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Combination of Higgs measurements from ATLAS and CMS: couplings and κ-framework

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Results from the most recent statistical combinations of Higgs boson measurements across decay channels by the ATLAS and CMS experiments are presented. Both analyses use LHC proton-proton collision data recorded at $\sqrt{s}$ = 13 TeV with the respective detectors, where the ATLAS (CMS) analysis combines measurements with integrated luminosities ranging from 24.5-79.8 (35.9-137) fb^{-1} depending on the decay channel. Measurements of cross sections, signal strengths and coupling modifiers are reported, alongside an interpretation using effective field theory.

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1. Introduction

Since the discovery of the Higgs boson in 2012 [1–3], direct searches for physics beyond-the-standard-model (SM) have been fruitless. Attention has therefore shifted towards precision measurements as an indirect tool to search for deviations from the SM. An extensive programme has been developed at the LHC to measure and characterise the Higgs boson, where the ultimate precision is achieved via the statistical combination of measurements across decay channels. This report details the most recent[1] combinations of Higgs boson measurements [4, 5] performed by the ATLAS and CMS experiments [6, 7], with input analyses using 24.5-79.8 and 35.9-137 fb^{-1} of proton-proton collision data at $\sqrt{s}$ = 13 TeV respectively.

2. Combination inputs

Both the ATLAS and CMS combinations include measurements in the H $\rightarrow \gamma\gamma$, ZZ^*, WW^*, $\tau\tau$, bb and $\mu\mu$ decay channels. Each input analysis targets at least one of the following production modes: gluon fusion (ggH), vector boson fusion (VBF), associated production with a vector boson (VH, V = W or Z) and associated production with a top quark-antiquark pair (ttH). Subdominant production modes including production in association with a single top quark (tH) and ZH production initiated by gluons (ggZH) are included in the analyses that have some sensitivity to them. Moreover, the ATLAS combination includes searches for decays into invisible final states and measurements of off-shell Higgs boson production in order to constrain beyond-the-SM effects in Higgs boson decay. All references to the individual input analyses can be found in Refs [4, 5].

The statistical methodology of the combinations follow the same procedure, as described in Ref. [9]. In all measurements, the Higgs boson mass is taken to be $m_H = 125.09 \pm 0.11(\text{syst}) \pm 0.21(\text{stat})$ GeV, determined from the ATLAS and CMS Run 1 combined mass measurement [10].

3. Results

Signal strength modifiers, μ, are defined as the ratio of the measured Higgs boson yield to the SM expectation. A common signal strength modifier, which scales all signal processes equally, is measured in the CMS combination to be $\mu = 1.02^{+0.07}_{-0.06} = 1.02 \pm 0.04(\text{th}) \pm 0.04(\text{exp}) \pm 0.04(\text{stat})$, where the total uncertainty has been decomposed into theoretical systematic, experimental systematic and statistical components. Each component is measured to have a similar magnitude of approximately 4%. Similarly, the ATLAS measurement of a common signal strength modifier is $\mu = 1.11^{+0.09}_{-0.08} = 1.11^{+0.05}_{-0.04}(\text{sig th}) \pm 0.03(\text{bkg th})^{+0.05}_{-0.04}(\text{exp}) \pm 0.05(\text{stat})$. Here, the theoretical systematic is further decomposed into separate contributions from signal and background modelling.

Independent signal strengths, μ_i and μ^f are measured for each production mode ($i \rightarrow H$) and decay channel ($H \rightarrow f$) respectively. Figure 1 shows the results for μ_i and μ^f from the CMS combination. All of the major production modes, namely ggH, VBF, VH and ttH, are now measured with greater than 5σ significance. The splitting of the 1σ confidence interval into systematic and statistical components highlights that for many of the measured parameters, the systematic component is now comparable, if not larger than, the statistical.

[1]At the time of the LHCP 2020 conference. ATLAS have since superseded this with a new combination, first presented at ICHEP 2020, which includes updated measurements in a number of decay channels [8].

