PROCEEDINGS OF SCIENCE

EFT interpretation of high-P_T results

Ashish Sharma[a,*]

[a] *Indian Institute of Technology, Madras, India*

E-mail: ashish.sharma@cern.ch

High P_T results can be interpreted using the EFT approach, and any deviation from SM predictions would be a clear sign of new physics. Since EFT is model-independent so this is suitable to search BSM physics. High P_T results are measured particularly in the Higgs sector during STXS measurement and interpreted in terms of EFT Wilson's coefficients. This draft covers combined measurements of Higgs boson productions and decay with the ATLAS Run 2 data and Combined measurements of Higgs couplings with the CMS Run 2 data. Both CMS and ATLAS results are interpreted using the EFT approach successfully.

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*Speaker

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1. Introduction

In this note, High P_T is referred to as P_T of any physics process which is above flavour physics. There are many high P_T physics processes, e.g., Higgs, top, W/Z productions, which set constraints on EFT parameters.

As we know that following the discovery of the Higgs boson by the ATLAS [1] and CMS [2] experiments, its properties have been probed using proton–proton collision data produced by the Large Hadron Collider (LHC) at CERN. Higgs boson production and decay rates were measured using the Run 1 data set collected in the years 2011 and 2012, through the combination of ATLAS and CMS measurements.

In search for physics beyond the SM (BSM), potential deviations of combined Higgs boson production and decay rate measurements from SM predictions are interpreted within the context of a SM Effective Field Theory (SMEFT) framework describing the SM as a low-energy manifestation of a more complete BSM theory by means of additional higher-dimensional operators which modify the tensor structure of Higgs boson couplings.

Different results from CMS and ATLAS of Higgs are demonstrated using EFT framework. Differential cross-section of various Higgs productions can be interpreted in the EFT framework with the CMS and ATLAS experiments.

2. Combined measurements of Higgs boson production and decay with the ATLAS experiment

Measurements of Higgs boson production cross sections and branching fractions is based on the combination of analyses of the Higgs boson decay modes of H$\rightarrow \gamma\gamma, ZZ^*, WW^*, \tau\tau, b\bar{b}, \mu\mu, Z\gamma$ and searches for decays into invisible final states using up to 139 fb^{-1} of proton–proton collision data collected at $\sqrt{s}$ = 13 TeV with the ATLAS detector. Combined cross section measurements are presented for the gluon–gluon fusion (ggF) and vector-boson fusion (VBF) processes, and for associated production with vector bosons (VH) or top-quarks (tH, $t\bar{t}H$).

Simplified Template cross-section (STXS) Simplified template cross-sections are defined through a partition of the phase space of the SM Higgs production processes into a set of non-overlapping regions. These regions are defined in terms of the kinematics of the Higgs boson. All regions are defined for a Higgs boson rapidity y_H satisfying $|y_H| \leq 2.5$, corresponding approximately to the region of experimental sensitivity. The measurements use the regions of phase space specified by the Stage 1.2 splitting of the STXS framework. The measured event yields are described as

$$n_k^{signal} = \mathcal{L}_k \sum_i \sum_f (\sigma \times B)_{if} (A \times \epsilon)_{if}^k \tag{1}$$

Where i is the production and f is the decay modes. $\mathcal{L}_k$ is the integrated luminosity of the data set used in category k and $(A \times \epsilon)_{if}^k$ is the acceptance times efficiency factor in category k for production mode i and final state f. The cross section times branching fraction $(\sigma \times B)_{if}$ for each relevant pair (i, f) are the parameters of interest of the model. The fit parameters chosen for the combined STXS measurements are the cross sections for Higgs boson production in STXS region times the branching fraction for the $H \rightarrow ZZ^*$ decay, $(\sigma \times B)_{i,ZZ}$, and the ratios of branching fractions B_f/B_{ZZ} for the other final states f.

