PROCEEDINGS OF SCIENCE

Higgs Effective Field Theory results with the ATLAS and CMS experiments at the LHC

Andrea Sciandra[a,*,†]

[a] *Santa Cruz Institute for Particle Physics, University of California at Santa Cruz, 1156 High Street, Santa Cruz, CA, USA*

E-mail: asciandr@ucsc.edu

The framework of Effective Field Theory (EFT) Lagrangians is an effective and systematic way to search for physics beyond the Standard Model at the LHC using distributions of events in many topologies. A large number of measurements performed by ATLAS and CMS experiments in the Higgs sector of the Standard Model include EFT interpretations. They provide complementary constraints, although with various choices of bases and interpretation frameworks. No significant deviations from the Standard Model predictions have been observed so far, as constraints on relevant Wilson coefficients have been extracted.

The Tenth Annual Conference on Large Hadron Collider Physics - LHCP2022
16-20 May 2022
online

*Speaker

†On behalf of the ATLAS and CMS Collaborations

PoS(LHCP2022)195

Unquestionable evidence for New Physics (NP) beyond the Standard Model (SM) and the Higgs boson has not been found at the LHC yet. There is an increasing focus on indirect exploration of the Higgs-boson sector, involving the interpretation of several measurements and searches with fewer and fewer assumptions made. A SM Effective Field Theory framework [1], whose operators are suppressed by a NP scale Λ [2], allows for indirect probes of new signals in an agnostic and systematic way. Necessary assumptions are that NP degrees of freedom can be integrated out, that the Higgs boson is SM-like and that NP can manifest itself through higher-dimension effective interactions between the different SM fields. The Warsaw basis [3] is a non-redundant set of higher-dimension effective operators mostly used by ATLAS and CMS to extract results, including 59 (plus Hermitian conjugate) dimension-6 operators. Indirect sensitivity to NP effects is enhanced on the observables' tails as compared to the bulk [4], where Λ is typically chosen to be 1 TeV.

1. ATLAS differential and inclusive $H \to \gamma\gamma$: EFT interpretation

The differential unfolded measurement of $H \to \gamma\gamma$ production rates [5] is performed as a function of 5 different observables: the di-photon system p_{T}, the number of jets, the di-jet mass and angle distance in the transverse plane ($\Delta\Phi_{jj}$), the leading-jet p_{T}. Uncertainties are dominated by the limited number of available events and results are in agreement with the SM predictions. The $\Delta\Phi_{jj}$ observable proves to be significantly sensitive to CP-odd coefficients. The sizable effect of quadratic terms is from dimension-6 operators is accessed by extracting limits on Wilson coefficients with and without including such terms. The effect of their inclusion proves to be significant, opening to the need to include 8-dimensional operators in the next version of these measurements. Limits on eight different Wilson coefficients are extracted, one at a time with others fixed at 0. No significant deviation from the SM is observed.

2. CMS off-shell Higgs-boson production evidence: BSM scenarios for the on/off-shell interplay

NP may appear in the measurement of the Higgs-boson decay width, where a null width would translate into absence of SM Higgs-boson contributions. On the other hand, a large width would enhance SM production rates at high off-shell Higgs-boson mass values. The off-shell Higgs-boson production is very sensitive to CP-violating couplings, in particular to HVV contributions. The recent results by the CMS Collaboration in the $H \to ZZ^{\star} \to 2\ell 2\nu$ channel [6] provided evidence (3.6σ exclusion of null-width scenario) for the production of off-shell Higgs bosons. The effect of HVV couplings on the Higgs-boson width has been tested by means of a parameterization of anomalous HVV contributions: CP-conserving, CP-violating and the first-order term in the expansion of SM-like tensor structure with dipole form factor in invariant masses of the two Z bosons. In the narrow-width [7] approximation, ratios can be expressed through fractional contributions of the different couplings to the cross-section of a given decay. The underlying assumption is for NP not to contribute to the ggF loop amplitudes. Limits on the three aforementioned HVV couplings are obtained. Results are extracted with fixed and free Higgs-boson width, and in combination with the $ZZ^{*} \to 4\ell$ channel, discussed in the next section.

