Measurements of Higgs boson properties using a combination of different Higgs decay channels

Nicolas Morange,
On behalf of the ATLAS Collaboration

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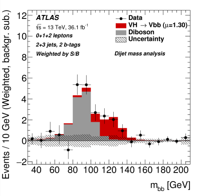
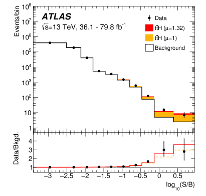
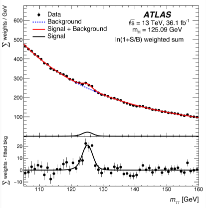
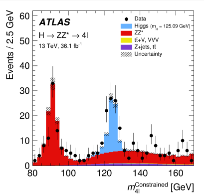
A 125 GeV Higgs is a gift !

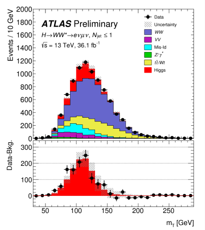
- $H \to 4\ell$ and $H \to \gamma\gamma$ high resolution channels
  - ⇒ Precision measurements of Higgs mass and Differential distributions
- Many other modes accessible: $H \to WW$, $H \to \tau\tau$, ttH, $VH(\to bb)$, $H \to \mu\mu$
  - ⇒ Very complementary analyses
  - ⇒ Combination very beneficial, and gives a broad set of results

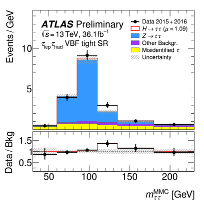






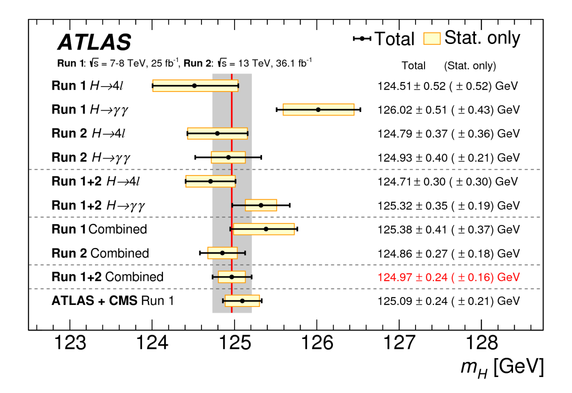






Combination of $H \to 4\ell$ and $H \to \gamma\gamma$ channels: HIGG-2016-33

- See Talk by William Leight !
- 2 per-mille precision



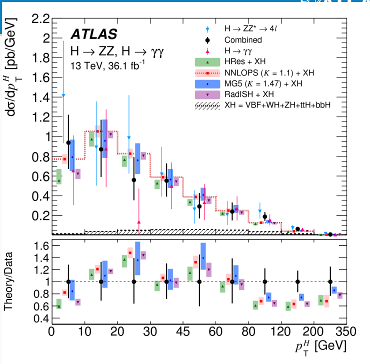
Differential Cross-sections: HIGG-2017-11

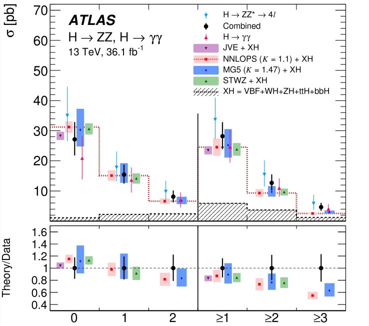
- Total and differential measurements in $H \to 4\ell$ and $H \to \gamma\gamma$ channels
- Corrected to common fiducial volume
  - Typical acceptance factors 50%
- Comparisons of p_T^H, $|y^H|$, N_{jets} and p_T^{j1} with state-of-the-art calculations

Results

- Total cross-section: $57.0^{+6.0}_{-5.9}(\text{stat.})^{+4.0}_{-3.3}(\text{syst.})$ pb
- Differential distributions dominated by stat uncertainties (20 – 30%)
- Channels in agreement with each other
- Good agreement with the predictions

