SMEFT fits:
Open questions and ideas for Snowmass-2021

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SMEFT and Snowmass

- "Snowmass" is the planning exercise ⇒ focus on future facilities
  - — identify key reference measurements to compare facilities

    $pp,\ e^+e^-,\ \gamma\gamma,\ \mu^+\mu^-,\ ep\ (\sqrt{s})\ldots$ have their unique features
  - — highlight strong and weak aspects / complementarity in Physics reach
  - — chance to develop analysis tools / approaches, but secondary
- SMEFT is the framework for Higgs, Top, EW, + … measurements
  - — sensitivity to higher scale beyond direct reach (change in kinematics and yields)
  - — take advantage of correlated effects for tighter constraints on deviations from SM

    ⇒ global Fits
  - — some effects may not be correlated or different impact (by physics or construction)

    ⇒ dedicated Fits
- Extensive experience from LHC (H,t,EW,EFT) WG, other…
  - — most complete projections from the European Strategy Group

Example: CP-violating Operators

- At Snowmass-2013 considered dedicated CP fits (also see backup)

  arXiv:1310.8361 (CP-odd admixture $H \to \tau^+\tau^-, 4\ell, t\bar{t}H, ggH, \mathrm{VBF}, VH, \ldots$)

  — potential baryogengesis connection to CP in the Higgs sector

  — connection to the EDM measurements

  — well-defined stand-alone reference measurement

  — input to the global SMEFT fits, currently missing in most global fits

- Be careful not to interpret yield as CP:

  Physics message may be lost behind certain fits…

HL-LHC report: arXiv:1902.00134

CP-even CP-odd

$$\mu_{ZH}^{14\mathrm{TeV}} = 1.00 + 0.54\,\tilde{c}_{Z\gamma}^2 + 2.80\,\tilde{c}_{ZZ}^2 + 0.95\,\tilde{c}_{Z\gamma}\tilde{c}_{ZZ}$$
$$\mu_{WH}^{14\mathrm{TeV}} = 1.00 + 0.84\,\tilde{c}_{Z\gamma}^2 + 3.87\,\tilde{c}_{ZZ}^2 + 3.63\,\tilde{c}_{Z\gamma}\tilde{c}_{ZZ}$$
$$\mu_{\mathrm{VBF}}^{14\mathrm{TeV}} = 1.00 + 0.25\,\tilde{c}_{Z\gamma}^2 + 0.45\,\tilde{c}_{ZZ}^2 + 0.45\,\tilde{c}_{Z\gamma}\tilde{c}_{ZZ}$$

  — CP-sensitive kinematic observables are the key in doing CP measurements

$pp,\ e^+e^-,\ \gamma\gamma,\ \mu^+\mu^-,\ ep\ (\sqrt{s})\ldots$ have their unique features with beam polarization production mechanisms,…

