HIGGS COUPLING FROM ATLAS

Les Rencontres de Physique de La Vallee d'Aoste
La Thuile 24/2-2/3 2013

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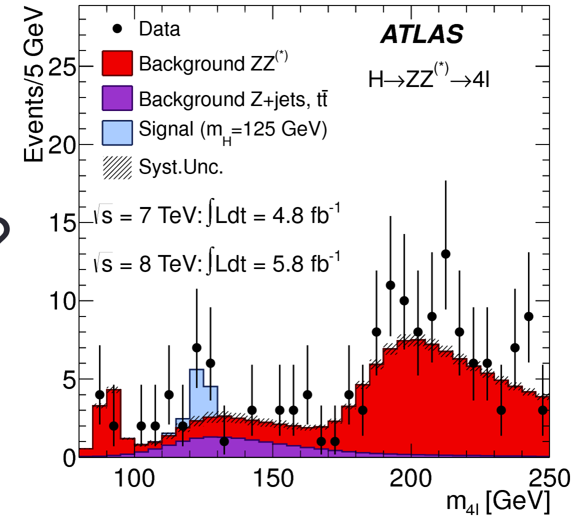
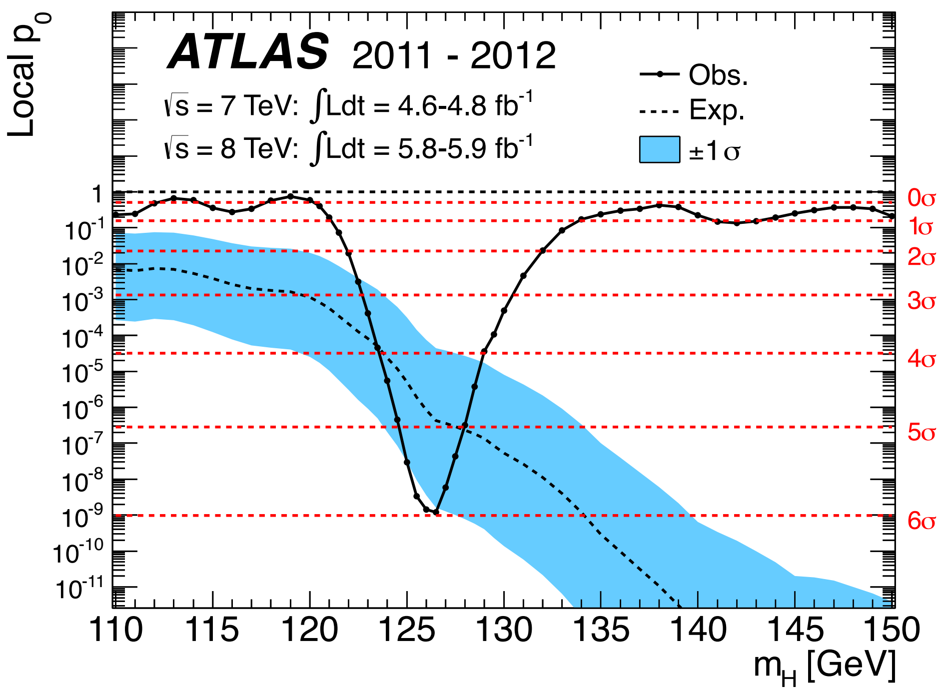
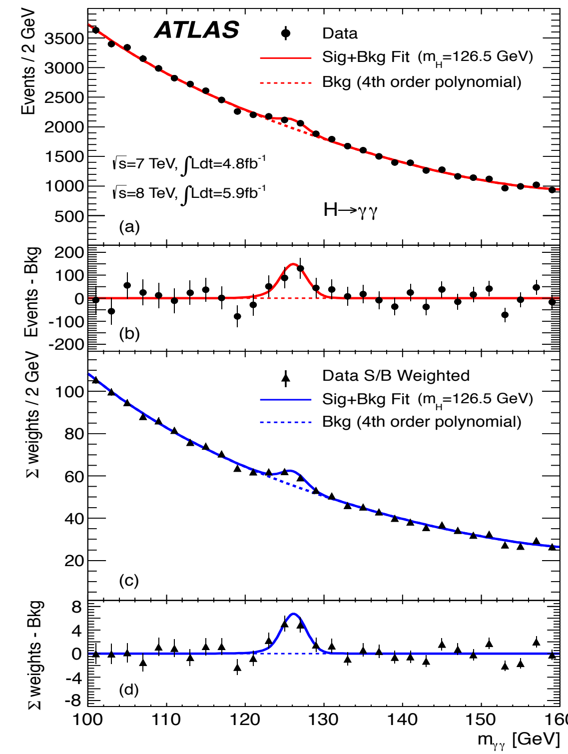
On behalf of the Atlas collaboration

Outline

- Is the new particle the "Higgs boson"?
  - Does it couple to matter and vector boson fields as in the Standard Model?
  - Can we infer the Higgs Lagrangian ?





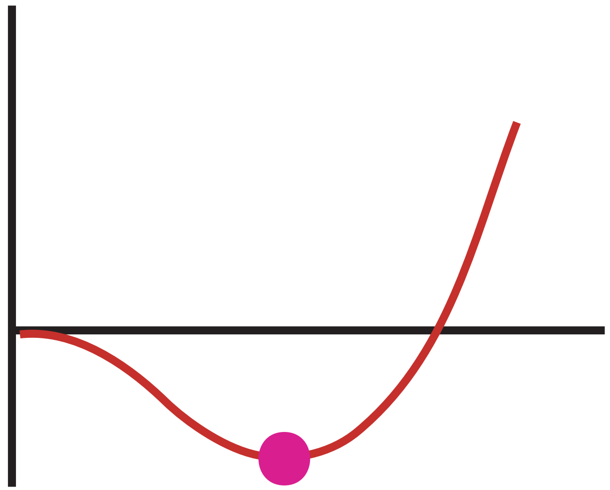


Higgs coupling in SM

- Given Higgs Mass no free parameter in the SM !

$$V(|\varphi|) = \mu^2|\varphi|^2 + \lambda|\varphi|^4$$

$$m_h = \sqrt{2|\mu^2|} = \sqrt{\lambda/2}v$$



With $$m_W^2 = \frac{g^2}{4}v^2 \qquad m_Z^2 = \frac{g^2 + g'^2}{4}v^2$$

$$m_W/m_Z = \cos\theta_w$$

Then Higgs – Boson and Higgs – Fermion (Yukawa) interaction perfectly determined given particle masses

EWK Lagrangian

$$\mathcal{L}_{EW} = \mathcal{L}_K + \mathcal{L}_N + \mathcal{L}_C + \mathcal{L}_H + \mathcal{L}_{HV} + \mathcal{L}_{WWV} + \mathcal{L}_{WWVV} + \mathcal{L}_Y$$

$$\mathcal{L}_K = \sum_f \bar{f}(i\partial\!\!\!/ - m_f)f - \frac{1}{4}A_{\mu\nu}A^{\mu\nu} - \frac{1}{2}W^+_{\mu\nu}W^{-\mu\nu} + m_W^2 W^+_\mu W^{-\mu} - \frac{1}{4}Z_{\mu\nu}Z^{\mu\nu} + \frac{1}{2}m_Z^2 Z_\mu Z^\mu + \frac{1}{2}(\partial^\mu H)(\partial_\mu H) - \frac{1}{2}m_H^2 H^2$$

$$\mathcal{L}_N = eJ^{em}_\mu A^\mu + \frac{g}{\cos\theta_W}(J^3_\mu - \sin^2\theta_W J^{em}_\mu)Z^\mu$$

$$\mathcal{L}_C = -\frac{g}{\sqrt{2}}\left[\bar{u}_i\gamma^\mu\frac{1-\gamma^5}{2}M^{CKM}_{ij}d_j + \bar{\nu}_i\gamma^\mu\frac{1-\gamma^5}{2}e_i\right]W^+_\mu + h.c.$$

$$\mathcal{L}_H = -\frac{gm_H^2}{4m_W}H^3 - \frac{g^2m_H^2}{32m_W^2}H^4 \qquad \mathcal{L}_Y = -\sum_f \frac{gm_f}{2m_W}\bar{f}fH$$

$$\mathcal{L}_{HV} = \left(gm_W H + \frac{g^2}{4}H^2\right)\left(W^+_\mu W^{-\mu} + \frac{1}{2\cos^2\theta_W}Z_\mu Z^\mu\right)$$

$$\mathcal{L}_{WWV} = -ig[(W^+_{\mu\nu}W^{-\mu} - W^{+\mu}W^-_{\mu\nu})(A^\nu\sin\theta_W - Z^\nu\cos\theta_W) + W^-_\nu W^+_\mu(A^{\mu\nu}\sin\theta_W - Z^{\mu\nu}\cos\theta_W)]$$

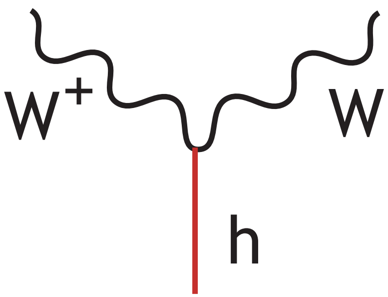
$$\mathcal{L}_{WWVV} = -\frac{g^2}{4}\{[2W^+_\mu W^{-\mu} + (A_\mu\sin\theta_W - Z_\mu\cos\theta_W)^2]^2 - [W^+_\mu W^-_\nu + W^+_\nu W^-_\mu + (A_\mu\sin\theta_W - Z_\mu\cos\theta_W)(A_\nu\sin\theta_W - Z_\nu\cos\theta_W)]^2\}$$

Precision measurement of the Higgs couplings will be possibly one of the most important driver of the field in the next decade(s) (provided no surprises behind the corner)

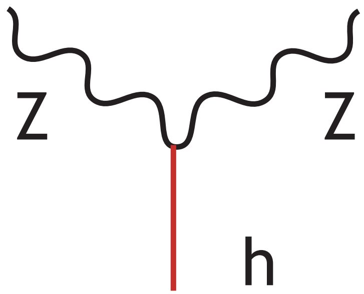
Higgs Coupling/tree level decays

$$\mathcal{L}_H = -\frac{g m_H^2}{4 m_W} H^3 - \frac{g^2 m_H^2}{32 m_W^2} H^4 \qquad \mathcal{L}_Y = -\sum_f \frac{g m_f}{2 m_W} \bar{f} f H$$

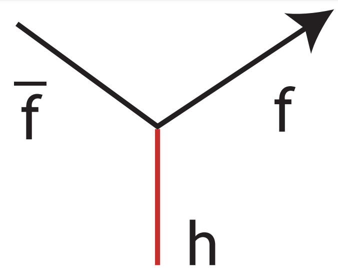
$$\mathcal{L}_{HV} = \left(g m_W H + \frac{g^2}{4} H^2 \right) \left(W_\mu^+ W^{-\mu} + \frac{1}{2\cos^2\theta_W} Z_\mu Z^\mu \right)$$



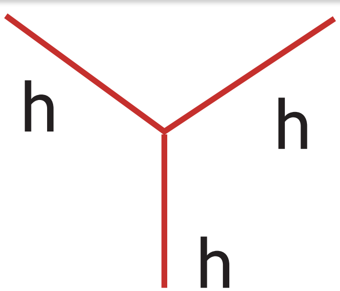
$= g\, M_W = 2\, M_W^2/v$



$= g\, M_W / 2\cos(\theta_w)^2 = M_z^2/v$



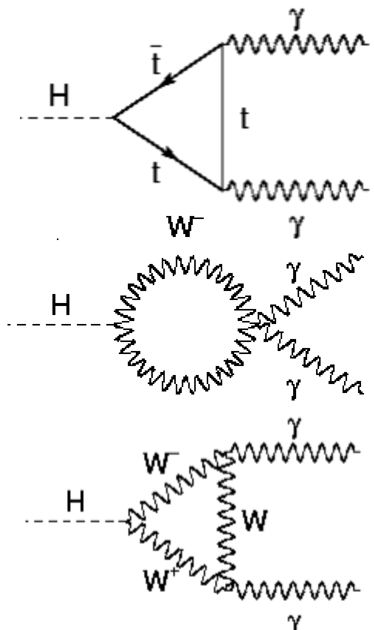
$= -g\, m/2M_W = -m/v$



$= -3\, m_H^2/v$

That's not for now, wait for >10 yr

Higgs coupling/important loops !

