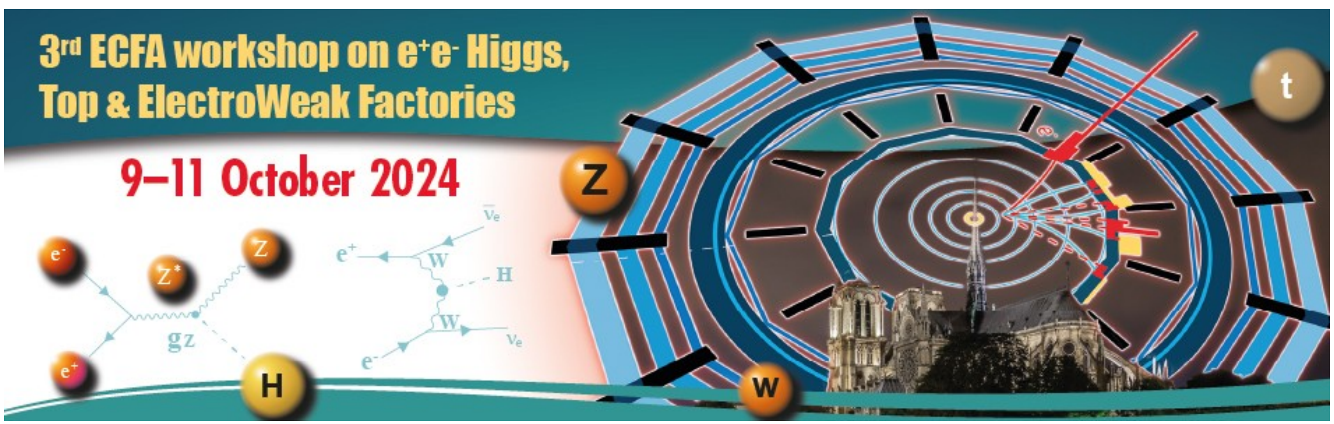
Key new results of the Higgs/top/EW and GLOBal interpretation groups

Summary of HTE and GLOB sessions at the ECFA workshop in Paris

OBO: Karsten Köneke (Goettingen), Chris Hayes (Oxford), Fabio Maltoni (Louvain/Bologna), Jorge de Blas (U. Granada), Alexander Grohsjean (DESY), Sven Heinemeyer (IFT Madrid), Junping Tian (U. Tokyo), Marcel Vos (IFIC- CSIC/UV, Valencia)

ECFA Plenary, CERN, 14/11/2024



EXCELENCIA SEVERO OCHOA

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Dedicated to the victims of the Valencia flash flood

Image: EFE/Biel Aliño

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Addressing questions beyond previous work (1)

