H(126) @ ATLAS

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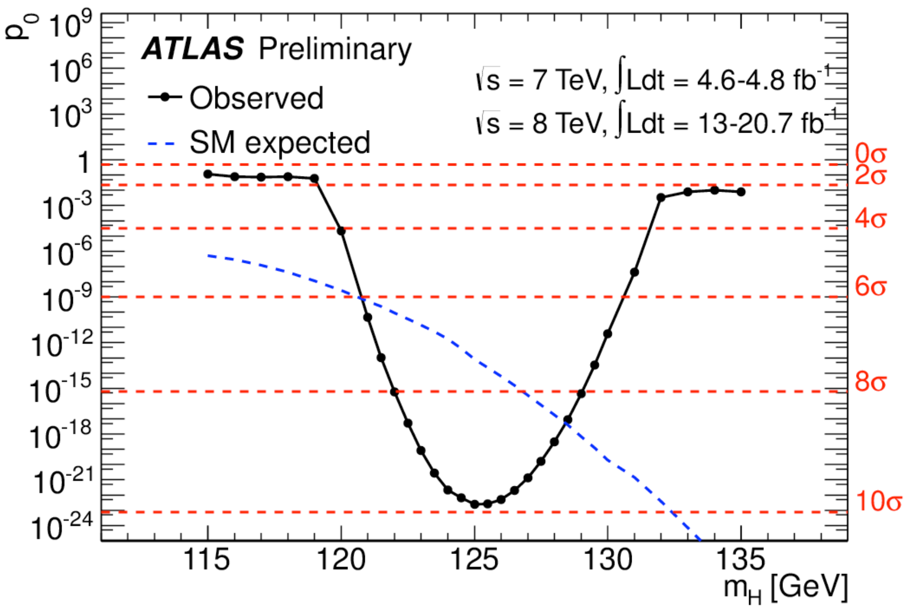
Outline:

Introduction

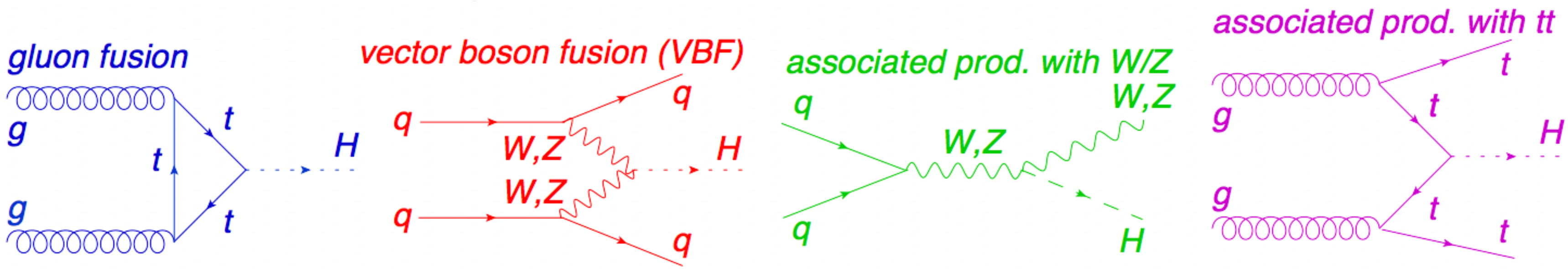
Recent results on Higgs searches

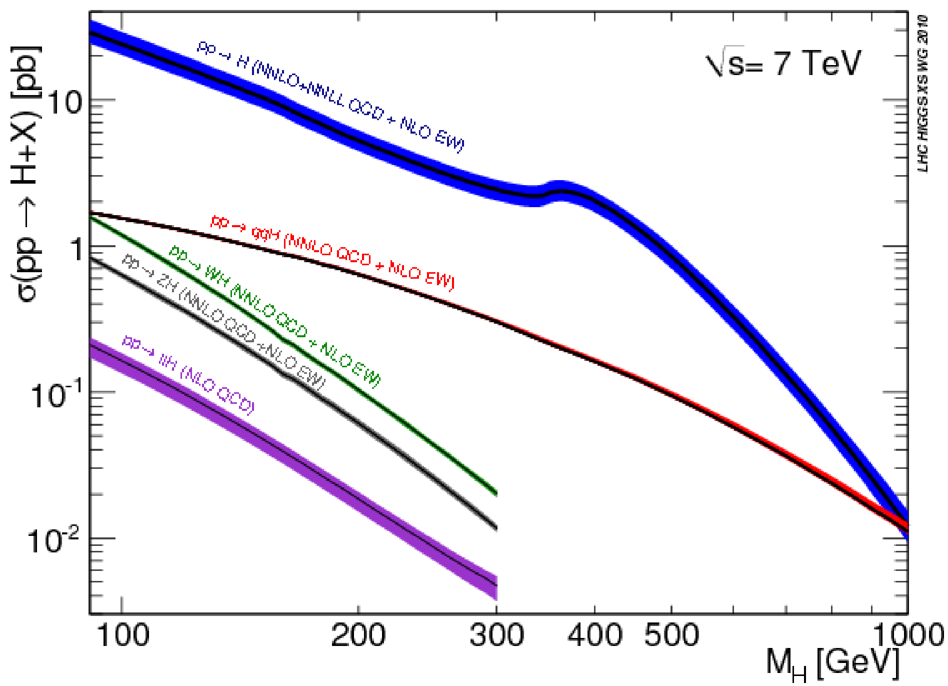
Recent results on Higgs properties

Summary

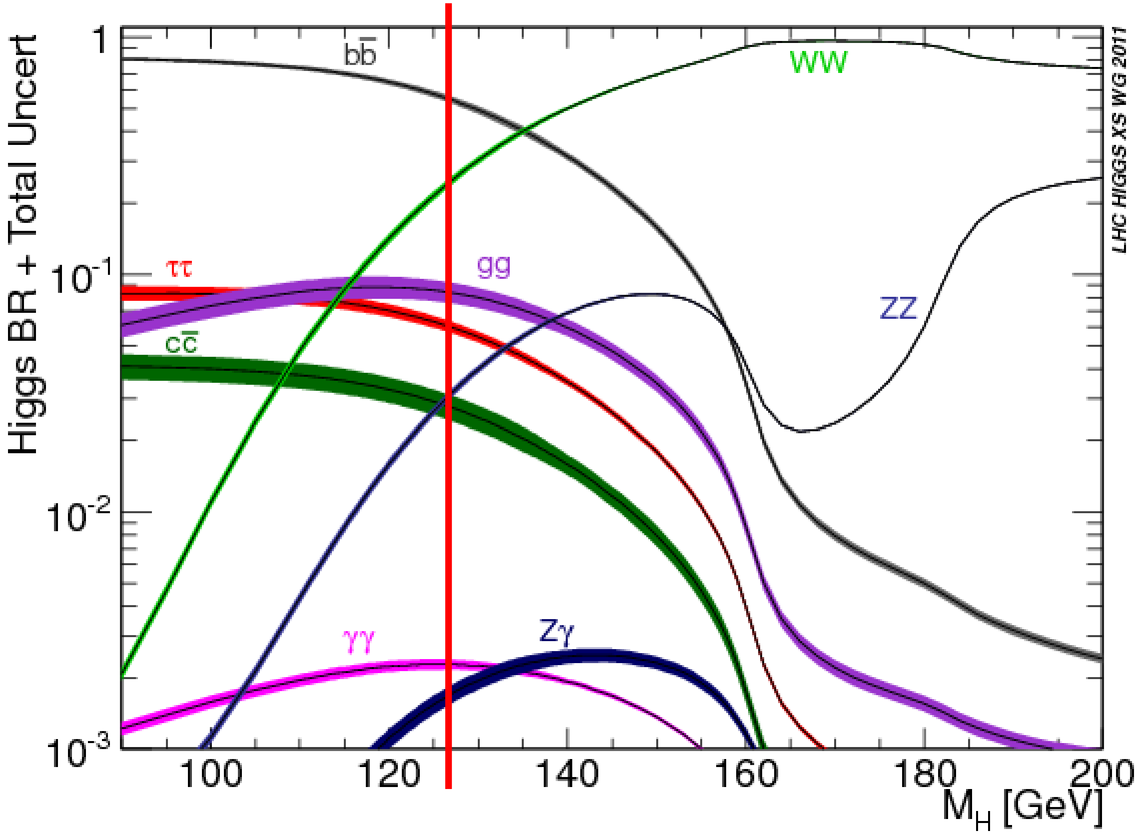


Production


gluon fusion
g
g
t
t
t
H
vector boson fusion (VBF)
q
q
W,Z
W,Z
q
q
H
associated prod. with W/Z
q
q
W,Z
W,Z
H
associated prod. with tt
g
g
t
t
t
t
H


√s= 7 TeV
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD + NLO EW)
pp → WH (NNLO QCD + NLO EW)
pp → ZH (NNLO QCD +NLO EW)
pp → ttH (NLO QCD)
LHC HIGGS XS WG 2010
σ(pp → H+X) [pb]
10
1
10^{-1}
10^{-2}
100
200
300
400
500
1000
M_H [GeV]

Decay



126 GeV a good place to be with many accessible channels

Combined measurements across many production and decay modes gives access to ratio's of couplings

Introduction

Search channels largely defined by predicted production and decay in SM (+benchmark BSM) and expected ability to detect a signal above background

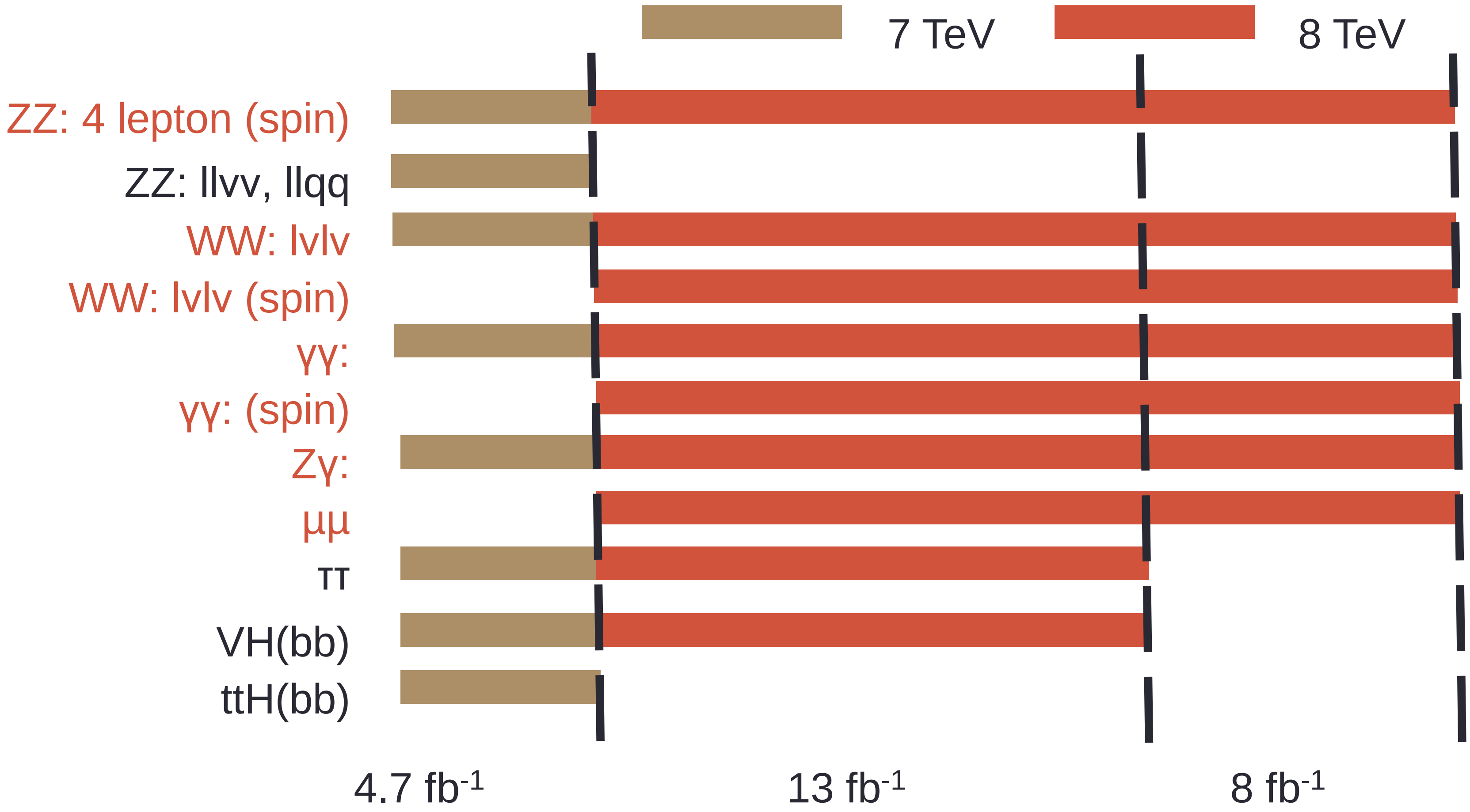
Original emphasis – many channels, maximise sensitivity to SM

Channel	ggF	VBF	VH	ttH	Spin	Mass
$\gamma\gamma$	✓	✓	✓		✓	✓
$Z \to 4l$	✓	✓	✓		✓	✓
$WW \to l\upsilon l\upsilon$	✓	✓			✓	
$Z\gamma$	✓					
$\tau\tau$	✓	✓	✓			
$\mu\mu$	✓					
bb			✓	✓		

Beyond discovery emphasise precise measurement and distinguish between different production modes by looking for extra signatures, leptons, jets, MET

Continue to search for additional Higgs bosons.

Data sets for SM Analyses



Updated at Winter Conferences this year

ATLAS-CONF-2013-013

Higgs to 4 leptons

Updated for winter conferences with full $25fb^{-1}$ data set

Golden channel – clear signature and low background

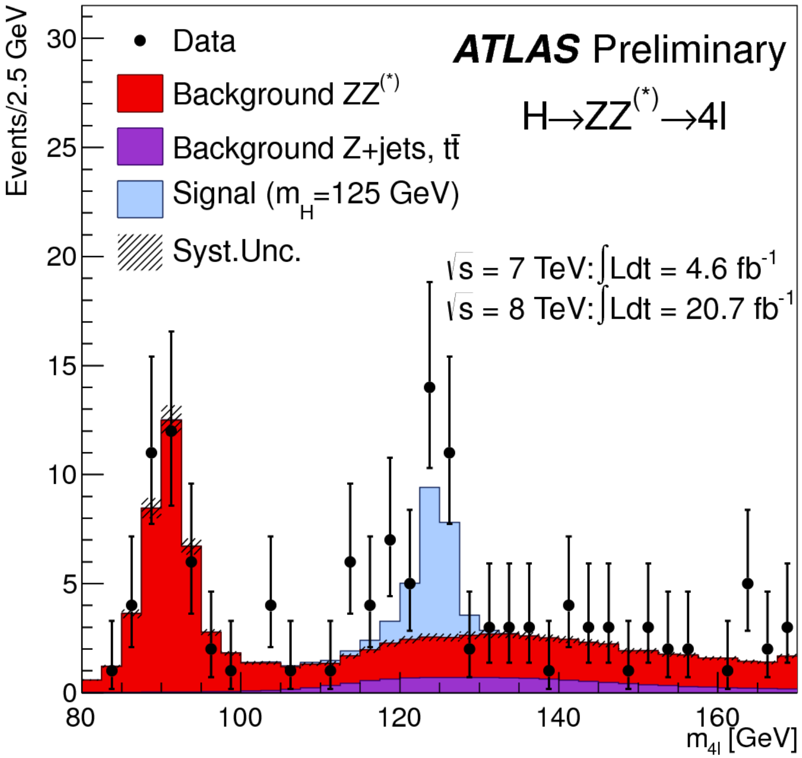
S/B ~ 1.4

4 final states:
4e, 4μ, 2e2μ, 2μ2e

Single and double lepton triggers

At least 2 pairs same flavour opposite sign isolated leptons

One tight, one loose Z mass constraint



ATLAS-CONF-2013-013

Higgs to 4 leptons

Updated for winter conferences with full 25fb^{-1} data set

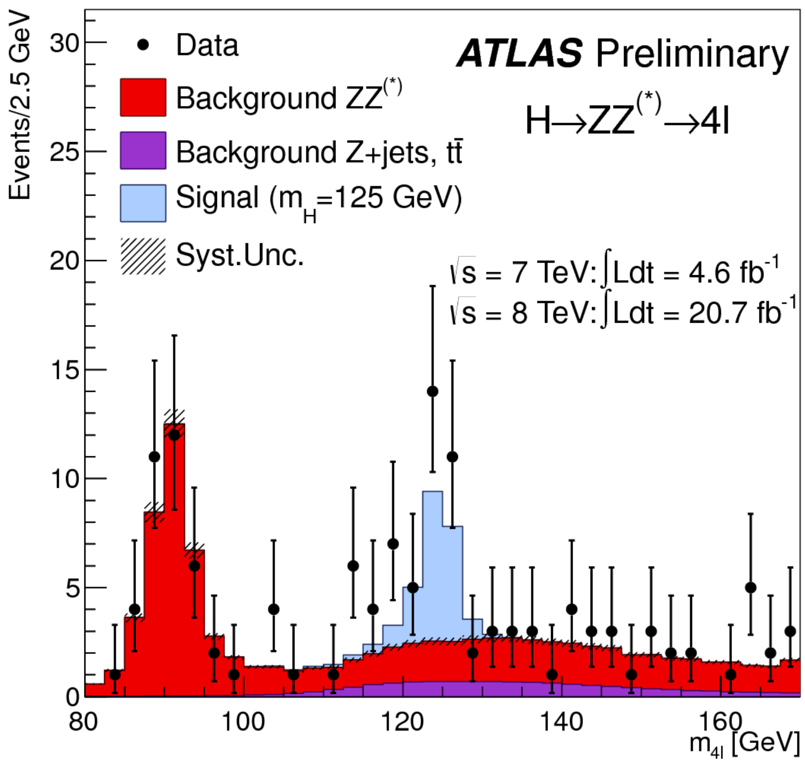
Golden channel – clear signature and low background

S/B ~ 1.4

Updates since end of last year:

improved lepton pair selection
loosened 2nd Z mass constraint
and improved treatment of FSR

New categorizations:
VBF-like : jet tags
VH-like: extra lepton tag



ATLAS-CONF-2013-013

Higgs to 4 leptons

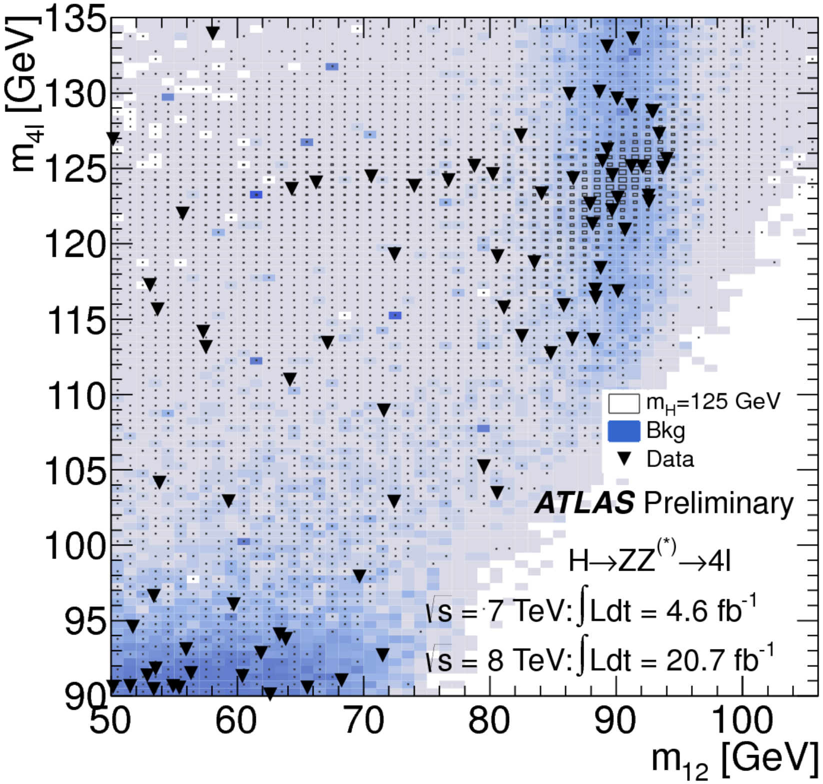
Extract signal from 4-lepton invariant mass

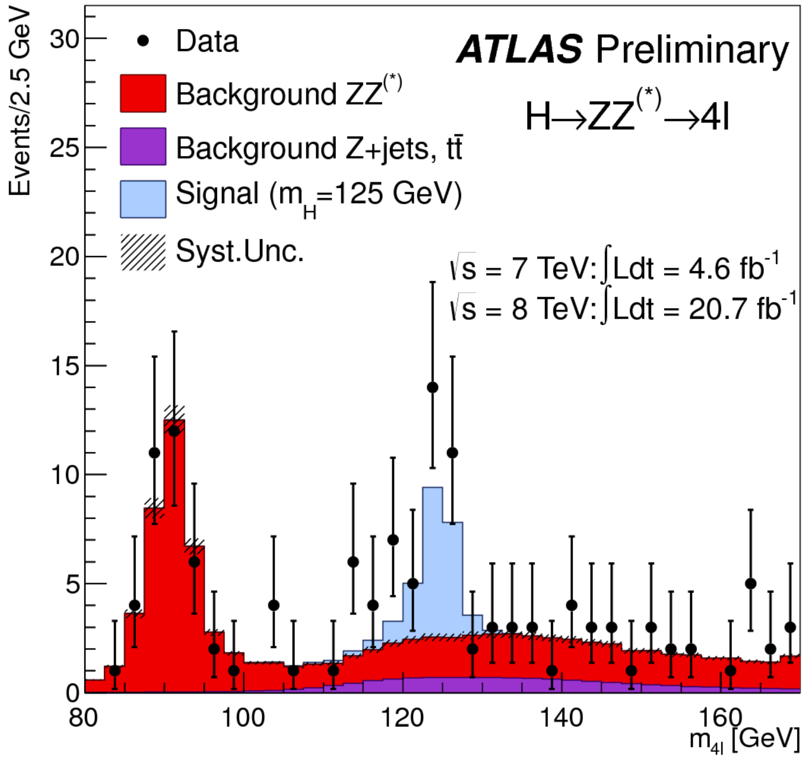
Main backgrounds:

SM ZZ* production (irreducible, from MC)

Top, Z+jets (reducible, data driven techniques)

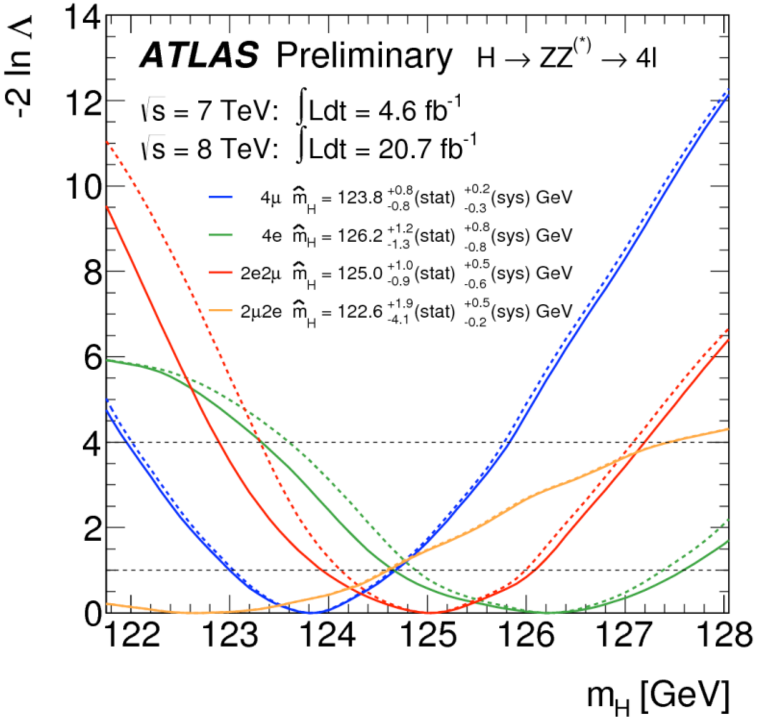
S/B ~ 1.4



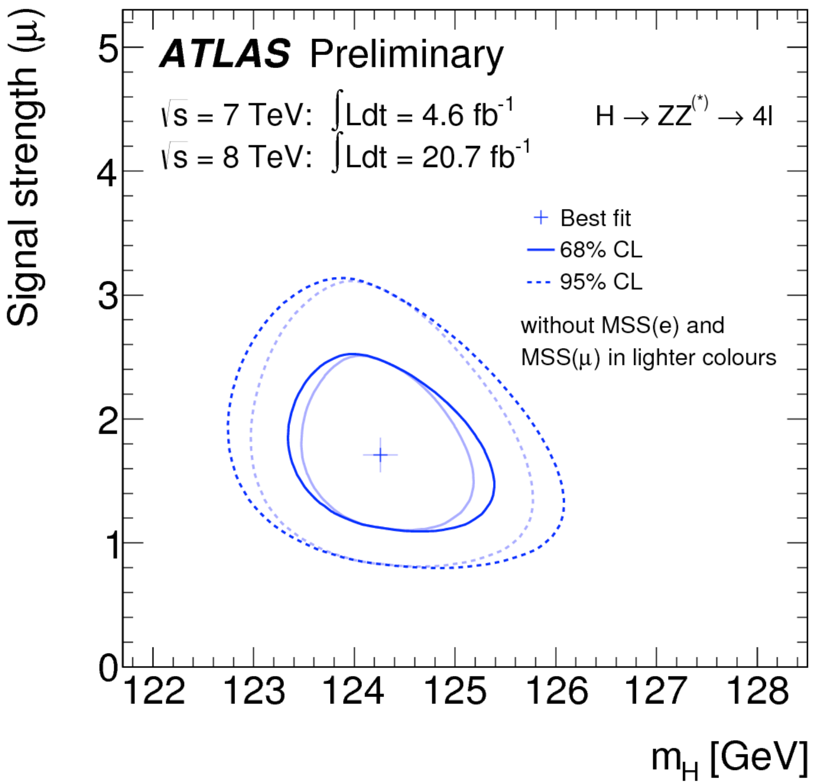


ATLAS-CONF-2013-013

Higgs to 4 leptons



Significance now **6.6σ** (SM expectation 4.4σ)



m_H = 124.3 ± 0.6 (stat) ± 0.4 (syst) GeV

$\mu(124.3) = 1.7^{+0.5}_{-0.4}$

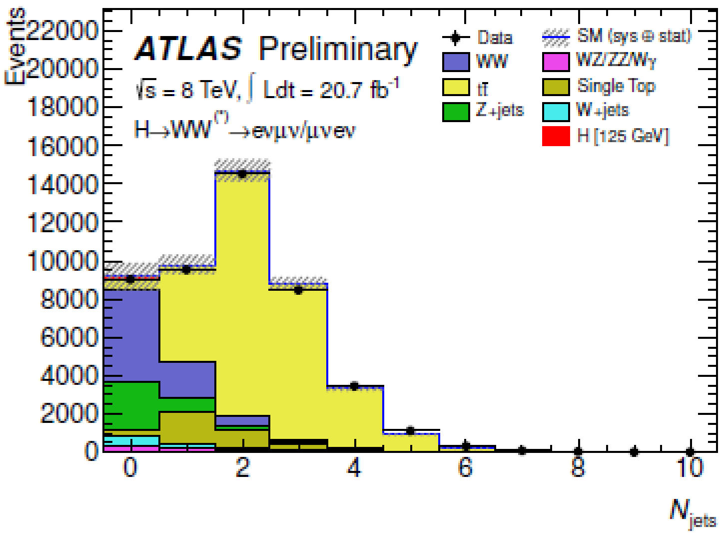
One VBF-tag event at 123.5 GeV, expect 0.4 from SM (in low mass region)

