“Global SMEFT Fit Team” Activities

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Why do we need SMEFT fits to collider data?

To test the validity of the SM. Inclusion of data from a variety of precision measurements can increase the power of the test.

To connect deviations from the SM in a number of observables to interpretations in terms of specific BSM models.

To extract Higgs boson couplings. We cannot directly measure the Higgs width. So we need a model to relate Higgs BR's and other data to Higgs partial widths and couplings. SMEFT (w., e.g., truncation at dimension 6) provides a very general such model.

Goals for SMEFT fitting at Snowmass:

prepare an illustrative global Higgs/EW fit including future lepton collider results

prepare an illustrative global Higgs/EW fit based on the combination of future hadron and lepton collider results

understand the general issues in global fitting (appropriateness of the SMEFT framework, model-independence, most appropriate operator set or subset)

understand the subtleties of combining HL-LHC and lepton collider data into a global fit

"illustrative" = not the final word, but a concrete realization to critique and improve

Current members of our team:

Jorge de Blas, Christophe Grojean, Jiayin Gu, Michael Peskin, Junping Tian

Anyone who would like to help is welcome to join.

We have all been involved in previous SMEFT projections done for the European Strategy Study:

Jorge, Christophe (and Jiayin): arXiv:1905.03764
(ECFA Higgs panel report)

based on the approach of Di Vita et al., arXiv:1711.03978, De Blas et al., arXiv:1907.04311.

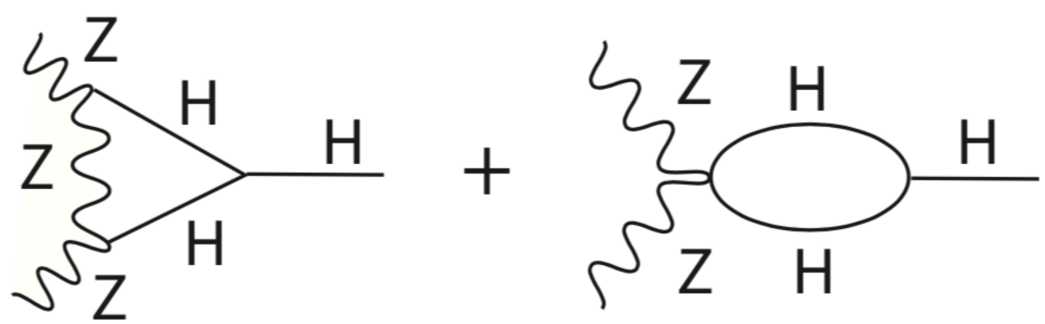
Michael, Junping: arXiv:1903.01629, 1908.11299
(ILC white papers)

based on the approach of Barklow et al., arXiv: 1708.08912, 1708.09079

As you might expect, our studies had different philosophies. The EPS study tried to use as large a set as possible hadron and lepton collider projections. The ILC study tried to use only e+e- collider projections, to the greatest extent possible.

In addition, our studies had technical differences. We have spent most of our time so far trying to understand and resolve these.

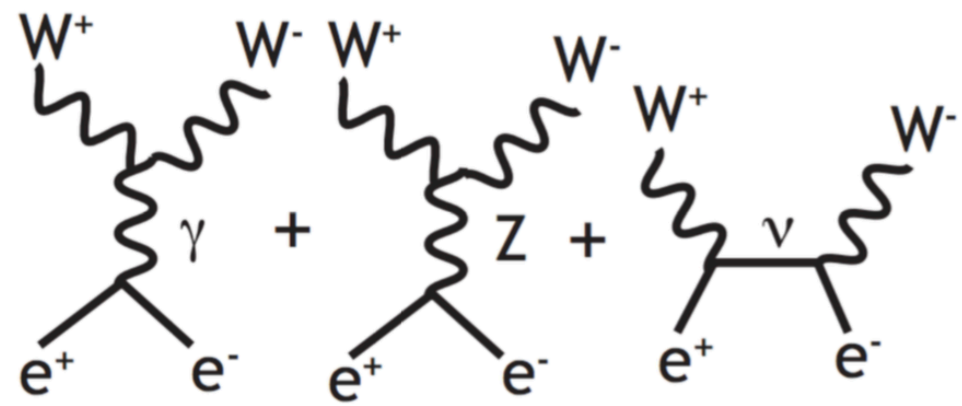
e.g., the analysis that most stresses SMEFT Higgs fits is the extraction of the 1-loop effect of the Higgs self-coupling from the residual information after fitting all other Higgs couplings.



error on c6 for c6-only fit / full SMEFT fit

	ECFA fit	ILC fit
ILC 250+500	32% / 58%	25% / 56%
FCCee 240+365	21% / 44%	18% / 57%
FCCee 4 det.	15% / 27%	12% / 35%

a more extended example: $e^+e^- \to W^+W^-$



There are full-simulation studies for ILC done by Rosca, Marchesini, and List at 500 GeV and 1 TeV. These used the dependence on only 3 of the 5 decay angles measured in full event reconstruction. The studies fit for the 3 parameters of the WWV vertices assuming SU(2)xU(1)

$$g_Z \ , \kappa_A \ , \lambda_A$$

However, SMEFT predicts corrections to the eeZ and $e\nu W$ vertices that were not included in this analysis. Also, one could achieve greater sensitivity using all 5 rather than 3 decay angles.