Improving underlying projections: **any fit is as good as its inputs**

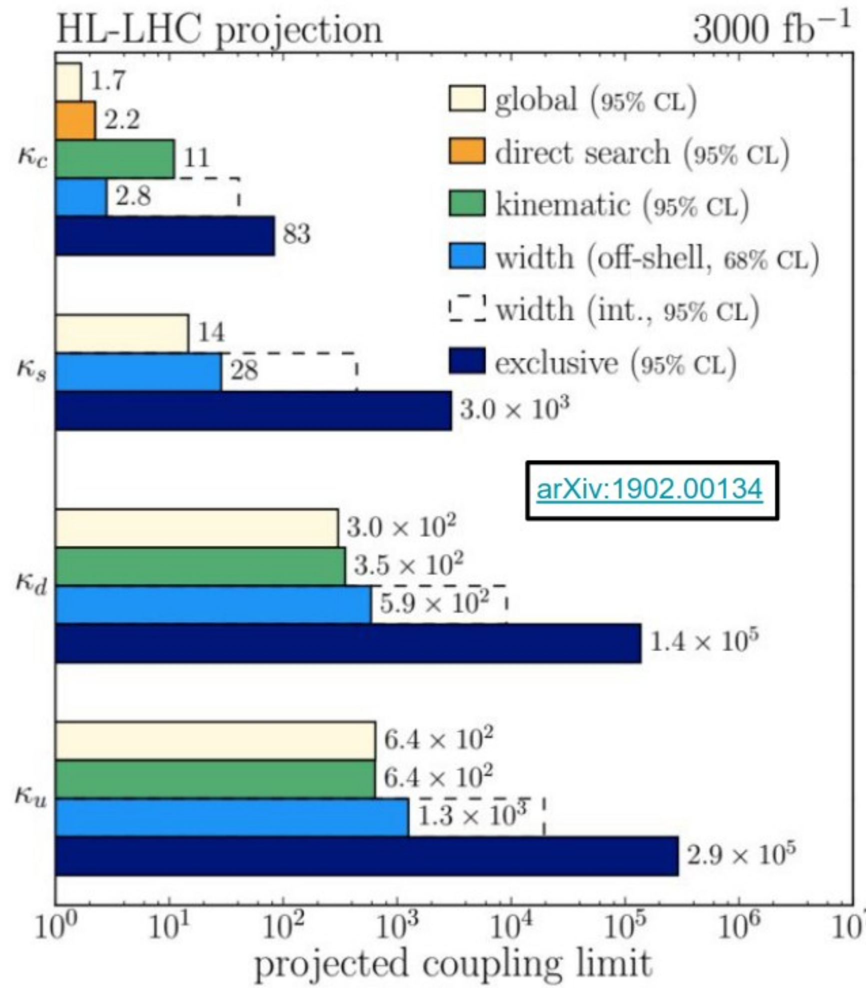
Higgs to strange coupling

The Higgs-to-strange coupling is hard to measure

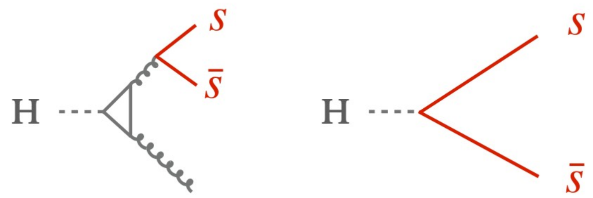
BR(H → ss) = 0.024%

strange tagging requires PID
(not ATLAS & CMS forte)

Too hard for the HL-LHC



Higgs to strange coupling



Dalitz decay ($\alpha_s^3 y_t^2$) Yukawa decay (y_s^2)

Can we:

- define a Higgs to strange coupling theoretically?
  yes, https://indico.cern.ch/event/1409233/#2-strange-higgs-decays-strong
- control fragmentation systematics?
  yes, Z-pole run is ideal to settle this once and for all
- design a detector with excellent Particle ID?
  yes, but PID comes at a prize ($\rightarrow$specialized flavour experiment?)
- tag strange quarks?
  yes, ML-based taggers are getting better fast!
- measure the strange quark Yukawa?
  yes, sort of, at O(100%) precision

Expected sensitivity (%) of σ(ZH).BR(H⟶jj) at 68% CL **L = 10.8ab-1**

240 GeV	H⟶bb	H⟶cc	H⟶gg	H⟶ss	H⟶ZZ	H⟶WW	H⟶ττ
Combined (BNL)	0.21	1.66	0.8	104.99	10.07	1.16	3.97
Combined (APC)	0.22	1.65	0.93	121	9.56	1.11	3.79

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The Higgs self-coupling from di-Higgs production

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

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG
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 $H \to b\bar{b}$ is the dominant Higgs decay channel
- adding $Z \to \tau\tau$ 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%!!!

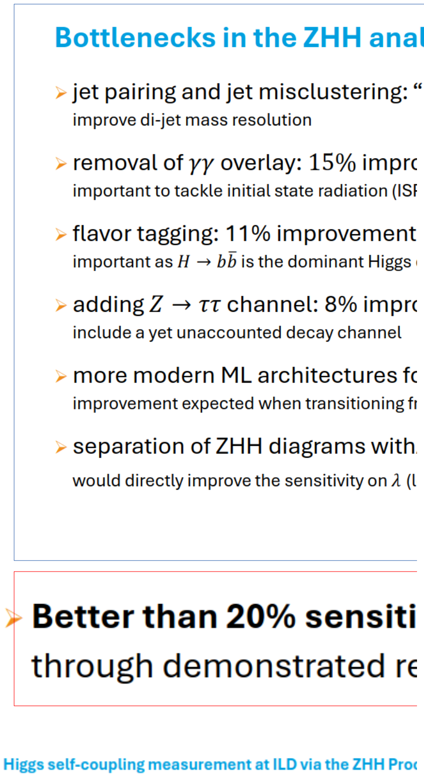
Higgs self-coupling measurement at ILD via the ZHH Process at multiple COM energies | 3rd ECFA Workshop on e+e- Higgs/EW/Top Factories | 2024/10/10 | Paris | Bryan Bliewert