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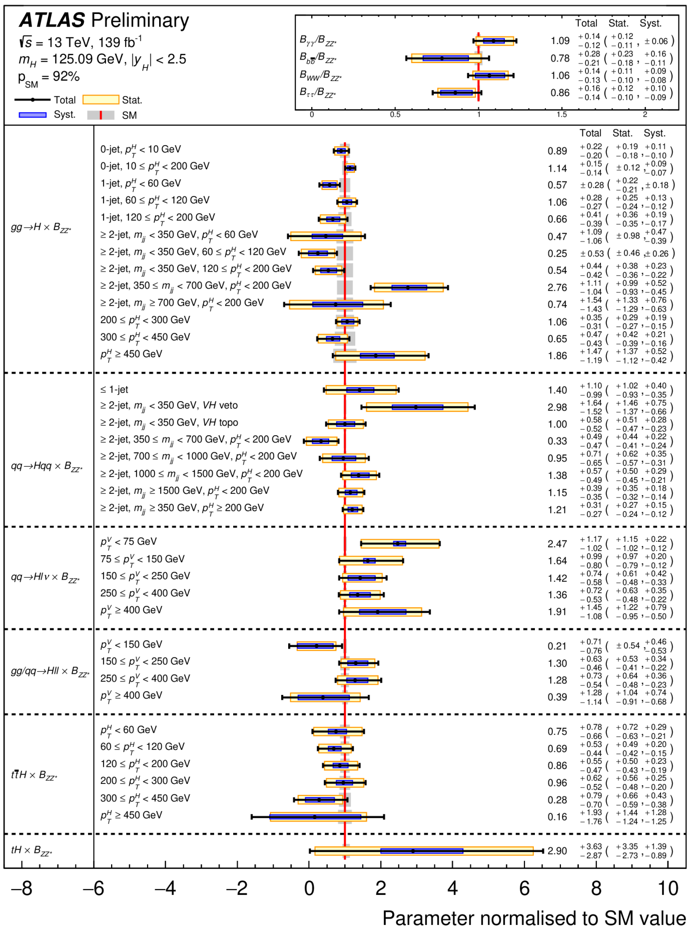

Figure 1: Best-fit values and uncertainties for the cross sections in each measurement region and of the ratios of branching fractions B_f/B_{ZZ} , normalised to the SM predictions for the various parameters.

2.1 Interpretation within the SM Effective Field Theory framework

In the SMEFT, the SM Lagrangian is extended by higher-dimension operators which have the same field content and the same, linearly realised, $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ local gauge symmetry as the SM. The general effective Lagrangian takes the form

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \mathcal{L}^{(5)} + \mathcal{L}^{(6)} + \mathcal{L}^{(7)} + \ldots.. \text{ where} \mathcal{L}^{D} = \sum_{i}^{n_D} \frac{C_i^D}{\Lambda^{D-4}} O_i^D \tag{2}$$

where Λ is the energy scale at which new physics is assumed to appear, $O_i^{(D)}$ are the operators of the dimension-D invariant under the SM gauge group and $C_i^{(D)}$ are the corresponding dimensionless coupling constants, the so-called Wilson coefficients. Operators with $d = 5$ and $d = 7$ violate lepton and/or baryon number conservation and are not relevant for Higgs physics.

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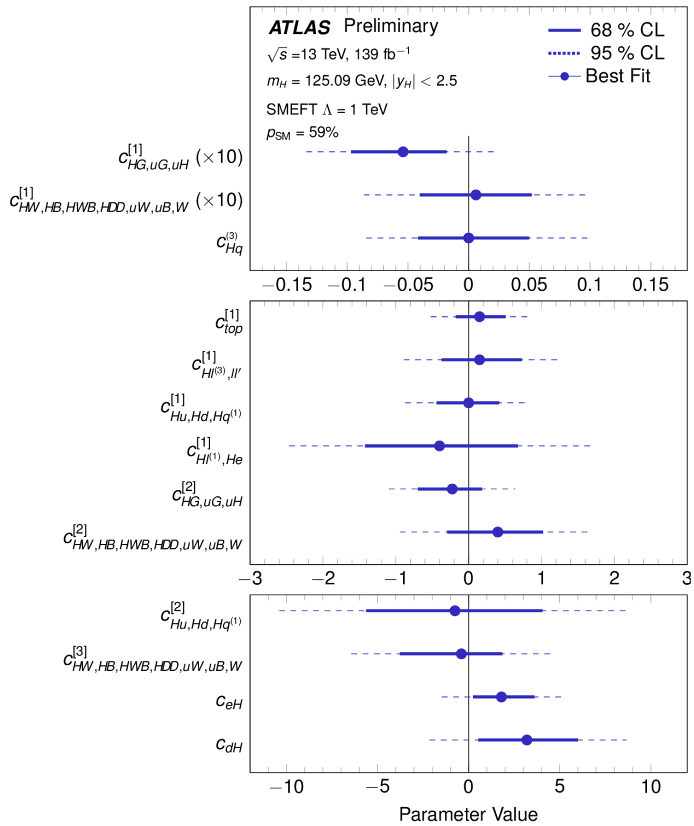

