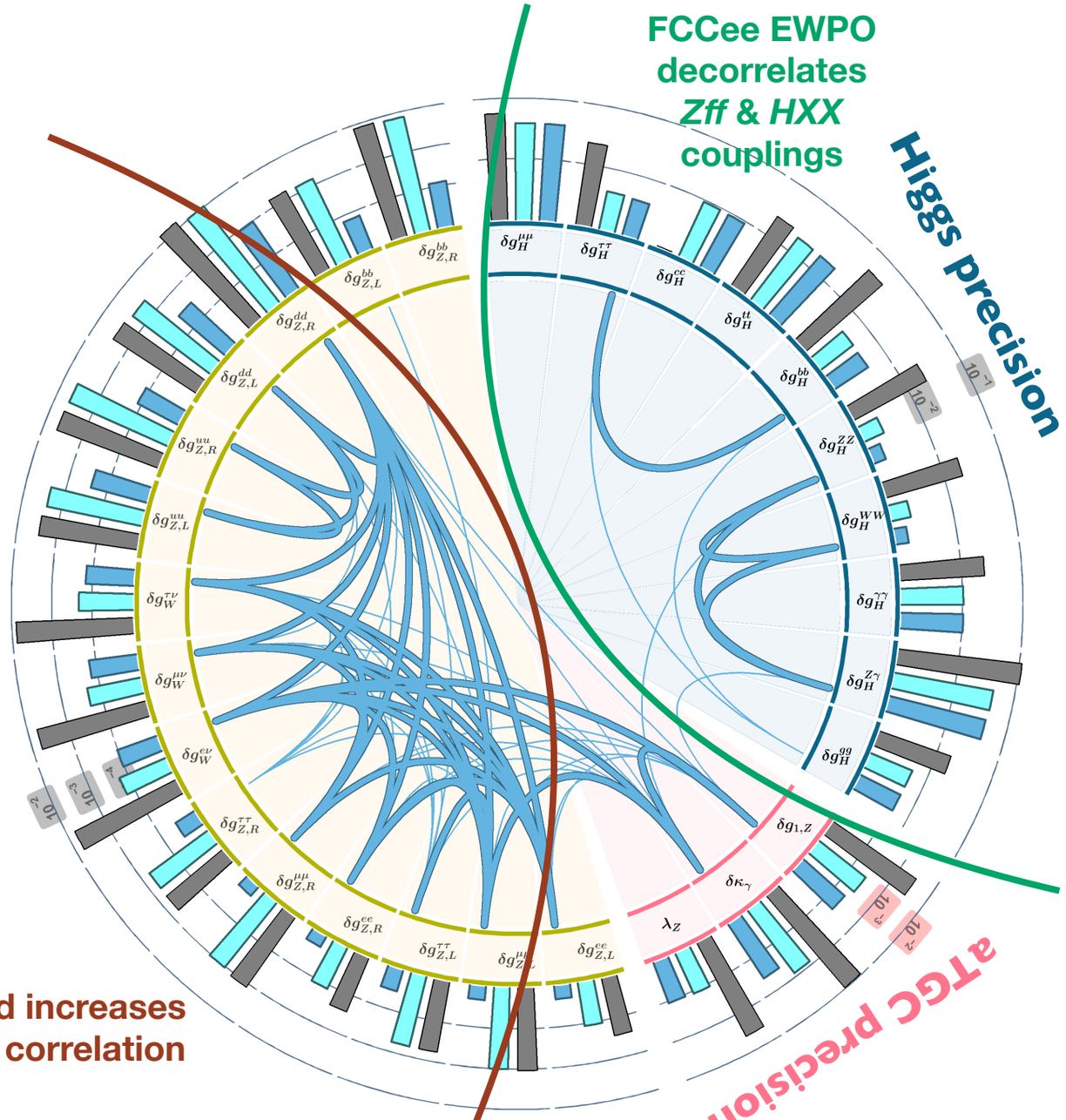
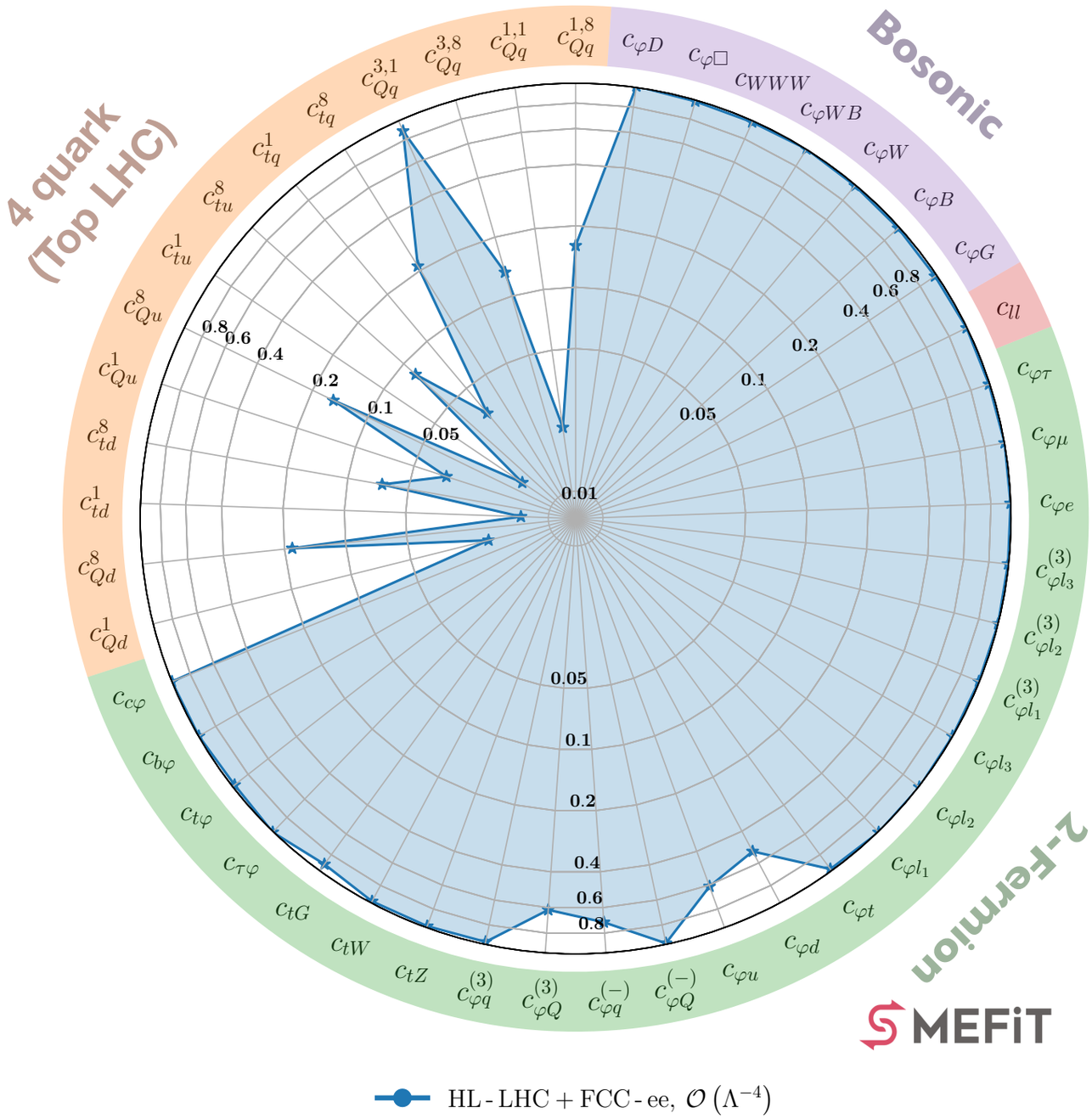




