Review of current ATLAS Higgs physics results

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On behalf of the ATLAS Collaboration

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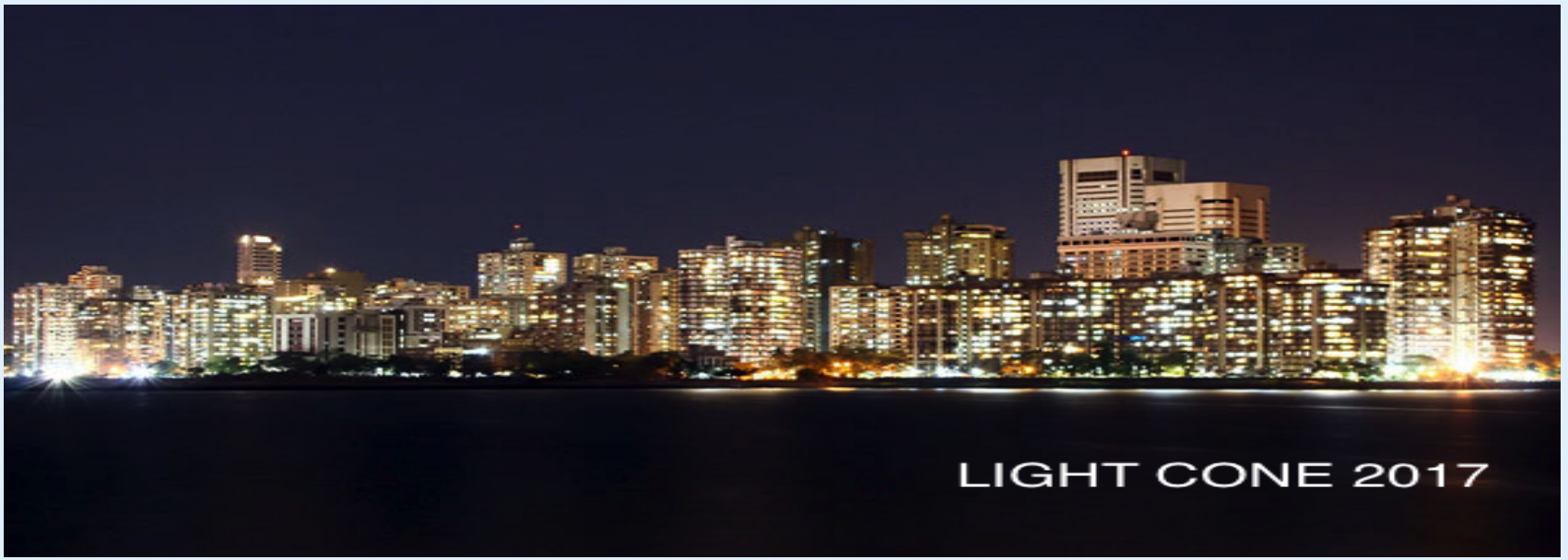
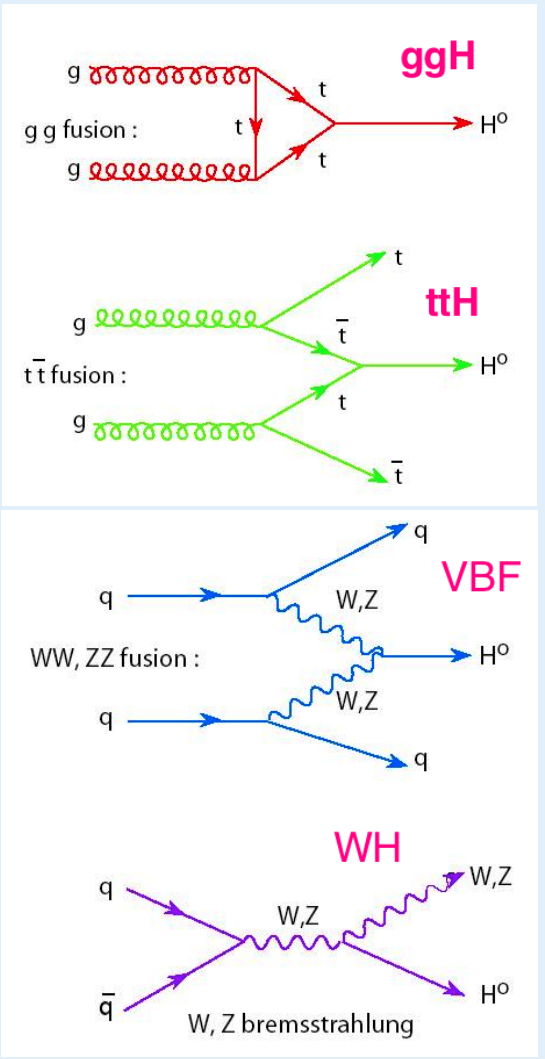


This talk will cover the latest ATLAS Higgs result

- Focus on the results from 2017
- Focus on SM Higgs
- Split between the bosonic decay and fermionic decay
  - Bosonic decay will focus on $H \to ZZ$, $H \to \gamma\gamma$ and $H \to Z\gamma$
    - The first two mentioned channels are confirmed in Run2.
  - Fermionic decay will focus on $H \to \mu\mu$, $H \to bb$
    - These channels are not observed in individual channels.

$H \to WW$, $H \to \tau\tau$ are in back-up

Higgs production modes

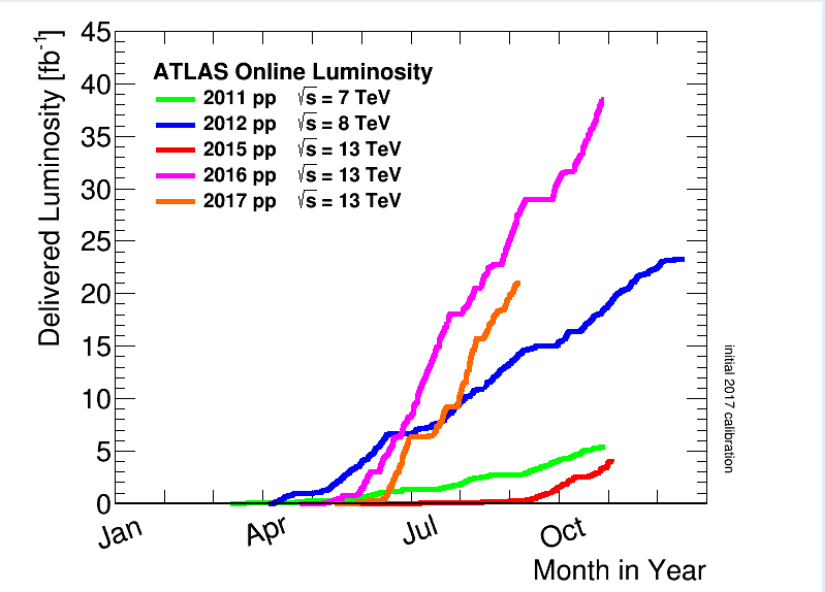


Introduction

A lot of data have been collected in Run2 at 13 TeV

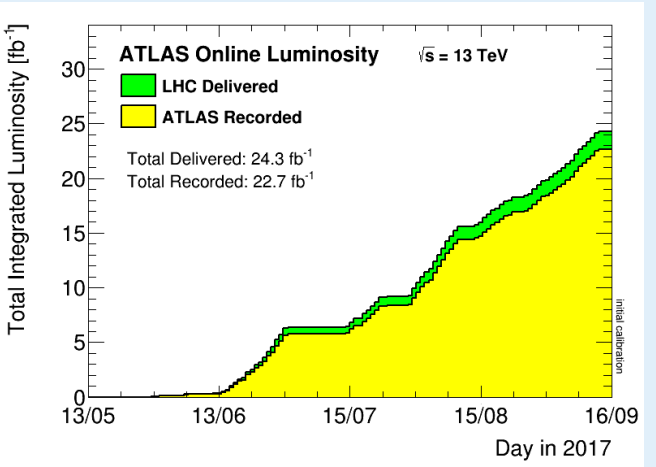
- Higgs cross section increases significantly with $\sqrt{S}$

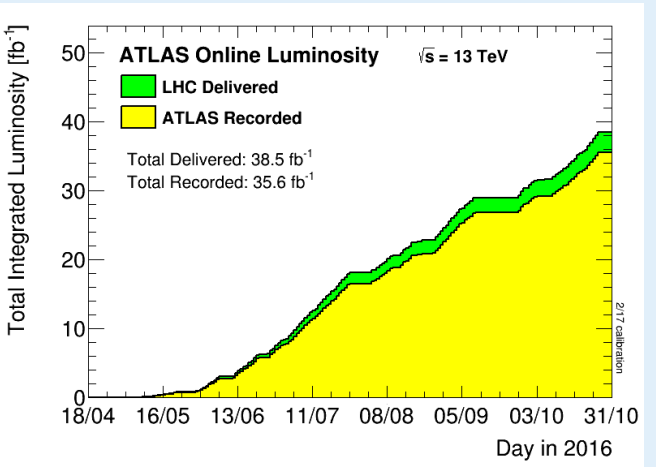
$\sqrt{S}$	σ_H
7TeV	18.9pb
8TeV	24.1pb
13TeV	62.6pb



Many more Higgs particles to analyze!