Figure 2: Summary of observed measurements of the parameters $c_i^{'}$ within the SMEFT linearised model. The ranges shown correspond to 68% (solid) and 95% (dashed) confidence level intervals.

3. Combined measurements of the Higgs boson couplings at 13 TeV in the CMS experiment

This analysis describes combined measurements of the Higgs boson production rates, decay rates, coupling modifiers, an indirect constraint of the Higgs boson self-coupling, and a fit to the effective field theory (EFT) parameters. Following analyses listed in table 1 are included for the combined measurement of Higgs boson couplings. Couplings of effective field theory are described in this note.

3.0.1 Measurements of the effective field theory couplings

In this section, an interpretation of Higgs boson production and decay rates in terms of constraints on EFT couplings in the Higgs Effective Lagrangian (HEL) model is presented. he HEL implementation extends the SM Lagrangian by introducing 39 flavor independent dimension-6 operators. n order to constrain the EFT couplings, a parametrization of the EFT variations in the stage 0, stage 1.0, and stage 1.1 bins of the STXS has been derived and HEL parameters are represented as c_j. A simultaneous maximum likelihood fit is performed, considering variations in the following HEL parameters: c_G, c_A, c_u, c_d, c_l, c_{HW}, c_{WW} and c_B; the remaining c_j are fixed to zero. The parameters c_{WW} and c_B are fit together in the combination $c_{WW} - c_B$. Two

CADI	Channel
HIG-19-001	$H \to ZZ$ (STXS 1.1)
HIG-18-029	$H \to \gamma\gamma$ (STXS 1.0)
HIG-16-042	$H \to WW$
HIG-18-032	$H \to \tau\tau$
HIG-17-019	$H \to \mu\mu$
HIG-17-010	$H \to bb$ boosted
HIG-18-018	$ttH \to \gamma\gamma$
HIG-18-019	$ttH \to lep$
HIG-17-018	$ttH \to lep$
HIG-18-030	$ttH \to bb$
HIG-18-016	$VHH \to bb$ (2017 dataset)
HIG-16-044	$VHH \to bb$ (2016 dataset)
HIG-18-007	$VHH \to \tau\tau$

Table 1: Analyses included in the combined measurement

likelihood scans are performed for each of the considered POIs in which the other parameters are either profiled during the minimization or are fixed to the SM.

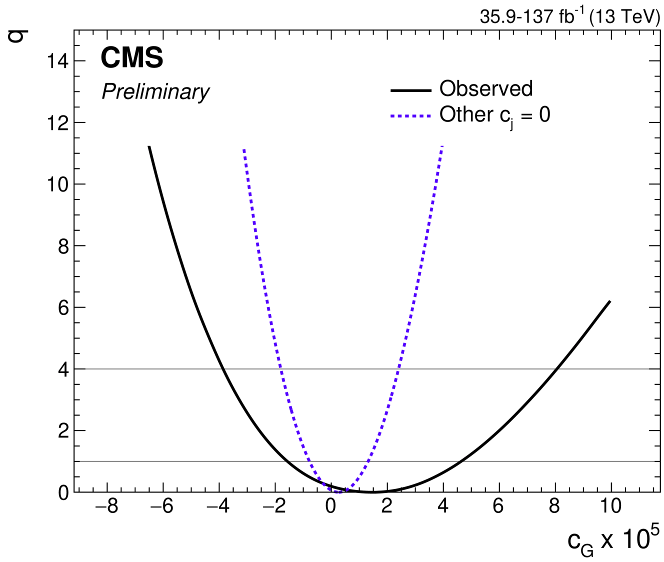

Figure 3: Profiled likelihood scans for c_G. The solid black line correspond to the fit in which all parameters are allowed to vary simultaneously and the dashed blue line to the fits where only one parameter is varied at a time

