EFT Interpretation Uncertainty in LHC Searches

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The most exciting and future-oriented goal that we can address with SMEFT analyses is to have a tool which will enable a straightforward test of future models against LHC and other precision measurement data; this is the vision of a SMEFT analysis as the successor to the LEP ElectroWeak Working Group analysis. If we are to achieve this vision, though, we must produce constraints which are accurate and useful. Previous EFT analyses have historically not considered the uncertainties inherent in the new perturbation series introduced in the EFT, and as a result have produced “constraints” that are fairly easy to evade with minimal model-building effort, leading to their wholesale (and deserved) neglect by the model-building community as potential indications of what is and is not constrained by LHC data. Following this same approach, though it may fulfill some other vision of the SMEFT's utility, will manifestly not achieve a tool which is actually useful for discriminating model viability with respect to precision measurements. It is unavoidable that our analysis must carefully consider the effects of higher order in perturbation theory effects, and either calculate them explicitly and consider them part of our signal or make an honest estimate of their magnitude and treat them as uncertainties in our interpretation.

The former approach will have the severely deleterious effect of wildly expanding the parameter space we are interested in, so the latter must be at least our initial response. I have proposed and applied to dijet and dilepton final states at the LHC a framework to estimate these errors by using the one portion of the calculation at $\mathcal{O}\left(\frac{1}{\Lambda^4}\right)$ which we can perform with the parameters we are already studying. The terms quadratic in dimension-6 Wilson coefficients arising from the squaring of an amplitude at $\mathcal{O}\left(\frac{1}{\Lambda^2}\right)$ are well-defined; these can be thought of as analogous to the differences in a calculation at fixed order in QCD when considering different scales. These are similarly well-defined and only a contribution to the full next order result, and have long been used as a probe of the scale of effects at the next order in perturbation theory.

In this framework, having already determined what Wilson coefficients contribute to a process, constructed linear combinations which correspond to experimentally distinguishable effects of the SMEFT, and selected exemplar parameters to simulate as a stand-in for any contribution of the same type, we calculate in pseudodata with identical Wilson coefficients both a signal and an error distribution, σ_s, σ_e, which, in `MadGraph` and `SMEFTSim` notation correspond to `NP^2==1` and `NP==1` respectively. Then, in a fit to data, we take our signal model to be defined binwise as $\sigma_{SM} + \frac{\mathcal{C}_{\rm fit}}{\mathcal{C}_{sim}}\sigma_s \pm f\left(\mathcal{C}_{\rm fit}\right)\sigma_e$, where $\mathcal{C}_{{\rm fit},sim}$ are the fitted and simulated values of the dimensionful Wilson coefficient, and $f\left(\mathcal{C}_{\rm fit}\right)$ is a function chosen to rescale the error distribution to account for the dependence on multiple unknown Wilson coefficients at dimension-8. An example function would be

$$f\left(\mathcal{C}_{\rm fit}\right) = \frac{\mathcal{C}_{\rm fit}^2}{\mathcal{C}_{sim}^2} + \frac{g_{SM}^2\sqrt{N_8}\sqrt{1+C_{\rm fit}^2}}{\Lambda_{fit}^4\mathcal{C}_{sim}^2}, \tag{1}$$

where g_{SM} is the relevant SM coupling for the process of interest, N_8 is an estimate of the number of operators at dimension-8 which could contribute to such a process, and $\mathcal{C}_i = \frac{C_i}{\Lambda^2}$.

Note here the separation of the Wilson coefficient from the NP scale in the second term; it is important that we not allow a strong would-be bound on a dimension-6 contribution to suppress our estimate of dimensionless Wilson coefficients at higher scales to be far smaller than unity - this ensures that any region of phase space where the scale of new physics is below the probed energy will be assigned interpretive errors that are large compared to the putative signal. Other functional forms which achieve similar goals may well also be reasonable estimates of our uncertainty.