Combination of Higgs properties at ATLAS and CMS

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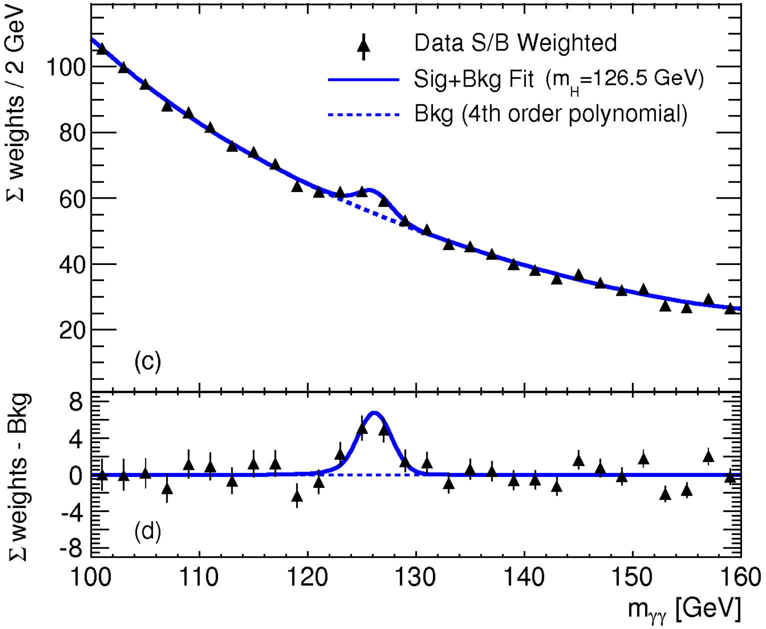
Tohoku University, Sendai, Japan

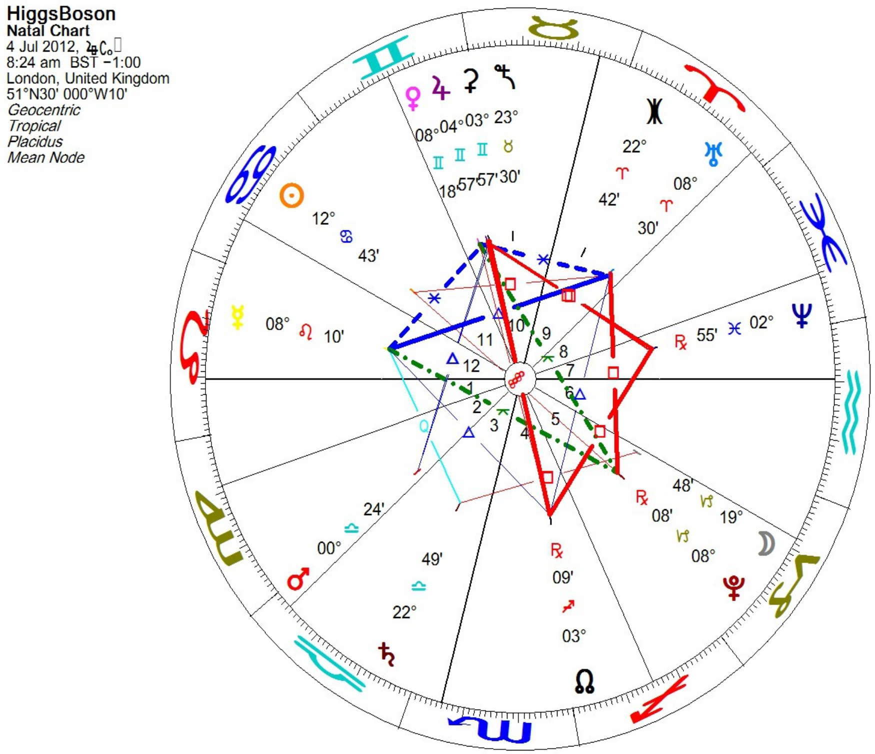
Outline

- Introduction and methodology
- Mass measurement
- Couplings
- Spin-parity discrimination

Focus on results obtained from combination of different channels.
Details on individual analyses in summaries and specific talks.

Thanks to A. David, G. Petrucciani, O.Davignon and H. Wang
for comments and help in preparing this talk.





A quest started 50 years ago...