Global SMEFT fit results in FCC feasibility report

Towards an EW/Higgs/Top FCC-ee fit

- Extension more adding Top operators/observables to the EW/Higgs fit



E. Celada et al., JHEP 09 (2024) 091

- Fit to HLLHC+ FCC-ee including simultaneously EW, Higgs at Top measurements
- LHC Top WG flav. assumptions:

$$U(2)_q \times U(2)_u \times U(3)_d \times [U(1)_l \times U(1)_e]^3$$

- Also including:
  - NLO QCD effects in LHC obs.
  - Impact of quadratic terms

Global SMEFT fit results in FCC feasibility report

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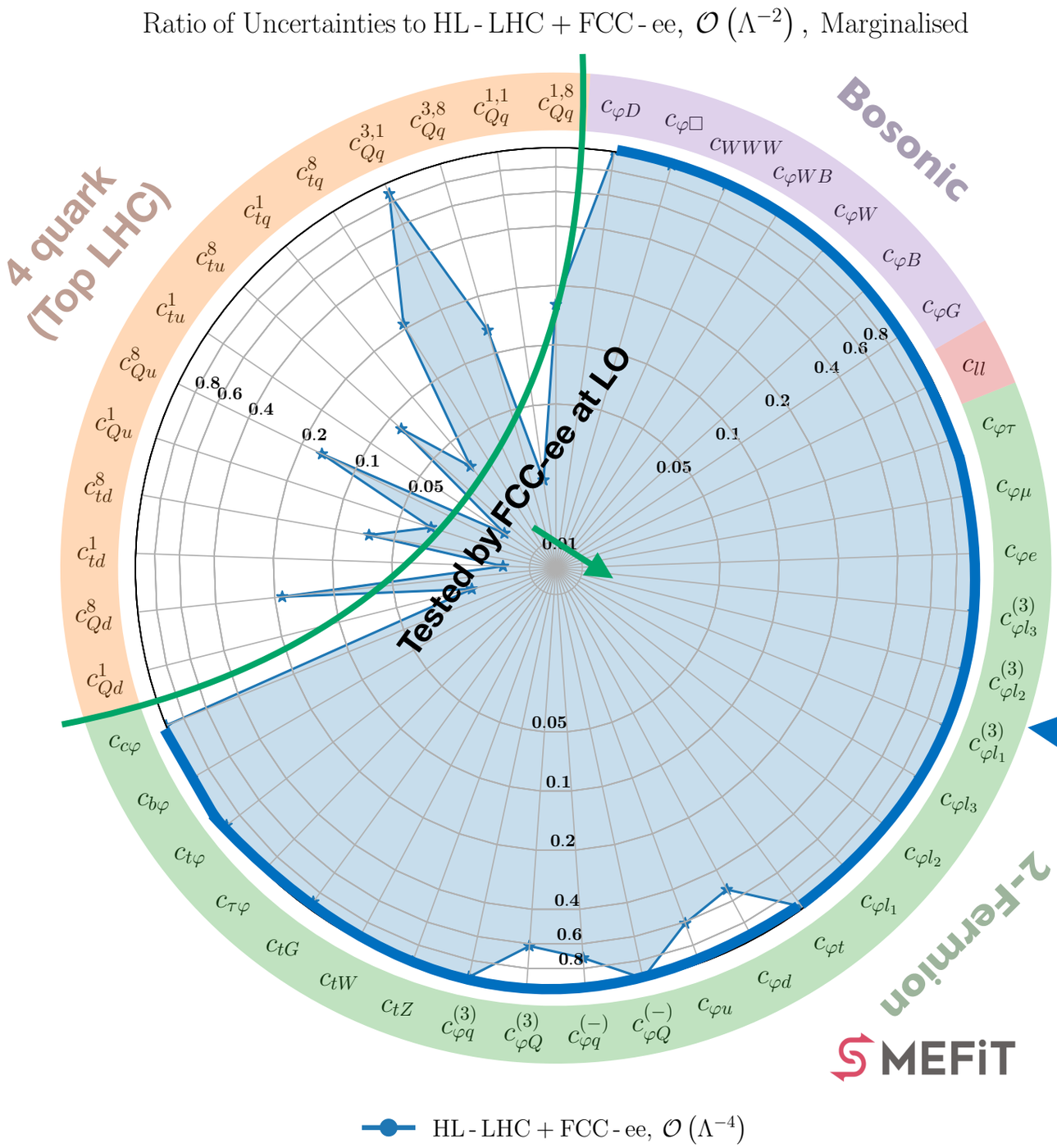