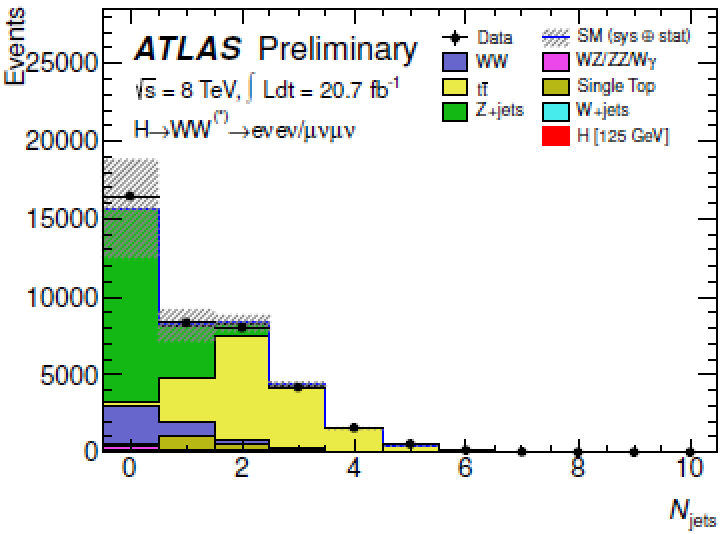
ATLAS-CONF-2013-030

Higgs to 2 leptons and 2 neutrinos

Select for 2 OS leptons (e or μ) + missing ET + VBF jet tagging for Njets>=2

Categorize according to lepton flavour, jet multiplicity and dilepton mass: varying backgrounds, S/B and sensitivity to production modes





For Njets=0,1 ggF dominates production
For Njets>=2, additional jet requirements mean VBF dominates
(VH included in signal model but effectively negligible)

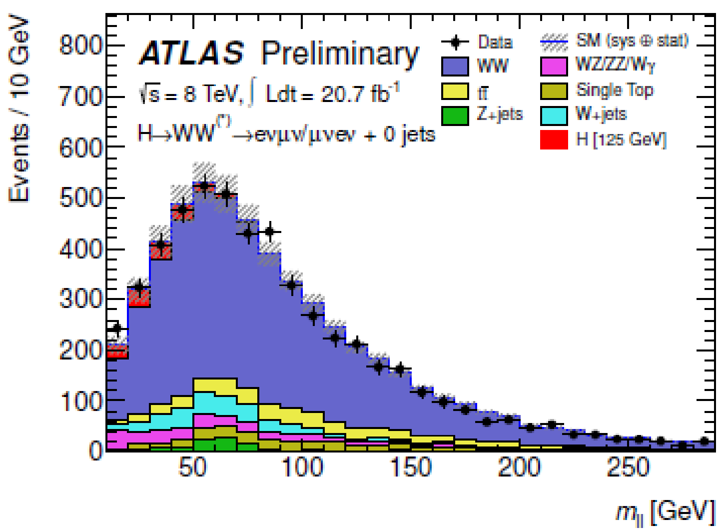
ATLAS-CONF-2013-030

Higgs to 2 leptons and 2 neutrinos

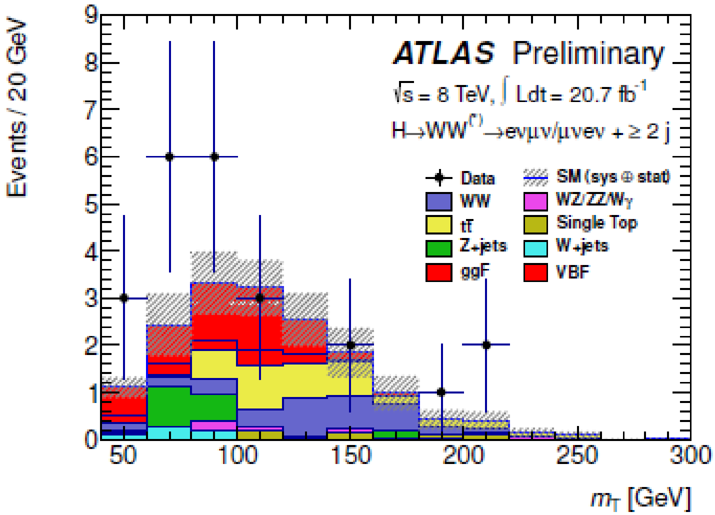
Select for 2 OS leptons (e or μ) + missing ET + VBF jet tagging for Njets>=2

Updated since Dec-12

- Same flavour channels
- VBF tag category
- Optimised lepton cuts
- Additional categorisation
- Optimised control regions
- Reanalysis of 7TeV sample



(a) $m_{\ell\ell}$ for $N_{\rm jet}=0$, $e\mu+\mu e$

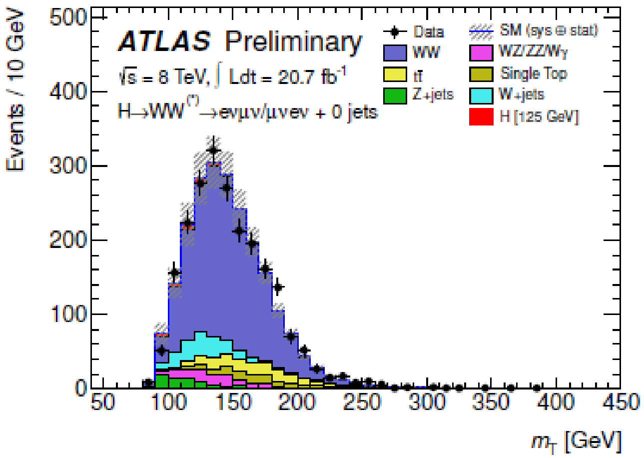


(e) $m_{\rm T}$ for $N_{\rm jet}\geq 2$, $e\mu+\mu e$

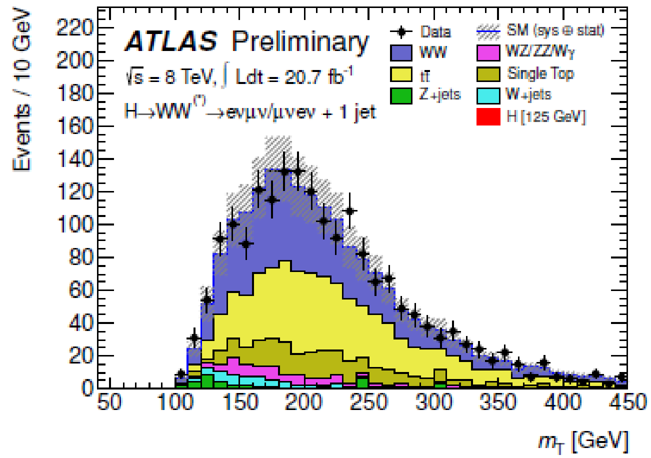
ATLAS-CONF-2013-030

Higgs to 2 leptons and 2 neutrinos

Dominant (WW, top, ττ) backgrounds modelled with MC normalised in control regions



(a) m_T for $N_{jet} = 0$

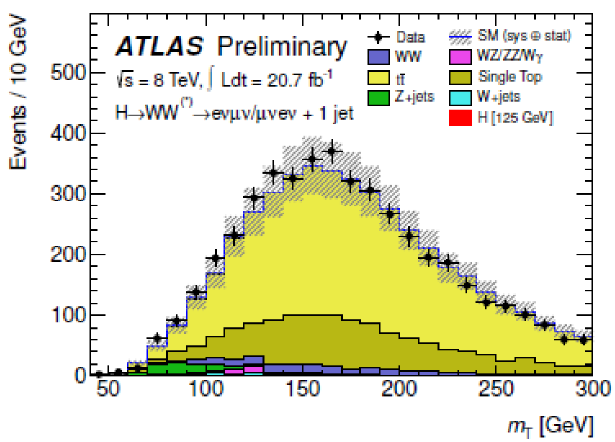


(b) m_T for $N_{jet} = 1$

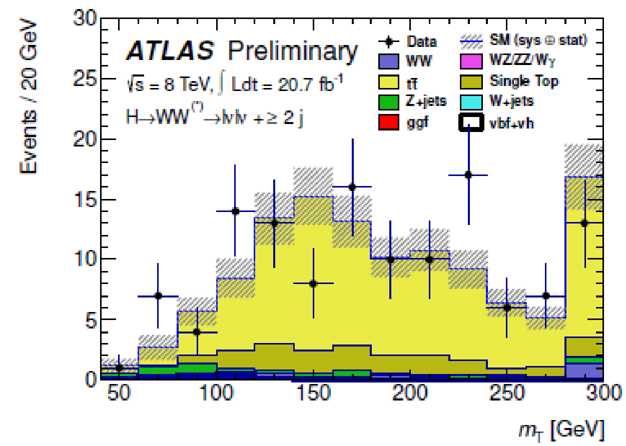
W+jets from data driven method

Z/γ* backgrounds suppressed with cuts on MET, m_{ll}, and recoil

From MC for OF
Data driven for SF



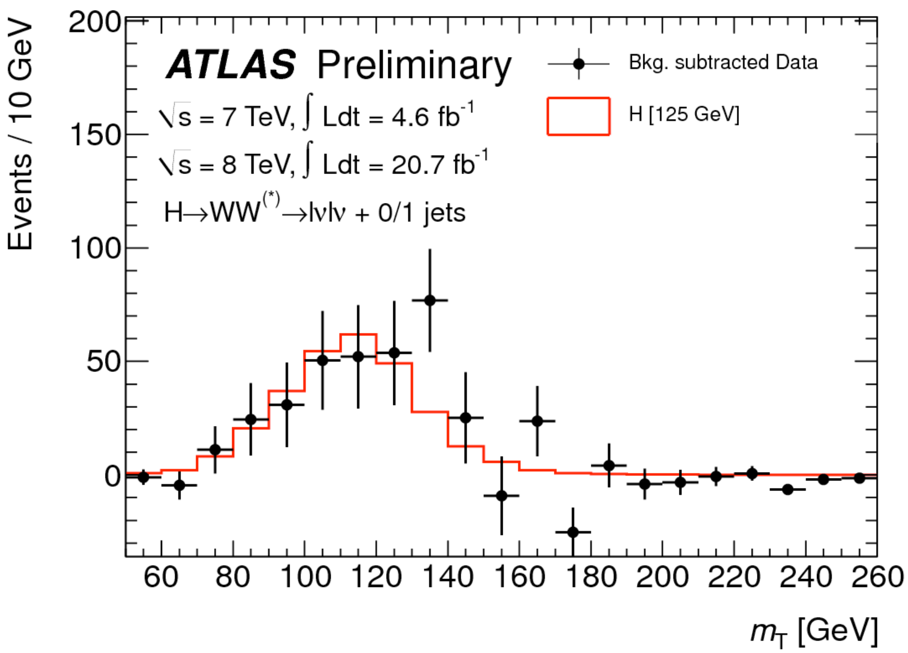
(a) $N_{jet} = 1$



(b) $N_{jet} \geq 2$

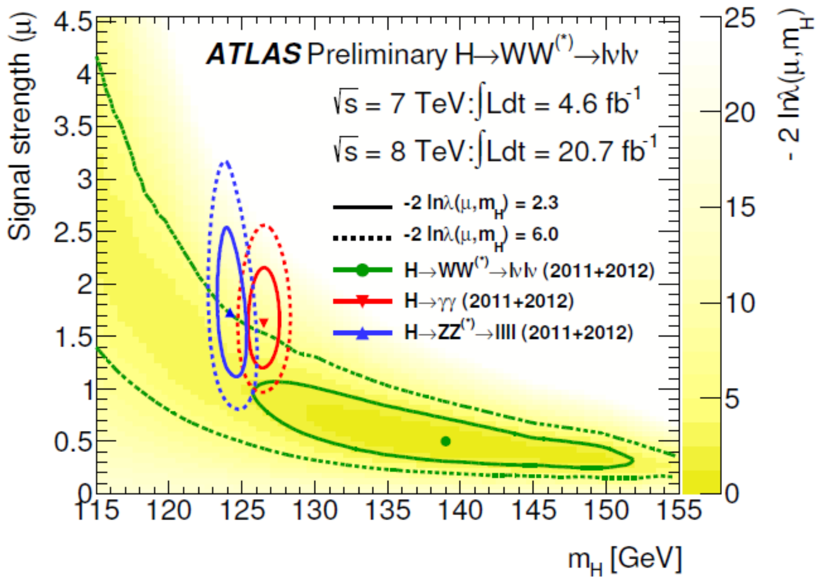
ATLAS-CONF-2013-030

Higgs to 2 leptons and 2 neutrinos



Highest significance at M_H=140, 4.1σ

Significance at M_H=125, 3.8σ



At M_H=125

μ_{obs} = 1.01 ± 0.21(stat) ± 0.19 (theo) ± 0.12 (exp) + 0.04 (lumi)

Dominant theory uncertainties from WW background and signal yields

ATLAS-CONF-2013-030

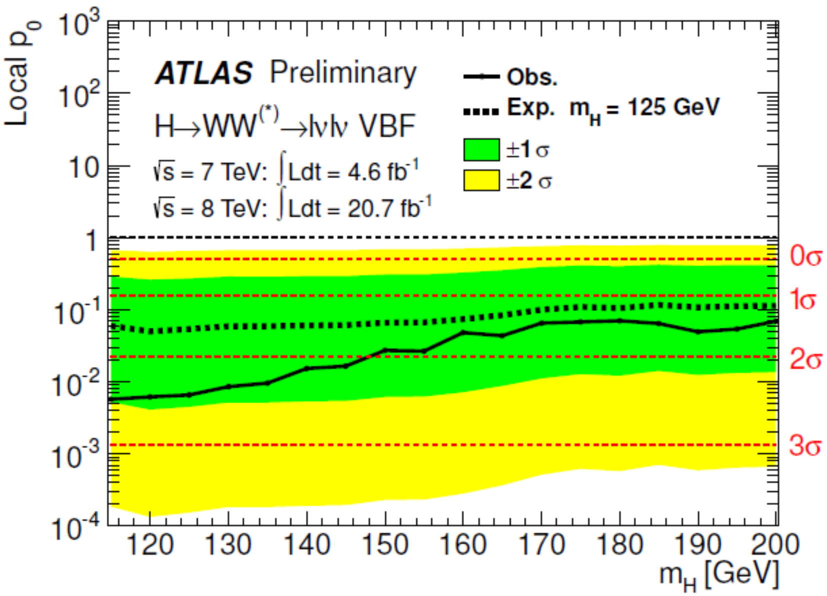
Higgs to 2 leptons and 2 neutrinos

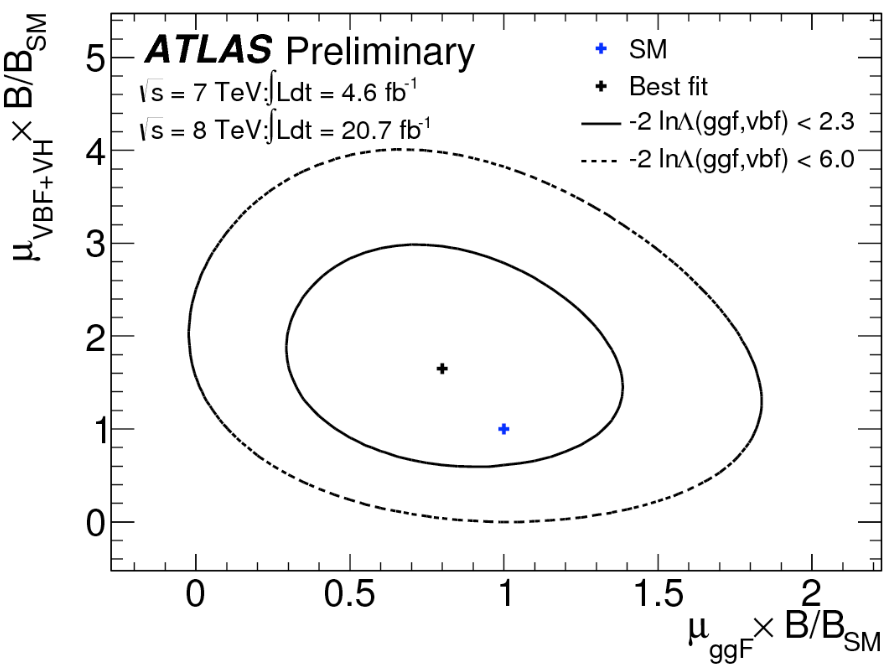
Fit for VBF, profiling ggF as background:

$\mu^{VBF}_{obs} = 1.66 \pm 0.67(stat) \pm 0.42\ (syst)$

Fit for ggF, profiling VBF as background:

$\mu^{ggF}_{obs} = 0.82 \pm 0.24(stat) \pm 0.28\ (syst)$





ATLAS-CONF-2013-012

Higgs to photons

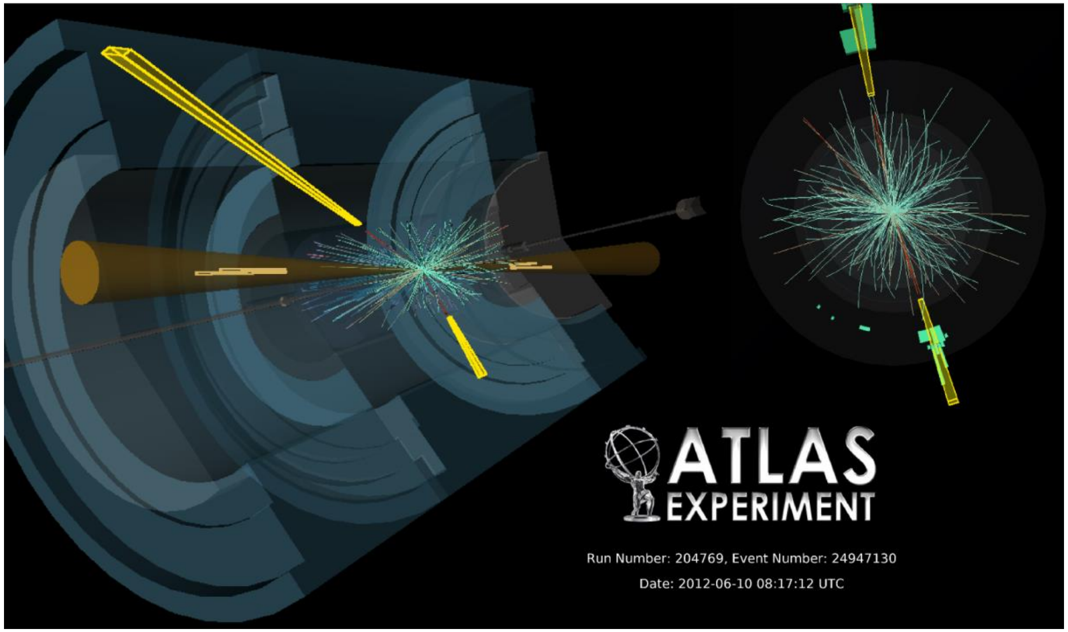
Low BR but clean signature of isolated di-photons

Large diphoton backgrounds mitigated by excellent mass resolution ~1.8 GeV

Select events with two high pT isolated photons

Categorize events for resolution, S/B and production mode

Signal extracted from fits to diphoton invariant mass



ATLAS-CONF-2013-012

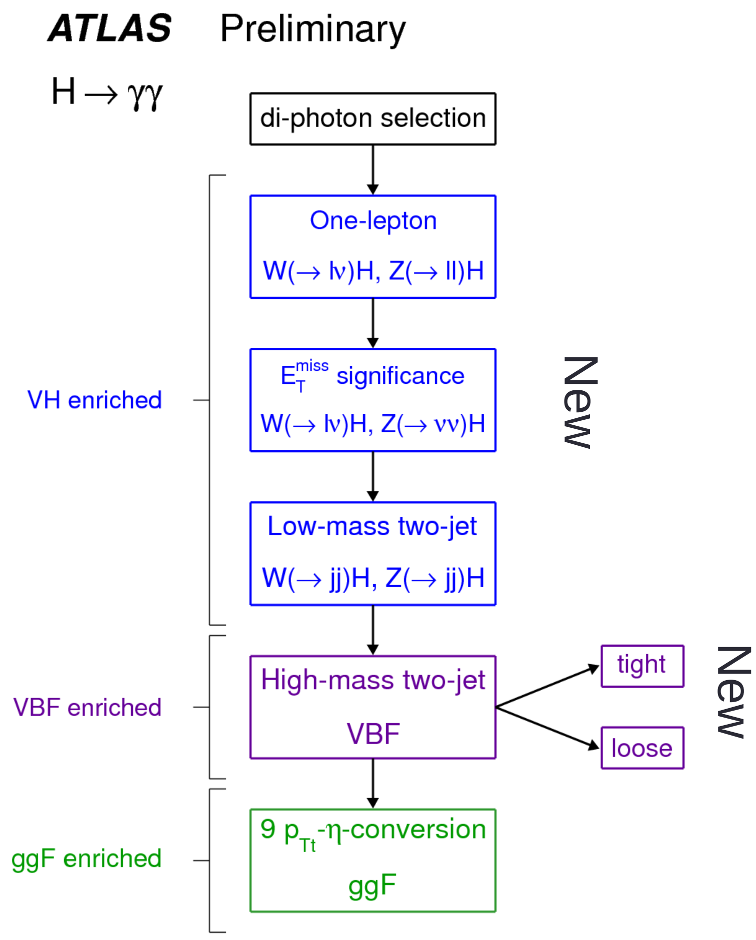
Higgs to photons

Low BR but clean signature of isolated di-photons

Improvements since Dec-2012

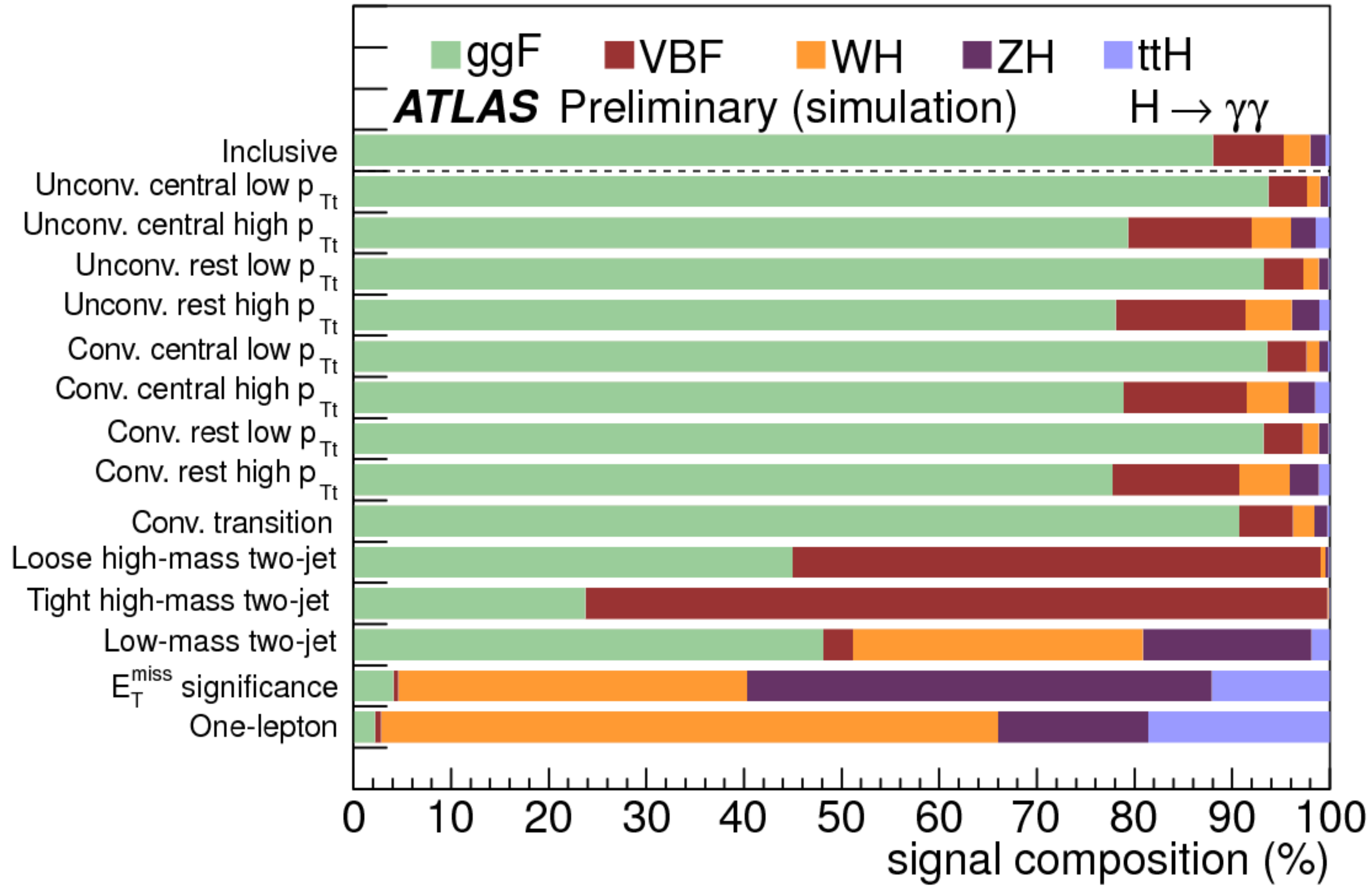
Improved categorisation for VH+VBF
Fiducial cross section measurement
Reduced uncertainties

