The Higgs Boson Properties Measurements by Combining Different Production and Decay Channels

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Introduction

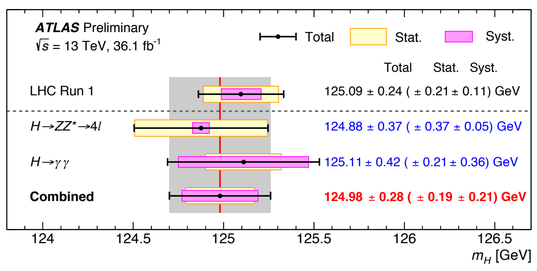
- The combination of measurements of Higgs boson production in the $H \to \gamma\gamma$ and $H \to ZZ^* \to 4l$ decay channels are presented
- Using proton–proton collision data corresponding to an integrated luminosity of 36.1 fb^{-1} produced by the LHC at $\sqrt{s} = 13$ TeV
- All measurements are performed assuming a Higgs boson mass of $125.09 \pm 0.21(stat.) \pm 0.11(syst.)$ GeV

Individual channel measurements

- $H \to \gamma\gamma$
- The signal is extracted using an unbinned likelihood fit to the diphoton invariant mass distribution
- $H \to ZZ^* \to 4l$
- Reconstructs the intermediate Z bosons using their decays to electrons and muons
- Requires the four-lepton invariant mass to be between 118 and 129 GeV
- In the categories where a BDT is employed, the signal is extracted through a binned fit to the BDT discriminant
- In other categories the signal estimation is based on event counting

Combined mass measurement

- A measurement of the mass of the Higgs boson is improved with respect to the previous one obtained with ATLAS Run 1 data
- Derived from a combined fit to the invariant mass spectra of the decay channels



- This result is in excellent agreement with and has similar uncertainty to the LHC Run 1 average

Total cross section

- Based on the inclusive signal yield in each decay channel independent of production mode
- Each channel yield is measured by fitting the inclusive mass distribution

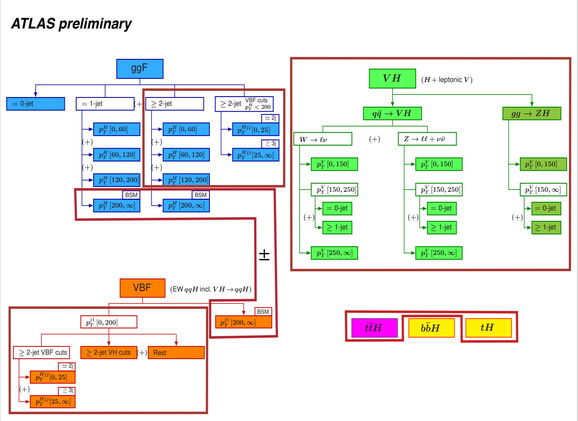
Decay channel	Total cross section ($pp \to H + X$)		
	$\sqrt{s}$ =7 TeV	$\sqrt{s}$ =8 TeV	$\sqrt{s}$ =13 TeV
$H \to \gamma\gamma$	35^{+13}_{-12} pb	$30.5^{+7.5}_{-7.4}$ pb	$47.9^{+9.1}_{-8.6}$ pb
$H \to ZZ^* \to 4l$	33^{+21}_{-16} pb	37^{+9}_{-8} pb	$68.0^{+11.4}_{-10.4}$ pb
Combination	34 ± 10 (stat.) $^{+4}_{-2}$ (syst.) pb	$33.3^{+5.5}_{-5.3}$ (stat.) $^{+1.7}_{-1.3}$ (syst.) pb	$57.0^{+6.0}_{-5.9}$ (stat.) $^{+4.0}_{-3.3}$ (syst.) pb
SM prediction [8]	19.2 ± 0.9 pb	24.5 ± 1.1 pb	$55.6^{+2.4}_{-3.4}$ pb

