PROCEEDINGS OF SCIENCE

Measurements of Higgs couplings to fermions and bosons at the LHC

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With the full Run 2 pp collision dataset collected at 13 TeV, very detailed measurements of Higgs boson properties can be performed using its decays into bosons and fermions. At the same time, the search for Higgs-boson pair production can profit from the large integrated luminosity to provide more and more stringent limits. This document presents measurements of Higgs boson properties using decays into bosons and fermions and their combination, including production mode cross sections and simplified template cross sections, as well as their interpretations. Searches for non-resonant Higgs-boson pair production, as well as their combination, are also discussed.

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1. Introduction

The Standard Model (SM) predicts the Higgs boson interactions to be described by:

$$\mathcal{L} = -\frac{m_f}{v}\bar{f}f\,H + \frac{2m_W^2}{v}W_\mu W^\mu H + \frac{m_Z^2}{v}Z_\mu Z^\mu H + \frac{m_V^2}{v^2}V_\mu V^\mu H^2 + \frac{m_H^2}{2v}H^3 + \frac{m_H^2}{8v^2}H^4 \,.$$

Here, f represents the SM fermions, v the vacuum expectation value of the Higgs field, and $V \in \{W, Z\}$. The Lagrangian $\mathcal{L}$ implies that Higgs bosons couple to all massive SM particles, and more strongly to particles with higher masses. Moreover, all couplings in the Lagrangian are purely CP-even. This report summarises the measurements conducted by the ATLAS [1] and CMS [2] collaborations to test these expectations using data collected at the LHC from 2015 to 2018.

2. Cross Section Measurements

A recent coupling measurement in an already observed decay channel is the ATLAS measurement in the $H \to \tau\tau$ final state [3]. To be able to measure the Higgs-boson production cross sections for the individual production mechanisms, the collected data are split into multiple signal regions (SRs), each with different relative contributions per production process. In each SR, the invariant di-τ mass distribution is used as input to a template likelihood fit. The resulting cross section values are shown in Figure 1 (left).

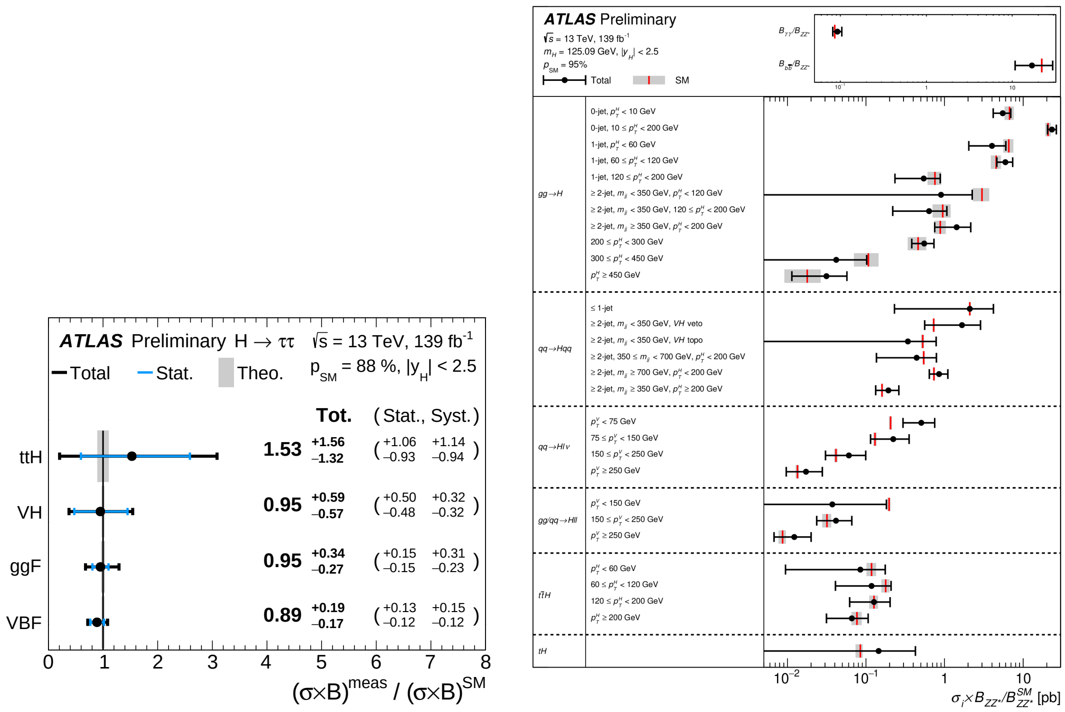

Figure 1: Left: Process-dependent Higgs-boson production cross sections obtained in the di-τ final state [3]. Right: Combined STXS measurement in the $H \to \gamma\gamma$, $H \to ZZ$ and $H \to bb$ final states [4].

