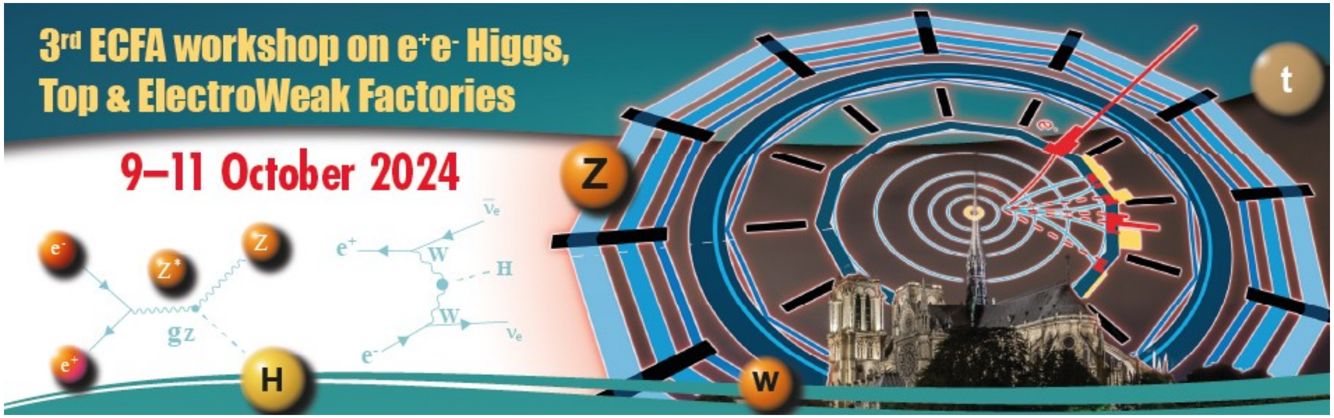
Status of studies in the GLOBal interpretation group

Jorge de Blas (U. Granada), Alexander Grohsjean (DESY), Sven Heinemeyer (IFT Madrid), Junping Tian (U. Tokyo), Marcel Vos (IFIC- CSIC/UV, Valencia)

ECFA Higgs/top/EW factory studies, Paris, October 2024



EXCELENCIA SEVERO OCHOA

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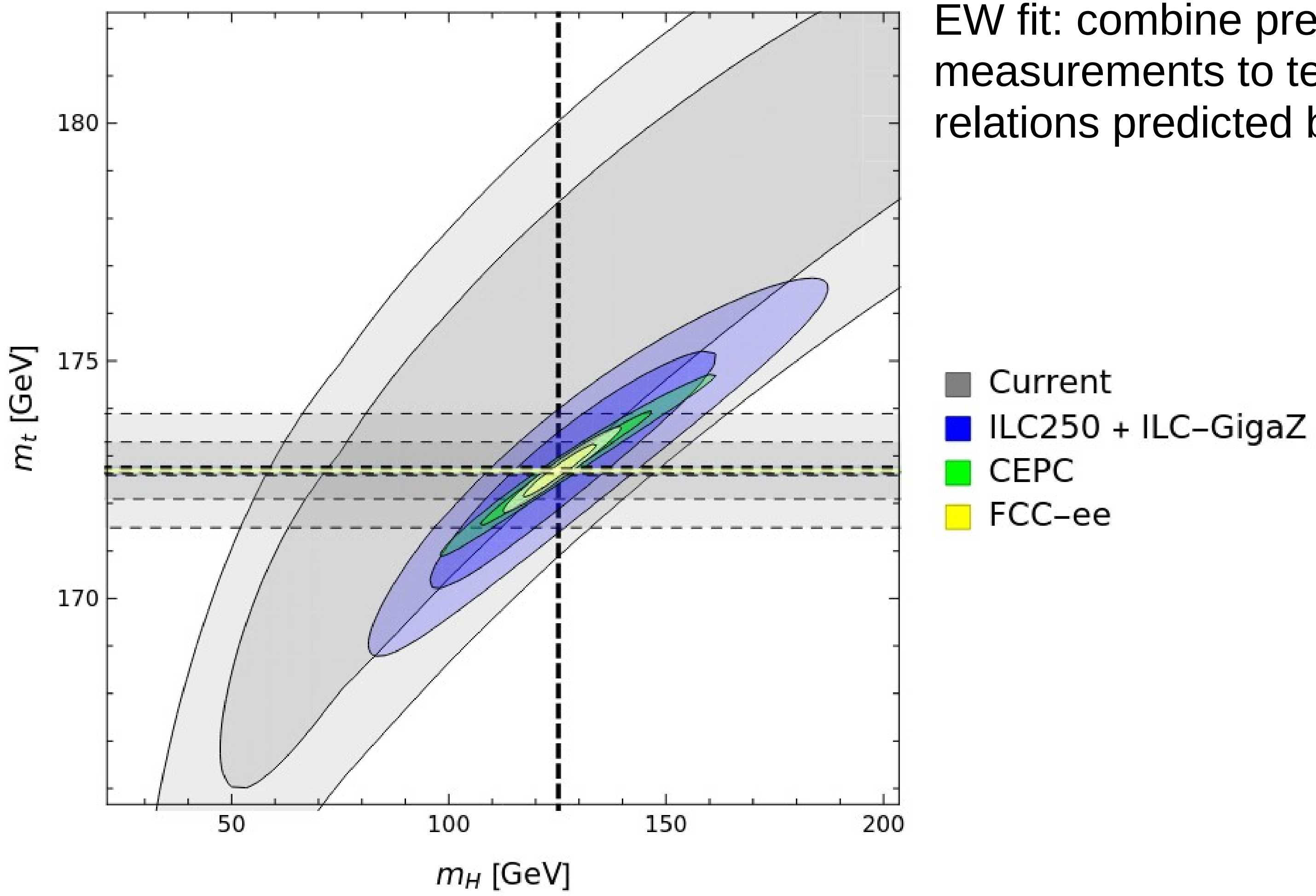
Global analysis



