EF01: Higgs Boson Properties

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Snowmass21 : Energy Frontier kick-off

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Goals

EF01 will study Higgs properties, including mass, width, and couplings, **at proposed future colliders including pp, e+e-, and ep machines**. Double Higgs production and subsequent limits on the Higgs self-coupling will be included in the EF01 activities, along with the combination of measurements of single and double Higgs production.

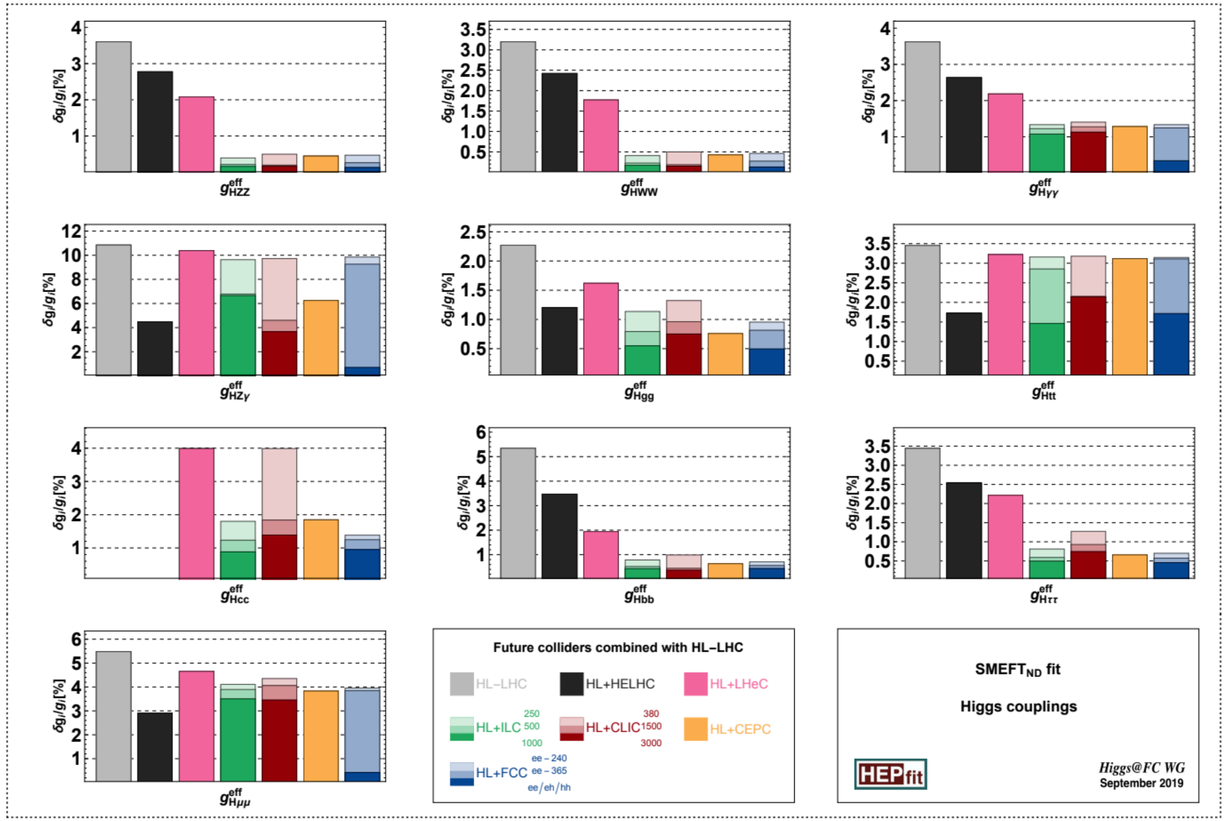
- Higgs mass and width
- Higgs decays (includes H to invisible and rare decays)
- Higgs production modes: inclusive and differential (includes ttH)
- HH production (includes resonant production)
- Higgs self-coupling
- Anomalous couplings (including CP violation)
- Inputs to the Global Fit