Collected data at ATLAS

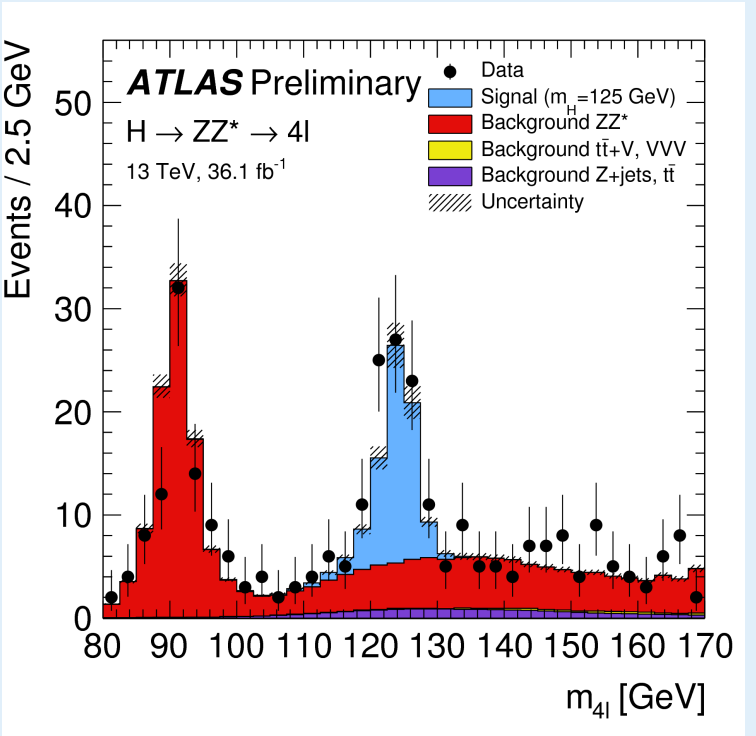




$H \to ZZ/\gamma\gamma$

Selection:

- At least four leptons
- Two same-flavour opposite-sign (SFOS) lepton pairs,
  - $(4\mu$, 2e2μ,2μ2e, 4e)
- Requirement of the invariant mass m_{4l} :
  $115\ \text{GeV} < m_{4l} < 130\text{GeV}$



Number of events:

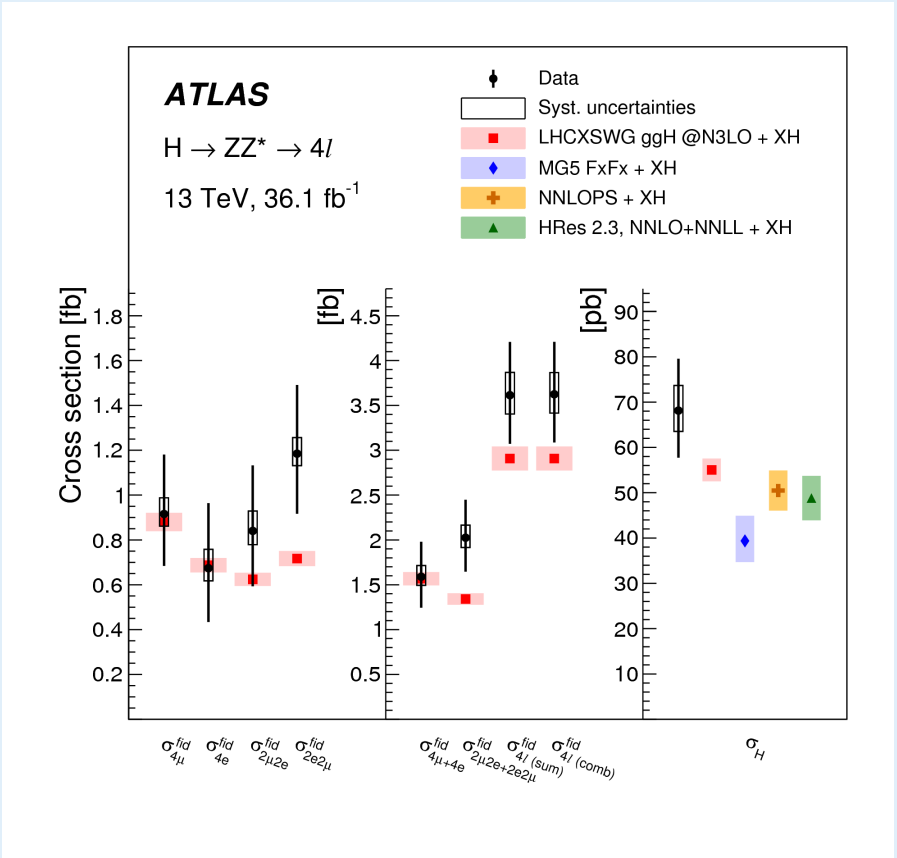
Final state	Signal (125 GeV)	ZZ^*	$Z+$jets, $t\bar{t}$, WZ, ttV,VVV	Expected	Observed
4μ	20.6 ± 1.7	15.9 ± 1.2	2.0 ± 0.4	38.5 ± 2.1	38
$2e2\mu$	14.6 ± 1.1	11.2 ± 0.8	1.6 ± 0.4	27.5 ± 1.4	34
$2\mu2e$	11.2 ± 1.0	7.4 ± 0.7	2.2 ± 0.4	20.8 ± 1.3	26
$4e$	11.1 ± 1.1	7.1 ± 0.7	2.1 ± 0.4	20.3 ± 1.3	24
Total	57 ± 5	41.6 ± 3.2	8.0 ± 1.0	107 ± 6	122

Result

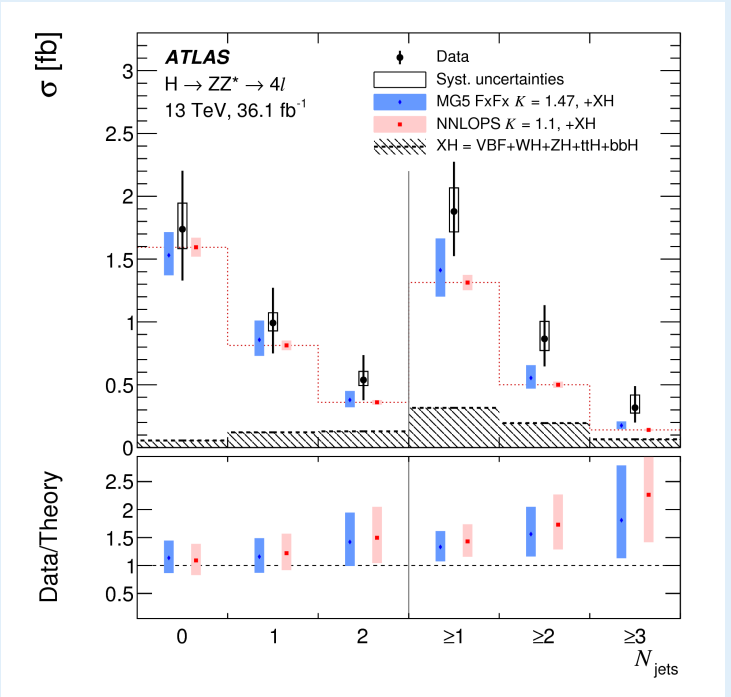
The inclusive fiducial σ_H is measured to $3.62^{+0.53}_{-0.50}(stat)^{+0.25}_{-0.20}(sys)$fb

The Standard Model prediction of $2.91 \pm 0.13 fb$

σ_H measured for $H \to ZZ^* \to 4l$



Fiducial σ_H vs. the N_{jets}.

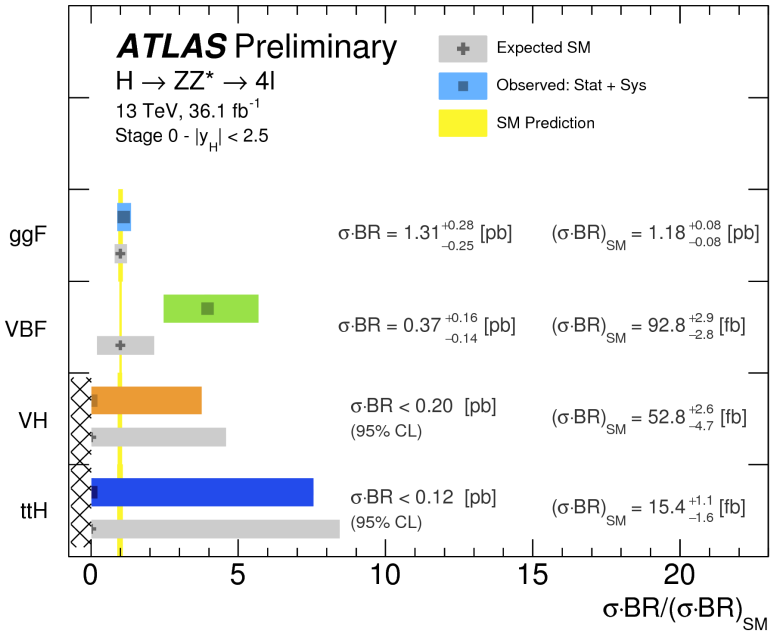


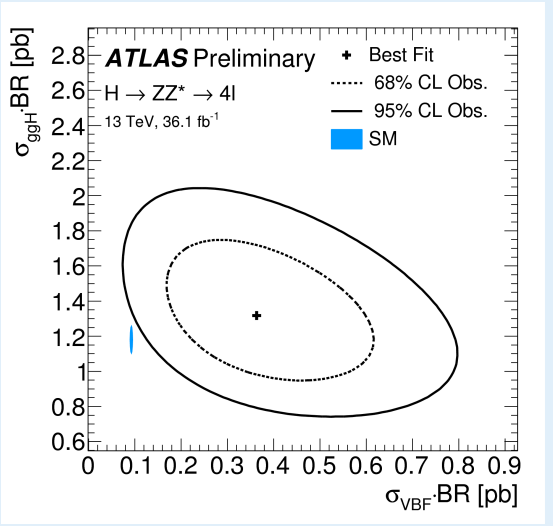
Needs to be tested with more data and more accurate QCD calculations