Lepton and jet tags for VH
and VBF sensitivity



ATLAS-CONF-2013-012

Higgs to photons



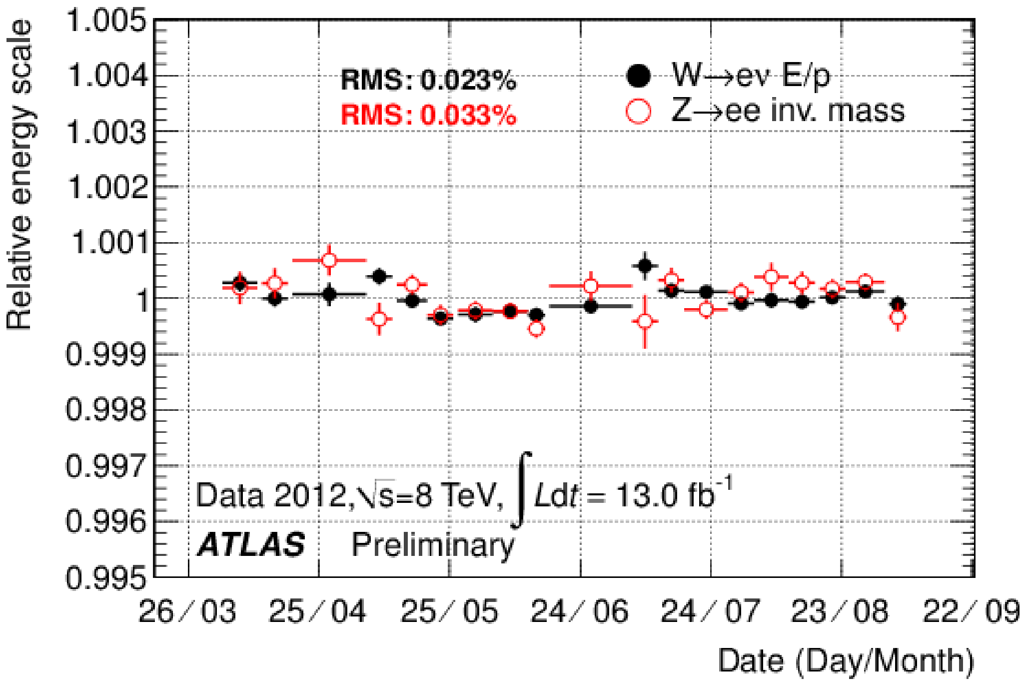
ATLAS-CONF-2013-012

Higgs to photons

Energy scale key to mass measurement
Important when combining many categories

Derived from tuned MC + dielectron and Zγ data

Calorimeter response stable at 0.1% level wrt. time/pile-up



Overall scale uncertainty ~0.6%
Driven by material modelling
and errors on in-situ calibration

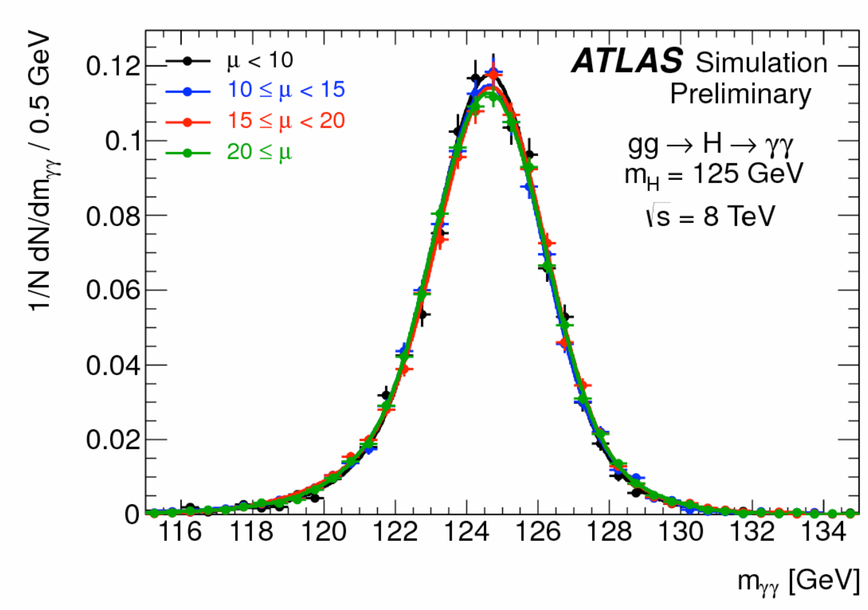
ATLAS-CONF-2013-012

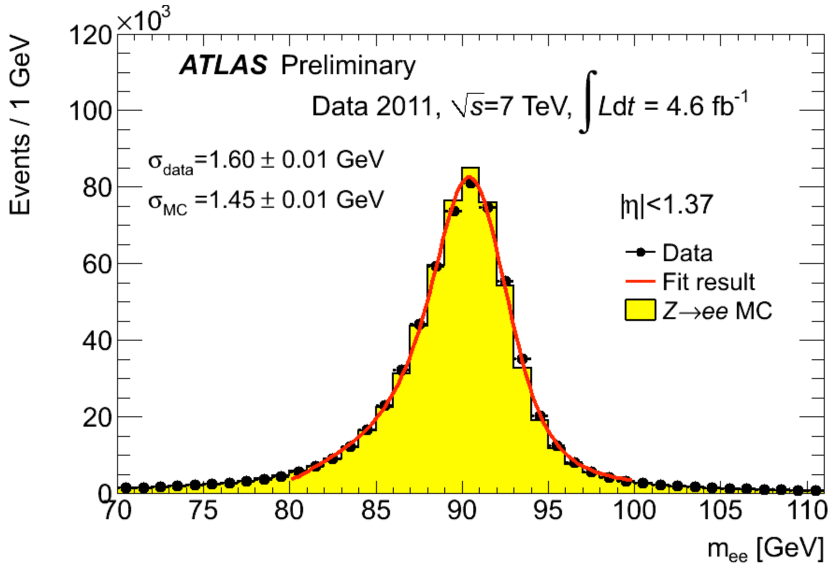
Higgs to photons

Mass resolution critical to sensitivity

Photon energy resolution
Vertex identification
- photon pointing

Additional constant-term smearing in MC derived from Z studies with electrons:
1% central, 1.5-2.5% forward





Uncertainty on photon resolution 14-23%

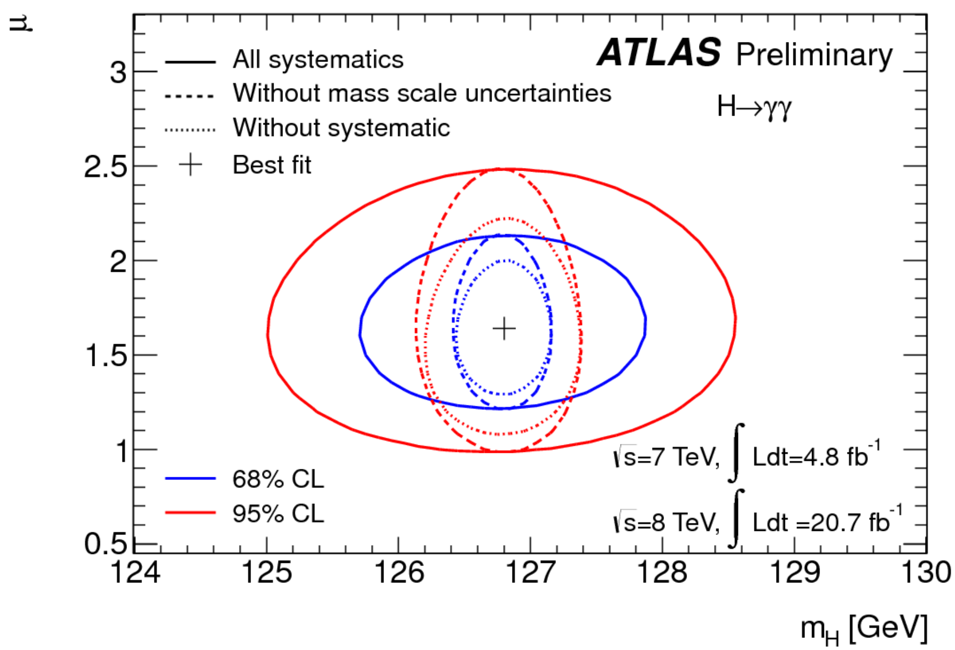
ATLAS-CONF-2013-012

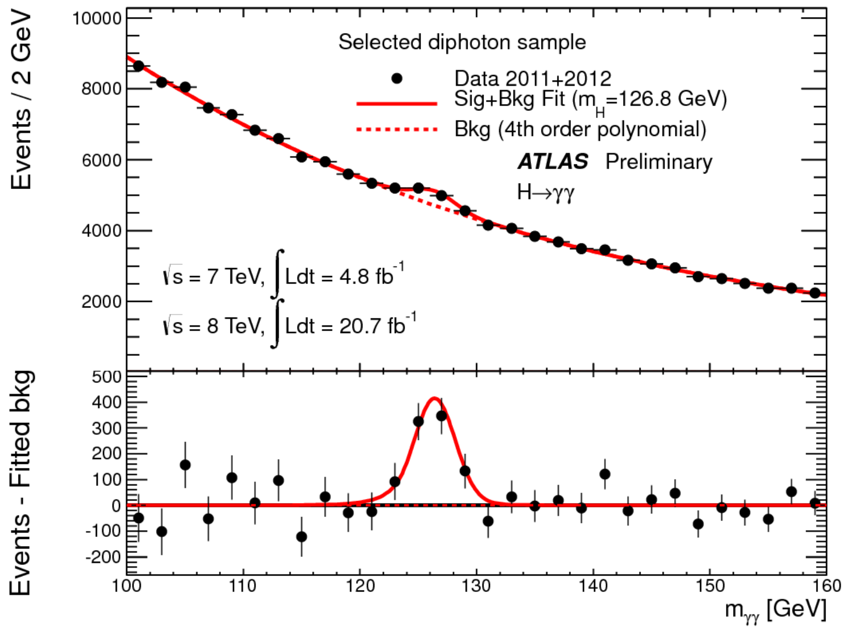
Higgs to photons

Observed significance 7.4σ (4.1σ exp.)

$\mu = 1.65 \pm 0.24(\text{stat}) \pm 0.22(\text{syst})$

Consistent with SM at 2.3σ





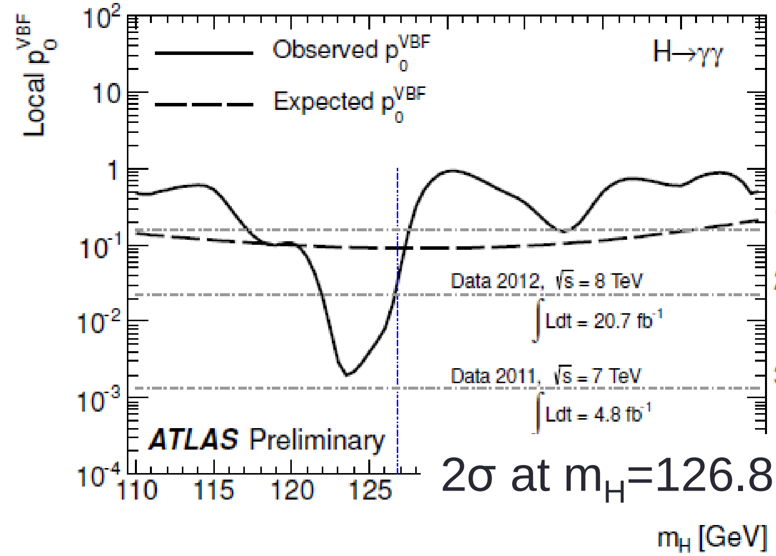
$m_H = 126.8 \pm 0.2(\text{stat}) \pm 0.7(\text{syst})$ GeV

Fit prefers mass 1.8σ narrower than nominal. Better than a perfectly uniform calorimeter. Probably due to background fluctuation. 10% lower yield if no fit of resolution.

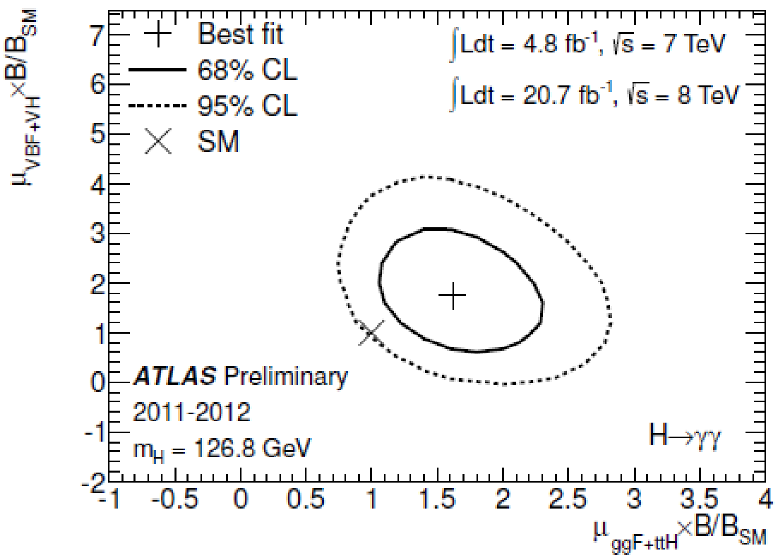
ATLAS-CONF-2013-012

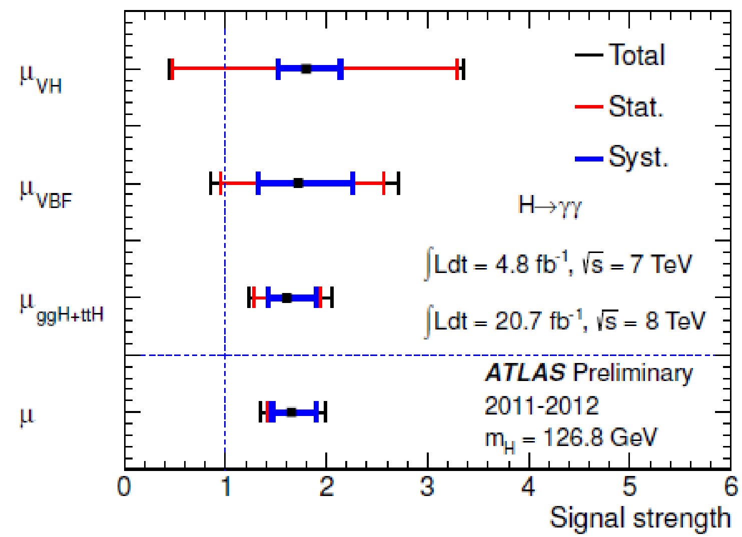
Higgs to photons

Exploit VBF categories to extract signal strength assuming ggF is background



2σ at m_H=126.8 GeV





Fiducial cross section: 8TeV data:
$|\eta| < 2.37$, $p_T\gamma > 40/30$ GeV

$\sigma_{fid} \times BR = 56.2 \pm 12.5$ fb [$\pm$10.5(stat) $\pm$ 6.5(syst) $\pm$ 2.0(lumi)]

ATLAS-CONF-2013-010

Higgs to muons

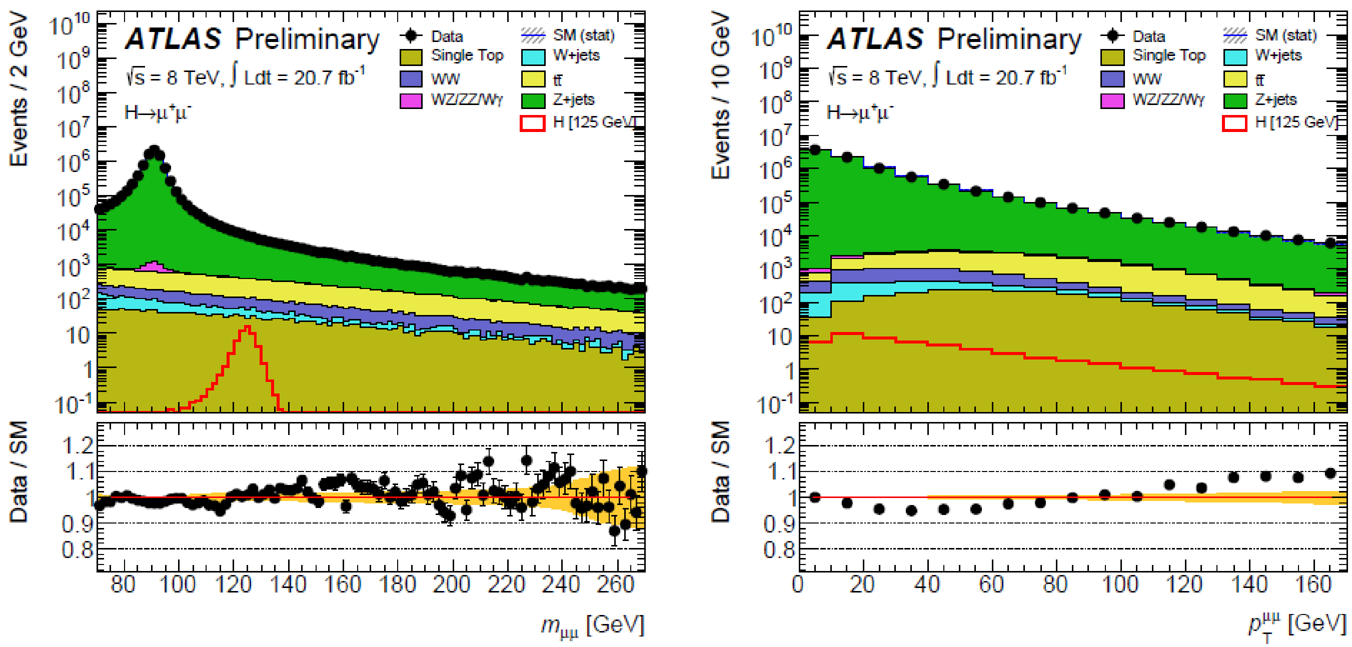
Probe Yukawa interactions for second generation fermions

Select events with two OS isolated high pT muons

Huge Z/γ* background dominates

Extract signal from dimuon mass spectrum

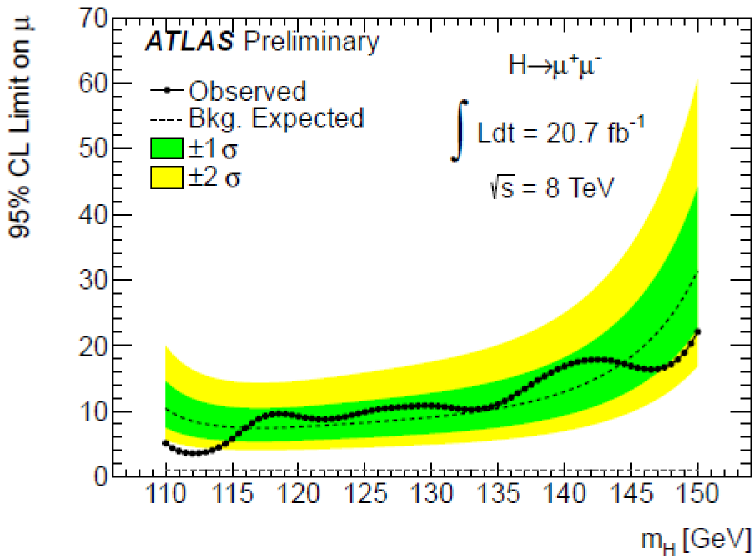
Mass resolution ~2.3 GeV @ 125

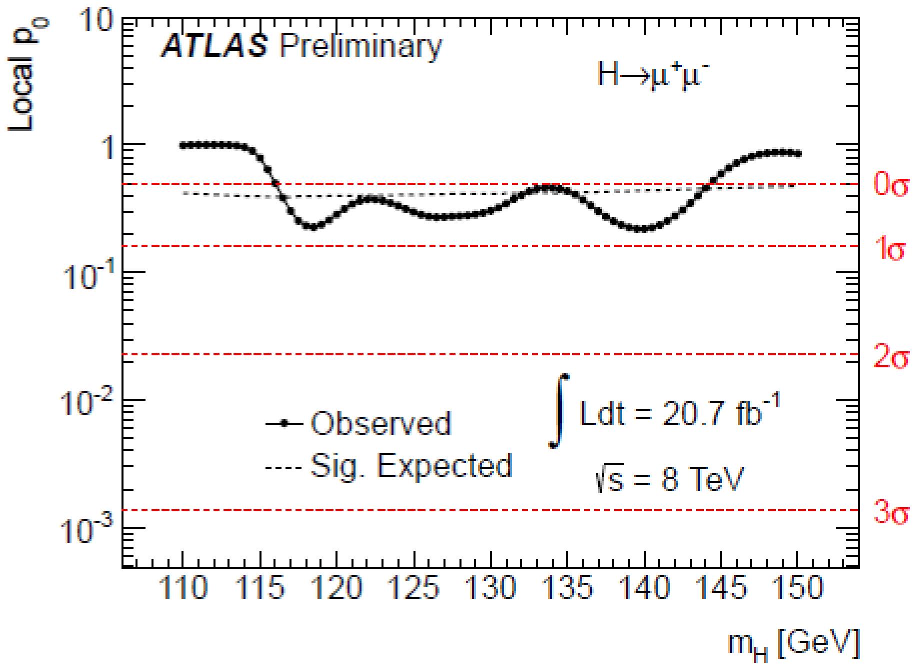


ATLAS-CONF-2013-010

Higgs to muons

Probe Yukawa interactions for second generation fermions





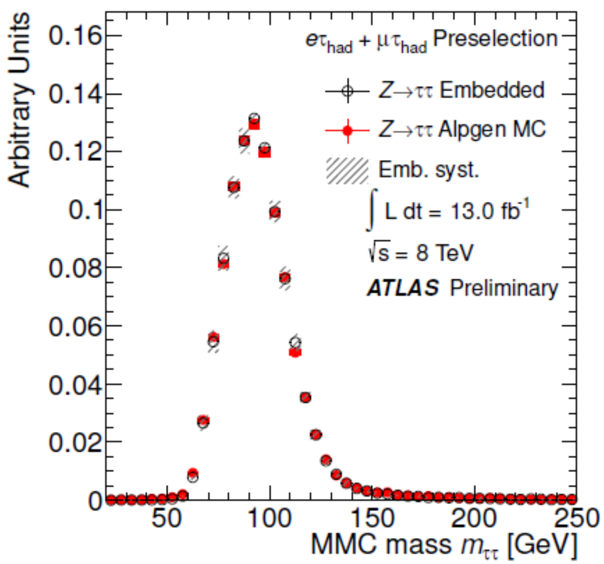
No evidence for a signal at present
Not yet sensitive to SM rates