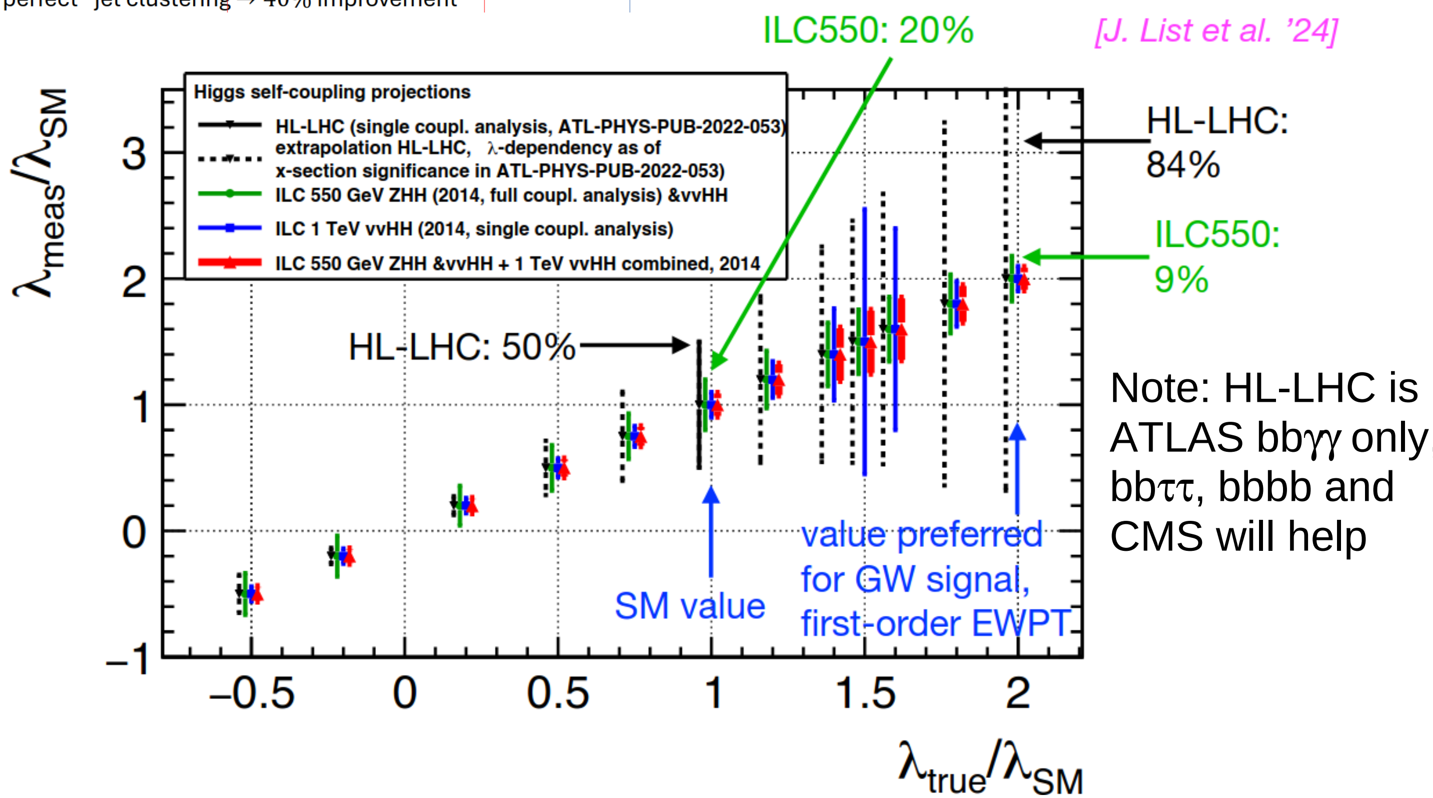
Also Higgs factory projections have a lot of room for improvement!!