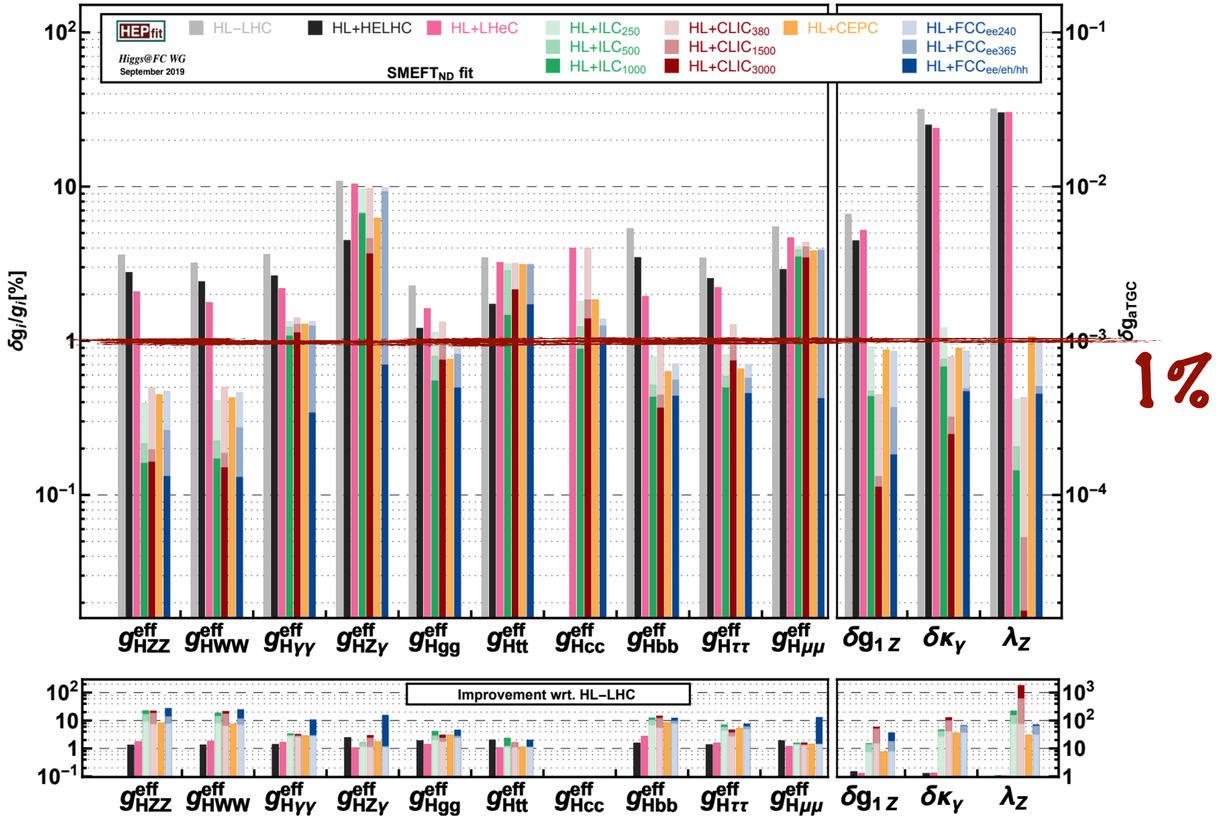
Higgs physics at future colliders

- The goal is to measure Higgs boson couplings with extremely good precision to unveil new effects beyond the Standard Model
  - **Precision of O(1%) level or below** and insensitive to systematic errors
- This requires high energy collider experiments designed for high precision:
  - Complementarity between e^+e^- and p-p machines will eventually lead to the most precise understanding of the Higgs couplings
  - ***Where US will decide to lead/participate ?***

