Higgs and new physics at high energy

Carlos Solans
On behalf of the ATLAS and CMS collaborations

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Outline

- Introduction
- Higgs mass and spin parity
- Higgs couplings
- Limits on new physics
- Conclusion

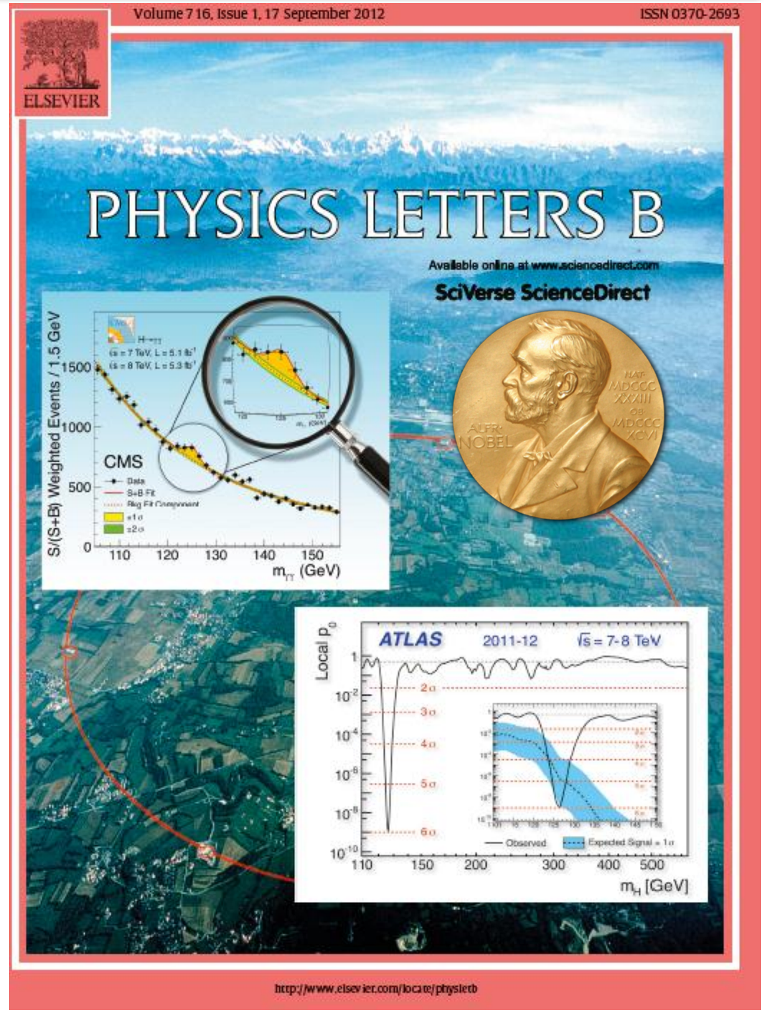
Since there are no other Higgs talks at the conference we introduce the Higgs production and decay modes. We update on mass and signal strength, and spin parity measurement. Note on evidence for VBF production. Explain the search for deviations from SM in different benchmark scenarios. Finally update on recent results of interpretations beyond the SM.

- Abstract: State of the art on Higgs coupling measurements and SUSY and other Higgs searches using the ATLAS and CMS experiments

Higgs boson discovery

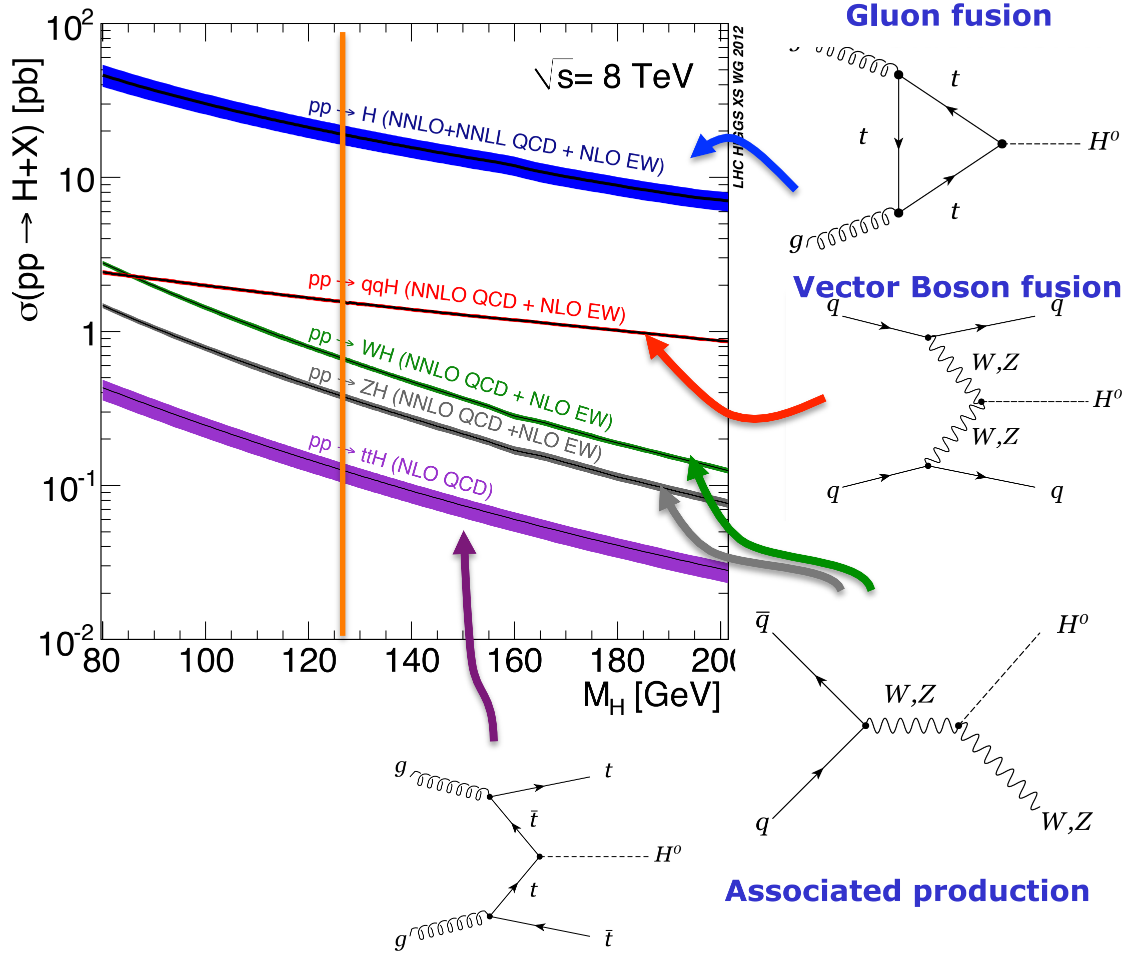
- ATLAS and CMS experiments observed a new particle compatible with the SM Higgs boson in July 2012
  - … and Nobel prize has been awarded

- Precision measurements of the properties of the new boson are of critical importance
  - … is the new boson solely responsible for the electroweak symmetry breaking?



SM Higgs boson production at the LHC

- Considering a 125.5 GeV Higgs at $\sqrt{s}$ = 8 TeV
- Gluon Fusion (*gg*F)
  - **gg → H**
  - 19 pb (87%)
  - With no specific topology
- Vector Boson Fusion (VBF)
  - **qq → qqH**
  - 1.6 pb (7.3%)
  - With specific jet topology
- Associated production with vector bosons (VH) or top pairs (ttH)
  - **qq → WH, ZH, ttH**
  - 0.70, 0.41, 0.13 pb (5.7%)



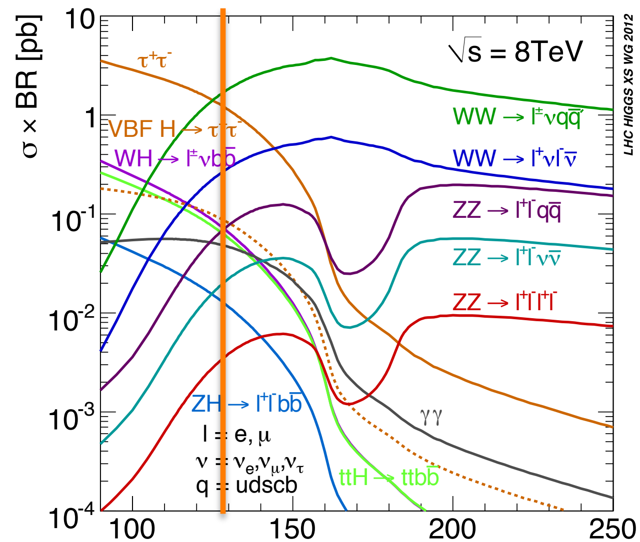
$\Delta\sigma/\sigma$ for pp at8 TeV

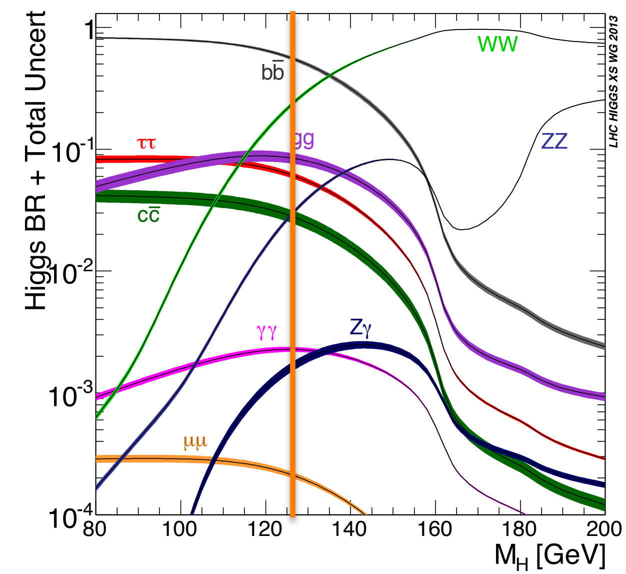
Process	QCD scale	PDF+α_s	Total (linear sum)
ggF	±8%	±8%	±15%
$t\bar{t}$H	±7%	±8%	±15%
VBF	±1%	±4%	±5%
VH	±1%	±4%	±5%

Detailed description at CERN Yellow Reports I, II and III (***arXiv:1101.0593***, ***arXiv:1201.3084*** and ***arXiv:1307.1347***)
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

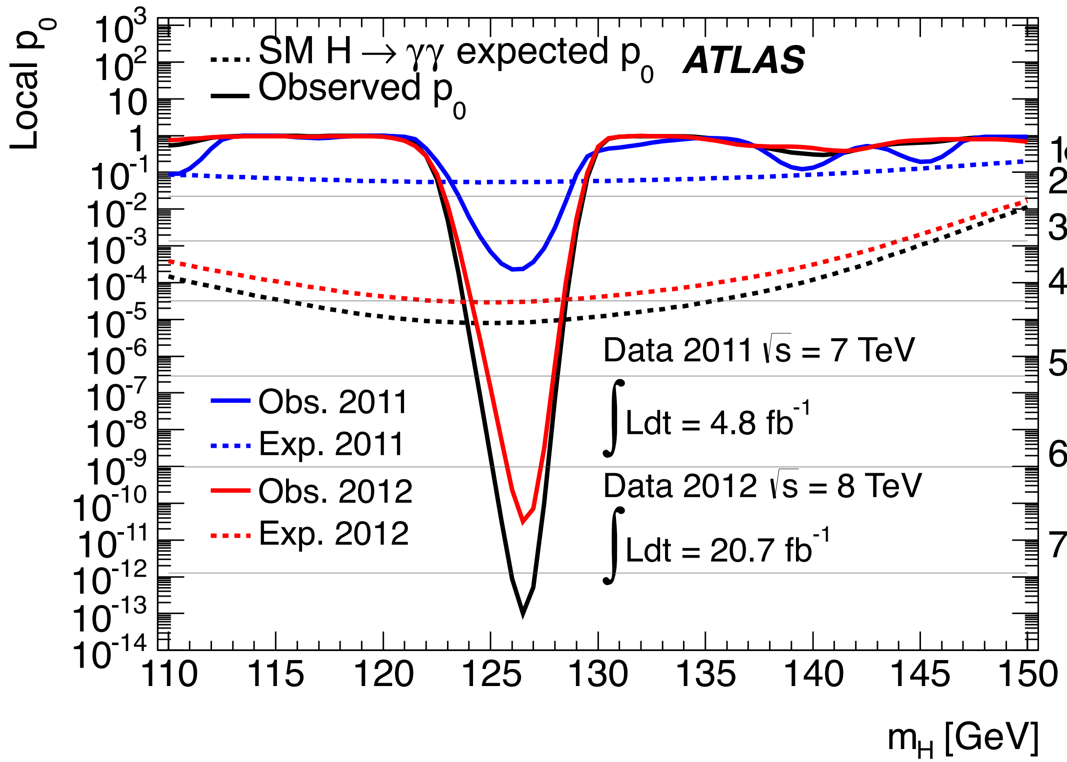
SM Higgs boson decays at the LHC

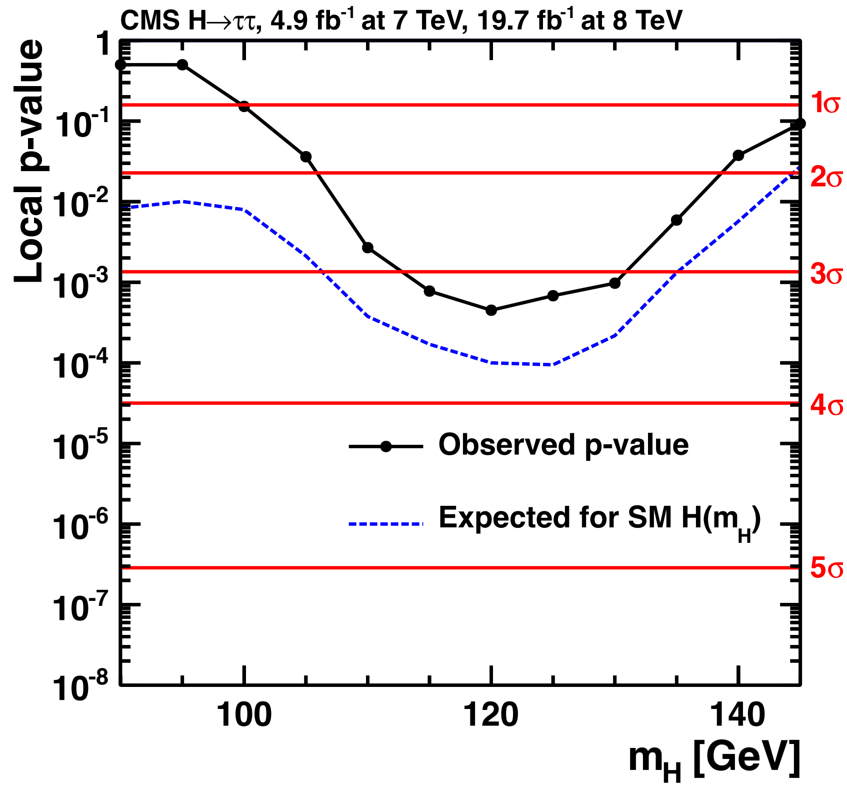
- Higgs boson decay channels considering m_H = 125.5 GeV are
  - H → bb
    - BR ($H \rightarrow bb$): 56.9 %
    - large BR, Yukawa coupling
  - H → WW
    - BR ($H \rightarrow WW$): 22.3%
    - large BR, gauge boson coupling
  - H → ττ
    - BR ($H \rightarrow \tau\tau$): 6.2 %
    - Yukawa coupling
  - H → ZZ
    - BR ($H \rightarrow ZZ$): 2.8 %
    - high mass resolution, high S/B, gauge boson coupling
  - H → γγ
    - BR ($H \rightarrow \gamma\gamma$): 0.24 %
    - high mass resolution, loop coupling dominated by gauge boson coupling





Evidence for a 125 GeV Higgs





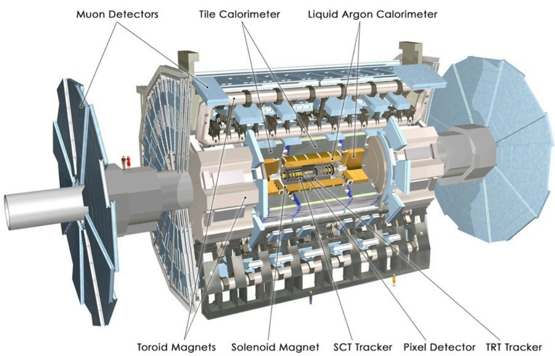
Phys. Lett. B 726 (2013), pp. 88-119

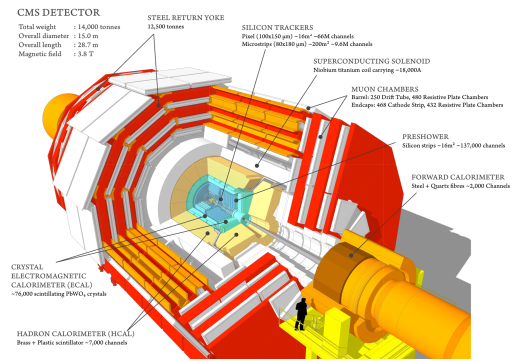
CMS-HIG-13-004 submitted to JHEP

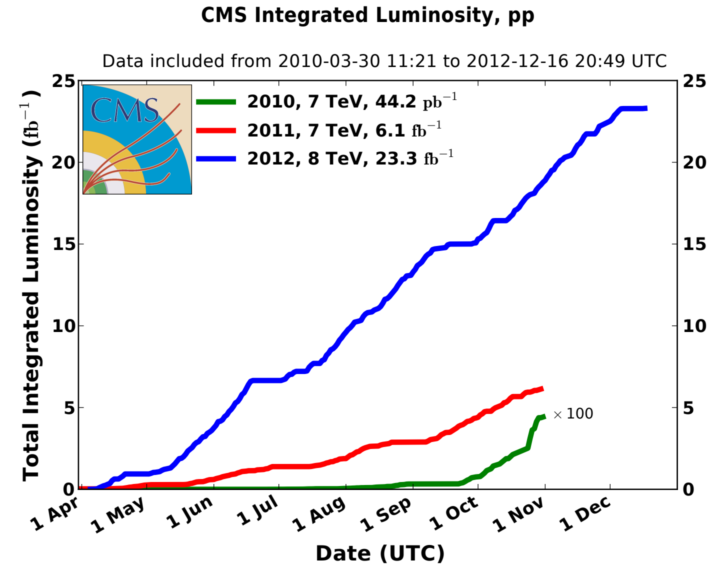
- Evidence of a Higgs boson like particle at 7σ level in the $H \rightarrow \gamma\gamma$ channel (ATLAS), and even at 3σ level in the $H \rightarrow \tau\tau$ channel (CMS)