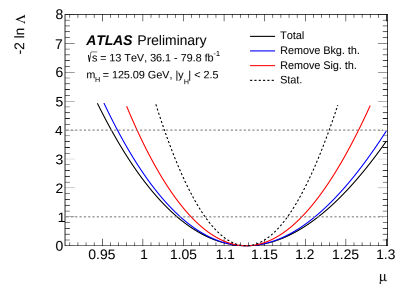
p-values [%]	p_T^H	$\lvert y^H \rvert$	N_{jets}	p_T^{j1}
NNLOPS ($K = 1.1$)	29	92	43	6
HRES	16	–	–	–
RADISH + NNLOJET	30	–	–	–
SCETLIB	–	91	–	23
MADGRAPH5_AMC@NLO ($K = 1.47$)	77	91	65	–





NEW Combination of all main Higgs analyses: ATLAS-CONF-2018-031

- $H \to \gamma\gamma$, $H \to 4\ell$, $H \to WW \to e\nu\mu\nu$, $H \to \tau\tau$, $VH(\to bb)$, ttH, $H \to \mu\mu$
- Run 2 data: 79.8 fb^{-1} for $H \to \gamma\gamma$, $H \to 4\ell$, $H \to \mu\mu$, 36.1 fb^{-1} for the others
- Complementarity of analyses: probe all production modes and decay channels accessible at the LHC
- Correlation of uncertainties: choice not always straightforward. Detailed studies performed.



Uncertainty source	$\frac{\Delta\mu}{\mu}$ [%]
Statistical uncertainties	4.5
Systematic uncertainties (excl. MC stat.)	6.1
Theory uncertainties	4.8
Signal	4.3
Background	2.3
Experimental uncertainties	4.0
Luminosity	2.1
Fake leptons	1.2
Jets, E_T^{miss}	1.3
Flavour tagging	0.9
Background modeling	1.2
Electrons, photons	2.2
Muons	0.3
τ-lepton	0.4
Other	1.5
MC stat. uncertainties	1.5

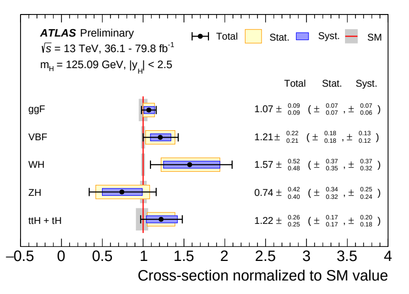
Global Signal Strength

- Most basic measurement: $\mu = (\sigma \times B)/(\sigma \times B)_{\mathrm{SM}}$
- $\mu = 1.13 \pm 0.05(\text{stat.}) \pm 0.05(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.03(\text{bkg th.})$
- Compatible with SM at 13% level
- Uncertainties: dominated by signal and background modelling/prediction

$\Rightarrow$ Relevance of cross-section measurements

Production cross-sections

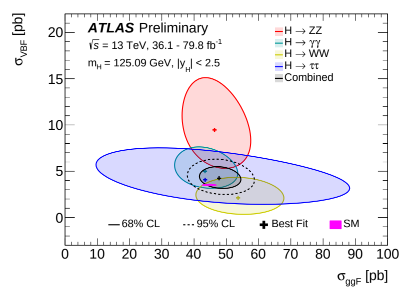
- Measured for $|y^H| < 2.5$, assuming SM BR
- Single-experiment observation of VBF
- ZH/WH only process not observed yet
  - Driven by $VH(\to b\bar{b})$
- All values compatible with SM (global compat 51%)
- Measured uncertainty on ggF not far from uncertainty of SM prediction
- Related measurement of $\sigma_i \times B_f$: show relative importance of each channel



Process ($\|y_H\| < 2.5$)	Value [pb]	Uncertainty [pb] Total	Stat.	Exp.	Sig. th.	Bkg. th.	SM pred. [pb]	Significance obs. (exp.)
ggF	47.8	± 4.0	± 3.1	$^{+2.7}_{-2.2}$	± 0.9	± 1.3	44.7 ± 2.2	-
VBF	4.25	$^{+0.77}_{-0.74}$	± 0.63	$^{+0.39}_{-0.35}$	$^{+0.25}_{-0.21}$	$^{+0.14}_{-0.11}$	3.515 ± 0.075	6.5 (5.3)
WH	1.89	$^{+0.63}_{-0.58}$	$^{+0.45}_{-0.42}$	$^{+0.29}_{-0.28}$	$^{+0.25}_{-0.16}$	$^{+0.23}_{-0.22}$	1.204 ± 0.024	4.1 (3.7)
ZH	0.59	$^{+0.33}_{-0.32}$	$^{+0.27}_{-0.25}$	± 0.14	$^{+0.08}_{-0.02}$	± 0.11	$0.794^{+0.033}_{-0.027}$	
$t\bar{t}H+tH$	0.71	± 0.15	± 0.10	± 0.07	$^{+0.05}_{-0.04}$	$^{+0.08}_{-0.07}$	$0.586^{+0.034}_{-0.050}$	5.8 (5.3)

