EFT Discussion - EF04 Inputs

A. Belloni - University of Maryland
A. Freitas - University of Pittsburgh
J. Tian - University of Tokyo

General Remarks

- Unified description for all measurements
  - Synergies between LHC, future ee / pp / ep, low-energy measurements
- EFT as a common theoretical tool to evaluate experimental sensitivities
  - NP scales (individual operators with assumption on Wilson coefficient)
  - Higgs / Top-quark / EW couplings (projections in multi-operators space)
- Validity in various EFT applications
  - Impact of ignored higher dimensional operators (i.e., D-8, or not completed D-6 set)
  - Uncertainty due to NLO EFT effects
  - Still making sense at O(1) TeV e+e- / O(100) TeV pp?
- Multi-TG (and multi-Frontier) joint effort
  - A lot of existing work done by ESG
  - Relax assumption: way to accommodate Higgs exotic decays?
  - Impact from Top-quark loop? Higgs self-coupling in single Higgs process?

The ESG Legacy

		Operator	Notation	Operator	Notation
Class 1	X^3	$\varepsilon_{abc} W_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathscr{O}_W$		
	ϕ^6	$(\phi^\dagger\phi)^3$	$\mathscr{O}_\phi$		
	$\phi^4 D^2$	$(\phi^\dagger\phi)\Box(\phi^\dagger\phi)$	$\mathscr{O}_{\phi\Box}$	$(\phi^\dagger D_\mu\phi)((D^\mu\phi)^\dagger\phi)$	$\mathscr{O}_{\phi D}$
	$X^2\phi^2$	$\phi^\dagger\phi B_{\mu\nu}B^{\mu\nu}$ $\phi^\dagger\sigma_a\phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathscr{O}_{\phi B}$ $\mathscr{O}_{\phi WB}$	$\phi^\dagger\phi W_{\mu\nu}^a W^{a\mu\nu}$ $\phi^\dagger\phi G_{\mu\nu}^A G^{A\mu\nu}$	$\mathscr{O}_{\phi W}$ $\mathscr{O}_{\phi G}$
Class 2	$\psi^2\phi^2$	$(\phi^\dagger\phi)(\bar{l}_L^i\phi e_R^j)$ $(\phi^\dagger\phi)(\bar{q}_L^i\phi d_R^j)$	$(\mathscr{O}_{e\phi})_{ij}$ $(\mathscr{O}_{d\phi})_{ij}$	$(\phi^\dagger\phi)(\bar{q}_L^i\tilde{\phi}u_R^j)$	$(\mathscr{O}_{u\phi})_{ij}$
Class 3	$\psi^2\phi^2 D$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{l}_L^i\gamma^\mu l_L^j)$ $(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{e}_R^i\gamma^\mu e_R^j)$ $(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{q}_L^i\gamma^\mu q_L^j)$ $(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{u}_R^i\gamma^\mu u_R^j)$ $(\tilde{\phi}^\dagger iD_\mu\phi)(\bar{u}_R^i\gamma^\mu d_R^j)$	$\left(\mathscr{O}_{\phi l}^{(1)}\right)_{ij}$ $(\mathscr{O}_{\phi e})_{ij}$ $(\mathscr{O}_{\phi q}^{(1)})_{ij}$ $(\mathscr{O}_{\phi u})_{ij}$ $(\mathscr{O}_{\phi ud})_{ij}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu^a\phi)(\bar{l}_L^i\gamma^\mu\sigma_a l_L^j)$ $(\phi^\dagger i\overleftrightarrow{D}_\mu^a\phi)(\bar{q}_L^i\gamma^\mu\sigma_a q_L^j)$ $(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{d}_R^i\gamma^\mu d_R^j)$	$(\mathscr{O}_{\phi l}^{(3)})_{ij}$ $(\mathscr{O}_{\phi q}^{(3)})_{ij}$ $(\mathscr{O}_{\phi d})_{ij}$