EW fit: combine precision measurements to test the relations predicted by the SM

Snowmass studies: https://arxiv.org/pdf/2209.08078, https://arxiv.org/pdf/2209.11267

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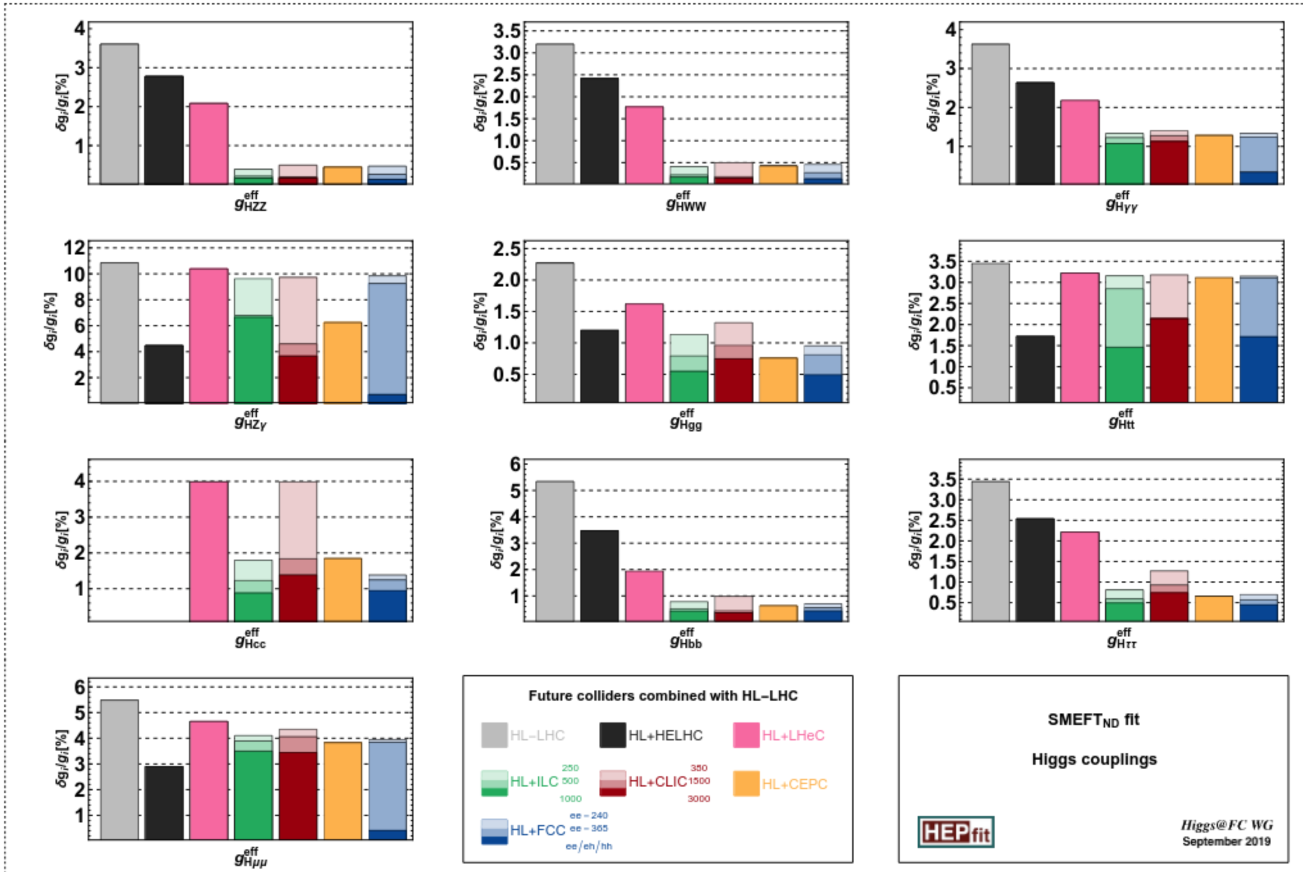
Global analysis of the Higgs sector



Global analysis is a moving target; this fit incluces Higgs/EW projections (and some top).

