Higgs Properties measurements in ATLAS

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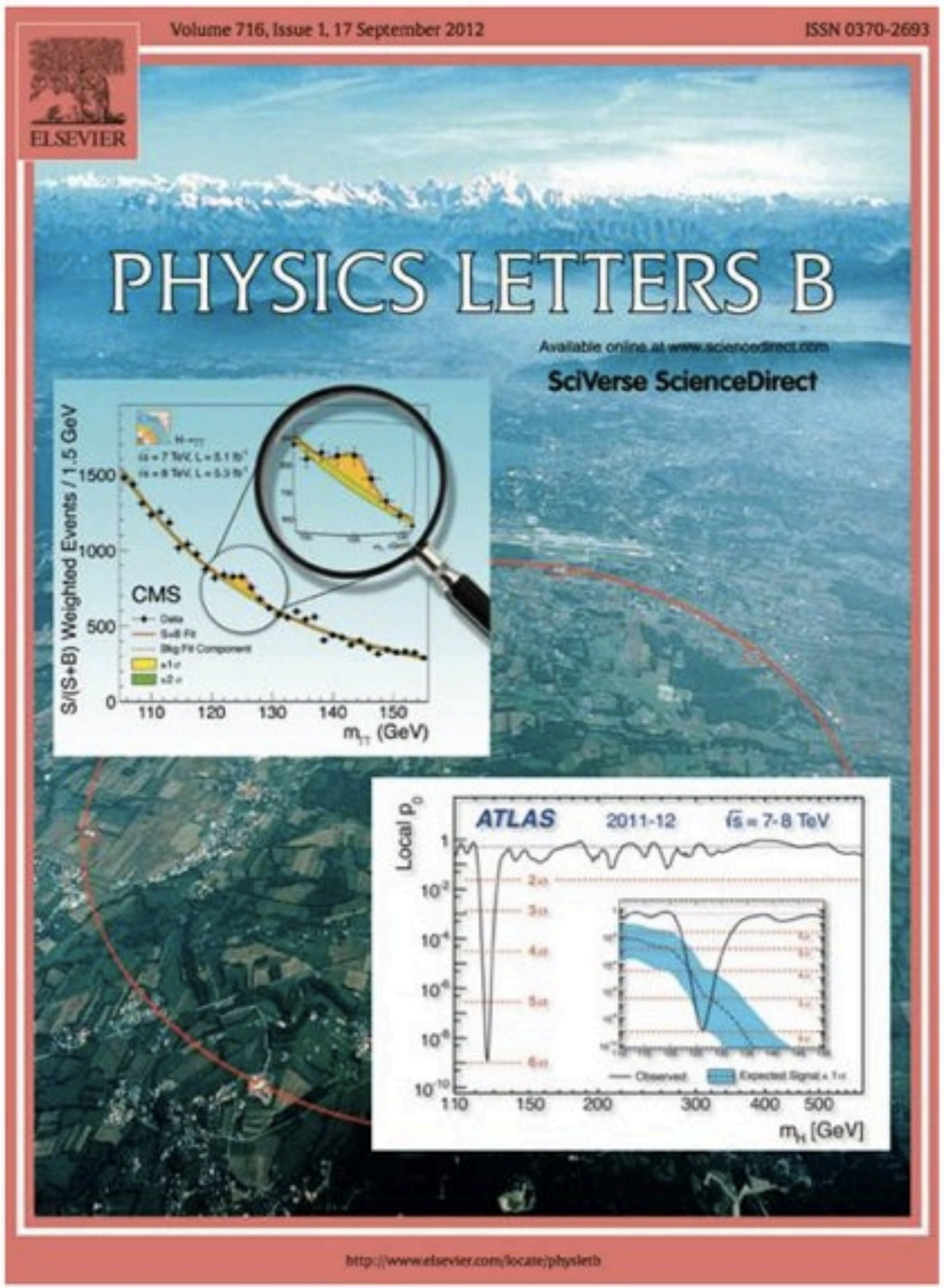
ATLAS Publications



Phys. Lett. B 716 (2012), Issue 1

New

CERN-PH-EP-2013-102

Submitted to: Physics Letters B

Evidence for the spin-0 nature of the Higgs boson using ATLAS data

http://arxiv.org/abs/1307.1427

New

CERN-PH-EP-2013-103

Submitted to: Physics Letters B

Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

http://arxiv.org/abs/1307.1432

New

Outline

- Mass measurements
  - Using $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^*$
- Spin, CP determination
- Signal strengths, Coupling scale factors
- Several latest results

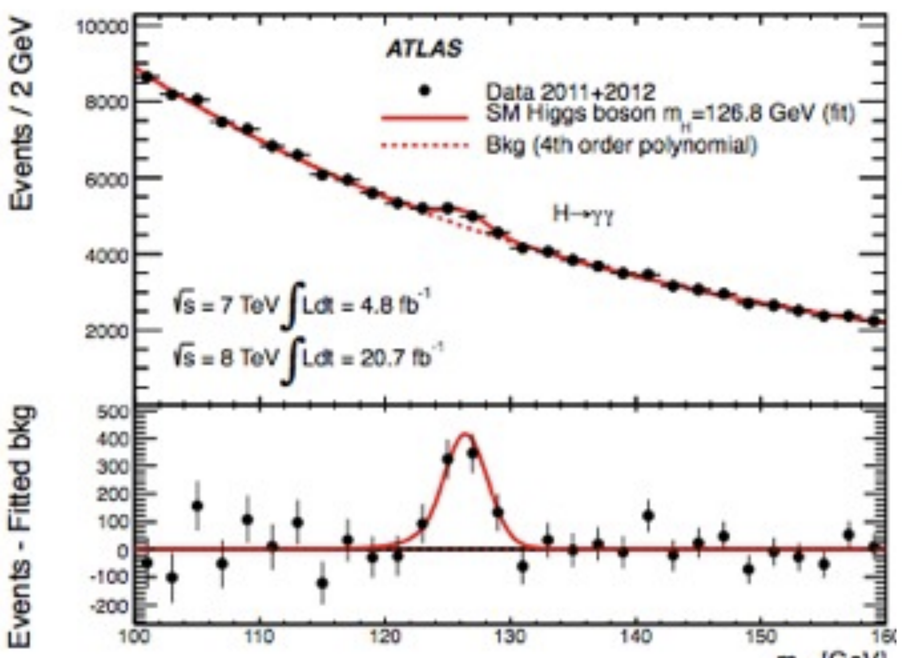
Individual channels

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV	
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu$, 2-jet VBF, ℓ-tag$\}$	4.6
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{$2-jet VBF$\}$	4.8
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{$0-jet, 1-jet, 2-jet VBF$\}$	4.6
		2012 $\sqrt{s}$ =8 TeV	
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu$, 2-jet VBF, ℓ-tag$\}\}$	20.7
$H \to \gamma\gamma$	–	14 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{$2-jet VBF$\} \oplus \{\ell$-tag, $E_{\mathrm{T}}^{\mathrm{miss}}$-tag, 2-jet VH$\}$	20.7
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{$0-jet, 1-jet, 2-jet VBF$\}$	20.7

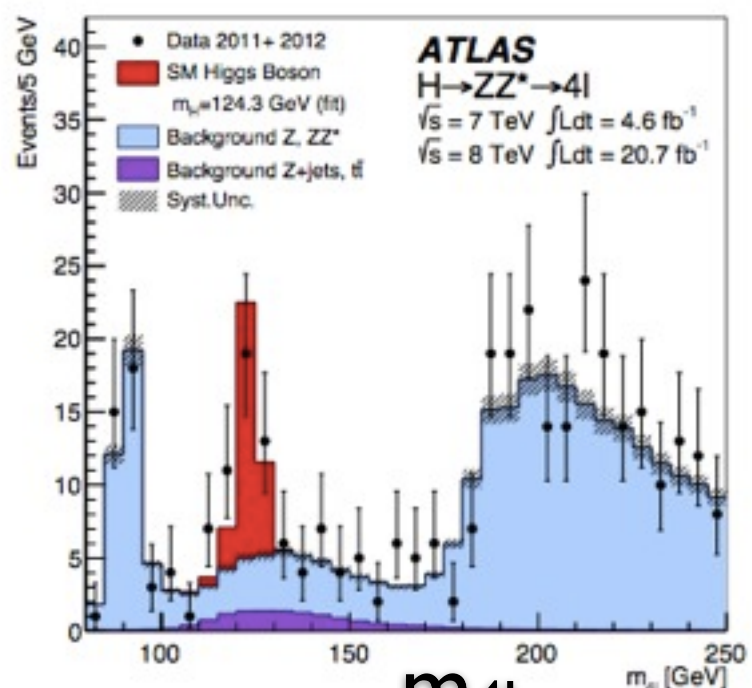
- Categories of individual channels in combined model.
- ττ and bb results are not included in the paper

Mass determination

H→γγ http://arxiv.org/abs/1307.1427 H→ZZ*



$m_{\gamma\gamma}$



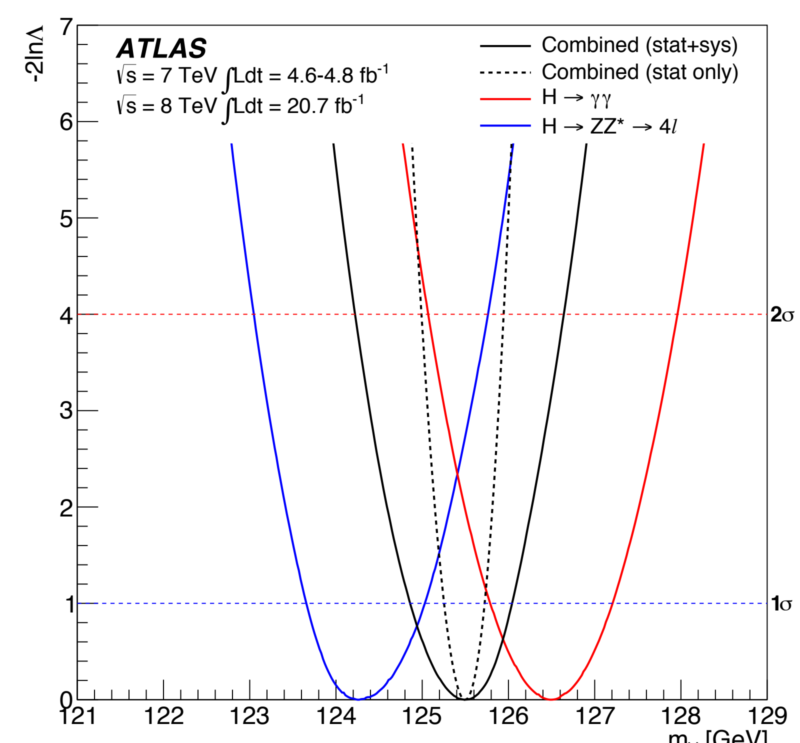
m_{4l}

- dominant systematics of H→γγ include:
  - Z->ee calibration, Imperfect knowledge of material of ECAL , Relative calibration of different layers of ECAL Diff. in