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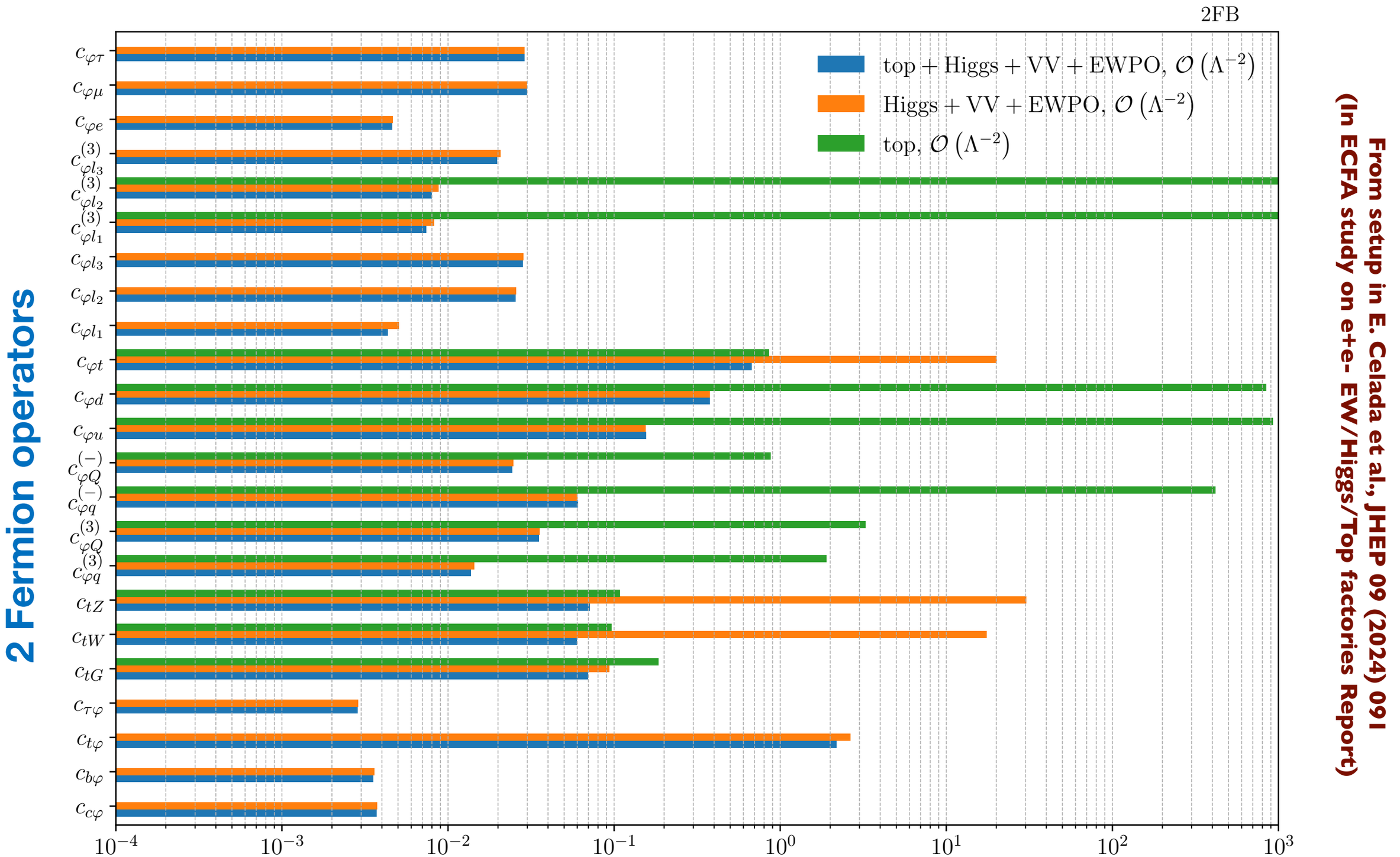
- Also including:
  - NLO QCD effects in LHC obs.
  - Impact of quadratic terms
    ⇒Small for operators tested by FCC-ee precision measurements