Detector performance

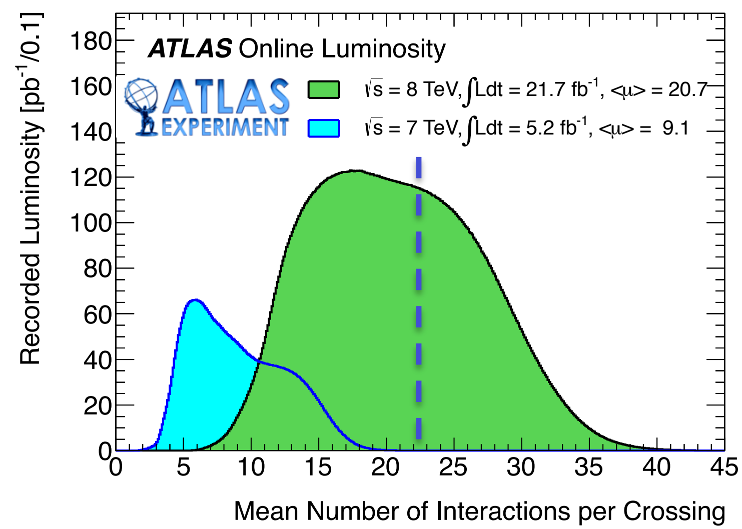
- ATLAS and CMS kept very high data taking efficiency during Run-I
  - ~90% of the delivered luminosity usable for physics







Year	√s	ATLAS	CMS
2011	7 TeV	4.8 fb^{-1}	5.1 fb^{-1}
2012	8 TeV	20.7 fb^{-1}	18.6 fb^{-1}

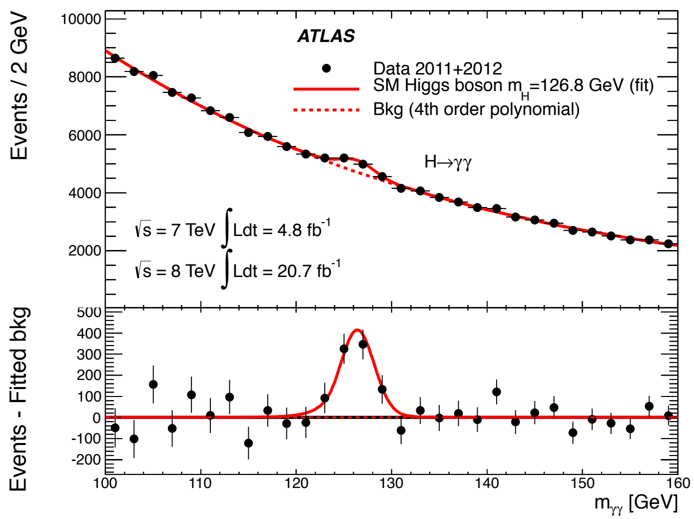


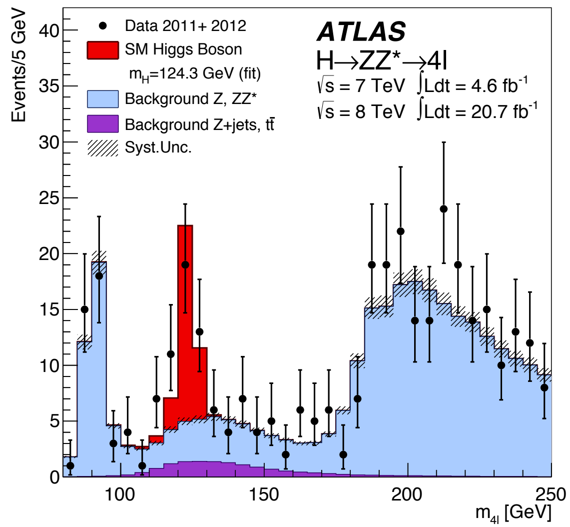
- Pile-up during Run-I was above design value
  - Challenge to mitigate it's impact on trigger, computing and reconstruction of physics objects

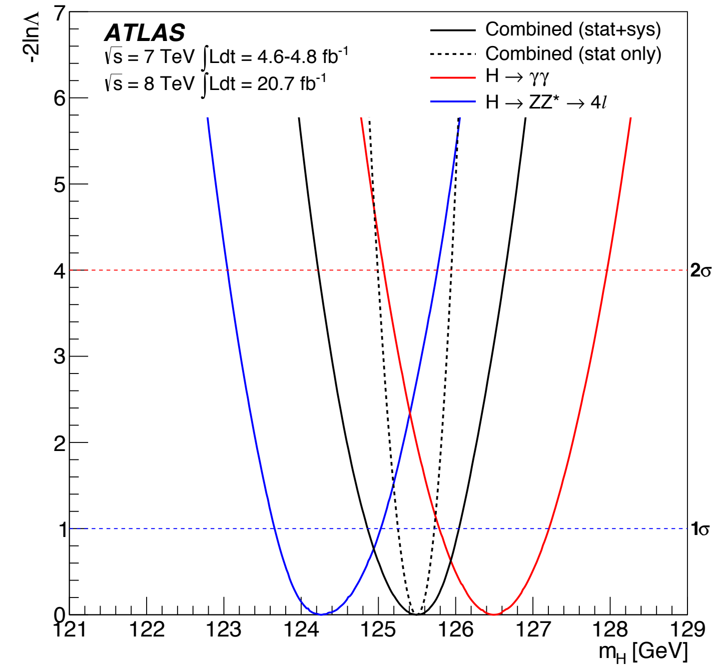
Higgs mass and spin parity measurement

ATLAS Higgs mass measurement

- ATLAS measures Higgs mass with 25 fb^{-1} from
  - $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$ channels
  - $H \rightarrow ZZ \rightarrow 4l$: 1D fit with kinematic constraints on Z







$$m_H^{\gamma\gamma} = 126.8 \pm 0.2(\text{stat}) \pm 0.7(\text{syst})\text{GeV} \quad m_H^{4l} = 124.3^{+0.6}_{-0.5}(\text{stat})^{+0.5}_{-0.3}(\text{syst})\text{GeV}$$

Use profile likelihood ratio

$$\Lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}}(\mu))}{L(\hat{\mu}, \hat{\theta})}$$

to quantify m_H confidence intervals with nuisance parameters θ ($\mu_{\gamma\gamma}$, μ_{4l}, theory, and experimental systematics)

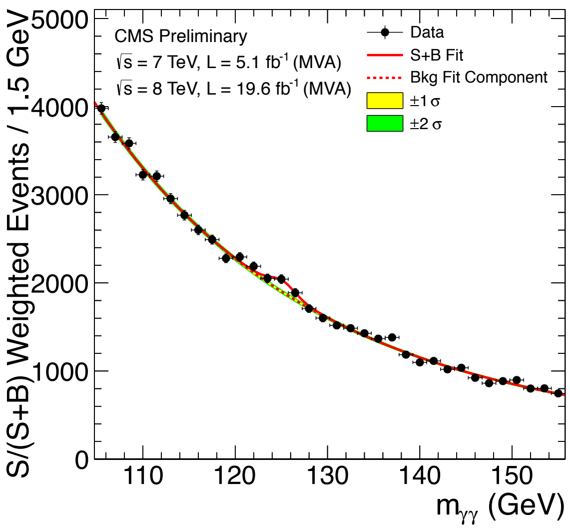
- Mass measurement with independent signal strengths yields:

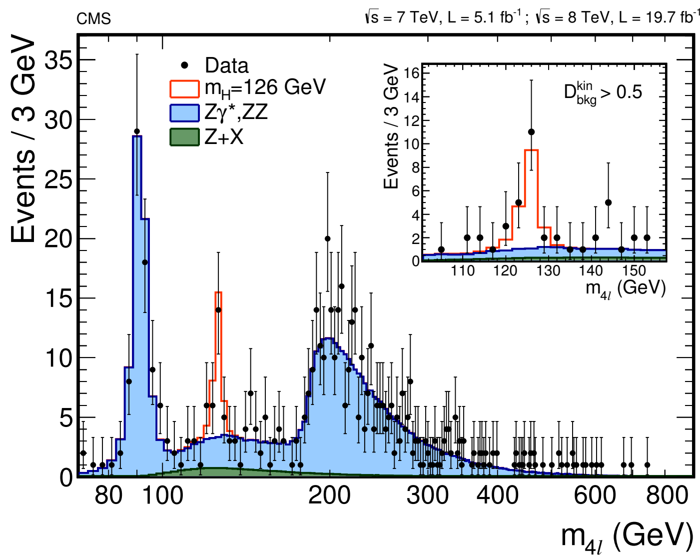
$$m_H = 125.5 \pm 0.2(\text{stat})^{+0.5}_{-0.6}(\text{syst})\text{GeV}$$

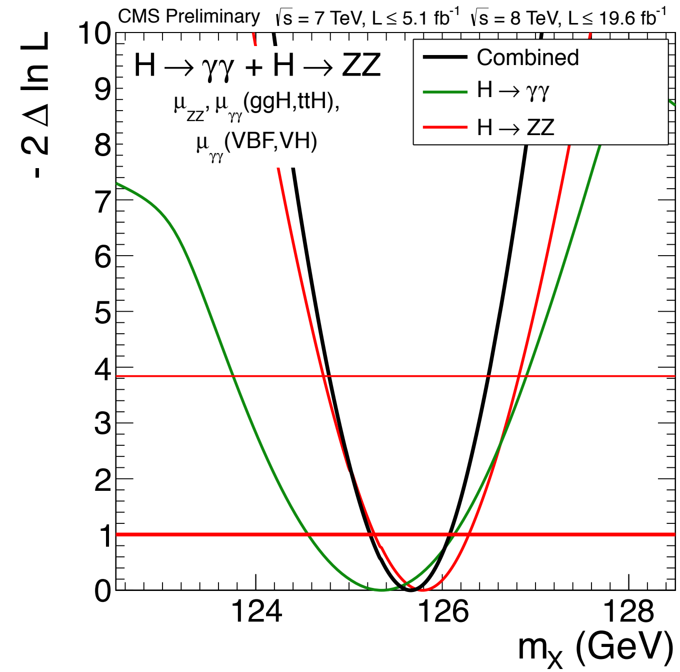
ATLAS-CONF-2013-014

CMS Higgs mass measurement

- CMS measures Higgs mass at 25 fb^{-1} from
  - $H \rightarrow \gamma\gamma$: combined fits to all event categories
  - $H \rightarrow ZZ \rightarrow 4l$: 3D Likelihood







Use similar likelihood ratio with slightly different naming convention

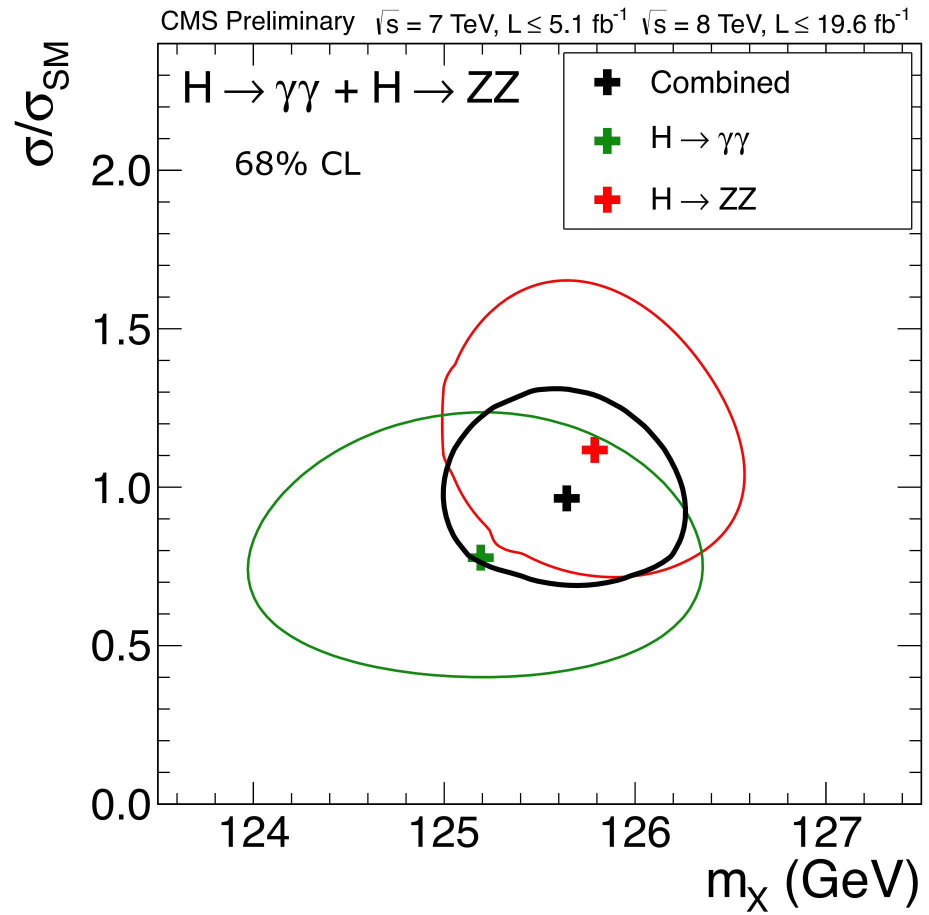
$$q(a) = -2\ln \frac{\mathcal{L}(\mathrm{obs}\,|\,s(a)+b,\,\hat{\theta}_a)}{\mathcal{L}(\mathrm{obs}\,|\,s(\hat{a})+b,\,\hat{\theta})}$$

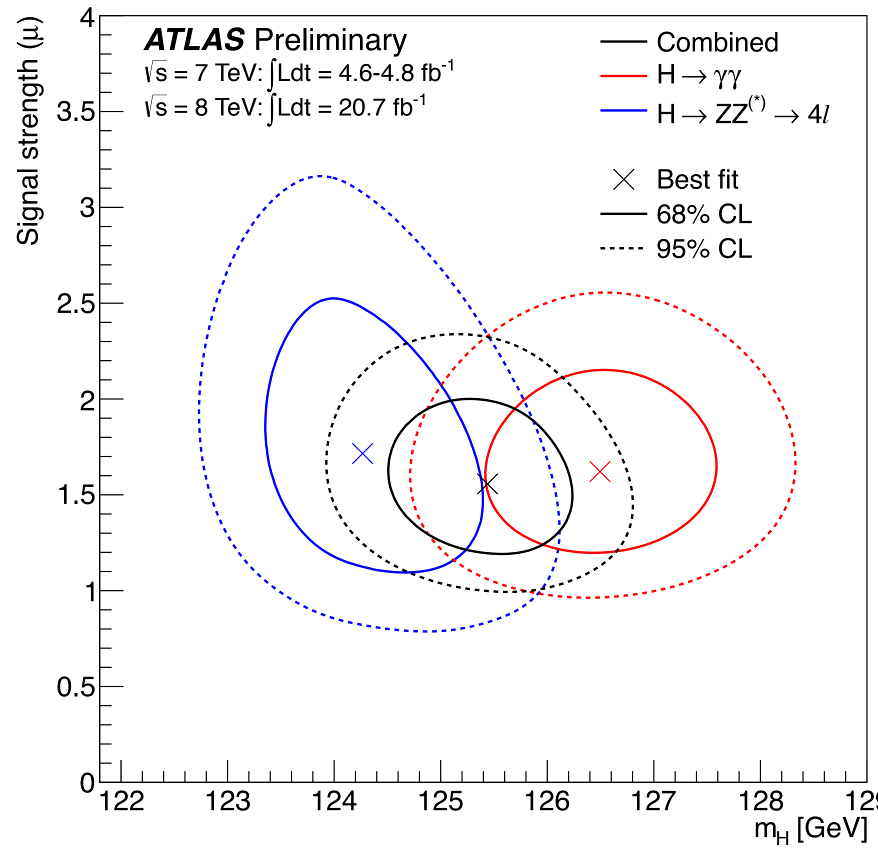
- Mass measurement with independent signal strengths yields:

$$m_H = 125.7 \pm 0.3(\mathrm{stat}) \pm 0.3(\mathrm{syst})\mathrm{GeV}$$

CMS-PAS-HIG-13-005

Higgs mass measurement





$$m_H = 125.7 \pm 0.3(\text{stat}) \pm 0.3(\text{syst})\text{GeV}$$

CMS-PAS-HIG-13-005

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

ATLAS-CONF-2013-014

Compatibility between channels

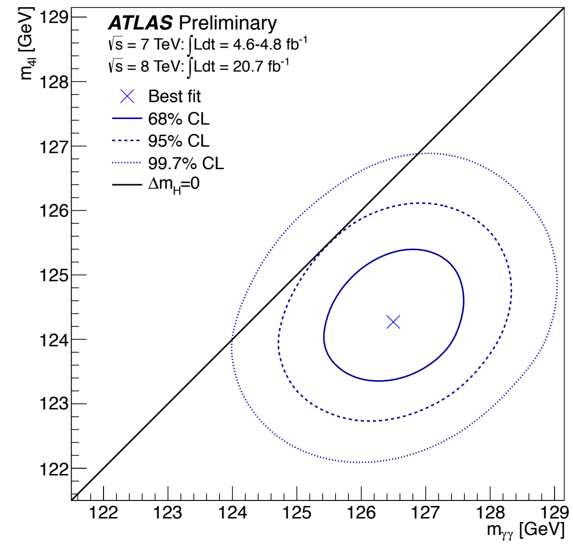
- The individual mass measurements, $m_{\gamma\gamma}$ and m_{4l}, are slightly correlated due to the common EM scale systematic (for photons in $m_{\gamma\gamma}$ and electrons in m_{4l})
  - Pulls $m_{\gamma\gamma}$ down by 350 MeV in combined fit
- Consistency with Δm=0 is tested by likelihood function where average mass m_H is profiled in the fit

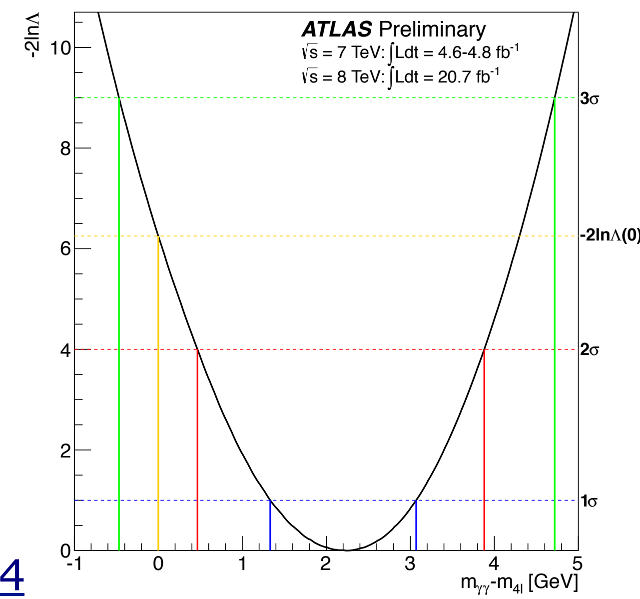
$$\Lambda(\Delta m_H) = \frac{L(\Delta m_H\,,\,\hat{\hat{\mu}}_{\gamma\gamma}(\Delta m_H)\,,\,\hat{\hat{\mu}}_{4\ell}(\Delta m_H)\,,\,\hat{\hat{m}}_H(\Delta m_H)\,,\,\hat{\hat{\theta}}(\Delta m_H))}{L(\hat{\Delta m}_H, \hat{\mu}_{\gamma\gamma}, \hat{\mu}_{4\ell}, \hat{m}_H, \hat{\theta})}$$