State-of-the-art machinery has moved on:

Higgs/EW/top, Ellis et al.

NLO predictions, SMEFiT

RGE evolution and mixing

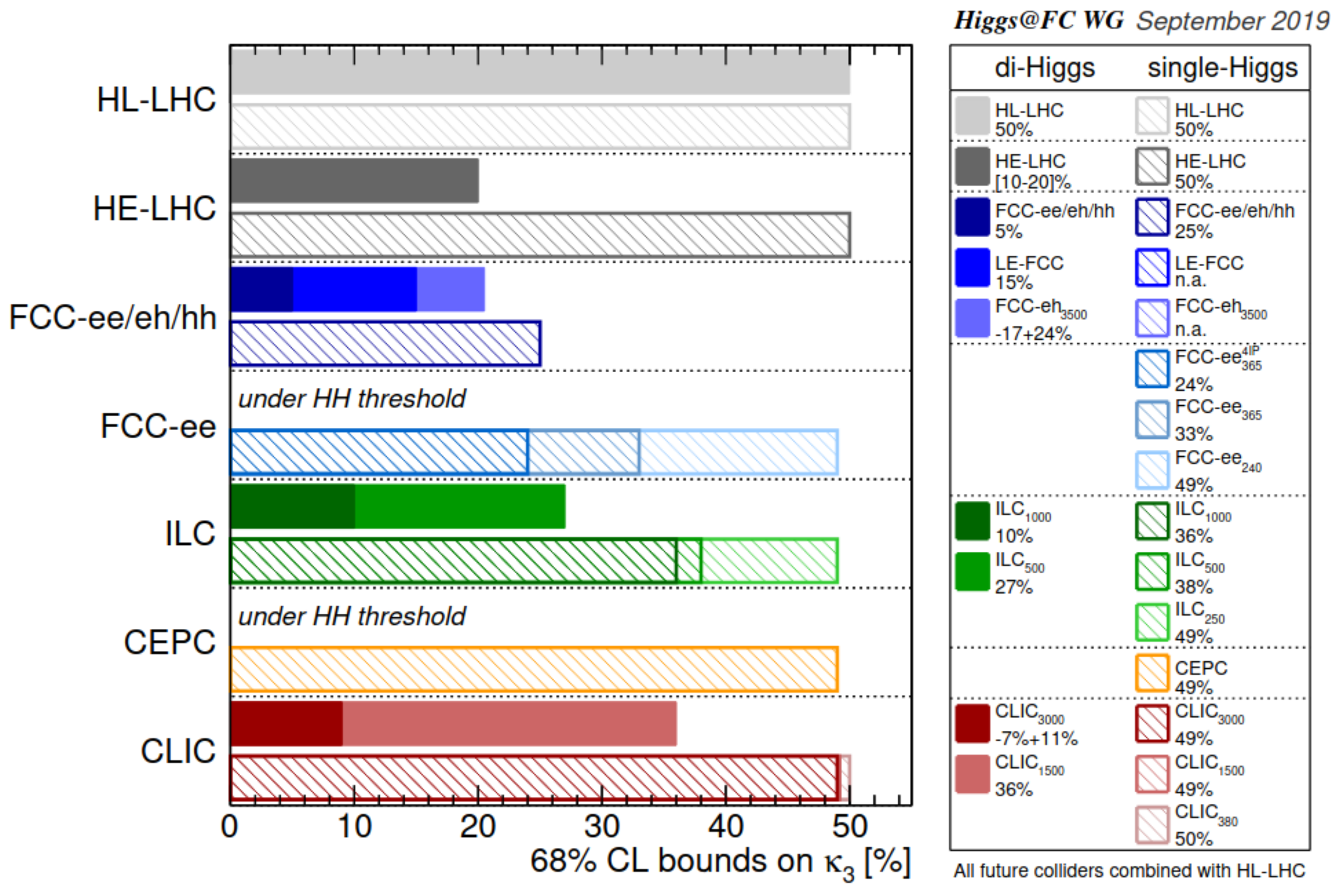
New connections among Higgs/EW/top sectors

Physics briefing book of previous streategy update: https://arxiv.org/pdf/1910.11775

Global?