Talk by Bryan Bliewert on the ZHH analysis at 500/550 GeV

The Higgs self-coupling from di-Higgs production

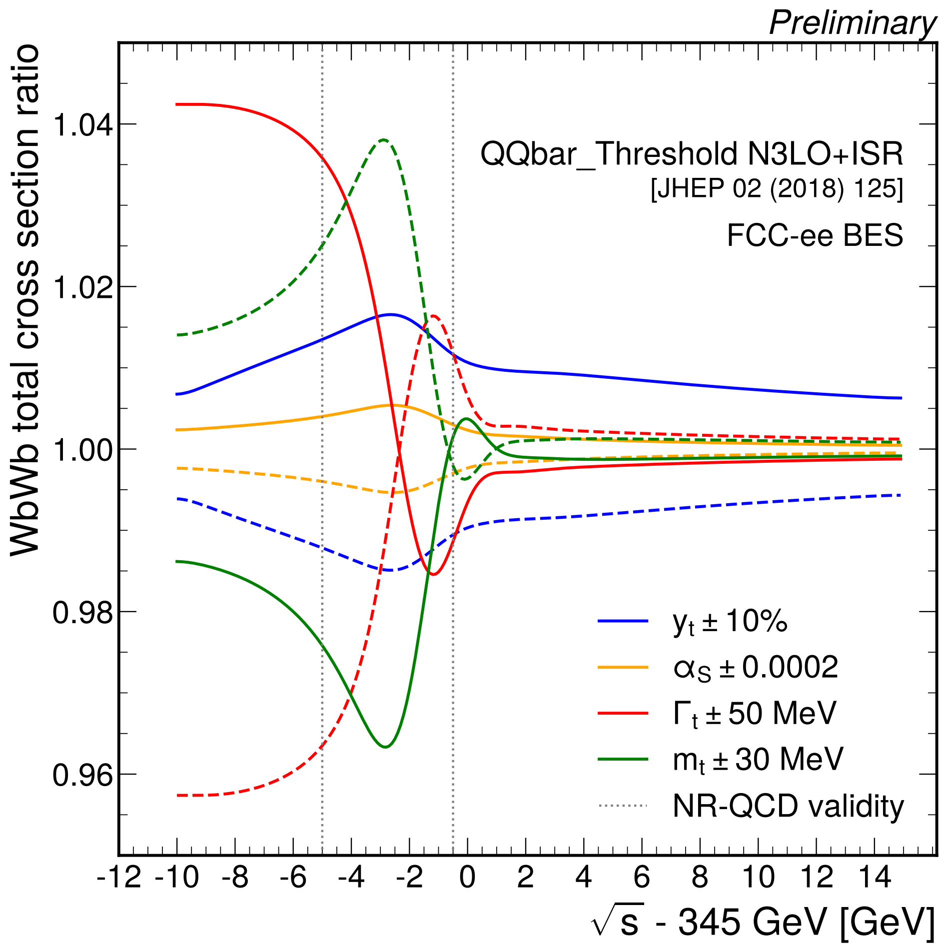
LHC experiments are deploying a huge effort to observe pair production; more aggressive HL-LHC projections are appearing (ESPPU ‘19: 50% precision)





Note: FCChh claims to eventually measure the self-coupling to O(5%) precision

Top quark mass from threshold scan



Fast-simulation study in FCCee environment, using state-of-the-art tools

Profile likehood fit, **in-situ control of b-tagging efficiency and background**

Statistical uncertainty: < 10 MeV
with 410/fb over 10 scan points

Theory uncertainty ~40 MeV
Fit of PS “threshold” mass

Machine-related uncertainties OK
- synchrotron radiation (circular)
- luminosity spectrum (linear)

Talks by Matteo Defranchis and Ankita Mehta

Addressing questions beyond previous work (2)

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

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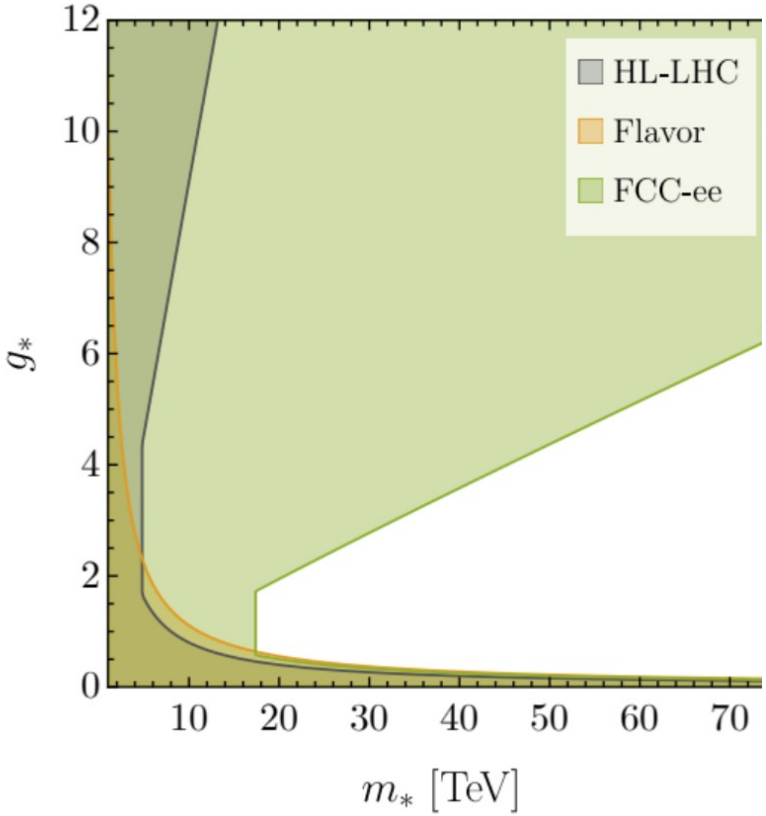
Indirect bounds on New Physics: TeraZ vs. top