- γγ: 126.8 ± 0.2(stat.) ± 0.7 (sys) GeV
- ZZ*: 124.3 ± 0.6(stat.) ± 0.5 (sys) GeV
- comb.: 125.5 ± 0.2(stat.) ± 0.6 (sys)

Compatibility with same mass hypothesis: 1.3%(1.5%, ensemble tests)

$$\Lambda(m_H) = \frac{L(m_H\,,\,\hat{\hat{\mu}}_{\gamma\gamma}(m_H)\,,\,\hat{\hat{\mu}}_{4\ell}(m_H)\,,\,\hat{\hat{\theta}}(m_H))}{L(\hat{m}_H, \hat{\mu}_{\gamma\gamma}, \hat{\mu}_{4\ell}, \hat{\theta})}$$



m_H

http://arxiv.org/abs/1307.1427

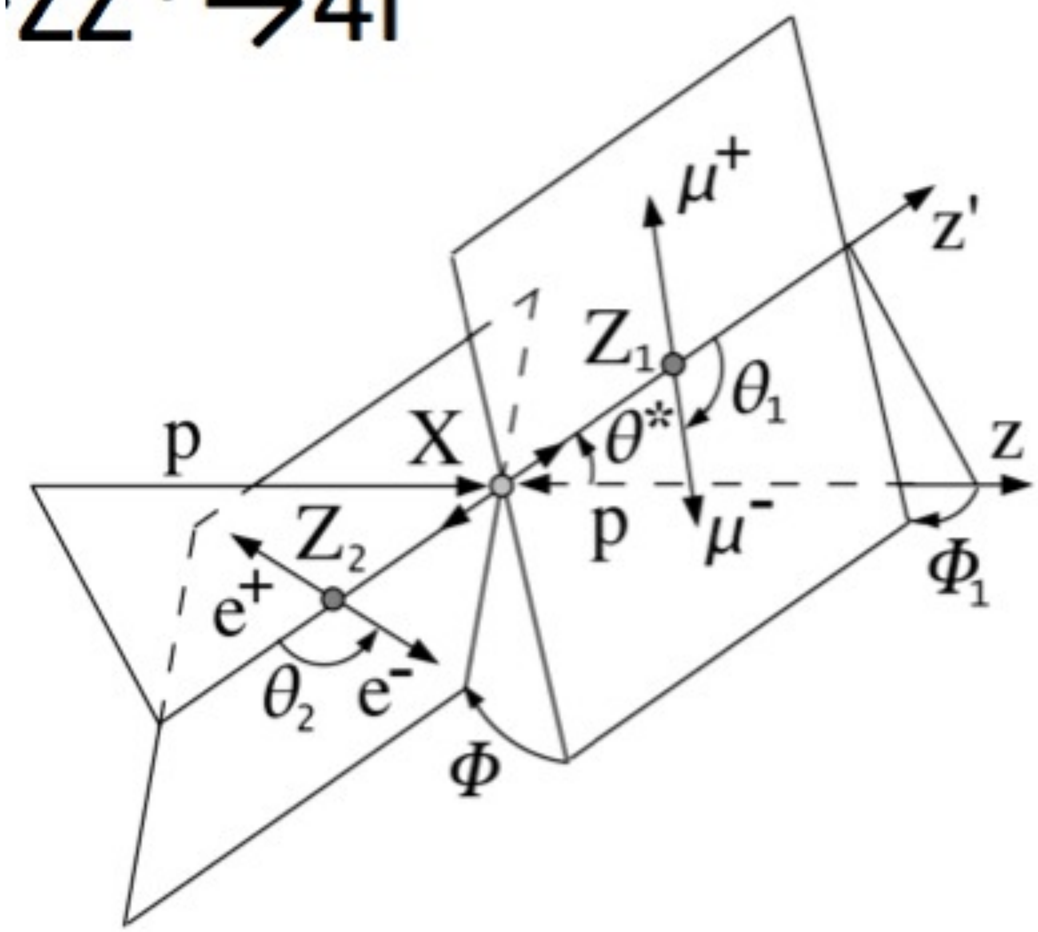
Spin and Parity

- H→γγ

$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_T^{\gamma\gamma}/m_{\gamma\gamma})^2}} \frac{2p_T^{\gamma 1} p_T^{\gamma 2}}{m_{\gamma\gamma}^2}$$

  - Fit the cosθ* distribution in signal region with the background shape extracted using side-bands

ZZ*→4l



- H→ZZ*
  - BDT analysis using decay angles and masses of intermediate Z bosons
  - sensitive to spin and parity.
- H→WW*
  - Discriminating variables: m_{ll}, $\Delta\Phi_{ll}$, p_{Tll}, m_T
  - Two separate BDT classifiers: one to distinguish the $J^P = 0^+$ from all backgrounds, second to separate alternative spin-parity hypotheses

Spin and Parity

Test statistic

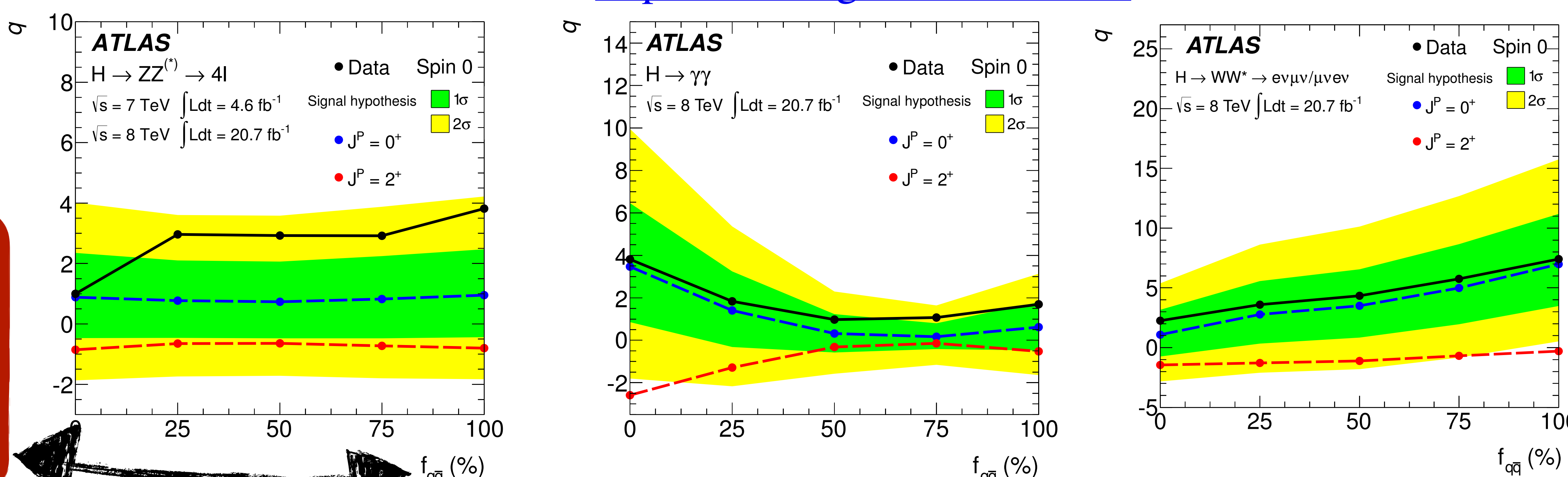
$$q = \log \frac{\mathcal{L}(J^P = 0^+, \hat{\hat{\mu}}_{0^+}, \hat{\hat{\theta}}_{0^+})}{\mathcal{L}(J^P_{\text{alt}}, \hat{\hat{\mu}}_{J^P_{\text{alt}}}, \hat{\hat{\theta}}_{J^P_{\text{alt}}})}$$

Rejection based on "CLs"