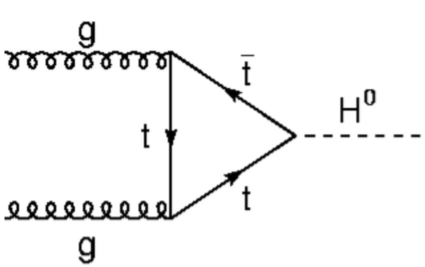


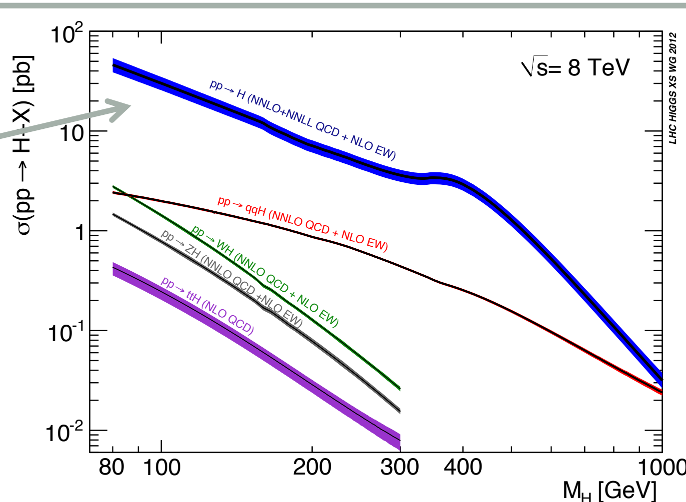
Gamma Gamma decay drives the signal significance, proceeds through fermion and boson loops: W and top most important, negative interference:

W and Top amplitude weights in the H→γγ partial width:

$$\sim \kappa_\gamma^2 = |1.28\ \kappa_W - 0.28\ \kappa_t|^2$$

Decay

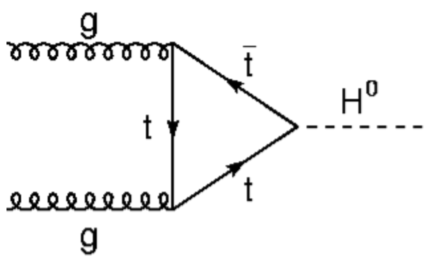




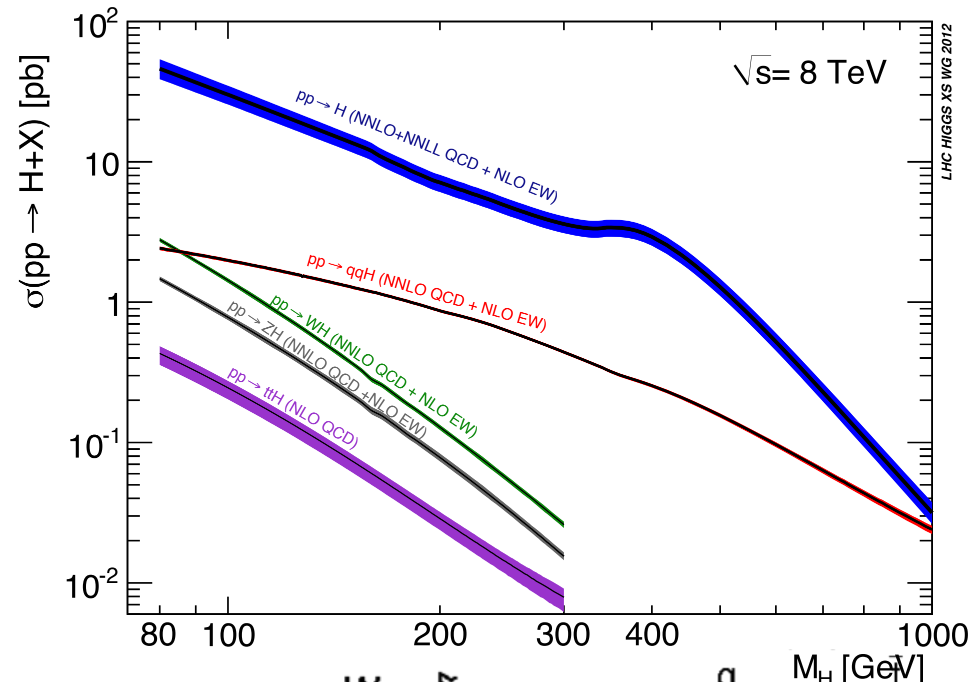
Gluon fusion provides dominant Higgs boson production mechanism Top loop dominant (-10% interference from bottom loop).

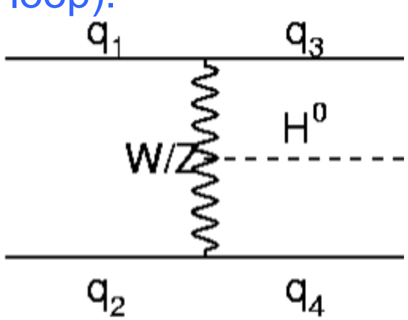
Production

Higgs coupling/exclusive production channels

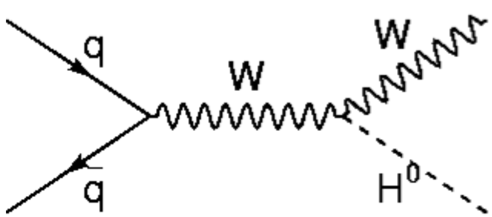


Gluon fusion provide dominant Higgs boson production mechanism
Top loop dominant (-10% interference from bottom loop).

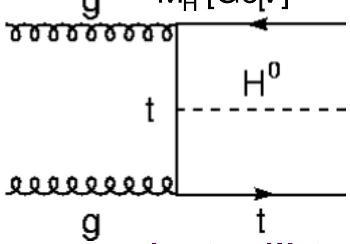




VBF ~7% inclusive xsec, distinct signature, access to W/Z Higgs couplings



Clean signature with leptons, allowing access to H→bb and W/Z Higgs coupling



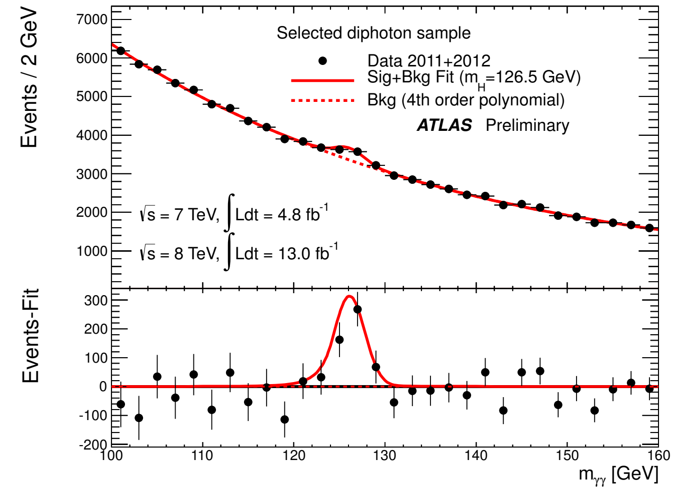
Low rate, but will test directly Top Yukawa coupling

SIGNAL STRENGTH MEASUREMENTS

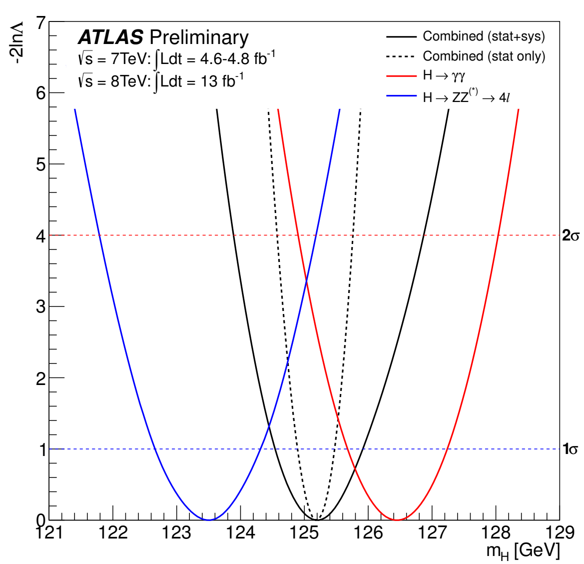
Atlas December Update

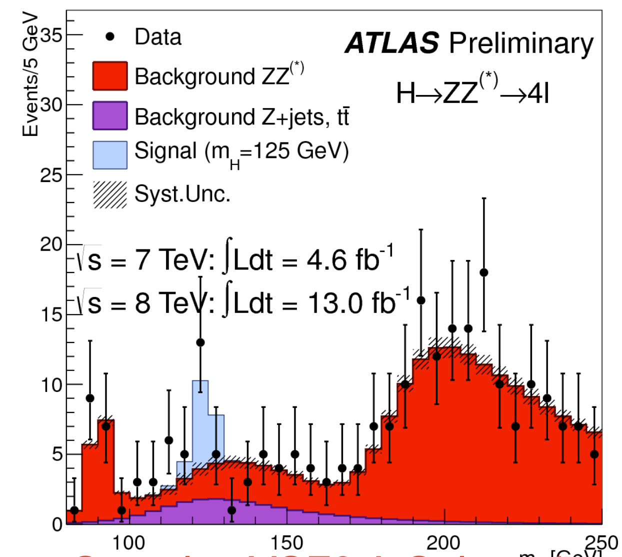
- Latest combination from Atlas
- All major channels updated with 5fb^{-1} @ 7 TeV + 13 fb^{-1} @ 8 TeV
- Local significance exceeding 6σ in H→γγ and 4σ in H→4l
- New H→WW H→bb, H→ττ updated for HCP
- E.Petit talk yesterday for full details
- Combined best fit Higgs mass from the high resolution channels:

$m_H = 125.2 \pm 0.3(stat) \pm 0.6(sys)$



See also YSF3 M.Schwoerer





See also YSF3 A.Salvucci

New

Overall signal strength

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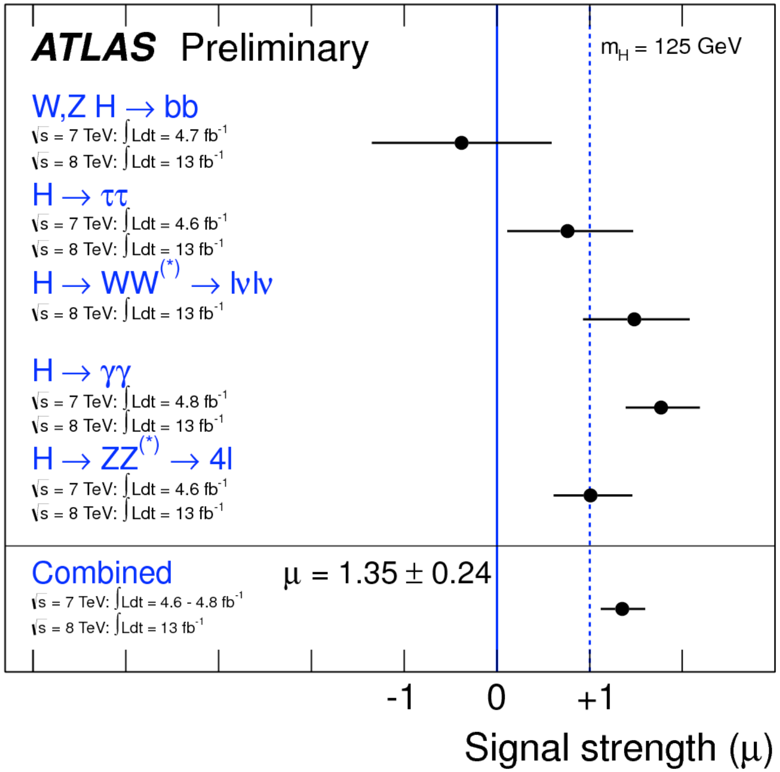