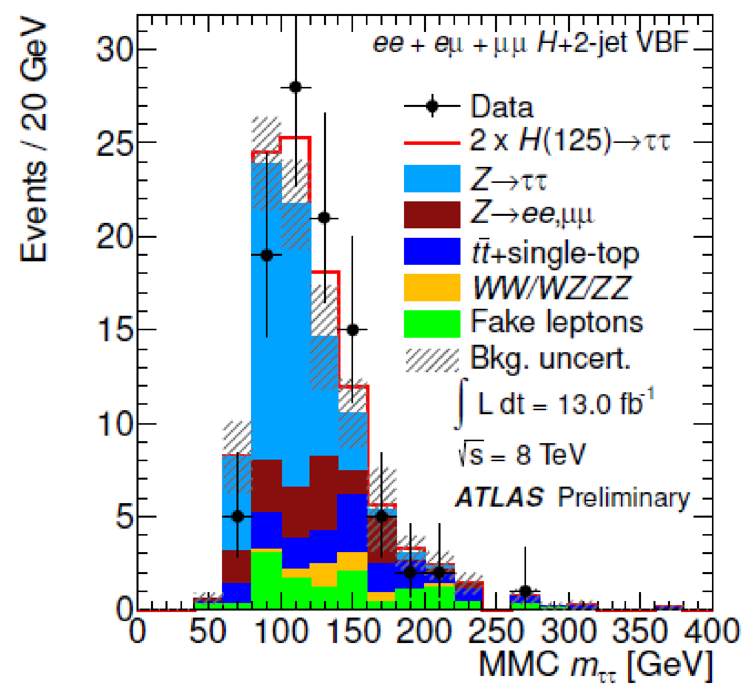
ATLAS-CONF-2012-160

Higgs to taus

Select events with two opposite sign tau candidates – 0,1 or 2 leptonic decays

Categorize according to lepton and jet multiplicities and event kinematics enhances S/B and sensitivity to ggF, VH and VBF production modes

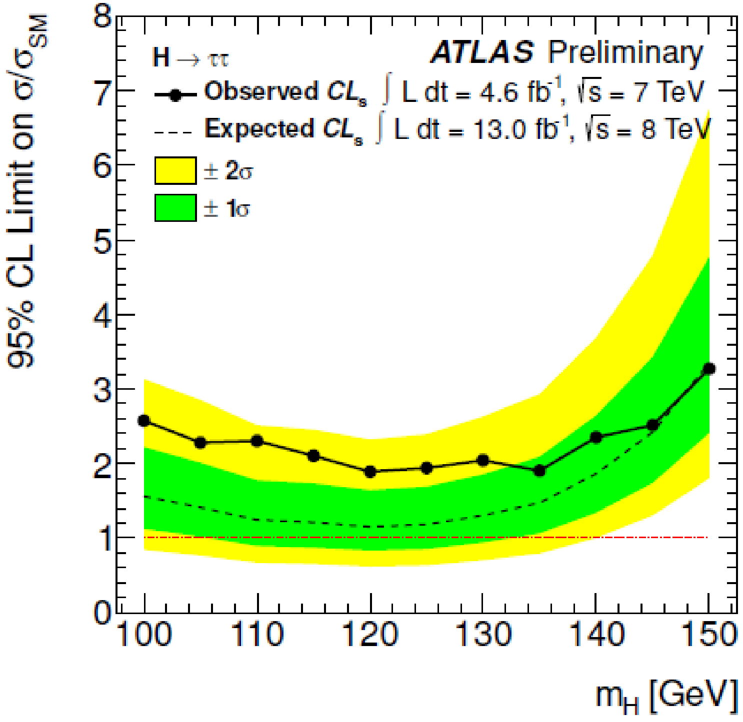


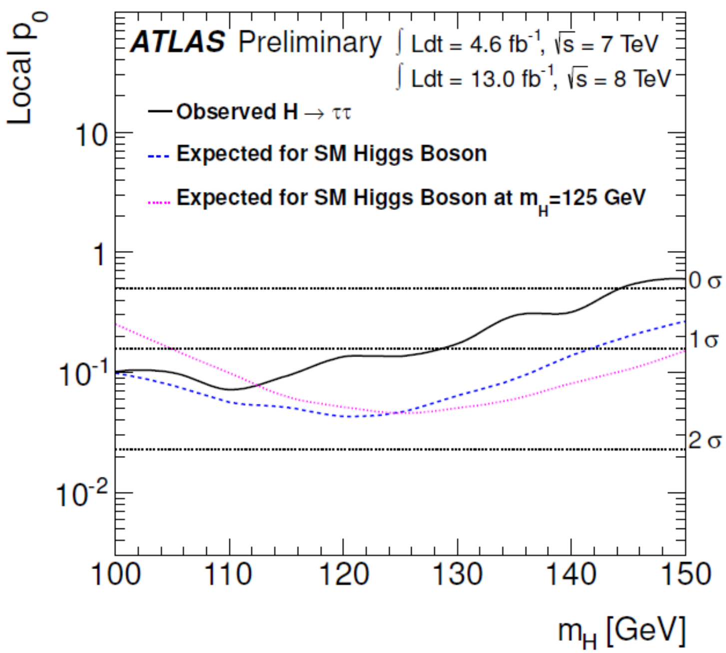


Dominant background $Z/\gamma^*\rightarrow\tau\tau$, model enhanced from data using $\mu\mu$ events

ATLAS-CONF-2012-160

Higgs to taus



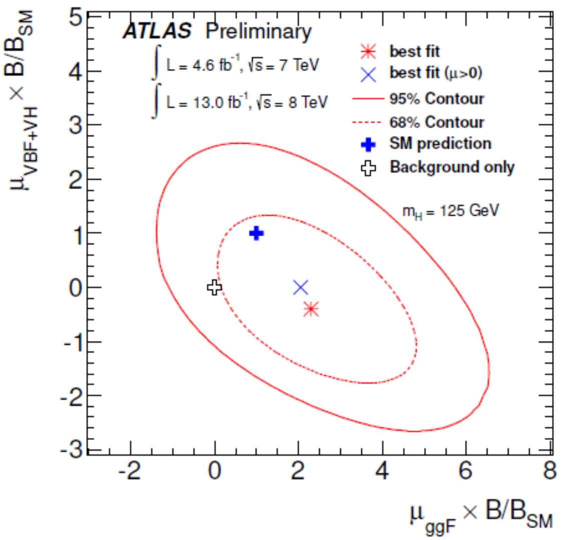


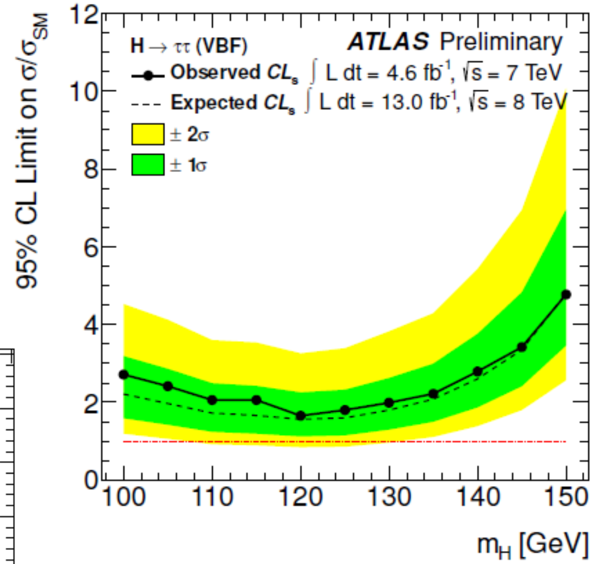
No evidence for a signal as yet – though some small excess of events
Compatible with SM so far…

ATLAS-CONF-2012-160

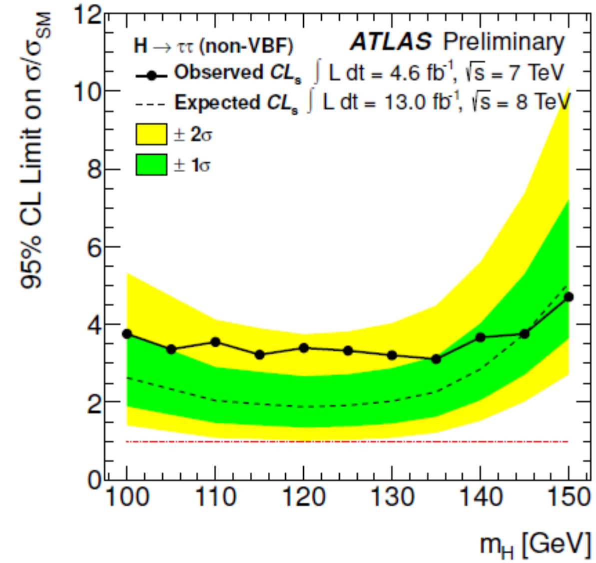
Higgs to taus

VBF versus non-VBF





(a) VBF categories



(b) Non-VBF categories

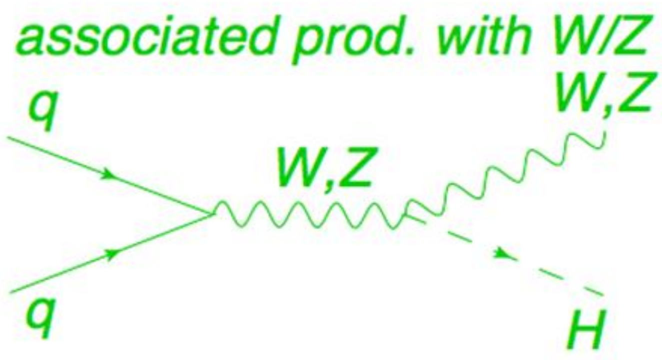
No evidence for a signal as yet – though some small excess of events
Compatible with SM so far…

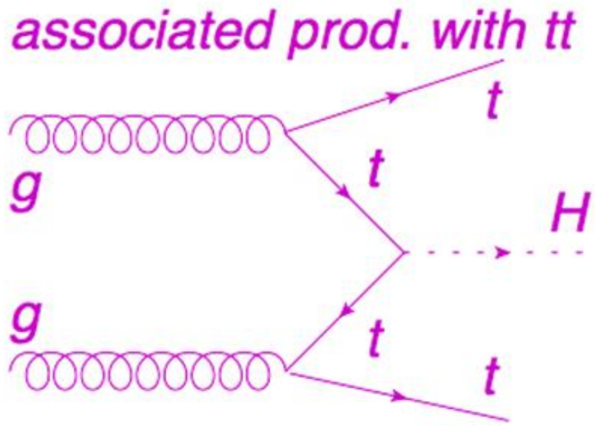
ATLAS-CONF-2012-161

Higgs to b quarks

Dominant BR at low mass for SM
Background not manageable for inclusive search (boosted maybe?)

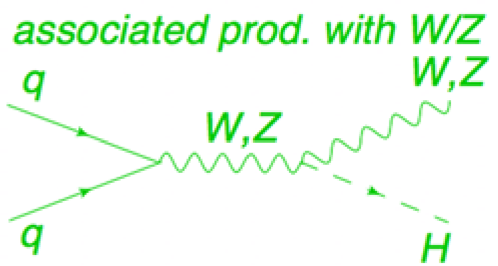
Extra signatures in VH and ttH modes make possible





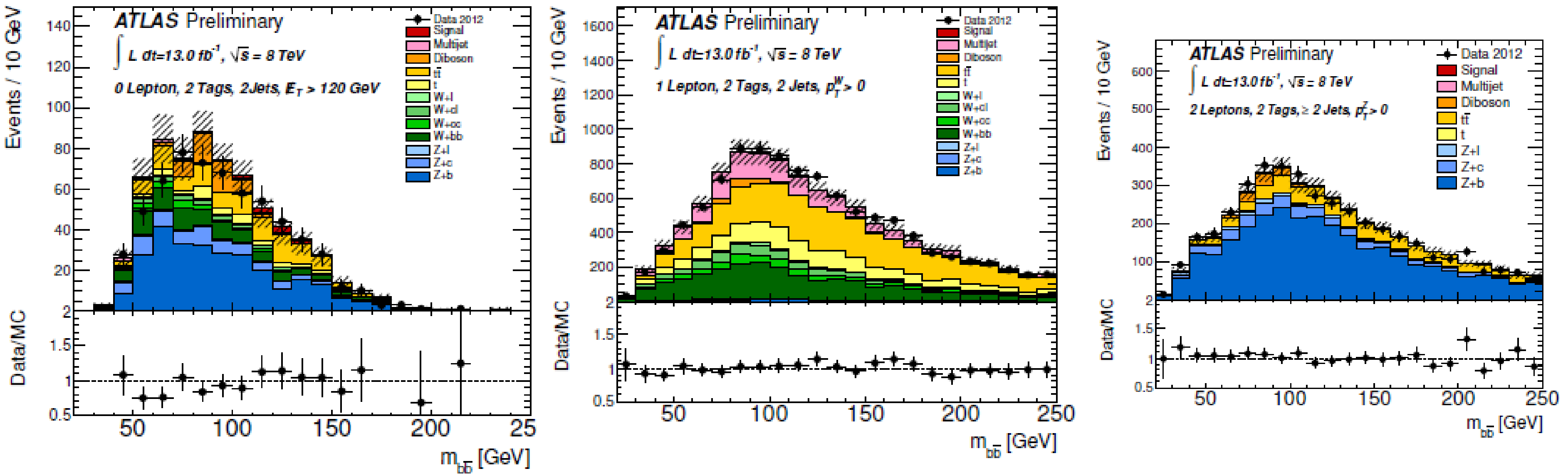
ATLAS-CONF-2012-161

Higgs to b quarks



Categorization:
- 0-leptons: jet multiplicity and 3 MET bins
- 1,2-leptons: 5 V pT bins

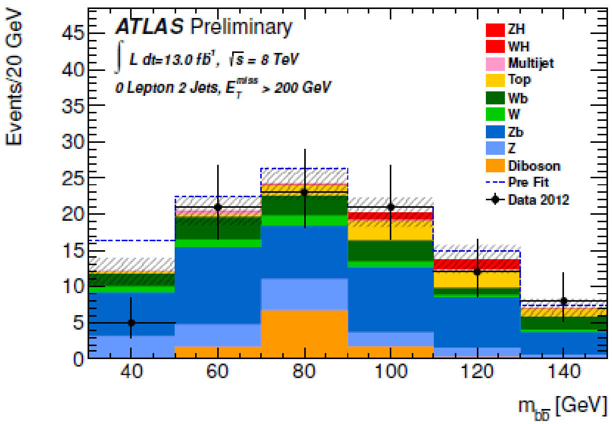
Most backgrounds from MC + data normalisation
Multi-jet data-driven
WZ and ZZ from simulation



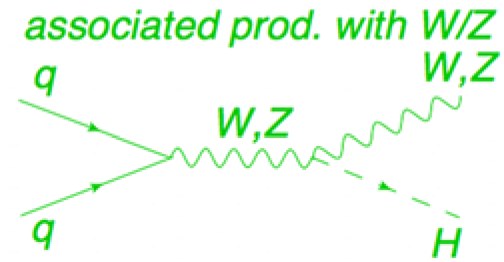
Dominant background vary by category – reduced with kinematic cuts

ATLAS-CONF-2012-161

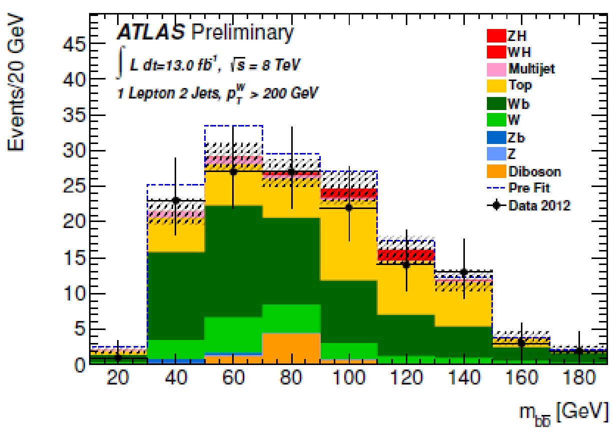
Higgs to b quarks



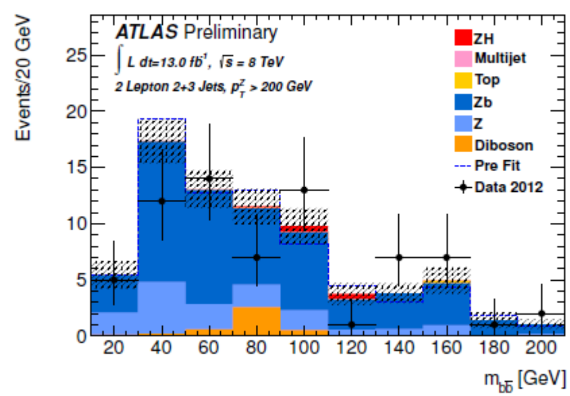
(e) $E_{\rm T}^{\rm miss} > 200$ GeV, 2 jets



Highest pT bins have the most sensitivity



(e) $p_{\rm T}^{W} > 200$ GeV



(e) $p_{\rm T}^{Z} > 200$ GeV

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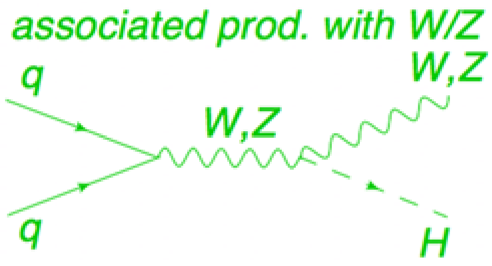
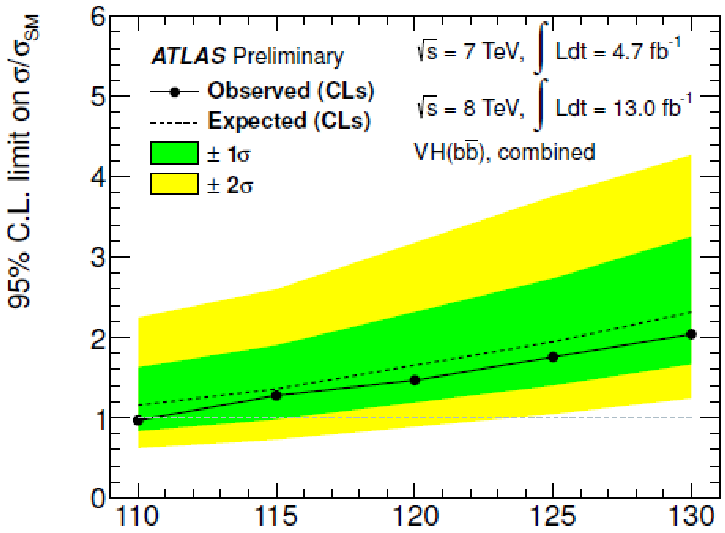
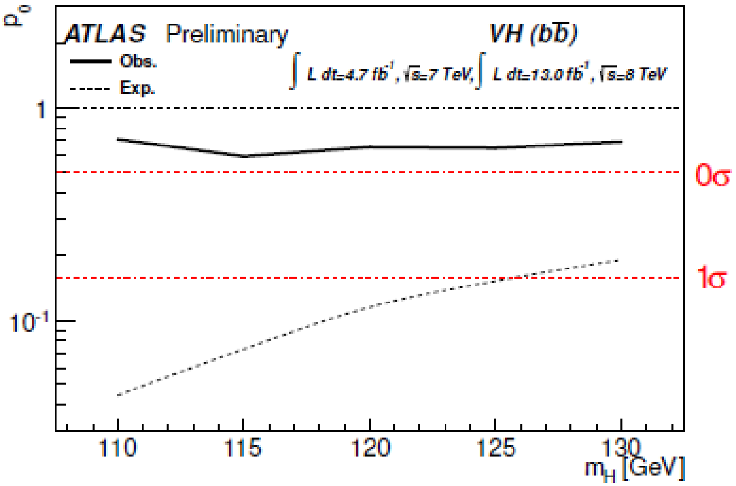
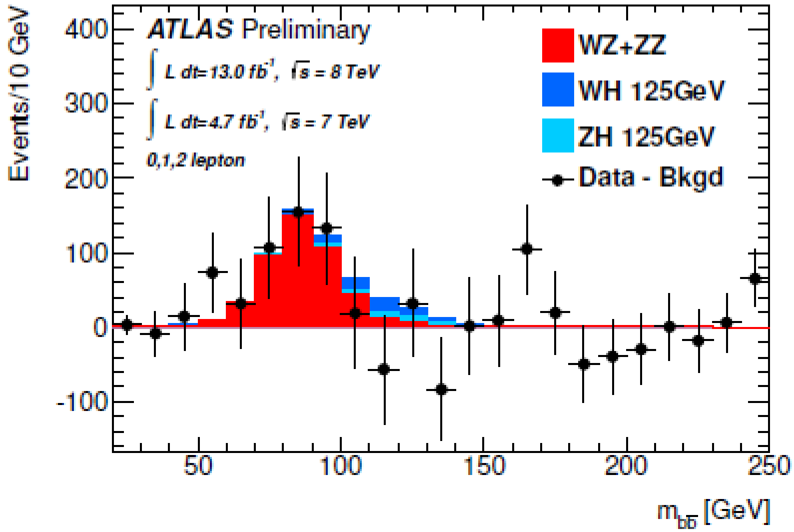
Higgs to b quarks





Approaching SM sensitivity, no sign of a signal yet





Cross check – search for diboson signal Observed with ~4σ

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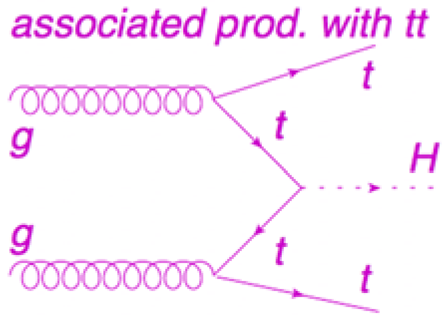
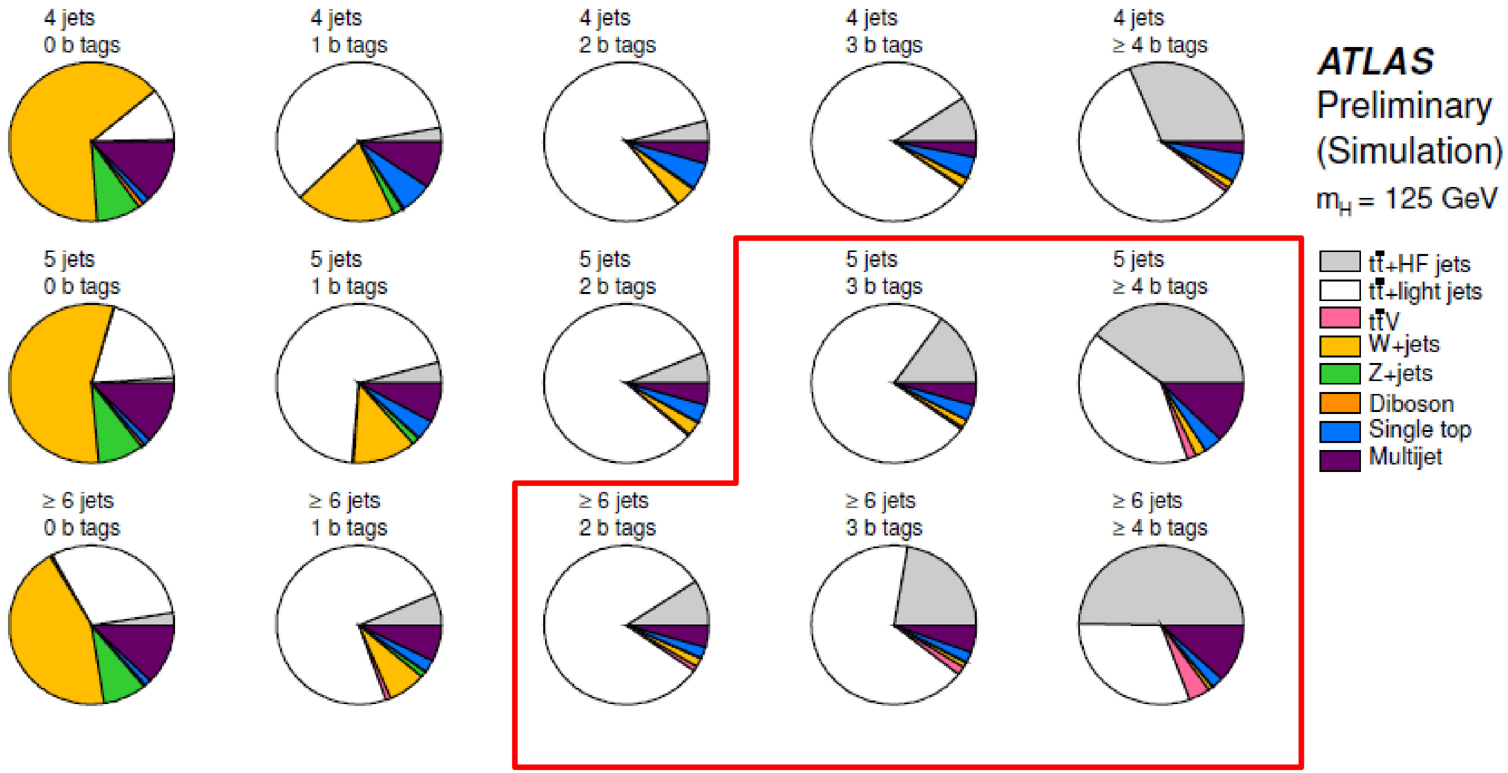


Higgs to b-quarks

One semi-leptonic top-decay + many jets signature:
1 lepton + high missing ET + >=4 jets

Events categorized according to multiplicity of jets and b-tagged jets



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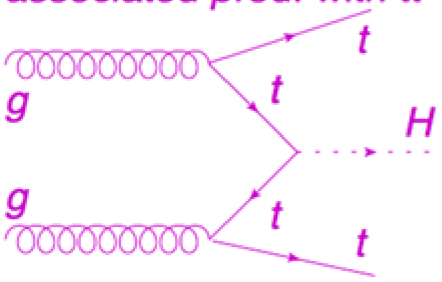
Higgs to b-quarks