To include kinematic information while minimising the impact of theoretical uncertainties, the simplified template cross section (STXS) framework was introduced. For this, each production process is split based on kinematic properties, such as the transverse momentum of the Higgs boson. A recent combined STXS measurement in ATLAS [4] is summarised in Figure 1 (right).

3. Searches for Unobserved SM Couplings

3.1 $H\mu\mu$ Yukawa coupling

Since the coupling of the Higgs boson to lighter particles is weaker, the $H \to \mu\mu$ branching ratio is relatively low, and the process has not yet been observed. Both the ATLAS and CMS experiments recently published analyses targeting $H \to \mu\mu$ decays [5, 6]. While ATLAS assumed only a Higgs-boson mass m_H of 125.09 GeV, CMS conducted a scan in m_H. The observed local p-value in dependence of m_H is shown in Figure 2 (left).

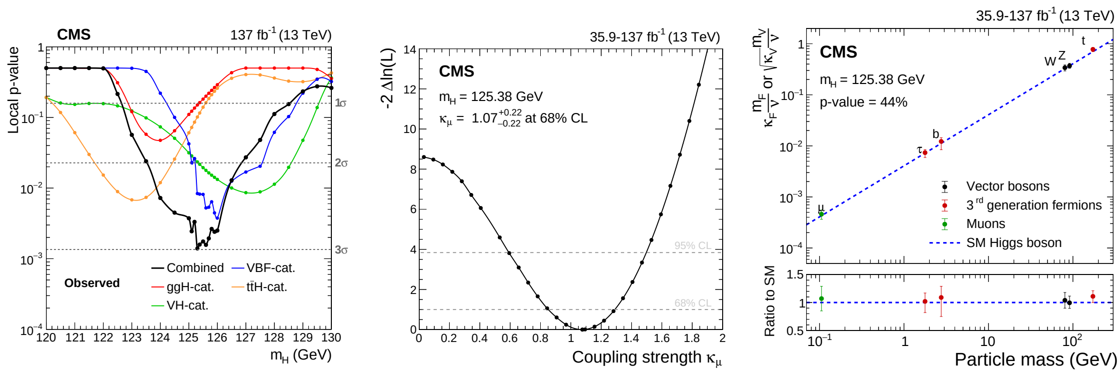

Figure 2: Left: Local p-value dependence on m_H in the $H \to \mu\mu$ search. Centre: Measurement of the $H\mu\mu$ coupling modifier κ_μ. Right: Higgs boson coupling strengths in dependence of the particle mass [5].

ATLAS observed (expected) a signal significance of 2.0 (1.7)σ. CMS obtained 3.0 (2.5)σ for $m_H = 125.38$ GeV, reporting the first evidence of the $H\mu\mu$ coupling. CMS also measured the $H\mu\mu$ coupling strength modifier $\kappa_\mu = \Gamma_\mu^{\mathrm{Obs}}/\Gamma_\mu^{\mathrm{SM}}$ with the decay width Γ_μ of the Higgs boson into muons, as shown in Figure 2 (centre). Figure 2 (right) shows a comparison of coupling strengths over three orders of magnitude, confirming the SM predictions for all measured coupling strengths.

3.2 Higgs Boson Pair Production

The not yet observed Higgs-boson pair (HH) production processes are sensitive to the modifiers of the trilinear self-coupling κ_λ and the quartic vector-boson coupling κ_{2V}. Gluon-gluon fusion (ggF) and vector-boson fusion (VBF) Feynman diagrams including these couplings are shown in Figure 3 (left). Studies on these couplings and the total cross section of HH production have recently been conducted in the $bb\gamma\gamma$ final state. The observed (expected) cross section limits at 95% confidence level (C.L.) are 4.1 (5.5) times the cross section predicted by the SM by ATLAS [7] and 7.7 (5.2) times by CMS [9]. Constraints have also been placed on κ_λ, as shown in Figure 3 (centre). ATLAS has constrained the HH production cross section to 4.7 (3.9) times the cross section