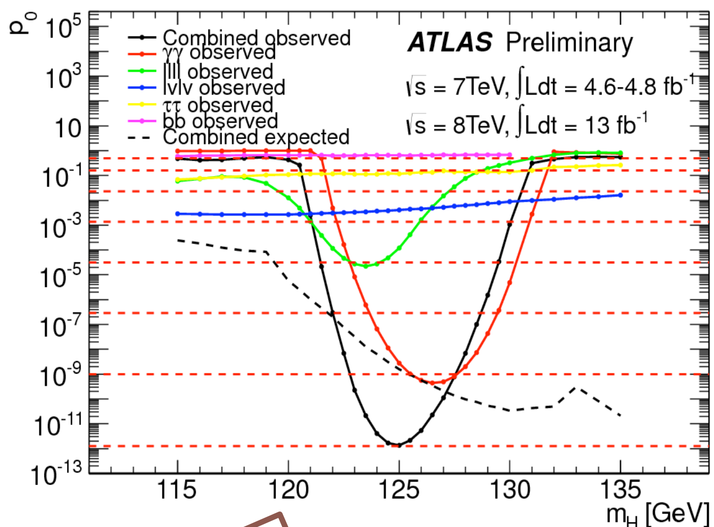

P-value(μ=1) 13%

Higgs Boson Decay	μ (m_H=125 GeV)
$VH \to Vbb$	-0.4 ± 1.0
$H \to \tau\tau$	0.8 ± 0.7
$H \to WW^{(*)}$	1.5 ± 0.6
$H \to \gamma\gamma$	1.8 ± 0.4
$H \to ZZ^{(*)}$	1.0 ± 0.4
Combined	1.35 ± 0.24

- *Best fit value:*
  - μ=1.35±0.19(*stat*)±0.15(*sys*)
- Moderate excess in H→$\gamma\gamma$

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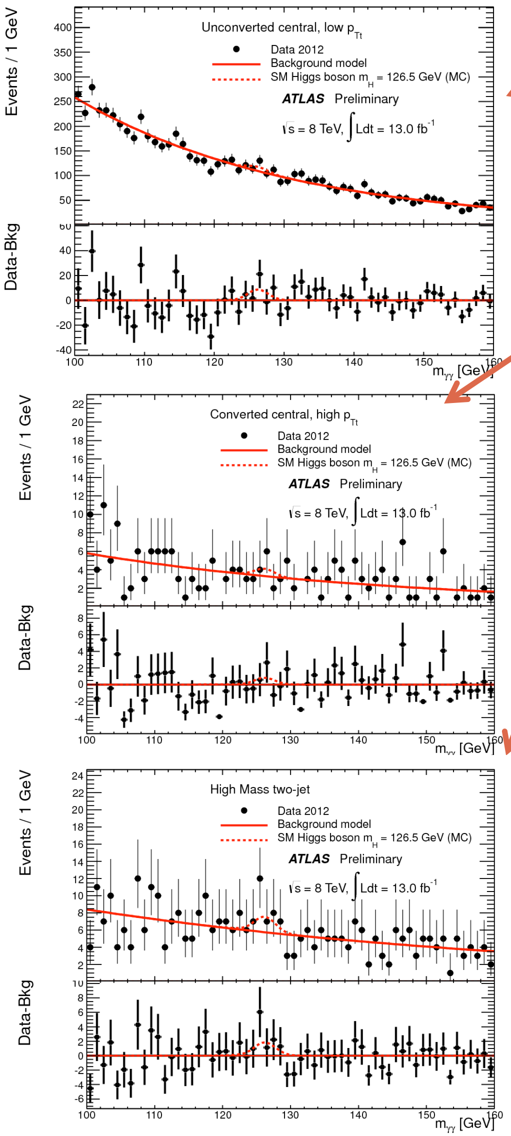
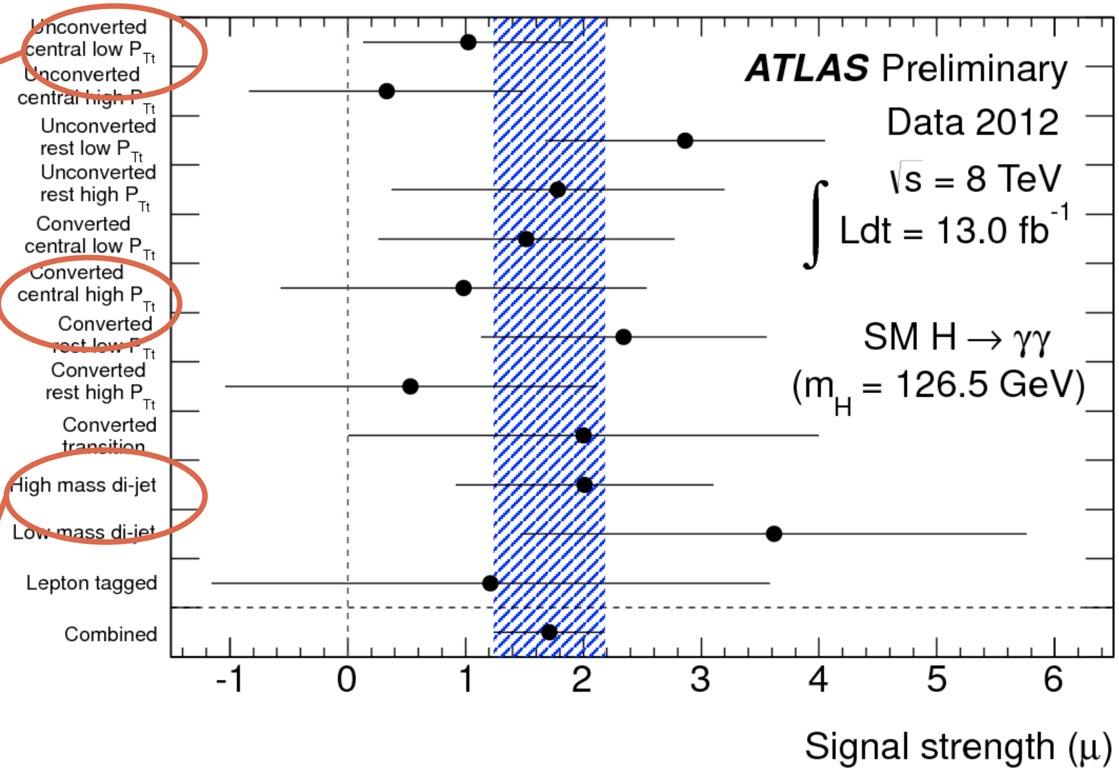
New

Looking deeper in H→γγ sub-channels





12 exclusive categories: conversion&quality (signal width & S/B) and p_{Tt} (different S/B and ggF/rest ratio) + 2 jet (high mass, VBF dominated) + 2 jet (low mass, VH) + lepton tagged (VH)

Moderate enhancement wrt to SM, no clear pattern

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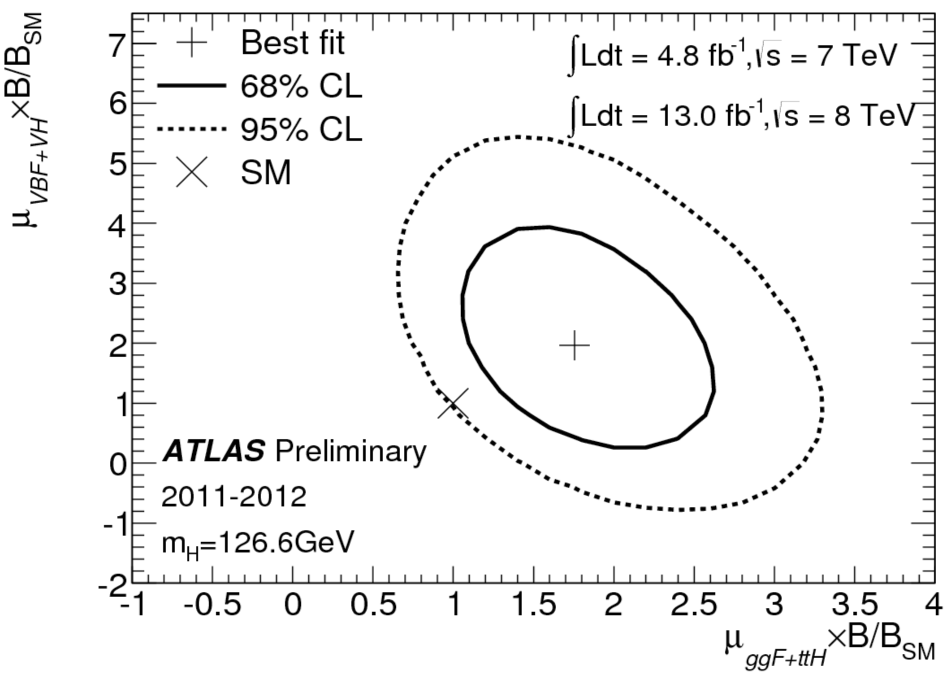
New

VBF vs ggF using H→γγ



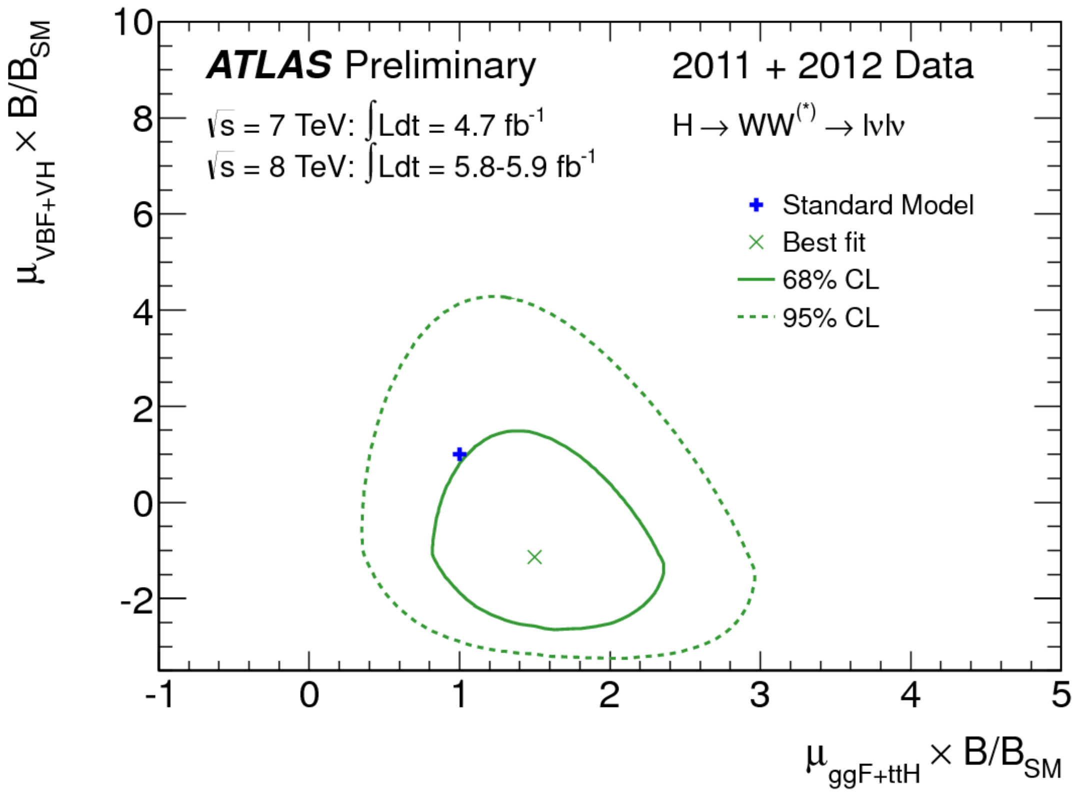
- Group together VBF+VH production and ggF+ttH as dependent on vector boson and top couplings, respectively
- Combined $\mu = 1.80 \pm 0.30(stat)^{+0.21}_{-0.15}(syst)^{+0.20}_{-0.14}(\text{theory})$

	Value	Statistic uncertainty	Systematic uncertainty	Theoretical uncertainty
$\mu_{ggF+ttH} \times B/B_{SM}$	1.8	±0.4	±0.2	±0.2
$\mu_{VBF} \times B/B_{SM}$	2.0	±1.2	±0.6	±0.3
$\mu_{VH} \times B/B_{SM}$	1.9	±2.5	±0.6	±0.4

Consistent with SM (μ=1) at 2.4 σ

Disclaimer: more conservative (flat) choice of theory uncertainty pdf would obviously reduce this “tension”!