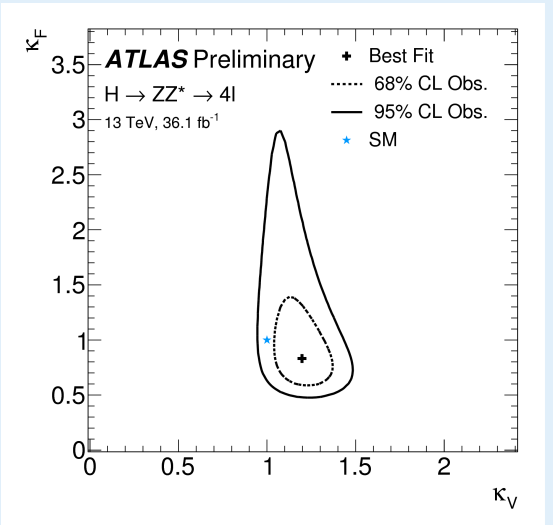
(More plots in backup)

Signal strength

$$\frac{\sigma \times B}{(\sigma \times B)_{SM}} = 1.28^{+0.18}_{-0.17}(stat)^{+0.08}_{-0.06}(exp)^{+0.08}_{-0.06}(th)$$





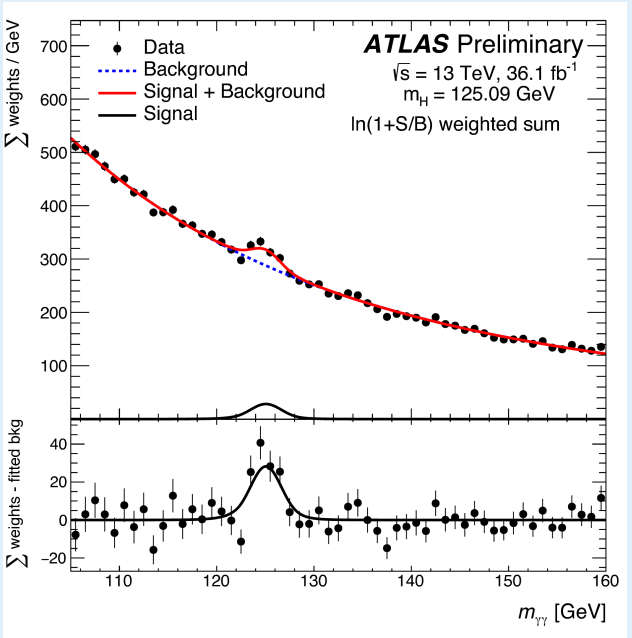


- Definition of κ_V and κ_F
  - Bosons: $\kappa_V = \kappa_W = \kappa_Z$
  - Fermions $\kappa_F = \kappa_t = \kappa_b = \kappa_c = \kappa_\tau = \kappa_\mu = \kappa_g$

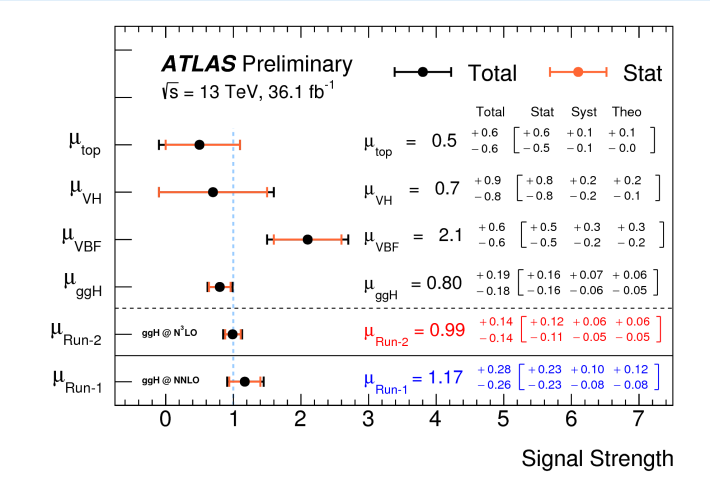
- Assumed no undetected or invisible Higgs boson decays

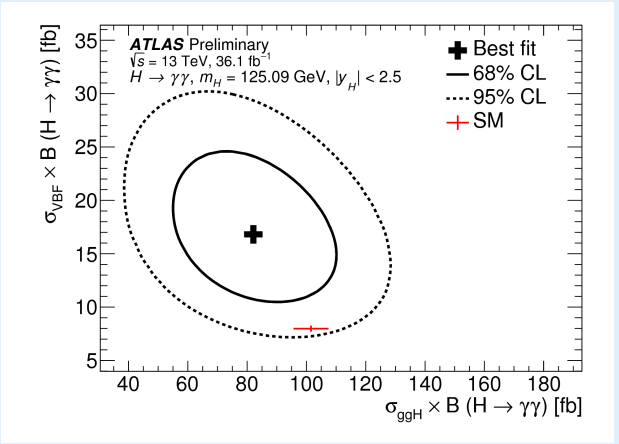
Selection

- Two isolated photons with $\frac{E_T}{m_{\gamma\gamma}} > 0.35$ and $\frac{E_T}{m_{\gamma\gamma}} > 0.25$
- $m_{\gamma\gamma} = \sqrt{2E_1E_2(1-cos\alpha)}$ is fitted between 105 GeV and 160 GeV
- Signal efficiency is 42%



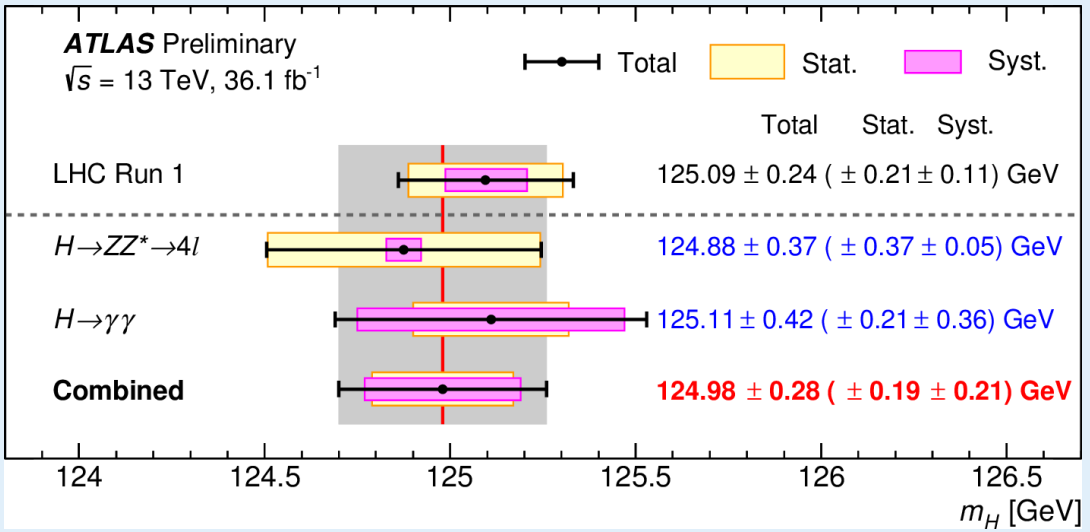
Signal strengths measured for the different production processes:



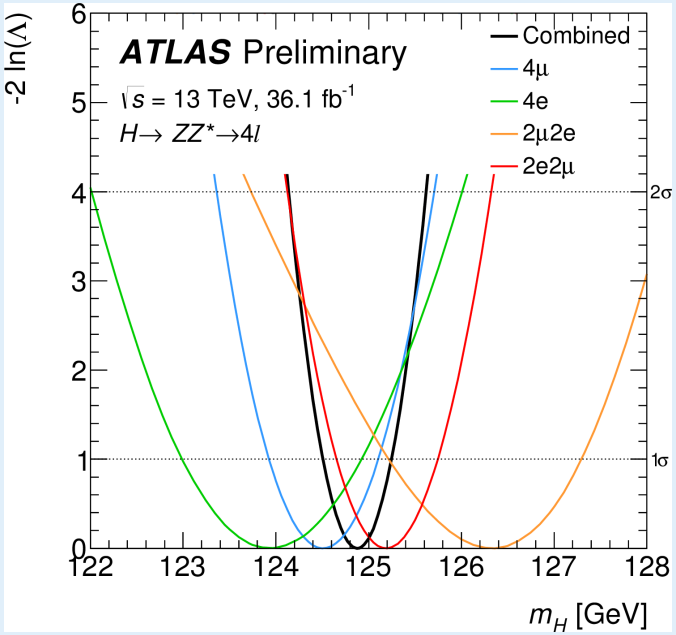


$\sigma_{VBF} \times B$ vs $\sigma_{ggH} \times B$

m_H is measured in combination of $H \to \gamma\gamma$, $H \to ZZ^* \to 4l$ ($36 fb^1$)



- Comparison with the combined m_H compared to the LHC run1 result.
- The main uncertainties are LAr calibrations and energy loss estimate in materials



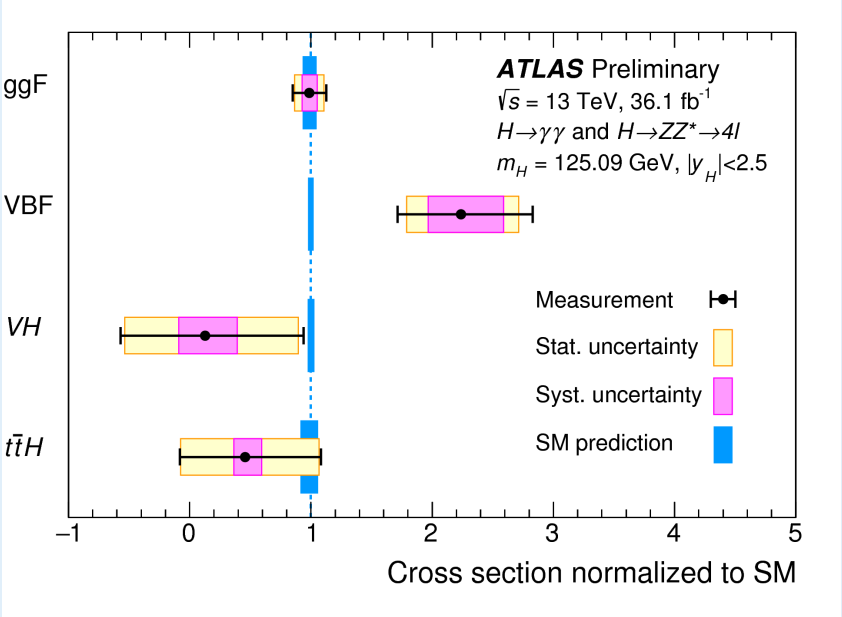
Main uncertainties on combined mass:

