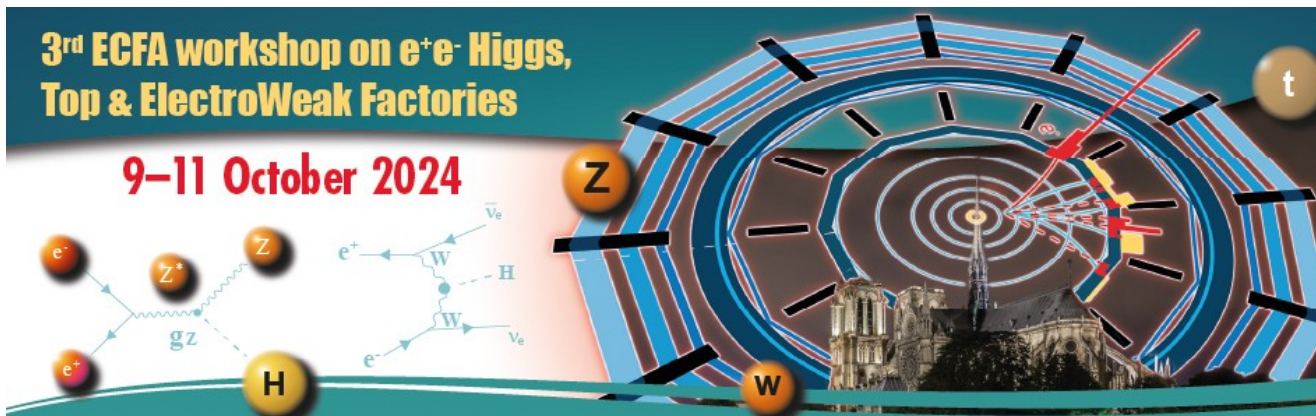


Status of studies in the GLOBal interpretation group

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



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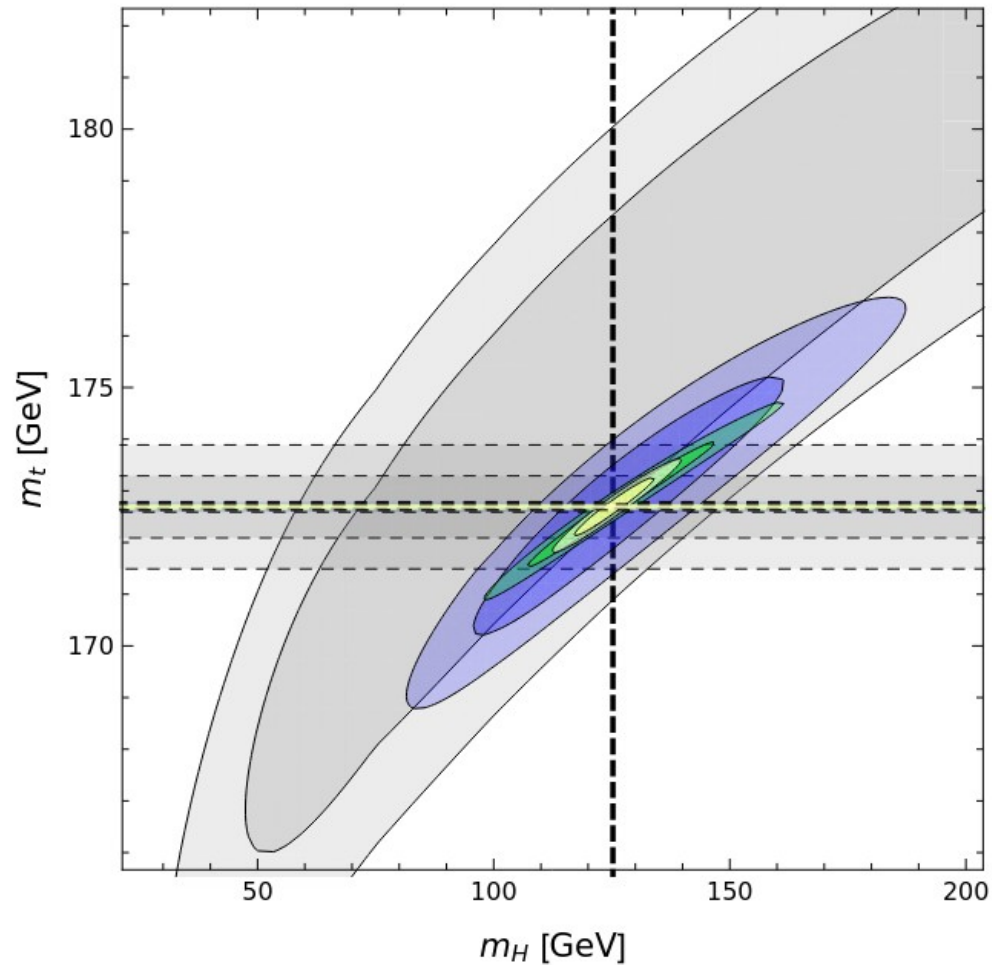
VNIVERSITAT
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Global analysis