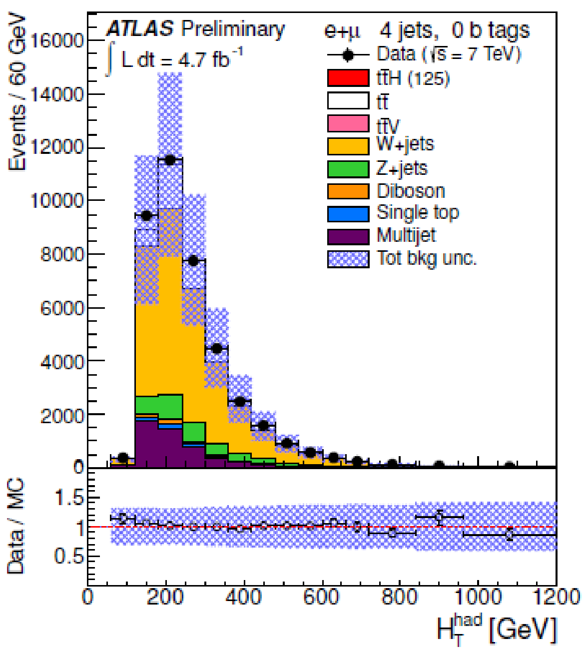
associated prod. with tt



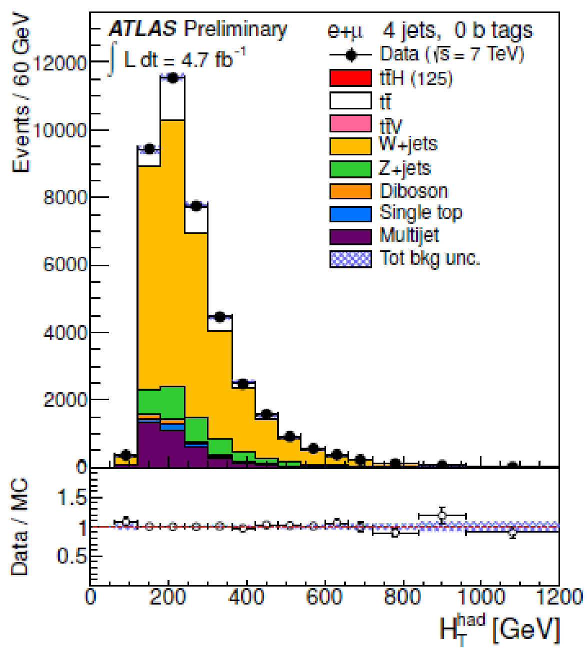
One semi-leptonic top-decay + many jets signature:
1 lepton + high missing ET + >=4 jets

Events categorized according to multiplicity of jets and b-tagged jets

Pre-Fit



Post-Fit



Background dominated categories provide strong constraints on uncertainties

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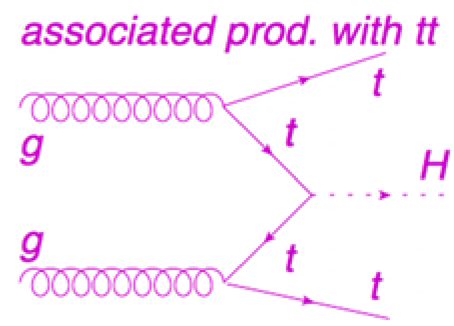
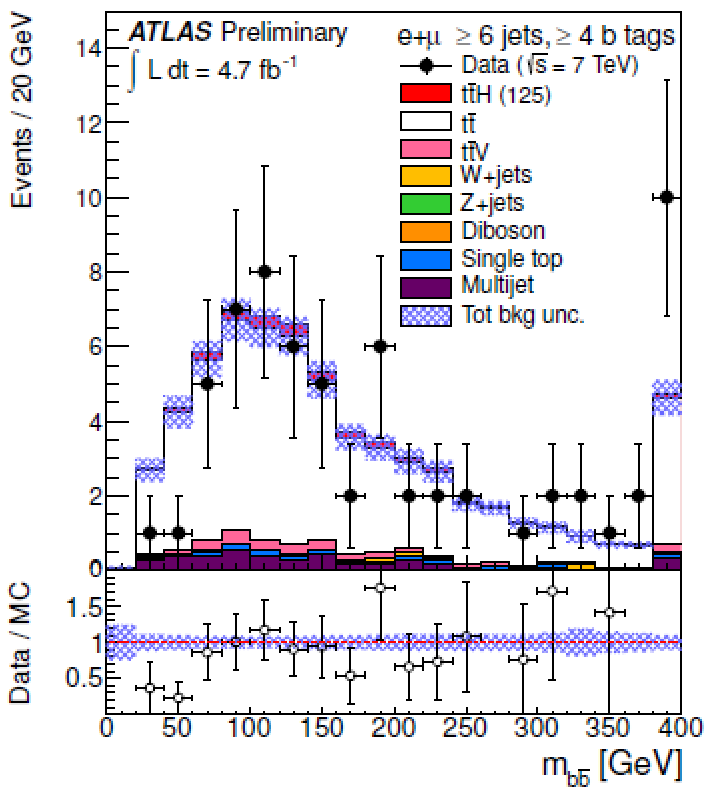
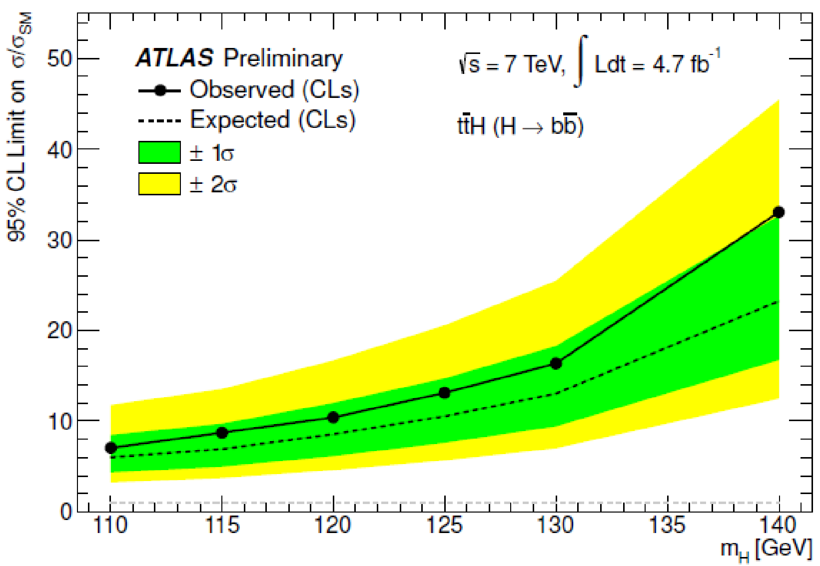
Higgs to b-quarks



In >=6-jet events, top candidates selected using kinematic fit. Remaining b-jets used to form m_{bb} to extract signal

In other cats. HT used





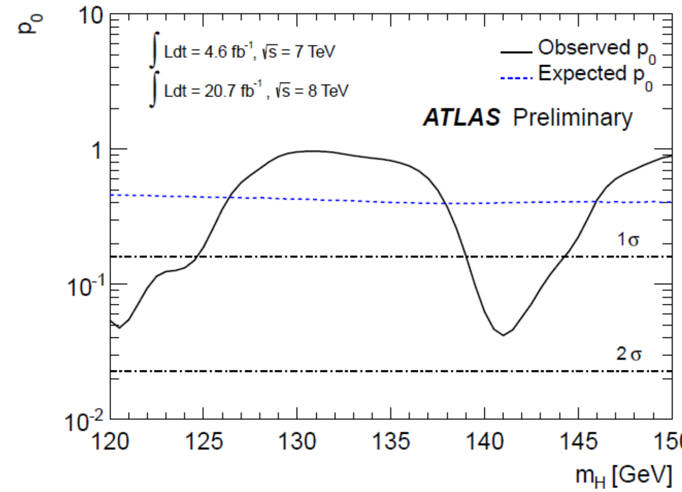
Some way from SM sensitivity but only 2011 data.

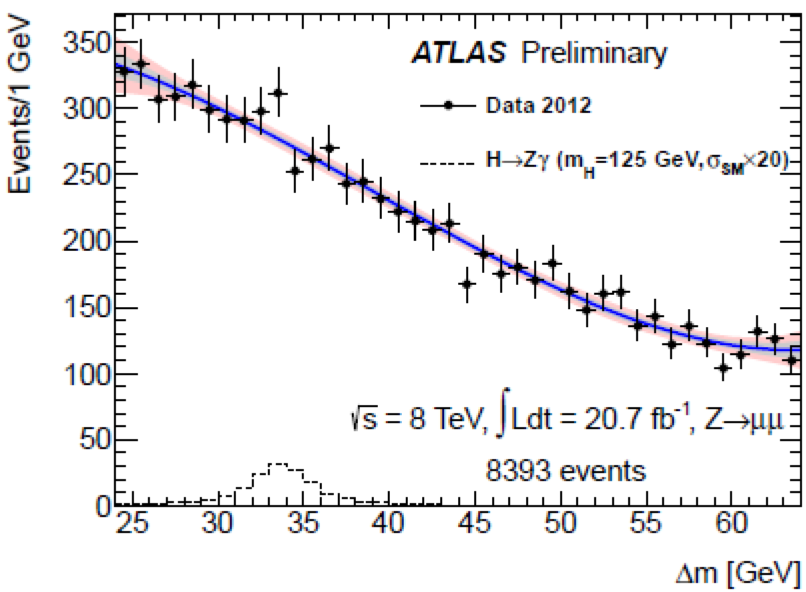
ATLAS-CONF-2013-009

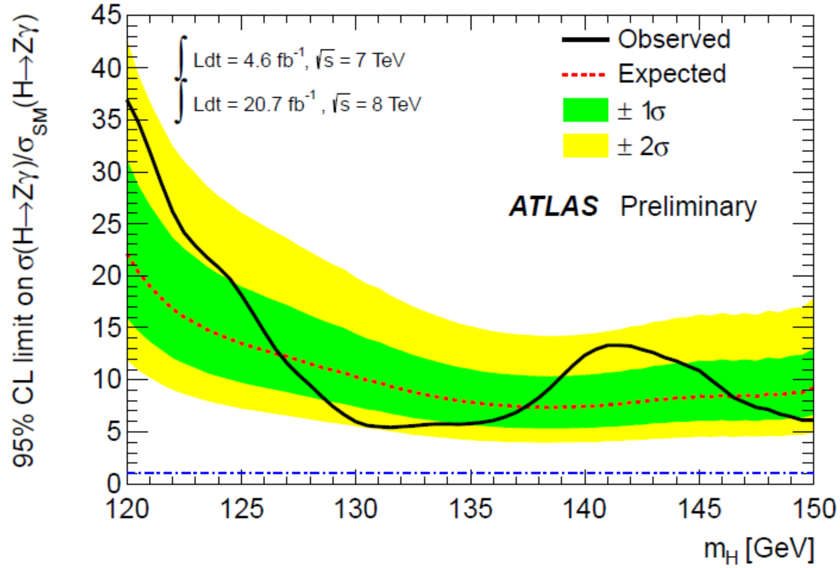
Higgs to Z + photon

Similar to diphoton channel
Loop production modes

Relative rate to diphoton interesting and sensitive to BSM



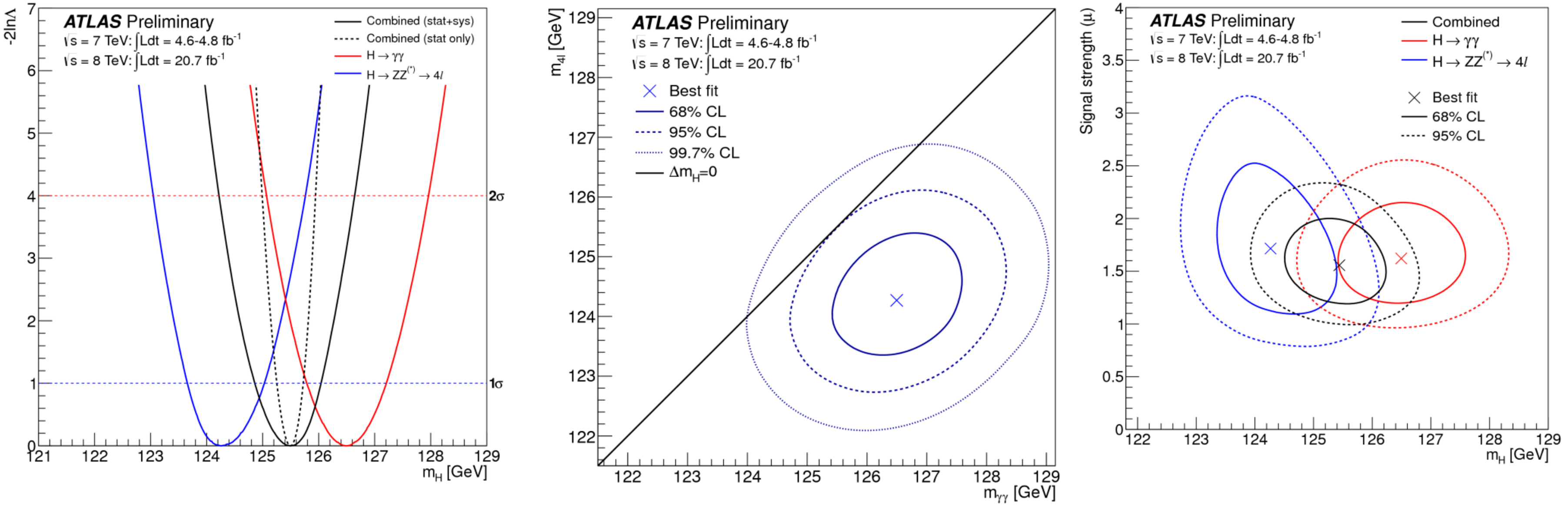




Higgs Mass

m_{4l} = 124.3 ± 0.6 (stat) ± 0.4 (syst) GeV $m_{\gamma\gamma}$ =126.8 ± 0.2(stat) ± 0.7(syst) GeV

m_H=125.5±0.2 (stat) $_{-0.6}^{+0.5}$ (syst) GeV

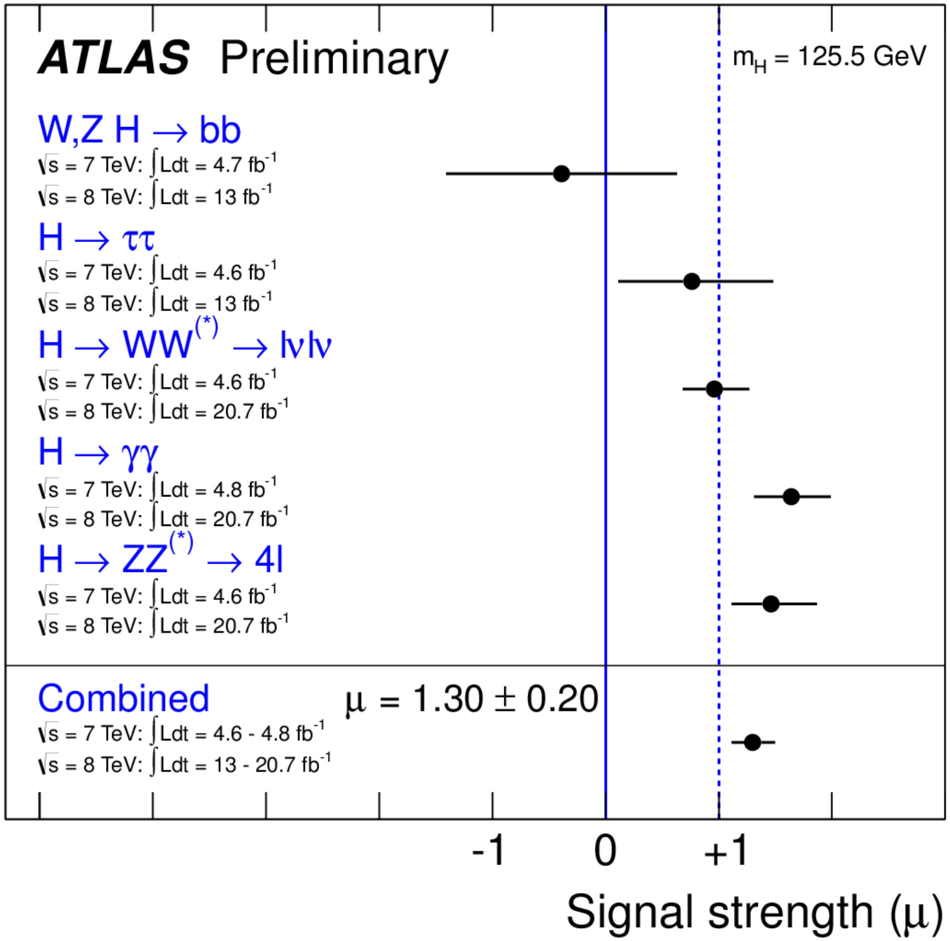


$\Delta m_H = m_{\gamma\gamma} - m_{4l} = 2.3_{-0.7}^{+0.6}$ (stat) ±0.6 (syst) GeV

Consistent with Δm_H = 0 at 2.3σ level

Higgs Signal Strength

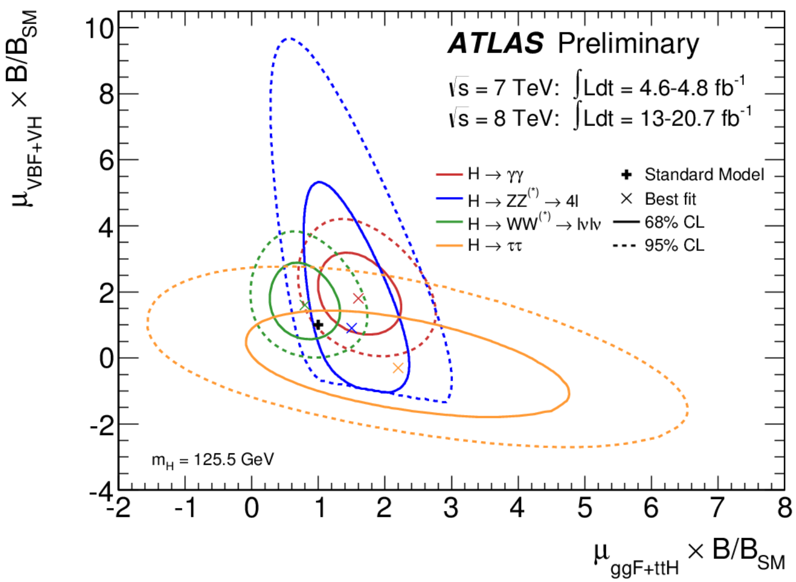
ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

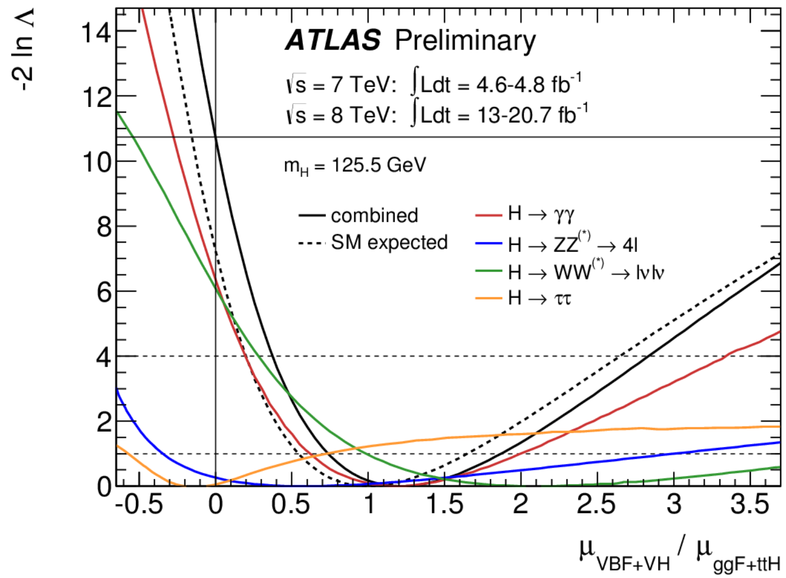


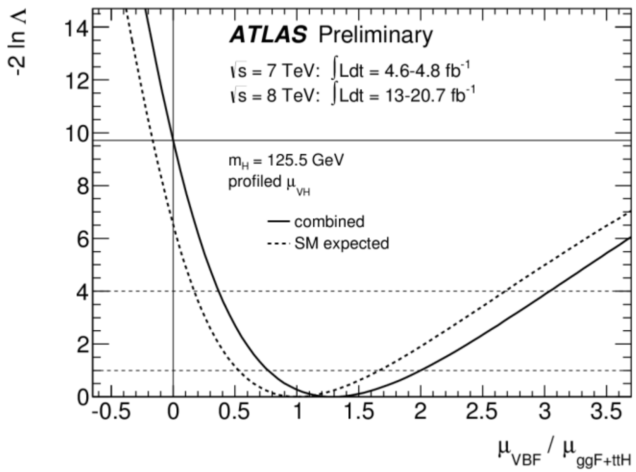
Consistent with the SM

Higgs Signal Strength

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34







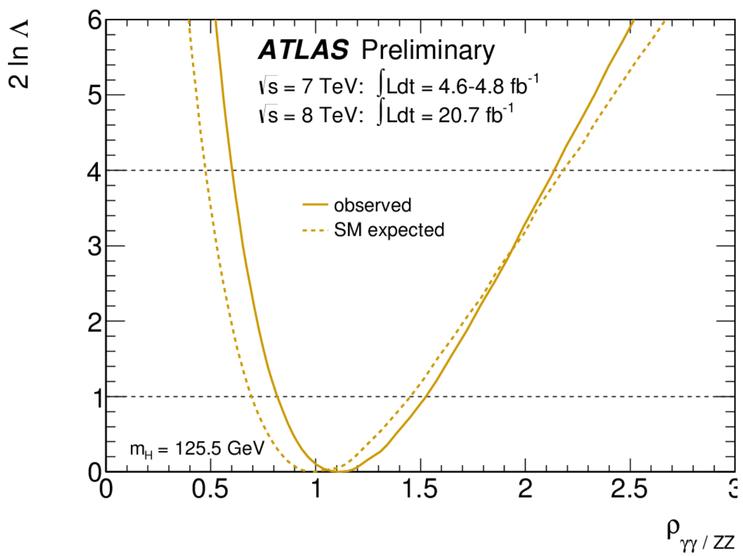
Model dependence in BR factored out in ratio allows for combination across channels

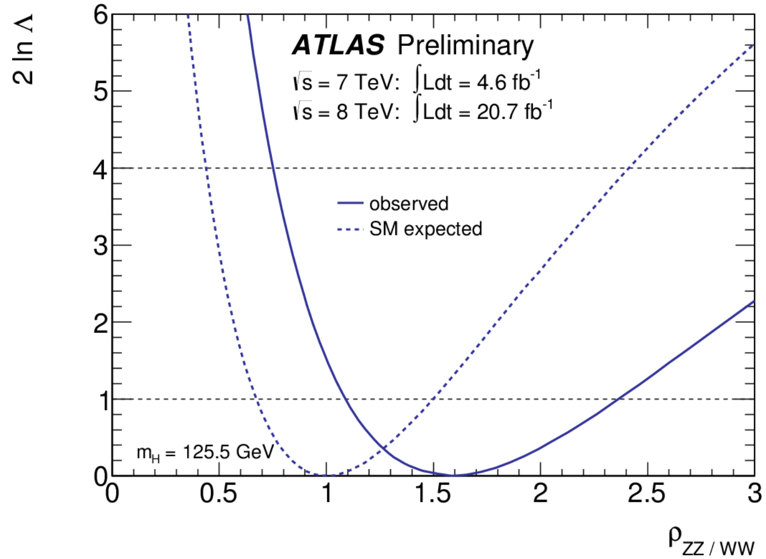
p-value for excluding VBF/ggF = 0
- 0.05% (fixing ratio VH/VBF)
- 0.09% (profiling ratio VH/VBF)

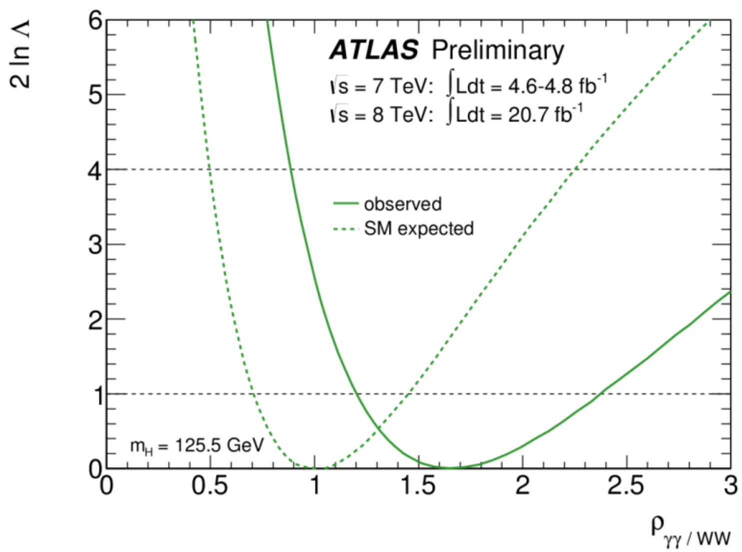
~ 3 sigmas

Higgs Signal Strength

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34







Ratios for same production mode but different final states

$$\rho_{\gamma\gamma/ZZ} = 1.1^{+0.4}_{-0.3}$$

$$\rho_{\gamma\gamma/WW} = 1.7^{+0.7}_{-0.5}$$

$$\rho_{ZZ/WW} = 1.6^{+0.8}_{-0.5}$$

In agreement with SM

Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

Largely use parameterisations from LHCHXSWG arXiv:1209.0040

$$(\sigma \cdot \mathrm{BR})(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2$$