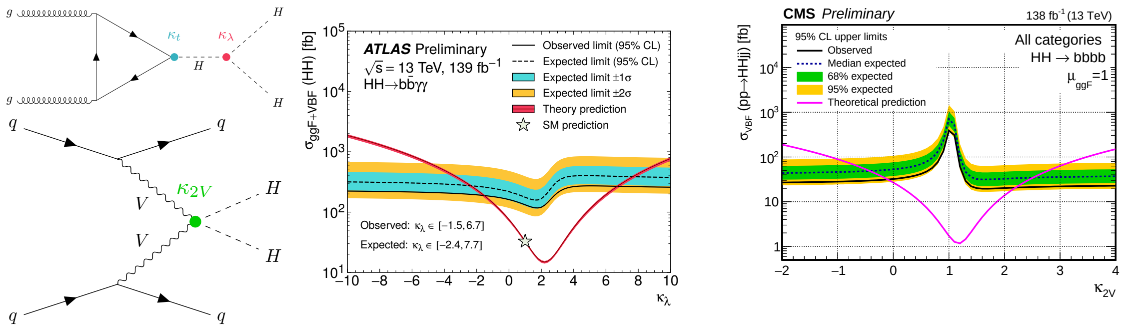

Figure 3: Left: Di-Higgs production Feynman diagrams showing the dependence on κ_λ and κ_{2V}. Centre: VBF+ggF cross section limit depending on κ_λ [7]. Right: VBF cross section limit depending on κ_{2V} [8].

predicted by the SM using events in the $bb\tau\tau$ final state [10]. CMS has constrained it to 3.6 (7.3) times using the $4b$ final state [8] and also placed constraints on κ_{2V}, as shown in Figure 3 (right).

4. Searches for Non-SM Couplings

The properties of Higgs boson Yukawa couplings to a fermion f can be described by

$$\mathcal{L}_{\text{Yukawa}} = -\frac{m_f}{v}\left(\bar{\psi}_f\,\kappa_f\,\left[\cos(\alpha) + \mathrm{i}\sin(\alpha)\gamma^5\right]\psi_f\right)H\,,$$

with the CP-mixing angle α. Using ttH events and the $H \to \gamma\gamma$ decay, the CP-odd and CP-even contributions to the top-Yukawa coupling were measured [11], as shown in Figure 4 (left).

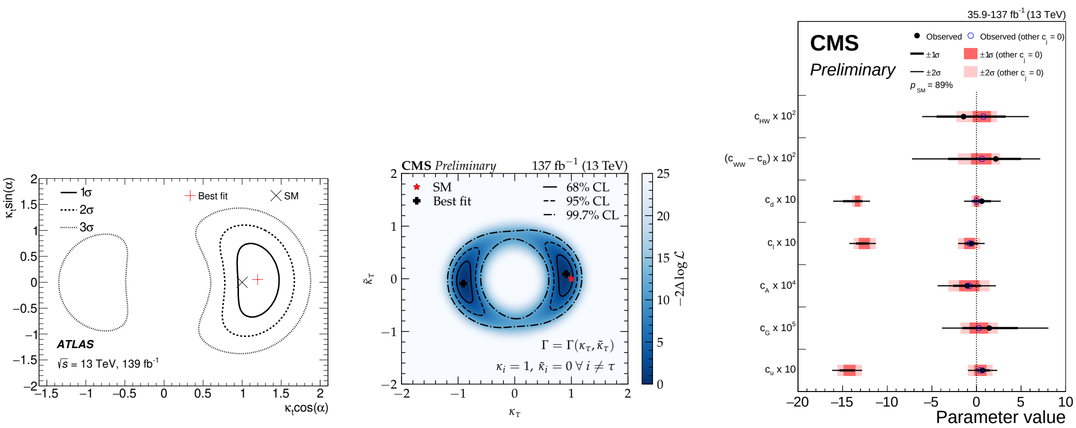

Figure 4: Left: Measurement of CP-odd and CP-even contribution to the top-Yukawa coupling [11]. Centre: Measurement of CP-odd ($\tilde{\kappa}_\tau$) and CP-even (κ_τ) contribution to the τ-Yukawa coupling [12]. Right: Measurement of Wilson coefficients of CP-even EFT operators [13].

Figure 4 (centre) shows a similar measurement of the CP properties of the $H\tau\tau$ coupling, measured in the di-τ final state [12]. Both measurements support the SM prediction of purely CP-even couplings. To test further couplings not predicted by the SM, effective field theories (EFTs) can be employed. In EFTs, dimensionless Wilson coefficients c_i quantify the strength of additional couplings i. A combined measurement [13] is summarised in Figure 4 (right), showing agreement of all investigated c_i with zero. Hence, no sign of additional couplings was found.

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