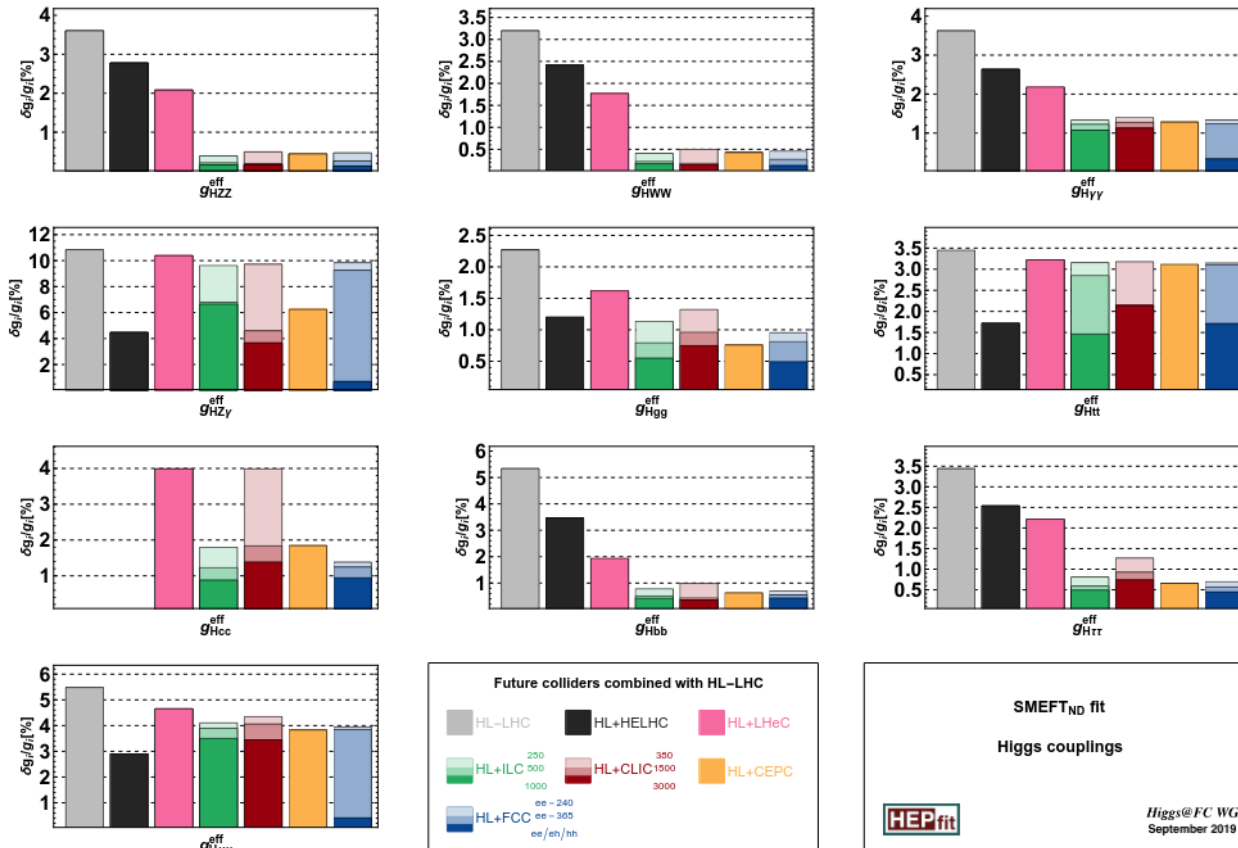


EW fit: combine precision measurements to test the relations predicted by the SM

- Current
- ILC250 + ILC-GigaZ
- CEPC
- FCC-ee

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

Global analysis of the Higgs sector



Global analysis is a moving target; this fit includes 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