- Measured mass difference is

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

  - **Mass difference compatible with zero at 2.4σ**





ATLAS-CONF-2013-014

ATLAS combined signal strength

- Updated integrated luminosity in 2012 dataset (20.3 fb^{-1} ± 2.8%), and evaluation of $H \rightarrow \tau\tau$ and $H \rightarrow bb$ channels at 125.5 GeV signal mass hypothesis (2-3% more signal yield)
- The signal strength to bosons

$$\mu^{\gamma\gamma, ZZ^*, WW^*} = 1.35 \pm 0.14(\mathrm{stat})^{+0.16}_{-0.14}(\mathrm{syst})$$

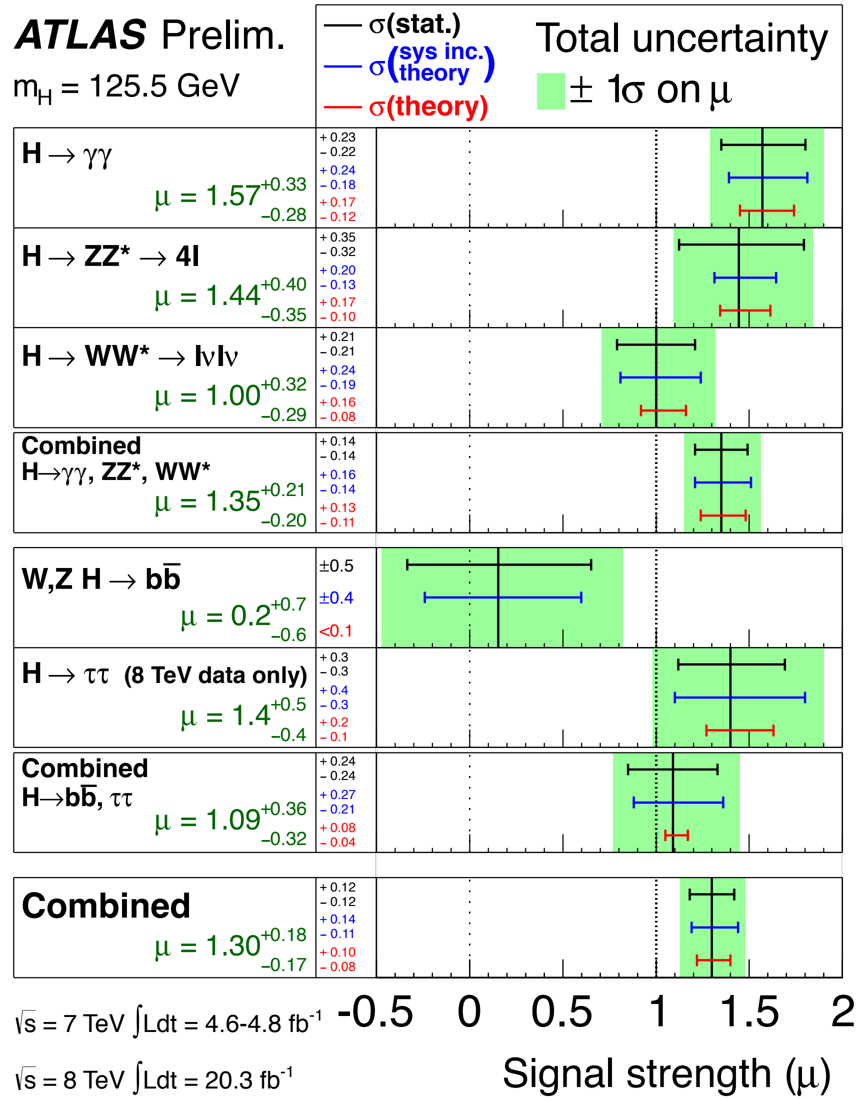
- And the signal strength to fermions

$$\mu^{bb,\tau\tau} = 1.09 \pm 0.24(\mathrm{stat})^{+0.27}_{-0.21}(\mathrm{syst})$$

- The overall signal strength becomes

$$\mu = 1.30 \pm 0.12(\mathrm{stat})^{+0.14}_{-0.11}(\mathrm{syst})$$

- Consistency with SM Higgs expectation is 7%

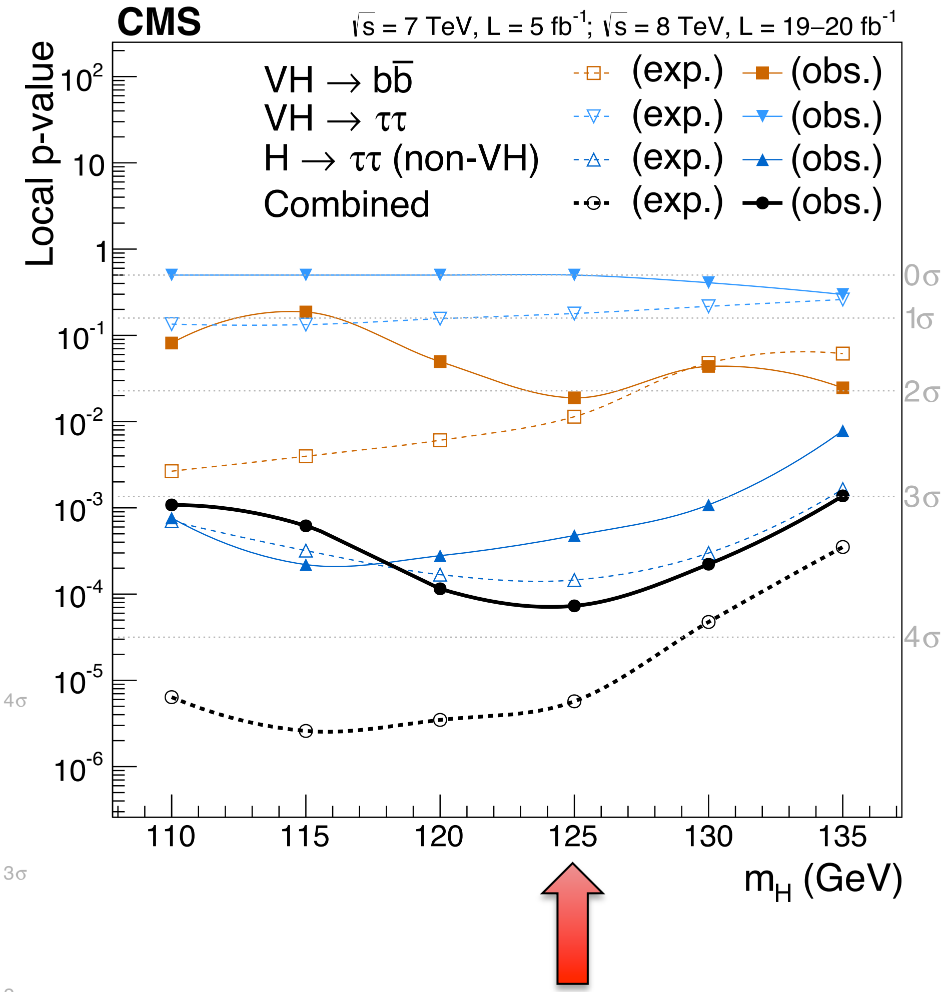


ATLAS-CONF-2014-009

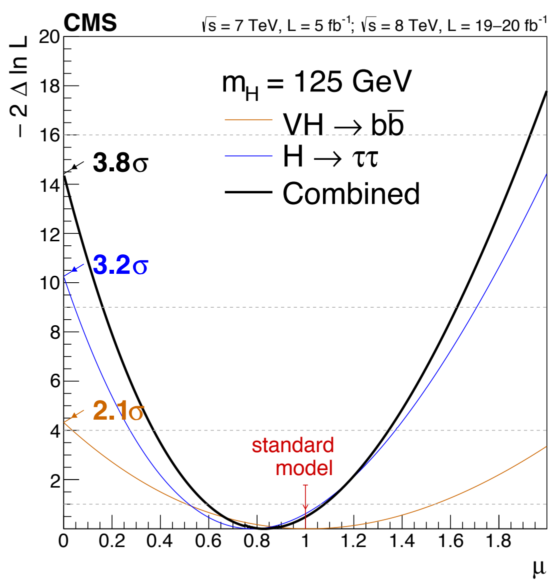
CMS signal strength to fermions

- Combined signal strength to fermions in H → bb and H → $\tau\tau$ channels with 25 fb^{-1}
  - Non-fermionic decay contributions expected for the standard model Higgs boson with a mass of 125 GeV are not scaled with μ

Channel ($m_H = 125$ GeV)	Significance (σ) Expected	Significance (σ) Observed	Best-fit μ
$VH \rightarrow b\bar{b}$	2.3	2.1	1.0 ± 0.5
$H \rightarrow \tau\tau$	3.7	3.2	0.78 ± 0.27
Combined	4.4	3.8	0.83 ± 0.24

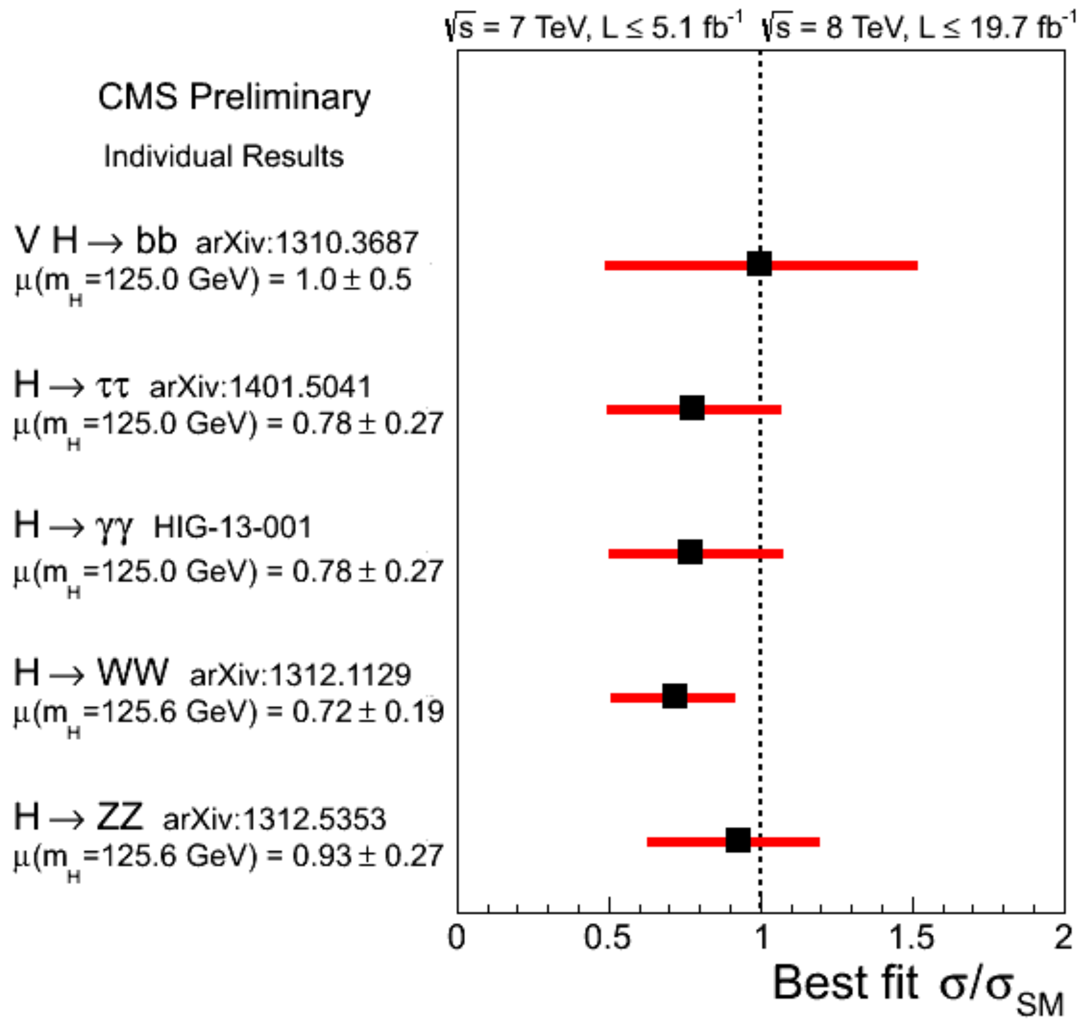


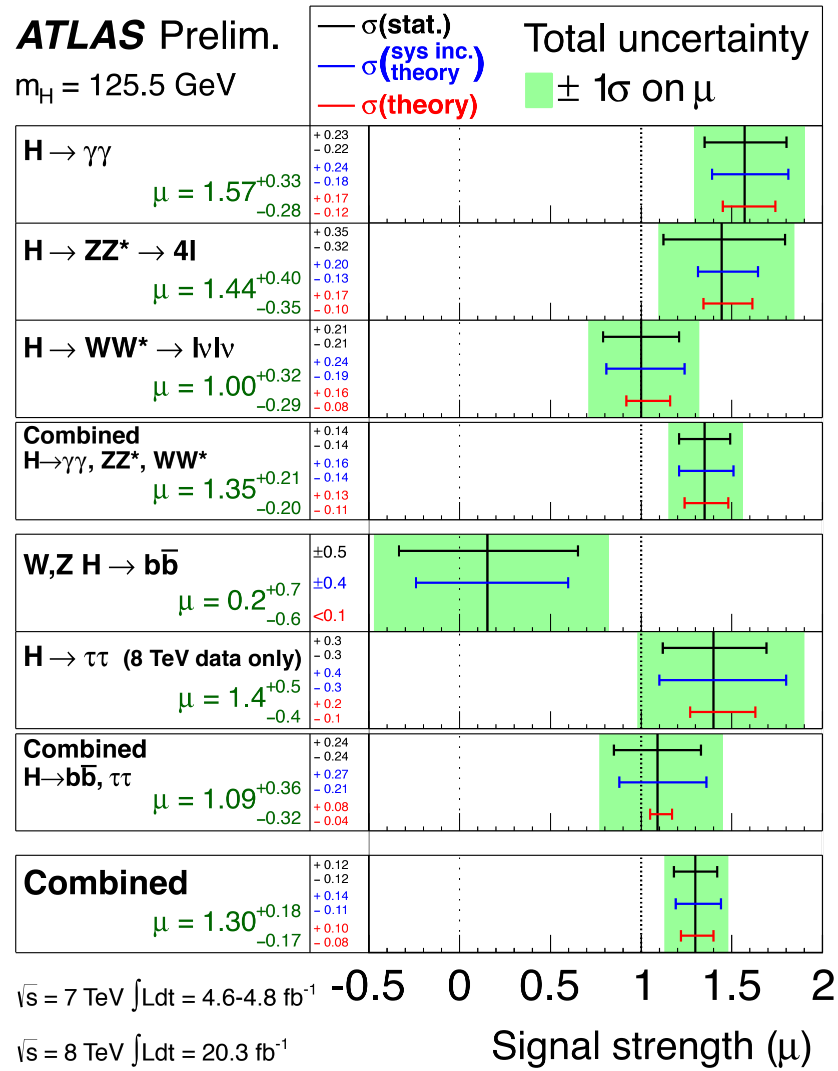
Maximum significance (3.8σ) at m_H=125 GeV measured as the probability for the background-only hypothesis to describe the data



CMS-HIG-13-032

Higgs signal strength





CMS Highlights

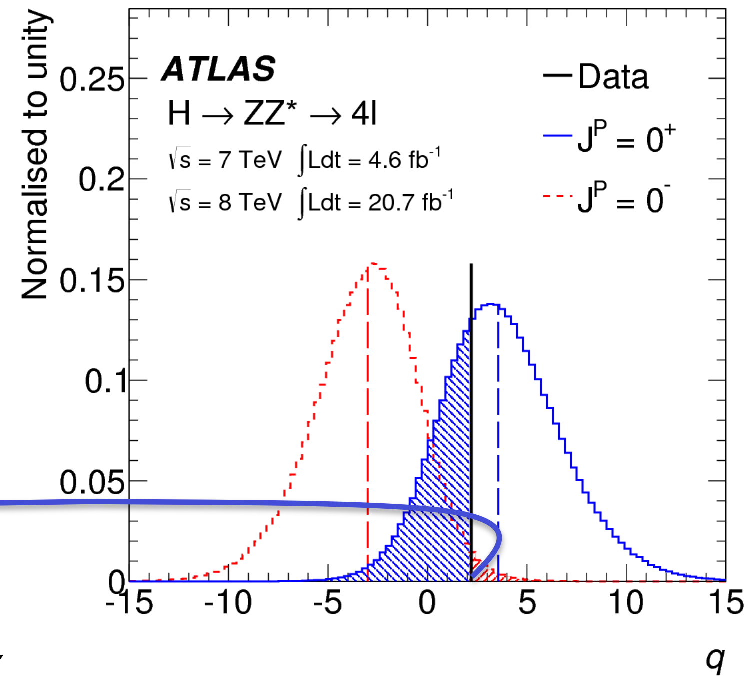
ATLAS-CONF-2014-009

Spin and parity measurement

- In the SM the Higgs boson is a spin-0 CP-even particle: $J^P = 0^+$
- Spin-1 is disfavored due to observation of $H \to \gamma\gamma$ events
  - Landau-Yang theorem forbids the direct decay of a spin-1 particle into a pair of photons
- The $J^P = 0^+$ hypothesis is tested against alternate ones, $J^P = 0^-, 1^+, 1^-, 2^+$
  - Similar likelihood and test statistic to mass measurement

$$L(\mathrm{data}|\mu,\theta) = \prod_j^{N_{chann}} \prod_i^{N_{bins}} P\left(N_{i,j}|\mu_j \cdot S_{i,j}^{(J^P)}(\theta) + B_{i,j}(\theta)\right) \times A_i(\theta)$$

$$q = log\frac{L\left(J^P = 0^+, \hat{\hat{\mu}}_0, \hat{\hat{\theta}}_0^+\right)}{L\left(J^P_{\mathrm{alt}}, \hat{\hat{\mu}}_{J^P_{\mathrm{alt}}}, \hat{\hat{\theta}}_{J^P_{\mathrm{alt}}}\right)} \qquad CL_s(J^P_{\mathrm{alt}}) = \frac{p_0(J^P_{\mathrm{alt}})}{1 - p_0(0^+)}$$