Global SMEFT fit results in FCC feasibility report

Towards an EW/Higgs/Top FCC-ee fit: Interplay of different sectors



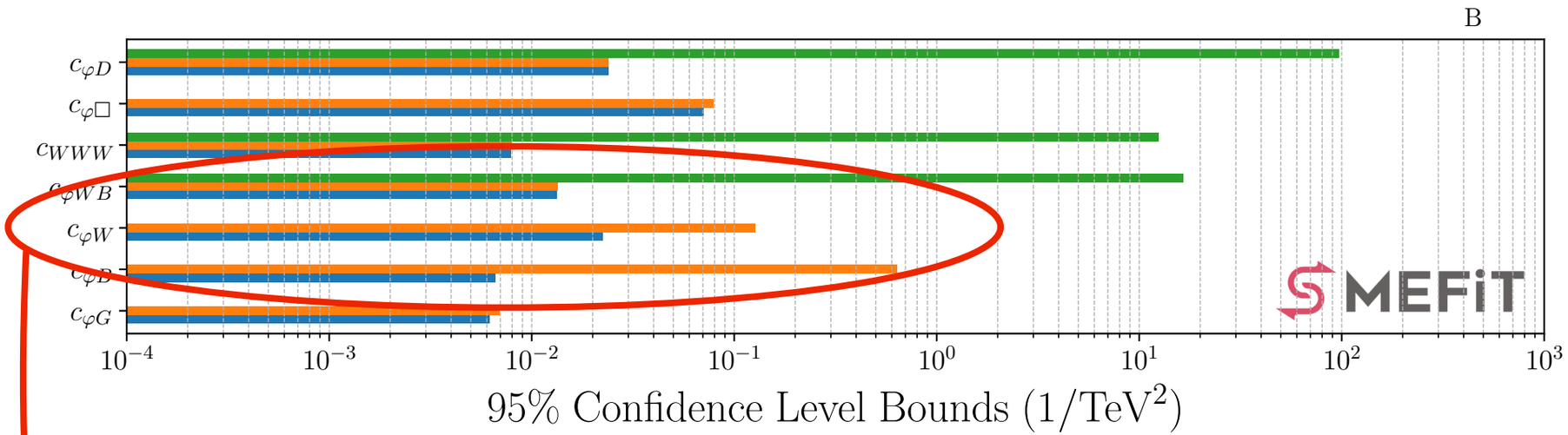
From setup in E. Celada et al., JHEP 09 (2024) 091
(In ECFA study on e+e- EW/Higgs/Top factories Report)

Bounds dominated by either EW+Higgs+VV or by Top data

Global SMEFT fit results in FCC feasibility report

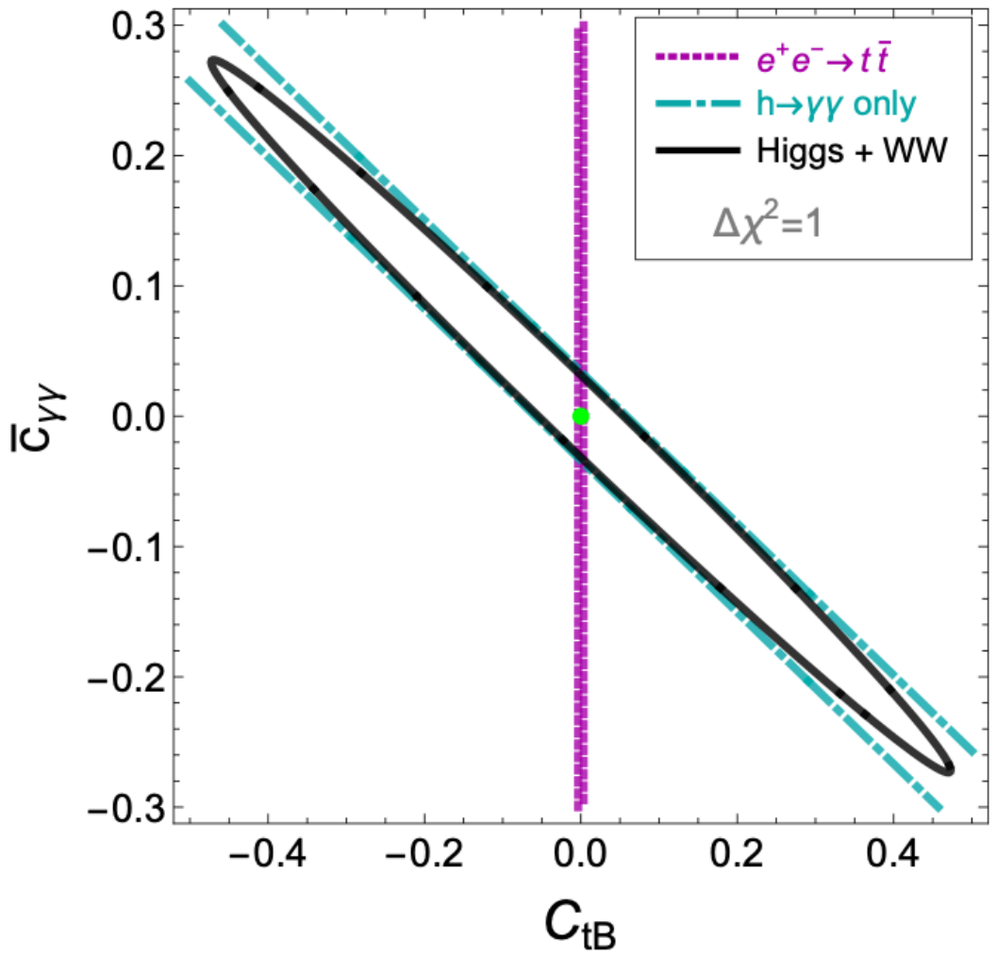
Towards an EW/Higgs/Top FCC-ee fit: Interplay of different sectors