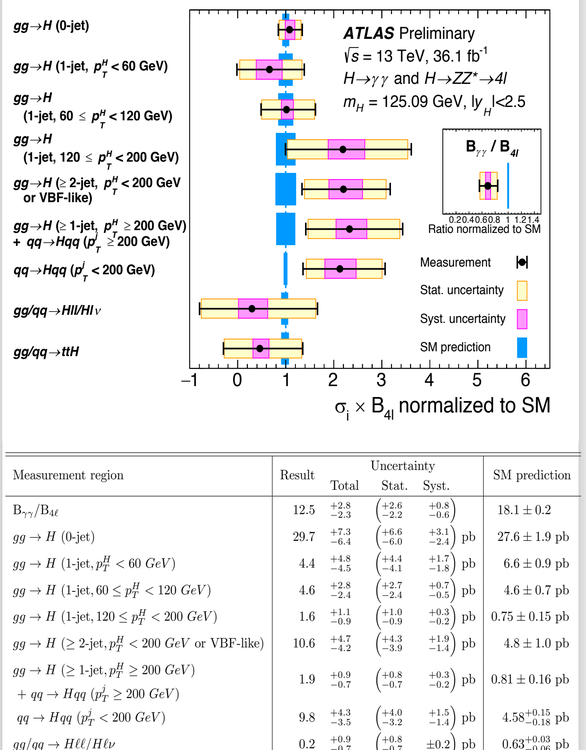
Global signal strength

- The event categorization reduces the statistical uncertainty relative to the total cross section measurement
- $\mu = \frac{\sigma \times B}{(\sigma \times B)_{SM}}$
- $\mu = 1.09 \pm 0.12 = 1.09 \pm 0.09(stat.)^{+0.06}_{-0.05}(exp.)^{+0.06}_{-0.05}(th.)$

Simplified template cross sections

- $y_j = \sum_i A_{ji} \cdot r_i \cdot (\sigma_i \cdot B_{4l})_{SM} \cdot r_f \cdot \left(\frac{B_f}{B_{4l}}\right)_{SM} \cdot \mathcal{L}$
- The framework reduces the reliance on the SM for cross-section measurements
- Higgs-boson rapidity y_H satisfying $|y_H| < 2.5$
- The merged STXS stage-1 regions

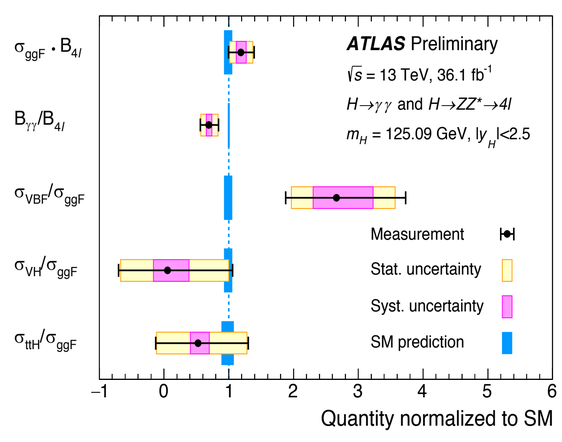




Measurement region	Result	Uncertainty Total	Stat.	Syst.	SM prediction
$B_{\gamma\gamma}/B_{4\ell}$	12.5	$^{+2.8}_{-2.3}$	$^{+2.6}_{-2.2}$	$^{+0.8}_{-0.6}$	18.1 ± 0.2
$gg \to H$ (0-jet)	29.7	$^{+7.3}_{-6.4}$	$^{+6.6}_{-6.0}$	$^{+3.1}_{-2.4}$ pb	27.6 ± 1.9 pb
$gg \to H$ (1-jet, $p_T^H < 60$ GeV)	4.4	$^{+4.8}_{-4.5}$	$^{+4.4}_{-4.1}$	$^{+1.7}_{-1.8}$ pb	6.6 ± 0.9 pb
$gg \to H$ (1-jet, $60 \le p_T^H < 120$ GeV)	4.6	$^{+2.8}_{-2.4}$	$^{+2.7}_{-2.4}$	$^{+0.7}_{-0.5}$ pb	4.6 ± 0.7 pb
$gg \to H$ (1-jet, $120 \le p_T^H < 200$ GeV)	1.6	$^{+1.1}_{-0.9}$	$^{+1.0}_{-0.9}$	$^{+0.3}_{-0.2}$ pb	0.75 ± 0.15 pb
$gg \to H$ ($\ge$ 2-jet, $p_T^H < 200$ GeV or VBF-like)	10.6	$^{+4.7}_{-4.2}$	$^{+4.3}_{-3.9}$	$^{+1.9}_{-1.4}$ pb	4.8 ± 1.0 pb
$gg \to H$ ($\ge$ 1-jet, $p_T^H \ge 200$ GeV) + $qq \to Hqq$ ($p_T^j \ge 200$ GeV)	1.9	$^{+0.9}_{-0.7}$	$^{+0.8}_{-0.7}$	$^{+0.3}_{-0.2}$ pb	0.81 ± 0.16 pb
$qq \to Hqq$ ($p_T^j < 200$ GeV)	9.8	$^{+4.3}_{-3.5}$	$^{+4.0}_{-3.2}$	$^{+1.5}_{-1.4}$ pb	$4.58^{+0.15}_{-0.18}$ pb
$gg/qq \to H\ell\ell/H\ell\nu$	0.2	$^{+0.9}_{-0.7}$	$^{+0.8}_{-0.7}$	± 0.2 pb	$0.63^{+0.03}_{-0.06}$ pb
$q\bar{q}/gg \to t\bar{t}H$	0.3	$^{+0.5}_{-0.4}$	$^{+0.5}_{-0.4}$	± 0.1 pb	$0.59^{+0.04}_{-0.05}$ pb