Source	Systematic uncertainty on m_H [MeV]
LAr cell non-linearity	90
LAr layer calibration	90
Non-ID material	60
ID material	50
Lateral shower shape	50
$Z \to ee$ calibration	30
Muon momentum scale	20
Conversion reconstruction	20

$H \to \gamma\gamma$, $H \to ZZ^* \to 4l$

ATLAS-CONF-2017-047

σ_H is measured in combination of $H \to \gamma\gamma$, $H \to ZZ^* \to 4l$ with $36 fb^1$



Measured σ_H

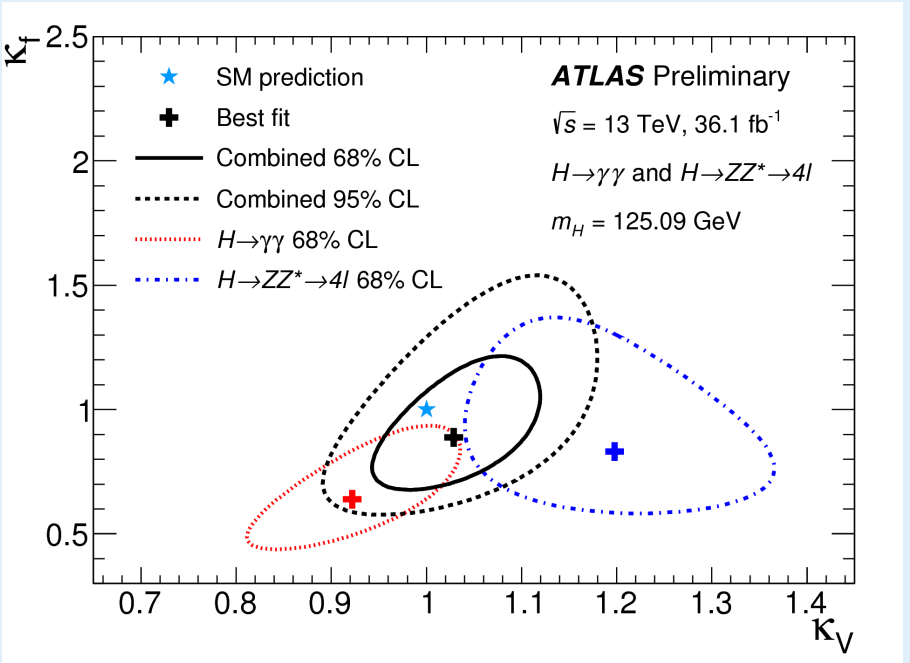
$\sigma_H = 57.0^{+6.0}_{-5.9}(stat)^{+4.0}_{-3.0}(sys)pb$

SM prediction: $\sigma_H = 55.6^{+2.4}_{-3.4}pb$

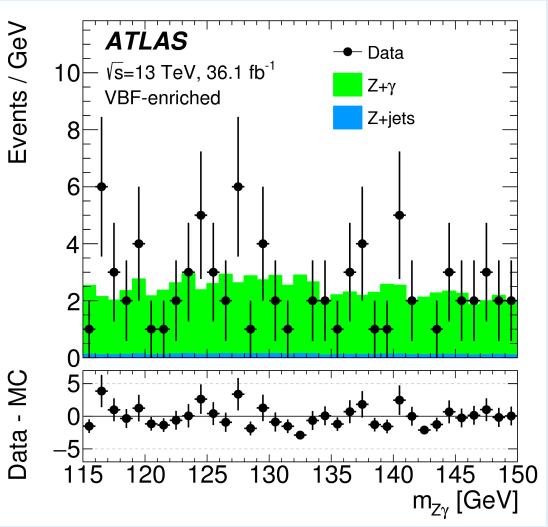
The κ framework:

The framework parameterizes H interactions as multiplicative coefficients to cross sections and partial widths

$$\sigma(i \to H \to f) = \kappa_i^2 \sigma_i^{SM} \frac{\kappa_f^2 \Gamma_f^{SM}}{\kappa_H^2 \Gamma_H^{SM}}$$



- Require two same-flavour opposite-charge leptons (SFOS) to form a Z boson candidate and at least one photon candidate



VBFenriched

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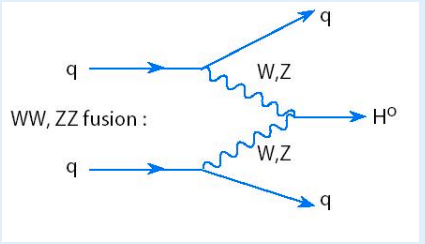

$\mu\mu$ low p_{Tt}

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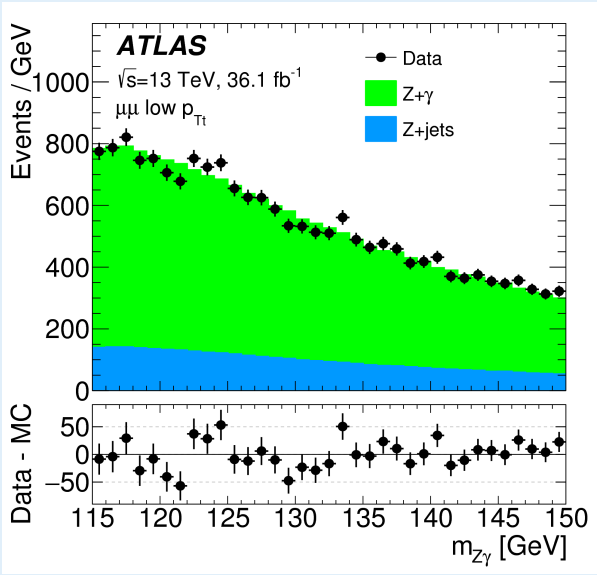
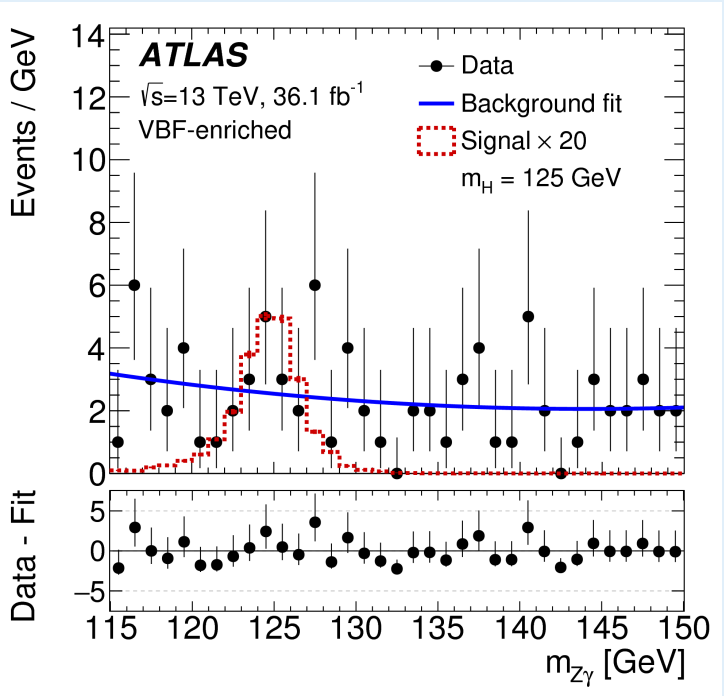


Split into 6 categories:

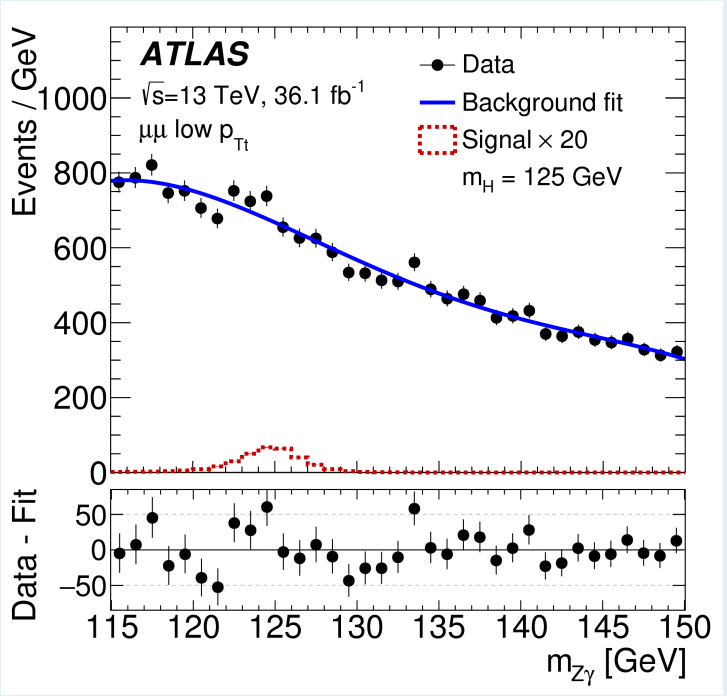
- VBF-enriched
- High relative P_T
- ee high p_{Tt}
- ee low p_{Tt}
- $\mu\mu$ high p_{Tt}
- $\mu\mu$ low p_{Tt}

Where $p_{Tt} = (2|p_x^Z p_y^\gamma - p_x^\gamma Z p_y^Z|)/P_T^{Z\gamma}$

VBFenriched



$\mu\mu$ low p_{Tt}



Most sensitive categories

Result:

The observed(expected) upper limit on $\sigma \cdot B$ is 6.6(5.2) times the SM prediction at 95% CL