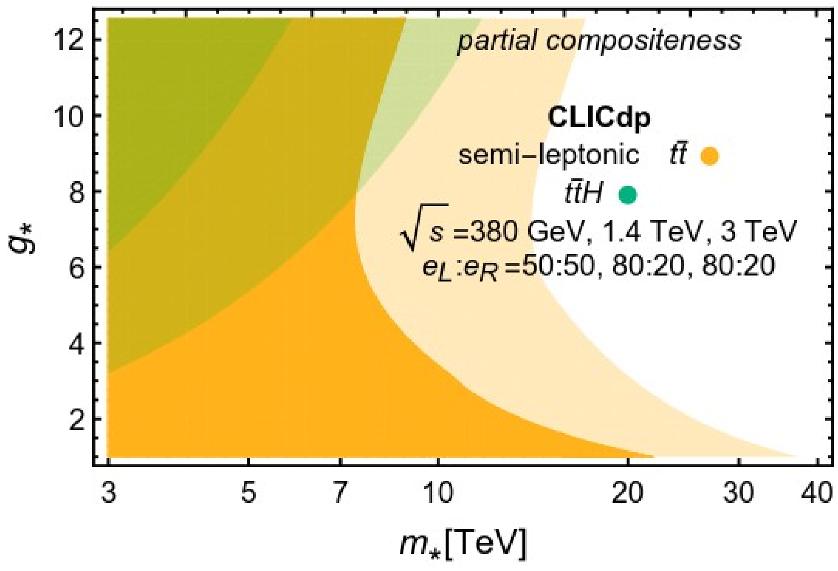
Composite Higgs scenarios where 3rd generation is special: t_R = composite

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

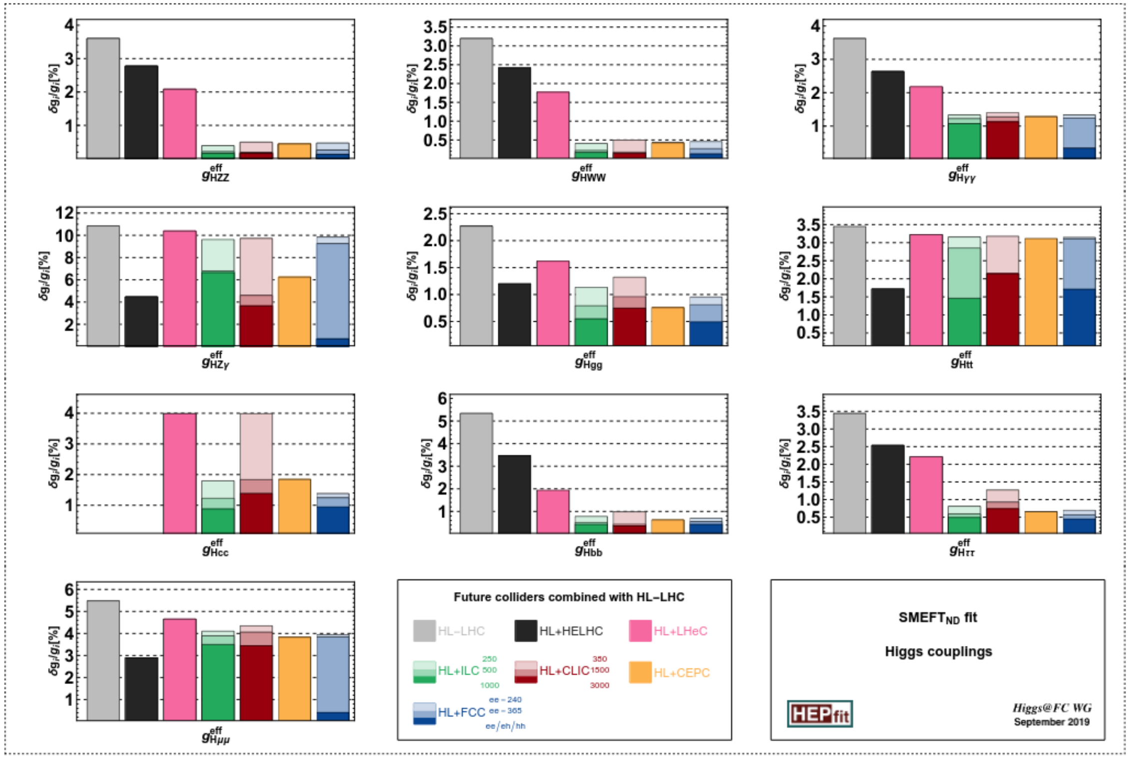
The 4-top operator, tested in tttt production, also has two-loop impact on EWPO
[Stefanek, 2407.09593]



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



Global analysis - Higgs sector



Global analysis is a moving target;

this fit incluces Higgs/EW projections (and some top).