Ratios of cross sections and branching fractions

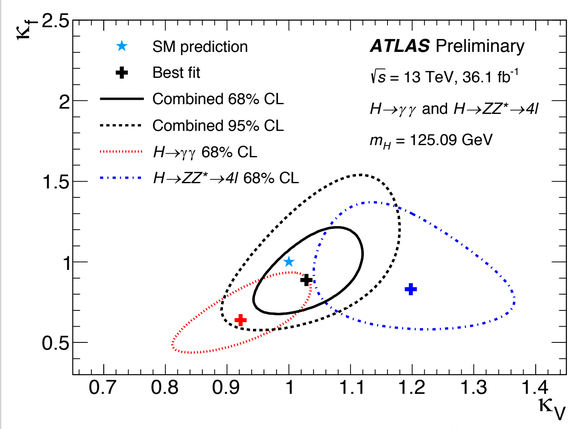
- $\sigma_i \cdot B_f = \sigma_{ggF} \cdot B_{4l} \cdot \left(\frac{\sigma_i}{\sigma_{ggF}}\right) \cdot \left(\frac{B_f}{B_{4l}}\right)$
- The measurements of $\sigma_{ggF} \cdot B_{4l}$, $\frac{\sigma_{VBF}}{\sigma_{ggF}}$, $\frac{\sigma_{VH}}{\sigma_{ggF}}$, $\frac{\sigma_{t\bar{t}H}}{\sigma_{ggF}}$ and $\frac{B_{\gamma\gamma}}{B_{4l}}$
- Common systematic uncertainties cancel, reducing model dependence and improving precision