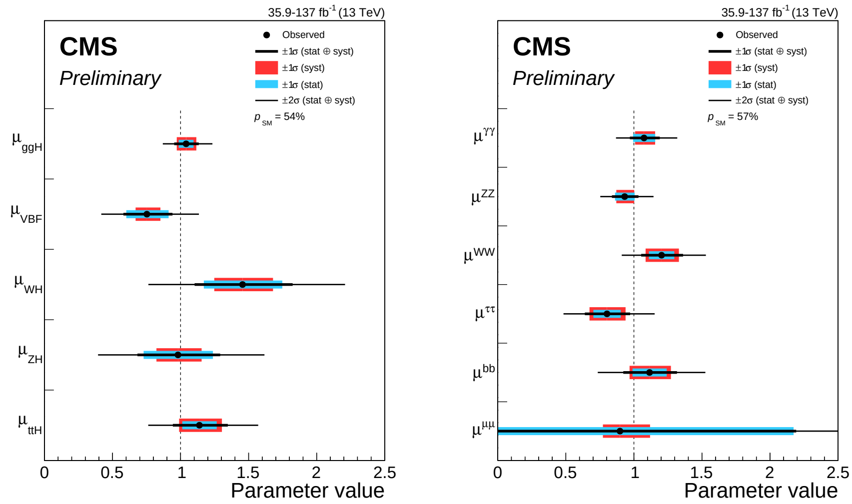

Figure 1: Signal strength modifiers measured in the CMS combination for production, μ_i (left) and decay, μ^f (right). The thick (thin) black lines correspond to the 1σ (2σ) confidence intervals. The 1σ intervals are decomposed into the systematic (red) and statistical (blue) components. Taken from Ref. [5].

Simplified template cross sections (STXS) provide a framework on which to perform increasingly granular Higgs boson measurements [11]. Each of the major Higgs boson production modes, including ggZH, are sub-divided into regions of phase space, or so-called “bins", using particle-level quantities such as the transverse momentum of the Higgs boson, p_T^H, and the jet multiplicity. ATLAS combines measurements at stage 1.0 of the STXS framework, as shown in Figure 2. With the current data, there is insufficient scope to measure all bins simultaneously, hence bins with low sensitivity or high correlations are merged, resulting in a 19 parameter fit. At this level of splitting the statistical uncertainties dominate. Overall, the results show good agreement with SM predictions, such that the probability of compatibility with the SM gives a p-value of $p_{\mathrm{SM}} = 89\%$.

The κ-framework introduces a set of multiplicative coupling modifiers to test for deviations in the couplings of the Higgs boson to other particles [12]. In the SM, all κ's are positive and equal to unity. The combinations provide measurements of the κ-framework for a number of different scenarios with varying assumptions. Figure 3 (left) shows the results of the resolved κ model from the ATLAS combination, in which loop processes such as ggH and $\mathrm{H} \to \gamma\gamma$ are resolved into their SM structures. This plot shows the reduced coupling strength modifiers as a function of the respective particle mass, demonstrating the alignment with the SM prediction in blue.

Finally, effective field theories (EFT) can be used to interpret deviations from SM predictions. CMS presents an interpretation of Higgs boson production and decay rates in terms of constraints on EFT couplings in the Higgs Effective Lagrangian [13, 14]. For this result, cross sections in the STXS framework and decay rates are parametrised in terms of Wilson coefficients, c_j, such that beyond-the-SM physics would manifest itself as deviations from zero in these coefficients. Figure 3 (right) shows the results of two types of fit using the EFT parametrisation: coefficients are measured independently assuming all other $c_j = 0$ (red bands and blue circles) and coefficients are measured simultaneously profiling the other c_j in the minimisation (black bands and black circles). All results are consistent with SM predictions, with the profiled fit giving a p-value of $p_{\mathrm{SM}} = 89\%$.