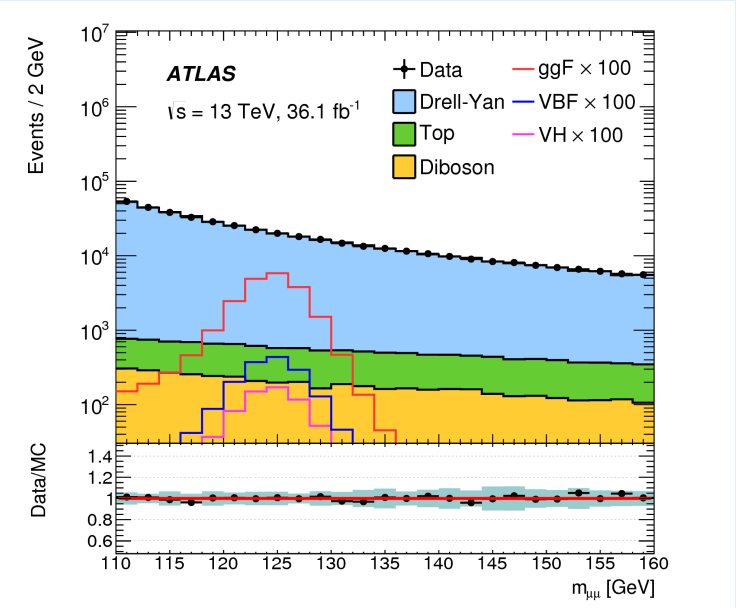
$H \rightarrow$ FERMIONS

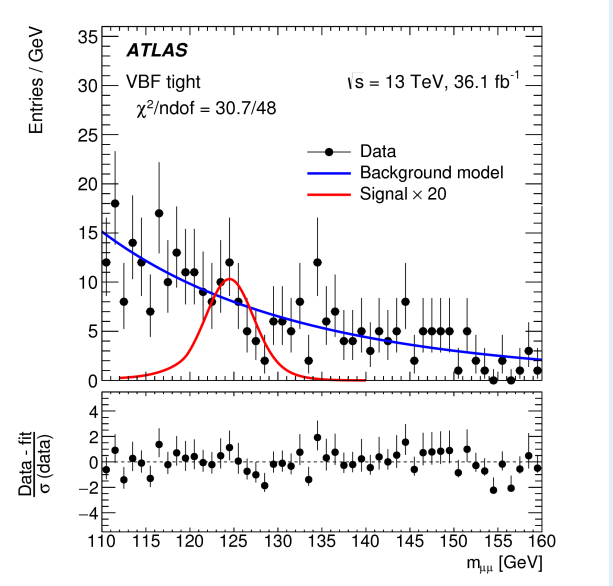
Main selection:

- 2 opposite sign muons
- $E_T^{MISS} < 80 GeV$
- Veto b-jets

Split in 8 sub-categories

- The VBF categories require events with at least two jets
- Rest split wrt to P_T^{μ} and η^{μ}





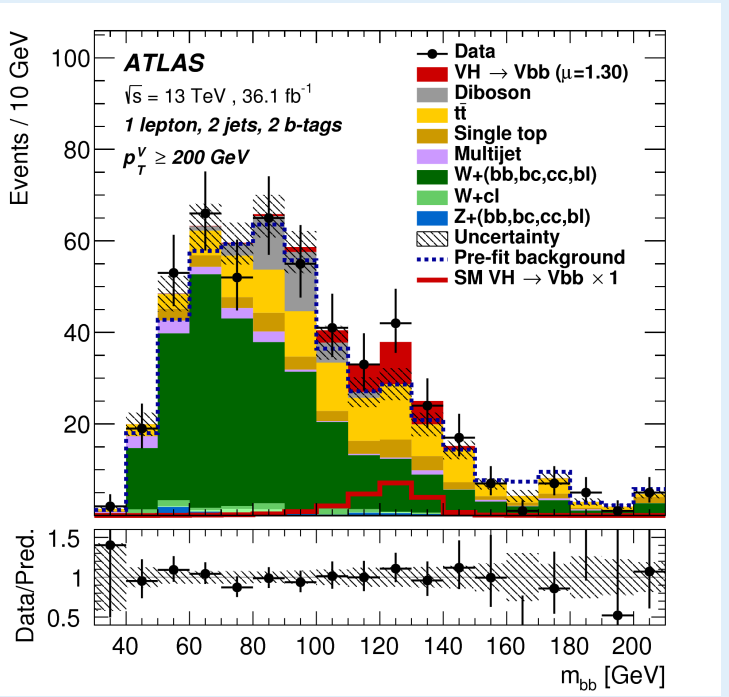
With ATLAS data from Run1+2 the observed(Expected) upper limit on $\sigma \times B$ is 2.8(2.9) at 95%CL

Analysis targeting $ZH \to \nu\nu bb$, $WH \to l\nu bb$ and $ZH \to llbb$

- The analysis is done by splitting into number of lepton and exactly 2 b-tagged jets.

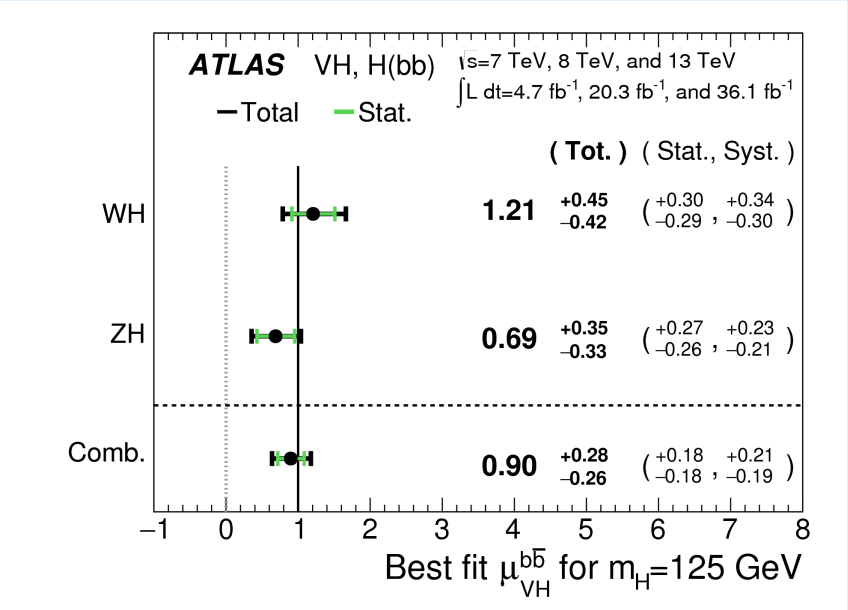
- 8 subcategories for signal region, and 6 CR

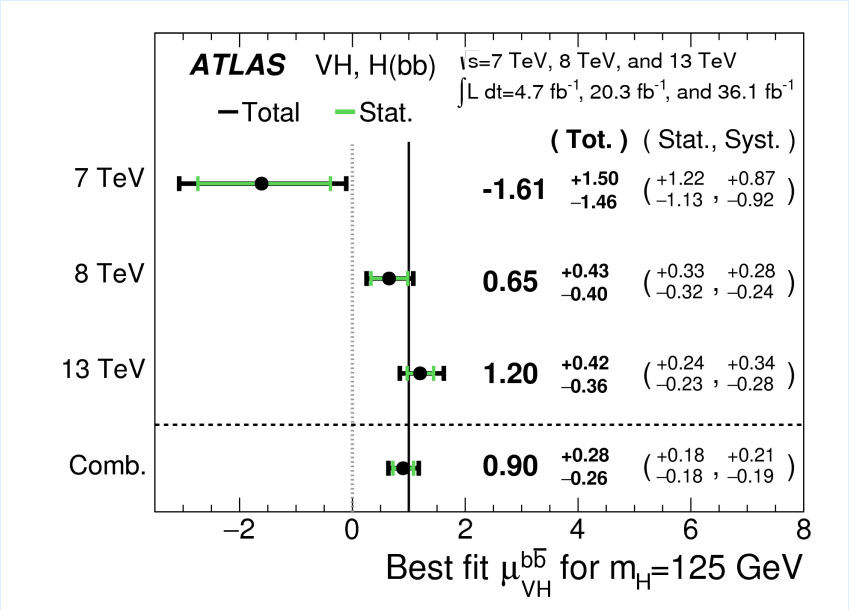
Channel	SR/CR	Categories			
		75 GeV $< p_{\mathrm{T}}^{V} <$ 150 GeV		$p_{\mathrm{T}}^{V} >$ 150 GeV	
		2 jets	3 jets	2 jets	3 jets
0-lepton	SR	-	-	BDT	BDT
1-lepton	SR	-	-	BDT	BDT
2-lepton	SR	BDT	BDT	BDT	BDT
1-lepton	W + HF CR	-	-	Yield	Yield
2-lepton	$e\mu$ CR	m_{bb}	m_{bb}	Yield	m_{bb}



Discriminating variable for 1 lepton case

Best fit





Run1+run2 results: $\mu = 0.90 \pm 0.18(stat.)^{+0.21}_{-0.19}(syst.)$.
Observed(expected) significance: $3.6\sigma(4.0\sigma)$

Evidence for bottom Yukawa coupling!

Conclusion

At ATLAS Higgs property measurements are performed by ATLAS at $\sqrt{s} = 7\text{TeV}$, $\sqrt{s} = 8\text{TeV}$ and $\sqrt{s} = 13\text{TeV}$

.

Run 2 data allows a precise testing of the Higgs properties.