VBF vs ggF using H→lνlν



- Same for H→WW on statistics used for discovery paper
- Consistent with SM point (1,1) at 1 σ level

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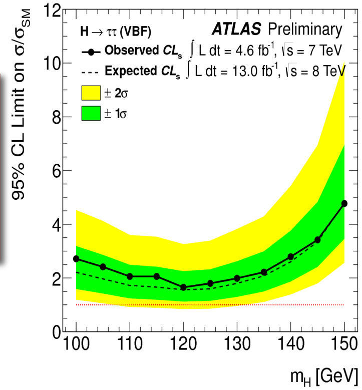
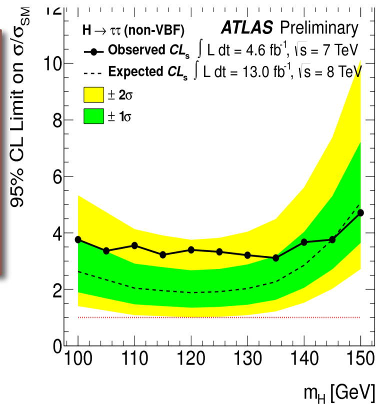
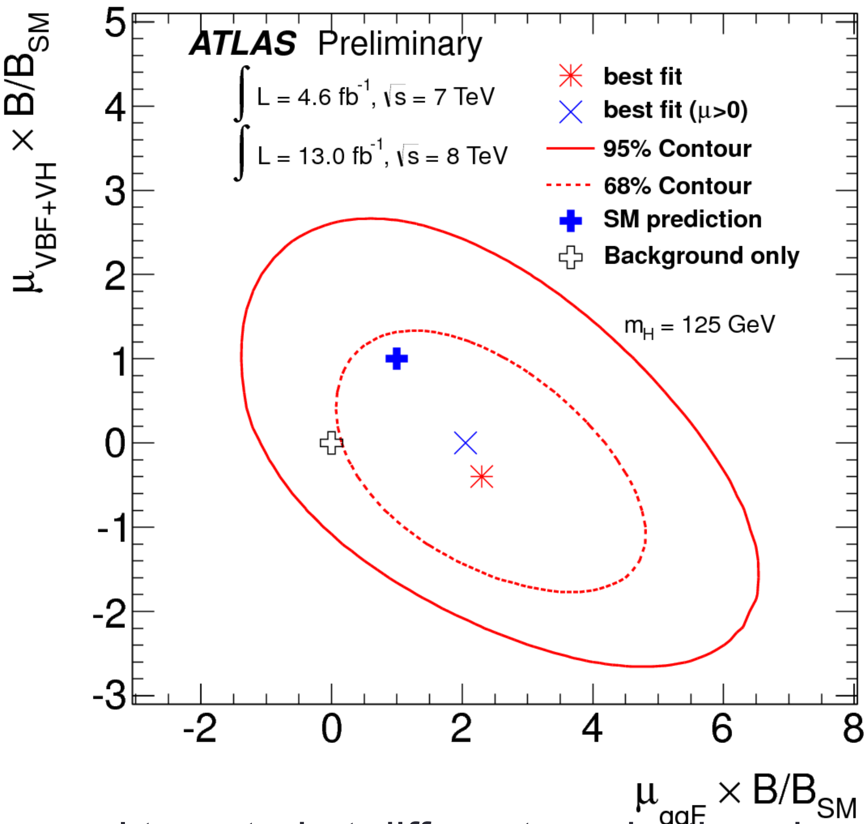
VBF vs ggF using $H\rightarrow\tau\tau$

VBF



Non-VBF





Combined significance: expected 1.7 σ, observed 1.1 σ

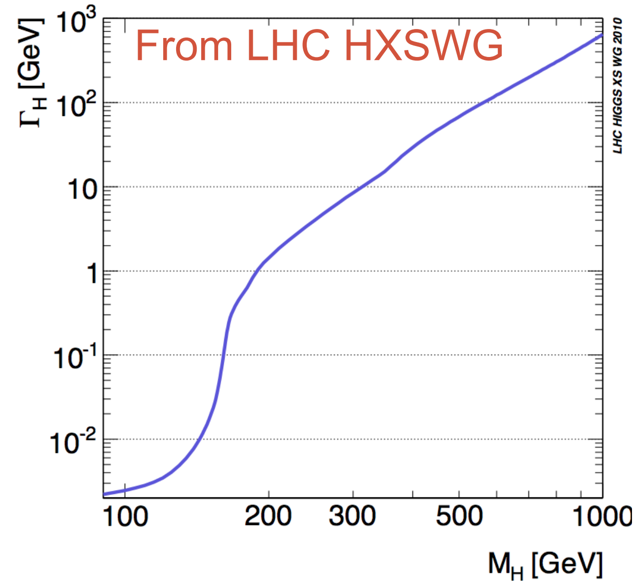
Combined signal strength μ= 0.7±0.7

- Many exclusive channel targeted at different production chan. (new 2 jet VH, improved VBF)
  - $\tau_l\tau_l$, +0,1,2 jet (VBF), 2jet (VH), $\tau_l\tau_h$,+0,1,2 jet (VBF) $\tau_h\tau_h$. 2jet (VBF)
- Strong sensitivity to VBF channel – equivalent or better than other Higgs decay channel

GLOBAL COUPLING FITS

General Strategy

based on recommendation in arXiv:1209.0040



- Assumptions
  - Single resonance
  - No modification to kinematics (tensor structure of the interaction as in the SM)
  - Zero width approximation
- Cross sections can then be written as

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

- Parameterize deviation from SM through scaling factor for couplings such that

$$\Gamma_{ff} = \kappa_f^2 \Gamma_{ff}^{SM} \;\; ; \; \Gamma_H = \kappa_H^2 \Gamma_H^{SM} \;\; ; \;\; \sigma_i = \kappa_i^2 \sigma_i^{SM}$$

- Taking into account dependency from various sub-components in loop process scale factors e.g.:

$$\kappa_{\gamma\gamma}^2 = \kappa_{\gamma\gamma}^2(\kappa_t;\kappa_w;m_H) \;\; ; \;\; \kappa_{ggH}^2 = \kappa_{ggH}^2(\kappa_b;\kappa_t;m_H)$$

- SM prediction incudes state-of-the-art higher order corrections. Accuracy breaks for k!=1, but important NLO QCD corrections factorize

General Strategy/Benchmark Fits

- Total width cannot be directly measured at LHC
  - Assume no invisible/undetected decays are possible such that:

$$\Gamma_H = \kappa_H^2 \Gamma_H^{SM} = \kappa_H^2(\kappa_i, m_H)\Gamma_H^{SM} \quad i = l, t, b, \tau, g, W, Z\ldots$$

  - Measure ratio of coupling scale factors k_i, including one ratio to the total Higgs width

- Current dataset do not allow yet the determination of all the coupling scale factors → Atlas performed the following (simplified) fits:
  - **κ_V vs. κ_F**: universal scale for boson and for fermions
  - **κ_W vs κ_Z**: W vs. Z boson (custodial symmety)
  - **κ_u vs. κ_d**: fermion type, up vs. down (all up/down type fermions receive universal corrections)
  - **κ_q vs. κ_l**: quarks vs. leptons
  - **κ_g vs. κ_γ**: model independent test for BSM contribution to 1-loop coupling
  - **BR_{inv}**: test invisible or undetected decays in total width assuming BSM effect only in loops and SM tree level couplings

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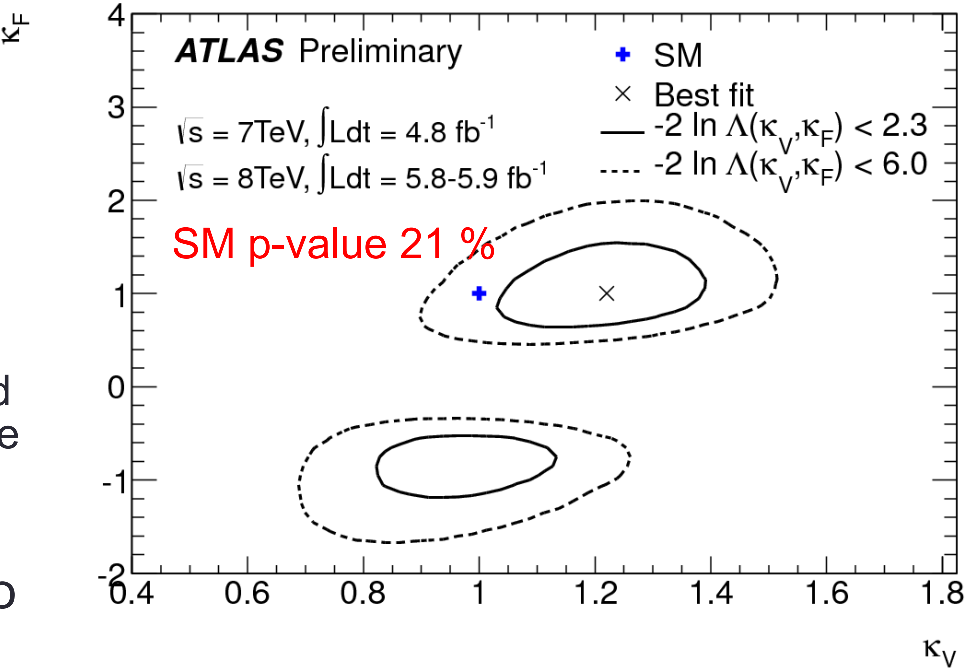
Ingredients

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	4.8	[10]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8	[11]
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet}\} \otimes \{\text{low, high pile-up}\}$	4.7	[12]
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet}, VH\}$	4.7	[13]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e,\mu\} \otimes \{\text{0-jet}\} \otimes \{E_{\mathrm{T}}^{\mathrm{miss}} < 20\text{ GeV}, E_{\mathrm{T}}^{\mathrm{miss}} \geq 20\text{ GeV}\} \oplus \{e,\mu\} \otimes \{\text{1-jet}\} \oplus \{\ell\} \otimes \{\text{2-jet}\}$	4.7	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{\text{1-jet}\}$	4.7	
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\text{ GeV}\}$	4.6	[14]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{<50, 50-100, 100-200, \geq 200\text{ GeV}\}$	4.7	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{<50, 50-100, 100-200, \geq 200\text{ GeV}\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	5.8	[10]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9	[11]
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet, 2-jet}\}$	5.8	[15]

Note this analysis uses statistics and analysis available in Summer 2012, in particular H→bb and H→ττ uses 2011 data only

Vector Boson vs Fermion

- Fit for an "universal" vector boson modifier (k_V) vs a fermion "modifier" (k_F)
- Assumptions:
  - Higgs decay in SM particles (scaling total width with K's)
  - only SM particle present in the gg and $\gamma\gamma$ loops (relating these widths with the scaling factor k's)
- Double degenerate mimima due to quadratic dependence and W/top interference effect in H→$\gamma\gamma$ width :
  - SM point (1,1) reflect to (0.64, -0.64) in H→$\gamma\gamma$ analysis alone
- Other decay modes allow some disambiguation

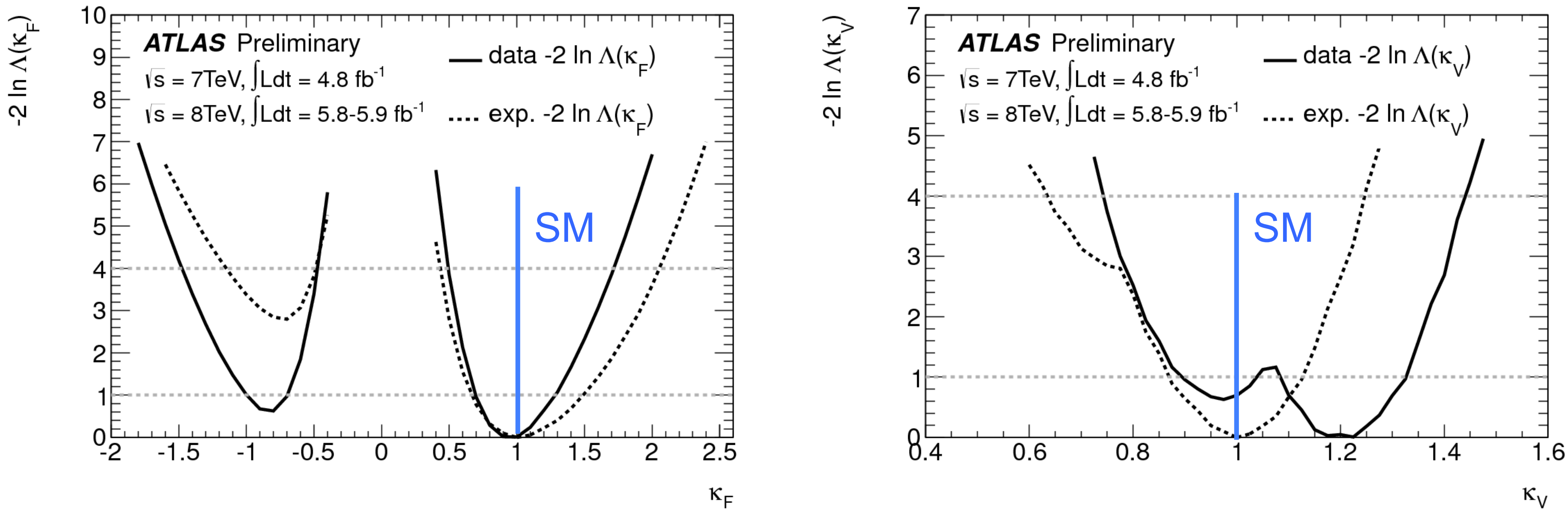


$\kappa_F \in [-1.0, -0.7] \cup [0.7, 1.3]$ @ 68%C.L.;
$\kappa_V \in [0.9, 1.0] \cup [1.1, 1.3]$ @ 68%C.L.