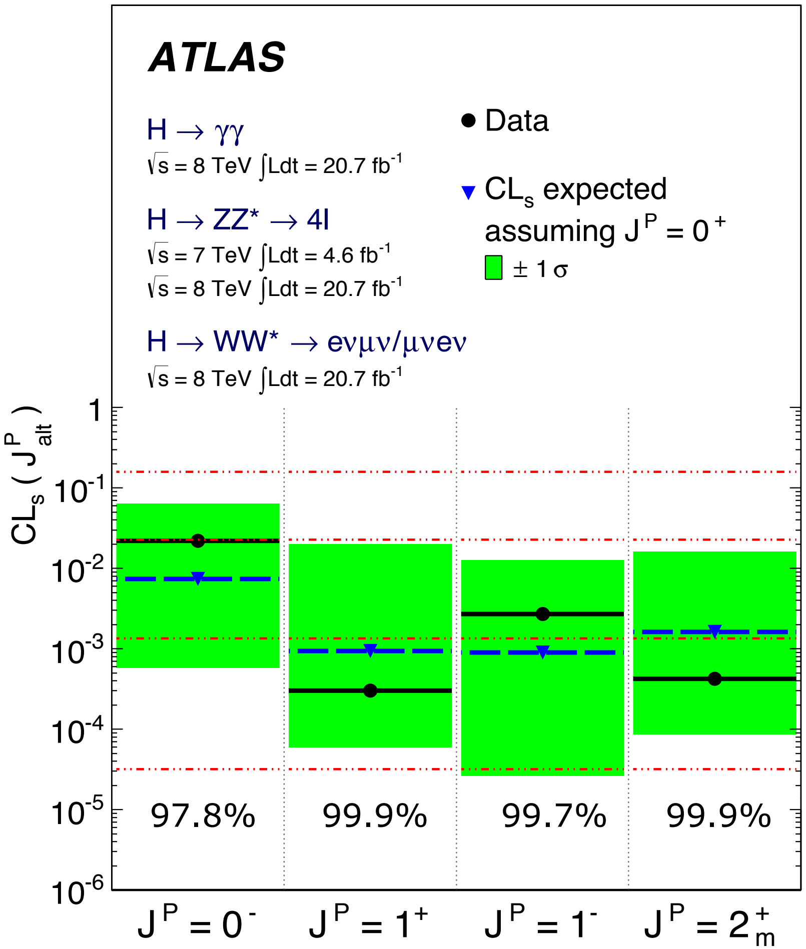


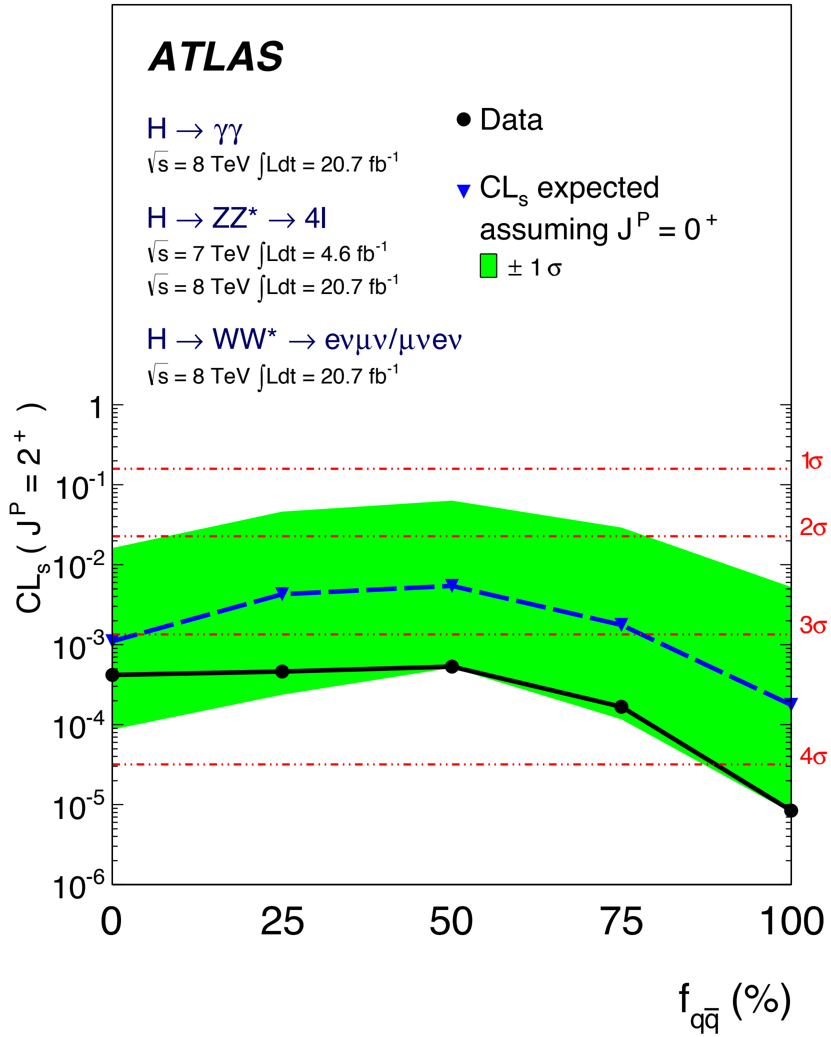
- ATLAS combines $H\to\gamma\gamma$, $H\to WW^*$, $H\to ZZ$
  - Assuming a m_H = 125.5 GeV

Phys. Lett. B 726 (2013), pp. 120-144
ATLAS-CONF-2013-040

Spin and parity measurement ATLAS

- Alternative hypothesis $J^P = 0^-, 1^+, 1^-, 2^+$ are excluded at >97%





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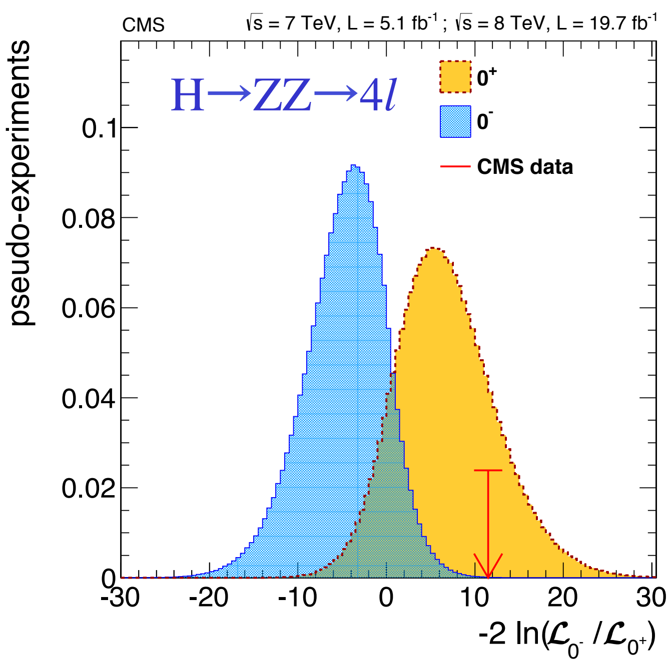
Spin and parity measurement CMS

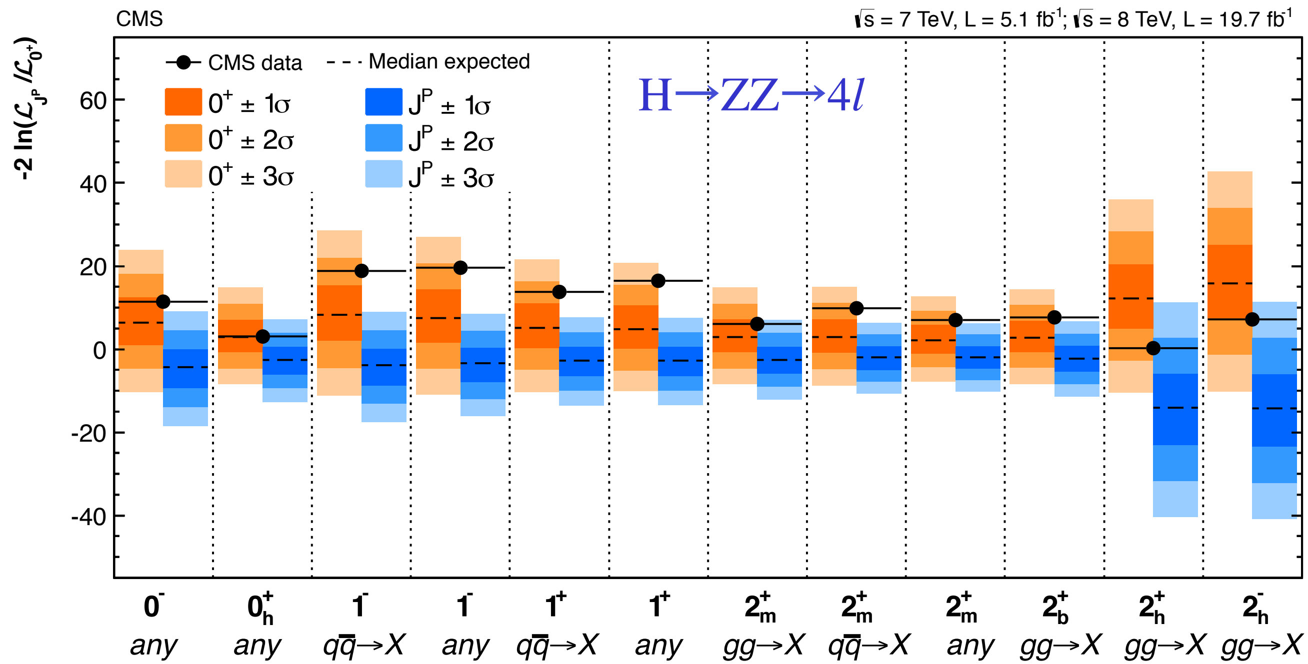
- A two-dimensional likelihood is used using discriminants
  - Four-lepton invariant mass and the separation of the Higgs boson signal from the ZZ using angular variables
  - Between the SM Higgs (0^+) and the alternative J^P hypothesis
- Results
  - Pseudo-scalar and spin-one boson are excluded at a >99%
  - Spin-two boson hypotheses are excluded at a >95%

$$\mathcal{L}_{2D}^{J^P} \equiv \mathcal{L}_{2D}^{J^P}(\mathcal{D}_{\rm bkg}, \mathcal{D}_{J^P}).$$

$$\mathcal{D}_{\rm bkg} = \left[1 + \frac{\mathcal{P}^{\rm kin}_{\rm bkg}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell}) \times \mathcal{P}^{\rm mass}_{\rm bkg}(m_{4\ell})}{\mathcal{P}^{\rm kin}_{0^+}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell}) \times \mathcal{P}^{\rm mass}_{\rm sig}(m_{4\ell}|m_{0^+})}\right]^{-1}$$

$$\mathcal{D}_{J^P} = \left[1 + \frac{\mathcal{P}^{\rm kin}_{J^P}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell})}{\mathcal{P}^{\rm kin}_{0^+}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

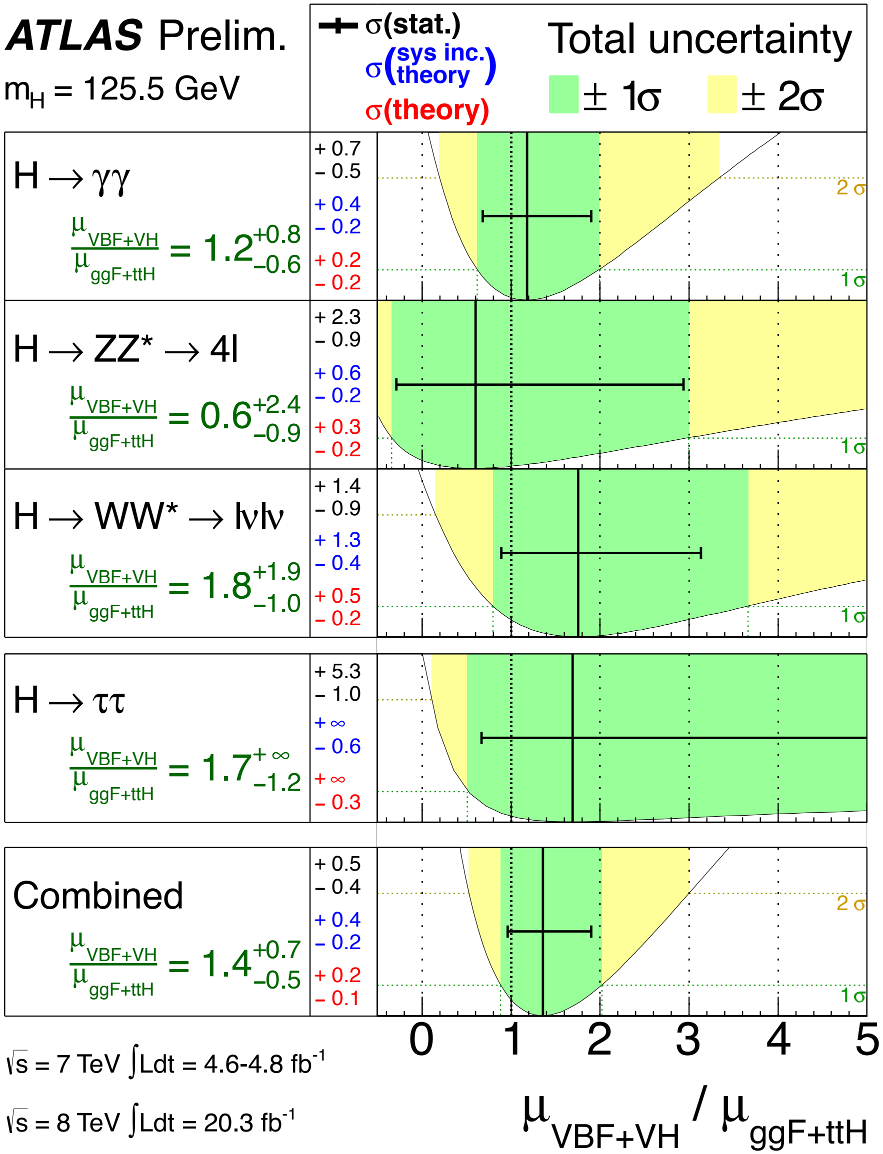




CMS-HIG-13-023

Higgs couplings

Strong VS electroweak production



- To study the couplings to fermions and bosons, we separate the signal strength for ggF or ttH ($\mu_{ggH+ttH}$) and VBF or VH production (μ_{VBF+VH})
  - Ratio probes the existence of EW production in a model independent way

$$\mu_{\mathrm{VBF+VH}}/\mu_{\mathrm{ggF}+ttH} = 1.4^{+0.5}_{-0.4}\,(\mathrm{stat})\,^{+0.4}_{-0.2}\,(\mathrm{sys}).$$

- To probe existence of VBF production alone, μ_{VH} is made independent and profiled
  - Evidence at 4.1σ of VBF production

$$\mu_{\mathrm{VBF}}/\mu_{\mathrm{ggF}+ttH} = 1.4^{+0.4}_{-0.3}\,(\mathrm{stat})\,^{+0.6}_{-0.4}\,(\mathrm{sys})$$

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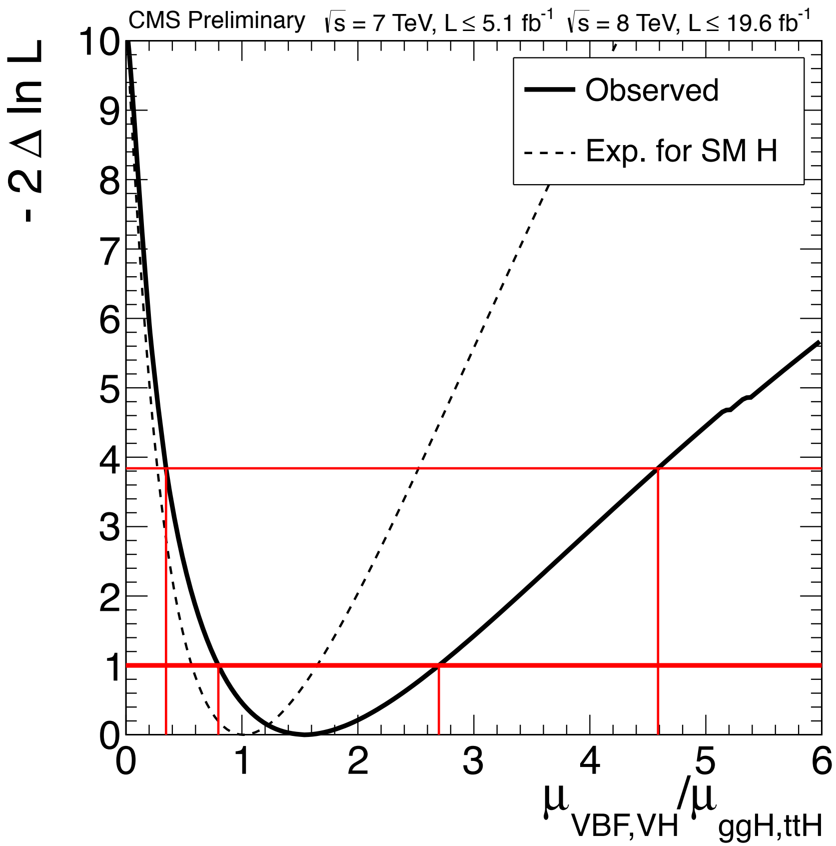
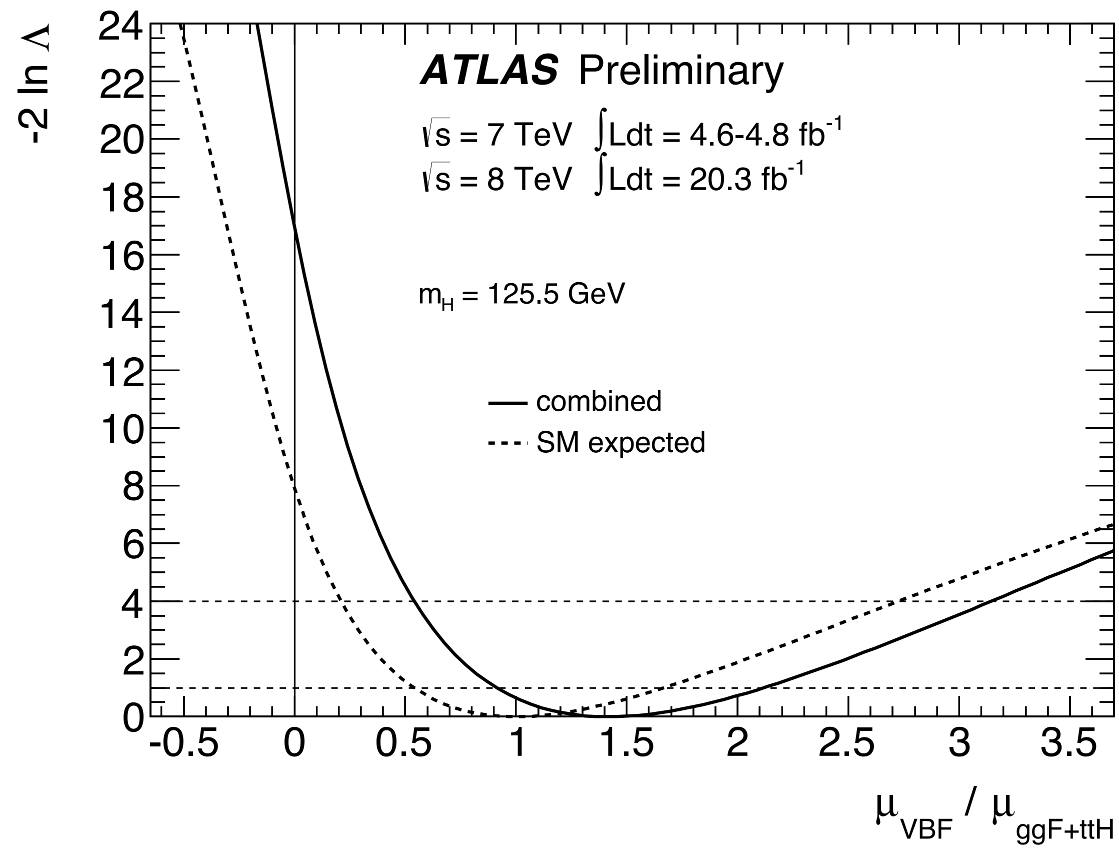
Evidence for VBF production





$$\mu_{\mathrm{VBF,VH}}/\mu_{\mathrm{ggF,ttH}} = 1.538^{+1.611}_{-0.743}$$

$$\mu_{\mathrm{VBF}}/\mu_{\mathrm{ggF}+ttH} = 1.4^{+0.4}_{-0.3}\,(\mathrm{stat})\,^{+0.6}_{-0.4}\,(\mathrm{sys})$$