- Several decay channels are considered especially involving bosons
  - So far all couplings and differential distributions regarding the Higgs particle have been consistent with the standard model, but the statistical uncertainties precludes definite conclusions.
  - Mass measurement also updated
- There are found evidence for bottom Yukawa coupling

BACK-UP

Selection and categories:

Channel	Preselection cuts
$\tau_{\text{lep}}\tau_{\text{lep}}$	Exactly two isolated opposite-sign leptons Events with τ_{had} candidates are rejected 30 GeV$< m_{\tau\tau}^{\text{vis}} <$ 100 (75) GeV for DF (SF) events $\Delta\phi_{\ell\ell} < 2.5$ $E_{\text{T}}^{\text{miss}} > 20$ (40) GeV for DF (SF) events $E_{\text{T}}^{\text{miss,HPTO}} > 40$ GeV for SF events $p_{\text{T}}^{\ell_1} + p_{\text{T}}^{\ell_2} > 35$ GeV Events with a b-tagged jet with $p_{\text{T}} > 25$ GeV are rejected $0.1 < x_{\tau_1}, x_{\tau_2} < 1$ $m_{\tau\tau}^{\text{coll}} > m_Z - 25$ GeV
$\tau_{\text{lep}}\tau_{\text{had}}$	Exactly one isolated lepton and one medium τ_{had} candidate with opposite charges $m_{\text{T}} < 70$ GeV Events with a b-tagged jet with $p_{\text{T}} > 30$ GeV are rejected
$\tau_{\text{had}}\tau_{\text{had}}$	One isolated medium and one isolated tight opposite-sign τ_{had}-candidate Events with leptons are vetoed $E_{\text{T}}^{\text{miss}} > 20$ GeV $E_{\text{T}}^{\text{miss}}$ points between the two visible taus in ϕ, or min$[\Delta\phi(\tau, E_{\text{T}}^{\text{miss}})] < \pi/4$ $0.8 < \Delta R(\tau_{\text{had}_1}, \tau_{\text{had}_2}) < 2.4$ $\Delta\eta(\tau_{\text{had}_1}, \tau_{\text{had}_2}) < 1.5$
Channel	VBF category selection cuts
$\tau_{\text{lep}}\tau_{\text{lep}}$	At least two jets with $p_{\text{T}}^{j_1} > 40$ GeV and $p_{\text{T}}^{j_2} > 30$ GeV $\Delta\eta(j_1, j_2) > 2.2$
$\tau_{\text{lep}}\tau_{\text{had}}$	At least two jets with $p_{\text{T}}^{j_1} > 50$ GeV and $p_{\text{T}}^{j_2} > 30$ GeV $\Delta\eta(j_1, j_2) > 3.0$ $m_{\tau\tau}^{\text{vis}} > 40$ GeV
$\tau_{\text{had}}\tau_{\text{had}}$	At least two jets with $p_{\text{T}}^{j_1} > 50$ GeV and $p_{\text{T}}^{j_2} > 30$ GeV $p_{\text{T}}^{j_2} > 35$ GeV for jets with $\lvert\eta\rvert > 2.4$ $\Delta\eta(j_1, j_2) > 2.0$
Channel	Boosted category selection cuts
$\tau_{\text{lep}}\tau_{\text{lep}}$	At least one jet with $p_{\text{T}} > 40$ GeV
All	Failing the VBF selection $p_{\text{T}}^{H} > 100$ GeV

Number of events:

$\tau_{\text{lep}}\tau_{\text{lep}}$	VBF	Boosted
Total signal	11 ± 4	38 ± 13
Total background	130 ± 7	3400 ± 64
Data	152	3428

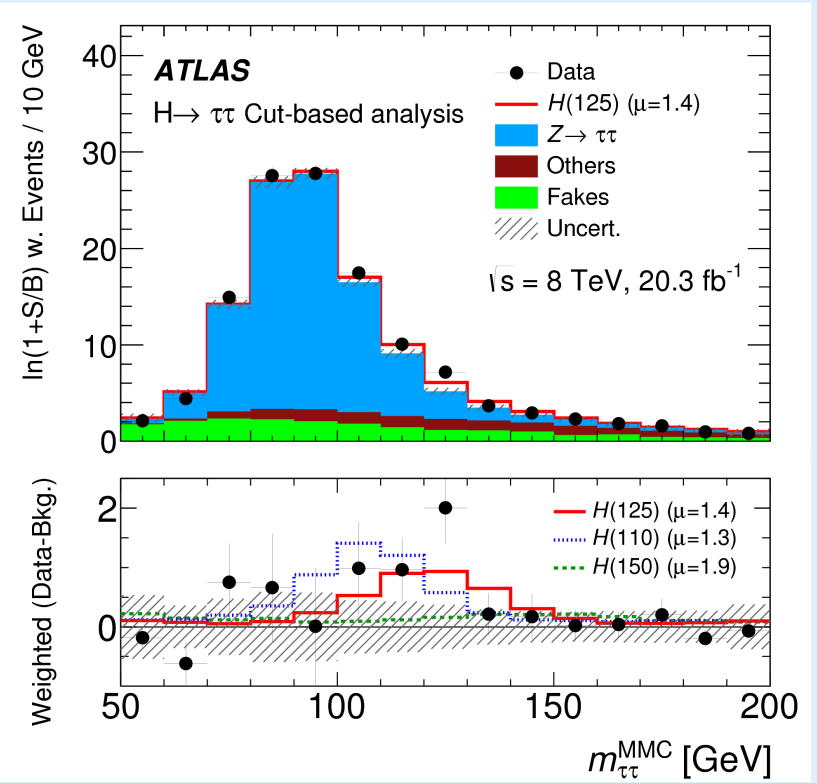
$\tau_{\text{lep}}\tau_{\text{had}}$	Tight VBF	Loose VBF	Boosted
Signal	8.8 ± 3	17 ± 6	52 ± 17
Background	52 ± 4	398 ± 17	4399 ± 73
Data	62	407	4435

$\tau_{\text{had}}\tau_{\text{had}}$	VBF high p_{T}^{H}	VBF low p_{T}^{H}		Boosted	
		tight	loose	high p_{T}^{H}	low p_{T}^{H}
Signal	5.7 ± 1.9	5.2 ± 1.9	3.7 ± 1.3	17 ± 6	20 ± 7
Background	59 ± 4	86 ± 5	156 ± 7	1155 ± 28	2130 ± 41
Data	65	94	157	1204	2121

Fitted μ values

	Fitted μ values		
	$\sqrt{s}$	Multivariate analysis	Cut-based analysis
$\tau_{\text{lep}}\tau_{\text{lep}}$	8 TeV	$1.9^{+1.0}_{-0.9}$	$3.2^{+1.4}_{-1.3}$
$\tau_{\text{lep}}\tau_{\text{had}}$	8 TeV	$1.1^{+0.6}_{-0.5}$	$0.7^{+0.7}_{-0.6}$
$\tau_{\text{had}}\tau_{\text{had}}$	8 TeV	$1.8^{+0.9}_{-0.7}$	$1.6^{+0.9}_{-0.7}$
All channels	8 TeV	$1.53^{+0.47}_{-0.41}$	$1.43^{+0.55}_{-0.49}$

Combined mass for $\tau_{lep}\tau_{lep}$, $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$



Measurements of the Higgs boson production cross section via Vector Boson Fusion (VBF) and associated (WH) production

VBF:

	Signal region	$Z \rightarrow \tau\tau$ CR	Top-quark CR
Preselection	Two isolated leptons ($\ell = e, \mu$) with opposite charge $p_{\mathrm{T}}^{\mathrm{lead}} > 25GeV$ ($p_{\mathrm{T}}^{\mathrm{lead}} > 22GeV$ for muons in 2015), $p_{\mathrm{T}}^{\mathrm{sublead}} > 15GeV$ $m_{\ell\ell} > 10GeV$, $N_{\mathrm{jet}} \geq 2$		
	$N_{b\text{-jet}} = 0$	$N_{b\text{-jet}} = 0$	$N_{b\text{-jet}} = 1$
A BDT is trained at this level. Eight discriminant variables are used: $\Delta\phi_{\ell\ell}$, $m_{\ell\ell}$, m_{T}, Δy_{jj}, m_{jj}, $p_{\mathrm{T}}^{\mathrm{tot}}$, $\sum_{\ell,j} m_{\ell j}$, and $\eta_{\ell}^{\mathrm{centrality}}$			
Selection	$m_{\tau\tau} < 66.2GeV$	$\lvert m_{\tau\tau} - m_Z \rvert < 25GeV$	–
	–	$m_{\ell\ell} < 80GeV$	–
	OLV applied, CJV applied, BDT > -0.8		
	SR1: $-0.8 <$ BDT ≤ 0.7	–	–
	SR2: $0.7 <$ BDT ≤ 1	–	–

WH

Category	Z-dominated SR ≥ 1 SFOS pair	Z-depleted SR no SFOS pair
Preselection	Three isolated leptons (p_{T} >15 GeV) total charge $= \pm 1$ ≥ 1 lepton matches to the trigger	
Background Rejection	$N_{\mathrm{jet}} \leq 1$, $N_{b\text{-jet}} = 0$	
	$E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV	–
	$\lvert m_{\ell^+\ell^-} - m_Z \rvert > 25$ GeV	$Z/\gamma^* \rightarrow ee$ veto
	$m_{\ell^+\ell^-}^{\mathrm{max}} < 200$ GeV	
	$m_{\ell^+\ell^-}^{\mathrm{min}} > 12$ GeV	$m_{\ell^+\ell^-}^{\mathrm{min}} > 6$ GeV
$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ topology	$\Delta R_{\ell_0\ell_1} < 2.0$	