These results represent the current most powerful constraints from Higgs boson measurements on the majority of HEL parameters considered. The improvements with respect to the constraints in a previous result by the ATLAS collaboration, are a consequence of the larger integrated luminosity, the introduction of analyses specifically targeting ttH production, and the inclusion of additional decay channels, namely H $\to$ WW, H $\to$ bb and H $\to \tau\tau$.

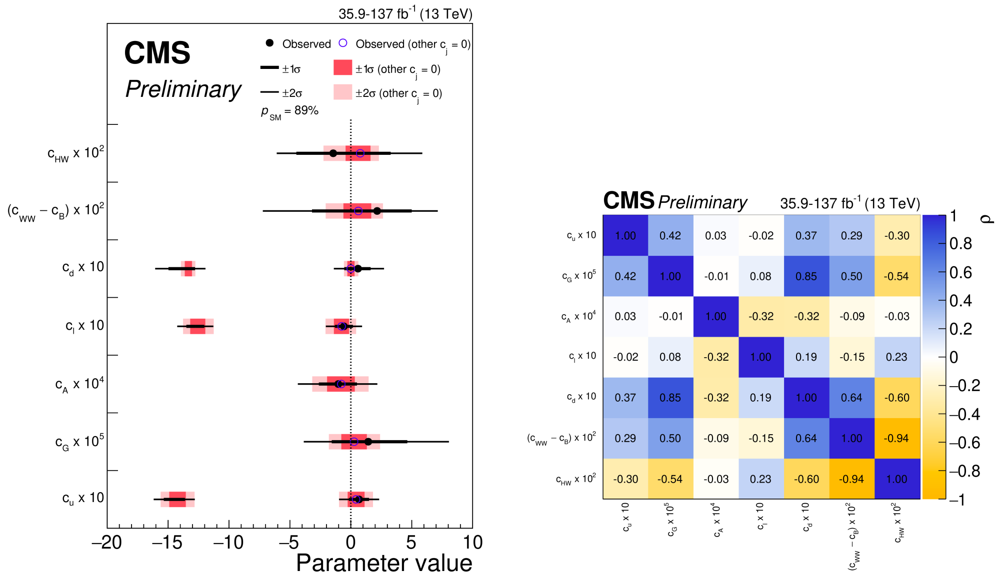

Figure 4: Summary plot for HEL parameter scans. Best fit values when profiling (fixing) other parameters are shown by solid black (hollow blue) points. The ± 1 and ± 2 confidence intervals are represented by thick and thin black lines for profiled scenario, and the green and yellow bands for the fixed scenario.

4. Conclusion

This note presents the interpretation of high P_T results from CMS and ATLAS using Effective Field Theory (EFT) framework. Due to limitations, only Higgs results at high P_T are presented.

Combined measurements of Higgs boson productions and decay with the ATLAS detector are presented and interpreted these results using EFT approach. Wilson's coefficients in Warsaw basis are measured and figure 2 represents their observed values.

Combined measurements of the Higgs boson couplings at 13 TeV also presented from CMS experiments and interpreted these results in Higgs Effective Lagrangian (HEL) model. All HEL model parameters c_i are scan twice as shown in figure 3.

Results from both ATLAS 2 and CMS 4 experiments are consistent with the Standard Model (SM) theoretical predictions and no Beyond Standard Model (BSM) signature has been observed.

References

[1] Aad, Georges and others, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, CERN-PH-EP-2012-218.

[2] Chatrchyan, Serguei and others, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, CERN-PH-TH-2012-284, LHCHXSWG-2012-00.

[3] ATLAS collaboration, *Combined measurements of Higgs boson production and decay with the ATLAS experiment*, ATLAS-CONF-2021-053

[4] CMS Collaboration, *Combined measurements of the Higgs boson couplings at 13 TeV in the CMS experiment*, CMS PAS HIG-19-005