State-of-the-art has advanced:

- Higgs/EW/top, Ellis et al.
- NLO predictions, SMEFiT
- RGE evolution and mixing

Explore the intricate connections among Higgs/EW/top sectors

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

SMEFT fits

[Of determining the
Higgs couplings]

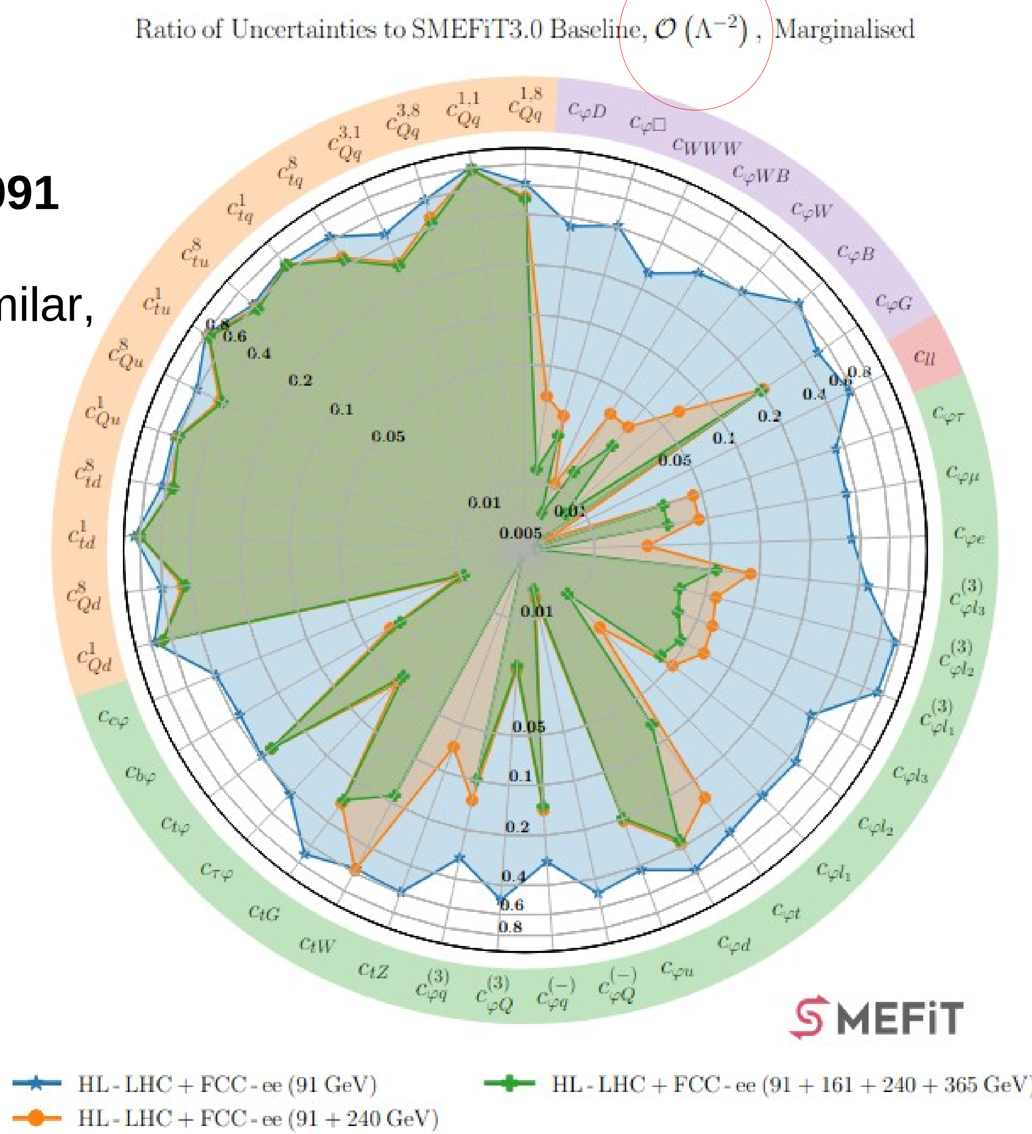
The traditional κ parametrization is not up to the task. We suggest that a method based on SMEFT is more physical, complete, and model-independent.