Bosonic operators



Approx. flat direction in $H\to\gamma\gamma$ between Bosonic operators and weak dipoles

Lifted by $e^+e^- \to tt$



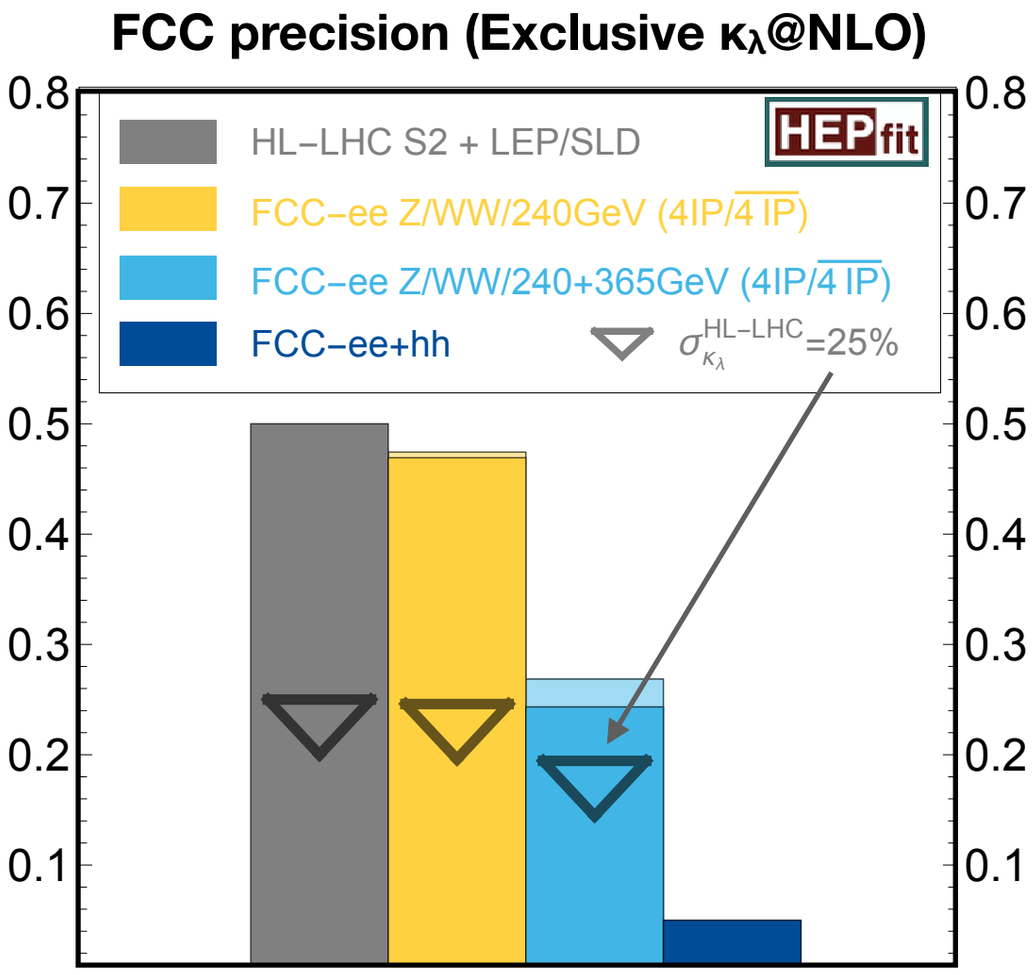
G. Durieux et al., Chin.Phys.C 42 (2018) 12, 123107