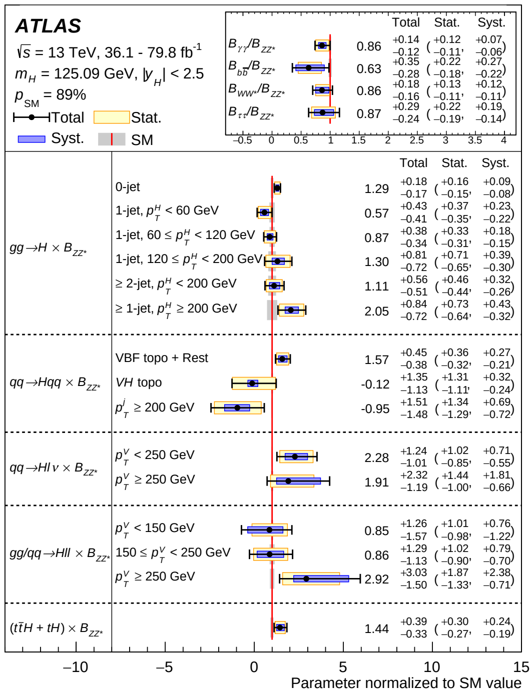

Figure 2: The best-fit values and 1σ confidence intervals from the ATLAS combination for cross sections in stage 1.0 of the STXS framework, as well as ratios of branching fractions, B^f/B^{ZZ}, relative to the SM predictions for the measured parameters. Taken from Ref. [4].

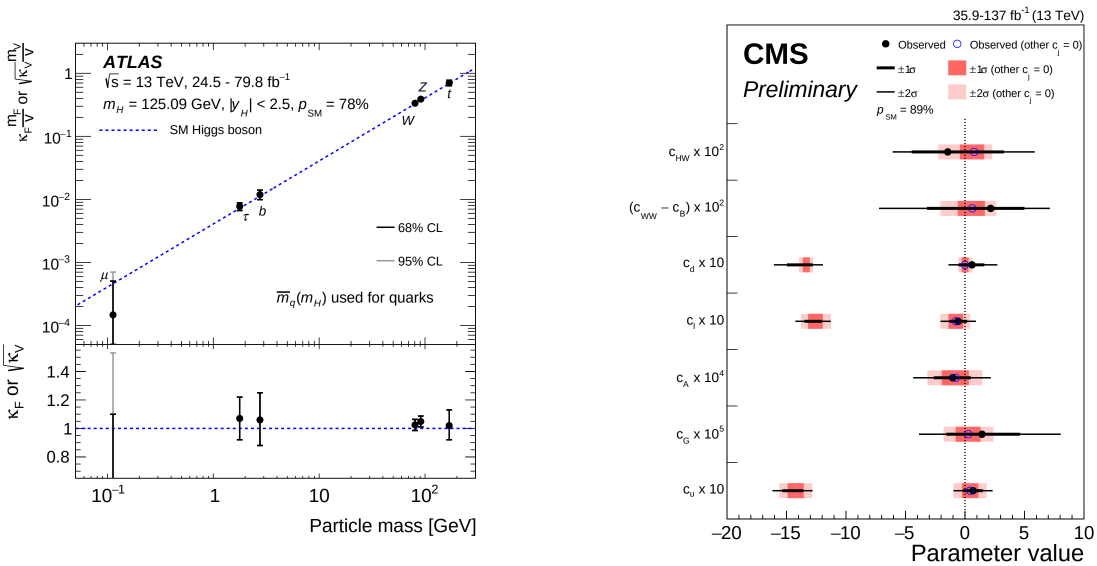

Figure 3: (Left) Reduced coupling modifiers ($\kappa_f m_f/v$ for fermions and $\sqrt{\kappa_V} m_V/v$ for gauge bosons, where $v = 246$ GeV) as a function of the particle mass, from the ATLAS combination [4]. The bottom panel highlights the best-fit values and 1σ confidence intervals for the resolved scenario κ parameters. (Right) Best-fit values and confidence intervals for parameters of the Higgs Effective Lagrangian, from the CMS combination [5].

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