ILC solution: Use extrapolations to estimate the results for 5 angles and for 250 GeV. Define modified effective parameters g_Z , κ_A , λ_A to include the leading effects of electron vertex corrections.

ECFA solution: Ignore the full-simulation studies; instead use the "optimal observable" formalism to estimate the best possible results.

Optimal observables

Diehl,Nachtmann; Gunion, Grzadkowski, He

This is an idealized version of unbinned likelihood analysis. It is useful for a strictly linear SMEFT fit.

Let $d\sigma/d\Omega$ be the fully differential cross section, to be integrated over the full phase space (5-d in this case). Write it out as

$$= d\sigma/d\Omega|_{SM} + \sum_n \Delta d\sigma/d\Omega_n c_n \equiv \Sigma + \Delta_n c_n$$

For one variable and simply integrating over phase space, the expected error would be

$$\frac{1}{\sigma^2} = \frac{(\int d\Omega\, \Delta \cdot \mathcal{L})^2}{\int d\Omega\, \Sigma \cdot \mathcal{L}} \quad \sim N$$

Then the best constraint, taking account of the differential distribution, is

$$C^{-1}_{mn} = \int d\Omega \frac{\Delta_m \Delta_n}{\Sigma} \cdot \mathcal{L}$$

This is a very attractive formula:

$$C_{mn}^{-1} = \int d\Omega \frac{\Delta_m \Delta_n}{\Sigma} \cdot \mathcal{L}$$

You can add as many dependent variables as you wish. Changes of variables and (linear) dependences of some variables on others can be implemented by linear algebra. Constraints and efficiencies can be imposed by restricting the integration over phase space.

Putting $|\cos\theta| < 0.9$ for jets, < 0.95 for leptons seems to account for most of the event reconstruction inefficiency.

Simple comparison to full-sim: (diagonal) errors

g_Z	full phase space	angular cuts	ILD full-sim
250 GeV	1.60	1.80	3.11
500 GeV	0.58	0.61	0.88
1000 GeV	0.25	0.25	0.21

κ_A	full phase space	angular cuts	ILD full-sim
250 GeV	2.45	2.73	4.81
500 GeV	0.66	0.68	1.20
1000 GeV	0.24	0.24	0.26

λ_A	full phase space	angular cuts	ILD full-sim
250 GeV	1.84	2.05	3.87
500 GeV	0.52	0.55	1.31
1000 GeV	0.18	0.19	0.22

much simpler than full-sim, but it has the correct scaling with energy and number of phase space variables

For inclusion in the SMEFT fit, use 10 variables:

$$e \ , \ g_L \ , \ g_R \ , \ g_Z \ , \ g_W \ , \ \kappa_A \ , \ \kappa_Z \ , \ \lambda_A \ , \ \lambda_Z \ , \ BR$$

where $BR = BR(W \to \ell\nu)$, and add 2 nuisance variables

$$\delta N \ , \ \delta P_{eff}$$

Since at lepton colliders the process $e^+e^- \to W^+W^-$ is used to determine the effective luminosity and polarization, need to compute these dependences and marginalize over these variables.

This is not a replacement for a full-sim study, but it is a simple tool that one can use to gain insight and improve the next iteration.

It turns out that the replacing the previous ILC inputs by this method has a negligible effect on the global Higgs coupling fit.

More questions to ask:

Both analyses use strictly linear dependence on dim-6 SMEFT coefficients, and tree-level expressions for the differential dependences Δ_m . Should this be improved ?

It is not so obvious. At this level, the SMEFT fit closes, with no soft directions. Higher orders in perturbation theory bring in additional dim-6 operators. Terms quadratic in SMEFT coefficients of dim-6 operators are at the same level as terms linear in dim-8 operators. But, if we introduce the required new operators without assumptions about their magnitude, the fit will not close.

Lepton colliders have an advantage here over hadron colliders. Electroweak corrections are at the percent level in the Δ_m term, hence usually negligible. The parameter q^2/Λ^2, where Λ^2 is the scale of new physics, is small, and so keeping only the leading term here makes sense. The situation is different at the LHC, especially when the philosophy "energy helps accuracy" is used.

I hope that, for the purpose of next-generation experiments, the simple linear, lowest-order treatment of Δ_m suffices. This should be debated at Snowmass. Of course the SM term should be computed as accurately as possible.

The situation is more complicated for fits to LHC data alone, and there is an ongoing discussion in the LHC EFT working group. Let's see what we can learn from them.

There is much work still to be done. But our team has gotten started, and we hope to advance the art of SMEFT fitting before the end of Snowmass. Please join us in these discussions.