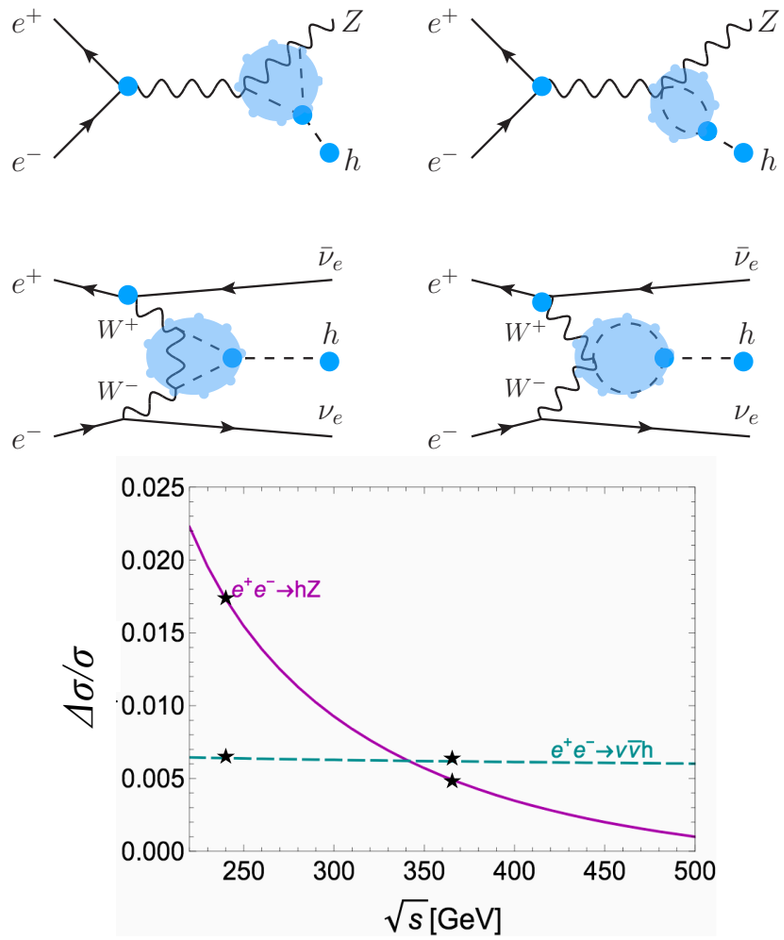
From setup in E. Celada et al., JHEP 09 (2024) 091 (In ECFA study on e+e- EW/Higgs/Top factories Report)

Global SMEFT fit results in FCC feasibility report

Characterization of Higgs boson & role of EW: Higgs self-coupling

- Simple estimate of FCC-ee sensitivity to the Higgs self-coupling via loop effects





Based in SMEFT analysis including ALL LO contributions
BUT ONLY the one-loop effects from κ_λ