ZH production offers sensitivity to:

- Higgs self-coupling at NLO (McCullough, arXiv:1312.3322)
- other operators at LO (di Via et al., arXiv:1711.03978)
- many other operators at NLO (arXiv:2406.03557, arXiv:2409.11466)



Physics briefing book of previous streategy update: https://arxiv.org/pdf/1910.11775

Scope

Wednesday: SMEFT EW, top & Higgs

Thursday: non-standard Higgs, Higgs self-coupling from ZH measurements, high-energy operation

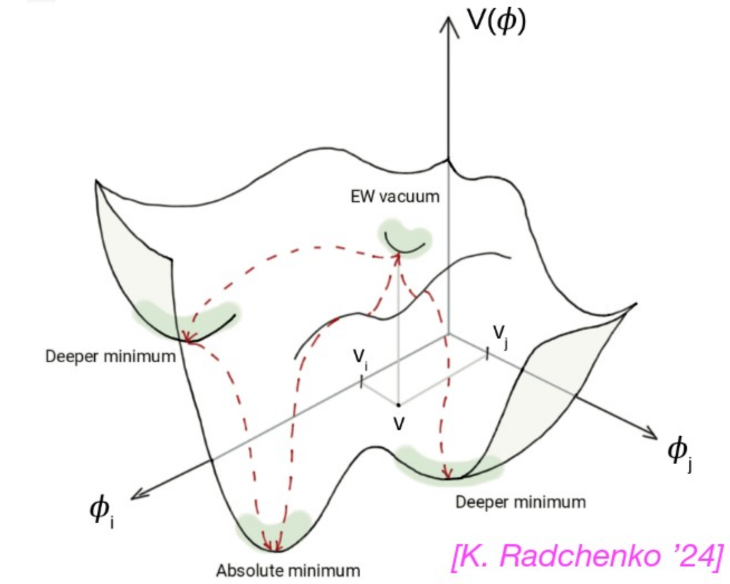
Addressing questions beyond previous work

Improving underlying projections: **any fit is as good as its inputs**
Leonard Reichenbach (WW), Xunwu Zuo (ttbar), Andrea Maria (ZH), Bryan Bliewert (HH)

Advancing SMEFT: Global Higgs/EW/top fits at NLO and including RGE evolution
Pier Paolo Giardino, Ben Stefanek, Michael Peskin, Jaco ter Hoeve, M.V.

Higgs self coupling: the holy grail of HEP*
Johannes Braathen and Georg Weiglein on BSM effects, Bliewert, Giardino, M.V.
(see also focus topic report by Junping Tian)

*Georg Weiglein



SMEFT fits

[Of determining the
Higgs couplings]

The traditional κ parametrization is not up to the task. We suggest that a method based on SMEFT is more physical, complete, and model-independent.

Michael Peskin's talk

Previous strategy update: Higgs coupling projections in the kappa and EFT framework.
The next strategy update: EFT only, using fits with linear D6 dependence as baseline.
(my proposal, up for discussion)

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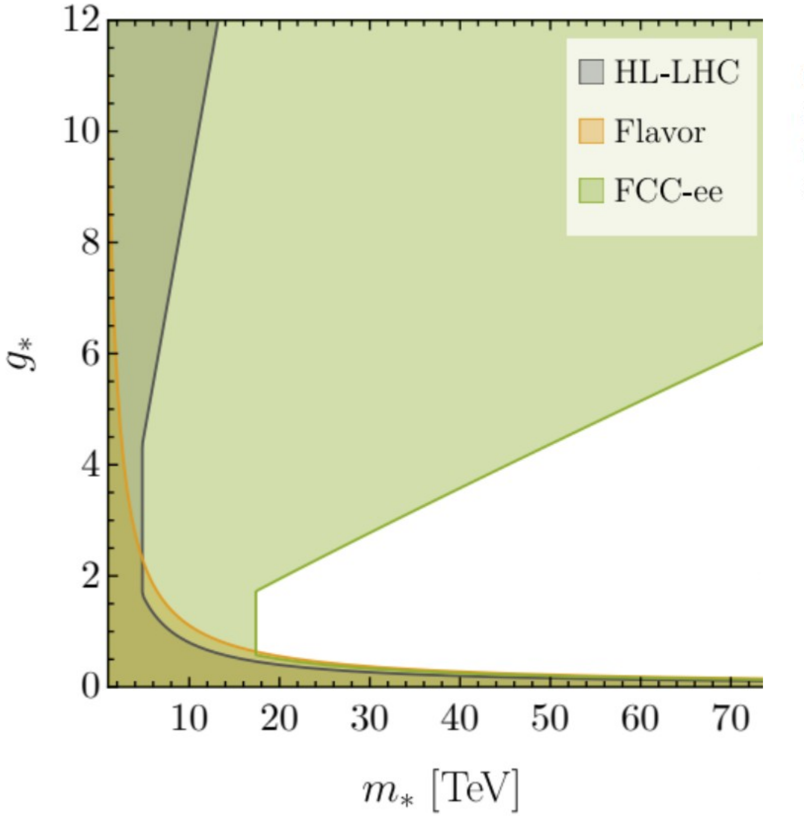
TeraZ potential vs. Top measurements