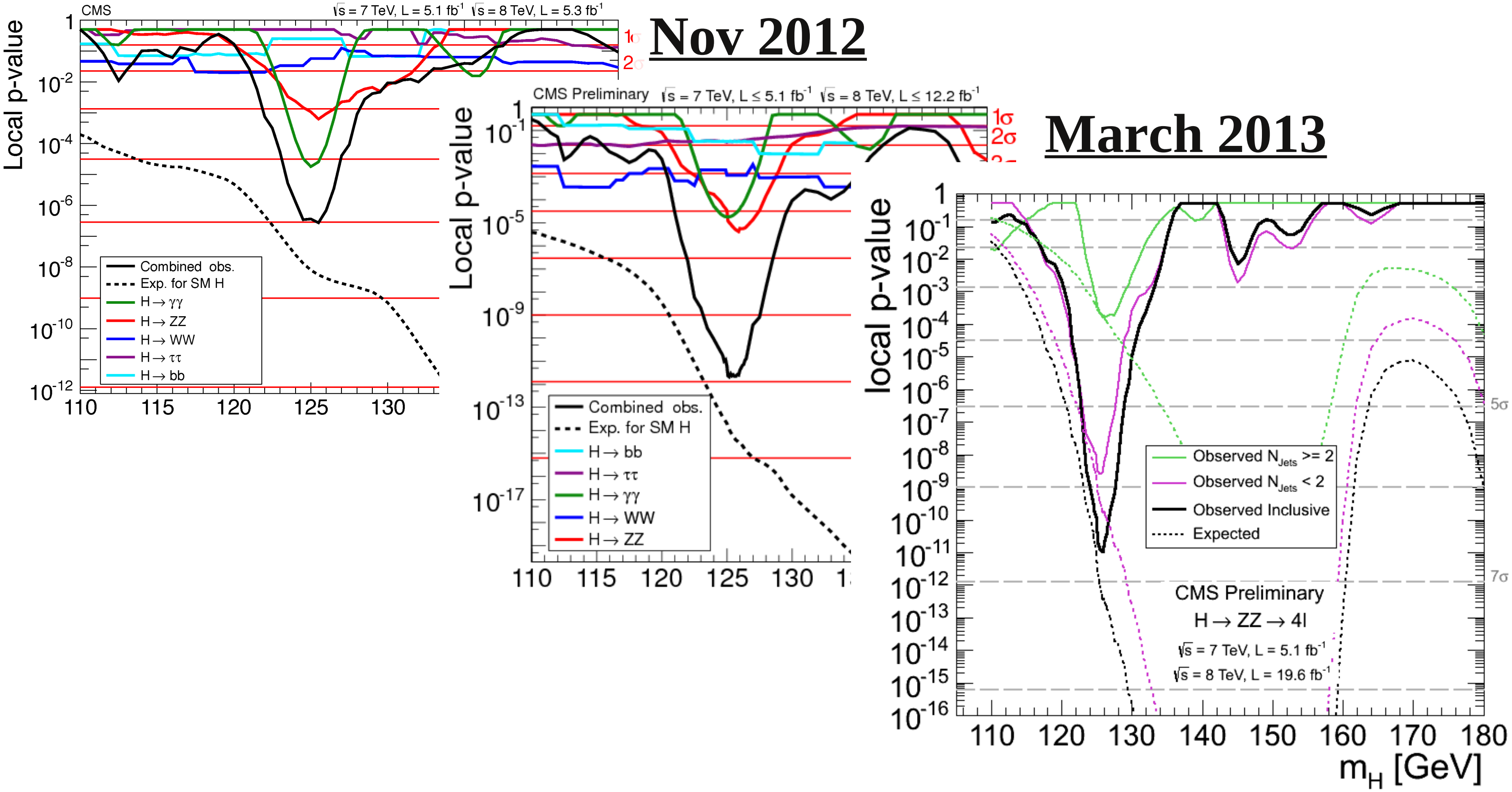
July 4th 2012: announcement of discovery

The fun is just started !