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; it led to significant discussion)

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

SMEFiT

wilson

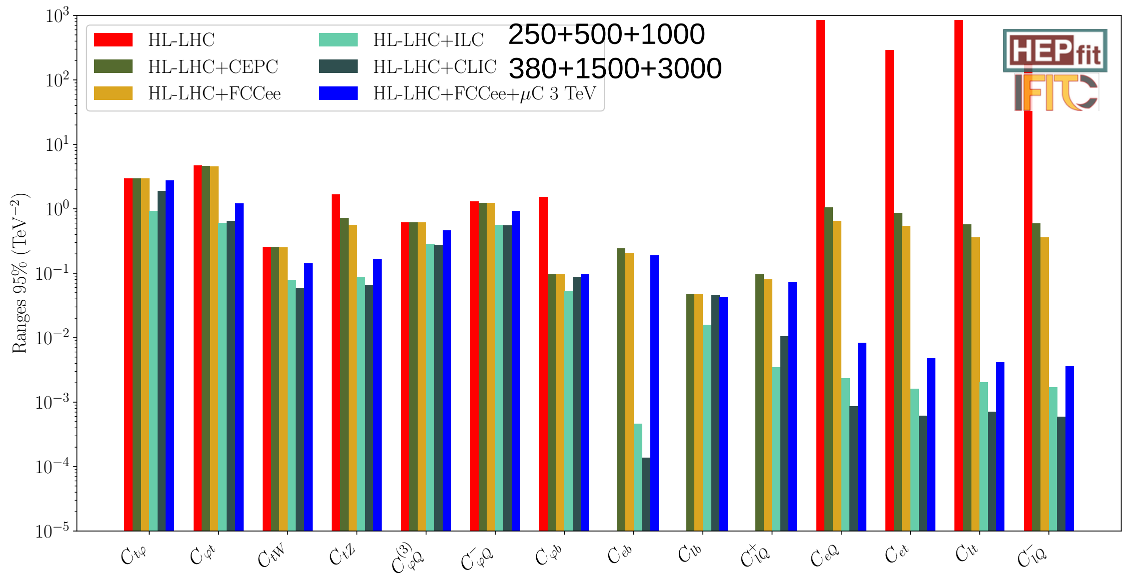
[1804.05033] Aebischer, Kumar, Straub

Fit to the top sector (M.V.)

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

Addressing issues beyond previous work (3)

A global analysis of the Higgs self coupling

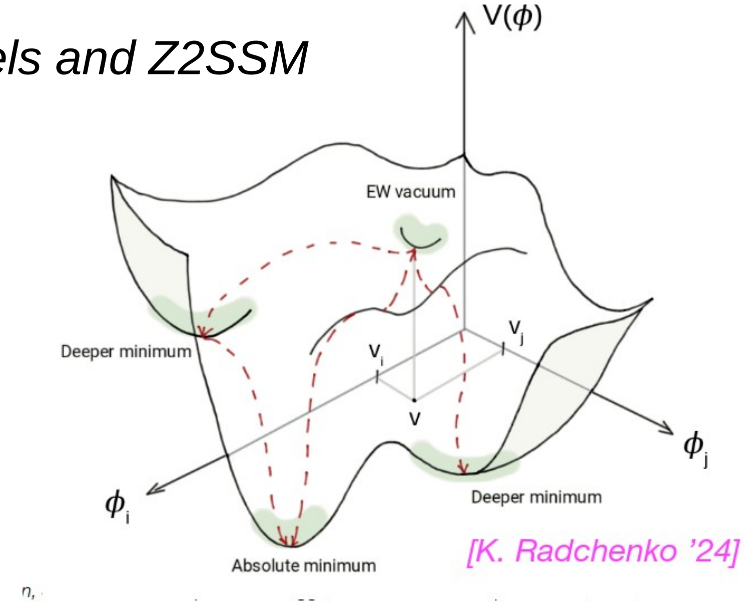
(see focus topic report by Junping Tian)