3. Higgs-boson anomalous couplings by CMS in the $ZZ^* \to 4\ell$ and $\tau\tau$ decay channels

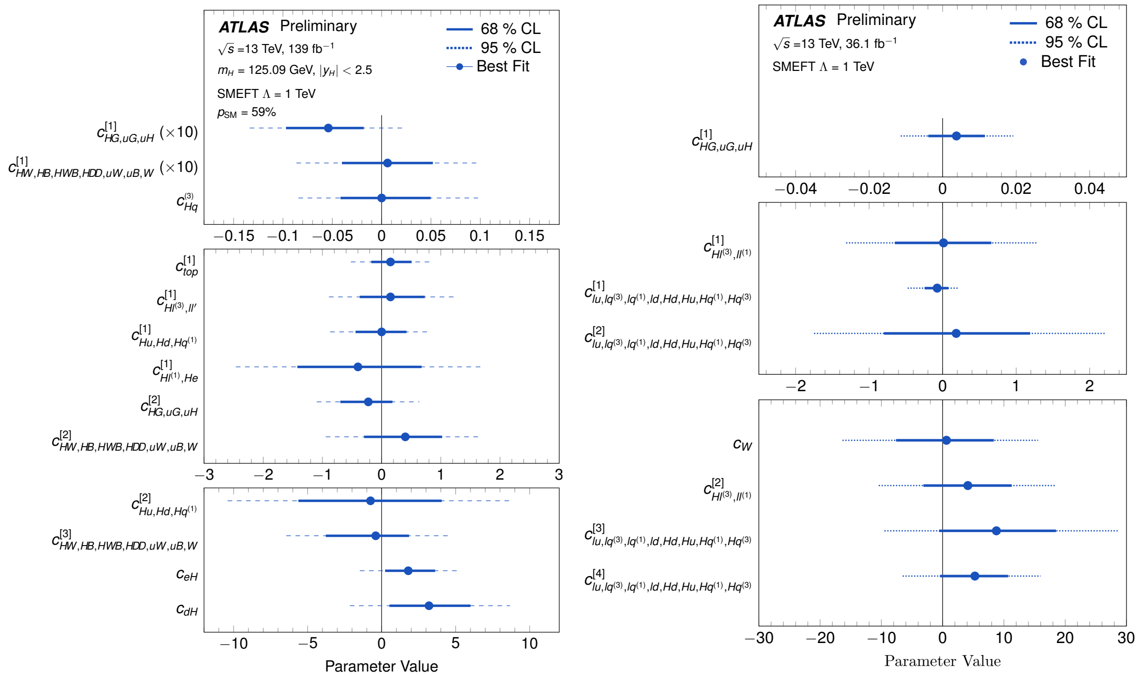
A comprehensive study of CP violation, anomalous couplings and tensor structure in the Higgs-boson interactions has been accomplished exploiting the $H \to ZZ^* \to 4\ell$ channel [8]. Detector-level matrix-element-based observables are defined using kinematic properties of particles in production and decay. The parameterization of production and decay is based on scattering amplitude, and directly matched to SMEFT formulation by imposing the $SU(2) \times U(1)$ symmetry. CP-even/odd Higgs-gluon effective and top-quark Yukawa couplings are constrained by dedicated ggH and ttH categories. The operator basis is chosen to be the couplings of mass eigenstates: SMEFT results are translated to bosonic dimension-6 operators in Warsaw basis. In the extraction of results only one out of three parameters among c_{HW}, c_{HWB} and c_{HB} is independent. Within the context of anomalous couplings, differential cross-sections are parameterised as a function of couplings describing HVV, Hff and Hgg vertices. In all of the cases, production-mode signal strengths are in agreement with SM predictions. A study of anomalous interactions of the Higgs boson with vector bosons is performed in the $H \to \tau\tau$ [9] decay channel, too. Both ggH and $VBF + VH$ production modes are targeted, and the four most sensitive decay channels are exploited (avoiding di-electron and -muon final states dominated by Z-boson production). Anomalous CP-even/odd couplings, whose impact is probed by means of matrix-element variables, are translated into EFT parameters. The combination with 4ℓ and $\gamma\gamma$ provides competitive limits on CP-conserving and CP-violating Higgs-to-gluon effective couplings, where CP-conserving and CP-violating Yukawa couplings are constrained by dedicated ttH channels.