Current projections: Higgs couplings

arXiv:1910.11775
arXiv:1905.03764



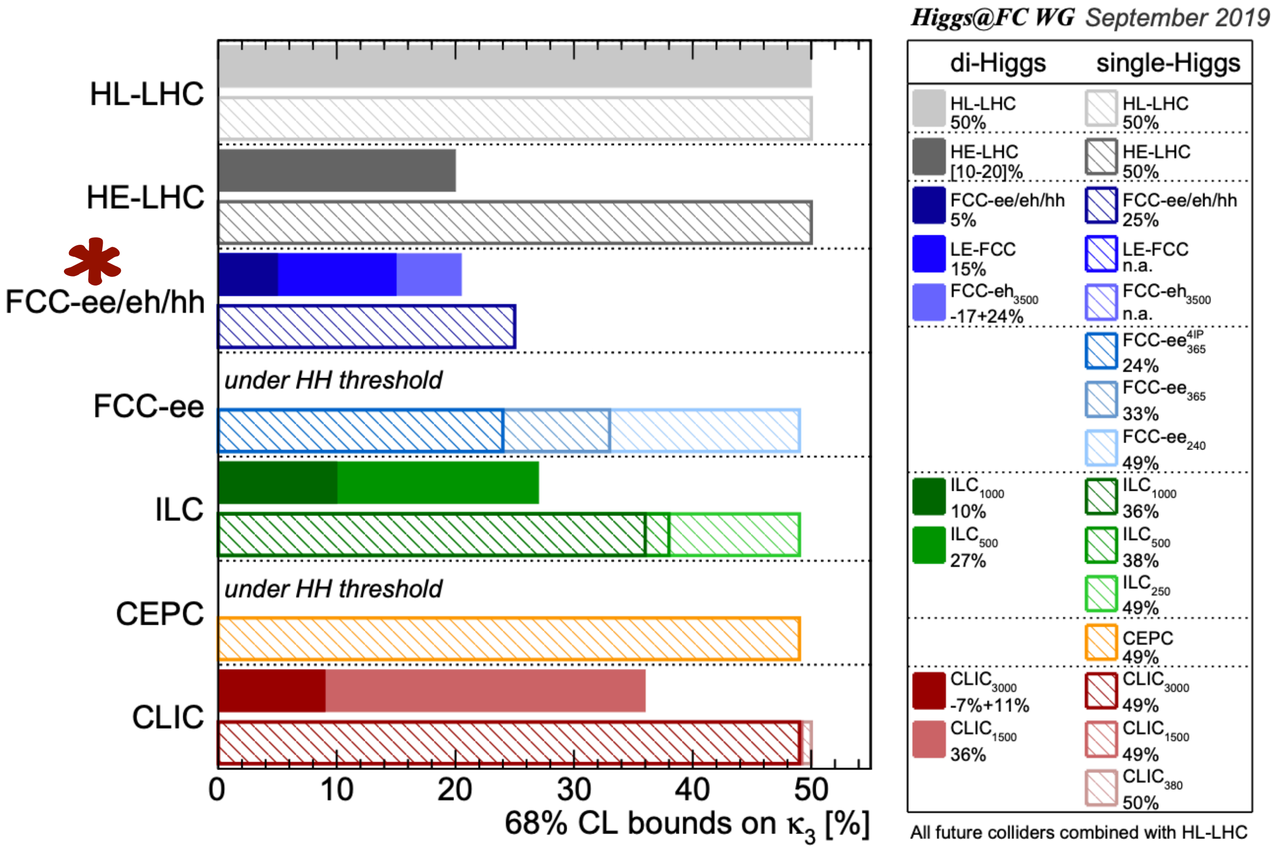


We plan to build on the work done in the context of the European Strategy and **identify missing or outdated experimental or theory studies**

Current projections: Higgs self-coupling

arXiv:1910.00012
arXiv:1905.03764

The goal for **future machines** beyond the HL-LHC should be to be able to reach at least **gold quality (5-10%)** precision for the Higgs boson self-coupling



conservative?

collider	single-H	HH	combined
HL-LHC	100-200%	50%	50%
$CEPC_{240}$	49%	–	49%
ILC_{250}	49%	–	49%
ILC_{500}	38%	27%	22%
ILC_{1000}	36%	10%	10%
$CLIC_{380}$	50%	–	50%
$CLIC_{1500}$	49%	36%	29%
$CLIC_{3000}$	49%	9%	9%
FCC-ee	33%	–	33%
FCC-ee (4 IPs)	24%	–	24%
HE-LHC	-	15%	15%
FCC-hh *	-	5%	5%

* arXiv:2004.03505 2.9-5.5% depending on the systematic assumptions

EF01: EW Physics: Higgs Boson properties and couplings

Conveners	Sally Dawson, Andrey Korytov, Caterina Vernieri
Mailing-list	SNOWMASS-EF-01-HIGGS_PROPERTIES@FNAL.GOV (instructions)
Slack channel	ef01-higgs_properties (instructions)
Next Event	May 27 12pm ET, joint with EF02

Link to the Twiki

- We are collecting here expressions of interest from the community to participate in our studies
- Clear synergies with :
  - **EF02**: all high energy Higgs physics is in EF01 (SM) and EF02 (BSM)
  - **EF04**: precision measurements that are sensitive to Higgs effects
- But also with instrumentation and accelerator groups

EF01 meetings:

- **Bi-weekly on Wednesdays, noon-2pm EST**
- First kick-off meeting on **May 21**, O(100) participants
  - Review of the ESG studies from C. Grojean
  - Overview of Higgs studies at e^+e^- colliders from M. Peskin
  - Report from FCC-hh from M. Magano (more on June 10)
- **May 27**, joint discussion with EF02 on HH
- **June 10**, Discussion of differential Higgs measurements and needed theory and experimental inputs

https://indico.fnal.gov/category/1135/

Higgs Boson properties

MASS

- Ultimate precision on this observable is an important benchmark for future detectors performance

WIDTH

- We can determine it from data from the knowledge of all Higgs decays and a model of each decay amplitude or from direct measurements
  - Use existing studies to make consistent comparisons between opportunities and evaluate the different set of assumptions derived for future hadron and e^+e^- colliders
  - What improvements on current studies can we envision, both theoretically and experimentally?