The Higgs self-coupling is he holy grail of HEP*

*Georg Weiglein

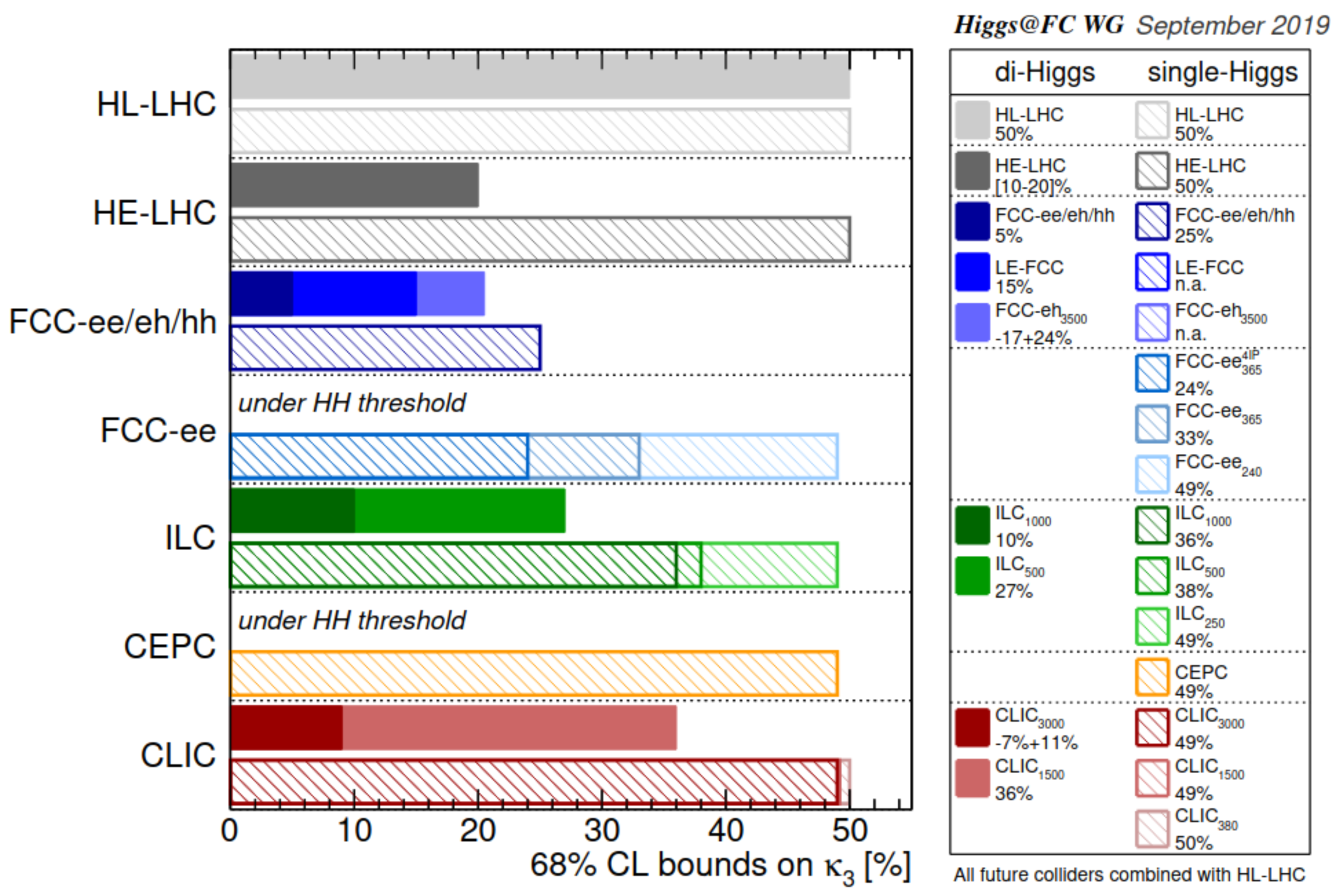
λ_{hhh} can **deviate significantly from SM prediction** (by up to a factor **~10**), for otherwise theoretically and experimentally allowed points, due to **mass-splitting effects in radiative corrections involving BSM scalars**

Johannes Braathen, discussing Inert Doublet Models and Z2SSM



Higgs self-coupling

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

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

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

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

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

Impact of self-coupling Cϕ ~ 0.01

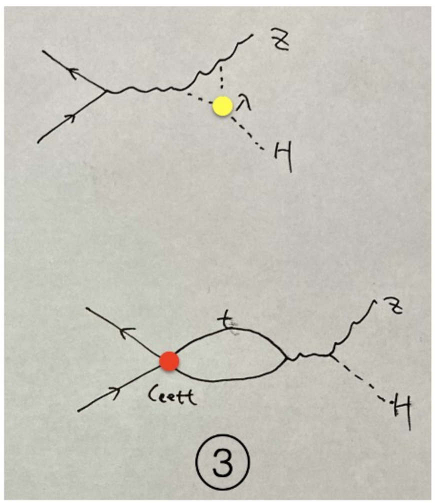
Impact of top operators is similar; need to be constrained with auxiliary data

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

Summary of the summary

ECFA Higgs/top/EW factory study yields:

- more solid foundations for e+e- prospects:

Higgs self-coupling, ZH, $H\rightarrow\tau\tau$, top mass, …

- new ambitions:

Higgs-to-strange coupling, differential analysis of ZH angular observables

- a more global view:

full SMEFT analysis including NLO and RGE evolution

Progress beyond 2019 physics briefing book in all these areas

Check out the original talks here!

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Conclusion

People are suprisingly passionate about top loops!

Thanks to all speakers and attendants very lively sessions