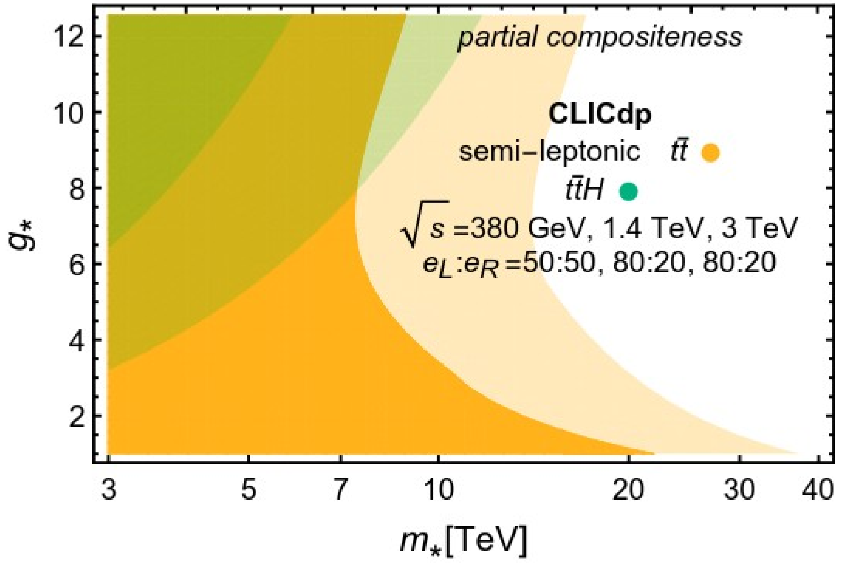
Composite Higgs scenarios where 3rd generation is special: t_R = composite

EW precision at the Z-pole offers stringent bounds
[Allwicher, Cornella, Isidori, Ben Stefanek, 2311.00020]

The 4-top operator, tested in tttt production, also has two-loop impact on EWPO
[Stefanek, 2407.09593]



For comparison: bounds from
e+e- → tt and e+e- → ttH



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SMEFiT results (Jaco ter Hoeve)