Assume all signals near 126 come from a single resonance of zero width, with SM-like coupling structure

Total width = sum of all decays widths (+ invisible)

Decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

Largely use parameterisations from LHCHXSWG arXiv:1209.0040

$$(\sigma \cdot \mathrm{BR})(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa^2_{\mathrm{VBF}}(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma^{\mathrm{SM}}_{\mathrm{WH}}} = \kappa_W^2$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ZH}}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}\mathrm{H}}}{\sigma^{\mathrm{SM}}_{t\bar{t}\mathrm{H}}} = \kappa_t^2$$

Assume all signals near 126 come from a single resonance of zero width, with SM-like coupling structure

Total width = sum of all decays widths (+ invisible)

Decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma^{\mathrm{SM}}_{WW^{(*)}}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma^{\mathrm{SM}}_{ZZ^{(*)}}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma^{\mathrm{SM}}_{b\bar{b}}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma^{\mathrm{SM}}_{Z\gamma}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

Loops can be resolved into constituent contributions assuming SM or left as free parameter -> BSM

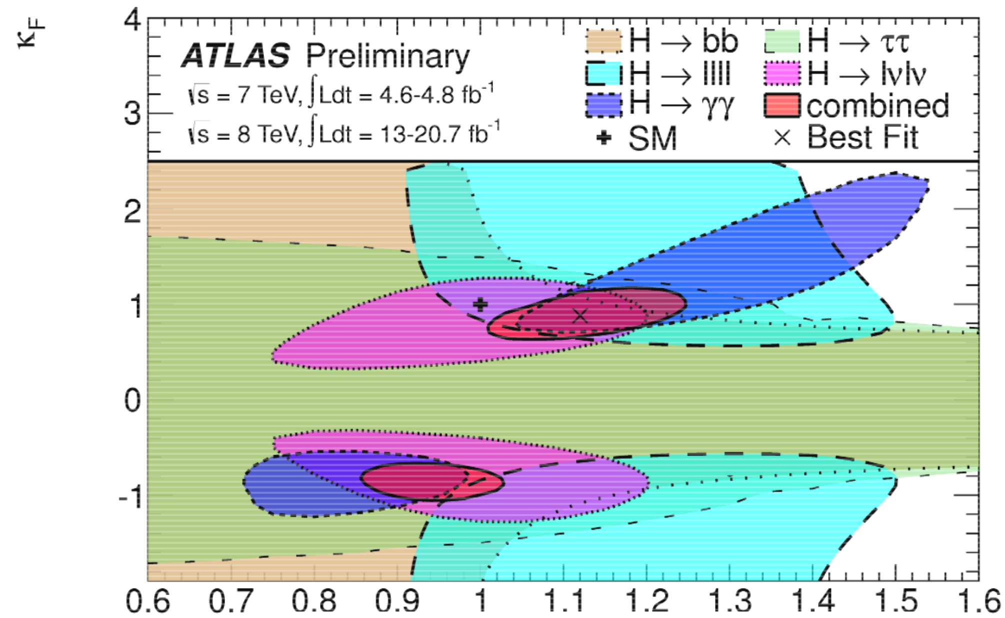
Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

2 parameter model

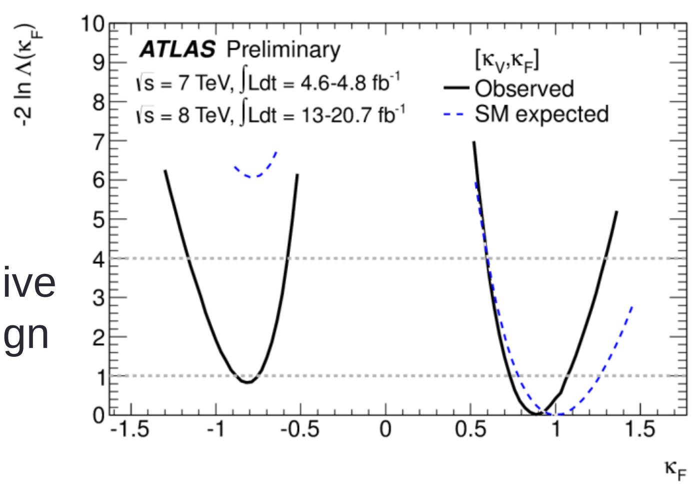
$$\kappa_V = \kappa_W = \kappa_Z$$
$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_g$$

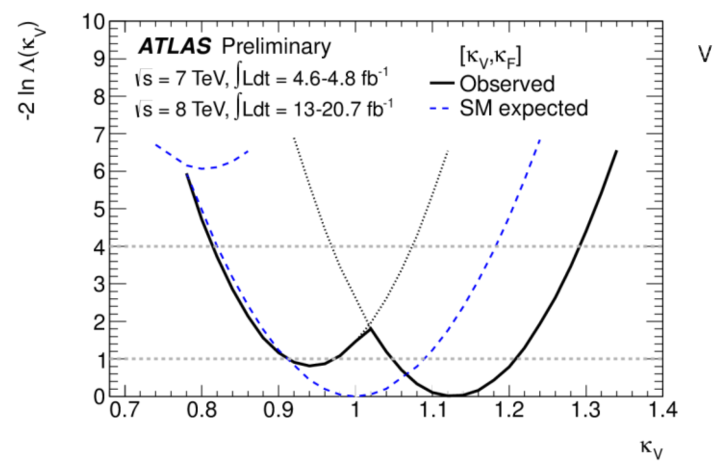
$$\kappa_F \in [-0.88, -0.75] \cup [0.73, 1.07]$$
$$\kappa_V \in [0.91, 0.97] \cup [1.05, 1.21] \quad .$$



$$\Gamma_{\gamma\gamma} \backsim |\alpha\kappa_F + \beta\kappa_V|^2$$

photon loop could give access to relative sign





Higgs fits

ATLAS-CONF-2013-14
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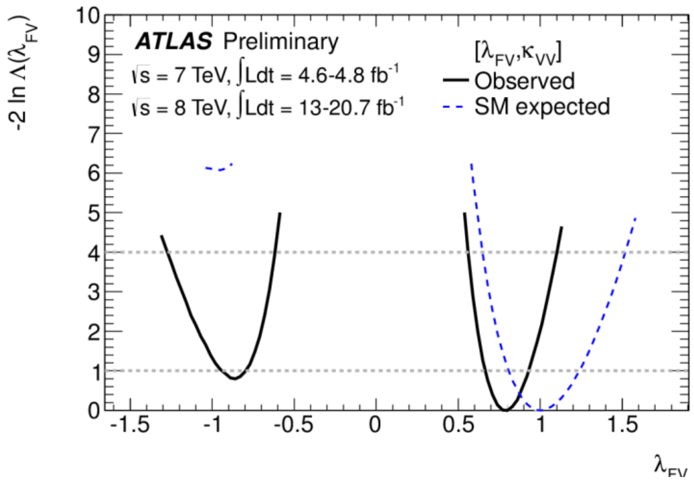
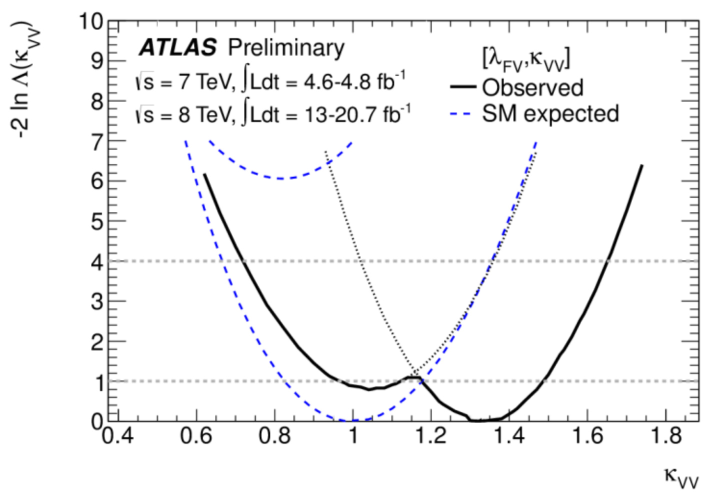
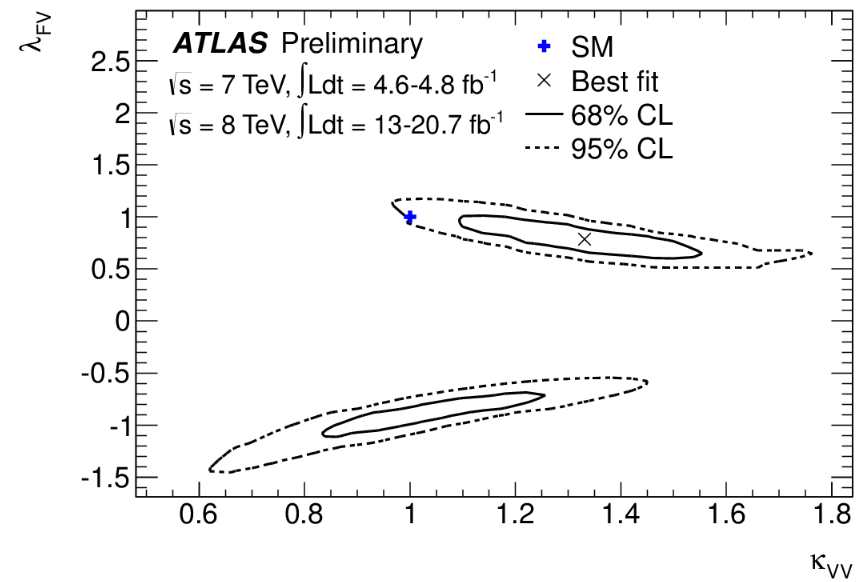
2 parameter model but no assumption on the total width

$$\lambda_{FV} = \kappa_F / \kappa_V$$
$$\kappa_{VV} = \kappa_V \cdot \kappa_V / \kappa_H$$







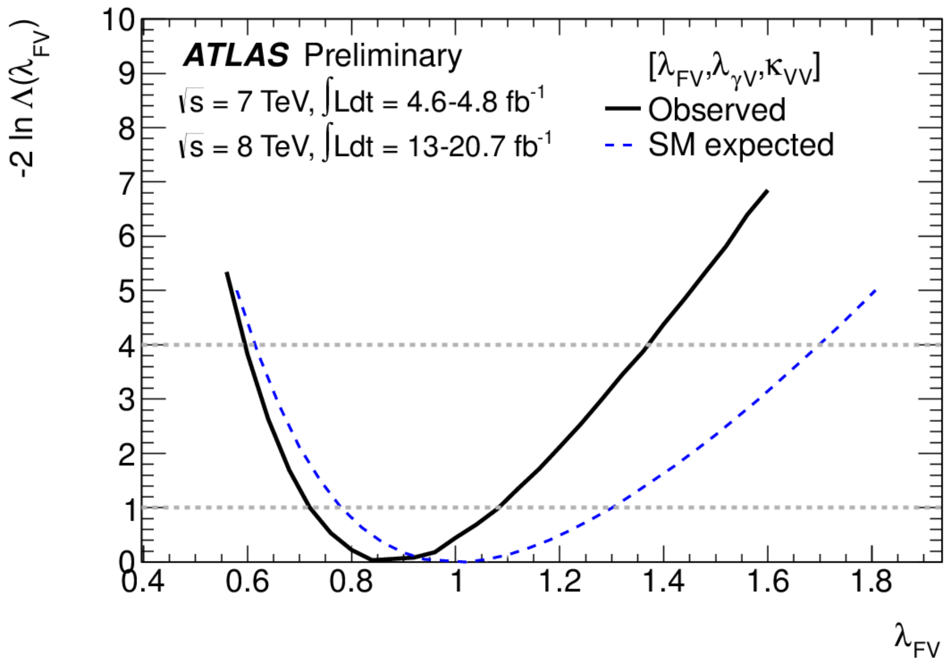
$$\lambda_{FV} \in [-0.94, -0.80] \cup [0.67, 0.93]$$
$$\kappa_{VV} \in [0.96, 1.12] \cup [1.18, 1.49] \quad .$$

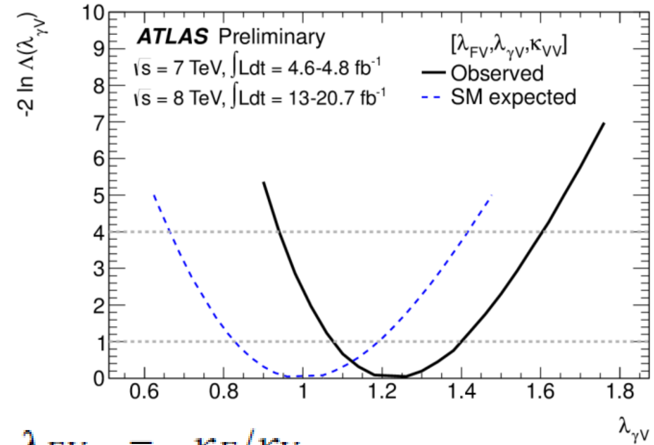
Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

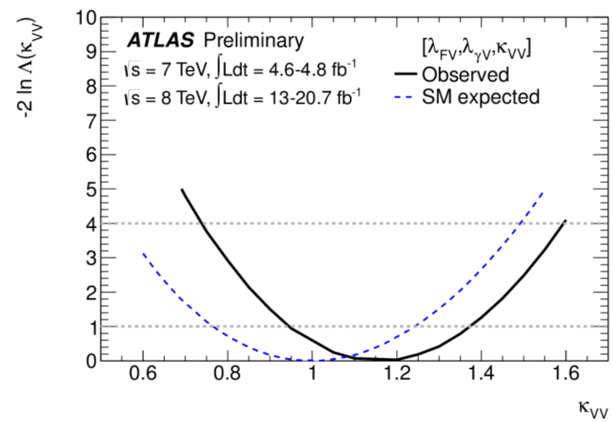
3 parameter model – don't resolve the photon loop

$$\lambda_{FV} = 0.85^{+0.23}_{-0.13}$$
$$\lambda_{\gamma V} = 1.22^{+0.18}_{-0.14}$$
$$\kappa_{VV} = 1.15 \pm 0.21$$





$$\lambda_{FV} = \kappa_F / \kappa_V$$
$$\lambda_{\gamma V} = \kappa_\gamma / \kappa_V$$
$$\kappa_{VV} = \kappa_V \cdot \kappa_V / \kappa_H$$

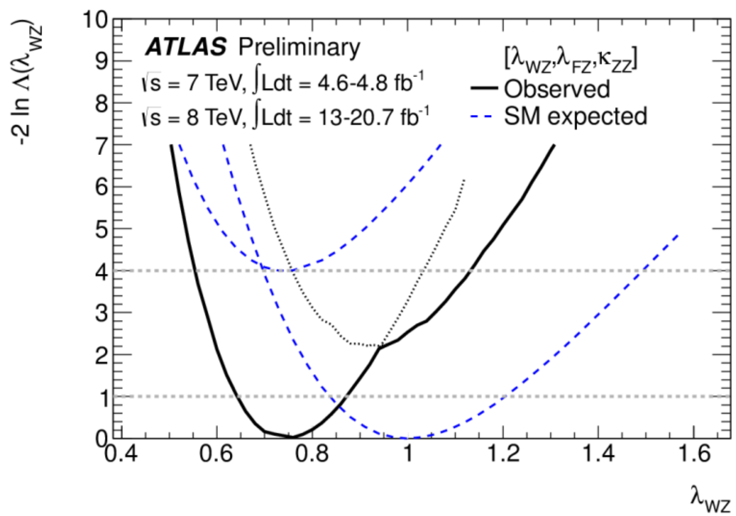


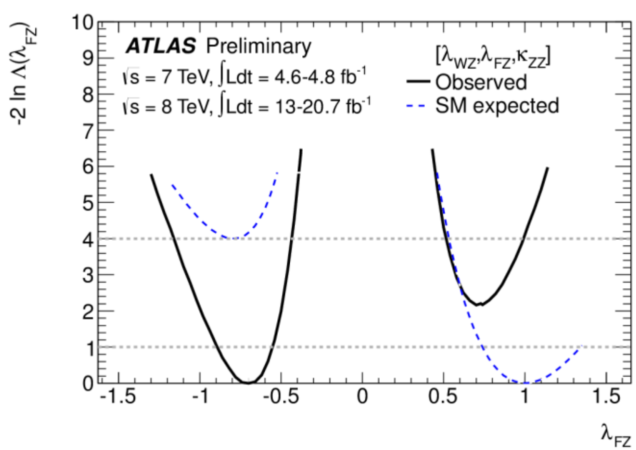
3D compatibility with SM 9%

Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

Custodial symmetry





$$\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$$
$$\lambda_{WZ} = \kappa_W / \kappa_Z$$
$$\lambda_{FZ} = \kappa_F / \kappa_Z \quad .$$

$$\lambda_{WZ} \in [0.64, 0.87]$$
$$\lambda_{FZ} \in [-0.89, -0.55]$$
$$\kappa_{ZZ} \in [1.20, 2.08]$$

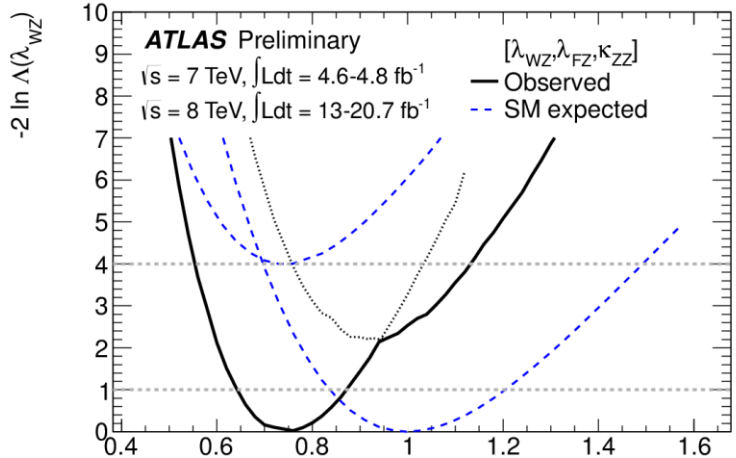
λ_{FZ} prefers non-physical region but not strongly compared with +ve quadrant minimum

3D SM compatibility 5%

Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

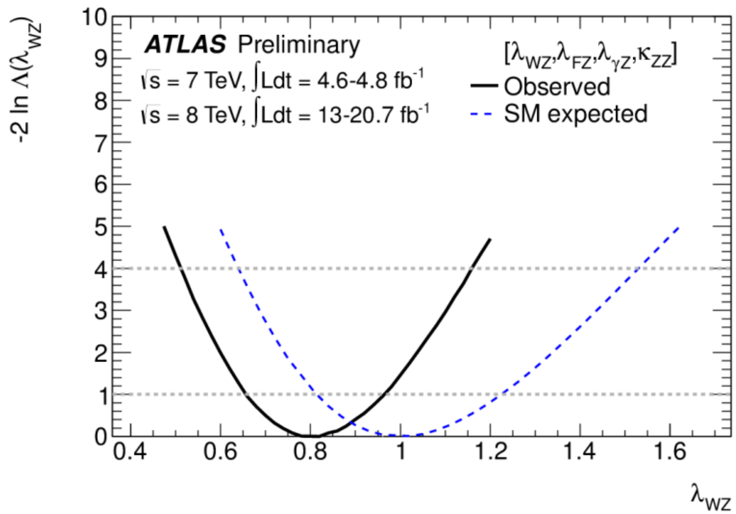
Custodial symmetry



3D SM compatibility 5%

$$\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$$
$$\lambda_{WZ} = \kappa_W / \kappa_Z$$
$$\lambda_{FZ} = \kappa_F / \kappa_Z \quad .$$

$$\lambda_{WZ} \in [0.64, 0.87]$$
$$\lambda_{FZ} \in [-0.89, -0.55]$$
$$\kappa_{ZZ} \in [1.20, 2.08]$$



Decouple from diphoton rate

$$\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$$
$$\lambda_{WZ} = \kappa_W / \kappa_Z$$
$$\lambda_{\gamma Z} = \kappa_\gamma / \kappa_Z$$
$$\lambda_{FZ} = \kappa_F / \kappa_Z \quad .$$

$$\lambda_{WZ} = 0.80 \pm 0.15$$
$$\lambda_{\gamma Z} = 1.10 \pm 0.18$$
$$\lambda_{FZ} = 0.74^{+0.21}_{-0.17}$$
$$\kappa_{ZZ} = 1.5^{+0.5}_{-0.4}$$

4D SM compatibility 9%

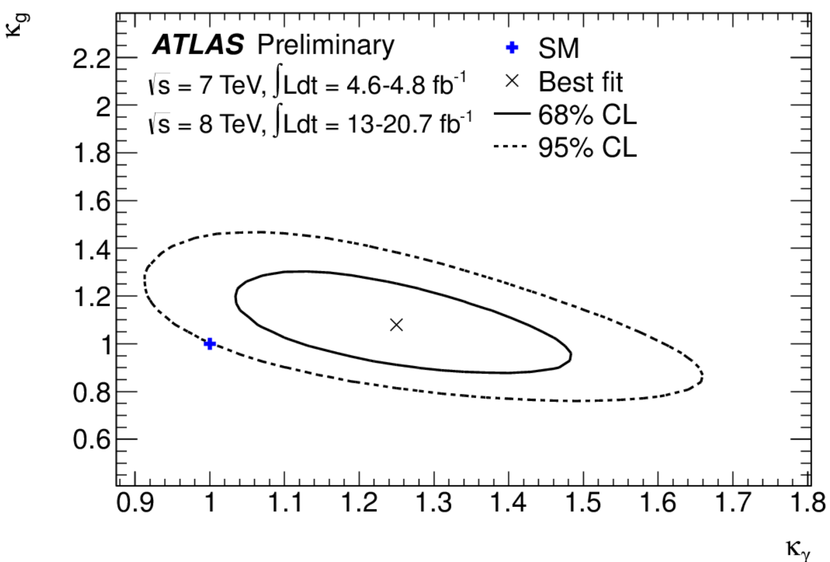
Higgs fits

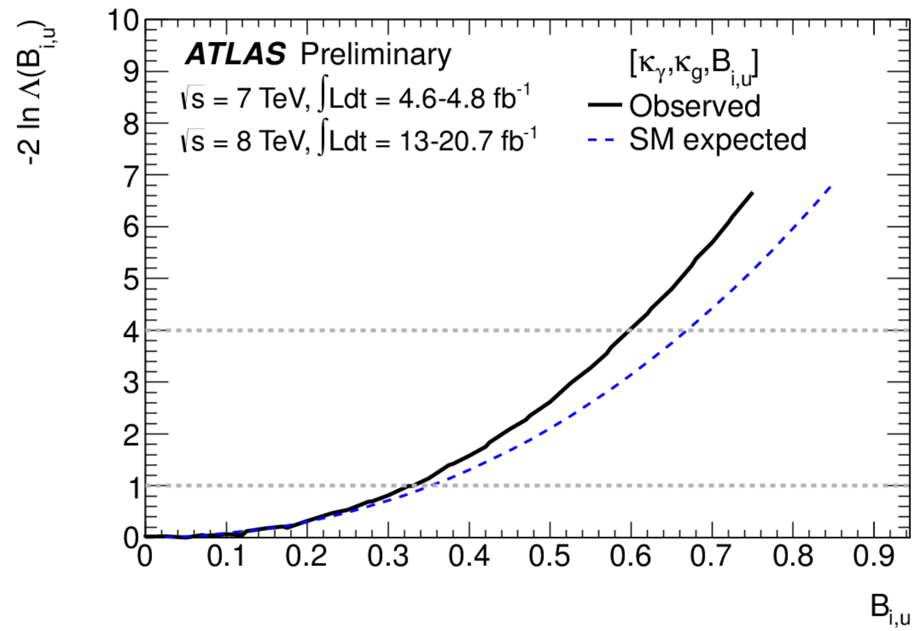
ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

Probing the loops

$$\kappa_g = 1.08 \pm 0.14$$
$$\kappa_\gamma = 1.23^{+0.16}_{-0.13}$$

$$\Gamma_H = \frac{\kappa_H^2(\kappa_i)}{(1 - BR_{inv.,undet.})}\Gamma_H^{SM}$$





$$\kappa_g = 1.08^{+0.32}_{-0.14}$$
$$\kappa_\gamma = 1.24^{+0.16}_{-0.14}$$
$$BR_{inv.,undet.} < 0.33$$

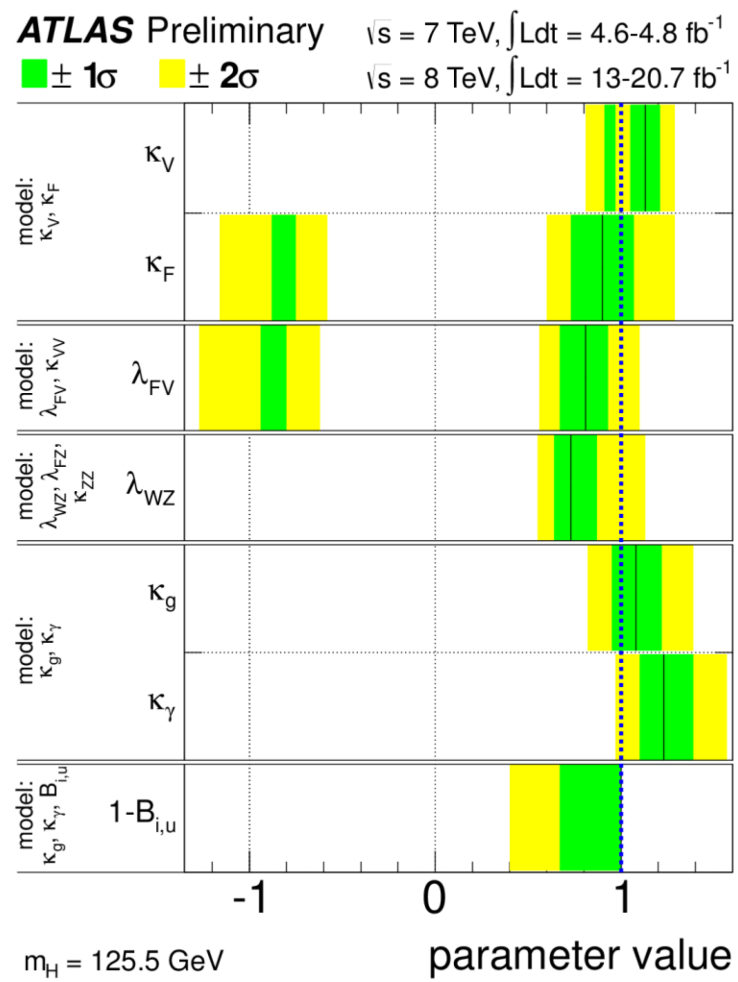
2D SM compatibility 5%

3D SM compatibility 10%

Higgs fits

ATLAS-CONF-2013-14
ATLAS-CONF-2013-34

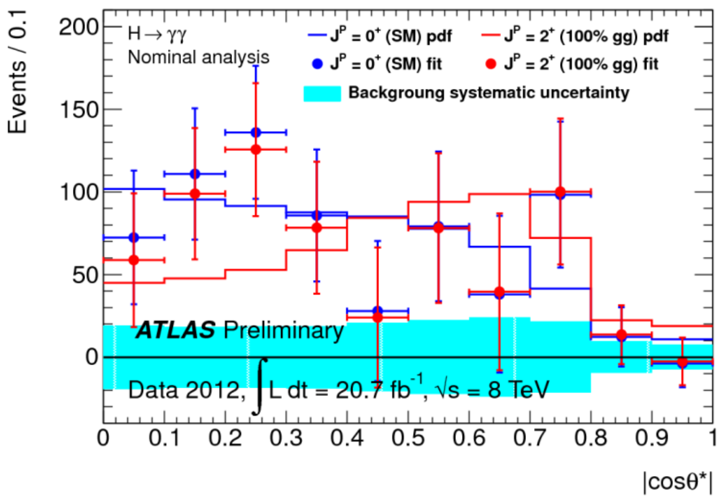
No significant deviation from the SM seen in any of the benchmark fits performed.