Correlations

- Low correlations between measured cross-sections
- ggF vs VBF: -14%
- Highlight complementarity of analysis channels

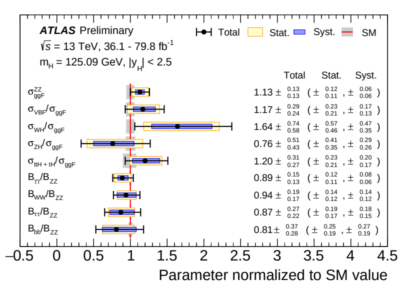


Ratios of cross-sections and BR

Measure x-sec and BR using $gg \to ZZ \to 4\ell$ as reference

$$(\sigma \times B)_{if} = \sigma^{ZZ}_{\mathrm{ggF}} \cdot \left(\frac{\sigma_i}{\sigma_{\mathrm{ggF}}}\right) \cdot \left(\frac{B_f}{B_{ZZ}}\right),$$

- Model independent measurement
- Some uncertainties cancel in the ratios



κ Framework

Simple parameterization of cross-sections and partial widths

$$\sigma_i \cdot B_f = \kappa_i^2 \sigma_i^{SM} \frac{\kappa_f^2 \Gamma_f^{SM}}{\kappa_H^2 \Gamma_H^{SM}}$$

- Same approach as for Run 1
- Validity limited to leading orders, but quite versatile
  - Relations between κs introduced to probe various aspects of Higgs couplings
  - κ_H fixed by the others if no non-SM decays

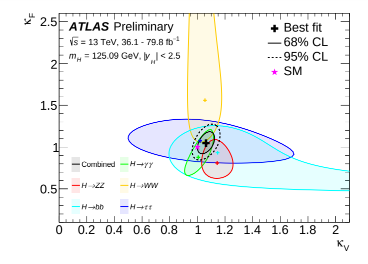
Simplest results

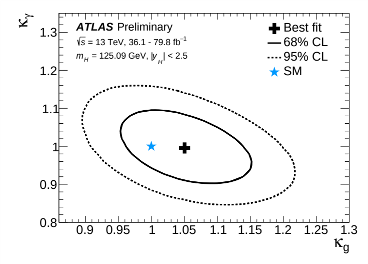
Fermion and Gauge Couplings

- Fit κ_V and κ_F, mapped to the productions and decays
  - e.g $H \to \gamma\gamma$ depends on κ_V^2, κ_F^2, $\kappa_V \kappa_F$
- Compatibility with SM: 30.6%

Effective Photon and Gluon Couplings

- Fit κ_g and κ_γ
- Probes non-SM contributions to the loops
- Compatibility with SM: 70.5%
- If allow additional $B_{\rm BSM}$: limit $B_{\rm BSM} < 0.13$

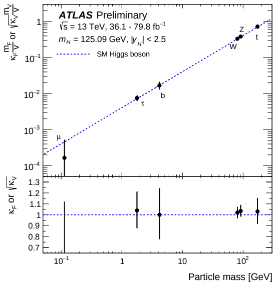




SM Parameterization

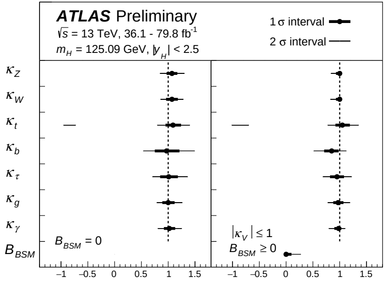
- Assumes: SM structure of the loops, no BSM decays
- Consistency test of SM
- All κ close to 1 within uncertainties
- Compatibility with SM: 79%

Parameter	Result
κ_Z	$1.07^{+0.11}_{-0.10}$
κ_W	1.04 ± 0.10
κ_b	$1.00^{+0.24}_{-0.22}$
κ_t	$1.03^{+0.12}_{-0.11}$
κ_τ	$1.04^{+0.17}_{-0.16}$
κ_μ	< 1.63 at 95% CL.