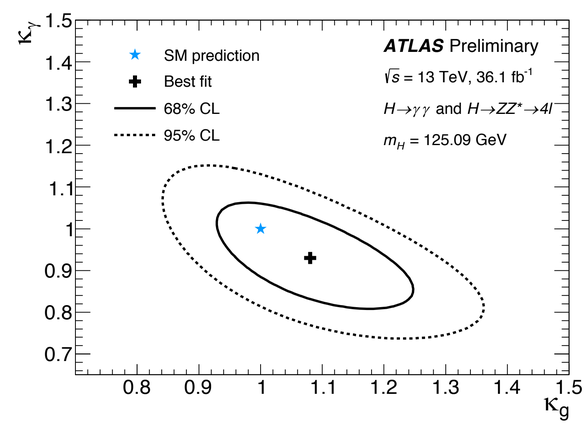


Quantity		Result	Uncertainty Total	Stat.	Exp.	Th.	SM prediction
$\sigma_{ggF} \cdot B_{4\ell}$	[fb]	6.6	$^{+1.2}_{-1.0}$	$^{+1.1}_{-1.0}$	± 0.4	± 0.2	$5.6^{+0.3}_{-0.4}$
$B_{\gamma\gamma}/B_{4\ell}$		12.5	$^{+2.8}_{-2.3}$	$^{+2.6}_{-2.2}$	$^{+0.9}_{-0.7}$	± 0.2	18.1 ± 0.2
$\sigma_{VBF}/\sigma_{ggF}$	[10^{-2}]	21.5	$^{+8.5}_{-6.3}$	$^{+7.3}_{-5.6}$	$^{+2.8}_{-1.7}$	$^{+3.6}_{-2.2}$	$7.9^{+0.4}_{-0.6}$
σ_{VH}/σ_{ggF}	[10^{-2}]	0.2	$^{+4.5}_{-3.4}$	$^{+4.2}_{-3.2}$	$^{+1.2}_{-0.9}$	$^{+0.9}_{-0.4}$	$4.5^{+0.2}_{-0.3}$
$\sigma_{t\bar{t}H}/\sigma_{ggF}$	[10^{-2}]	0.7	$^{+1.0}_{-0.9}$	$^{+1.0}_{-0.9}$	$^{+0.2}_{-0.1}$	± 0.1	1.3 ± 0.1

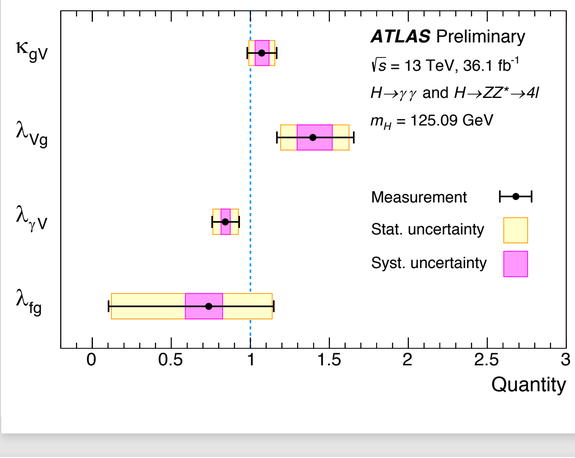
Results in the κ framework

- In order to characterize deviations from the SM expectations
- $\sigma(i \to H \to f) = \kappa_i^2 \sigma_i^{SM} \frac{\kappa_f^2 \Gamma_f^{SM}}{\kappa_H^2 \Gamma_H^{SM}}$
- The individual channel measurements are combined to obtain confidence intervals for the κ_i coefficients





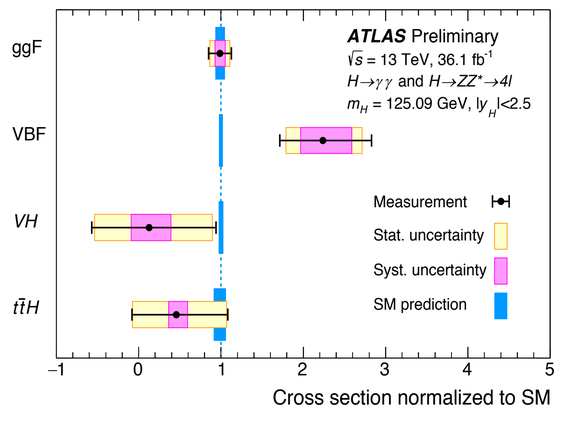
- $\kappa_V = 1.03 \pm 0.06$, $\kappa_f = 0.89^{+0.20}_{-0.15}$. (the coeffcients of couplings to fermions κ_f and weak vector bosons κ_V)
- $\kappa_g = 1.08^{+0.11}_{-0.10}$, $\kappa_\gamma = 0.93^{+0.09}_{-0.08}$. (the coeffcients of interaction with gluons and photons)
- $\kappa_{gV} = \frac{\kappa_g \kappa_V}{\kappa_H}$, $\lambda_{Vg} = \kappa_V/\kappa_g$, $\lambda_{fg} = \kappa_f/\kappa_g$, $\lambda_{\gamma V} = \kappa_\gamma/\kappa_V$