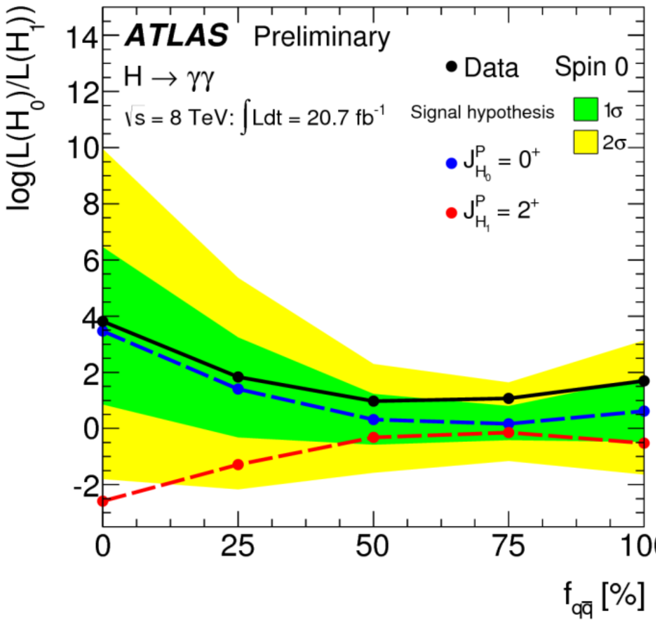


Higgs Spin Studies

ATLAS-CONF-2013-029

Compare 0+ with 2+ "graviton" model with minimal couplings in diphotons





Fit 2D product PDF in $m_{\gamma\gamma}$ x cosθ*

$f_{q\bar{q}}$ (%)	Spin hypothesis	p-values (%) expected	p-values (%) observed	$1 - CL_S(2^+)$ (%)
0	0^+	1.2	58.8	99.3
	2^+	0.5	0.3	
25	0^+	5.2	60.9	94.6
	2^+	3.9	2.1	
50	0^+	19.8	70.8	74
	2^+	18.7	7.6	
75	0^+	31.9	90.2	66
	2^+	30.5	3.3	
100	0^+	14.8	79.8	88
	2^+	13.5	2.5	

2+ disfavoured for ggF production

Higgs Spin Studies

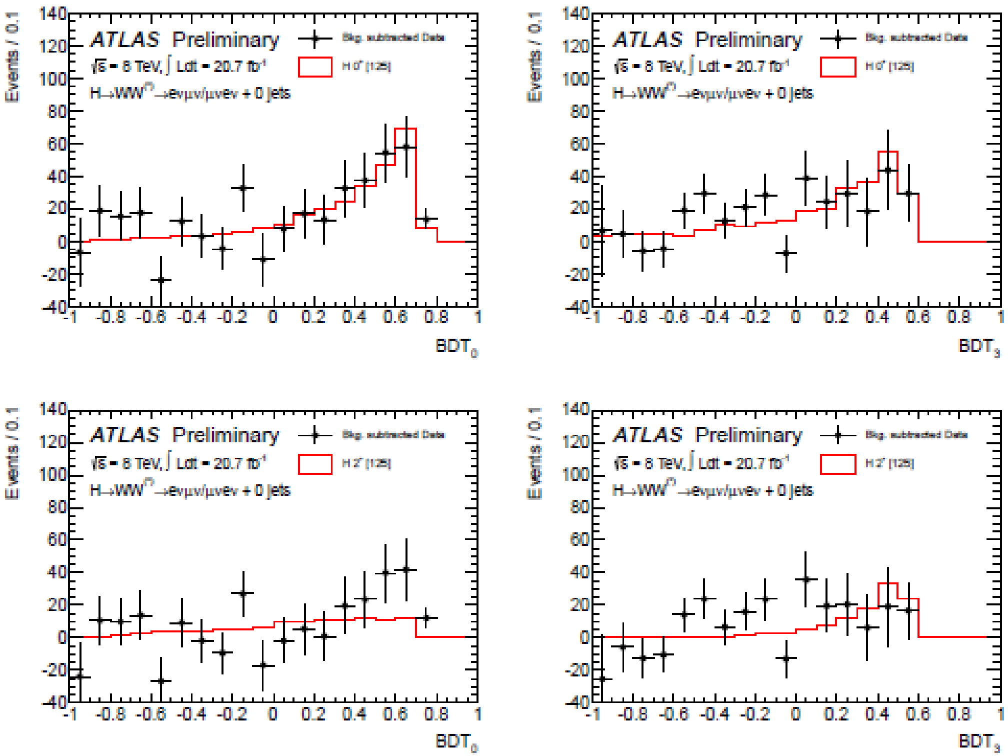
ATLAS-CONF-2013-031

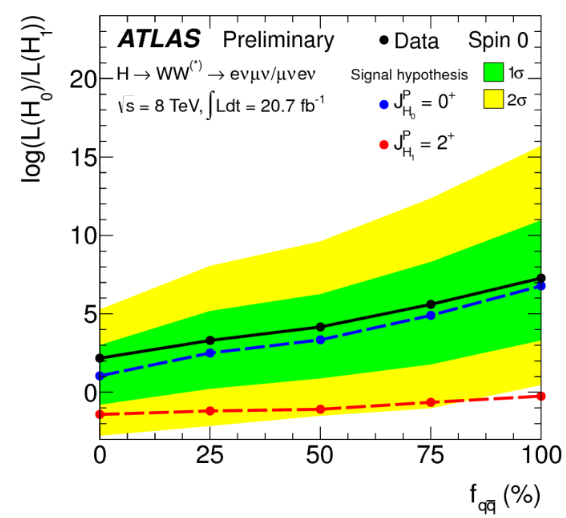
Compare 0+ with 2+ “graviton” model with minimal couplings in WW→llvv

Slightly different selection to rate analysis to remove spin dependent assumptions

Variable	Spin analysis	Rate analysis [5]
common $e\mu/\mu e$ lepton selection		
$E_{T,rel}^{miss}$	> 20 GeV	> 25 GeV
N_{jets}	0 jets	$0, 1, \geq 2$ jet selections
$p_T^{\ell\ell}$	> 20 GeV	> 30 GeV
$m_{\ell\ell}$	< 80 GeV	< 50 GeV
$\Delta\phi_{\ell\ell}$	< 2.8	< 1.8

BDTs trained to reject background versus each signal hypothesis





Data favour 0+ model

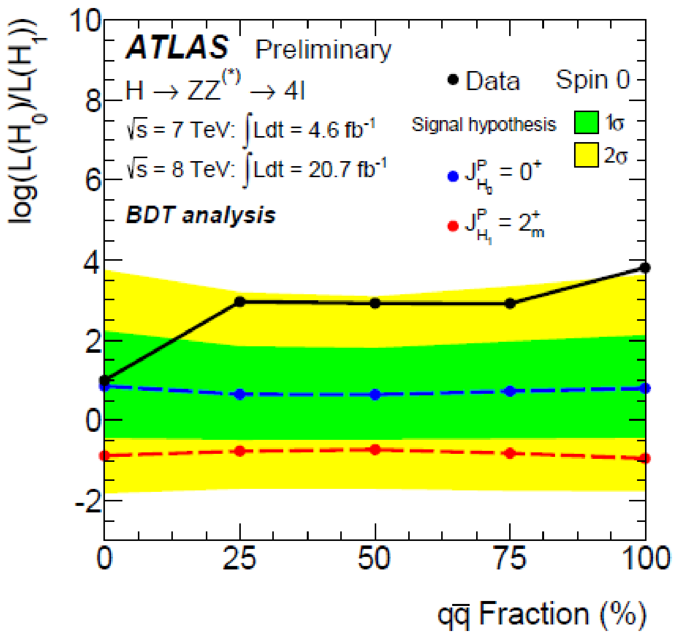
Higgs Spin Studies

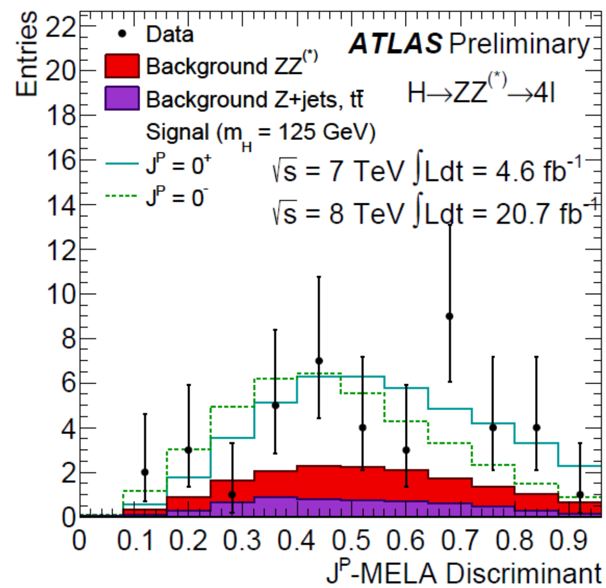
ATLAS-CONF-2013-013

Compare 0+ with variety of spin models in 4leptons

0- and 1+ excluded at >97.5%CL in favour of 0+

Data also favour 0+ versus 2+ with little variation versus qq fraction





2 approaches MELA and BDT

		BDT analysis				J^P-MELA analysis			
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	CL_S	tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	CL_S
		expected	observed	observed*		expected	observed	observed*	
0^-	p_0	0.0037	0.015	0.31	0.022	0.0011	0.0022	0.40	0.004
1^+	p_0	0.0016	0.001	0.55	0.002	0.0031	0.0028	0.51	0.006
1^-	p_0	0.0038	0.051	0.15	0.060	0.0010	0.027	0.11	0.031
2^+_m	p_0	0.092	0.079	0.53	0.168	0.064	0.11	0.38	0.182
2^-	p_0	0.0053	0.25	0.034	0.258	0.0032	0.11	0.08	0.116

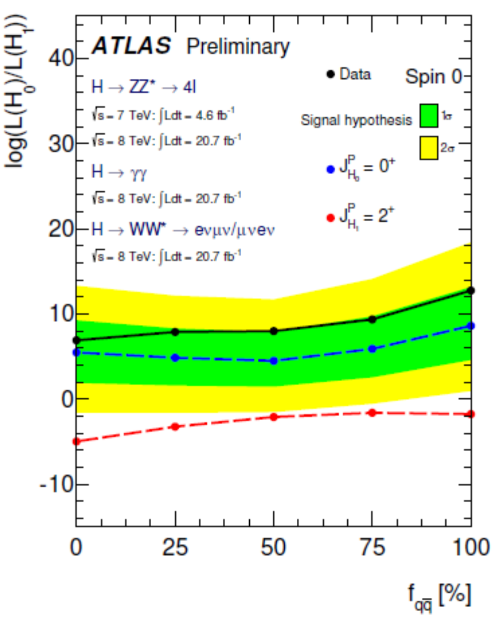
Higgs Spin Studies

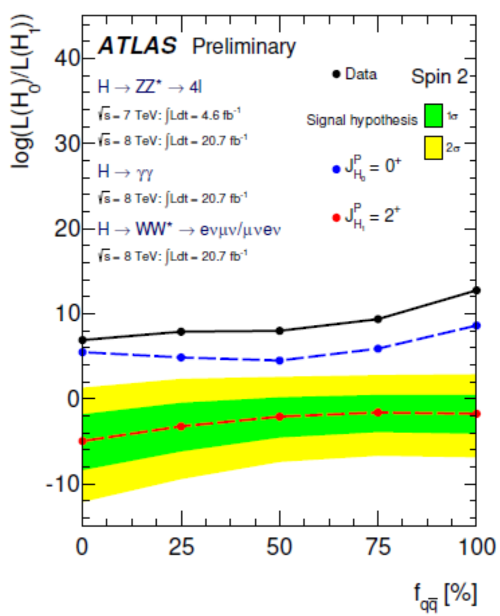
ATLAS-CONF-2013-040

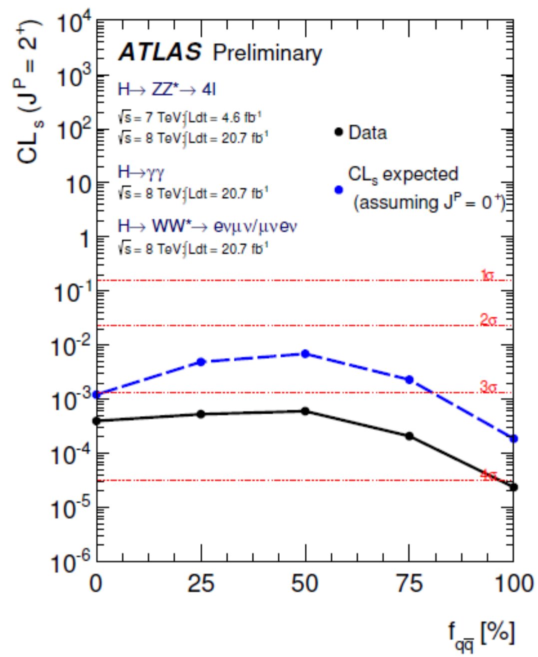
Combine all the 0+ versus 2+ studies

$f_{q\bar{q}}$	Spin-2 assumed exp. $p_0(J^P = 0^+)$	Spin-0 assumed exp. $p_0(J^P = 2^+)$	obs. $p_0(J^P = 0^+)$	obs. $p_0(J^P = 2^+)$	$CL_s(J^P = 2^+)$
100%	$3.4 \cdot 10^{-3}$	$9.4 \cdot 10^{-5}$	0.82	$0.4 \cdot 10^{-5}$	$0.2 \cdot 10^{-4}$
75%	$1.0 \cdot 10^{-2}$	$1.1 \cdot 10^{-3}$	0.82	$3.7 \cdot 10^{-5}$	$2.1 \cdot 10^{-4}$
50%	$1.5 \cdot 10^{-2}$	$3.5 \cdot 10^{-3}$	0.85	$9.1 \cdot 10^{-5}$	$6.0 \cdot 10^{-4}$
25%	$6.8 \cdot 10^{-3}$	$2.4 \cdot 10^{-3}$	0.81	$1.0 \cdot 10^{-4}$	$5.3 \cdot 10^{-4}$
0%	$1.6 \cdot 10^{-3}$	$6.1 \cdot 10^{-4}$	0.65	$1.4 \cdot 10^{-4}$	$4.0 \cdot 10^{-4}$

2+ excluded at better than 99.9%CL versus 0+ for all qq fractions

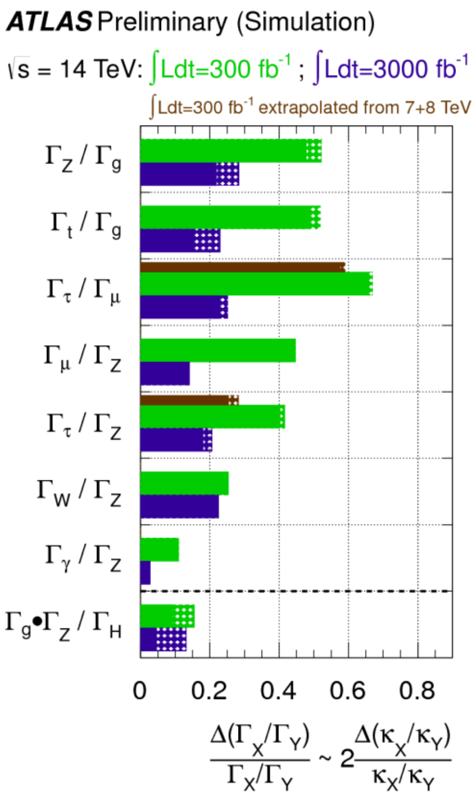


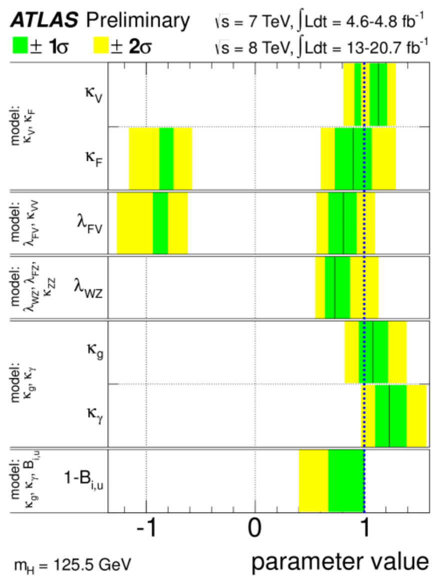




Summary and prospects

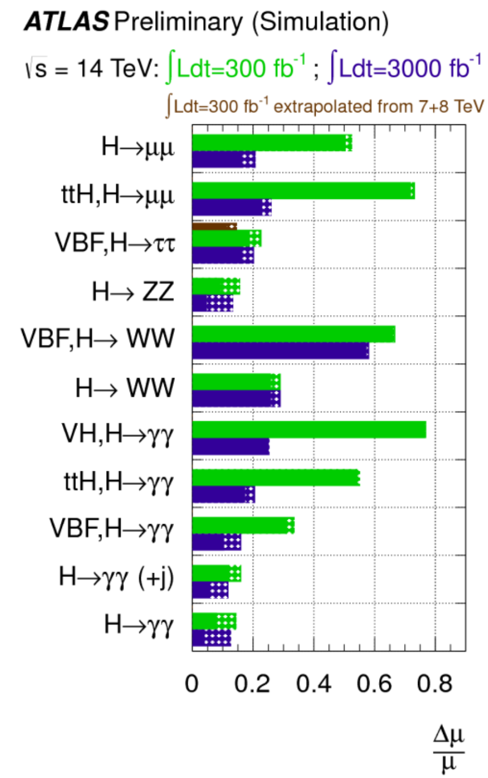
Huge programme of work searching for a measuring Higgs boson signals





Results so far are largely compatible with Standard Model

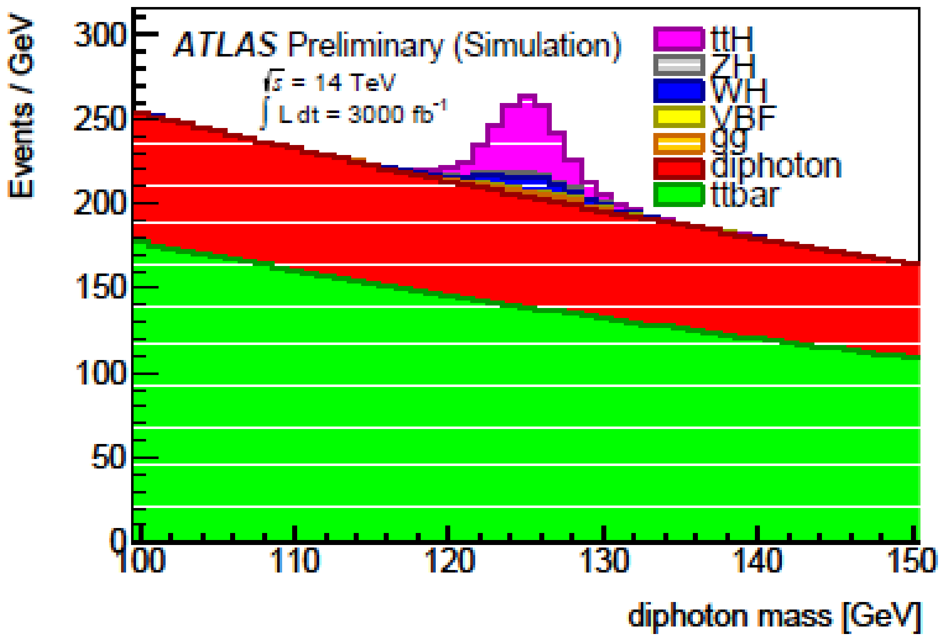
More interesting results still to come with full 2011+2012 data-set and beyond

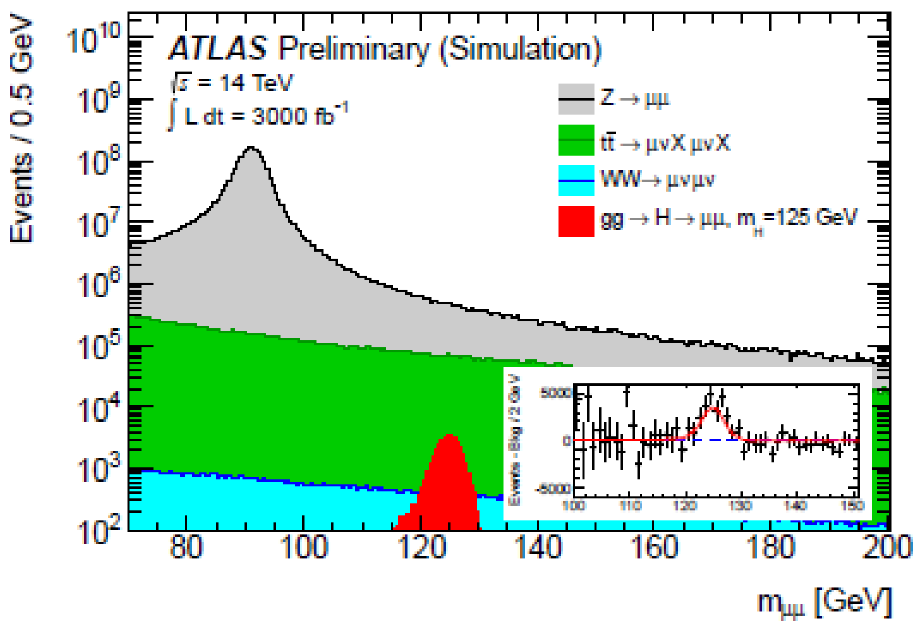


Summary and prospects

Higgs signal firmly established

But plenty of work still to do for the foreseeable future!