D-6 operators included in global SMEFT fit by ESG

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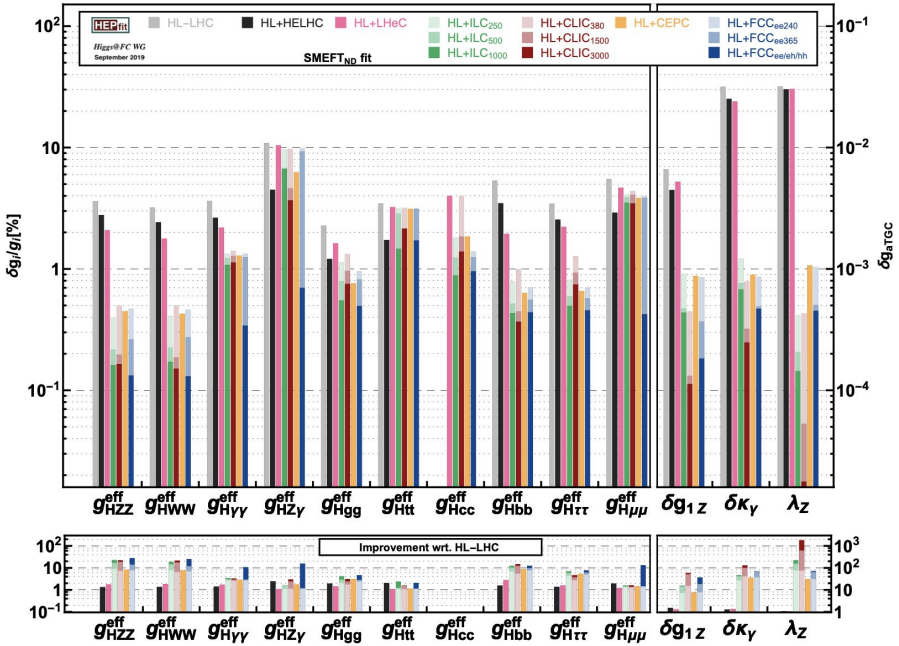
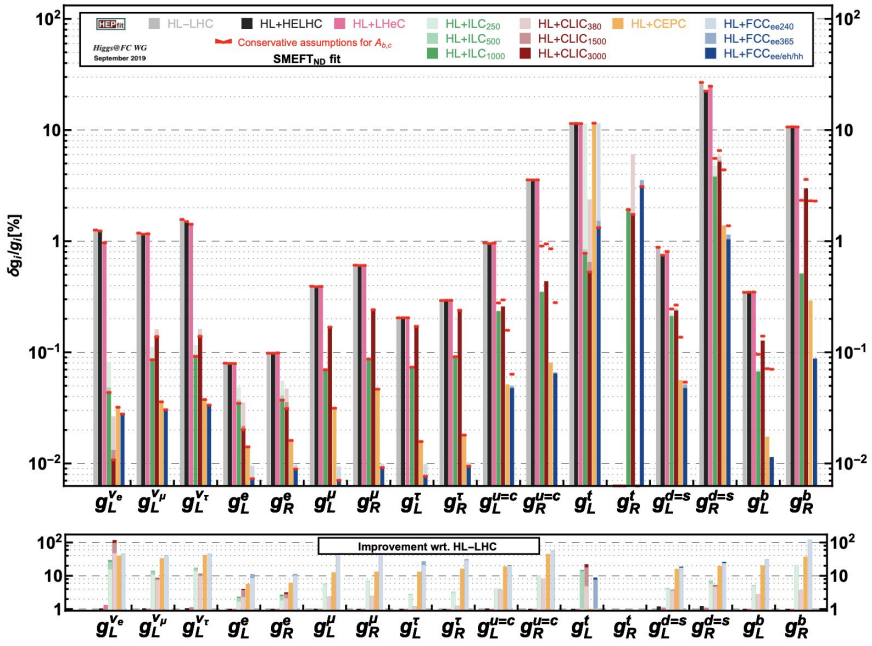
ESG Inputs