Higgs/EW/top fits on projections

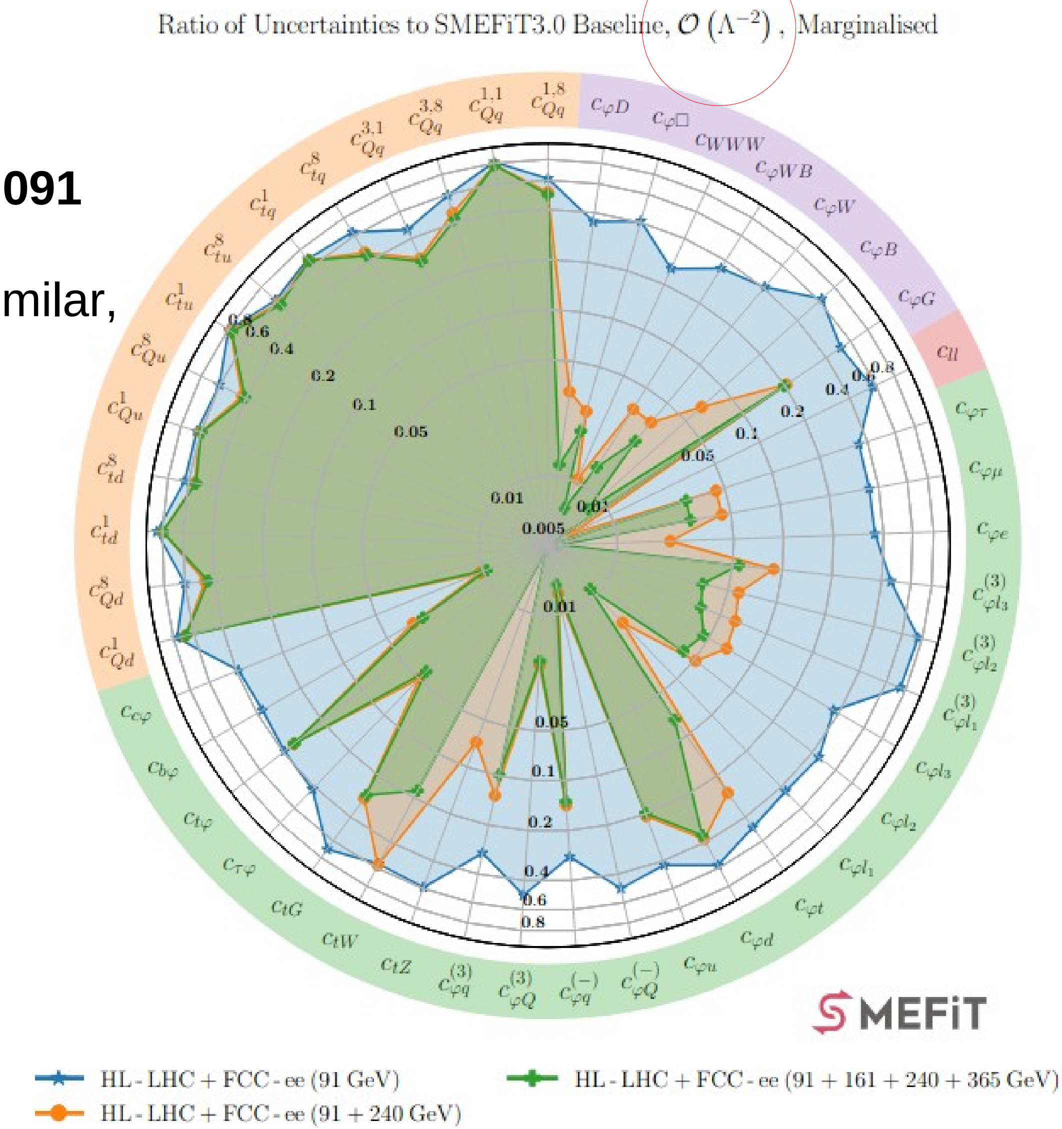
Results beyond JHEP 09 (2024) 091

Linear-only bounds: quadratic is similar, except for qqtt operators

RGE evolution: small changes, except tttt operators

Todo: eett operators, different collider projects

[1804.05033] Aebischer, Kumar, Straub



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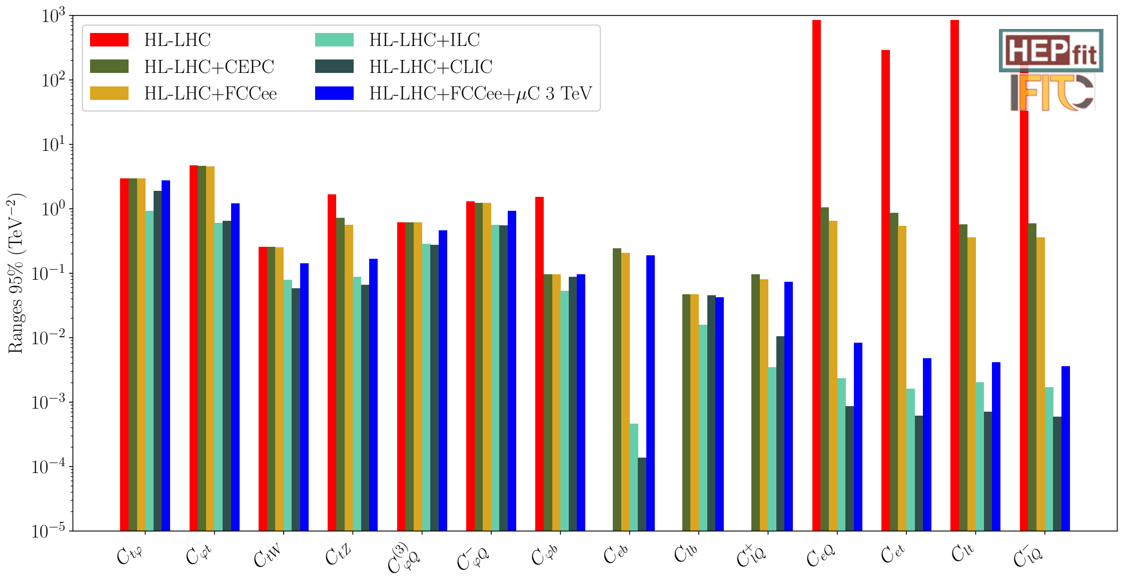
Fit to the top sector

IFIT/C collaboration fits top and bottom operators

Excellent bounds on operators that affect EW interactions of the top quark

TO DO: finalize fits, compare to SMEFiT, write paper



HL-LHC on eett operators:
Quadratic global: O(1)
Linear individual: O(1-10 TeV^{-2})
Linear global: O(100 TeV^{-2})

e+e- colliders on eett operators:
Linear fit, circular machine: O(1 TeV^{-2})
Linear fit, linear machine@1-3 TeV O(10^{-2} TeV^{-2})