- Evidence of VBF production at 3.21σ (CMS) and 4.1σ (ATLAS) against zero

CMS-PAS-HIG-13-005

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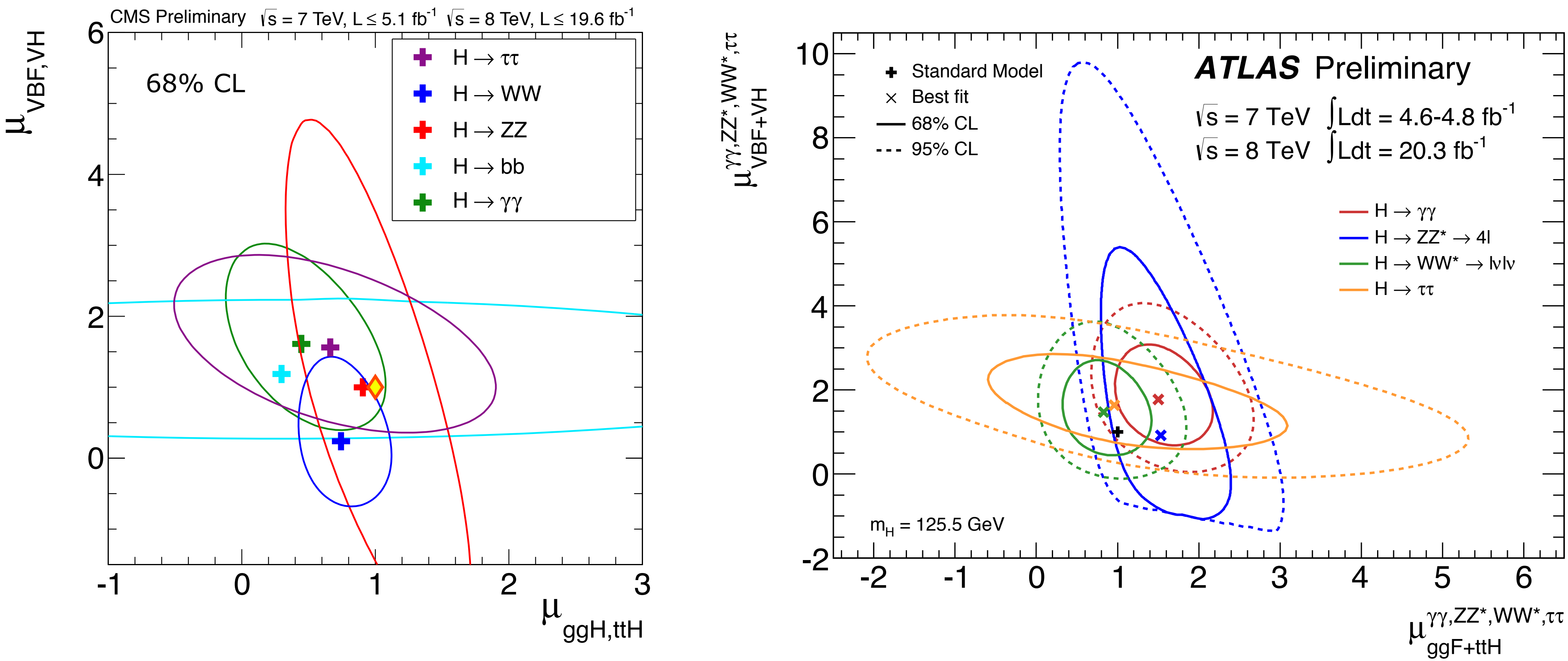
Evidence for VBF production



- SM Higgs boson point $\mu_{VBF,VH} = \mu_{ggH,ttH} = 1$ is within 1σ level of all channels

CMS-PAS-HIG-13-005

ATL-CONF-2014-009

Framework for coupling scale factor measurements

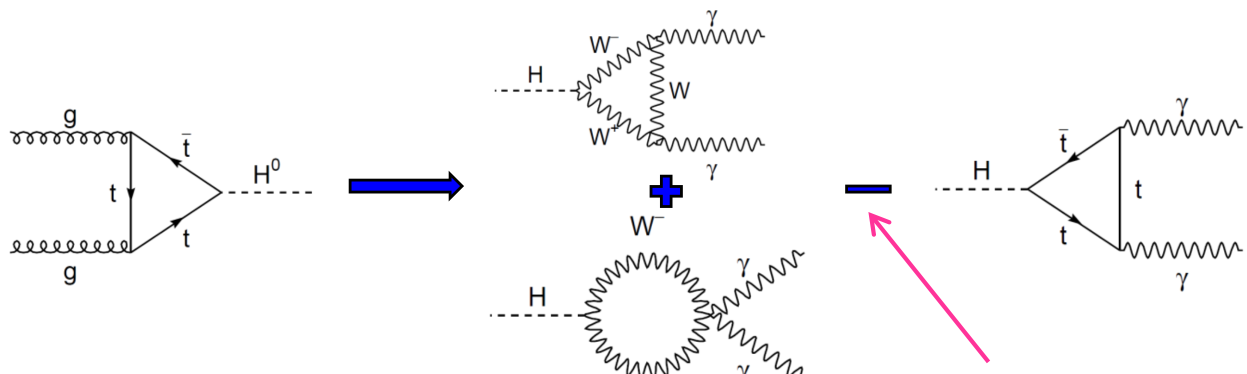
- Test SM by applying scale factors κ_i to each coupling and fitting for κ_i
  - Assume a single resonance with a mass of 125.5 GeV (ATLAS) or 125.7 GeV (CMS)
  - Zero width approximation

$$(\sigma \cdot \mathrm{BR})(gg \to H \to f) = \frac{\sigma_x \cdot \Gamma_f}{\Gamma_{\mathrm{tot}}} \qquad \Gamma_{\mathrm{tot}} = \sum \Gamma_i + \Gamma_{\mathrm{BSM}}$$

  - Test for modifications to the magnitude of the couplings
- For each final state, production and decay can involve several couplings
  - For example, with $H \to \gamma\gamma$ one can probe κ_g and κ_γ

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

Not all couplings accessible. Benchmark models defined by the LHC-XS-WG



Note: interference

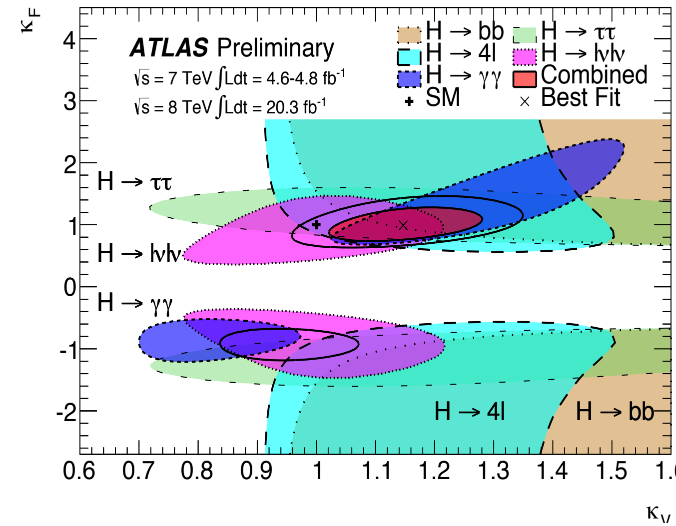
Fermion vs vector boson couplings

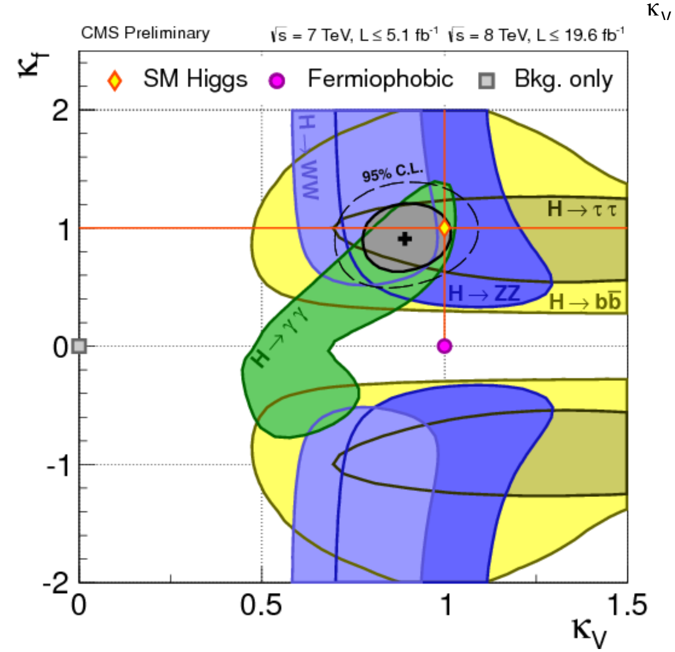
- Test the couplings to fermions and vector bosons assuming only SM particles contribute to $H \rightarrow \gamma\gamma$ and $gg \rightarrow H$ vertex loops
- **Scenario where only SM particles contribute to the total width**
  - The Fit parameters are the coupling scale factors for all fermions and for all vector bosons
  - $\kappa_V = \kappa_W = \kappa_Z$
  - $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_g$
- Measured couplings compatible with SM

$$\kappa_V = 1.15 \pm 0.08 \qquad \kappa_V \in [0.74, 1.06]$$

$$\kappa_F = 0.99^{+0.17}_{-0.15} \qquad \kappa_F \in [0.61, 1.33]$$

ATLAS CMS





Fermion vs vector boson couplings

- **Scenario with no assumption of total width**
- Parameters are the ratios of the scale factors

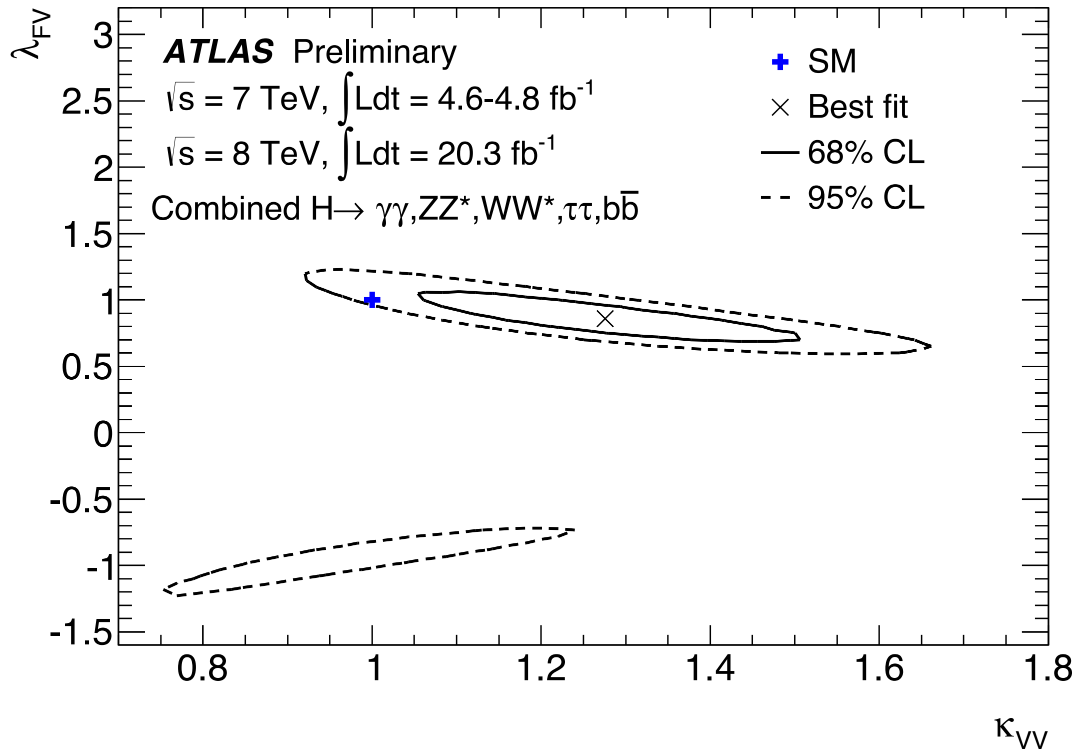
$$\lambda_{FV} = \kappa_F / \kappa_V$$

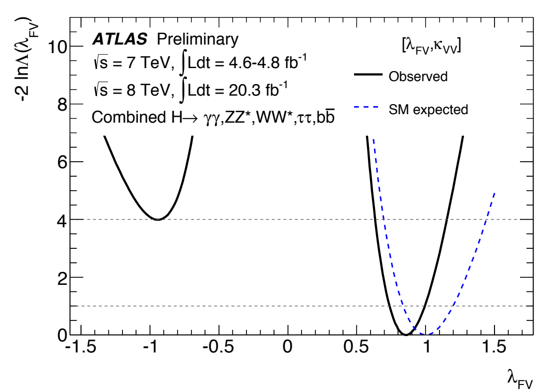
$$\kappa_{VV} = \kappa_V \cdot \kappa_V / \kappa_H$$

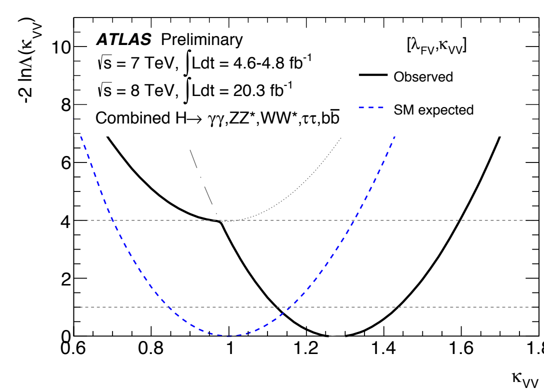
- Measurements in ATLAS consistent with large signal strength in bosonic decays

$$\lambda_{FV} = 0.86^{+0.14}_{-0.12}$$

$$\kappa_{VV} = 1.28^{+0.16}_{-0.15}$$







Custodial symmetry

- Identical coupling scale factors for the W and Z bosons are required within tight bounds by SU(2) custodial symmetry and ρ parameter measurements

$$g_{HVV} \approx m_V^2/v \qquad \rho = m_W^2/m_Z^2 \cdot cos^2\theta_W \approx 1$$

- We probe the coupling ratio of W and Z

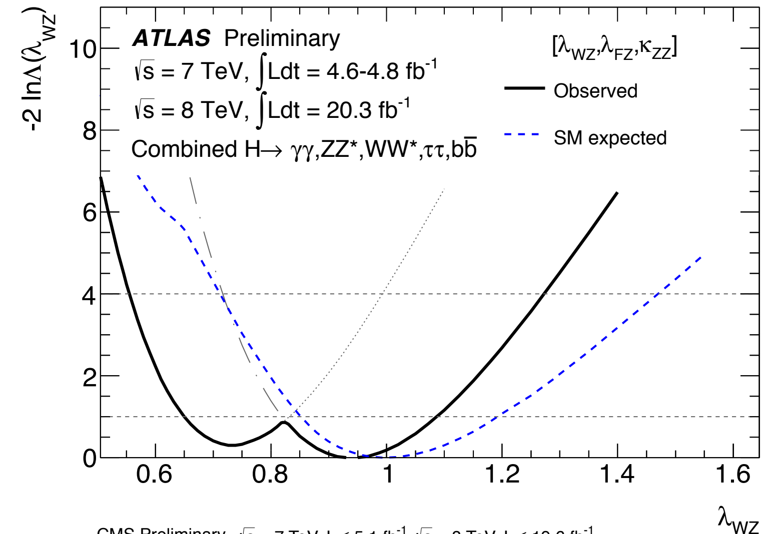
$$\lambda_{WZ} = \kappa_W/\kappa_Z$$

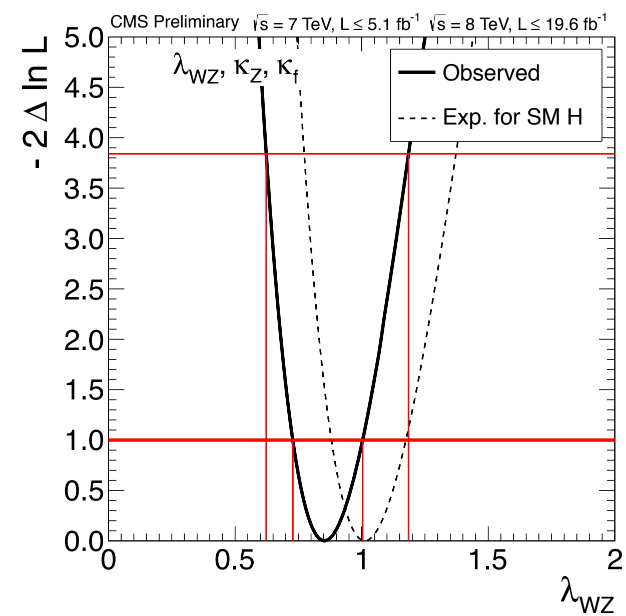
- **Assuming no BSM contributions**

$$\lambda_{WZ} = 0.94^{+0.14}_{-0.29}$$ ATLAS

$$\lambda_{WZ} \in [0.60, 1, 40]$$ CMS

- Allowing possible BSM contributions to the H→γγ loop by adding an effective scale factor ratio $\lambda_{\gamma Z}$
  - λ_{WZ} in agreement with the expectation of custodial symmetry