Quantity	Current	HL-LHC	FCC-ee	CEPC	ILC		CLIC	
					Giga-Z	250 GeV	Giga-Z	380 GeV
δm_{top} [MeV]	$\sim$500 [a]	$\sim$400 [a]	20 [b]	–	–	17 [b]	–	20-22 [b]
δM_Z [MeV]	2.1	–	0.1	0.5	–	–	–	–
$\delta \Gamma_Z$ [MeV]	2.3	–	0.1	0.5	1	–	1	–
$\delta \Gamma_{Z\to\text{had}}$ [MeV]	2.0	–	–	–	0.7	–	0.7	–
$\delta \sigma^0_{\text{had}}$ [pb]	37	–	4	5	–	–	–	–
δM_W [MeV]	12	7	0.7	1.0 (2-3) [c]	–	2.4 [d]	–	2.5
$\delta \Gamma_W$ [MeV]	42	–	1.5	3	–	–	–	–
$\delta \text{BR}_{W\to e\nu}[10^{-4}]$	150	–	3	3	–	4.2	–	11
$\delta \text{BR}_{W\to \mu\nu}[10^{-4}]$	140	–	3	3	–	4.1	–	11
$\delta \text{BR}_{W\to \tau\nu}[10^{-4}]$	190	–	4	4	–	5.2	–	11
$\delta \text{BR}_{W\to \text{had}}[10^{-4}]$	40	–	1	1	–	–	–	–
δA_e $[10^{-4}]$	140	–	1.1 [e]	3.2 [e]	5.1	10	10	42
δA_μ $[10^{-4}]$	1060	–	–	–	5.4	54	13	270
δA_τ $[10^{-4}]$	300	–	3.1 [e]	5.2 [e]	5.4	57	17	370
δA_b $[10^{-4}]$	220	–	–	–	5.1	6.4	9.9	40
δA_c $[10^{-4}]$	400	–	–	–	5.8	21	10	30
δA^μ_{FB} $[10^{-4}]$	770	–	0.54	4.6	–	–	–	–
δA^b_{FB} $[10^{-4}]$	160	–	30 [f]	10 [f]	–	–	–	–
δA^c_{FB} $[10^{-4}]$	500	–	80 [f]	30 [f]	–	–	–	–
δR_e $[10^{-4}]$	24	–	3	2.4	5.4	11	4.2	27
δR_μ $[10^{-4}]$	16	–	0.5	1	2.8	11	2.2	27
δR_τ $[10^{-4}]$	22	–	1	1.5	4.5	12	4.3	60
δR_b $[10^{-4}]$	31	–	2	2	7	11	7	18
δR_c $[10^{-4}]$	170	–	10	10	30	50	23	56
δR_ν $[10^{-3}]$ [g]	–	–	–	–	–	–	–	9.4
δR_{inv} $[10^{-3}]$ [g]	–	–	0.27	0.5	–	–	–	–

- Input measurements: electroweak precision observables
  - Higgs strength parameters @ HL-LHC & future colliders
  - TGC in e+e- → WW

ESG Results





- Precision of Higgs & EW couplings at HL-LHC & future colliders

Open Questions

- Can the treatment of input observables be improved? (keep same framework)
  - Full EFT treatment in e+e- → WW (TGC used differently among e+e- colliders)
  - Consistent inclusion of experimental & theoretical systematic uncertainties
  - Adding EFT theory errors (truncation at D-6)
  - Add more differential observables

- Can some of the assumptions be relaxed?
  - Constrained Higgs total width (no Higgs invisible/exotic decay was allowed)
  - Flavor Neutral Diagonality & Lepton Flavor Universality
  - Included only CP-even operators
  - Only Leading Order effects from D-6 operators

More Open Questions

- Can the operator basis be expanded to probe more kinds of new physics effects (naturally input observables have to be expanded)?
  - Include multi-boson & VBS measurements at (HL-)LHC; EFT validity
  - Include global EFT fits for top-quark EW sector
  - EFT fits at Next to Leading Order
    - Combined Higgs/EW/Top fit
    - Higgs self-coupling in single-Higgs processes
    - Top-Yukawa coupling in loop-induced Higgs decay / production
  - Global EFT fits for 4-fermion operators (synergy between low-energy measurements, EIC, LHC & future colliders); interplay with other operators

Possible Directions

- Really global fit unwieldy on time scale of Snowmass process
  - Extension or update of ESG studies, with updated experimental and theoretical inputs, would already be a success
- Discussions at EF TG meetings (Jun 4, Sep 24) identified a few topics of interest that shall be pursued
  - Explore the usage of differential measurements
  - Include multi-boson processes
  - Identify observables' sensitivity to CP-violating effects
  - Set framework for consistent treatment of top, Higgs, WW
  - Attempt relaxation of flavor assumptions (O(10) increase in number of operators…)
  - Do theory uncertainties right
  - Define strategy to assess sensitivity to new physics (while ensuring EFT validity)
- Many possible directions and short time scale require careful organization of effort