$$\text{CL}_s(J^P_{\text{alt}}) = \frac{p_0(J^P_{\text{alt}})}{1 - p_0(0^+)}$$

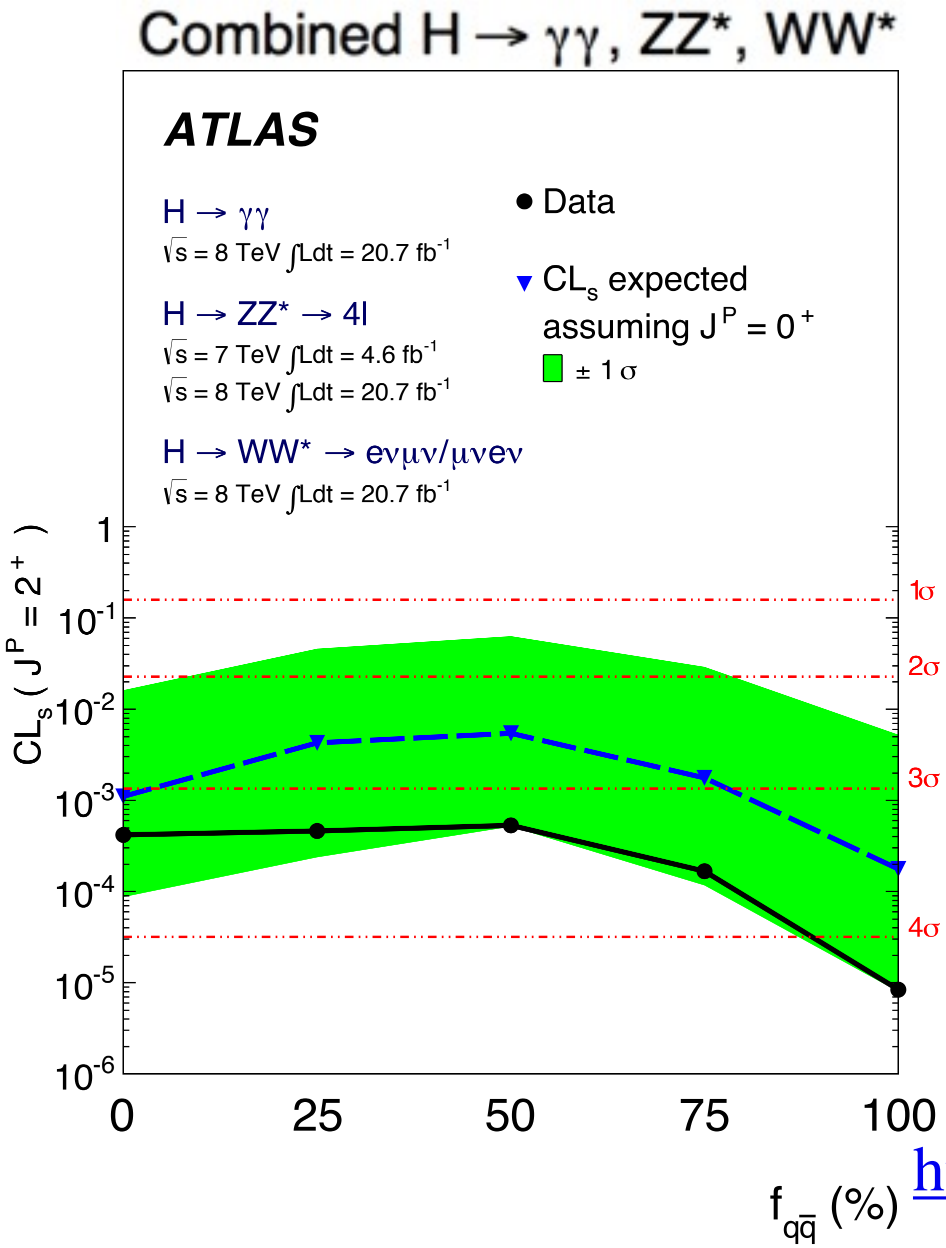
http://arxiv.org/abs/1307.1432

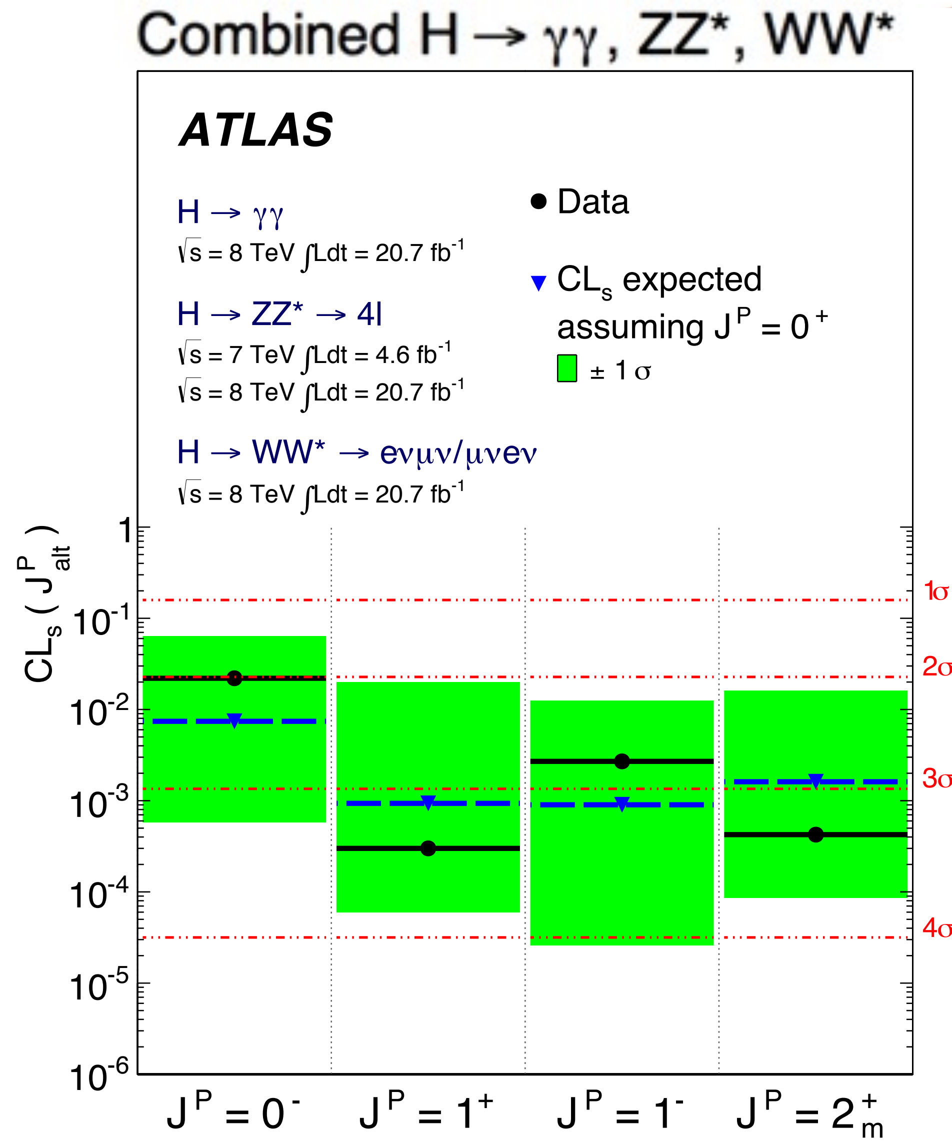
$f_{q\bar{q}}$



- ➡ Observed values of the test statistic (black solid line) as a function of the fraction of **$q\bar{q}$** production of the spin–2 state($f_{q\bar{q}}$) for ZZ*, γγ and WW*.
- ➡ Sensitivities are complementary at different **$q\bar{q}$** fraction

Spin and Parity

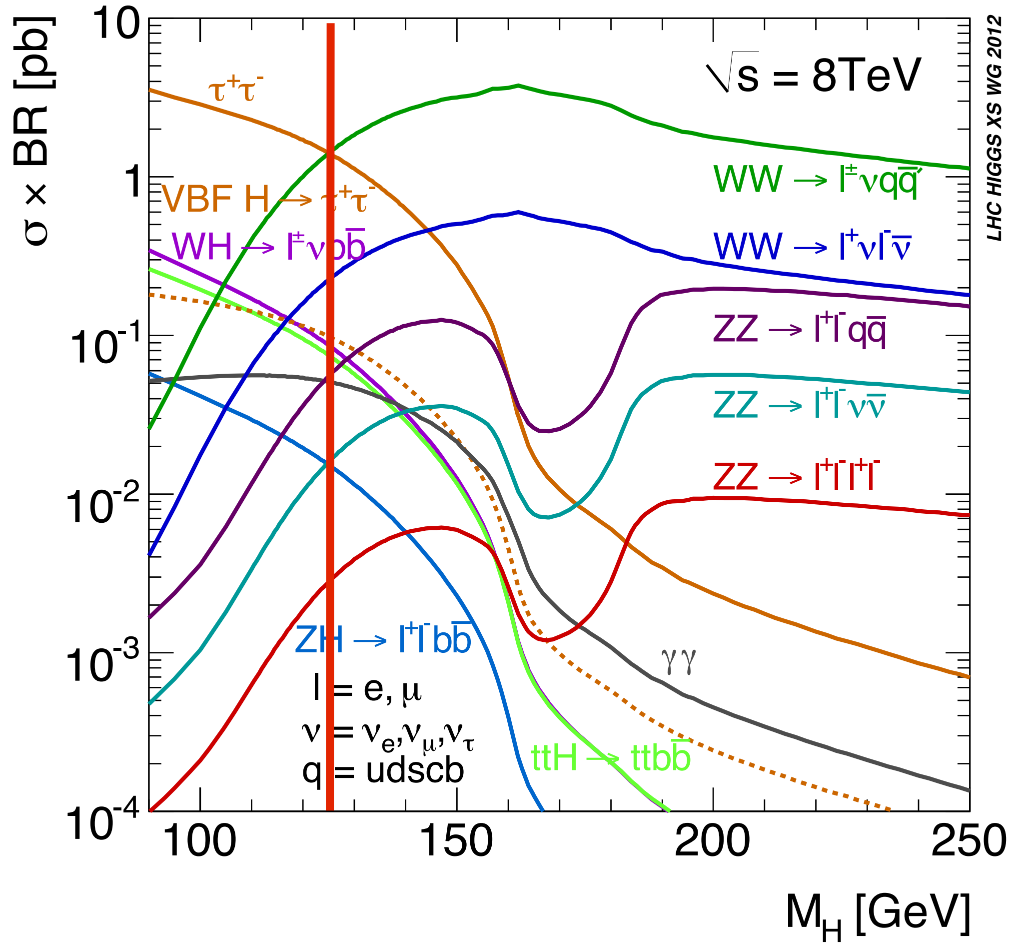




http://arxiv.org/abs/1307.1432

- CLs as a function of $\mathbf{q\bar{q}}$ fractions, exclusion of 2^+ hypotheses above 3σ
- CLs for different hypotheses. Exclusions of (0^-, 1^+, 1^-, 2^+_m) above 2σ