Up- and down-type fermion symmetry

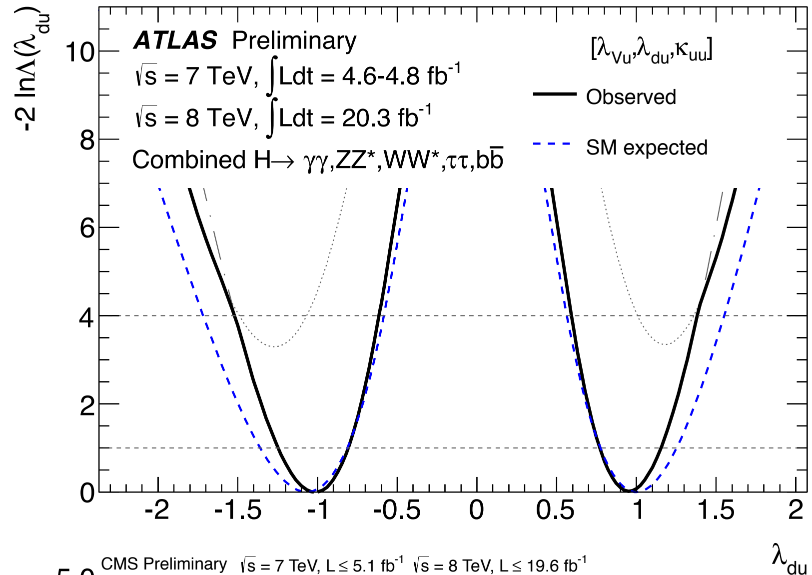
- Test for difference in couplings to up- and down-type quarks is of interest for two Higgs doublet models (MSSM-like)
- **We probe the SM with the ratio**

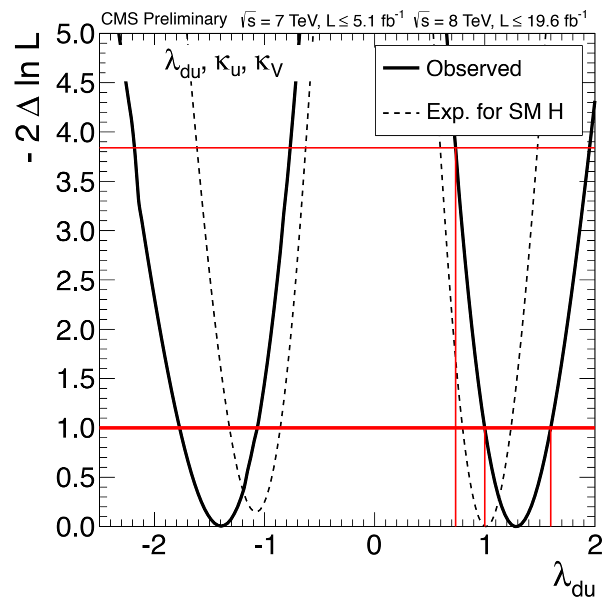
$$\lambda_{du} = \kappa_d/\kappa_u$$

- Measurements compatible with SM (λ_{du}=1) at 3.6σ level mostly coming from $\mathrm{H} \rightarrow \tau\tau$ in ATLAS

$$\lambda_{du} = 0.95^{+0.20}_{-0.18}$$ ATLAS

$$\lambda_{du} \in [0.74, 1.95]$$ CMS





Quark and lepton symmetry

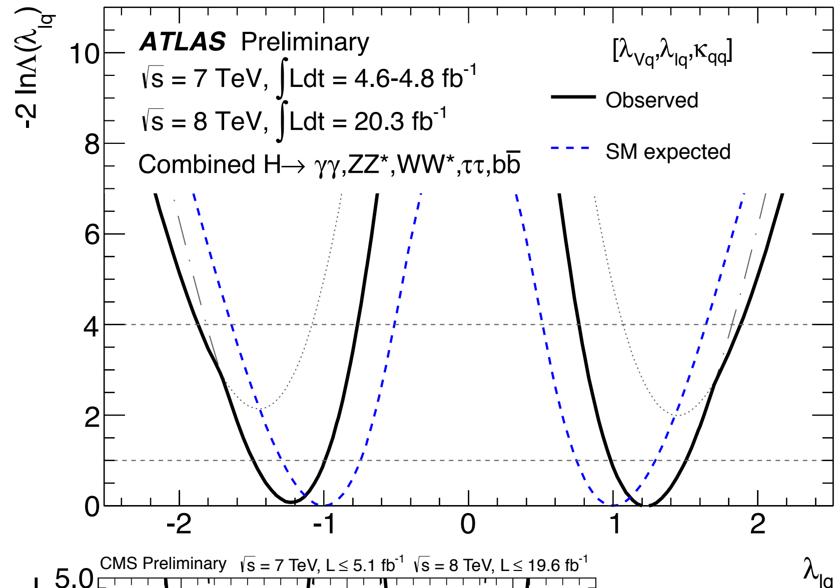
- Similar test is performed on the symmetry between the quark and lepton couplings
- **We probe the SM with the ratio**

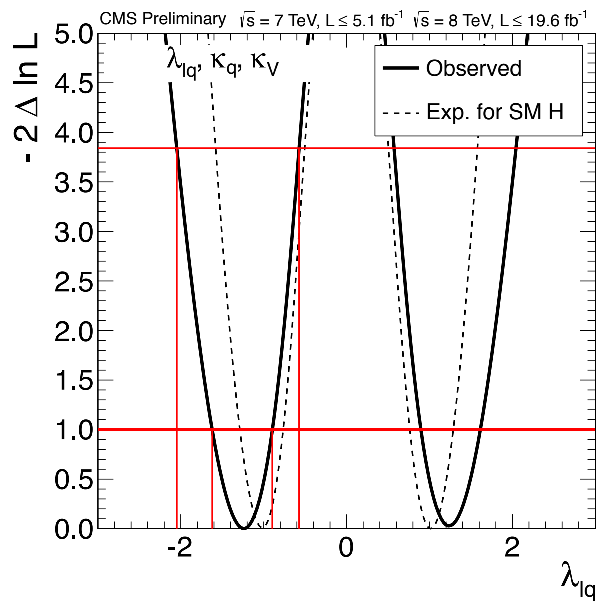
$$\lambda_{lq} \quad = \quad \kappa_l/\kappa_q$$

- Measurements compatible with SM (λ_{lq}=1) at 4.0σ level mostly coming from $\mathrm{H}\rightarrow \tau\tau$ in ATLAS

$$\lambda_{lq} = 1.22^{+0.28}_{-0.24}$$ ATLAS

$$\lambda_{lq} \in [0.57, 2.05]$$ CMS





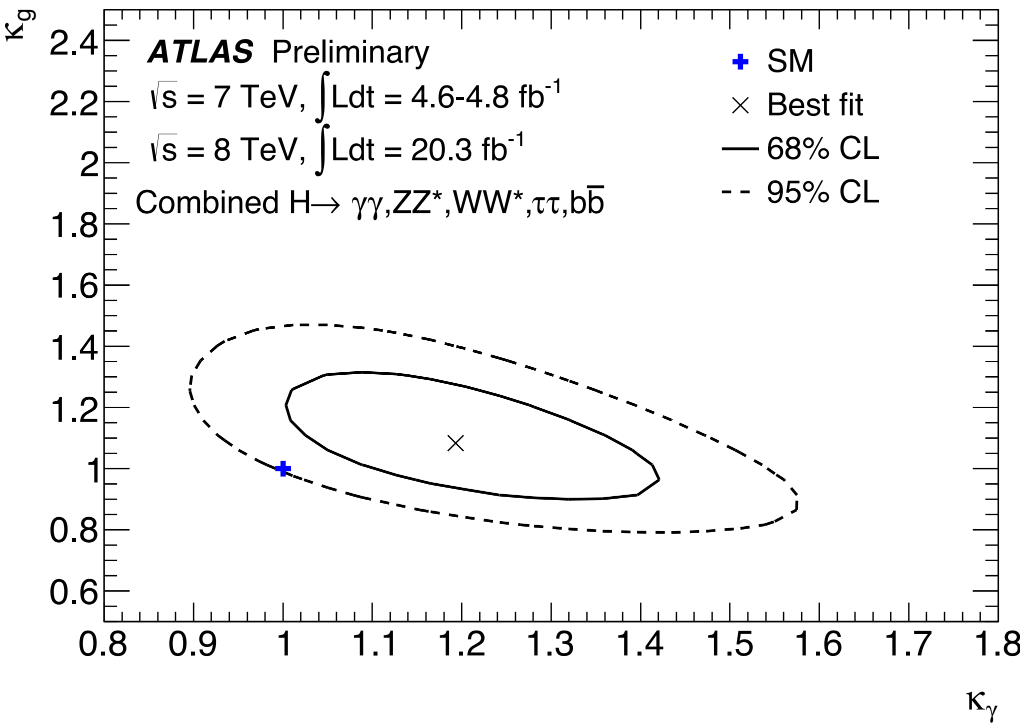
Probing BSM contribution

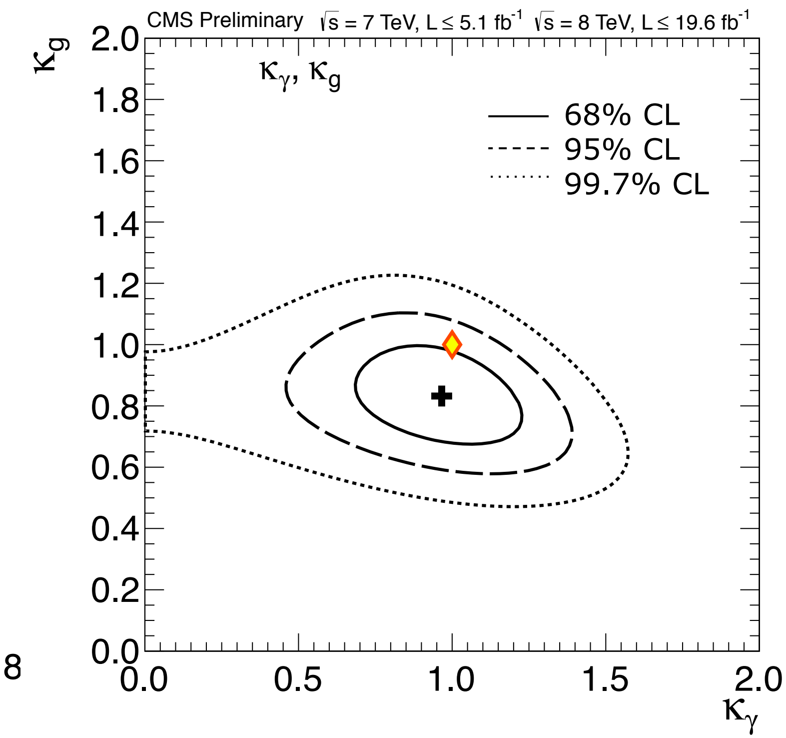
- We use Higgs loop induced processes $H \rightarrow \gamma\gamma$ and $gg \rightarrow H$ that are very sensitive to unknown heavy particles to search for BSM
- **Probe only SM particles contribute to the total width**
  - Free parameters are κ_γ and κ_g

$$\kappa_g = 1.08^{+0.15}_{-0.13} \qquad \kappa_g = 0.81^{+0.30}_{-0.20}$$
$$\kappa_\gamma = 1.19^{+0.15}_{-0.12}. \qquad \kappa_\gamma = 0.95^{+0.21}_{-0.37}$$

ATLAS CMS

~10% compatibility with SM



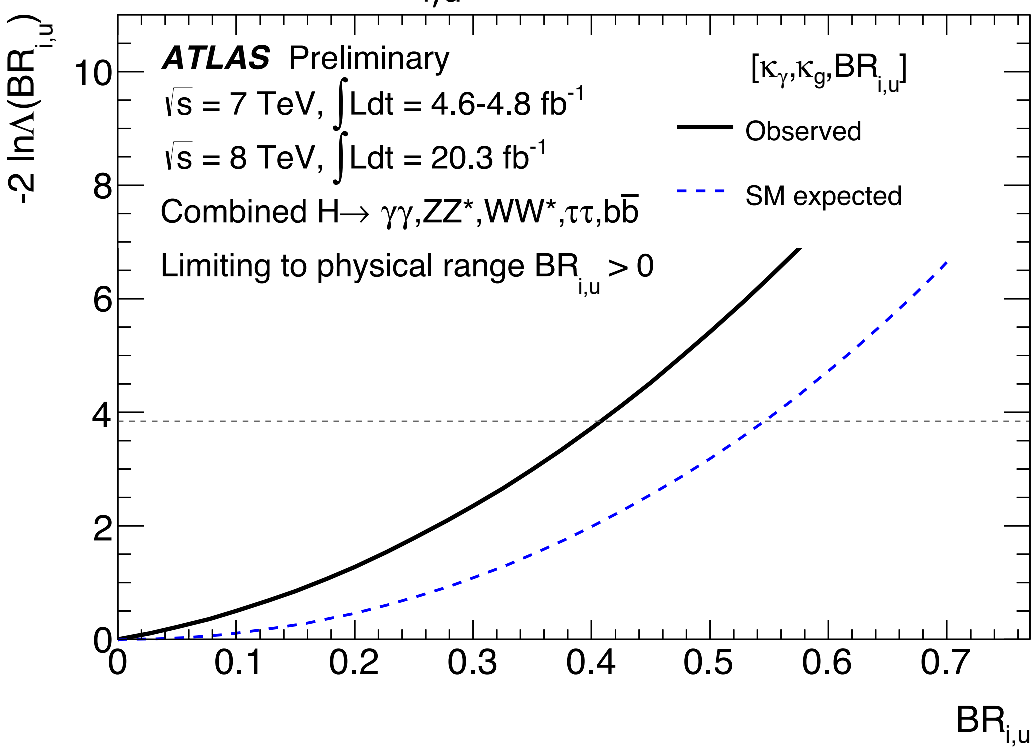


Probing BSM contribution

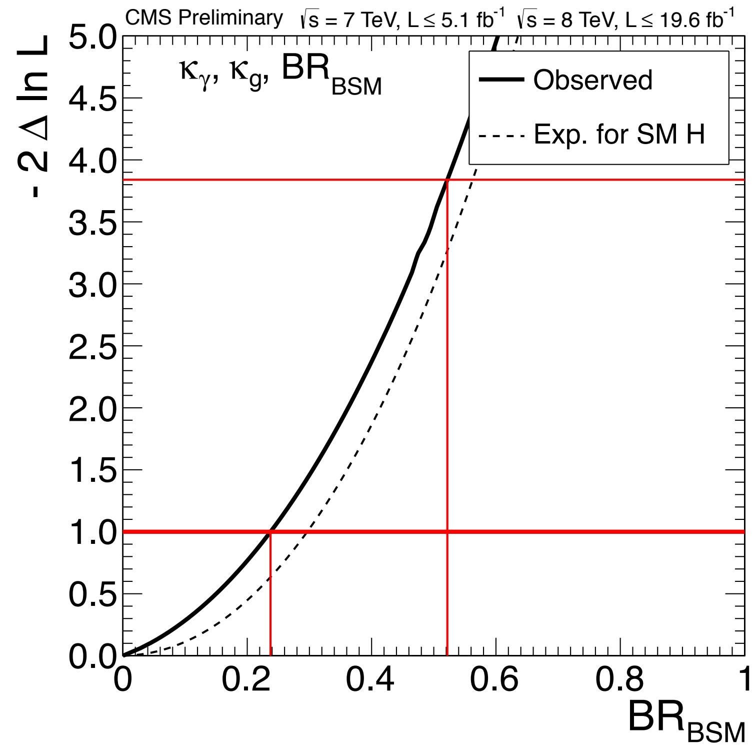
- **With unknown total width**
  - Probe invisible or undetected final states
  - Set upper limits at 95% CL on $BR_{i,u}$
  - Later can be interpreted in the frame of Dark Matter searches

$$BR_{i,u} = \Gamma_{i,u}/\Gamma_H = 1 - \frac{\kappa_H^2 \cdot \Gamma_H^{SM}}{\Gamma_H}$$