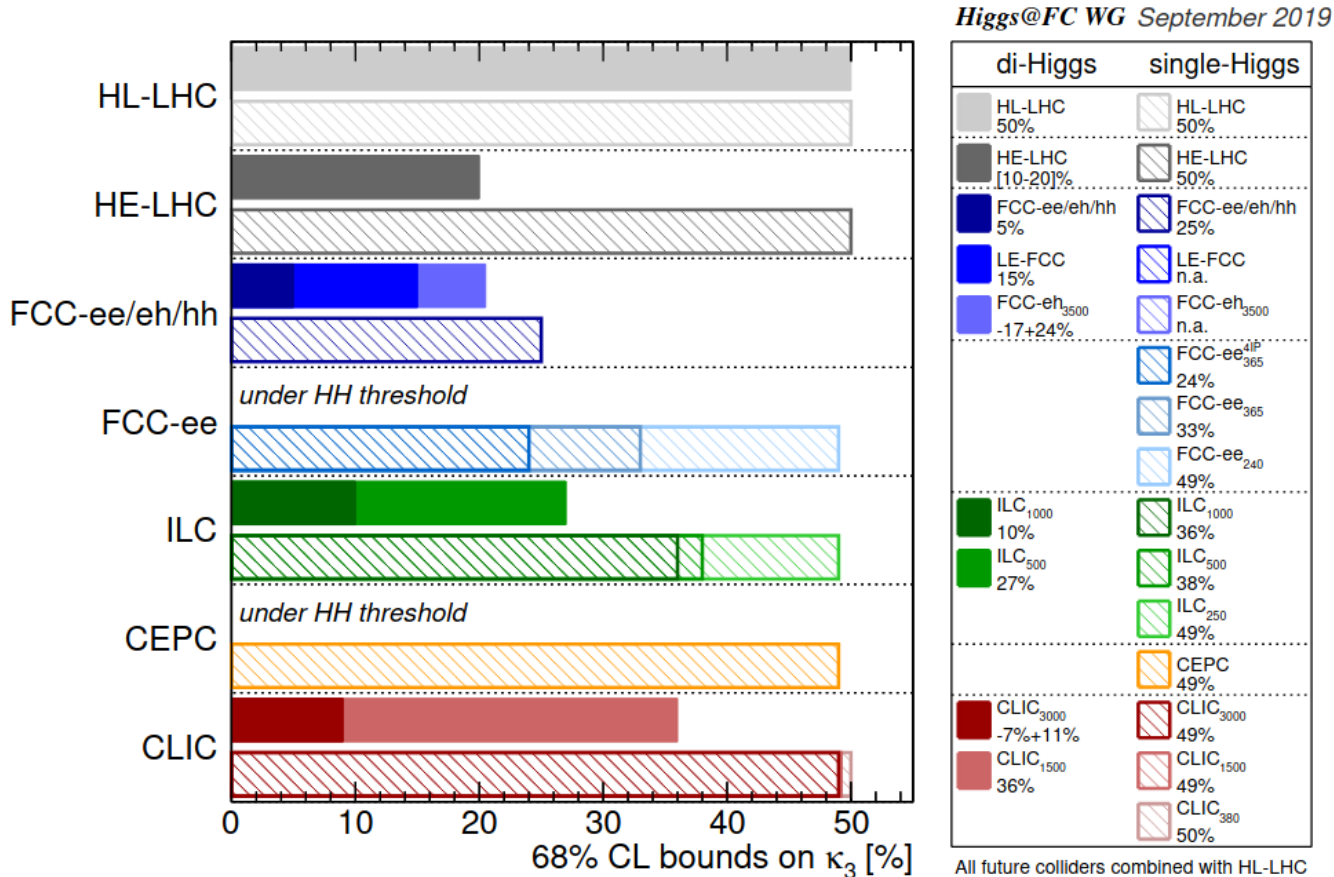
New connections among Higgs/EW/top sectors