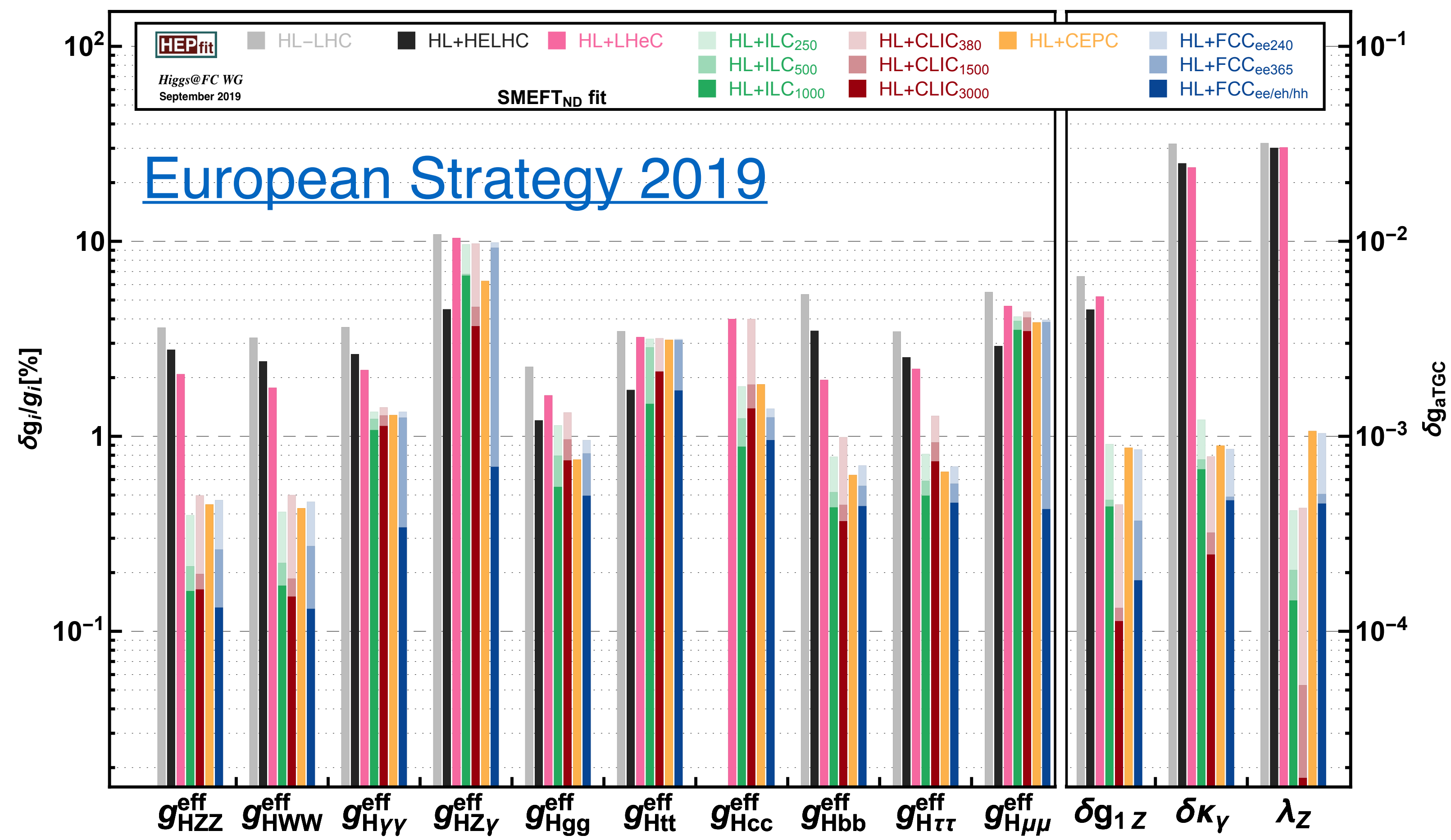
See review at the June EF01 meeting

SMEFT at Snowmass: Open Questions

- Tradeoff between complexity/reach and simplicity/scope
  - — what is better to illustrate certain point: implications for colliders?
  - — how much do correlations in a global fit help?
  - — how best to present dozens (or hundreds) of parameters not losing critical info?

e.g. effective couplings:

$$g_{HX}^{\mathrm{eff}\ 2} \equiv \frac{\Gamma_{H\to X}}{\Gamma_{H\to X}^{\mathrm{SM}}}$$



— look for structure:

if we include e.g. CPV:

$$f_{CP}^{HX} \equiv \frac{\Gamma_{H\to X}^{\mathrm{CP\,odd}}}{\Gamma_{H\to X}^{\mathrm{CP\,odd}} + \Gamma_{H\to X}^{\mathrm{CP\,even}}}$$

(Snowmass-2013)

$$\mathrm{SMEFT_{ND}} \equiv \{\delta m,\ c_{gg},\ \delta c_z,\ c_{\gamma\gamma},\ c_{z\gamma},\ c_{zz},\ c_{z\Box},\ \delta y_t,\ \delta y_c,\ \delta y_b,\ \delta y_\tau,\ \delta y_\mu,\ \lambda_z\}$$
$$+\left\{(\delta g_L^{Zu})_{q_i},(\delta g_L^{Zd})_{q_i},(\delta g_L^{Z\nu})_\ell,(\delta g_L^{Ze})_\ell,(\delta g_R^{Zu})_{q_i},(\delta g_R^{Zd})_{q_i},(\delta g_R^{Ze})_\ell\right\}_{q_1=q_2\neq q_3,\ \ell=e,\mu,\tau}$$