$\kappa_F \in [-1.5, -0.5] \cup [0.5, 1.7]$ @ 95%C.L.;
$\kappa_V \in [0.7, 1.4]$ @ 95%C.L.

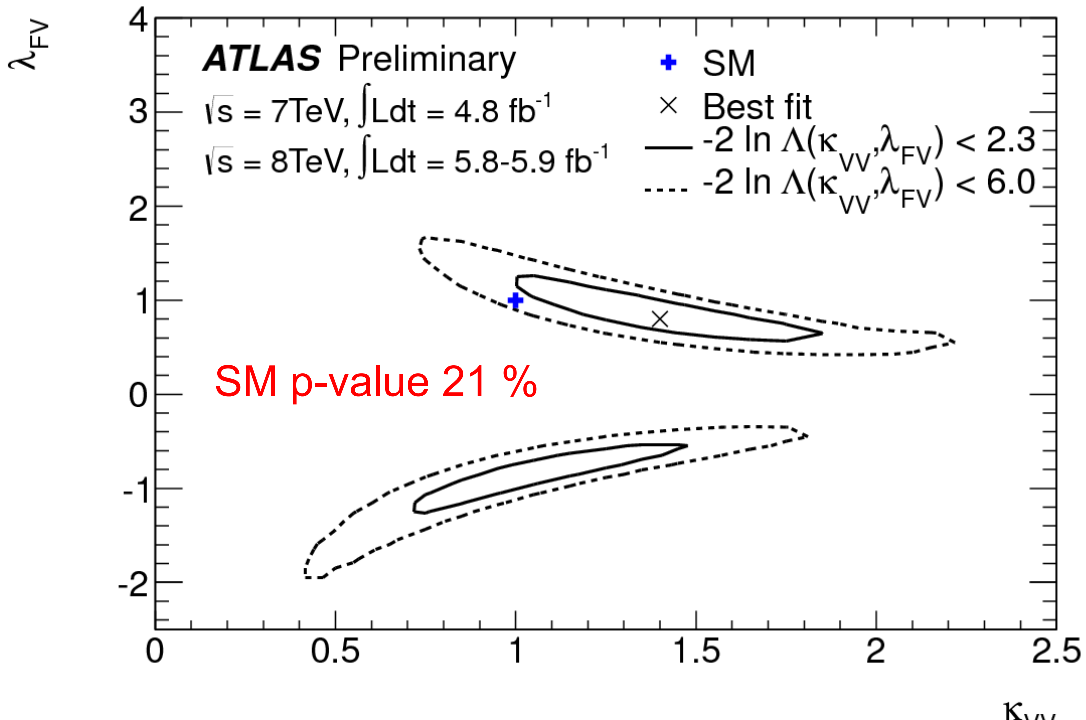
Th uncertainty: increase bounds by 20%

1D projections



- SM point (K_F>0) slightly preferred (1σ) by Atlas data (ICHEP12 dataset)
- Slightly larger separation expected for a SM injected signal (dashed lines)
- k_V pulled slightly by small $H \rightarrow \gamma\gamma$ excess
- k_F=0 (Fermiophobic) exluded at high confidence level with VBF-targeted analyses

Ratio of couplings



- Relaxing assumption on the total width, can fit only ratio of coupling modifier

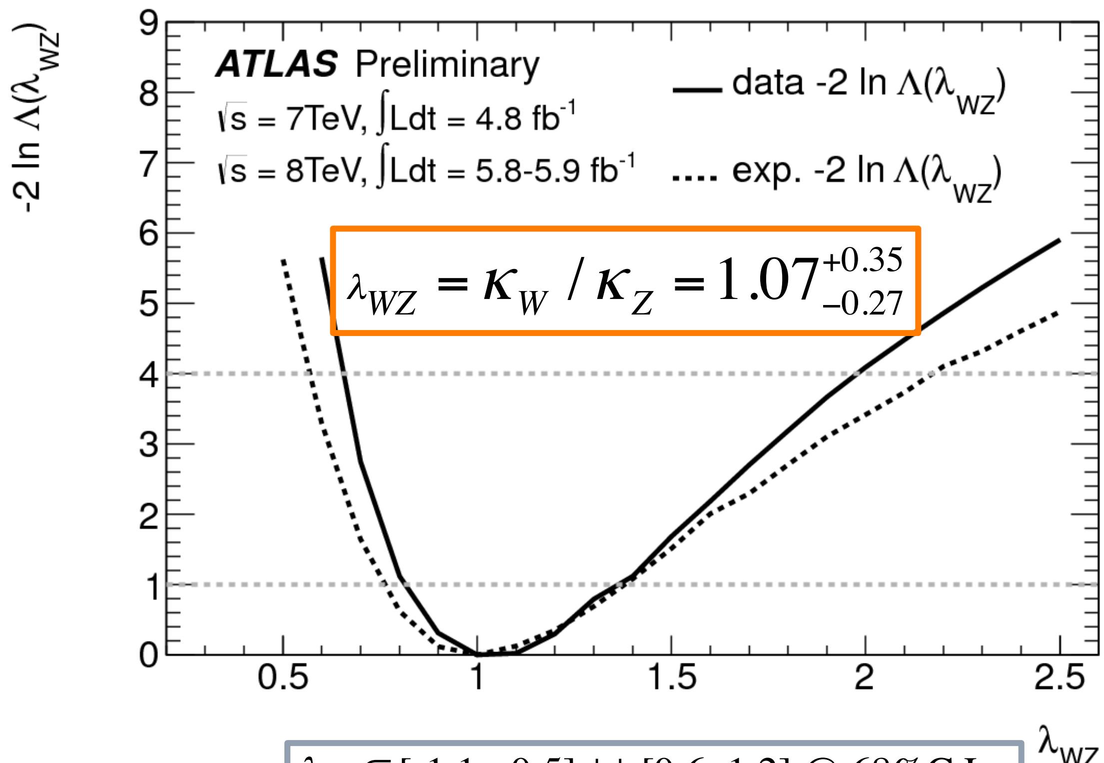
$$\lambda_{FV} = \kappa_F / \kappa_V \in [-1.1, -0.7] \cup [0.6, 1.1] \text{ @ } 68\%\text{C.L.};$$
$$\lambda_{FV} = \kappa_F / \kappa_V \in [-1.8, 0.5] \cup [0.5, 1.5] \text{ @ } 95\%\text{C.L.}$$

$$\kappa_{VV} = \kappa_v \cdot \kappa_v / \kappa_H = 1.2^{+0.3}_{-0.6}$$

Th uncertainty: 10%

Custodial symmetry W vs Z

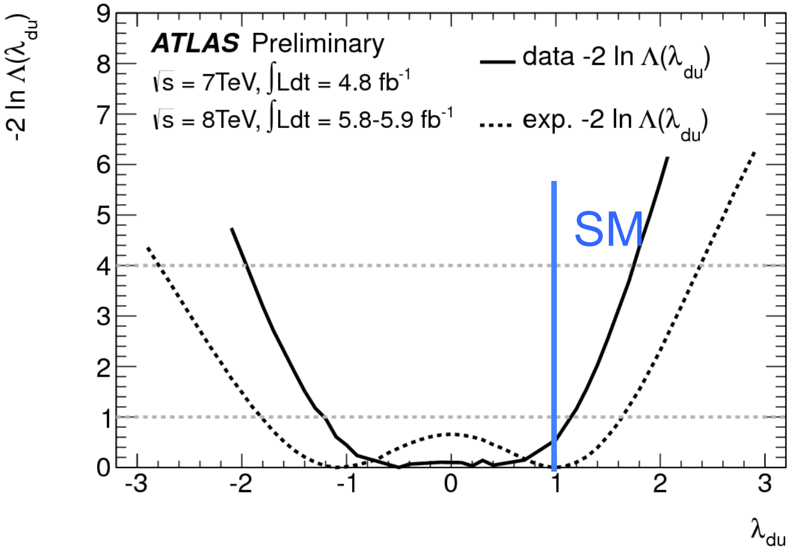
- Coupling to W and Z at the heart of EWSB
- Probing the ratio of W and Z scale factor; profile all other parameters : $\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$; $\lambda_{FZ} = \kappa_F / \kappa_Z$



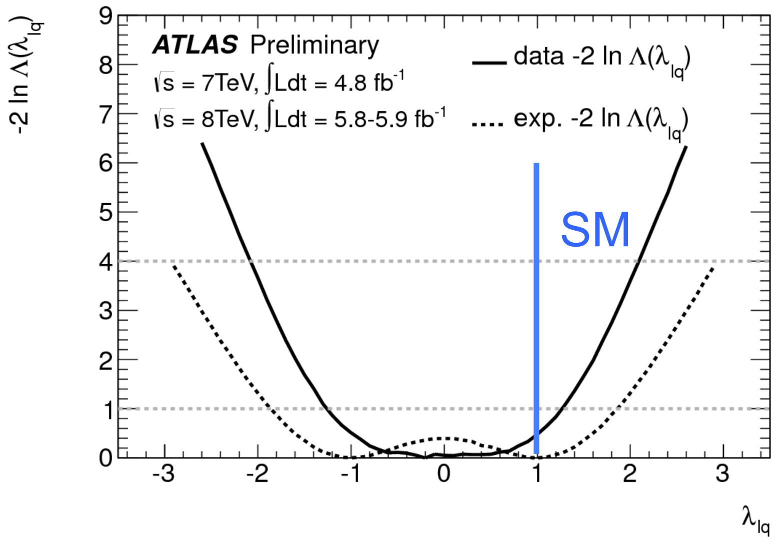
$\lambda_{FZ} \in [-1.1, -0.5] \cup [0.6, 1.2]$ @ 68%C.L.;

$\kappa_{ZZ} = 1.3^{+0.6}_{-0.6}$

Test up and down type fermion and quark versus lepton



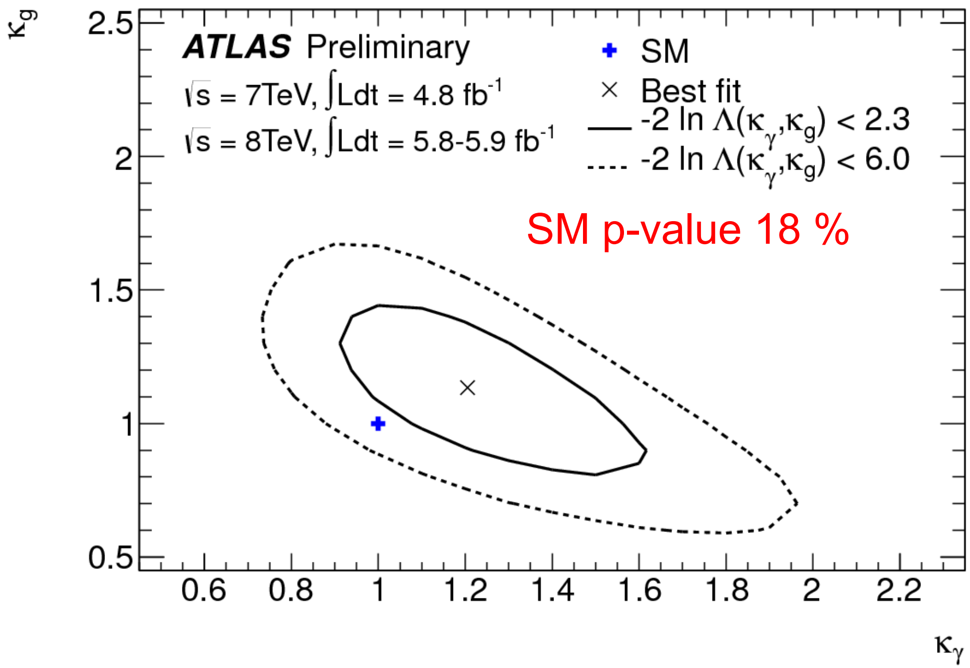
$\lambda_{du} = \kappa_d / \kappa_u \in [-1.2, 1.2]$ @ 68% C.L.