HIGGS TO 4 LEPTONS

Backup slides

Higgs to 4 leptons

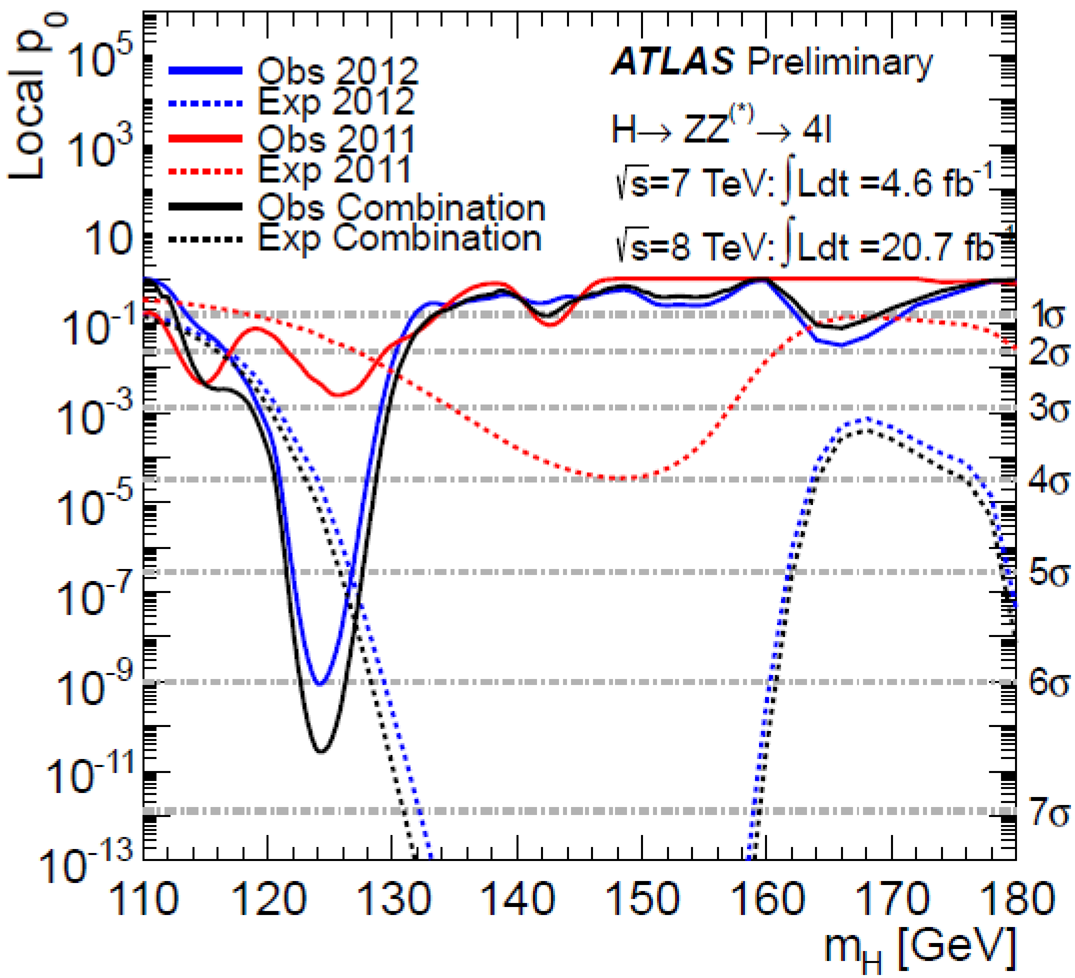
Event yields

Table 7: The numbers of expected signal events for the m_H=125 GeV hypothesis and background events together with the numbers of observed events, in a window of ±5 GeV around 125 GeV for 20.7 fb^{-1} at $\sqrt{s}$ = 8 TeV and 4.6 fb^{-1} at $\sqrt{s}$ = 7 TeV as well as for their combination.

	total signal full mass range	signal	$ZZ^{(*)}$	Z + jets, $t\bar{t}$	S/B	expected	observed
			$\sqrt{s}$ = 8 TeV				
4μ	5.8 ± 0.7	5.3 ± 0.7	2.3 ± 0.1	0.50 ± 0.13	1.9	8.1 ± 0.9	11
$2\mu 2e$	3.0 ± 0.4	2.6 ± 0.4	1.2 ± 0.1	1.01 ± 0.21	1.2	4.8 ± 0.7	4
$2e2\mu$	4.0 ± 0.5	3.4 ± 0.4	1.7 ± 0.1	0.51 ± 0.16	1.5	5.6 ± 0.7	6
$4e$	2.9 ± 0.4	2.3 ± 0.3	1.0 ± 0.1	0.62 ± 0.16	1.4	3.9 ± 0.6	6
total	15.7 ± 2.0	13.7 ± 1.8	6.2 ± 0.4	2.62 ± 0.34	1.6	22.5 ± 2.9	27
			$\sqrt{s}$ = 7 TeV				
4μ	1.0 ± 0.1	0.97 ± 0.13	0.49 ± 0.02	0.05 ± 0.02	1.8	1.5 ± 0.2	2
$2\mu 2e$	0.4 ± 0.1	0.39 ± 0.05	0.21 ± 0.02	0.55 ± 0.12	0.5	1.2 ± 0.1	1
$2e2\mu$	0.7 ± 0.1	0.57 ± 0.08	0.33 ± 0.02	0.04 ± 0.01	1.5	0.9 ± 0.1	2
$4e$	0.4 ± 0.1	0.29 ± 0.04	0.15 ± 0.01	0.49 ± 0.12	0.5	0.9 ± 0.1	0
total	2.5 ± 0.4	2.2 ± 0.3	1.17 ± 0.07	1.12 ± 0.17	1.0	4.5 ± 0.5	5
			$\sqrt{s}$ = 8 TeV and $\sqrt{s}$ = 7 TeV				
4μ	6.8 ± 0.8	6.3 ± 0.8	2.8 ± 0.1	0.55 ± 0.15	1.9	9.6 ± 1.0	13
$2\mu 2e$	3.4 ± 0.5	3.0 ± 0.4	1.4 ± 0.1	1.56 ± 0.33	1.0	6.0 ± 0.8	5
$2e2\mu$	4.7 ± 0.6	4.0 ± 0.5	2.1 ± 0.1	0.55 ± 0.17	1.5	6.6 ± 0.8	8
$4e$	3.3 ± 0.5	2.6 ± 0.4	1.2 ± 0.1	1.11 ± 0.28	1.1	4.9 ± 0.8	6
total	18.2 ± 2.4	15.9 ± 2.1	7.4 ± 0.4	3.74 ± 0.93	1.4	27.1 ± 3.4	32

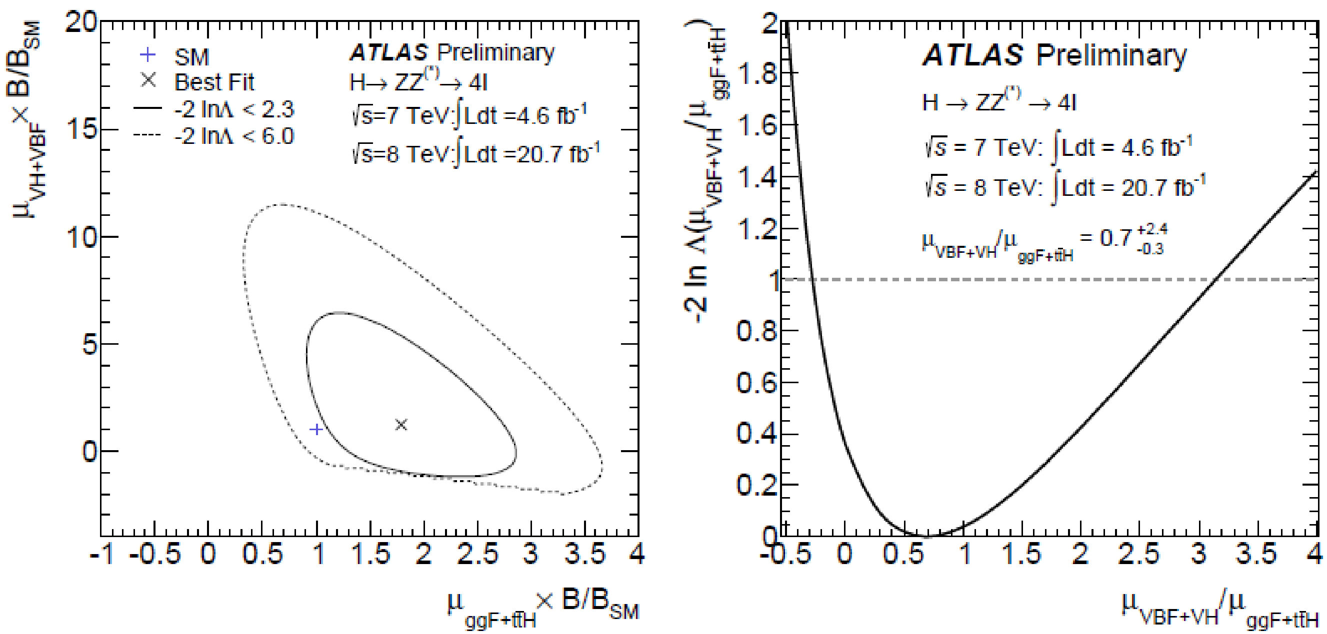
Higgs to 4 leptons

P-values



Higgs to 4 leptons

Likelihood scan



(a) (b)

Figure 11: (a) Likelihood contours in the $(\mu_{ggF+t\bar{t}H}, \mu_{VBF+VH})$ plane including the branching ratio factor B/B_{SM}. The quantity $\mu_{ggF+t\bar{t}H}$ (μ_{VBF+VH}) is a common scale factor for the ggF and $t\bar{t}H$ (VBF and VH) production cross sections. Only the part of the plane where the expected numbers of signal events in each category is positive is considered. The best fit to the data ($\times$) and $-2\ln\Lambda < 2.3$ (full) and 6.0 (dashed) contours are also indicated, as well as the SM expectation (+). (b) Results of a likelihood scan for $\mu_{VBF+VH}/\mu_{ggF+t\bar{t}H}$. The branching ratio factor B/B_{SM} cancels out in this ratio.

HIGGS TO 2 LEPTONS AND 2 NEUTRINOS

Backup slides

Higgs to 2 leptons and 2 neutrinos

MC Generators

Signal	MC generator	$\sigma \cdot \mathcal{B}$ (pb)
ggF	POWHEG [30]+PYTHIA8 [31]	0.44
VBF	POWHEG+PYTHIA8	0.035
VH	PYTHIA8	0.13

Background	MC generator	$\sigma \cdot \mathcal{B}$ (pb)
$q\bar{q}, gq \to WW$	POWHEG+PYTHIA6 [32]	5.7
$q\bar{q}, gq \to WW{+}2j$	Sherpa [33] with no $\mathcal{O}(\alpha_s)$ terms	0.039
$gg \to WW$	GG2WW 3.1.2 [34, 35]+HERWIG [36]	0.16
$t\bar{t}$	MC@NLO [37]+HERWIG	240
Single top: tW, tb	MC@NLO+HERWIG	28
Single top: tqb	AcerMC [38]+PYTHIA6	88
Z/γ^*, inclusive	ALPGEN+HERWIG	16000
$Z^{(*)} \to \ell\ell + 2j$	Sherpa processes up to $\mathcal{O}(\alpha_s)$	1.2
$Z^{(*)}Z^{(*)} \to 4\ell$	POWHEG+PYTHIA8	0.73
$WZ/W\gamma^*, m_{Z/\gamma^*}{>}7$	POWHEG+PYTHIA8	0.83
$W\gamma^*, m_{\gamma^*} \leq 7$	MadGraph [39–41]+PYTHIA6	11
$W\gamma$	ALPGEN+HERWIG	370

Higgs to 2 leptons and 2 neutrinos

Table 2: Selection listing for 8 TeV data. The criteria specific to $e\mu+\mu e$ and $ee+\mu\mu$ are noted as such; otherwise, they apply to both. Pre-selection applies to all $N_{\rm jet}$ modes. The rapidity gap is the y range spanned by the two leading jets. The $m_{\ell\ell}$ split is at 30 GeV. The modifications for the 7 TeV analysis are given in Section 6 and are not listed here. Energies, masses, and momenta are in units of GeV.

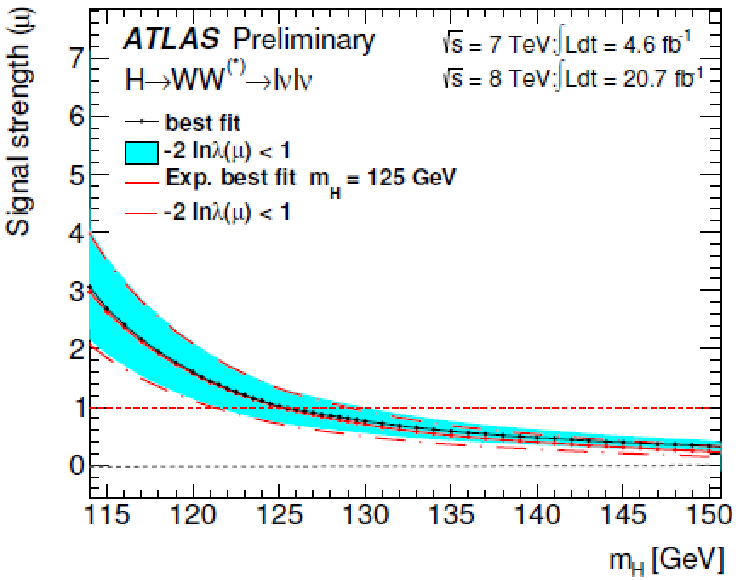
Category	$N_{\rm jet}=0$	$N_{\rm jet}=1$	$N_{\rm jet}\geq 2$
Pre-selection	Two isolated leptons ($\ell=e,\mu$) with opposite charge Leptons with $p_{\rm T}^{\rm lead}>25$ and $p_{\rm T}^{\rm sublead}>15$ $e\mu+\mu e$: $m_{\ell\ell}>10$ $ee+\mu\mu$: $m_{\ell\ell}>12$, $\lvert m_{\ell\ell}-m_Z\rvert>15$		
Missing transverse momentum and hadronic recoil	$e\mu+\mu e$: $E_{\rm T,rel}^{\rm miss}>25$ $ee+\mu\mu$: $E_{\rm T,rel}^{\rm miss}>45$ $ee+\mu\mu$: $p_{\rm T,rel}^{\rm miss}>45$ $ee+\mu\mu$: $f_{\rm recoil}<0.05$	$e\mu+\mu e$: $E_{\rm T,rel}^{\rm miss}>25$ $ee+\mu\mu$: $E_{\rm T,rel}^{\rm miss}>45$ $ee+\mu\mu$: $p_{\rm T,rel}^{\rm miss}>45$ $ee+\mu\mu$: $f_{\rm recoil}<0.2$	$e\mu+\mu e$: $E_{\rm T}^{\rm miss}>20$ $ee+\mu\mu$: $E_{\rm T}^{\rm miss}>45$ $ee+\mu\mu$: $E_{\rm T,STVF}^{\rm miss}>35$ -
General selection	- $\lvert\Delta\phi_{\ell\ell,MET}\rvert>\pi/2$ $p_{\rm T}^{\ell\ell}>30$	$N_{b\text{-jet}}=0$ - $e\mu+\mu e$: $Z/\gamma^*\to\tau\tau$ veto	$N_{b\text{-jet}}=0$ $p_{\rm T}^{\rm tot}<45$ $e\mu+\mu e$: $Z/\gamma^*\to\tau\tau$ veto
VBF topology	- - - -	- - - -	$m_{jj}>500$ $\lvert\Delta y_{jj}\rvert>2.8$ No jets ($p_{\rm T}>20$) in rapidity gap Require both ℓ in rapidity gap
$H\to WW^{(*)}\to\ell\nu\ell\nu$ topology	$m_{\ell\ell}<50$ $\lvert\Delta\phi_{\ell\ell}\rvert<1.8$ $e\mu+\mu e$: split $m_{\ell\ell}$ Fit $m_{\rm T}$	$m_{\ell\ell}<50$ $\lvert\Delta\phi_{\ell\ell}\rvert<1.8$ $e\mu+\mu e$: split $m_{\ell\ell}$ Fit $m_{\rm T}$	$m_{\ell\ell}<60$ $\lvert\Delta\phi_{\ell\ell}\rvert<1.8$ - Fit $m_{\rm T}$

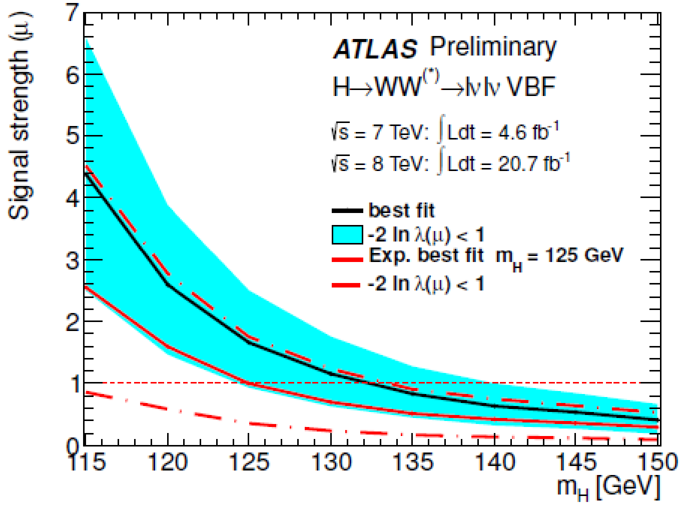
Higgs to 2 leptons and 2 neutrinos

Table 3: Background treatment listing. The estimation procedures for various background processes are given in four categories: normalised using a control region (CR); data-derived estimate (Data); normalised using the MC (MC); and normalised using the MC, but validated in a control region (MC + VR). The "($e\mu + \mu e$)" terms denote that for the $ee + \mu\mu$ channel in the same N_{jet} mode, the $e\mu + \mu e$ region is used instead, for reasons of purity and/or statistics. The "(merged)" terms indicate that the fully combined $e\mu + \mu e + ee + \mu\mu$ control region is used for all channels.

Channel	WW	Top	$Z/\gamma^* \to \tau\tau$	$Z/\gamma^* \to \ell\ell$	W+ jets	VV
$N_{\mathrm{jet}} = 0$						
$e\mu + \mu e$	CR	CR	CR	MC	Data	MC + VR
$ee + \mu\mu$	CR ($e\mu + \mu e$)	CR ($e\mu + \mu e$)	CR ($e\mu + \mu e$)	Data	Data	MC + VR
$N_{\mathrm{jet}} = 1$						
$e\mu + \mu e$	CR	CR	CR	MC	Data	MC + VR
$ee + \mu\mu$	CR ($e\mu + \mu e$)	CR ($e\mu + \mu e$)	CR ($e\mu + \mu e$)	Data	Data	MC + VR
$N_{\mathrm{jet}} \geq 2$						
$e\mu + \mu e$	MC	CR (merged)	CR	MC	Data	MC
$ee + \mu\mu$	MC	CR (merged)	CR ($e\mu + \mu e$)	Data	Data	MC

Higgs to 2 leptons and 2 neutrinos





VBF

Higgs to 2 leptons and 2 neutrinos

Table 13: Leading uncertainties on the signal strength μ for the combined 7 and 8 TeV analysis.

Category	Source	Uncertainty, up (%)	Uncertainty, down (%)
Statistical	Observed data	+21	−21
Theoretical	Signal yield ($\sigma \cdot \mathcal{B}$)	+12	−9
Theoretical	WW normalisation	+12	−12
Experimental	Objects and DY estimation	+9	−8
Theoretical	Signal acceptance	+9	−7
Experimental	MC statistics	+7	−7
Experimental	W+ jets fake factor	+5	−5
Theoretical	Backgrounds, excluding WW	+5	−4
Luminosity	Integrated luminosity	+4	−4
Total		+32	−29

HIGGS TO PHOTONS

Backup slides

ATLAS-CONF-2013-012

Higgs to photons

$\sqrt{s}$	8 TeV						
Category	N_D	N_S	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
Unconv. central, low p_{Tt}	10900	51.8	93.7	4.0	1.4	0.8	0.2
Unconv. central, high p_{Tt}	553	7.9	79.3	12.6	4.1	2.5	1.4
Unconv. rest, low p_{Tt}	41236	107.9	93.2	4.0	1.6	1.0	0.1
Unconv. rest, high p_{Tt}	2558	16.0	78.1	13.3	4.7	2.8	1.1
Conv. central, low p_{Tt}	7109	33.1	93.6	4.0	1.3	0.9	0.2
Conv. central, high p_{Tt}	363	5.1	78.9	12.6	4.3	2.7	1.5
Conv. rest, low p_{Tt}	38156	97.8	93.2	4.1	1.6	1.0	0.1
Conv. rest, high p_{Tt}	2360	14.4	77.7	13.0	5.2	3.0	1.1
Conv. transition	14864	40.1	90.7	5.5	2.2	1.3	0.2
Loose high-mass two-jet	276	5.3	45.0	54.1	0.5	0.3	0.1
Tight high-mass two-jet	136	8.1	23.8	76.0	0.1	0.1	0.0
Low-mass two-jet	210	3.3	48.1	3.0	29.7	17.2	1.9
E_T^{miss} significance	49	1.3	4.1	0.5	35.7	47.6	12.1
One-lepton	123	2.9	2.2	0.6	63.2	15.4	18.6
All categories (inclusive)	118893	395.0	88.0	7.3	2.7	1.5	0.5

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Higgs to photons

Table 2: Signal mass resolution (σ_{CB}), number of observed events, number of expected signal events (N_S), number of expected background events (N_B) and signal to background ratio (N_S/N_B) in a mass window around m_H = 126.5 GeV containing 90% of the expected signal for each of the 14 categories of the 8 TeV data analysis. The numbers of background events are obtained from the background + signal fit to the $m_{\gamma\gamma}$ data distribution.

$\sqrt{s}$	8 TeV				
Category	σ_{CB}(GeV)	Observed	N_S	N_B	N_S/N_B
Unconv. central, low p_{Tt}	1.50	911	46.6	881	0.05
Unconv. central, high p_{Tt}	1.40	49	7.1	44	0.16
Unconv. rest, low p_{Tt}	1.74	4611	97.1	4347	0.02
Unconv. rest, high p_{Tt}	1.69	292	14.4	247	0.06
Conv. central, low p_{Tt}	1.68	722	29.8	687	0.04
Conv. central, high p_{Tt}	1.54	39	4.6	31	0.15
Conv. rest, low p_{Tt}	2.01	4865	88.0	4657	0.02
Conv. rest, high p_{Tt}	1.87	276	12.9	266	0.05
Conv. transition	2.52	2554	36.1	2499	0.01
Loose High-mass two-jet	1.71	40	4.8	28	0.17
Tight High-mass two-jet	1.64	24	7.3	13	0.57
Low-mass two-jet	1.62	21	3.0	21	0.14
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	1.74	8	1.1	4	0.24
One-lepton	1.75	19	2.6	12	0.20
Inclusive	1.77	14025	355.5	13280	0.03

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Higgs to photons

Table 3: Cross sections for the Standard Model Higgs boson production with m_H = 126.5 GeV at $\sqrt{s}$ = 8 TeV [57, 58]. The branching ratio to the two photons decay mode is $2.28 \cdot 10^{-3}$ at m_H = 126.5 GeV. Gluon fusion and vector boson fusion cross sections are computed in the complex pole scheme at NNLL+NNLO QCD and NLO EW [58]. Associated production cross section are computed with zero-width-approximation at NNLO QCD and NLO EW. The ttH process cross section is computed with zero-width-approximation at NLO QCD. QCD scale (±Scale) and the PDF+α_s uncertainties are treated as non-correlated [68].

Process	Cross section (pb)	+Scale %	-Scale %	+(PDF+α_s)%	-(PDF+α_s)%
ggF	19.07	+7.2	-7.8	+7.5	-6.9
VBF	1.56	+0.2	-0.2	+2.6	-2.7
WH	0.67	+0.2	-0.6	+3.5	-3.5
ZH	0.38	+1.6	-1.5	+3.6	-3.6
ttH	0.13	+3.8	-9.3	+7.8	-7.8

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Higgs to photons

Table 4: Systematic uncertainty on the number of fitted signal events due to the background model for the $\sqrt{s}$ = 7 TeV (10 categories) and $\sqrt{s}$ = 8 TeV (14 categories) analyses. Three different background models are used depending on the category; an exponential function, a fourth order polynomial and the exponential of a second order polynomial.

Category	Parametrisation	Uncertainty [N_{evt}] $\sqrt{s}$ = 7 TeV	Uncertainty [N_{evt}] $\sqrt{s}$ = 8 TeV
Inclusive	4th order pol.	7.3	12.0
Unconverted central, low p_{Tt}	Exp. of 2nd order pol.	2.1	4.6
Unconverted central, high p_{Tt}	Exponential	0.2	0.8
Unconverted rest, low p_{Tt}	4th order pol.	2.2	11.4
Unconverted rest, high p_{Tt}	Exponential	0.5	2.0
Converted central, low p_{Tt}	Exp. of 2nd order pol.	1.6	2.4
Converted central, high p_{Tt}	Exponential	0.3	0.8
Converted rest, low p_{Tt}	4th order pol.	4.6	8.0
Converted rest, high p_{Tt}	Exponential	0.5	1.1
Converted transition	Exp. of 2nd order pol.	3.2	9.1
Loose high-mass two-jet	Exponential	0.4	1.1
Tight high-mass two-jet	Exponential	-	0.3
Low-mass two-jet	Exponential	-	0.6
E_T^{miss} significance	Exponential	-	0.1
One-lepton	Exponential	-	0.3

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Higgs to photons

Table 5: Summary of the impact of systematic uncertainties on the signal yields for the analysis of the 8 TeV data.

Systematic uncertainties	Value(%)			Constraint
Luminosity	±3.6			Log-normal
Trigger	±0.5			Log-normal
Photon Identification	±2.4			Log-normal
Isolation	±1.0			Log-normal
Photon Energy Scale	±0.25			Log-normal
Branching ratio	$\pm5.9\% - \pm2.1\%$ (m_H = 110 - 150 GeV)			Asymmetric Log-normal
Scale	ggF: $^{+7.2}_{-7.8}$ ZH: $^{+1.6}_{-1.5}$	VBF: $^{+0.2}_{-0.2}$ ttH: $^{+3.8}_{-9.3}$	WH: $^{+0.2}_{-0.6}$	Asymmetric Log-normal
PDF+α_s	ggF: $^{+7.5}_{-6.9}$ ZH: ±3.6	VBF: $^{+2.6}_{-2.7}$ ttH: ±7.8	WH: ±3.5	Asymmetric Log-normal
Theory cross section on ggF	Tight high-mass two-jet: Loose high-mass two-jet: Low-mass two-jet:	±48 ±28 ±30		Log-normal