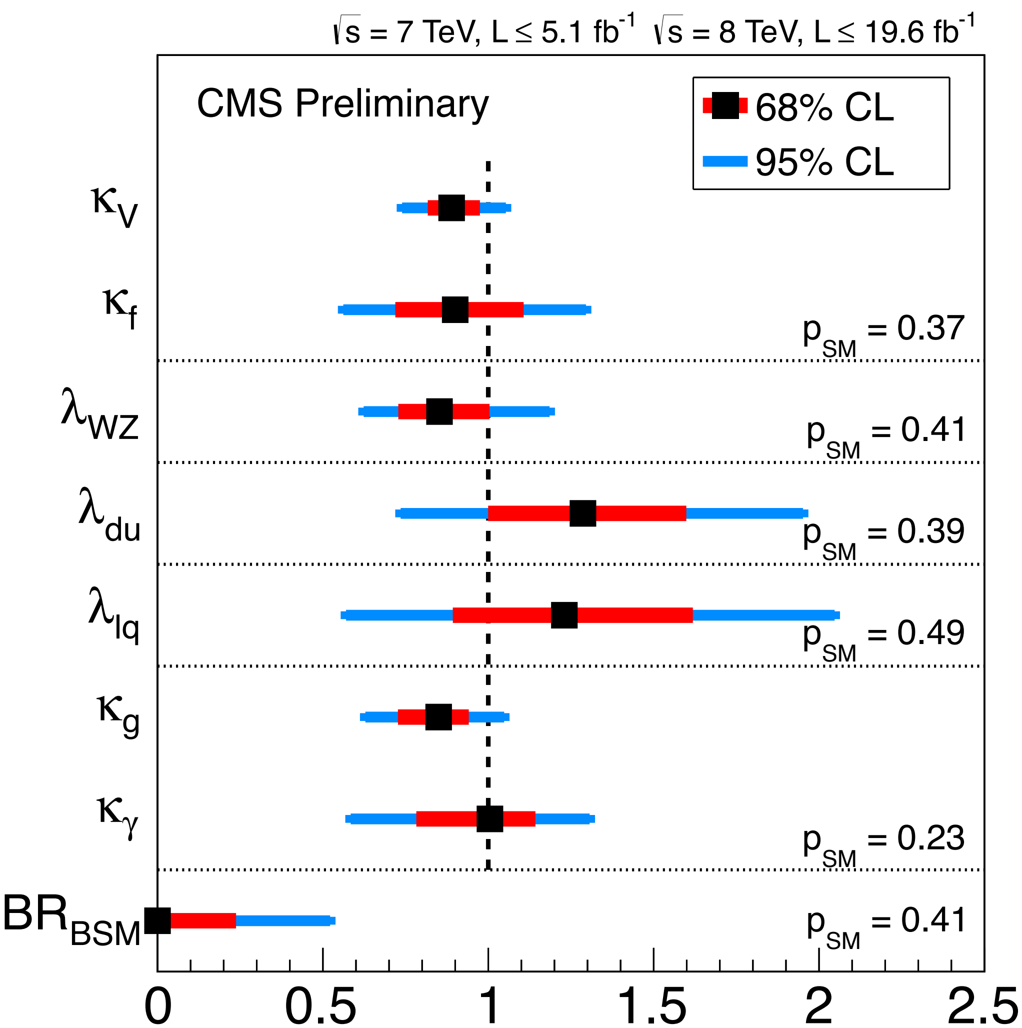
$BR_{i,u} < 0.41$ ATLAS



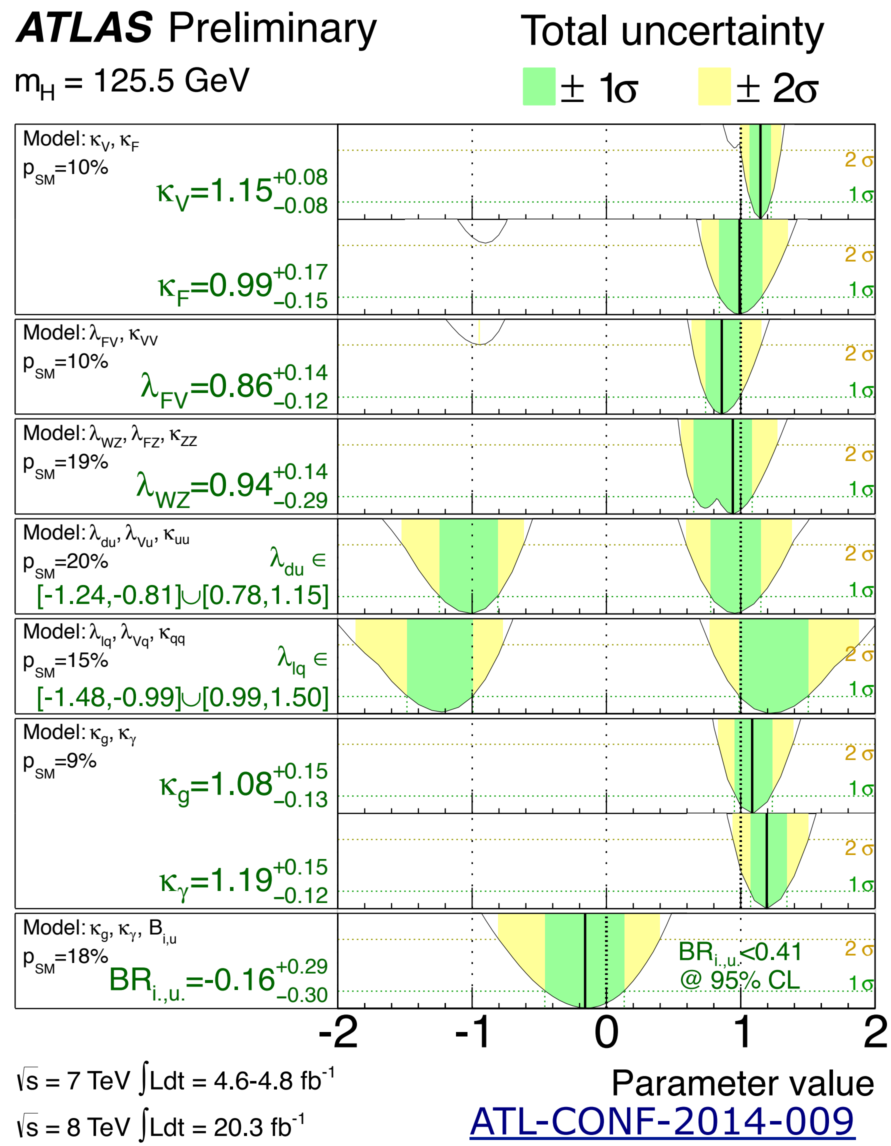
$BR_{BSM} < 0.52$ CMS



Higgs couplings for benchmark models



CMS-PAS-HIG-13-005



ATL-CONF-2014-009

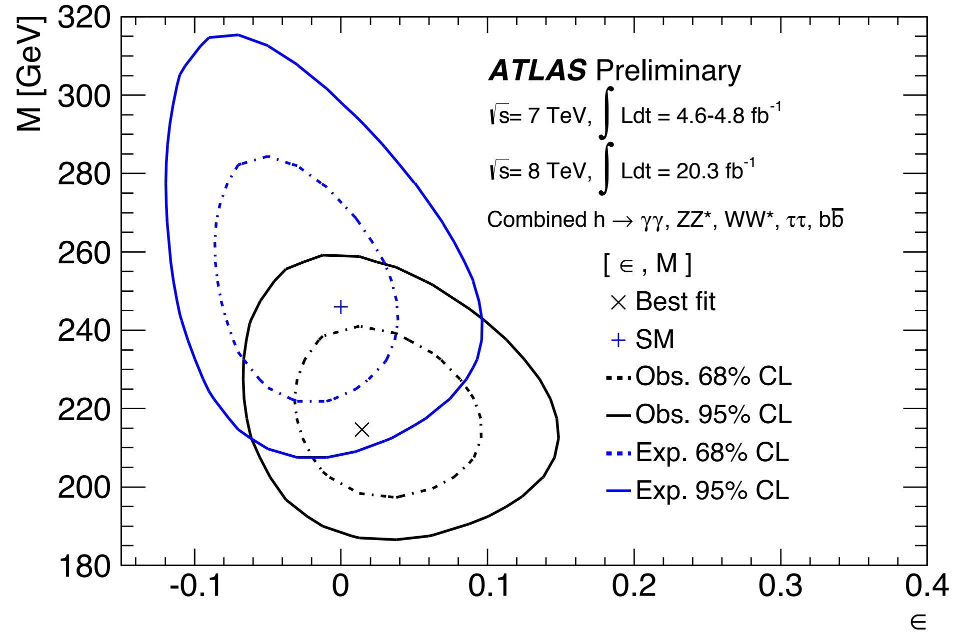
Limits on new physics

Mass scaling of couplings

- The coupling scale factors to different species of fermions and vector bosons can be expressed in terms of ε (mass scaling parameter) and *M* (vacuum expectation value)
  - SM is recovered at ε=0 and *M*=246 GeV

$$\kappa_{f,i} = v\frac{m_{f,i}^{\epsilon}}{M^{1+\epsilon}} \quad \kappa_{V,j} = v\frac{m_{V,j}^{2\epsilon}}{M^{1+2\epsilon}}$$

- Combined fits to measured rates are performed as a function of ε and *M*
  - Modifying production and decay rates accordingly assuming the narrow width approximation



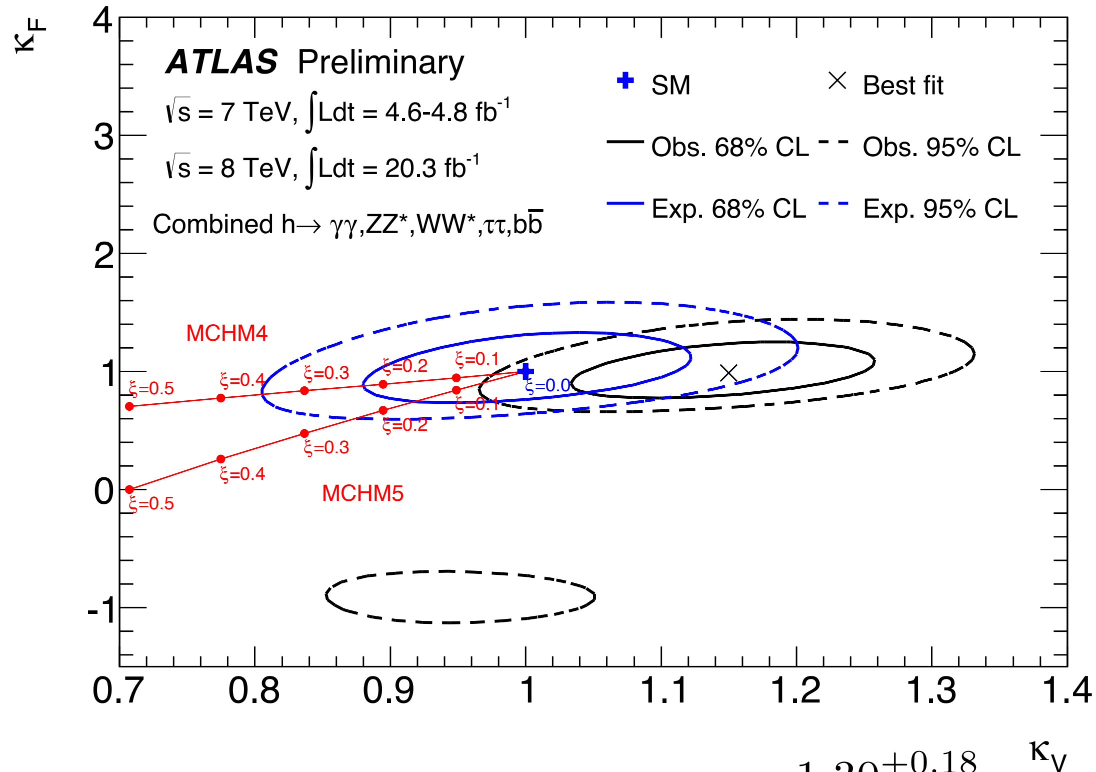
The best-fit point is compatible with the expectation for the SM Higgs boson within approximately 1.5σ

Best-fit of *M*<246 GeV due to μ_h>1

ATL-CONF-2014-010
arXiv:1303.3879

Minimal Composite Higgs Model

- If the Higgs were a composite particle the couplings to fermions and vector bosons would be modified by its compositeness scale, f
  - Scaling parameter $\xi = v^2/f^2$
  - SM recovered in $\xi \to 0$



- MCHM4 $f > 710$ GeV
  - Couplings: $\kappa = \kappa_V = \kappa_F = \sqrt{1-\xi}$,
  - Observed: $\xi = 1 - \mu_h = -0.30^{+0.17}_{-0.18}$
- MCHM5 $f > 640$ GeV
  - Couplings: $\kappa_V = \sqrt{1-\xi}$ $\kappa_F = \dfrac{1-2\xi}{\sqrt{1-\xi}}$
  - Observed : $\xi = -0.08^{+0.11}_{-0.16}$

$$\mu_h = 1.30^{+0.18}_{-0.17}$$

$$\kappa = \sqrt{\mu_h} = 1.14^{+0.09}_{-0.08}$$

$$\kappa_V = 1.15 \pm 0.08$$

$$\kappa_F = 0.99^{+0.17}_{-0.15}$$

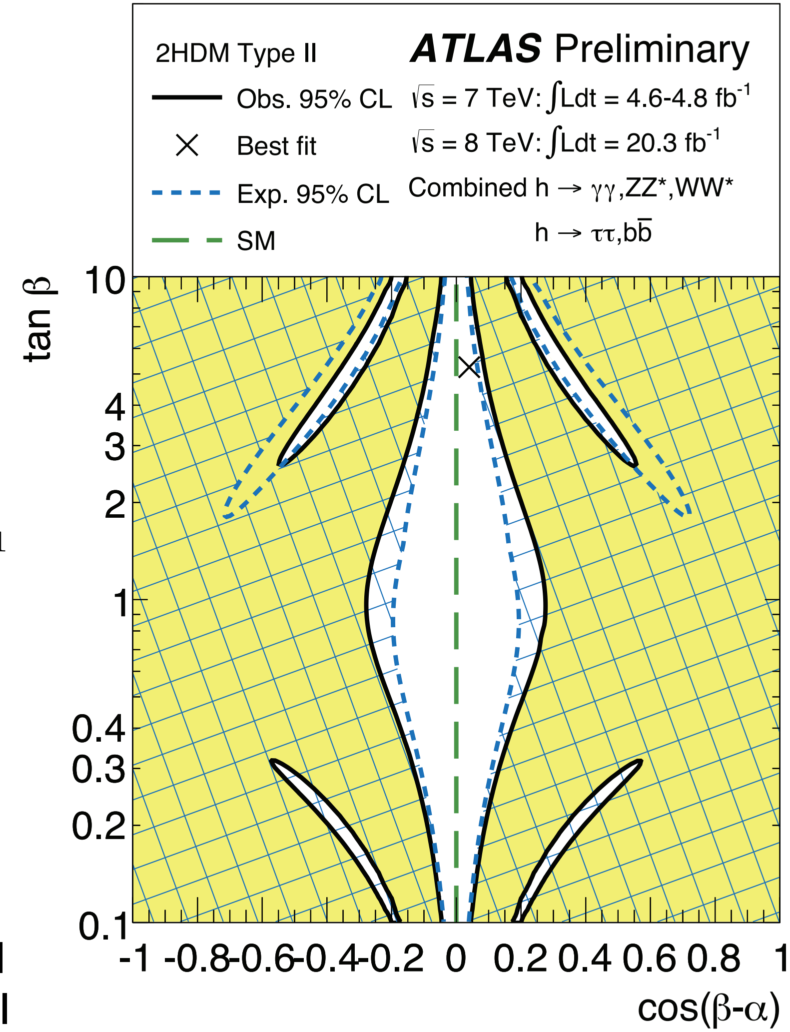
ATL-CONF-2014-010

Two Higgs Doublet Model

- In the 2HDM the SM Higgs sector is extended by an additional doublet predicting existence of five Higgs bosons
  - Two neutral CP-even (h, H), one neutral CP-odd (A), two charged bosons ($H^{\pm}$)
  - Each doublet has expectation value:

$$v_1^2 + v_2^2 = v^2 \approx (246\ \text{GeV})^2$$

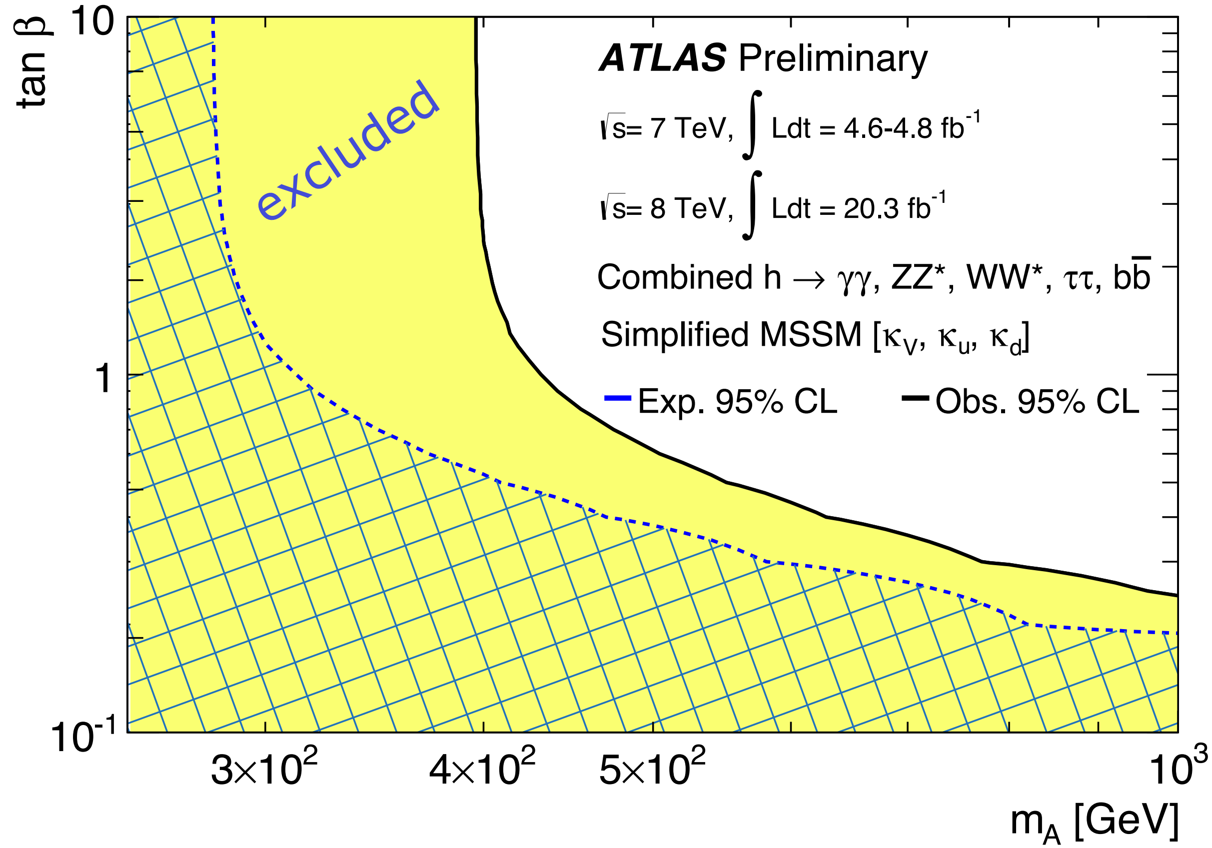
- Described by six parameters
  - Four boson masses: $m_h, m_H, m_A, m_{H^\pm}$
  - Mixing angle of the two neutral CP-even states: α
  - Ratio of the two vacuum expectation values: $\tan\beta \equiv v_2/v_1$
- Coupling of the two neutral CP-even Higgs to vector bosons fixed by gauge invariance
- Four types of 2HDM
  - Type I: one couples to vector bosons, other couples to fermions
  - **Type II: one couples to up-type quarks, the other couples to down-type quarks and leptons (MSSM-like)**
  - Type III: couples to quarks as type I, and leptons as type II
  - Type IV: couples to leptons as type I, and quarks as type II



ATL-CONF-2014-010

Simplified MSSM model

- 2HDM Type II results can be interpreted in a simplified MSSM model where couplings to vector bosons, up-type fermions and down type fermions are completely determined by m_A and tanβ
  - **Loop corrections from stops in ggF production and $\gamma\gamma$ decays are ignored**
  - Higgs boson decays to super-symmetric particles are neglected
  - SM couplings are turn cast in terms of m_A and tanβ
- Observed limit is stronger than expected since measured rates in $H \to \gamma\gamma$ and $H \to ZZ^* \to 4l$ are higher than predicted