$\lambda_{lq} = \kappa_l / \kappa_q \in [-1.3, 1.3]$ @ 68% C.L.

- For e.g. 2HDM expect different coupling to up and down type fermions;
- Different assumptions:
  - $k_d=k_b=k_\tau$ vs $k_t=k_u$ for up/down type fermion test (left)
  - $k_q=k_b=k_t$ vs $k_\tau=k_l$ for the lepton/quark test (right)
- Sensitivity from H→bb and H→ττ analysis (here only 2011 data), will greatly improve

Non SM contribution in loop



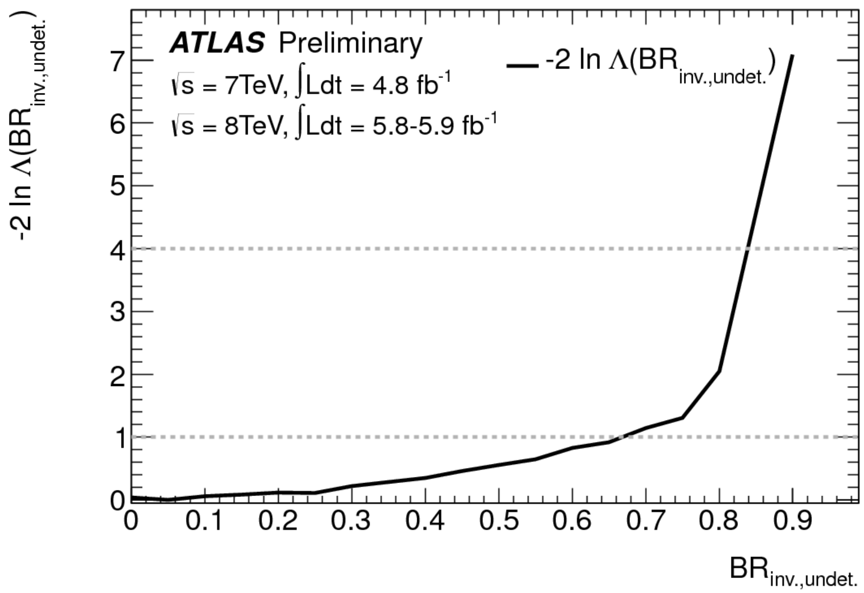
$$\kappa_\gamma = \left(\Gamma_{\gamma\gamma} / \Gamma_{\gamma\gamma}^{SM}\right)^{1/2} = 1.2^{+0.3}_{-0.2};$$

$$\kappa_g = \left(\sigma_{ggH} / \sigma_{ggH}^{SM}\right)^{1/2} = 1.1^{+0.2}_{-0.3}$$

Th uncertainty 15%

- Beyond SM particles coupling to Higgs could affect 1-loop decay widths
- Assume negligible contribution to total width from non SM particles contributing to invisible/background like decays
- Likelihood scan for effective scale factors for gluon and photon widths

Indirect bound on invisible width



$$\kappa_\gamma = \left(\Gamma_{\gamma\gamma} / \Gamma_{\gamma\gamma}^{SM}\right)^{1/2} = 1.2^{+0.3}_{-0.2};$$

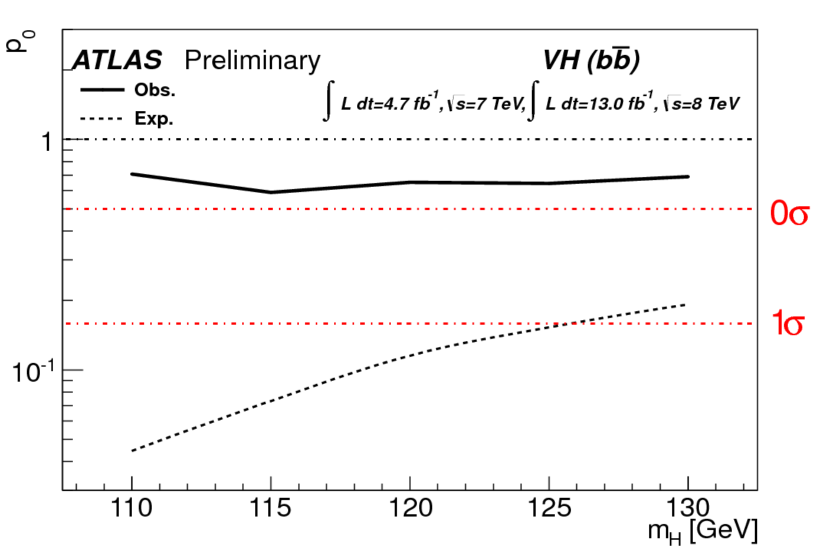
$$\kappa_g = \left(\sigma_{ggH} / \sigma_{ggH}^{SM}\right)^{1/2} = 1.1^{+1.4}_{-0.2};$$

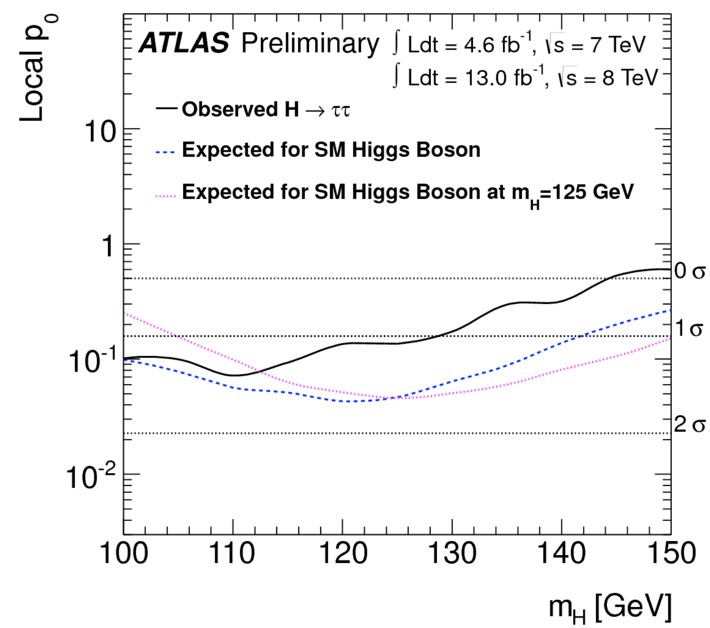
$$BR_{inv} < 0.68(0.84) \text{ @ } 68\% \text{ } (95\%) \text{ C.L.}$$

- Relaxing assumption on total width: allow undetectable and/or invisible decays
- Assume BSM effects only in 1-loop couplings
- Likelihood scan for effective scale factors for gluon and photon widths and total Higgs width, assuming no deviation in tree level contribution to Higgs width a bound on invisible width can be obtained from :

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

Short Term Perspective





- Full 8 TeV data not yet exploited, expect complete analysis for most relevant channels, and a new global analysis:
  - H→bb and H→ττ included here only for 7 TeV data, sensitivity will greatly improve with 8 TeV approved analysis
  - More exclusive channels for ZZ,γγ,WW coming and a factor > 2 more luminosity for these channels compared to analysis shown today
  - Expect significantly reduced uncertainties

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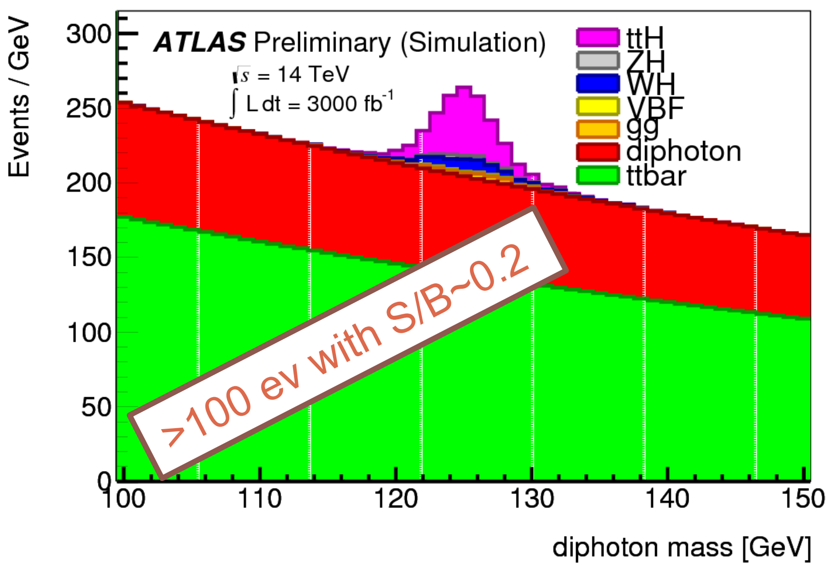
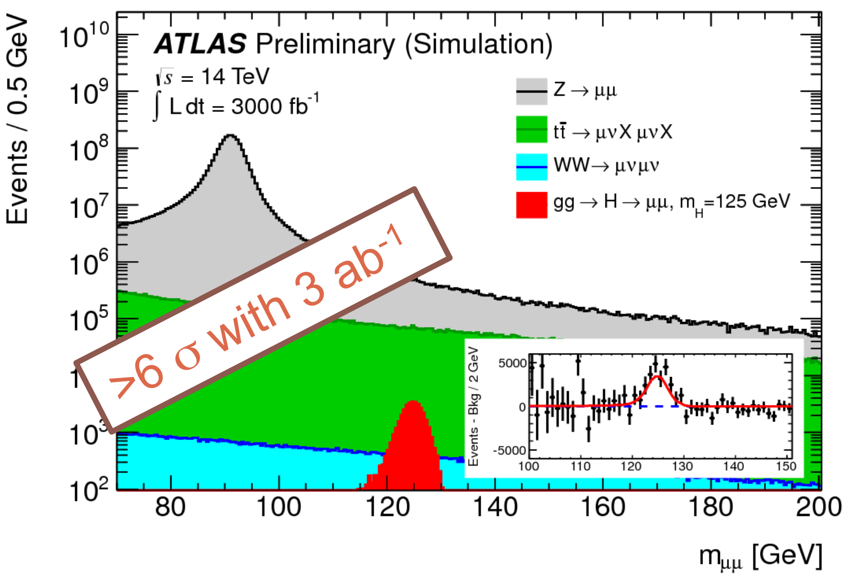
Perspective – HL-LHC





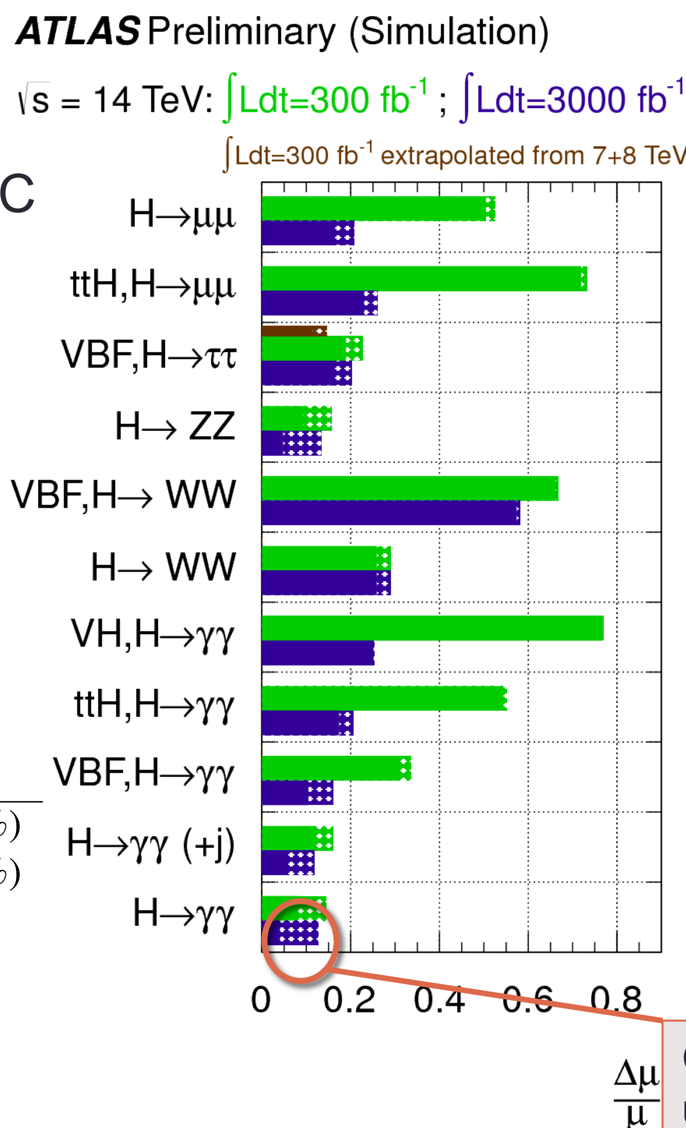
- In the context of the European Strategy, Atlas presented sensitivity studies based on present analyses, taking into account changes in the cut/identification to keep fakes at ~same level as of today
  - ZZ, γγ, WW, ττ (VBF) channels extrapolated to 300/3000 fb^{-1}
  - Low rate channels ttH (H→γγ) and H→μμ studied
  - di-Higgs production, most promising channel bbγγ: 15 ev exp/24 bkg (S/√B~3)
    - Need to combine other channels and combine experiments to measure λ_{HHH} to ~30%