Signal strength



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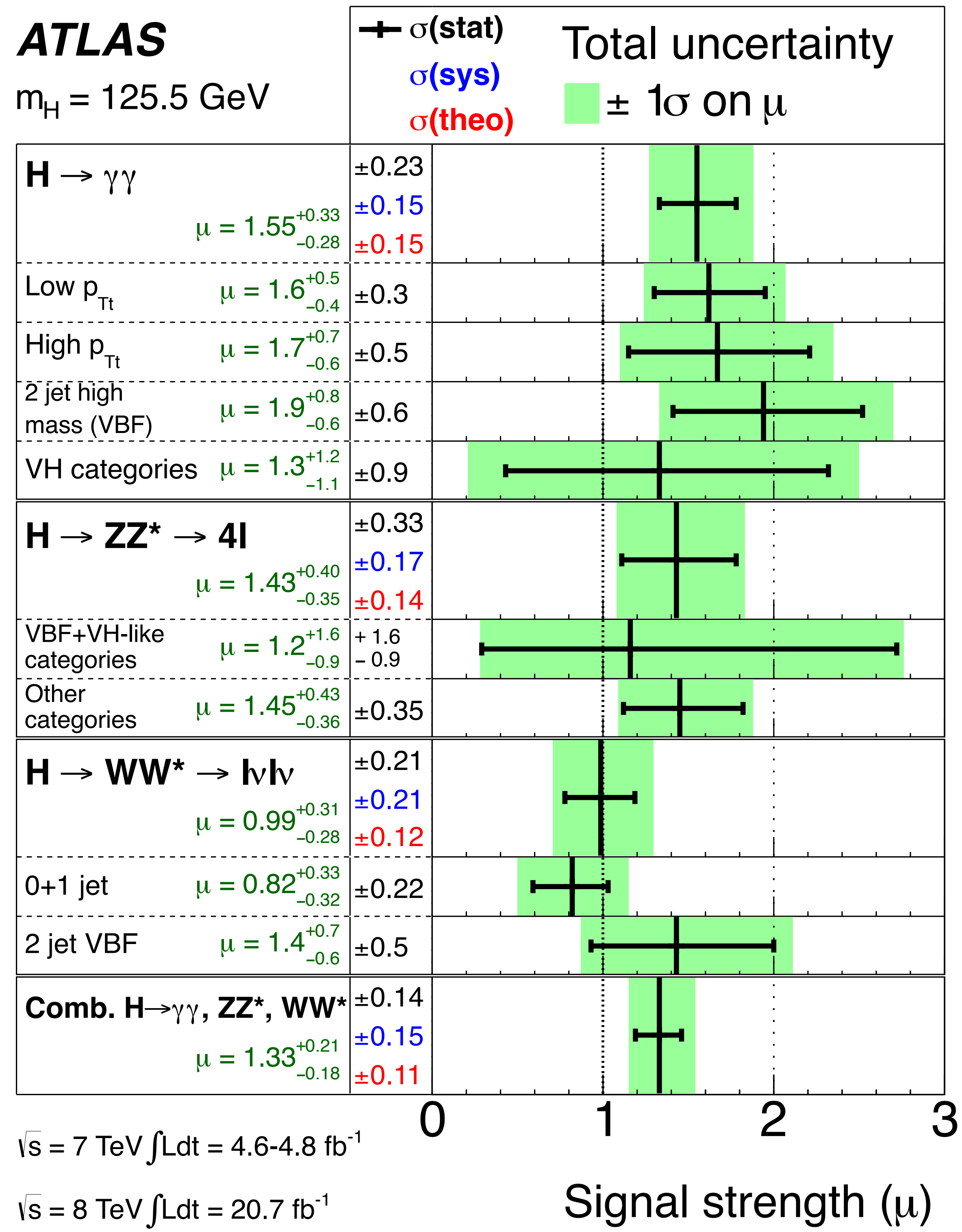
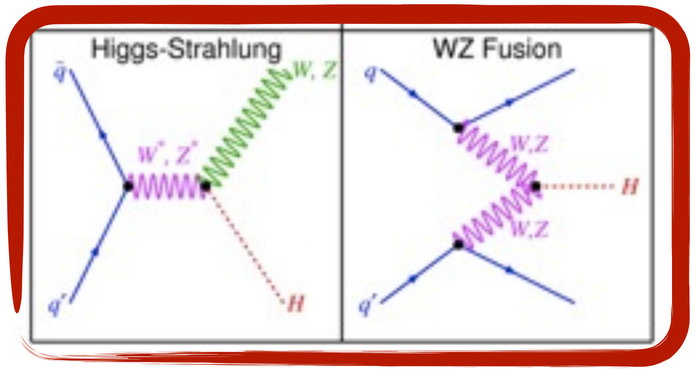
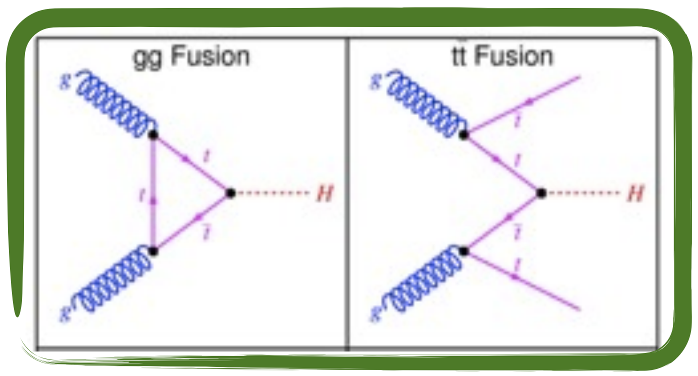
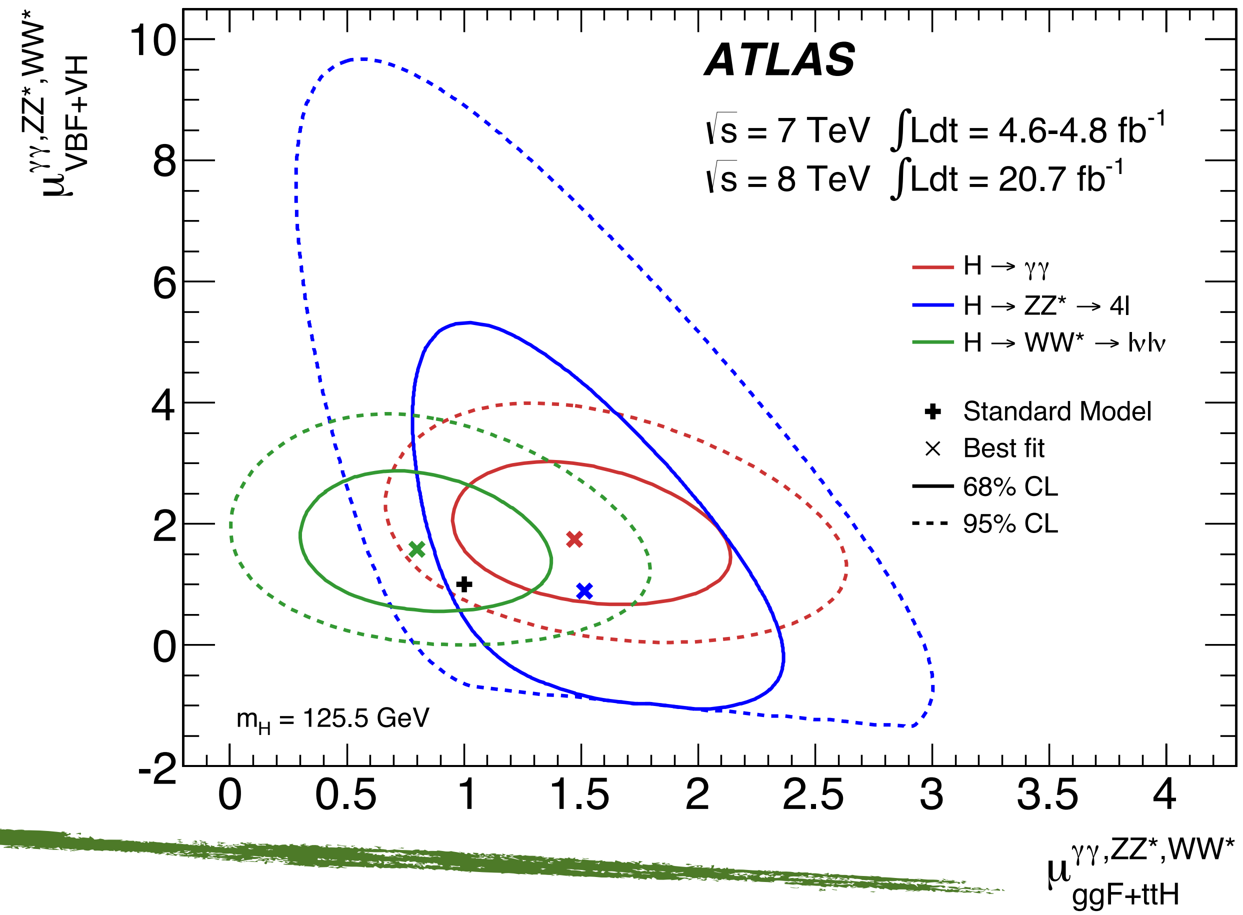


- Signal strengths: ratio of observed rate and SM expectation
- Best fit: 1.33 +0.21/-0.18
- Consistent with SM!

Vector-boson fusion

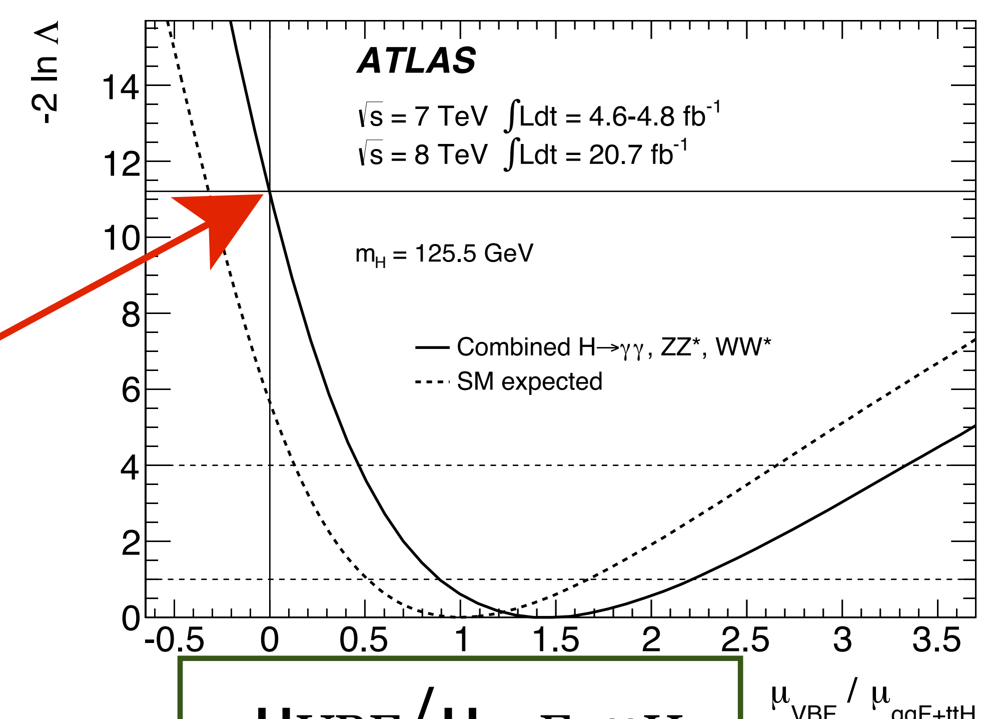






http://arxiv.org/abs/1307.1427

- $\mu_{VBF}/\mu_{ggF+ttH}$ independent of new physics in BR
- VBF discovery significance: 3.3 σ
- Consistent with SM



$\mu_{VBF}/\mu_{ggF+ttH}$

Coupling measurements

- Coupling strengths κ_i, λ_{jk}:
  - $g_F = \kappa_F \cdot m_F / vev$
  - $g_V = \kappa_V \cdot 2m_V^2 / vev$
  - $\lambda_{jk} = \kappa_j / \kappa_k$
- Assumptions includes: Only one Higgs. Only modify the coupling strengths. Width is negligible at 125.5GeV