Physics briefing book of previous strategy 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

	Searching for heavy neutrinos <i>Junping Tian</i>	Tracking for the modified <i>Victor Schwan</i>	Beamstrahlung background <i>Daniel Jeans</i>	First WWdiff results from <i>Leonhard R...</i>
	EFT Interactions of Dark <i>Giulio Marino</i>	Comprehensive Particle Identification Tool <i>Uli Einhaus</i>	The top quark EW couplings in the SMEFT <i>Marcel vos</i>	Performance of a Pixel 1 Projection Chamber <i>Peter Kluit</i>
15:00	Hints for New Higgs Boso... <i>Sumit Banik</i>	Jet flavor tagging and part... <i>Dr Taikan Su...</i>	Precise measurements <i>Xunwu Zuo</i>	A straw tracker for FCC-ee <i>Liang Guan</i>
	SUSY Parameter determin... <i>Gudrid Moor...</i>	ML-based Particle Flow fo... <i>Gregor Krzm...</i>	Mapping the SMEFT at H <i>Jaco ter Hoeve</i>	Advancing Particle Identi... <i>Dr Walaa M...</i>
	Dark Matter searches in m... <i>JAYITA LAHIRI</i>	Transformer-based Jet F... <i>Sara Aumiller</i>	Determination of large sys... <i>Michael Peskin</i>	
16:00	The ARC compact RICH d... <i>Serena Pezz...</i>	Machine Learning Techn... <i>Pantelis Kon...</i>		
11:00	Exploring the nature of he... <i>Jan Hajer</i>	Status of the Sherpa 3.0 e... <i>Daniel Reich...</i>	Non-universal probes of H... <i>Ben Stefanek</i>	R&D on Noble Liquid Cal... <i>Fares DJAMA</i>
	Heavy Neutral Leptons Se... <i>Sofia Giappi...</i>	Investigating New Physics... <i>Francesco P...</i>	ZH angular measuremen... <i>Andrea Sidd...</i>	Design and performance ... <i>Michaela Ml...</i>
	Probing the nature of HN... <i>Krzysztof Me...</i>	WG2: Technical Benchmar... <i>Alan Price</i>	Prospects for New Discov... <i>Dr Pier Paol...</i>	Estimation of the fluxes i... <i>Vincent BO...</i>
12:00	Searching for Heavy Neutr... <i>Dr Nicolò Valle</i>	Bunch Structure Studies at C3 <i>Lindsey Gray</i>	Projections for Higgs self-... <i>Bryan Bliewert</i>	Challenges ahead of the l... <i>Adrian Irls ...</i>
	Right-Handed Majorana N... <i>Jurina Nakaji...</i>	Luminosity Spectra (on zo... <i>Jürgen Reut...</i>	Sensitivity to detecting Ne... <i>Dr Johannes...</i>	Dual-Readout Fibre-Samp... <i>Ruggero Turra</i>
	Leptophilic Z' bosons at t... <i>José Zurita</i>	Beam-Induced Backgroun... <i>Dimitris Ntou...</i>	Physics case for an e ⁺ e ⁻ ... <i>Georg Weigl...</i>	Particle Flow Algorithm for Long Crystal Bar ECAL <i>Yang Zhang</i>

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)

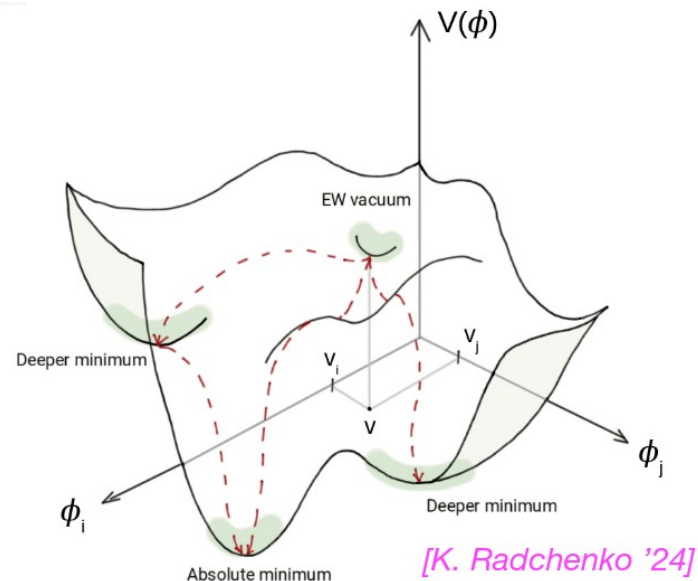
Advancing SMEFT: Global Higgs/EW/top fits at NLO and including RGE evolution

