ECFA Higgs@FutureColliders for ESU

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for the *Higgs@FutureColliders* team
LC Workshop Lausanne April 8,9 2019

Mandate agreed by RECFA in consultation with the PPG
"Higgs physics with future colliders in parallel and beyond the HL-LHC"

- In the context of exploring the Higgs sector, provide a coherent comparison of the reach with all future collider programmes proposed for the European Strategy update, and to project the information on a timeline.

- For the benefit of the comparison, motivate the choice for an adequate interpretation on framework (e.g. EFT, κ, ...) and apply it, and map the potential prerequisites related to the validity and use of such framework(s).

- For at least the following aspects, where achievable, comparisons should be aim for:
  - Precision on couplings and self-couplings (through direct and indirect methods)
  - Rare Higgs boson decays (SM), and precision on total width
  - Sensitivity to new high-scale physics through loop corrections
  - Sensitivities to CP violating effects

- In all cases the future collider information is to be combined with the expected HL-LHC reach, and the combined extended reach is to be compared with the baseline reach of the HL-LHC.

- In April 2019, provide a comprehensive and public report to inform the community.

Members of the working group
"Higgs physics with future colliders in parallel and beyond the HL-LHC"

- **Aleandro Nisati** (INFN - Roma) *working group chair*
- **Beate Heinemann** (DESY & Freiburg Univ.) ex-officio
- **Christoph Grojean** (DESY & Humboldt Univ.)
- **Elisabeth Petit** (CPPM - Marseille) [joined in March]
- **Fabio Maltoni** (Louvain/Bologna)
- **Jorge de Blas** (University of Padova and INFN - Padova)
- **Jorgen D'Hondt** (Brussels) - ex-officio
- **Keith Ellis** (Durham) - ex-officio
- **Maria Cepeda** (CIEMAT)
- **Riccardo Rattazzi** (EPFL)
- **Wouter Verkerke** (NIKHEF)

Work organisation

- Weekly meeting started on January 10th
  - Day-long internal workshop on March 21-22
- Scrutinised with care the documents submitted as input to the Update of the *European Strategy Symposium* in Granada (May 2019)
- Had invited talks from experts from future colliders (FC) communities on Higgs physics potential
  - FCC-ee, FCC-hh, CEPC, HE-LHC, ILC, CLIC, LHeC/HE-LHeC/FCC-eh
  - Muon Collider expert invited, talk scheduled
  - Had and still having extremely useful interactions with Higgs FC experts

Higgs Couplings

- Higgs boson couplings to elementary particles and Higgs boson selfcoupling dominant theme in the group activity

- Mandate of the team: ***provide a coherent comparison …***

- Have considered two basic Higgs coupling fit frameworks
  - the kappa framework, and
  - the EFT framework
  - ➔ use these two frameworks, the same for all FCs, to extract results on Higgs couplings in combination with HL-LHC
    - standalone FC Higgs sensitivities will be also released (in the kappa framework)

Kappa framework

- Kappa fit method described in https://arxiv.org/abs/1209.0040 : *LHC HXSWG interim recommendations to explore the coupling structure of a Higgs-like particle.*
    - $k^2_X = \Gamma_{H \to X} / \Gamma^{SM}_{H \to X}$
    - for top coupling above the ttH threshold: $k^2_t = \sigma_{ttH} / \sigma^{SM}_{ttH}$

- Not general parametrisation of BSM, but has the advantage of simple framework, largely known in the hep community

- Scheme adopted by Higgs@FutureColliders (H@FC):
    - **10 coupling modifiers** : k_W, k_Z, k_t, k_b, k_c, k_τ, k_μ, k_g, k_γ, $k_{Z\gamma}$
    - $k_H^2 = \Gamma_H / \Gamma_H^{SM} = \Sigma(k_j^2 \times BR^j_{SM})/(1-BR_{i,u})$ $(BR_{i,u} = BR_{inv} + BR_{unt})$
        - **BR_{inv}** = Higgs boson non-SM decays with invisible final states
        - **Br_{unt}** = Higgs boson non-SM decays difficult to separate from the background

    - **Higgs boson selfcoupling fixed to SM value**
    - **Low-energy machines don't have access to k_t**

Scenarios considered in the kappa fit study

- We are studying the following scenarios:

scenario	BR$_{unt}$	Future Collider (FC) standalone	FC + HL-LHC* combination
Kappa-1	Set to 0	yes	no
kappa-2	free	yes	no
kappa-3	Set to 0	no	yes
kappa-4	**free**	**no**	**yes**

BR$_{inv}$ is constrained from data in all cases

(*) for HL-LHC the additional constraint: $|k_V| < 1$ is imposed

EFT framework

- Many advantages offered by the EFT approach
  - Among these: describes correlation of New Physics (NP) effects in different types of observables in the Higgs sector and outside

- The following scenarios are under study:
  - We limit our analysis to Dim-6 Operators; we focus on holomorphic /SU(2)-linearly realised Lagrangian
  - We don't consider BSM Higgs boson decays

scenario	EWPO	Flavour
SMEFT 1	No uncertainties	universal
SMEFT 1'	No uncertainties	non universal
Repeat SMEFT 1 and 1' including Higgs selfcoupling (λ_3)		

scenario	EWPO	Flavour
SMEFT 2	Expected unc.	universal
SMEFT 2'	Expected unc.	non universal

- **EWPO**: electroweak precision observable

- **Flavour universality:**
  - $\delta g_{Htt} / \delta g^{SM}_{Htt} = \delta g_{Hcc} / \delta g^{SM}_{Hcc}$
  - $\delta g_{H\tau\tau} / \delta g^{SM}_{H\tau\tau} = \delta g_{H\mu\mu} / \delta g^{SM}_{H\mu\mu}$

We plan to show fit results in term of effective couplings, defined from physical observables (as opposed to showing dim-6 operator coefficients)

particular attention is also paid to

- Higgs boson selfcoupling analysis
- Higgs boson rare decays H$\rightarrow\mu\mu$, ee, Zγ

Not only couplings…

- Study and compare original FC contributions to the ESU on
  - Higgs CP
  - Higgs boson mass (includes an overview on Higgs boson width at different FCs)

H@FC Report preparation

- The goal is to distribute:
  - to the ESU PPG group
  - to the hep community at large

  a report on the work done. Tentative deadline: beginning of May.
  - This document will also include:
    - ❖ Highlights of preliminary Higgs sector perspective studies at the Muon Collider
    - ❖ An Outlook of studies that could be done with more time after the Symposium in Granada

- An advanced draft of this document will be sent *in confidence* to the FC colliders, by mid April (or so)
  - comments will be taken into account towards the presentation of the comparison at the Open Symposium in Granada.

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