With BSM couplings

- Add κ_g and κ_γ
- Allow or not B_{BSM} to probe for invisible decays
  - Limit at $B_{\mathrm{BSM}} < 0.26$

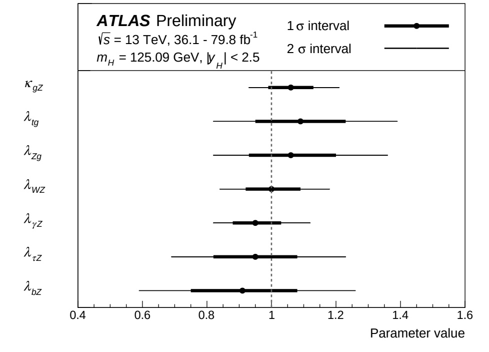


Coupling modifiers

- Ratios of κs
  - References are κ_g / κ_Z
- Most model-independent result

Results

- Measurements at the 8 – 16% level
- $t\bar{t}H$ observation reduces significantly the uncertainty on λ_{tg}
- SM compatibility 86%



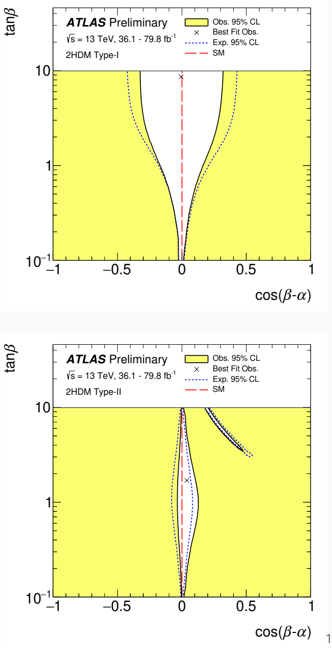
Two higgs Doublet Model

Interpretation of results with parameterizations targetting specific models

- 2HDM: Generic idea realised in broad classes of models
- Classification assuming no FCNC at tree level
  - Type I: vector bosons vs fermions
  - Type II: up-type quarks vs down-type quarks and charged leptons (e.g MSSM)
  - Lepton-specific, Flipped: mixed cases
- All couplings parametrized as function of mixing angles α and β between the Higgs bosons

Results

- Data consistent with alignment limit
- Narrow 'petal': $\cos(\beta+\alpha) \sim 0$, fermion couplings with same magnitude but opposite sign to SM

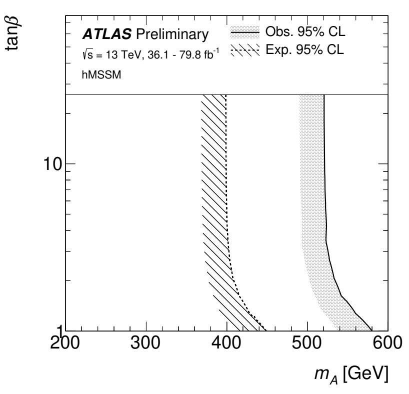


hMSSM

- Simplified MSSM model: corrections to mass matrix of Higgs bosons from top and stop only
- Lightest Higgs h identified with the observed one: SM-like couplings
- Couplings κ_V, κ_u, κ_d depend on $\tan\beta$ and m_A
- Limited validity for $\tan\beta \ll 1$

Results

- Data consistent with decoupling limit (large m_A)
- Stronger observed limit: linked to $\mu > 1$ in $H \to \gamma\gamma$ and $H \to 4\ell$, while physical boundary $\kappa_V < 1$



Differential Distributions

- $H \to 4\ell$ and $H \to \gamma\gamma$ allow already precise measurements
- Total cross-section $57.0^{+6.0}_{-5.9}(\mathrm{stat.})^{+4.0}_{-3.3}(\mathrm{syst.})$ pb
- Good agreement with with state-of-the art calculations

Results on Higgs Couplings

- Combination of 7 major complementary analyses
- Global signal strength $\mu = 1.13^{+0.09}_{-0.08}$
- Broad set of results on production cross-sections, coupling modifiers, BSM scenarios
- All results consistent with SM