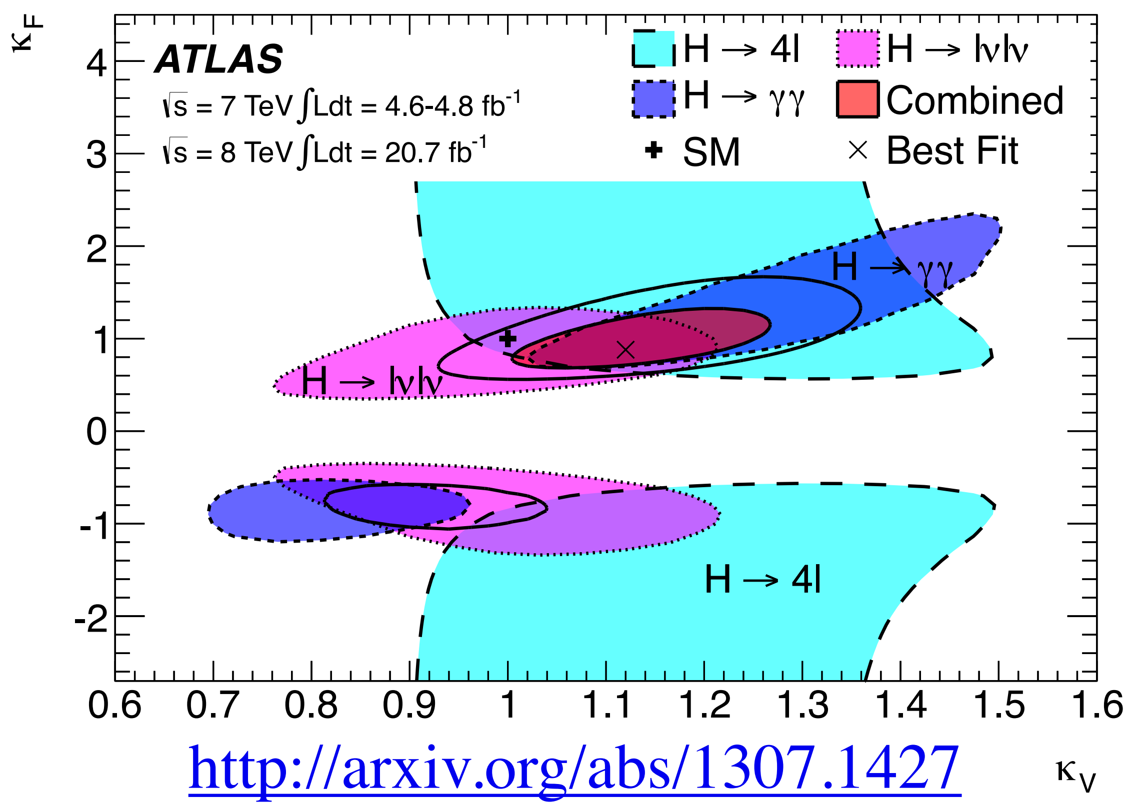
- Relate κ with μ:
  - $\text{Rate}_{i,j} = \sigma_i * \Gamma_j / \Gamma_{total}$
  - $\mu_{i,j} = \text{Rate}_{i,j} / \text{Rate}_{i,j;\,SM} = \kappa_i^2 * \kappa_j^2 / \kappa_H^2$
  - $\kappa_H^2 = \Sigma\, B_j * \kappa_j^2$

$$\sigma \cdot \text{BR}\,(gg \to H \to \gamma\gamma) \;=\; \sigma_{SM}(gg \to H) \cdot \text{BR}_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

http://arxiv.org/abs/1307.1427

Model	Probed couplings	Parameters of interest	Functional assumptions κ_V	κ_F	κ_g	κ_γ	κ_H	Example: $gg \to H \to \gamma\gamma$
1	Couplings to fermions and bosons	κ_V, κ_F	√	√	√	√	√	$\kappa_F^2 \cdot \kappa_\gamma^2(\kappa_F, \kappa_V)/\kappa_H^2(\kappa_F, \kappa_V)$
2		$\lambda_{FV}, \kappa_{VV}$	√	√	√	√	-	$\kappa_{VV}^2 \cdot \lambda_{FV}^2 \cdot \kappa_\gamma^2(\lambda_{FV}, \lambda_{FV}, \lambda_{FV}, 1)$
3	Custodial symmetry	$\lambda_{WZ}, \lambda_{FZ}, \kappa_{ZZ}$	-	√	√	√	-	$\kappa_{ZZ}^2 \cdot \lambda_{FZ}^2 \cdot \kappa_\gamma^2(\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$
4		$\lambda_{WZ}, \lambda_{FZ}, \lambda_{\gamma Z}, \kappa_{ZZ}$	-	√	√	-	-	$\kappa_{ZZ}^2 \cdot \lambda_{FZ}^2 \cdot \lambda_{\gamma Z}^2$
5	Vertex loops	κ_g, κ_γ	=1	=1	-	-	√	$\kappa_g^2 \cdot \kappa_\gamma^2 / \kappa_H^2(\kappa_g, \kappa_\gamma)$

Coupling to fermions and bosons
(Assumptions on total width)



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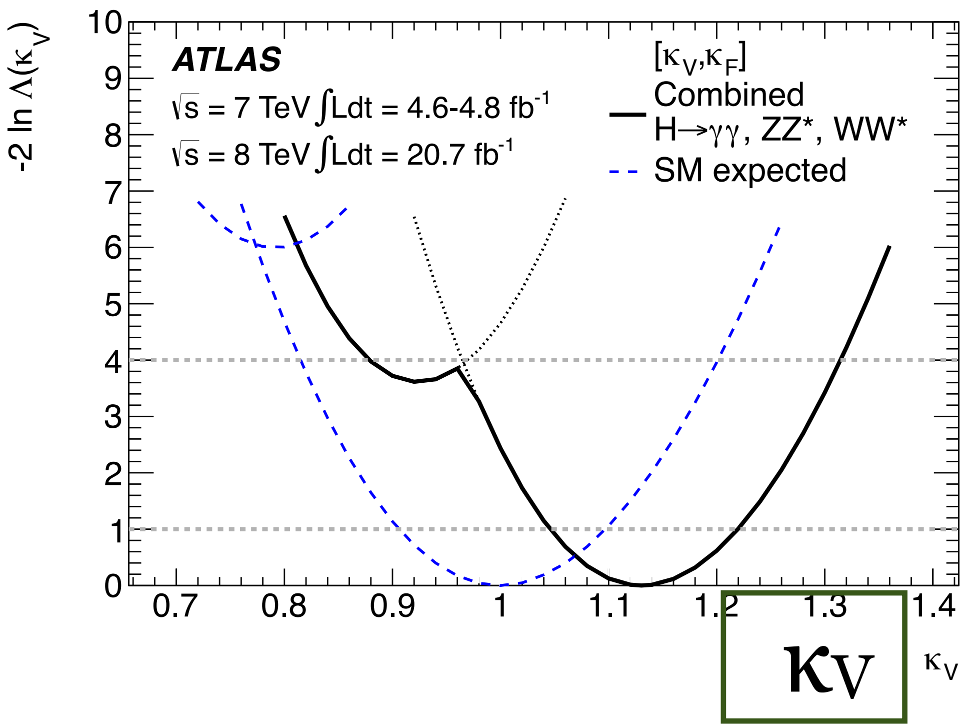
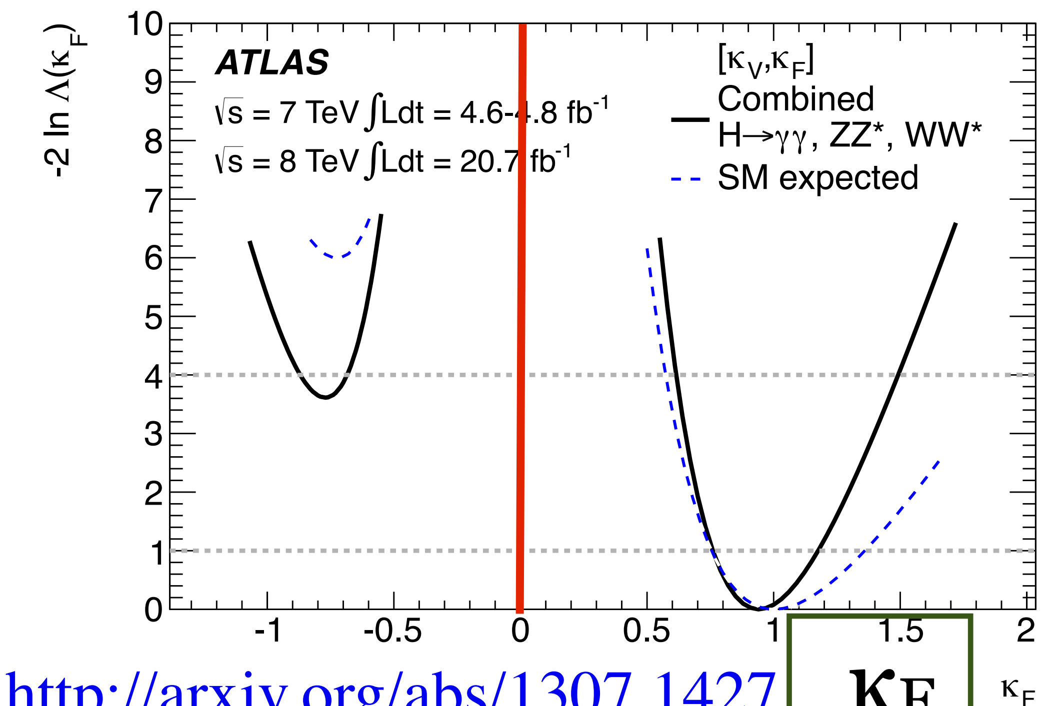
$$\kappa_\gamma^2(\kappa_F,\kappa_V) = 1.59 \cdot \kappa_V^2 - 0.66 \cdot \kappa_V\kappa_F + 0.07 \cdot \kappa_F^2$$

- 68% CL of κ_F: [0.76, 1.18]
- 68% CL of κ_V: [1.05, 1.22]
- Overall compatibility: 12%





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rejecting κ_F=0 at a significance >5σ