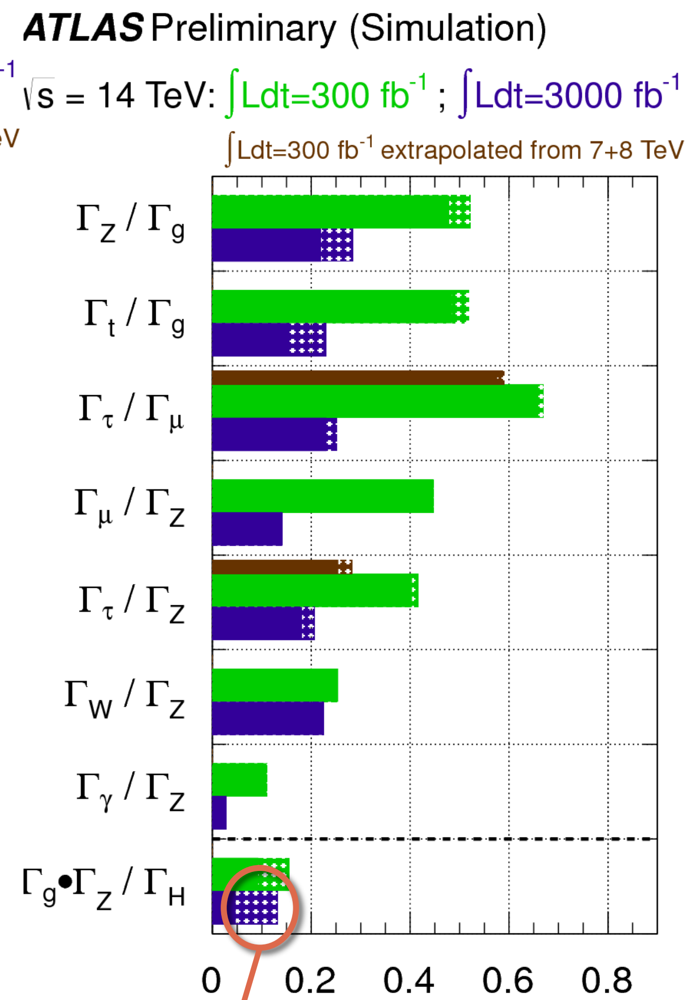
ATLAS-PHYS-PUB-2012-004

Perspective – HL-LHC

- Show case the potential for HL-LHC
  - Precision of a few percent seems reachable
- Ex. k_V vs k_F fit with (without) theory uncertainty

	300 fb^{-1}	3000 fb^{-1}
κ_V	3.0% (5.6%)	1.9% (4.5%)
κ_F	8.9% (10%)	3.6% (5.9%)





Current th uncertainty

$$\frac{\Delta(\Gamma_X/\Gamma_Y)}{\Gamma_X/\Gamma_Y} \sim 2\frac{\Delta(\kappa_X/\kappa_Y)}{\kappa_X/\kappa_Y}$$

Summary

- A ~125 GeV Higgs offers an unique opportunity to study at LHC a large range of decay and production channels
- A systematic study of all the data will allow a detailed understanding of the nature of the new found boson at the LHC
- Current precision still limited, and no hints of statistically significant deviations are seen:
  - W,Z gluon and γ couplings tested at the level of 30%
  - first indirect constraint on invisible decay width
- More precision and more general analysis will be possible already with full 7+8 TeV data to appear soon
- Looking forward to 13/14 TeV Run and possibly HL-LHC to finally reach the precision of few percent

SPARES

References

- [10] ATLAS Collaboration, *Observation of an excess of events in the search for the Standard Model Higgs boson in the $H \to ZZ(*) \to 4l$ channel with the ATLAS detector*, ATLAS-CONF-2012-092 (2012). http://cdsweb.cern.ch/record/1460411.
- [11] ATLAS Collaboration, *Observation of an excess of events in the search for the Standard Model Higgs boson in the gamma-gamma channel with the ATLAS detector*, ATLAS-CONF-2012-091 (2012). http://cdsweb.cern.ch/record/1460410.
- [12] ATLAS Collaboration, *Search for the Standard Model Higgs boson in the $H \to WW(*) \to l\nu l\nu$ decay mode with 4.7 fb^{-1} of ATLAS data at $\sqrt{s} = 7$ TeV*, submitted to Phys. Lett. **B** (2012), arXiv:1206.0756 [hep-ex].
- [13] ATLAS Collaboration, *Search for the Standard Model Higgs boson in the $H \to \tau^+\tau^-$ decay mode in $\sqrt{s} = 7$ TeV pp collisions with ATLAS*, submitted to JHEP (2012), arXiv:1206.5971 [hep-ex].
- [14] ATLAS Collaboration, *Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a b-quark pair with the ATLAS detector*, submitted to Phys. Lett. **B** (2012), arXiv:1207.0210 [hep-ex].
- [15] ATLAS Collaboration, *Observation of an Excess of Events in the Search for the Standard Model Higgs Boson in the $H \to WW(*) \to l\nu l\nu$ Channel with the ATLAS Detector*, ATLAS-CONF-2012-098 (2012). http://cdsweb.cern.ch/record/1462530.

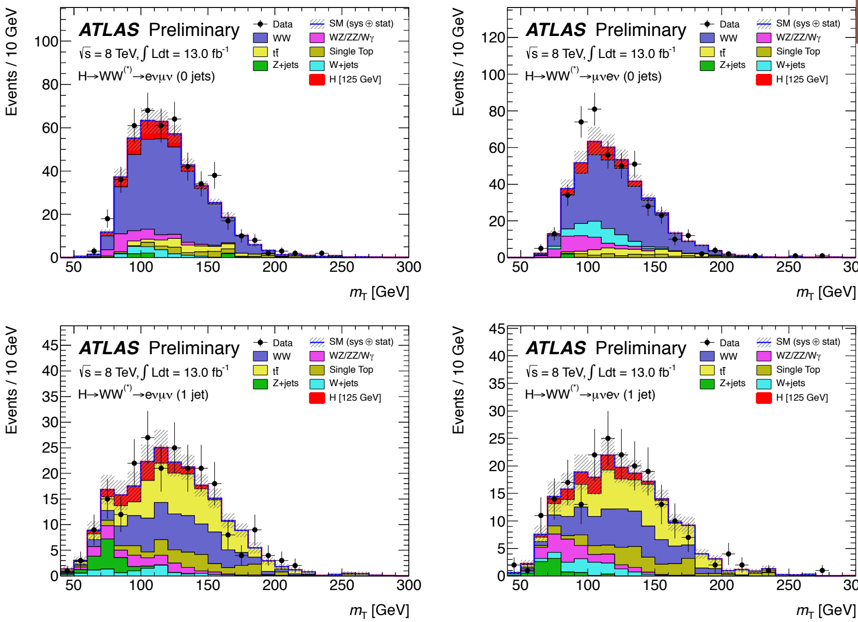
Ingredients

Decay	Sub-channel	N_{obs}	$\langle N_B \rangle$	$\langle N_{ggF} \rangle$	$\langle N_{VBF} \rangle$	$\langle N_{WH} \rangle$	$\langle N_{ZH} \rangle$	$\langle N_{ttH} \rangle$
$H \rightarrow \gamma\gamma$	low-p_{Tt}	7013	6820	138	6.3	3.1	1.8	0.4
	high-p_{Tt}	320	291	14.0	2.9	1.8	1.0	0.4
	2-jet	36	24.2	1.3	3.4	0.0	0.0	0.0
$H \rightarrow ZZ^{(*)} \rightarrow 4\ell$	–	14	5.4	5.6	0.5	0.1	0.1	0.0
$H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	0-jet	667	573	75.3	0.8	0.3	0.4	0.0
	1-jet	183	141	16.7	1.7	0.3	0.2	0.0
	2-jet	3	3.7	0.3	1.3	0.0	0.0	0.0
$H \rightarrow \tau^+\tau^-$	0-jet	9277	9305	17.6	0.6	0.1	0.3	0.0
	1-jet	393	406	3.6	1.0	0.1	0.2	0.0
	2-jet	22	28.2	0.3	0.9	0.0	0.0	0.0
	VH	164	152	0.7	0.1	0.2	0.3	0.0
$H \rightarrow b\bar{b}$	ZH	322	321	0.0	0.0	0.0	4.0	0.0
	WH	1266	1311	0.0	0.0	11.1	0.0	0.0

- For illustration purpose only: exclusive 2jet categories provide valuable information on VBF production

Signal strength H→lνlν (13 fb^{-1})

$$\mu = 1.48^{+0.35}_{-0.33}\,(\text{stat})^{+0.41}_{-0.36}\,(\text{syst theor})\,^{+0.28}_{-0.27}\,(\text{syst exp}) \pm 0.05\,(\text{lumi})$$



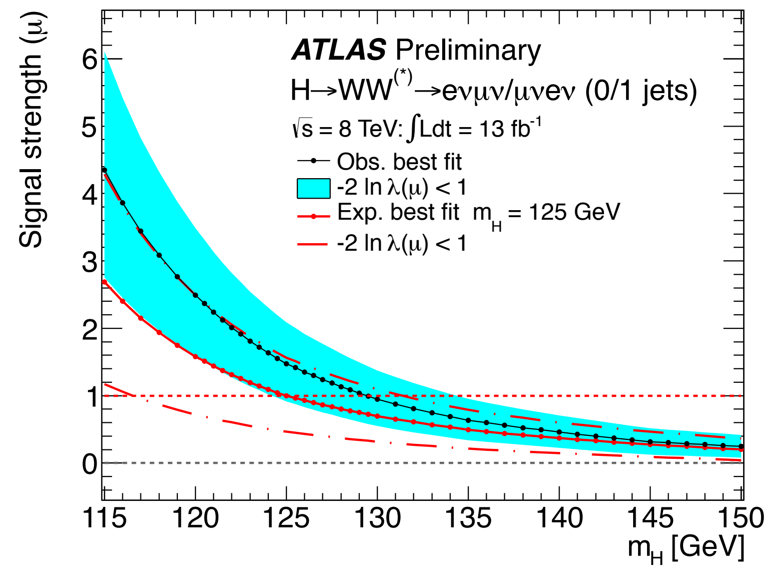
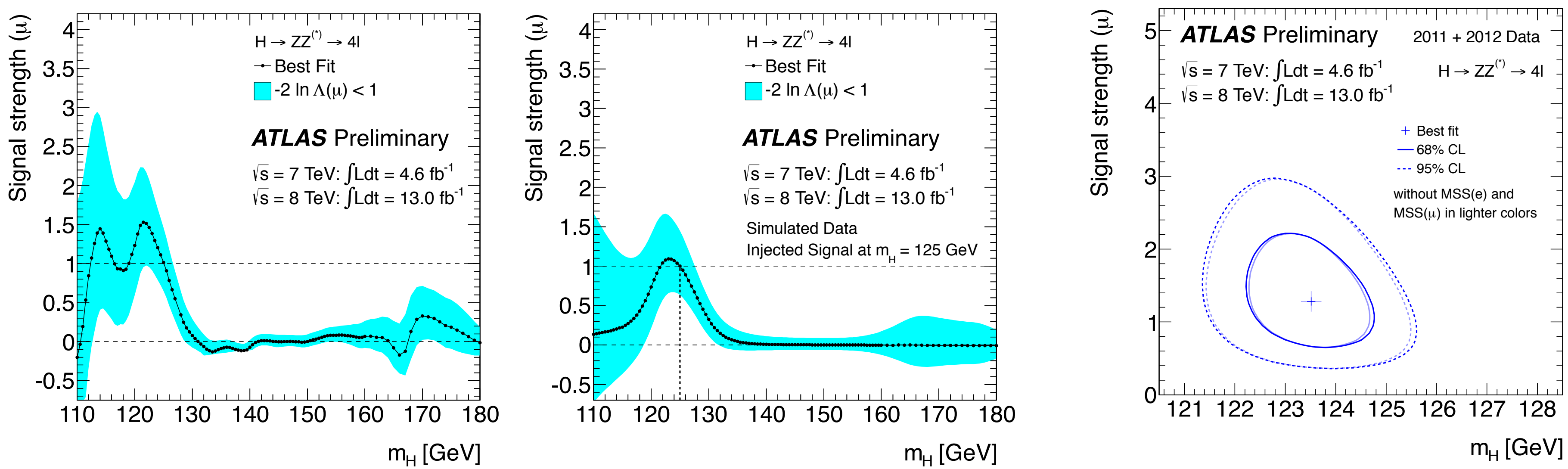


Table 7: Dominant contributions to the relative uncertainty on the measured signal strength for m_H = 125 GeV. The total relative uncertainty is also given. The large uncertainty on the signal strength from WW normalisation is due to the significant size of this background in comparison with the signal.