July 4th 2012

Nov 2012

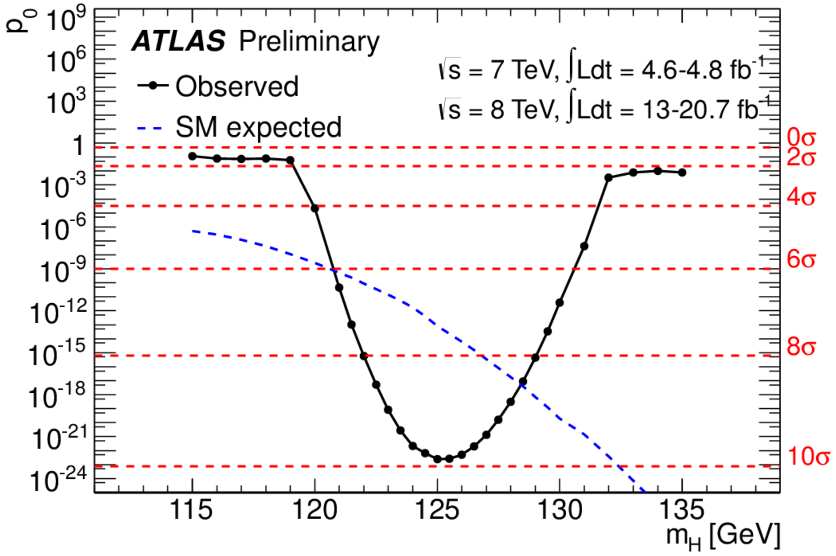
March 2013



As data accumulated, the evidences of a new boson with mass ~125 GeV reinforced.
Discovery from individual channels now !

Significance of excess from combination of channels
~10σ for both ATLAS and CMS .
“Discovery” by individual channels, HZZ and Hγγ

	Obs. significance (exp.)	
	ATLAS	CMS
H → ZZ → 4ℓ	**6.6 σ** (4.4σ)	**6.7 σ** (7.1σ)
H → γγ	**7.4 σ** (4.1σ)	3.9 σ (4.2σ)
H → WW → ℓνℓν	2.5 σ (1.6σ)	3.9 σ (4.2σ)
H → bb	-0.4 σ (1.0σ)	2.0 σ (2.1σ)
H → ττ	1.1 σ (1.7σ)	2.8 σ (2.7σ)



Time to measure properties...

Statistical combination aims to best exploit the information coming from individual channels; instrumental for early discovery of the boson.
Still needed for powerful and coherent characterization of new particle !

Since day 1 we knew:

- it is a boson
- mass about 125 GeV
- production cross section and BR roughly compatible with SM Higgs predictions

Not enough! We want to pin down:

- mass (and natural width)
- couplings to SM fields
- spin and parity

Look for deviations from SM Higgs, find hints of new physics

HIGGS BOSON *H*

The **HIGGS BOSON** is the theoretical particle of the Higgs mechanism, which physicists believe will reveal how all matter in the universe gets its mass. Many scientists hope that the Large Hadron Collider in Geneva, Switzerland, which collides particles at 99.99% the speed of light, will detect the elusive Higgs Boson

$10.49 PLUS SHIPPING

Wool felt, velour with gravel fill for maximum mass. MADE IN CHINA.

Statistical methodology

Yield observed in channel i
(i = HWW, HZZ, Hbb ...)

$$n_i = \boldsymbol{\mu_i} \times \sigma_{i,SM} \times BR_{i,SM} \times A_i \times \varepsilon_i \times \mathscr{L}$$

μ_i = **signal strength modifier**

Likelihood of observing n_i events for a given value of μ_i (no syst unc.) in presence of background, b_i

$$Poisson(n_i \mid \mu_i s_i + b_i) = \frac{(\mu_i s_i + b_i)^{n_i}}{n_i!} \; e^{-\mu_i s_i - b_i}$$

Background-only recovered fixing $\mu_i = 0$

Systematics unc treated as nuisance params;
Total likelihood depends on Parameter Of Interest (μ_i and/or M_H) and nuisances (θ_i).

$$L_i = L_i(\mu_i; \boldsymbol{\theta_i}) = P(n_i \mid \mu_i s_i + b_i) * \rho(\boldsymbol{\theta_i})$$

ρ → nuisance p.d.f. are typically
Log-N , Poisson or Gamma

$$L_{max}=L(obs \mid \hat{\mu}\, s_i+b_i;\hat{\theta})$$

Circumflex accent (^) indicates value of a param that maximizes L

Nuisance profiling: we evaluate L at a given μ_i, fixing all nuisances to the values that maximize L(μ_i).

$$q_0=\frac{L(obs \mid b_i;\hat{\theta}_{\mu=0})}{L_{max}}$$

Ratio of L for background-only over s+b, $\mathbf{q_0}$(μ_i), used as test statistics to quantify significance of excess (prob that background fluctuates such to mimic the obs excess).