Higgs production at large p_T

- European Strategy Studies focused on inclusive measurements : **new opportunities for measurements of the Higgs couplings at large Q^2**
  - BSM effects often grow with energy
  - Clear impact on the extraction of EFT constraints via correlations among different processes and kinematical regimes
  - Also this helps mitigating systematic uncertainties and maximizes the robustness of the results
    - i.e. pile-up rejection and trigger capabilities
- Few **examples**:
  - VH at large invariant mass (double differential distributions sometime needed to restore BSM/SM interference)
    - Probing the HWW coupling at high Q^2 in $pp \rightarrow WH$ at large mass or in VBF is complementary to measure BR($H \rightarrow WW$)
  - off-shell $gg \rightarrow H^* \rightarrow ZZ \rightarrow 4l$
  - Higgs + high-p_T jet

HH & self-coupling

- We will review both **resonant and non-resonant DOUBLE HIGGS PRODUCTION**
  - Any missing experimental studies and unexplored signatures?
    - For resonant: production of different-mass Higgs bosons?
    - **Synergy with EF02 on resonant HH production** : is there any new physics effect that demands a dedicated analysis or signature based analyses are enough?
  - *There is a new FCC-hh study, shall we expect updates from HL-LHC based on full Run 2 analyses?*
    - **VBF HH** not really covered for HL-LHC but first Run 2 results are now available - opportunity for hadronic machines
    - Significant improvements are possible in the context of ILC (M. Peskin)
- For the self-coupling constraints it is important to consider effects on the other Higgs couplings
  - Revise how to optimally combine double Higgs and single Higgs data:
    - ex: differential information, different center of mass of energies for e^+e^- colliders
- Beyond HH: **HHH & quartic coupling?**

Higgs Boson decays

- **RARE DECAYS**, including H→ μμ, H→cc
  - Possibilities to revisit the strategy at 100-TeV pp collider by removing the high p_T constraints and address systematic limitations by other means.
- Review of the assumptions on the constraints for **H→ INVISIBLE**
- Determination of the **HIGGS BOSON COUPLINGS:**
  - Higgs couplings must be determined in a big picture framework which includes EW and top observables and connects measurements at different scales
  - CP violating couplings - important role played by angular distributions
  - Global analysis within EF04, with EF01 responsible for the delivery of the Higgs observables

Higgs & (SM?)EFT

see also C. Grojean's talk

- **We will be working closely together with EF04 within the SMEFT framework:**
  - Estimate EFT uncertainties (NLO, dim-8 effects, linear vs quadratic…), new physics in backgrounds, theoretical constraints (positivity, analyticity)
  - More combined Higgs and top analysis
    1. effects of top dipoles or 4 fermion ops. with tops
    2. constraints on top EW couplings from their NLO effects in Higgs and diboson processes (particularly relevant for low-energy colliders below ttH threshold)
  - Include differential observables
  - Explore more flavor scenarios (and make connection with flavor data)
- SMEFT is a baseline, how we account for specific assumptions and model-dependency?
  - Complementarity with new physics searches

What's next?

- We plan to continue discussing and reviewing existing efforts to identify new questions to address during Snowmass
  - Attention also to the common assumptions and systematics when comparing different machines
- ILC and FCC communities have already provided preliminary feedback on the process and LOIs are on their way
  - Shall we expect provide updated projections for HL-LHC based on the full Run-2 results ?
    - ex: differential single H measurements and HH studies
- **Please submit your LOI**:
  - To suggests new studies
  - To summarize important information that you think it could be useful to this process including relevant bibliography
- If you would like to give a presentation at our meetings **email us**

Exciting unexplored opportunities to play with Higgs Boson at 100 TeV & e^+e^-, Join us !

spares

Which precision on κ_λ is needed?

arXiv:1910.00012

BRONZE 100%

SILVER 25-50%

GOLD 5-10%

PLATINUM 1%

Sensitivity to models with the largest new physics effects, in which new particles of few hundred GeV mass appear in tree diagrams or as s-channel resonances

Sensitivity to mixing of the Higgs boson with a heavy scalar with a mass of order 1 TeV

Sensitivity to a broad class of loop diagram effects that might be created by any new particle with strong coupling to the H

Sensitivity to typical quantum corrections to the Higgs self-coupling generated by loop diagrams