Global SMEFT fit results in FCC feasibility report

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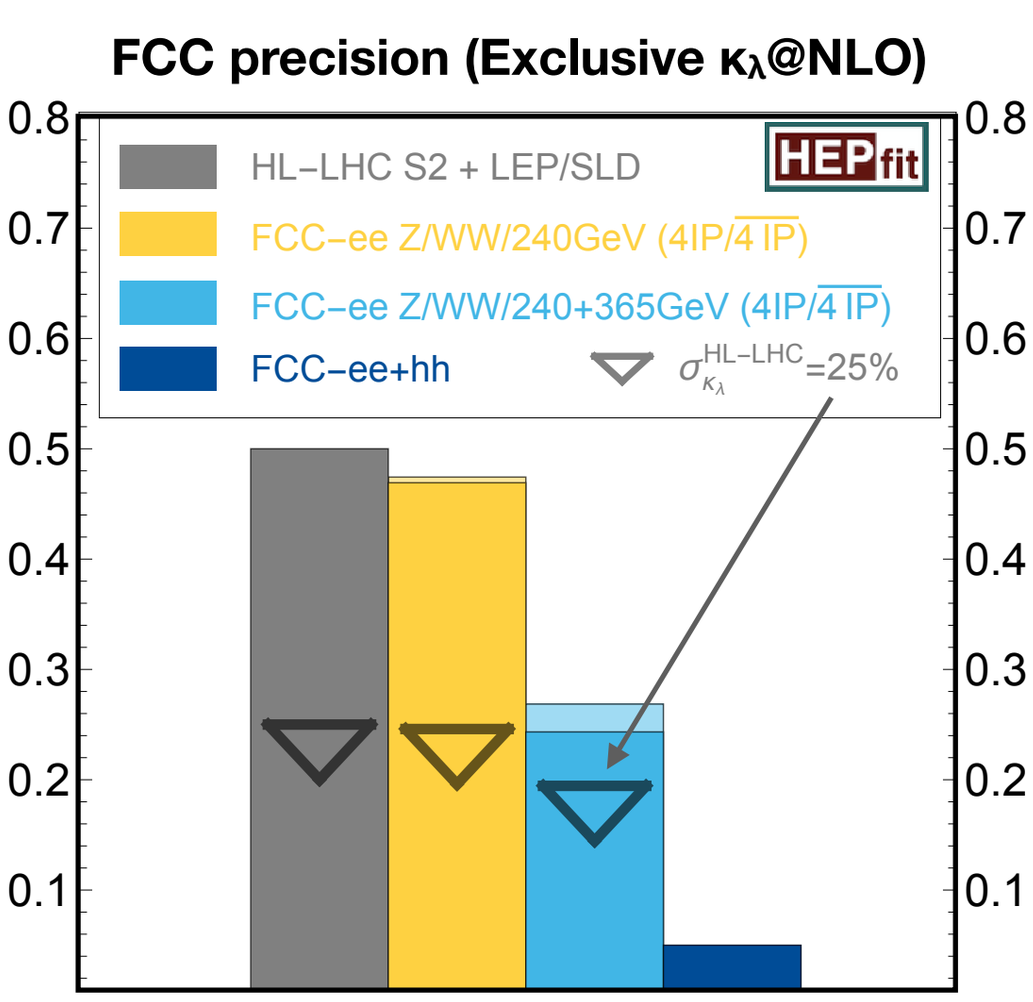
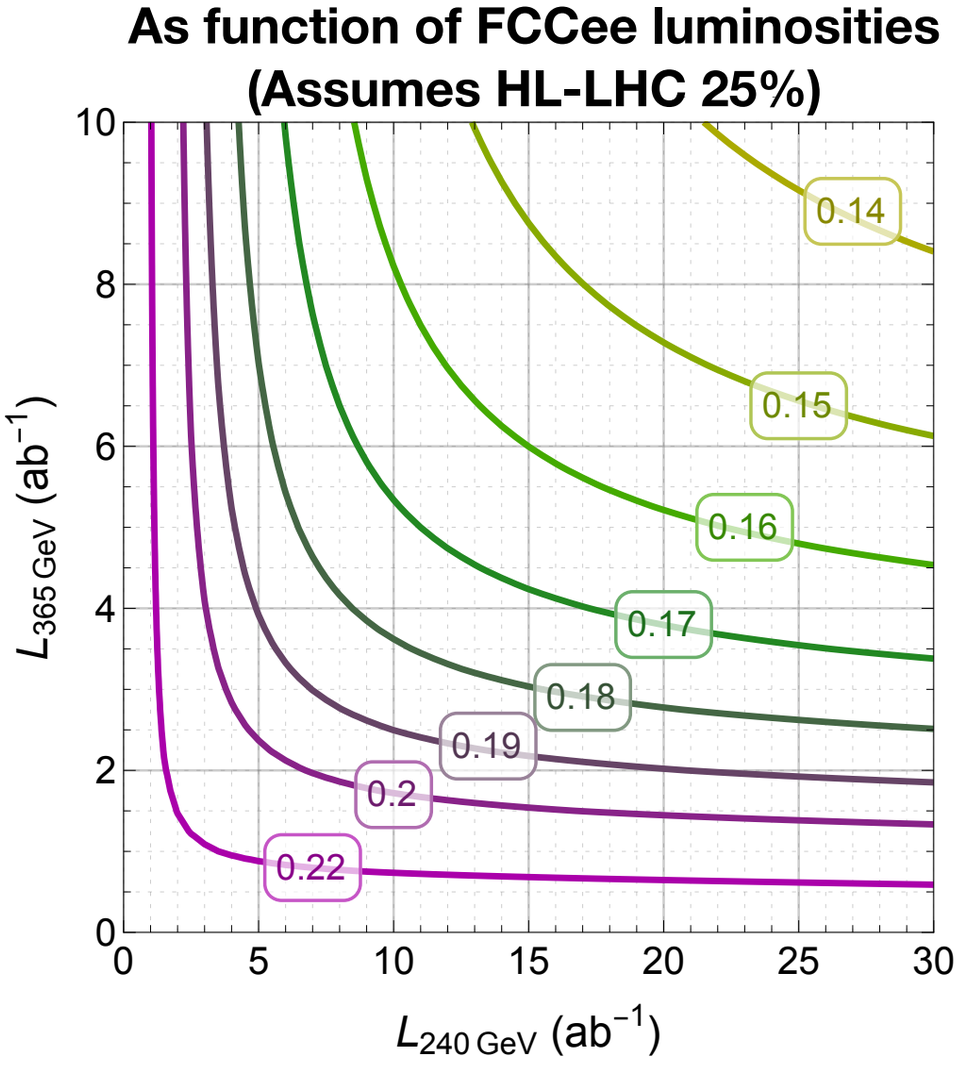