4. Steps towards global EFT efforts

The large space of EFT operators, and sometimes the degeneracy of their effect on the studied processes, requires a growing effort in the direction of combining more and more input analyses from different sectors of the SM. First important steps have been made in the Higgs sector, with the combination of several Higgs-boson production and decay channels [10], and in the combination of Higgs-boson decays to $H \to WW^\star$ with non-resonant WW production [11].

The Higgs combination exploits the simplified template cross-section (STXS) [12] framework: fiducial bins to measure kinematic properties of the Higgs boson production across decay channels. In fact, kinematic regions help isolate NP effects, typically tails of distributions with enhanced sensitivity. This approach does not require detector-level SMEFT simulation, as variations due to the presence of non-null Wilson coefficients can be considered as acceptance corrections. A total of 37 kinematic bins across five production modes, exploiting five major decay channels (bb, $WW^\star$, $\tau\tau$, $ZZ^\star$, $\gamma\gamma$), are defined. All of the measurements are still statistically limited. The SMEFT dependence in the STXS bins is parameterised as polynomials in Wilson coefficients, where only the linear dependence is considered for current results. SMEFTSim [13] (SMEFTatNLO [14]) is exploited for tree-level EFT contributions (loop-induced QCD processes). Many operators lead to similar modifications, so that there is not enough info in measurements to constrain them all and a Principal Component Analysis (PCA) [15] is needed. The Fisher information matrix is used to identify the sensitive directions to define the fit operator basis. The grouping of operators is dictated by the experimental sensitivity: sensitive components are extracted, while the rest of the operator combinations are fixed to their SM values. Limits are obtained by simultaneously measuring 3 Wilson coefficients and 10 their linear combinations. Results are shown in Figure 1a, where the compatibility p-value of observation with SM is 59%. Limits have been improved up to 70% with respect to the combination of only 4ℓ, $\gamma\gamma$ and $VH(bb)$ channels [15].

The combination of $H \to WW^{\star}$ and non-resonant WW measurements [11] constitutes a template analysis to identify and overcome challenges foreseen for future global EFT combinations of measurements. The input analyses are the ATLAS $H \to WW^{\star}$ ggH and VBF and non-resonant WW unfolded differential cross-section measurements performed with 36.1 fb^{-1} of data. The overlap between the two selections has been removed and the correlation of systematic uncertainties carefully studied to build the combined fit model. Alike for the Higgs combination, a PCA approach is adopted to define sensitive directions. Eight mutually orthogonal directions in SMEFT parameter space are probed, as shown in Figure 1b.



(a) **(b)**

Figure 1: (a) Summary of observed Higgs-combination measurements of the parameters within the SMEFT linearised model [10]. (b) Summary of observed $H \to WW^{\star}$ and non-resonant WW measurements in the space of the eigenvectors [11]. The ranges shown correspond to 68% (solid) and 95% (dashed) confidence level intervals.

These works represent a proof of concept towards more global EFT combinations, where the natural and challenging next step will be to perform a combined extraction of EFT parameters on all combined Higgs STXS and combined electro-weak measurements.

References

[1] I. Brivio and M. Trott, Phys. Rept. **793** (2019) 1

[2] R. Contino, M. Ghezzi, C. Grojean, M. Mühlleitner and M. Spira, JHEP **07** (2013) 035

[3] B. Grzadkowski, M. Iskrzynski, M. Misiak and J. Rosiek, JHEP **10** (2010) 085

[4] A. Biekötter, A. Knochel, M. Krämer, D. Liu and F. Riva, Phys. Rev. D **91**, 055029 (2015)

[5] ATLAS Collaboration, JHEP **08** (2022) 027

[6] CMS Collaboration, CMS-HIG-21-013

[7] M. Grazzini, JHEP **02** (2008) 043

[8] CMS Collaboration, Phys. Rev. D **104** (2021) 052004

[9] CMS Collaboration, CMS-PAS-HIG-20-007

[10] ATLAS Collaboration, ATLAS-CONF-2021-053

[11] ATLAS Collaboration, ATL-PHYS-PUB-2021-010

[12] LHC Higgs Cross Section Working Group, CERN-2017-002-M

[13] I. Brivio, JHEP **04** (2021) 073

[14] C. Degrande et al., Phys.Rev.D **103** (2021) 9, 096024

[15] ATLAS Collaboration, ATLAS-CONF-2020-053