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Global SMEFT Fits Including Theory Uncertainties: A Snowmass Letter of Interest

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Abstract: We propose to study the theoretical uncertainties inherent in non-resonant observables at the LHC in the example of VH production; while the Higgs decays in this process will be well-described by coupling shifts, the differential production information is subject to large uncertainties, particularly at higher center-of-mass energies. Studies including such errors have thus far been produced only for dijet and dilepton processes. We also will produce a proof-of-principle global fit which includes both on-shell data (like Higgs and Z-boson observables) and off-shell data which includes these theoretical errors, providing clear proof that searches that include these uncertainties are fully compatible with lower-energy precision measurements in the context of constraining the SMEFT. Only conservative bounds that include these errors are actually valuable for use on future models; without this care being taken it is entirely possible that a SMEFT analysis would indicate that a model is ruled out by LHC precision measurements when in fact it is perfectly consistent with the underlying data.

1 Background

The Standard Model Effective Field Theory (SMEFT) is a toolkit which enables the parameterization of effects of new physics (NP) at energy scales beyond the direct reach of our experiments, and has significant promise to be employed by the equivalent of the LEP ElectroWeak Working Group (EWWG) for the LHC, particularly in its high-luminosity phase, where despite the relatively messy hadronic environment impressive precision of Standard Model (SM) measurements is expected. Just as the LEP EWWG results provided pseudo-observables which were relatively straightforward to calculate in a new physics model, enabling model-builders to test their proposals without needing to fully recast the LEP analyses, a SMEFT-based interpretation of the totality of precision measurements in the SM (including low-energy scattering, flavor, LEP, and LHC results), along with automated matching tools to calculate the SMEFT Wilson coefficients induced by an arbitrary UV model (including loop-level matching) [1–3], will provide unprecedented ease of comparison for a new model to the complete set of precision measurements available in particle physics.

If these tools are to be of use to the community, however, it must be the case that quoted bounds are robust. If it is entirely plausible to develop UV theories which match on to "excluded" regions of the SMEFT parameter space but which are themselves perfectly allowed by the data that lead to that exclusion, then this effort will fail to properly parameterize the constraining power of our precision measurements. The goal of the SMEFT enterprise is to provide a quick cross-check that can rapidly indicate that a certain model is already robustly excluded by precise SM measurements, and therefore does not require further detailed study, with the intent of focusing the community's efforts more efficiently on models which present unique signatures beyond those precision measurements. If, however, further engineering can avoid those bounds, then all models will nonetheless merit more detailed study.

2 Proposed Study

We will employ the framework for theoretical errors described and applied in [4–6] to derive appropriately conservative constraints on SMEFT parameter space due to the differential distribution of VH production; this requires employing the SMEFT at order $\frac{1}{\Lambda^2}$ as the signal function, and the portion of the squared amplitude that is of order $\frac{1}{\Lambda^4}$ as a template for the generic size of all terms at that order to estimate the error associated with our truncation of the EFT perturbation series. This is exactly analogous to the exploration of higher-order uncertainties by using the variation with renormalization scale in renormalizable gauge theories; that also gives a partial result at next order, such that using it as a tool to estimate the possible size of the full next-order result is reasonable.

We will then combine the constraints that result from that first portion of the study, along with those previously found using these theoretical error techniques, with the precise lower-energy data available from electroweak precision data (LHC, LEP, and earlier) and from purely on-shell Higgs observables at the LHC. The latter data sources are much less subject to theoretical error, as the largest expansion parameter in those cases is $\frac{v^2}{\Lambda^2}$

rather than $\frac{E^2}{\Lambda^2}$, where v is the Higgs vacuum expecation value and E is the characteristic energy of the scattering process under study. This makes reasonable a flat, percentage estimate for theory errors, as has previously been proposed and explored [7, 8]. The technology needed to consistently combine these two types of SMEFT data has not been previously constructed, with the primary barrier to success being the explicit dependence of the theoretical errors on the signal parameters.

3 Anticipated Impact

This proof-of-concept fit, combining robust low-energy data with conservatively-interpreted nonresonant SMEFT effects, will establish the last step of utilization of the theoretical error estimates originally proposed in [4]. With this technology developed, there should be no remaining barrier to this more theoretically consistent, conservative, and therefore higher-utility approach to high-energy data in the SMEFT. Because these theoretical errors generically have nontrivial dependence on kinematics they can severely impact search design, and thus would be best implemented inside the experimental collaborations; we strongly advocate for their adoption in all SMEFT interpretations of precision observables. The involved techniques have been intentionally constructed to allow for ease of adoption in experimental collaborations; error estimates can be straightforwardly constructed using standard Monte Carlo codes and tools.

A global fit developed using the technology to be developed in this study would provide by far the easiest-to-use data preservation scheme for bounds on NP due to precision SM measurements; automated matching codes coupled with such a global fit would enable nearly effortless and instantaneous comparison of a completely novel UV model with the full spectrum of precision measurements, and provide a bound which is in fact robust and believable. A tool of this utility deserves the level of effort that has previously been invested in efforts like the LEP EWWG, from both the theoretical and experimental community.

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