All e+e- top data is good, high energy data are excellent

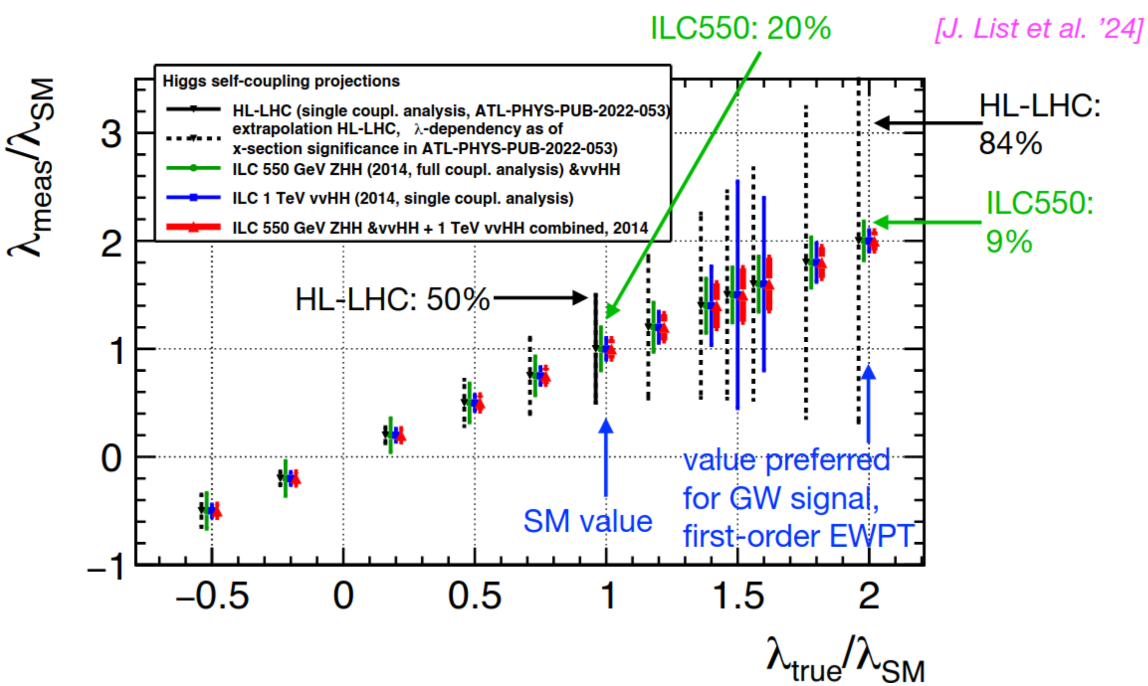
The Higgs self-coupling: HEP's next target

Key parameter of the SM, the experimental gateway to EW symmetry breaking, and a favourite spot to hide that elusive BSM physics.

λ_{hhh} can **deviate significantly from SM prediction** (by up to a factor **~10**), for otherwise theoretically and experimentally allowed points, due to **mass-splitting effects in radiative corrections involving BSM scalars**

Johannes Braathen, discussing Inert Doublet Models and Z2SSM

Georg Weiglein doubles down:
"the holy grail of HEP"



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Towards a truly global analysis of Higgs self-coupling from ZH

Indirect model-dependent probe of the Higgs self-coupling

Matthew McCullough
Phys. Rev. D **90**, 015001 – Published 1 July 2014; Erratum Phys. Rev. D **92**, 039903 (2015)

Pier Paolo Giardino: calculation of loop effects of top operators on ZH cross section, arXiv:2406.03557, arXiv:2409.11466

$$\sigma_{\mathrm{EFT,LO}}^{(\sqrt{s}=240\ \mathrm{GeV})}(\mathrm{fb}) = \sigma_{\mathrm{SM,LO}}^{(\sqrt{s}=240\ \mathrm{GeV})} + 25.3\, C_{\phi B} + 4.83\, C_{\phi D} + 29.0\, C_{\phi\Box} + 133\, C_{\phi W} + 64.5 C_{\phi WB} - 177\, C_{\phi e}[1,1] + 220\, C_{\phi l}^{+}[1,1]\,,$$

$$\frac{\sigma_{\mathrm{NLO}}}{\sigma_{\mathrm{SM,NLO}}} = 1 + \sum_i \frac{C_i(\mu)}{\Lambda^2}\left\{\Delta_i + \bar{\Delta}_i \log\frac{\mu^2}{s}\right\}$$