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)

TeraZ potential vs. Top measurements

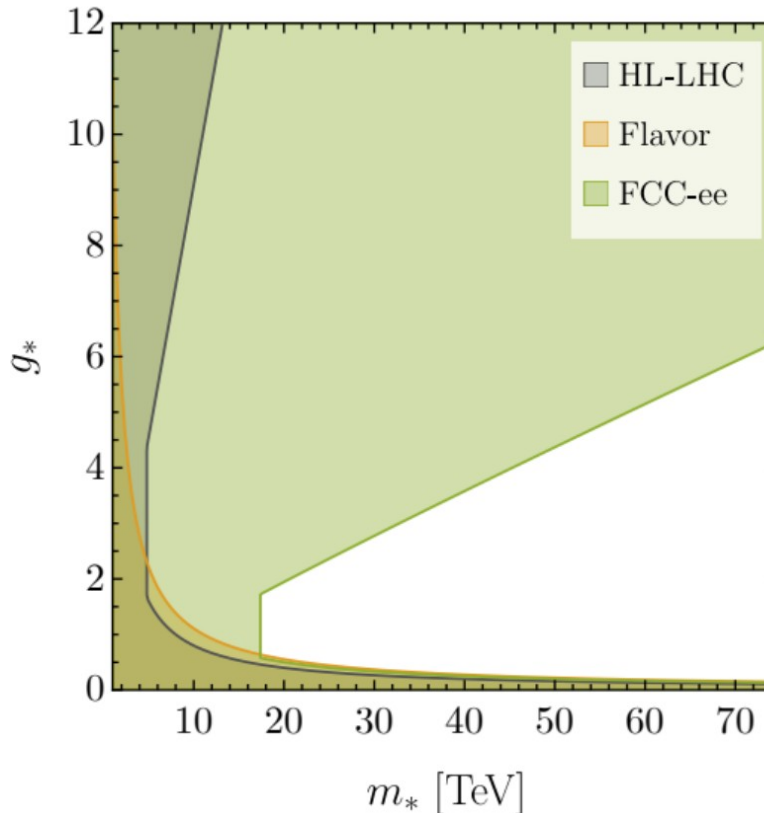
Composite Higgs scenarios where 3rd generation is special: $t_R = \text{composite}$

EW precision at the Z-pole offers stringent bounds

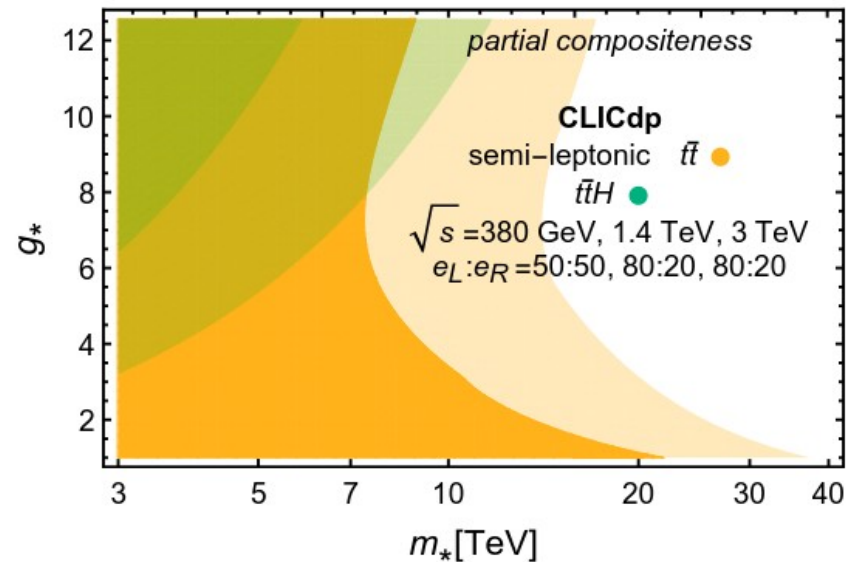
[Allwicher, Cornella, Isidori, Ben Stefanek, 2311.00020]