Source	Upward uncertainty (%)	Downward uncertainty (%)
Statistical uncertainty	+23	-22
Signal yield ($\sigma \cdot \mathcal{B}$)	+14	-9
Signal acceptance	+9	-6
WW normalisation, theory	+20	-20
Other backgrounds, theory	+9	-9
W+jets fake rate	+11	-12
Experimental + bkg subtraction	+14	-11
MC statistics	+8	-8
Total uncertainty	+41	-38

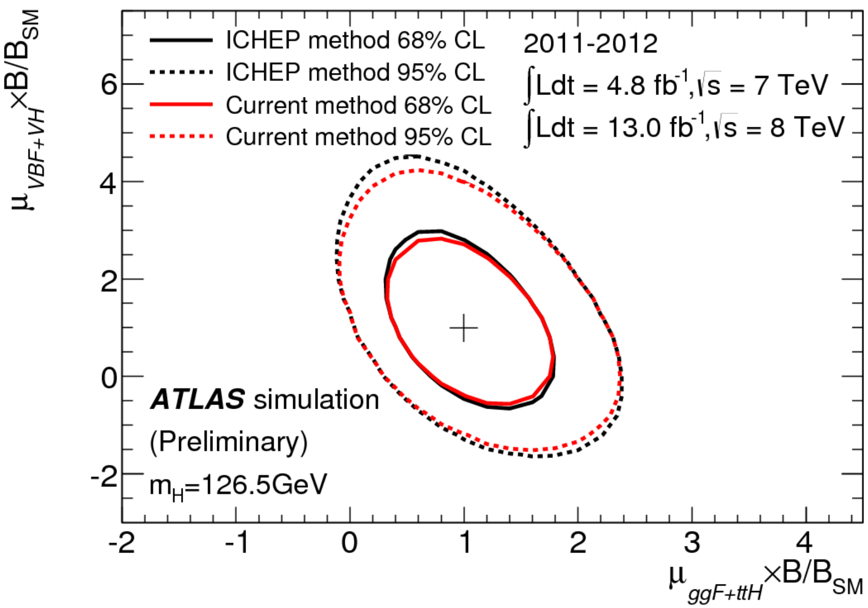
Signal strength H→ZZ (13 fb^{-1})

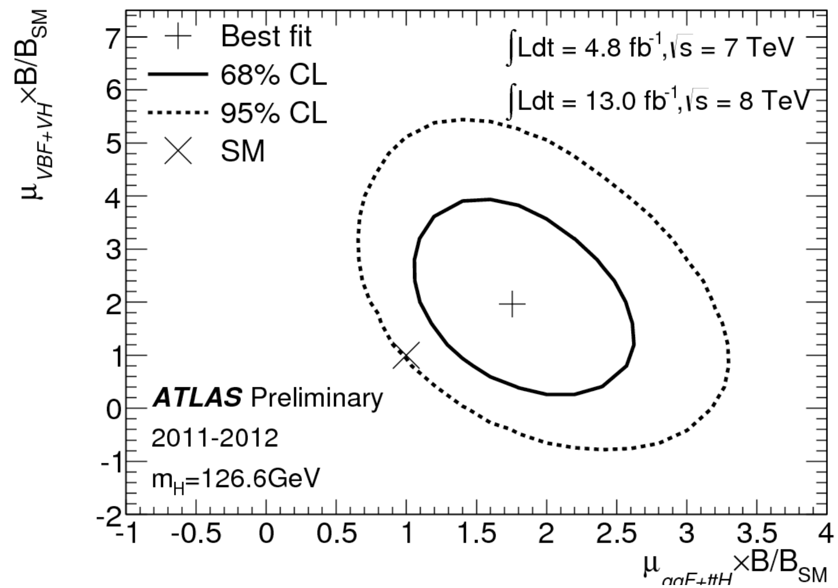


μ=1.3 + 0.5 -0.4 @ mH=123.5

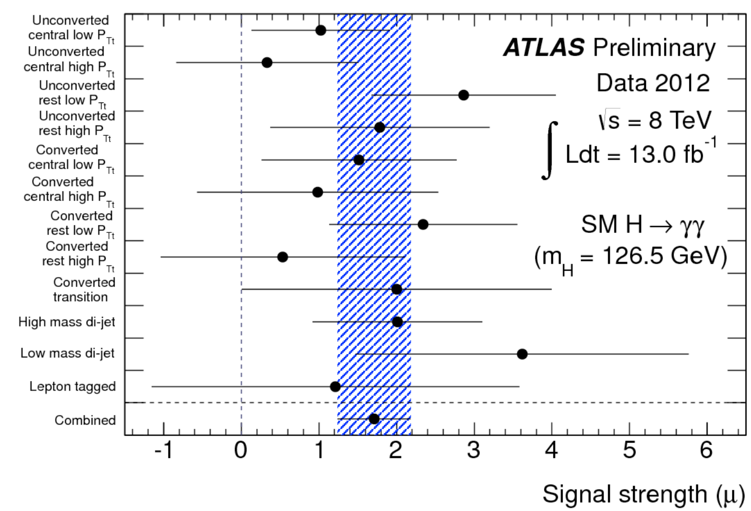
VBF vs ggF using H→γγ (13 fb^{-1} update)

Expected SM likelihood contours

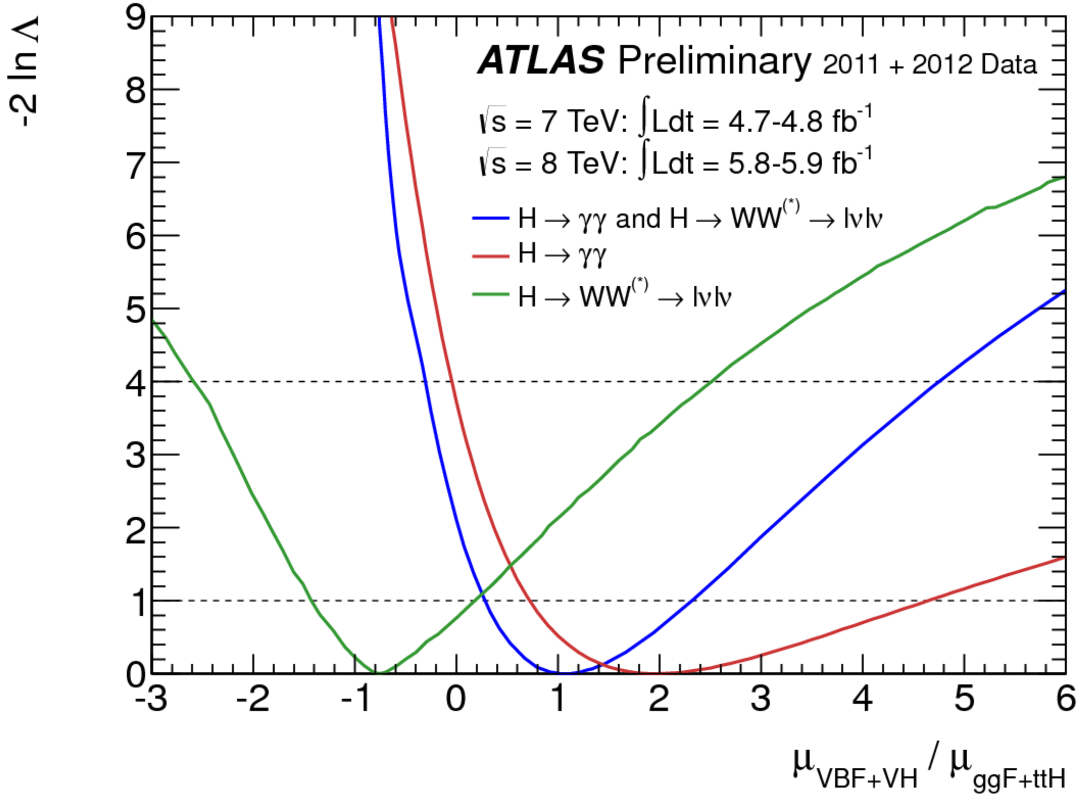




- Incresead sensitivity from 2 additional VH categories (2jet, lepton)

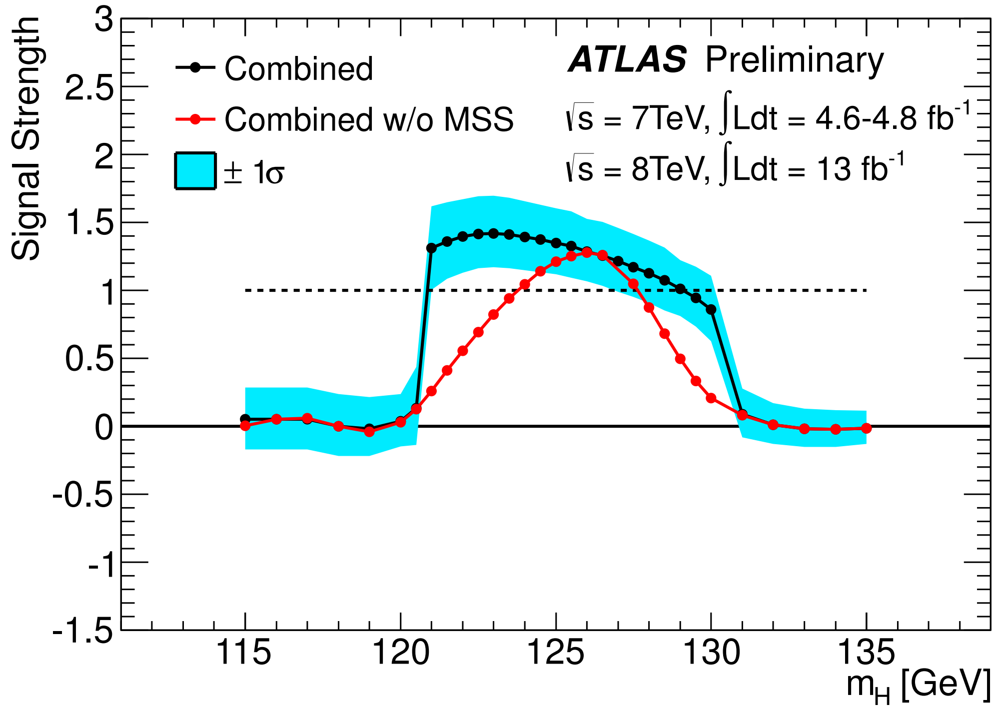


VBF/ggF ratio combined & by channel



- Double ratio allow a comparison between different channels to check consistency of production mechanism predictions (decay BR cancels)

Signal strength vs mass



- Signal strength vary by less than 10% for 123.5< mH < 126.5
- Mass scale systematics and large signal significance responsible for flat dependence of μ from mH