	$\sqrt{s} = 240$ GeV	
	Δ_i/Λ^2	$\bar{\Delta}_i/\Lambda^2$
C_ϕ	$-7.22\cdot10^{-3}$	0
$C_{uW}[3,3]$	$-1.63\cdot10^{-3}$	$4.01\cdot10^{-3}$
$C_{uB}[3,3]$	$0.15\cdot10^{-3}$	$-2.22\cdot10^{-3}$
$C_{u\phi}[3,3]$	$0.32\cdot10^{-3}$	0
$C_{\phi q}^{(1)}[3,3]$	$-1.34\cdot10^{-3}$	$-4.10\cdot10^{-3}$
$C_{\phi q}^{(3)}[3,3]$	$0.51\cdot10^{-3}$	$4.12\cdot10^{-3}$
$C_{\phi u}[3,3]$	$-0.54\cdot10^{-3}$	$3.49\cdot10^{-3}$
$C_{eu}[1,1,3,3]$	$0.01\cdot10^{-3}$	$-1.39\cdot10^{-2}$
$C_{lu}[1,1,3,3]$	$-0.02\cdot10^{-3}$	$1.73\cdot10^{-2}$
$C_{lq}^{(1)}[1,1,3,3]$	$-0.37\cdot10^{-2}$	$-1.80\cdot10^{-2}$
$C_{lq}^{(3)}[1,1,3,3]$	$-0.37\cdot10^{-2}$	$1.29\cdot10^{-2}$
$C_{qe}[3,3,1,1]$	$0.30\cdot10^{-2}$	$1.45\cdot10^{-2}$

Impact of self-coupling Cϕ ~ 0.01

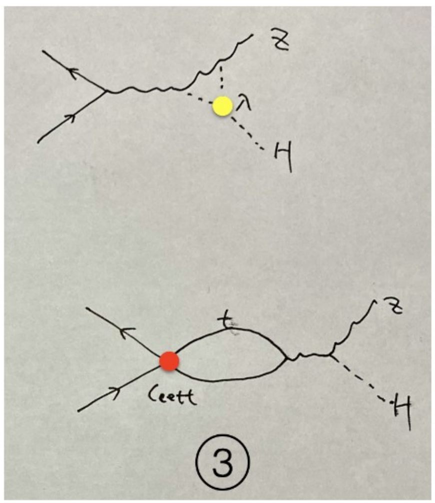
Impact of top operators is similar; need to be constrained with auxiliary data

A preliminary answer

Junping Tian, this WORKshop: slight degradation, after FCCee top data are added

(iv) first look at the global fit with NLO eett for $\Delta\lambda_{HHH}$

[ongoing work by: Yong Du, Jiayin Gu, JT]



- based on a fitting program for last ESU: 23 (Higgs + WW + EWPO) + 5 (eett) operators
- take directly covariance matrix as eett bounds (from Victor Miralles)
- reproduced (almost) the NLO calculation about eett in ZH

extra uncertainty induced by eett on σ_{ZH}

$\delta\sigma_{ZH}$ ~ 0.3% (1.5%) for 240 (365) GeV

a test fit for 5000 fb^{-1} (240) + 1500 fb^{-1} (365)

$\delta\lambda_{HHH}$ mildly degraded from 57% to 77%

[warning: this is very preliminary, many things to be done, e.g. include NLO eett in other observables as well.]

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If this is confirmed, the 365 GeV run is required for Higgs self-coupling determination

The Higgs self-coupling from di-Higgs production: addressing the experimental challenges

LHC experiments are deploying a huge effort to observe pair production; more aggressive HL-LHC projections are appearing (ESPPU '19: 50% precision)

Bottlenecks in the ZHH analysis

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DESY.

- jet pairing and jet misclustering: "perfect" jet clustering → 40% improvement
  improve di-jet mass resolution
- removal of $\gamma\gamma$ overlay: 15% improvement expected
  important to tackle initial state radiation (ISR)
- flavor tagging: 11% improvement expected from 5% eff. increase with newer LCFIPlus
  important as $H \rightarrow b\bar{b}$ is the dominant Higgs decay channel
- adding $Z \rightarrow \tau\tau$ channel: 8% improvement expected
  include a yet unaccounted decay channel
- more modern ML architectures for signal/background selection
  improvement expected when transitioning from BDTs to (e.g.) transformer-based models etc.
- separation of ZHH diagrams with/without the self-coupling
  would directly improve the sensitivity on λ (lower sensitivity factor)

All improvements are relative

Expected improvements from DESY-Thesis-16-027

- **Better than 20% sensitivity on λ in reach**
  through demonstrated reconstruction improvements

<20%!!!

Higgs self-coupling measurement at ILD via the ZHH Process at multiple COM energies | 3rd ECFA Workshop on e+e- Higgs/EW/Top Factories | 2024/10/10 | Paris | Bryan Bliewert

FCChh can eventually measure the self-coupling to 5%

Progress on our “homework”

Inputs for report expected from :

Jorge de Blas, Junping Tian, and others, Higgs boson self-coupling

SMEFiT collaboration, SMEFT fit Higgs/EW/top (+recent paper) DONE!

IFIT/C collaboration, SMEFT analysis of top sector (+future paper)

KIT team, Vts from e+e- → ttbar data (+ FCC notes)

CERN/Iran on top properties from threshold scan (+future paper)

Comparison of projections

Include top bounds

Progress beyond 2019 physics briefing book in all these areas

Conclusion

People are suprisingly passionate about top loops!

Thanks to all speakers and attendants for a very lively "global interpretation" session