Test of custodial symmetry

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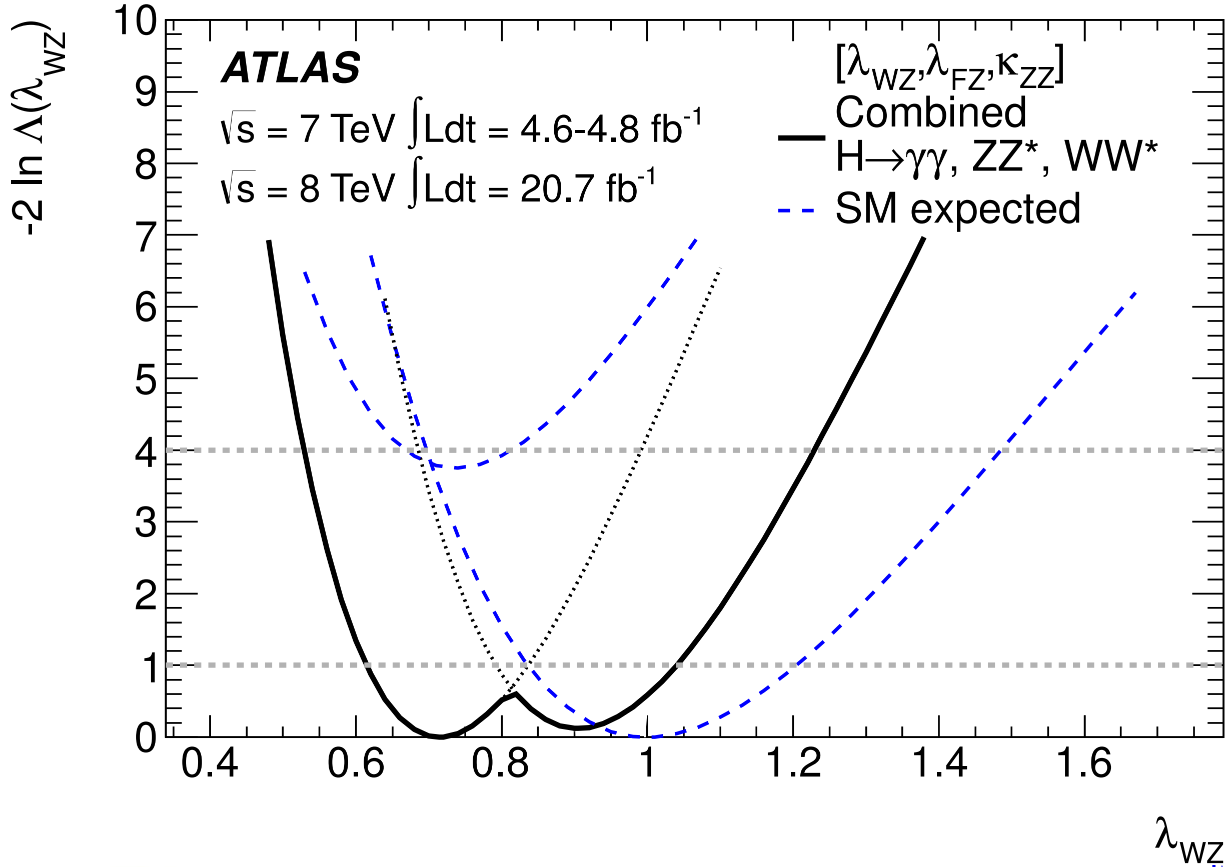
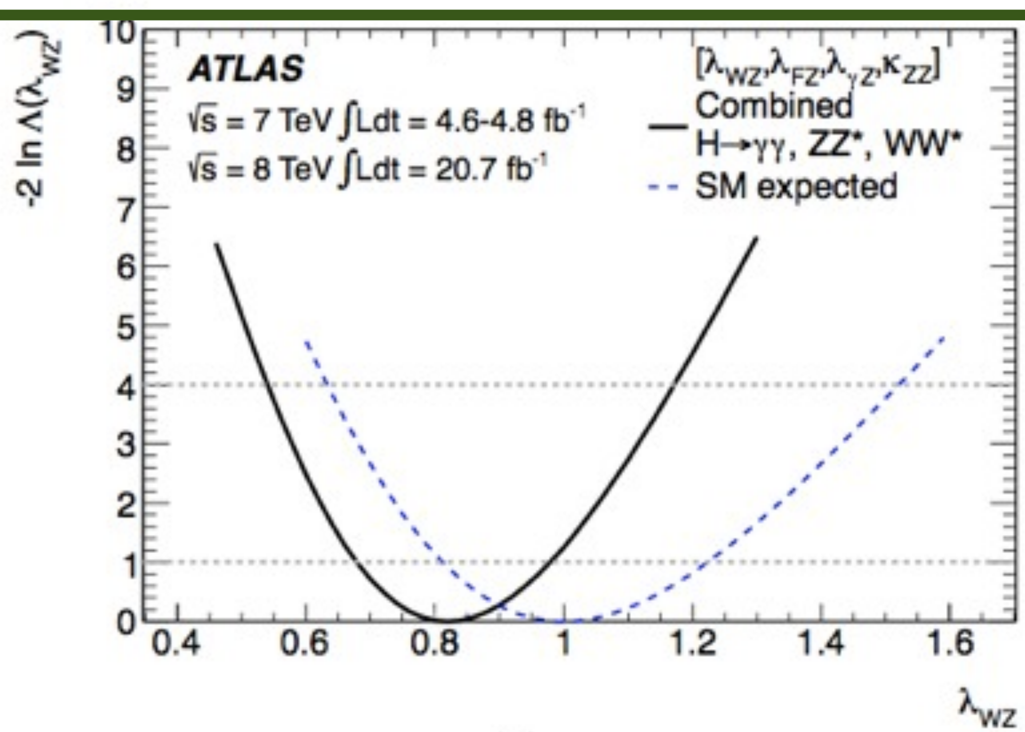


$$\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$$
$$\lambda_{WZ} = \kappa_W / \kappa_Z$$
$$\lambda_{FZ} = \kappa_F / \kappa_Z \; .$$

- ➡ With assumption on H→ γγ loop
- ➡ No assumption on H→ γγ loop
- ➡ From Ratio of BR of WW* and ZZ*



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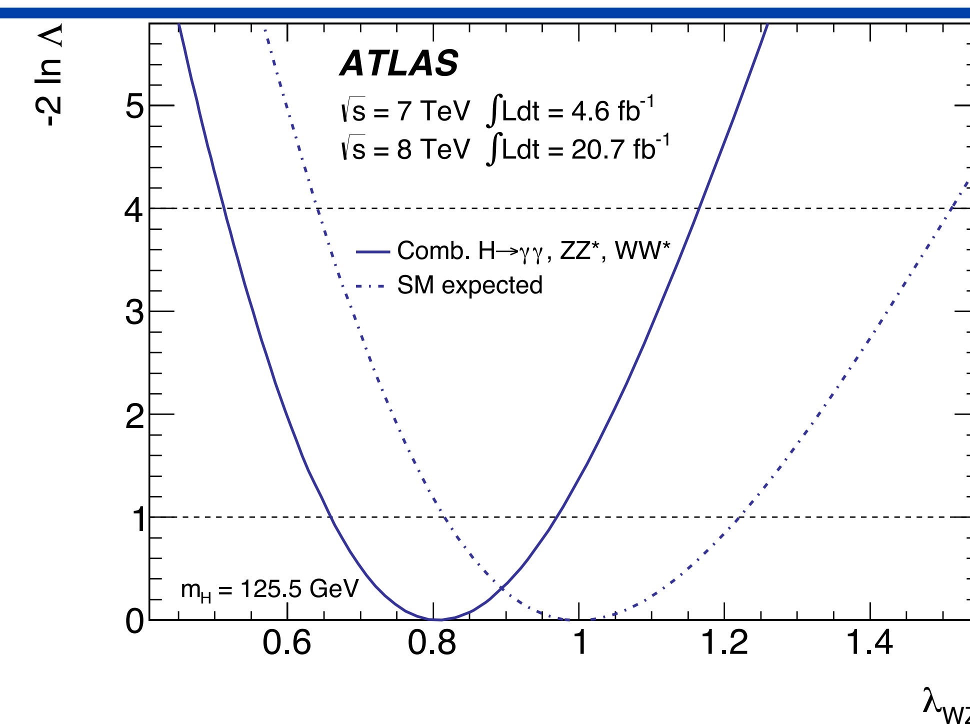

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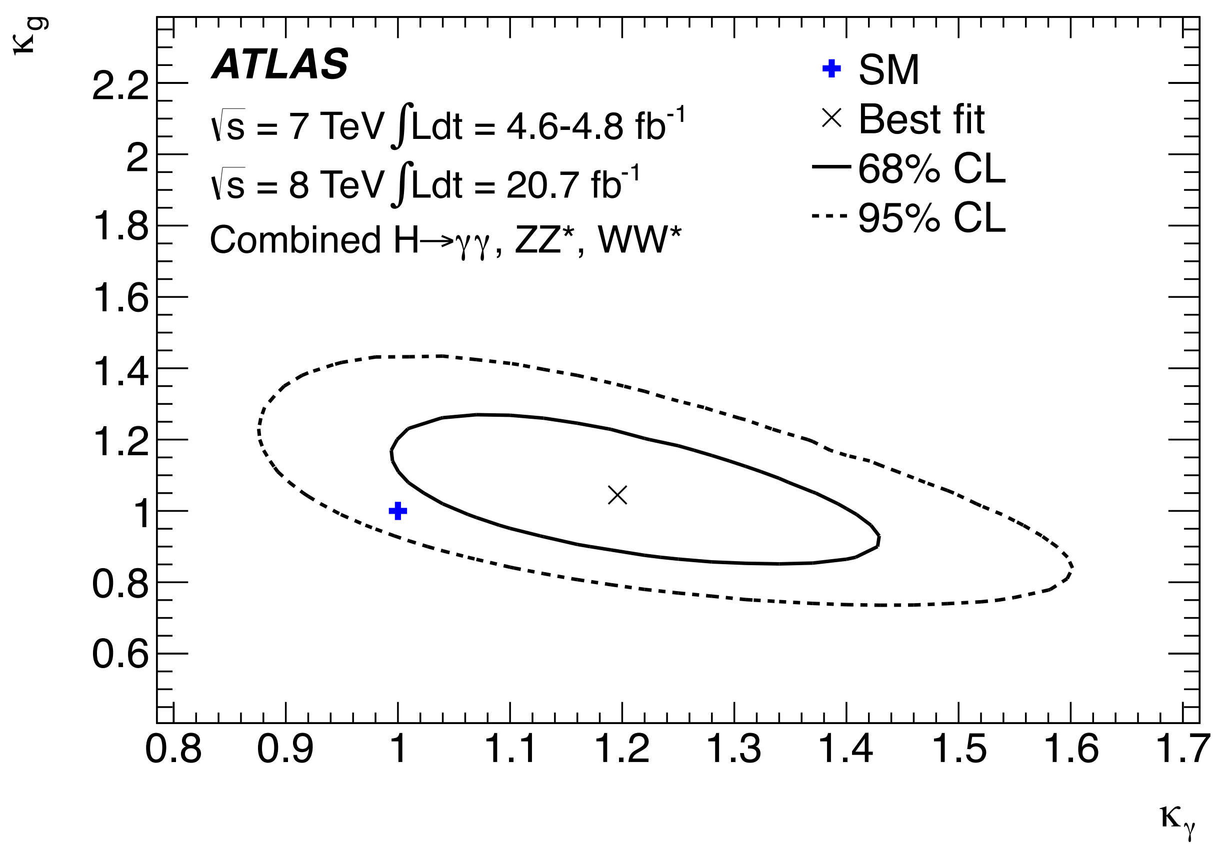
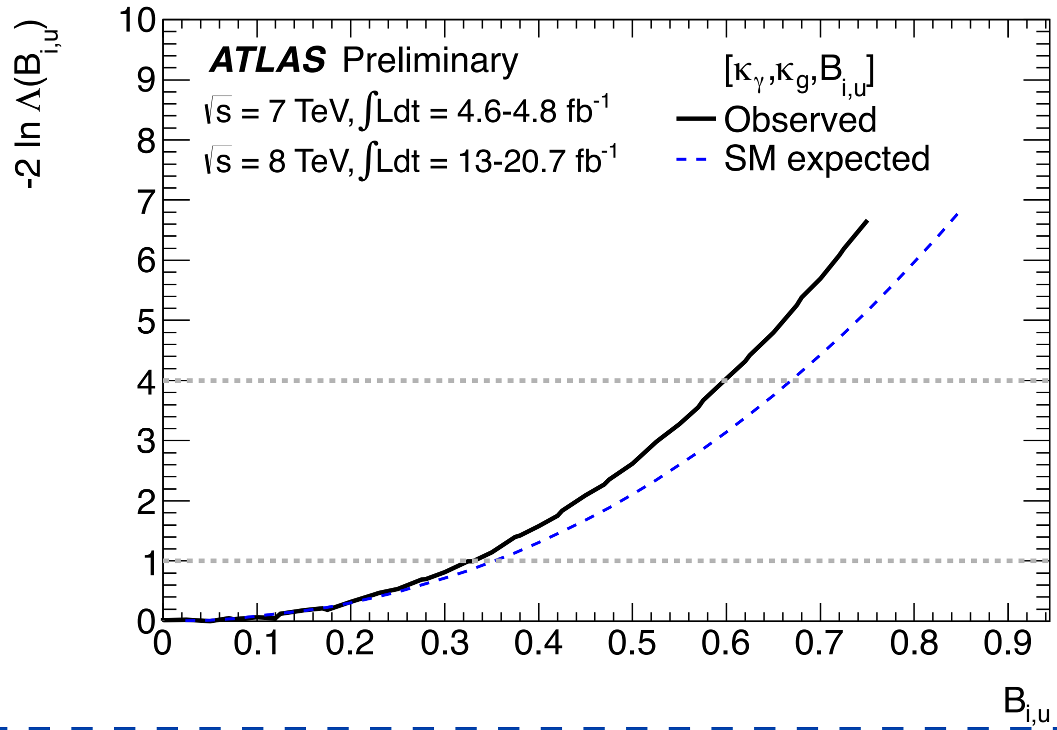
Constraints on loop processes