The 4-top operator, tested in $t\bar{t}t$ production, also has two-loop impact on EWPO

[Stefanek, 2407.09593]



For comparison: bounds from $e^+e^- \rightarrow t\bar{t}$ and $e^+e^- \rightarrow t\bar{t}H$



SMEFiT results (Jaco ter Hoeve)

Higgs/EW/top fits on projections

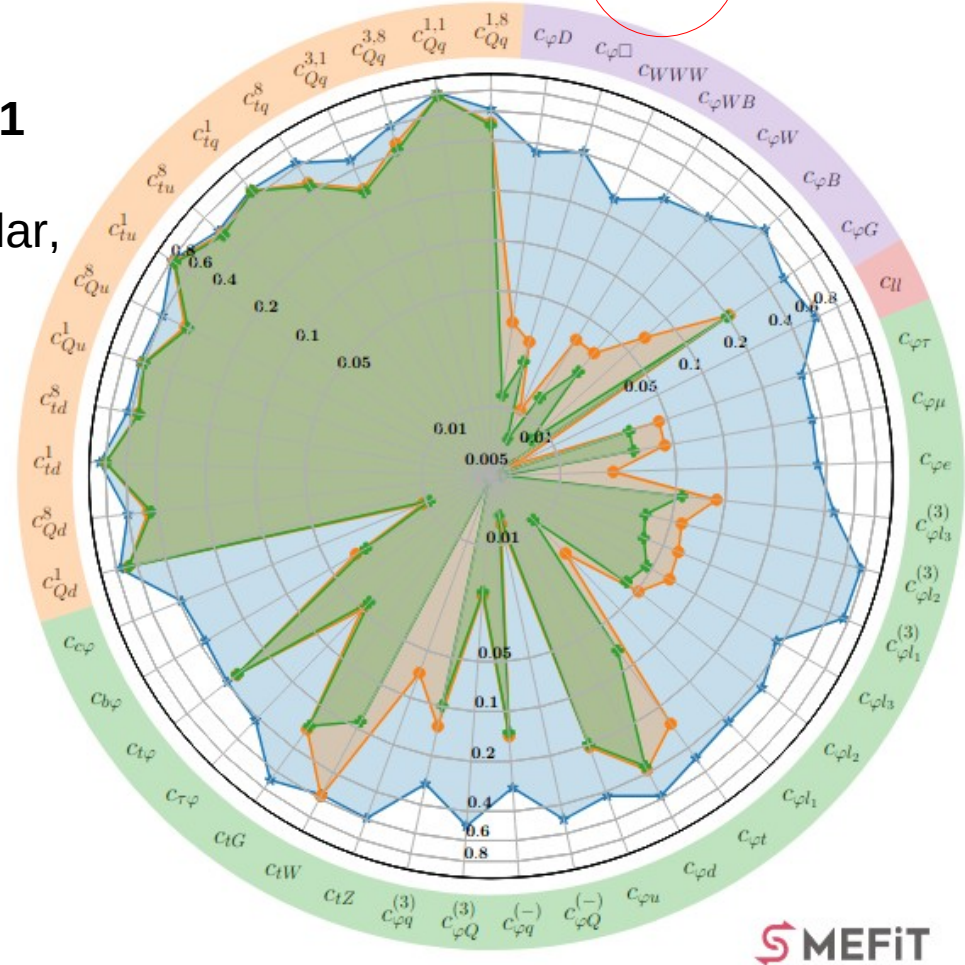
Results beyond JHEP 09 (2024) 091

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

RGE evolution: small changes, except ttt operators

Todo: eett operators, different collider projects

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



- ★ HL-LHC + FCC-ee (91 GeV)
- ✚ HL-LHC + FCC-ee (91 + 161 + 240 + 365 GeV)
- HL-LHC + FCC-ee (91 + 240 GeV)