Parameter	Result	Uncertainty Total	Stat.	Exp.	Th.
κ_{gV}	1.07	± 0.09	± 0.08	± 0.03	$^{+0.04}_{-0.03}$
λ_{Vg}	1.41	$^{+0.26}_{-0.23}$	$^{+0.23}_{-0.20}$	$^{+0.08}_{-0.06}$	$^{+0.09}_{-0.08}$
$\lambda_{\gamma V}$	0.84	$^{+0.09}_{-0.08}$	± 0.08	$^{+0.03}_{-0.02}$	± 0.01
λ_{fg}	0.74	$^{+0.41}_{-0.63}$	$^{+0.40}_{-0.62}$	$^{+0.06}_{-0.14}$	$^{+0.07}_{-0.05}$

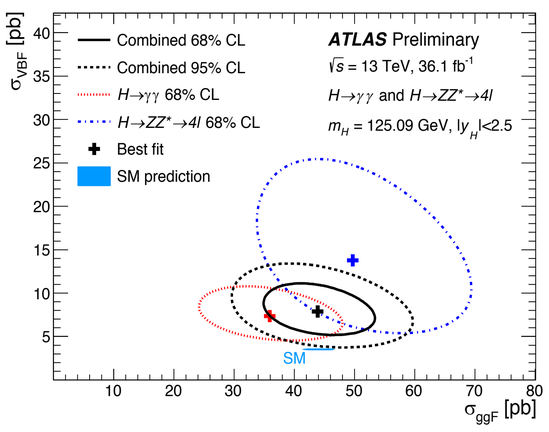
Production cross sections

- A combined fit is performed for the cross sections of ggF, VBF, VH, $t\bar{t}H$ for $|y_H| < 2.5$ and assuming SM branching fractions
- ggF and $t\bar{t}H$ productions include the $b\bar{b}H$ and tHX processes



Process ($\lvert y_H \rvert < 2.5$)	Result [pb]	Uncertainty [pb] Total	Stat.	Exp.	Th.	SM prediction [pb]
ggF	43.9	$^{+6.2}_{-6.0}$	$^{+5.5}_{-5.4}$	$^{+2.7}_{-2.3}$	± 1.2	$44.5^{+2.0}_{-3.0}$
VBF	7.9	$^{+2.1}_{-1.8}$	$^{+1.7}_{-1.6}$	$^{+0.8}_{-0.6}$	$^{+1.0}_{-0.7}$	$3.52^{+0.08}_{-0.07}$
VH	0.3	$^{+1.6}_{-1.4}$	$^{+1.5}_{-1.3}$	± 0.4	$^{+0.3}_{-0.2}$	$1.99^{+0.06}_{-0.05}$
$t\bar{t}H$	0.27	$^{+0.37}_{-0.32}$	$^{+0.36}_{-0.31}$	$^{+0.06}_{-0.05}$	$^{+0.05}_{-0.02}$	$0.59^{+0.03}_{-0.05}$

- The likelihood contours in the σ_{VBF} versus σ_{ggF} plane from $H \to \gamma\gamma$ and $H \to ZZ^* \to 4l$, and their combination



Conclusions

- The cross section of $pp \to H + X$ at $\sqrt{s} = 13$ TeV is measured to be $57.0^{+6.0}_{-5.9}(stat.)^{+4.0}_{-3.3}(syst.)$ pb, consistent with the SM prediction of $55.6^{+2.4}_{-3.4}$ pb
- The global signal strength is determined with the result $\mu = 1.09 \pm 0.12$
- The Higgs boson production cross sections are measured in a combined fit
- A combined fit is performed for $\sigma_{ggF} \cdot B_{4l}$, each production cross section relative to σ_{ggF}, and the ratio of branching fractions $B_{\gamma\gamma}/B_{4l}$
- The processes are divided into STXS regions and a combined measurement is performed
- The observed Higgs boson yields are used to obtain confidence intervals for κ modifiers
- No significant deviation from the Standard Model predictions is observed

References

- The ATLAS Collaboration. "Measurement of the Higgs boson mass in the $H \to ZZ^* \to 4l$ and $H \to \gamma\gamma$ channels with $\sqrt{s} = 13$ TeV pp collisions using the ATLAS detector" ATLAS-CONF-2017-046
- The ATLAS Collaboration. "Combined measurements of Higgs boson production and decay in the $H \to ZZ^* \to 4l$ and $H \to \gamma\gamma$ channels using $\sqrt{s} = 13$ TeV proton–proton collision data collected with the ATLAS experiment" ATLAS-CONF-2017-047

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