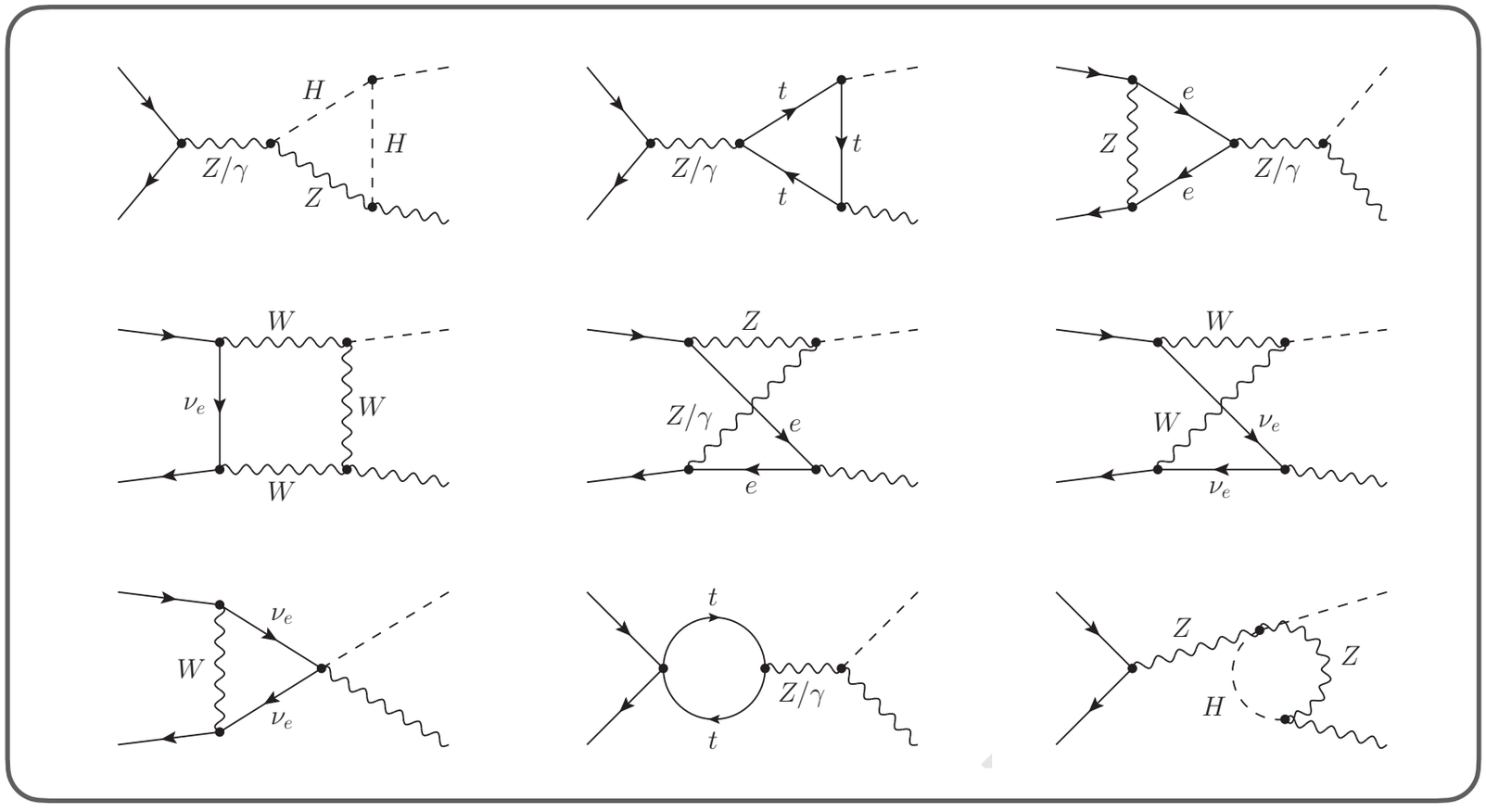
- You can still learn from this (e.g. need at least two energy points to separate κ_λ from LO), but a *"model-independent" interpretation of κ_λ within the SMEFT assumptions requires introducing all operators that contribute at NLO*!

From SMEFT point of view this cannot be seen as model-independent

Global SMEFT fit results in FCC feasibility report

Characterization of Higgs boson & role of EW: Higgs self-coupling

- Proper SMEFT estimate of FCC-ee sensitivity to the Higgs self-coupling via loop effects requires full NLO calculation. Recently computed for $e^+e^- \to ZH$:



K. Asteriadis et al., arXiv: 2409.11466 [hep-ph]

See S. Dawson's talk on Tuesday

- On top of the LO operators, a total of 6 boson operator (4 CP violating), 9 2-fermion operators and 14 four-fermion operators contribute to dimension 6 at NLO
- Some of them which will remain relatively weakly constrained at the LHC!

  $\Rightarrow e^+e^- tt$ operators $\Rightarrow$ Extend EW/Higgs/Top fit to NLO (WiP)

Concluding
Towards the 2026 European Strategy Update

Concluding…

- Comprehensive study of exploration/characterization of Higgs/EW sectors + progress made in adding Top sector into the global picture

- Several places where to improve current studies and issues to clarify. (Work in progress for the 2026 ESPP)

  ✓ Adopting more sensible flavor assumptions:

  - SMEFT$_{ND}$ could test all directions possible with the projections available at the time. Contrived from BSM point of view.
  - ESPP fits: Choose assumptions to increase coverage to BSM while consistent with flavor → Respect approximate SM flavor symmetries

$$G_{\rm SM} \approx U(2)_{q_L} \times U(2)_{u_R} \times U(2)_{d_R} \times U(1)_e \times U(1)_\mu \times U(1)_\tau$$

See e.g. L. Allwicher et al., JHEP 03 (2024) 049 for U(2)^5 (single operator sensitivity)

✓ RGE and NLO effects where relevant in the global fit

- Bring another layer of complementarity between different measurements
- Complicated to close a proper global fit
- Needed for precise assessment of κ_λ precision from Higgs loops

Results very soon

✓ Extending fits with other data sets (in particular FCC-hh!)

- Need input from experimental side…

Backup slides

Single operator NLO sensitivity: on vs. off pole

From V. Maura et al., arXiv: 2412.14241 [hep-ph]