CR	Process	Reference SR	Changes w.r.t. reference SR
CRa	$WZ/W\gamma^*$	Z-dominated	≥ 1 SFOS pair with $\lvert m_{\ell\ell} - m_Z \rvert < 25$ GeV
CRb	$Z\gamma$	Z-dominated	no Z-mass veto $\lvert m_{\ell\ell\ell} - m_Z \rvert < 15$ GeV $E_{\mathrm{T}}^{\mathrm{miss}} < 50$ GeV only $eee, \mu\mu e$
CRc	Z+jets	Z-dominated	≥ 1 SFOS pair with $\lvert m_{\ell\ell} - m_Z \rvert < 25$ GeV $E_{\mathrm{T}}^{\mathrm{miss}} < 50$ GeV $\lvert m_{\ell\ell\ell} - m_Z \rvert > 15$ GeV one lepton without an isolation requirement (NFs are derived for e-fake sample and μ-fake sample separately)
CRd	Top quark	Z-dominated	no $m_{\ell^+\ell^-}^{\mathrm{max}}$ and $\Delta R_{\ell_0\ell_1}$ cuts at least 1 jet one b-jet one lepton without an isolation requirement
CRe	Top quark	Z-depleted	no $m_{\ell^+\ell^-}^{\mathrm{max}}$ and $\Delta R_{\ell_0\ell_1}$ cuts at least 1 jet one b-jet one lepton without an isolation requirement

Category	CRa	CRb	CRc e-fake	CRc μ-fake	CRd	CRe
WH	1.0 ± 0.4	0.3 ± 0.0	0.4 ± 0.1	0.5 ± 0.0	0.2 ± 0.1	0.1 ± 0.1
Other Higgs	0.8 ± 0.0	0.0 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
VV	207 ± 15	163 ± 53	156 ± 13	163 ± 14	4.4 ± 0.8	1.0 ± 0.5
VVV	0.9 ± 0.2	0.0 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.2 ± 0.0
Top quark	3.7 ± 0.6	0.4 ± 0.2	7.3 ± 0.9	9.1 ± 1.2	234 ± 19	194 ± 19
Z+jets	2.5 ± 1.2	0.0 ± 0.0	230 ± 83	212 ± 73	2 ± 0.7	0.1 ± 0.1
Total background	215 ± 15	163 ± 52	394 ± 82	385 ± 71	240 ± 20	195 ± 19
Observed	217	163	393	387	241	195

VBF

WH

Result

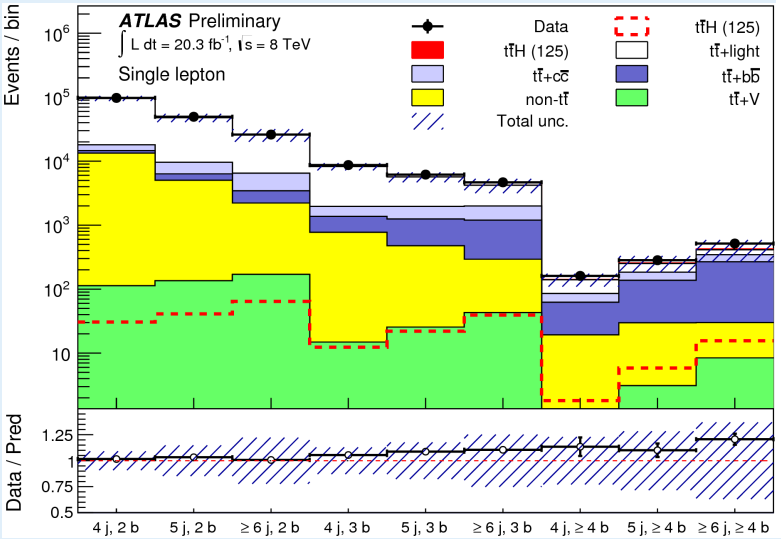
$\mu_{VBF} = 1.7^{+1.1}_{0.9}$

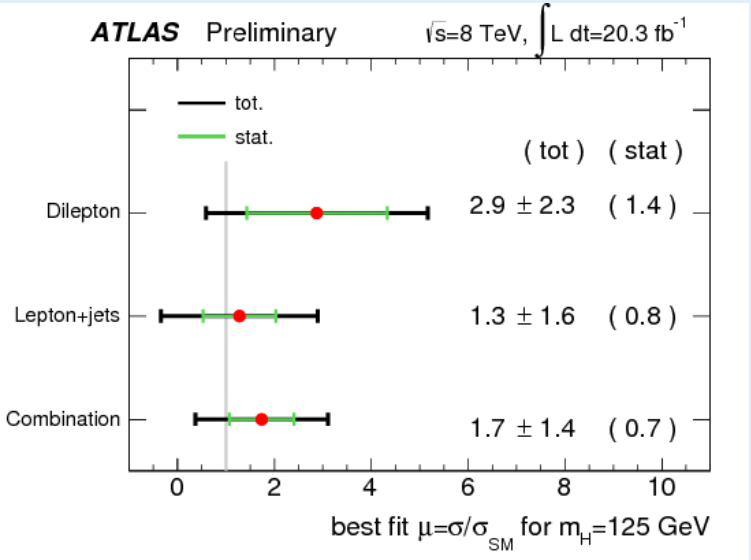
$\mu_{WH} = 3.2^{+4.4}_{4.2}$

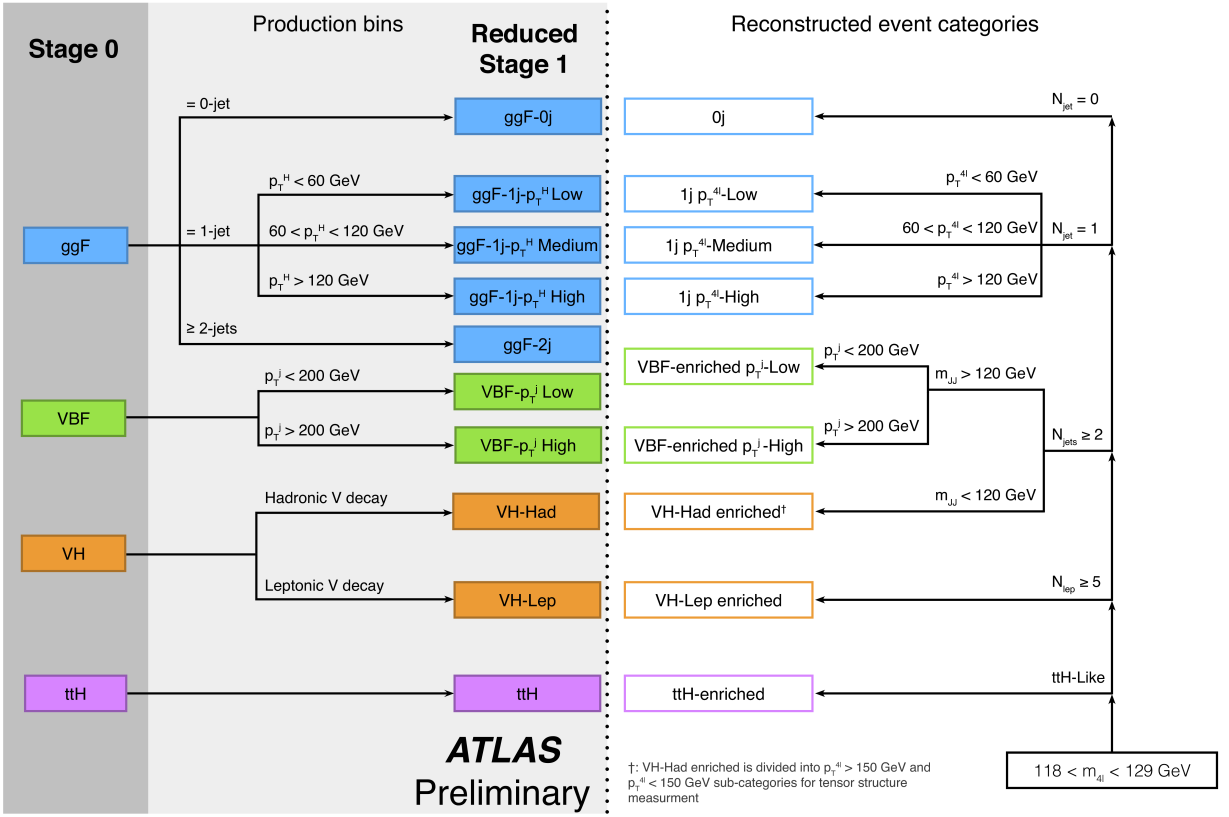
Search for the Standard Model Higgs boson produced in association with top quarks and decaying into $b\bar{b}$ in pp collisions at $\sqrt{s} = 8\,TeV$

Basic selection

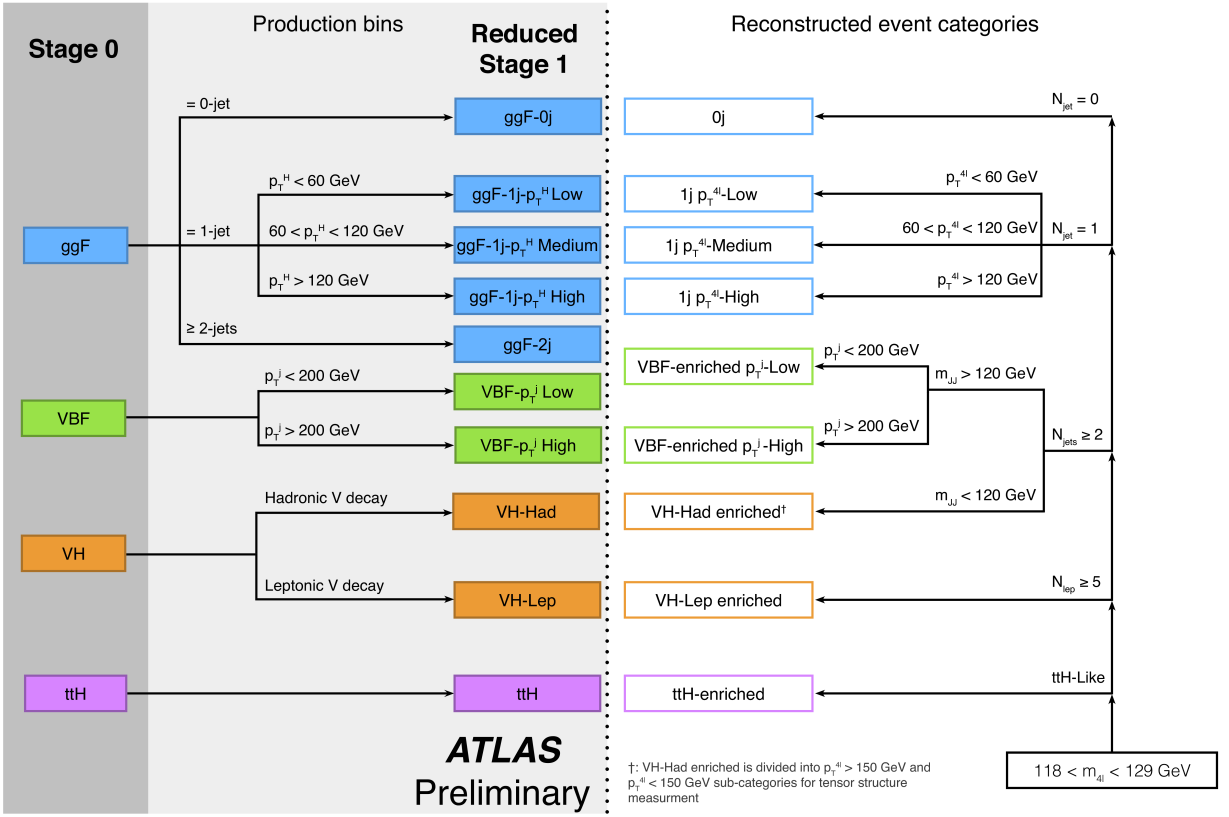
- ttbar selection
- Require additional b-jet
- Split the analyses according to the number of jets