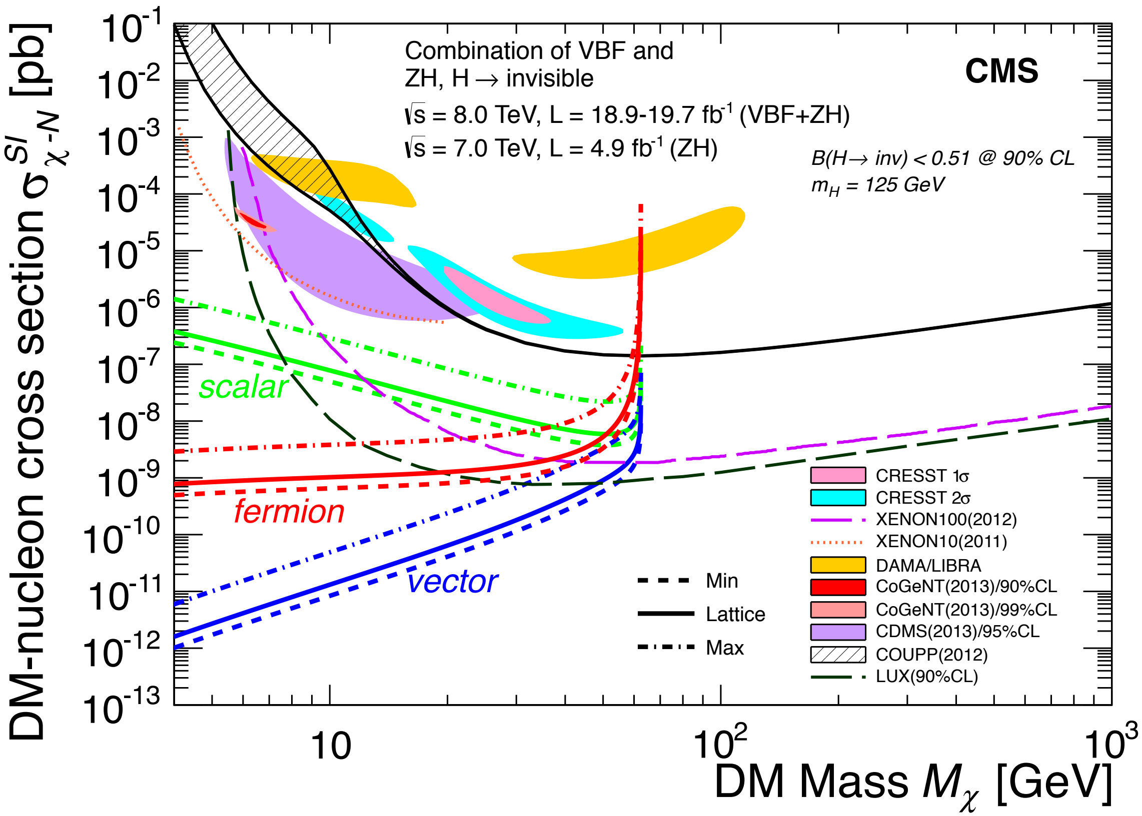


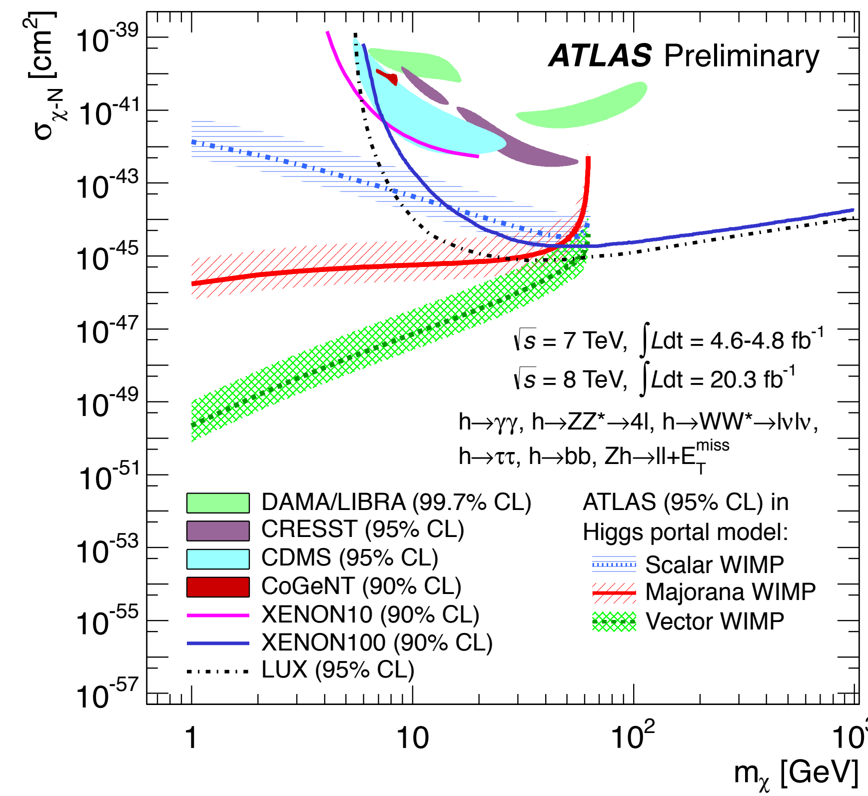
Observed (expected) exclusion limit at 95% CL $m_A > 400$ (280) GeV for $2 \leq \tan\beta \leq 10$

ATL-CONF-2014-010

Dark matter nucleon cross section

- Interpret the upper limit on $BR_{i,u}$ under the assumption of SM cross section, in the context of a Higgs portal model of Dark Matter (DM) interactions
- DM-nucleon elastic cross section for scalar, Majorana fermion or vector boson WIMP
  - Considerably more stringent at low mass and degrade as *m* approaches $m_h/2$





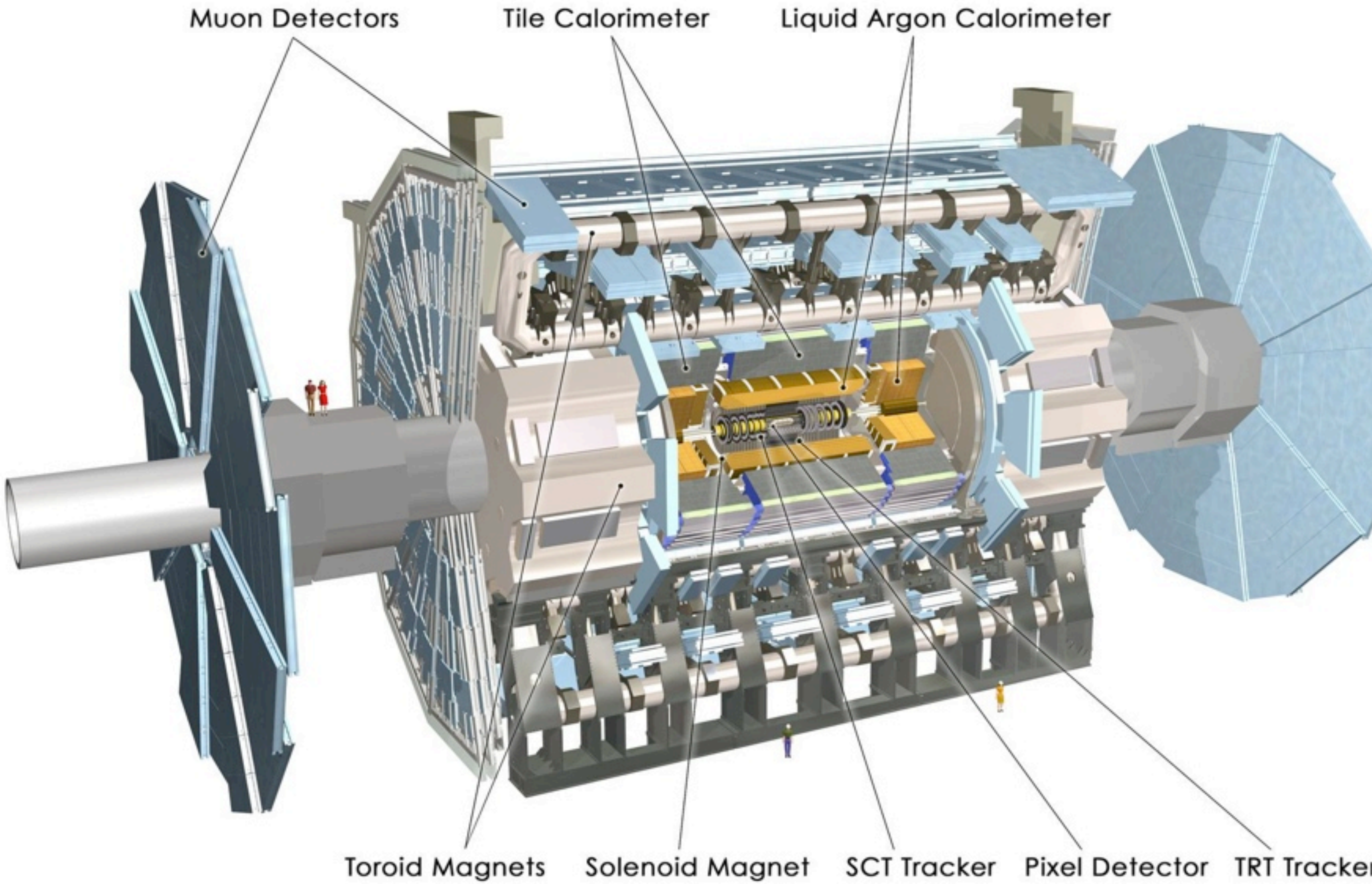
CMS-HIG-13-030 ATL-CONF-2014-010

Conclusions

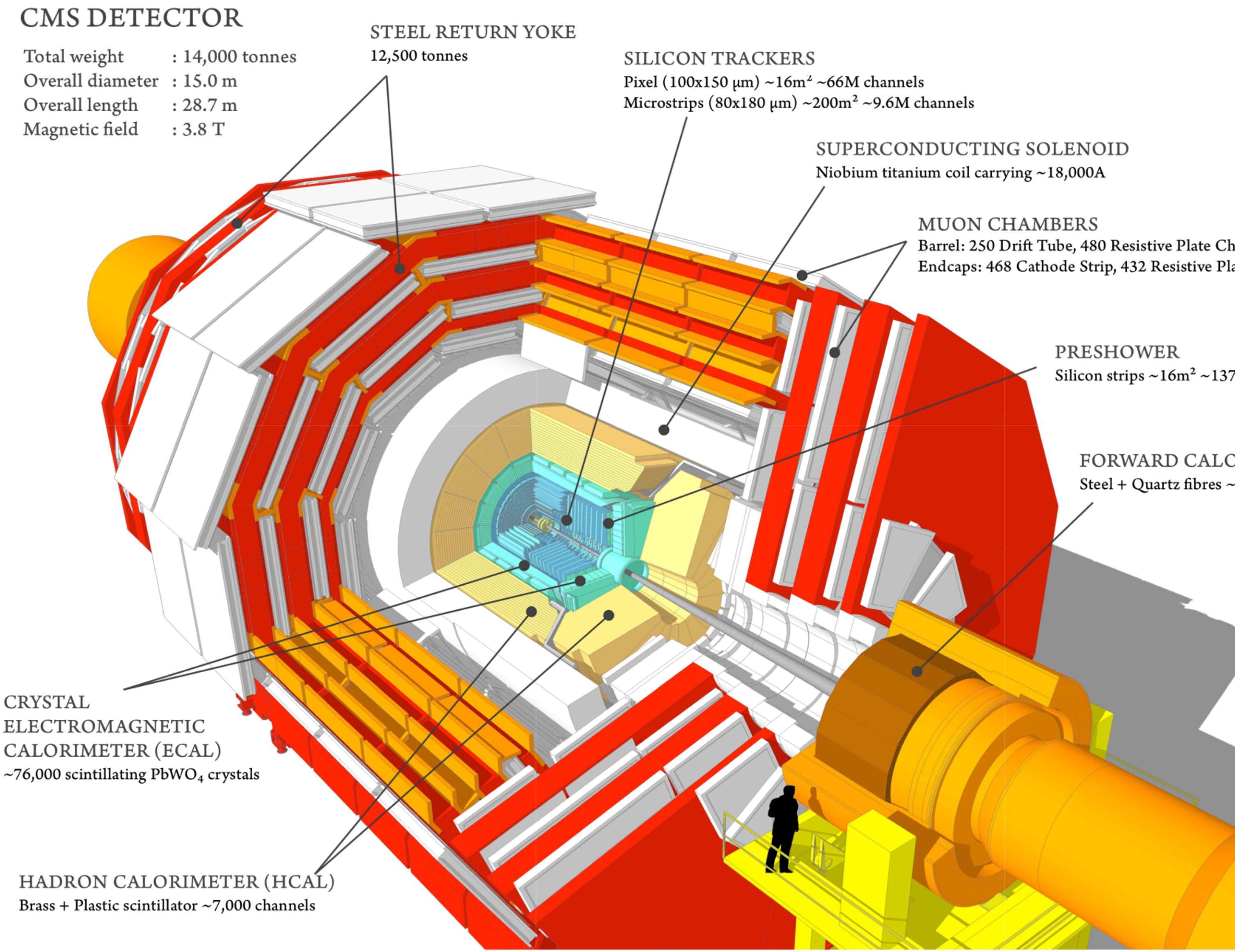
- The full Higgs physics potential of the LHC Run-I is almost exploited
- ATLAS and CMS discovered a Higgs like particle with mass compatible with 125 GeV
- Spin, parity and signal strength measurements compatible with SM Higgs boson ($J^P=0^+$, $\mu_{VBF+VH} = \mu_{ggH+ttH} = 1$)
- Differences up to 10% of the coupling scale factors and overall compatibility with SM predictions
- Run-II and beyond will offer the potential to more precisely measure couplings, further constrain rare decays, and determine a possible CP admixture

Backup

ATLAS experiments



CMS detector



Basic statistical procedure

- Construct a likelihood from Poisson probabilities with a parameter of interest (signal strength in this case)

$$L(\text{data}|\mu,\theta) = \text{Poisson}\left(\text{data}|\mu \cdot s\left(\theta\right) + b\left(\theta\right)\right) \times p(\tilde{\theta}|\theta)$$

μ:Signal strength θ:"nuisance" parameters

- Hypothesized value of mu is tested with a test statistic

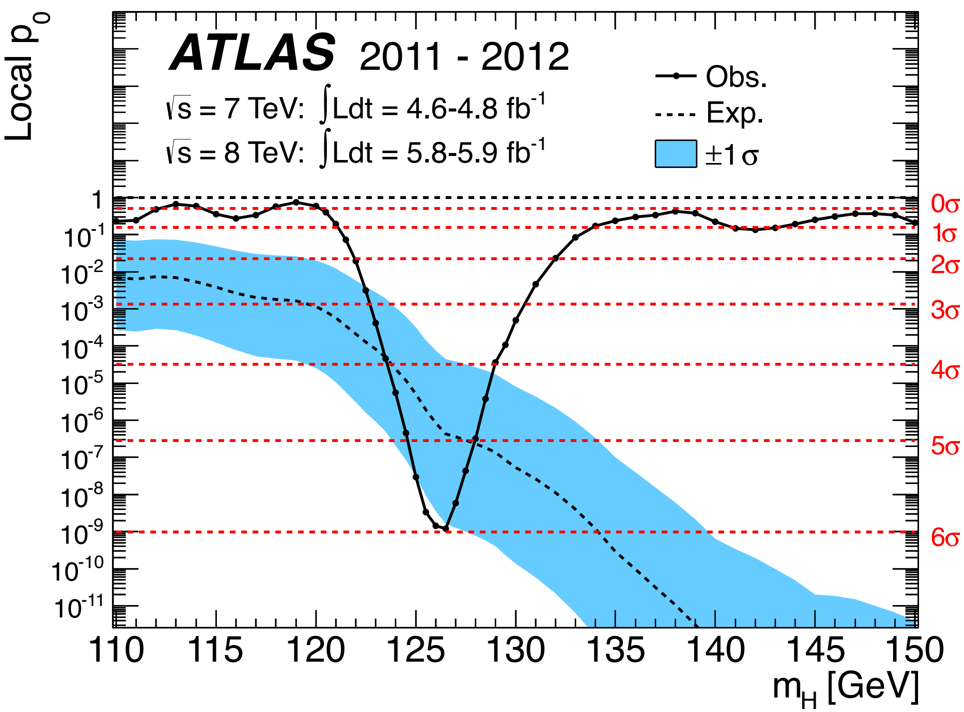
$$q_{\mu} = -2ln\Lambda(\mu) = -2ln\left[\frac{L\left(\mu,\hat{\hat{\theta}}(\mu)\right)}{L\left(\hat{\mu},\hat{\theta}(\mu)\right)}\right]$$

- Systematic uncertainties are included as nuisance parameters constrained by chosen pdfs (Gaussian, log-normal, …)
- Combination amounts to taking product of likelihoods from different channels

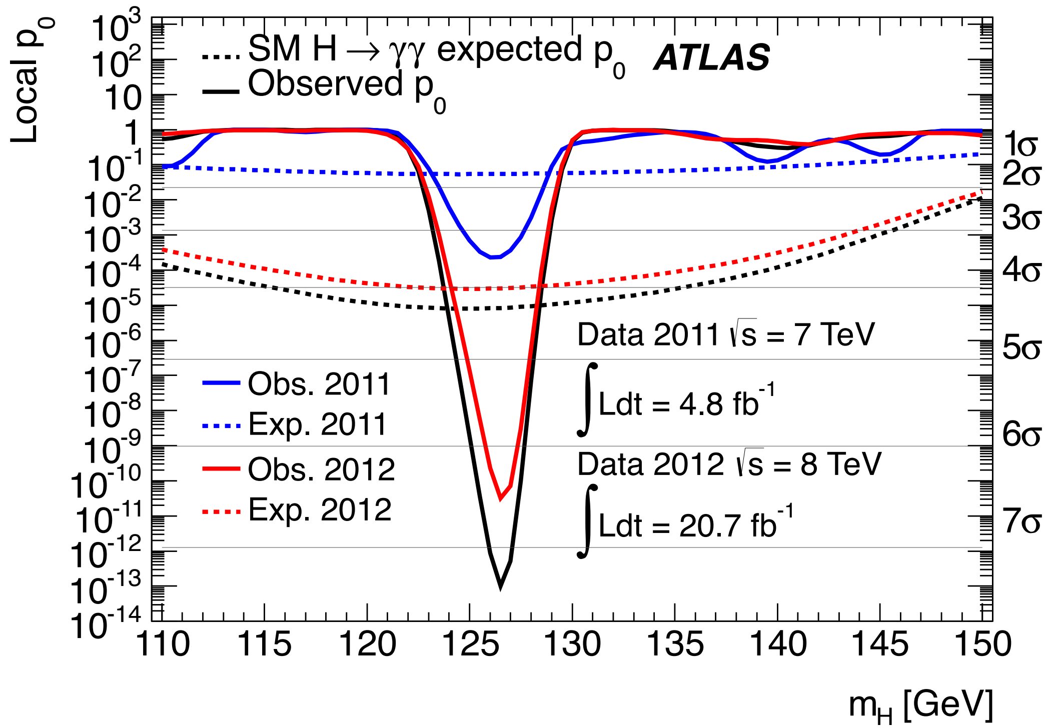
$$L(\text{data}|\mu,\theta) = \prod_i L_i(\text{data}_i|\mu,\theta_i)$$

arXiv:1007.1727

Higgs discovery



Phys. Lett. B 716 (2012) 1-29



Phys. Lett. B 726 (2013), pp. 88-119