http://arxiv.org/abs/1307.1427



Fix tree-level couplings

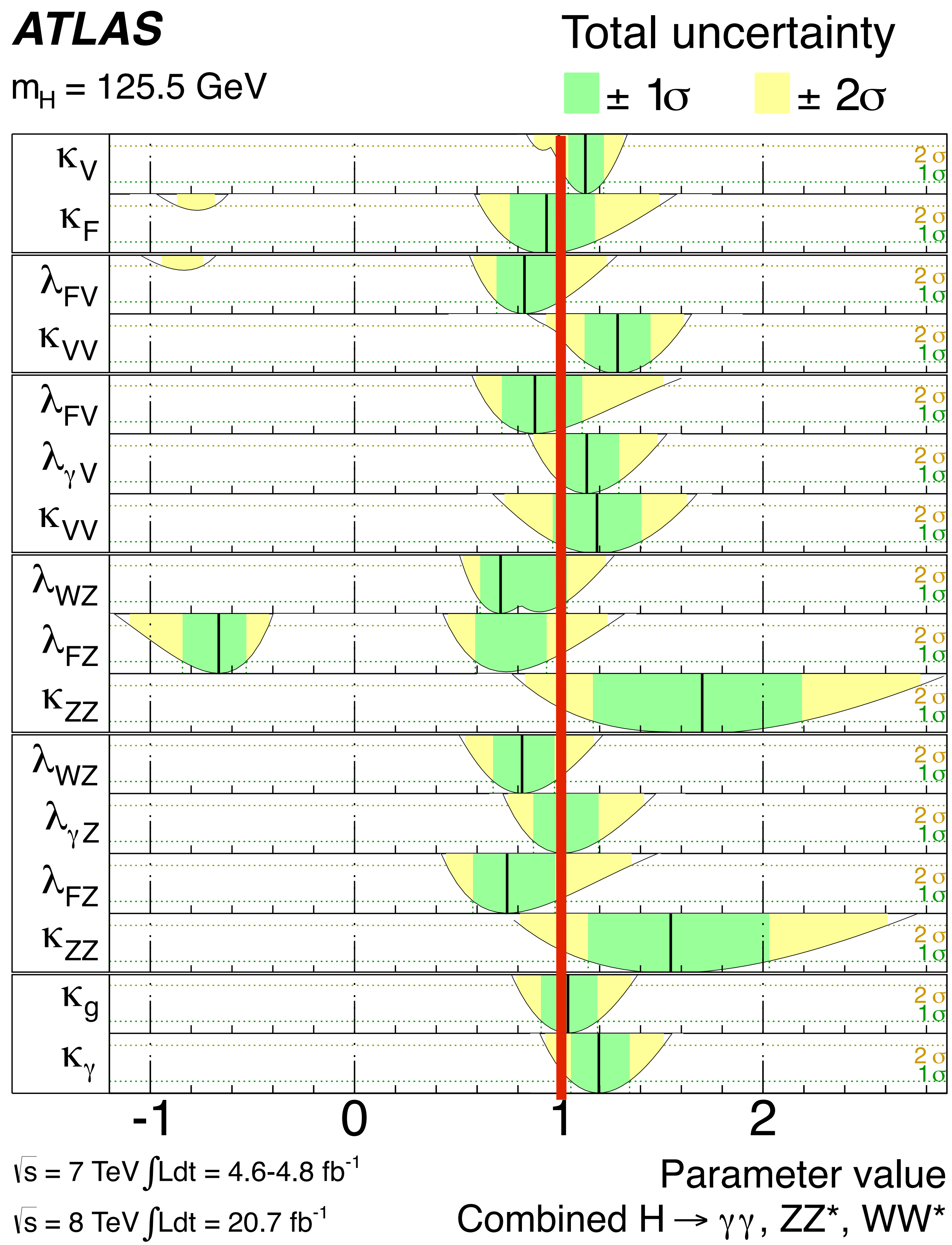
- Sensitive to potential new physics
- κ_γ: 1.20±0.15, κ_g: 1.04±0.14
- Overall compatibility: 14%



- Allowing non-SM contributions to total width
- $BR_{i,u}$ can be constrained
- With partial ττ and bb dataset

ATLAS-CONF-2013-034

Couplings overview



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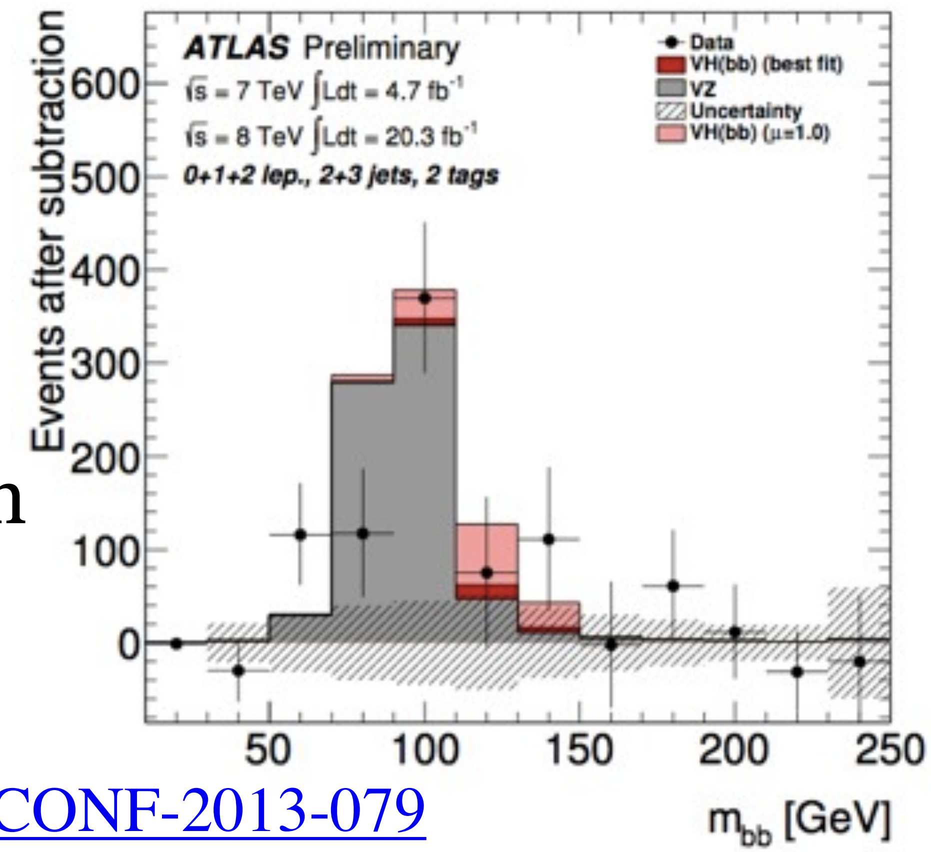
H→bb

- Full Run 1 luminosity used
  - 4.7(7TeV) + 20.3(8TeV) [fb^{-1}]
- Categorized based on number of leptons, jets and b-tagged jets, and on the p_T of vector boson candidate



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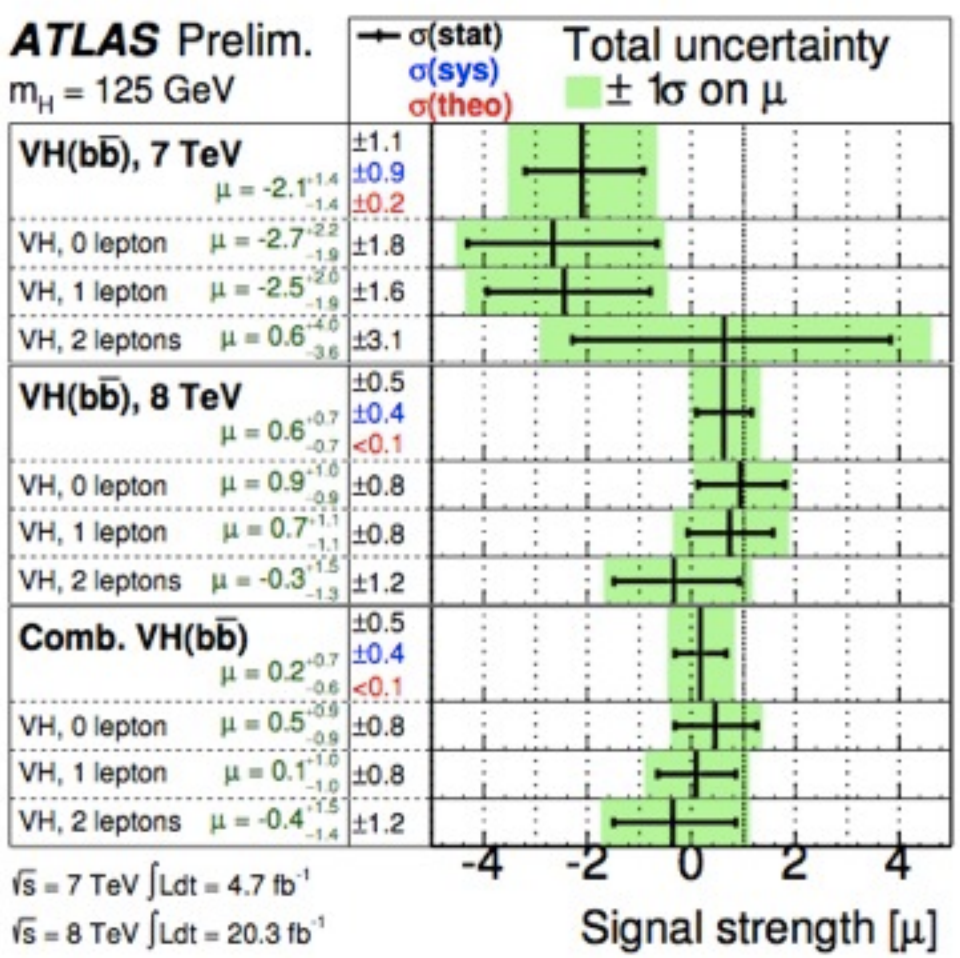
All bkg. subtracted except di-boson