Stage 0
Production bins
Reduced Stage 1
Reconstructed event categories
ggF
VBF
VH
ttH
= 0-jet
= 1-jet
≥ 2-jets
p_T^H < 60 GeV
60 < p_T^H < 120 GeV
p_T^H > 120 GeV
p_T^j < 200 GeV
p_T^j > 200 GeV
Hadronic V decay
Leptonic V decay
ggF-0j
ggF-1j-p_T^H Low
ggF-1j-p_T^H Medium
ggF-1j-p_T^H High
ggF-2j
VBF-p_T^j Low
VBF-p_T^j High
VH-Had
VH-Lep
ttH
0j
1j p_T^{4l}-Low
1j p_T^{4l}-Medium
1j p_T^{4l}-High
VBF-enriched p_T^j-Low
VBF-enriched p_T^j-High
VH-Had enriched†
VH-Lep enriched
ttH-enriched
N_{jet} = 0
N_{jet} = 1
N_{jets} ≥ 2
N_{lep} ≥ 5
ttH-Like
p_T^{4l} < 60 GeV
60 < p_T^{4l} < 120 GeV
p_T^{4l} > 120 GeV
p_T^j < 200 GeV
p_T^j > 200 GeV
m_{JJ} > 120 GeV
m_{JJ} < 120 GeV
118 < m_{4l} < 129 GeV
ATLAS
Preliminary
†: VH-Had enriched is divided into p_T^{4l} > 150 GeV and p_T^{4l} < 150 GeV sub-categories for tensor structure measurment

Leptons and jets	
Muons:	$p_T > 5$ GeV, $\|\eta\| < 2.7$
Electrons:	$p_T > 7$ GeV, $\|\eta\| < 2.47$
Jets:	$p_T > 30$ GeV, $\|y\| < 4.4$
Jet-lepton overlap removal:	$\Delta R(\text{jet}, \ell) > 0.1\,(0.2)$ for muons (electrons)
Lepton selection and pairing	
Lepton kinematics:	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12}):	SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Subleading pair (m_{34}):	remaining SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection (at most one quadruplet per channel)	
Mass requirements:	$50 < m_{12} < 106$ GeV and $12 < m_{34} < 115$ GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1\,(0.2)$ for same- (different-) flavour leptons
J/ψ veto:	$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
Mass window:	115 $GeV < m_{4\ell} < 130$ GeV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VBF-p_T^j Low
VBF-p_T^j High
VH-Had
VH-Lep
ttH
0j
1j p_T^{4l}-Low
1j p_T^{4l}-Medium
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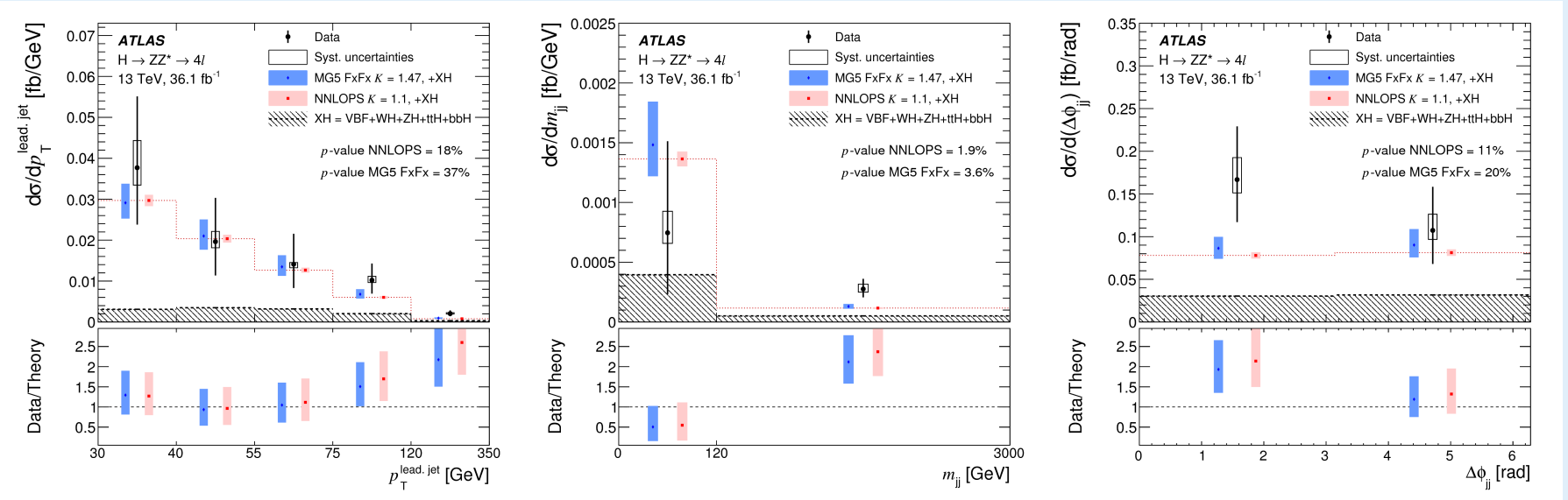
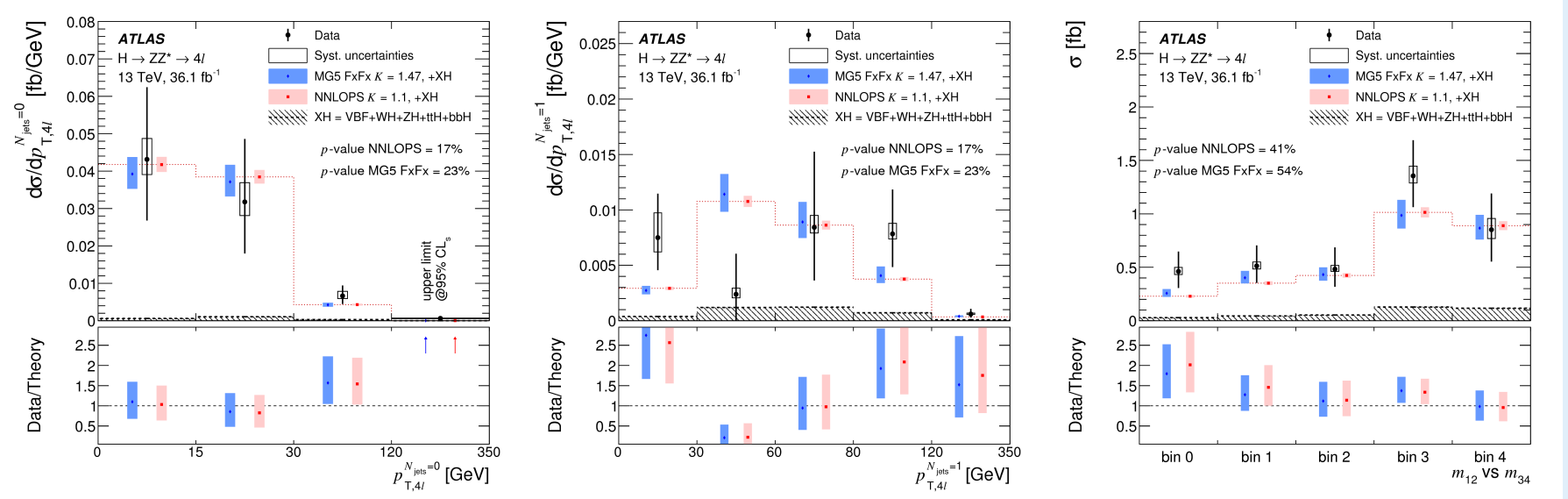
$H \to ZZ^* \to 4l$

arXiv:1708.02810




ATLAS
H → ZZ* → 4l
13 TeV, 36.1 fb-1
Data
Syst. uncertainties
MG5 FxFx κ = 1.47, +XH
NNLOPS κ = 1.1, +XH
XH = VBF+WH+ZH+ttH+bbH
p-value NNLOPS = 17%
p-value MG5 FxFx = 23%
upper limit @95% CLs
dσ/dp_T,4l^N_jets=0 [fb/GeV]
Data/Theory
p_T,4l^N_jets=0 [GeV]
dσ/dp_T,4l^N_jets=1 [fb/GeV]
p_T,4l^N_jets=1 [GeV]
p-value NNLOPS = 41%
p-value MG5 FxFx = 54%
σ [fb]
bin 0
bin 1
bin 2
bin 3
bin 4
m12 vs m34