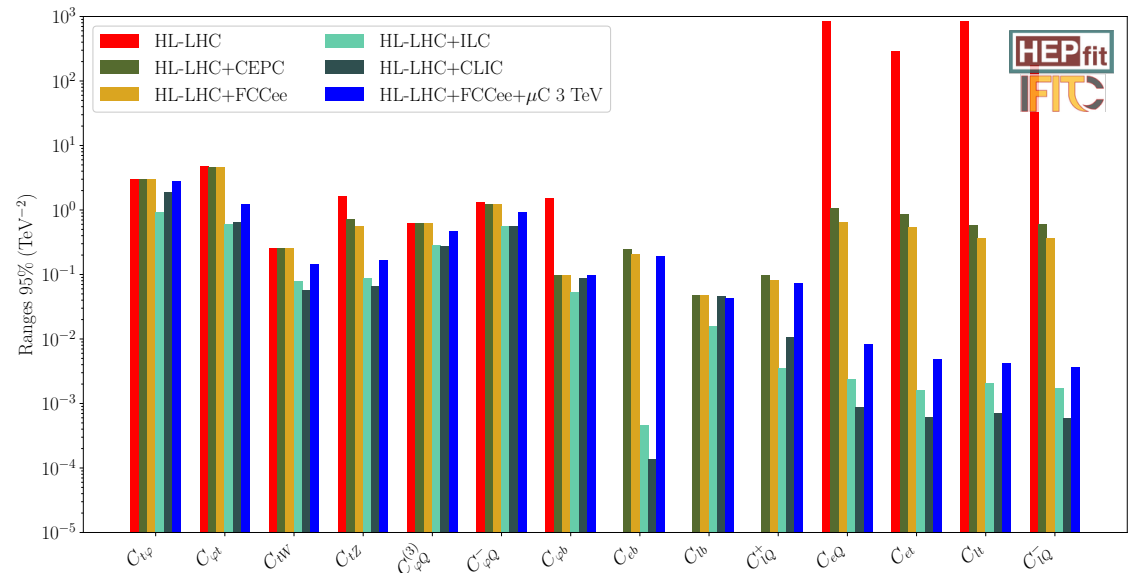
[1804.05033] Aebischer, Kumar, Straub

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: $O(1-10 \text{ TeV}^{-2})$
Linear global: $O(100 \text{ TeV}^{-2})$

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

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

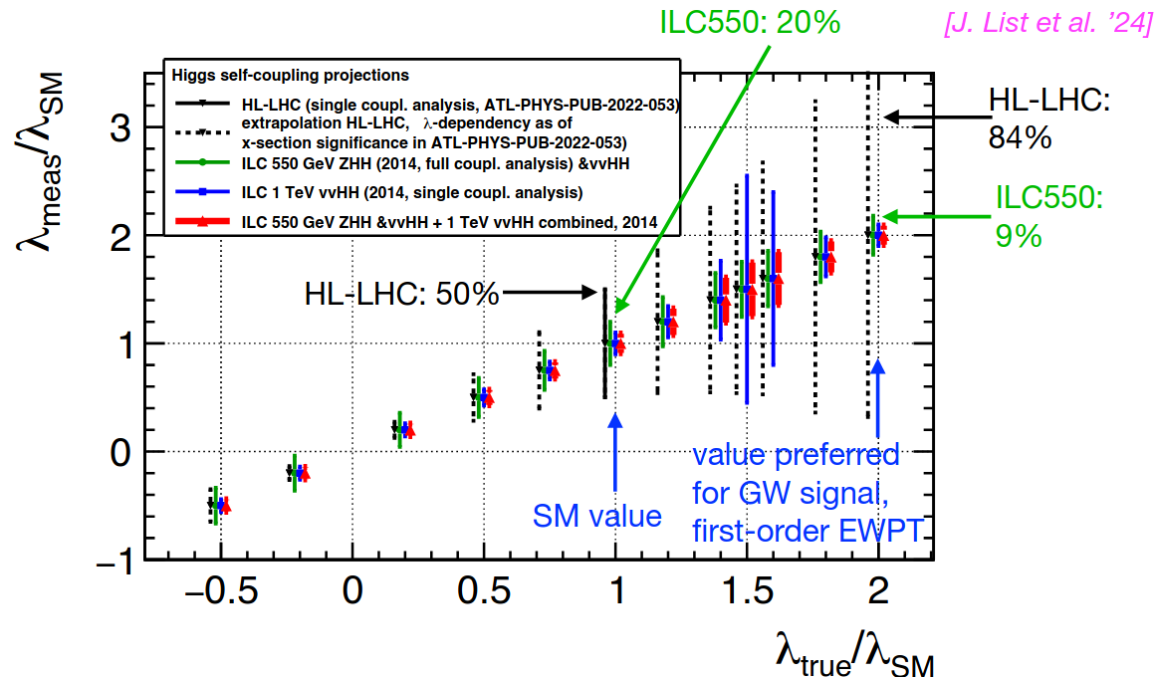
The Higgs self-coupling: HEP's next target