- Separate "di-boson fit" yields an overall μ_{VZ} =0.9 ± 0.2, good validation of the analysis!
- μ_{Higgs} =0.2 ± 0.5(stat.) ± 0.4(syst.) at 125GeV, with a limit to the no signal hypo. of 1.4 × SM

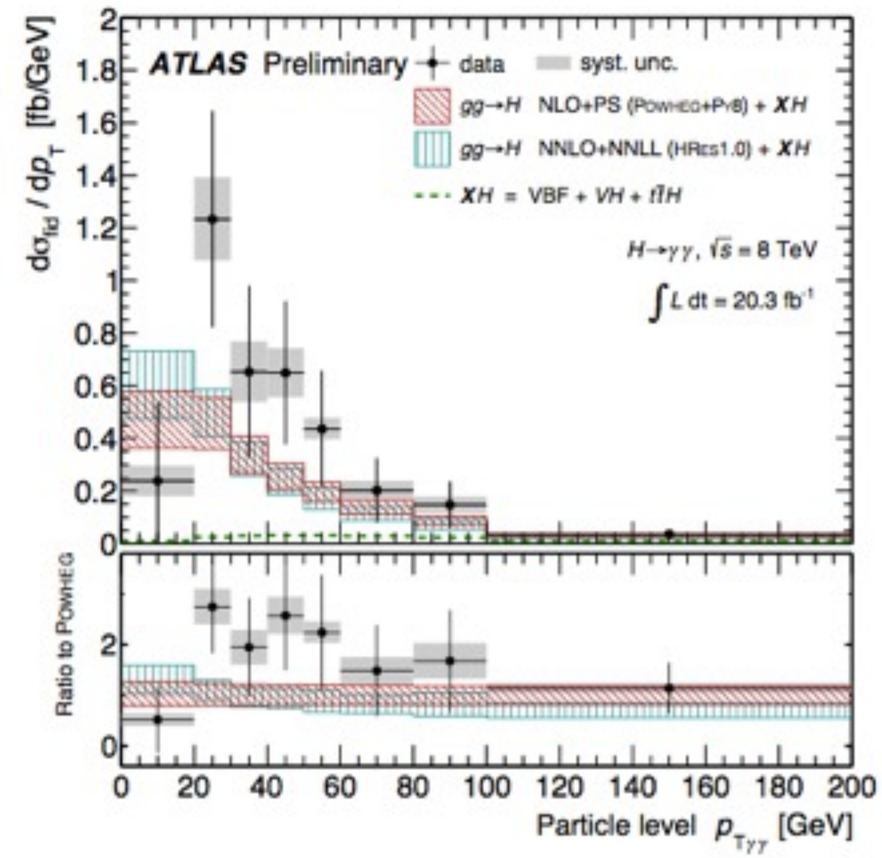
Diff. cross sections in γγ final states

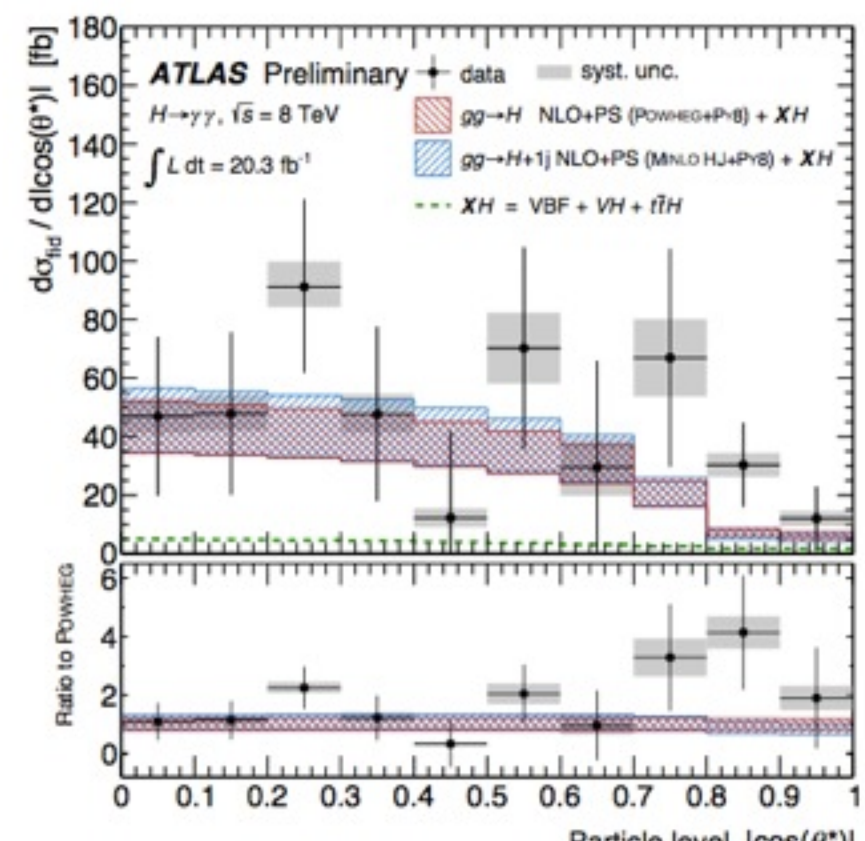
- 8TeV data, prediction at 126.8 GeV
- $d\sigma/dP_{T\gamma\gamma}$, $d|y_{\gamma\gamma}|$, $d|\cos(\theta^*)|$, dN_{jets}, $d\Phi_{jj}$, ...
- Sensitive to: PDF, QCD calculations, production mechanism, spin, lagrangian tensor structure, ...
- Unfolded to particle level

Probabilities of χ^2 tests for agreements between unfolded observation and theoretical prediction

	N_{jets}	$p_T^{\gamma\gamma}$	$\|y^{\gamma\gamma}\|$	$\|\cos\theta^*\|$	$p_T^{j_1}$	$\Delta\phi_{jj}$	$p_T^{\gamma\gamma jj}$
POWHEG	0.54	0.55	0.38	0.69	0.79	0.42	0.50
MINLO	0.44	–	–	0.67	0.73	0.45	0.49
HRES 1.0	–	0.39	0.44	–	–	–	–

No significant deviation from SM expectation





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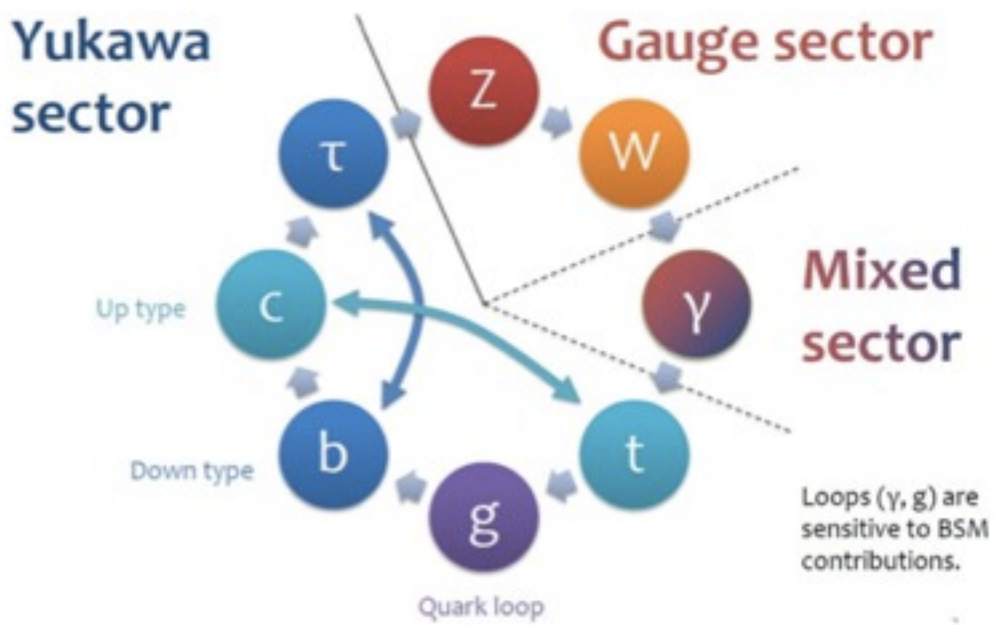
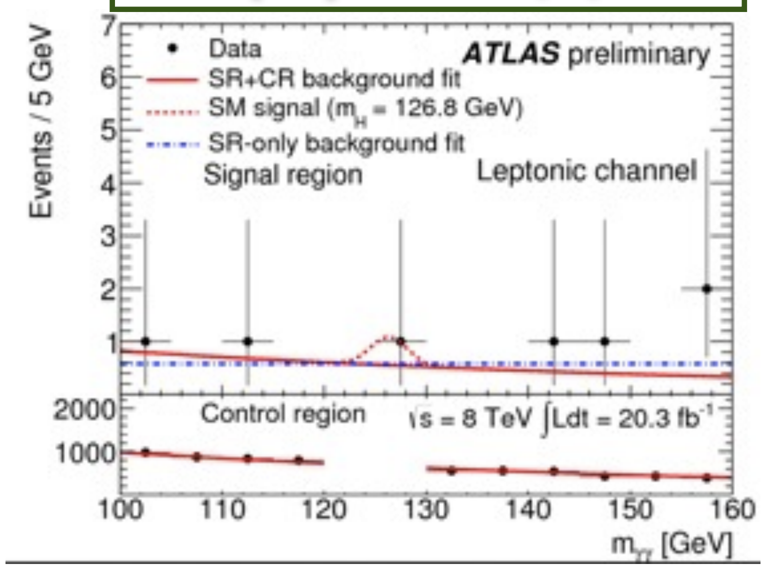
More to come...



(tt)H→γγ



ATLAS-CONF-2013-080

ττ,
ttH,
Zinv...

- μ and coupling combination
- mass determination after new calibration
- Spin/CP, possibly add H→ττ
- Differential distributions [H→γγ already showed on EPS]
- BSM Higgs include direct BSM searches

Conclusions

- The mass determined: 125.5 ± 0.2(stat.) ± 0.6 (sys) GeV
- Our data favors the 0^+, which provides evidence for the scalar nature of the Higgs boson
  - 0^- rejected at 97.8% CL, spin 1 at >99.7%, 2^+ at >99.9%
- Couplings to gauge bosons constrained at 10% level.
  - Couplings to fermions observed indirectly at >5σ
  - Observation of the VBF production process at 3.3σ
- The ratio of relative couplings to W and Z bosons measured to be consistent with unity.
- No significant anomalous contributions from gg and γγ loops are observed