SMEFT at Snowmass: Open Questions

- Common approach and input in global or dedicated Fits?
  - — different assumptions may lead to drastically different predictions / results
  - — cannot compare colliders with different assumptions
- Relaxing symmetries: CP, flavor universality and diagonality?
  - — can flavor or table-top experiments help?
  - — does it make a case for certain colliders?
- Incorporate Rare&Precision Frontier measurements?
  - — synergy between frontiers…
  - — reduce assumptions?
- Theoretical and experimental uncertainties specific to EFT
  - — in which cases are those important for Snowmass projections? (e.g. large q^2)
  - — both are typically not fully explored (e.g. assume SM kinematics in acceptance)

SMEFT at Snowmass: Ideas

Deeper connection of EW and Higgs fits:

- Vector boson scattering and off-shell Higgs
  - — interconnection of VBS and Higgs couplings, joint EW-Higgs fits
  - — total width Γ_H is an important parameter to consider in Snowmass studies
  - — lepton colliders have unique ways to approach this
  - — most global fits do not deal with Γ_H and couplings from off-shell Higgs
  - — most assume Γ_H from known decays, no unknown / exotic Higgs decays
  - — may consider total width Γ_H in the presence of unknown Higgs decays

    (even if SMEFT assumes no new particles up to scale $\Lambda \gg 100\,\mathrm{GeV}$)

- Inclusion of CP-odd operators
  - — see previous slides for discussion…

LHC EFT WG

- Many of these aspects running across Higgs, EW, Top,…
  can also be discussed in the new forum:

- New LHC EFT Working Group https://lpcc.web.cern.ch/lhc-eft-wg
  1st open meeting of the LHC EFT Working Group: 19-20 Oct. 2020

- Considering activities:
  - EFT Formalism
  - Predictions and tools
  - Experimental measurements and observables
  - Fits and related systematics
  - Benchmark scenarios from UV models
  - Dissemination and outreach

BACKUP

CPV from Snowmass-2013

- Higgs Working Group Report of the Snowmass-2013 Community Planning Study

  Chapter 1.4 devoted to spin and CP: arXiv:1310.8361

  – pp, e^+e^-, $\gamma\gamma$, $\mu^+\mu^-$ $(\sqrt{s})$ have their unique features in CP of H(125)

Collider	pp	pp	e^+e^-	e^+e^-	e^+e^-	e^+e^-	$\gamma\gamma$	$\mu^+\mu^-$	target
E (GeV)	14,000	14,000	250	350	500	1,000	126	126	(theory)
$\mathcal{L}$ (fb^{-1})	300	3,000	250	350	500	1,000	250		
spin-2^+_m	$\sim 10\sigma$	$\gg 10\sigma$	$>10\sigma$	$>10\sigma$	$>10\sigma$	$>10\sigma$			$>5\sigma$
$VVH^\dagger$	0.07	0.02	✓	✓	✓	✓	✓	✓	$< 10^{-5}$
$VVH^\ddagger$	$4\cdot 10^{-4}$	$1.2\cdot 10^{-4}$	$7\cdot 10^{-4}$	$1.1\cdot 10^{-4}$	$4\cdot 10^{-5}$	$8\cdot 10^{-6}$	–	–	$< 10^{-5}$
$VVH^\diamond$	$7\cdot 10^{-4}$	$1.3\cdot 10^{-4}$	✓	✓	✓	✓	–	–	$< 10^{-5}$
ggH	0.50	0.16	–	–	–	–	–	–	$< 10^{-2}$
$\gamma\gamma H$	–	–	–	–	–	–	0.06	–	$< 10^{-2}$
$Z\gamma H$	–	✓	–	–	–	–	–	–	$< 10^{-2}$
$\tau\tau H$	✓	✓	0.01	0.01	0.02	0.06	✓	✓	$< 10^{-2}$
ttH	✓	✓	–	–	0.29	0.08	–	–	$< 10^{-2}$
$\mu\mu H$	–	–	–	–	–	–	–	✓	$< 10^{-2}$

† estimated in $H \to ZZ^*$ decay mode

‡ estimated in $V^* \to HV$ production mode

$^\diamond$ estimated in $V^*V^* \to H$ (VBF) production mode

targeted couplings

comparison across facilities

theoretical interest

parameters of interest