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”



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

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

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

C_ϕ	$\sqrt{s} = 240 \text{ GeV}$	
	Δ_i/Λ^2	$\bar{\Delta}_i/\Lambda^2$
C_ϕ	$-7.22 \cdot 10^{-3}$	0
$C_{uW}[3, 3]$	$-1.63 \cdot 10^{-3}$	$4.01 \cdot 10^{-3}$
$C_{uB}[3, 3]$	$0.15 \cdot 10^{-3}$	$-2.22 \cdot 10^{-3}$
$C_{u\phi}[3, 3]$	$0.32 \cdot 10^{-3}$	0
$C_{\phi q}^{(1)}[3, 3]$	$-1.34 \cdot 10^{-3}$	$-4.10 \cdot 10^{-3}$
$C_{\phi q}^{(3)}[3, 3]$	$0.51 \cdot 10^{-3}$	$4.12 \cdot 10^{-3}$
$C_{\phi u}[3, 3]$	$-0.54 \cdot 10^{-3}$	$3.49 \cdot 10^{-3}$
$C_{eu}[1, 1, 3, 3]$	$0.01 \cdot 10^{-3}$	$-1.39 \cdot 10^{-2}$
$C_{lu}[1, 1, 3, 3]$	$-0.02 \cdot 10^{-3}$	$1.73 \cdot 10^{-2}$
$C_{lq}^{(1)}[1, 1, 3, 3]$	$-0.37 \cdot 10^{-2}$	$-1.80 \cdot 10^{-2}$
$C_{lq}^{(3)}[1, 1, 3, 3]$	$-0.37 \cdot 10^{-2}$	$1.29 \cdot 10^{-2}$
$C_{qe}[3, 3, 1, 1]$	$0.30 \cdot 10^{-2}$	$1.45 \cdot 10^{-2}$

Impact of self-coupling $C_\phi \sim 0.01$

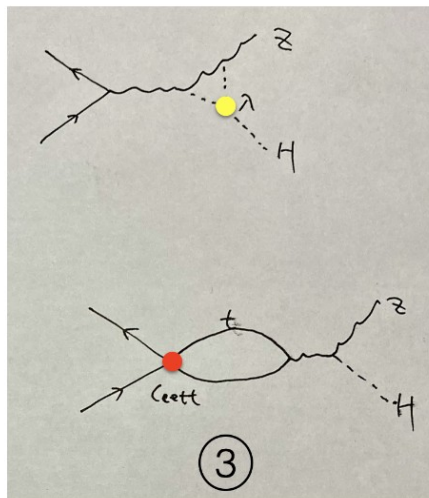
Impact of top operators is similar; need to be constrained with auxiliary data

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}

$\delta\sigma_{ZH} \sim 0.3\%$ (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



➤ 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)

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

KIT team, V_{ts} from $e^+e^- \rightarrow t\bar{t}$ data (+ FCC notes)

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

DONE!



Comparison of projections



Include top bounds

Progress beyond 2019 physics briefing book in all these areas

Conclusion

People are surprisingly passionate about top loops!

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