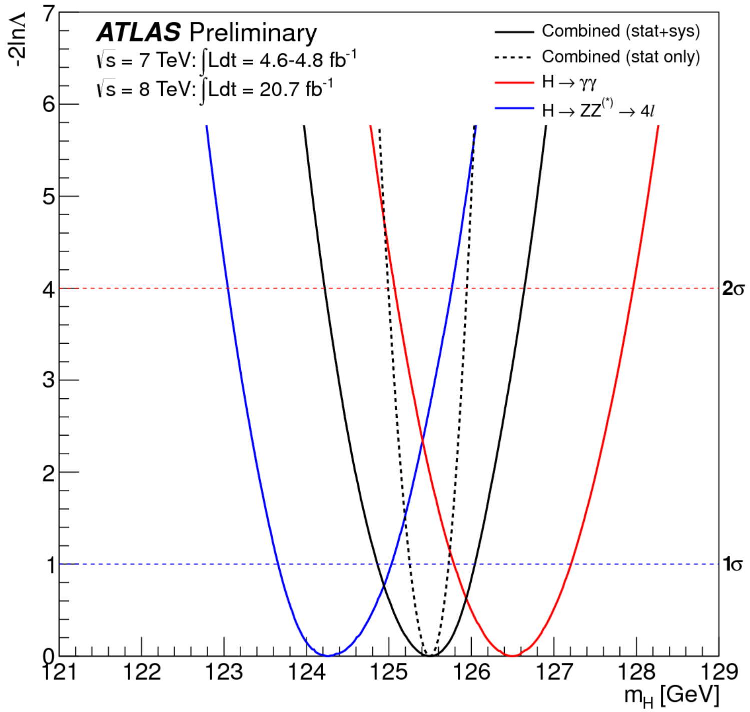
$$q=\frac{L(obs \mid \mu s_i+b_i;\hat{\theta}_{\mu})}{L_{max}}$$

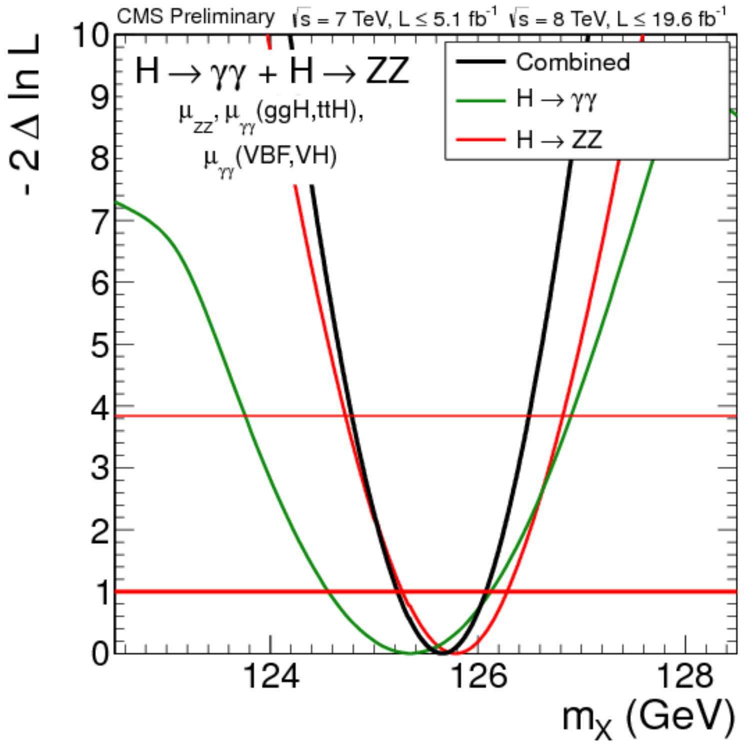
Min of likelihood-ratio, **q**(μ_i), used as test statistics to find most-probable value of μ_i ,error on measurement from variations of -2*ΔL.

Combination of different channels done multiplying individual likelihoods and defining test statistics from total L

Mass measurement

Both experiments use only **Hγγ and HZZ channels**, μ profiled as nuisance parameter



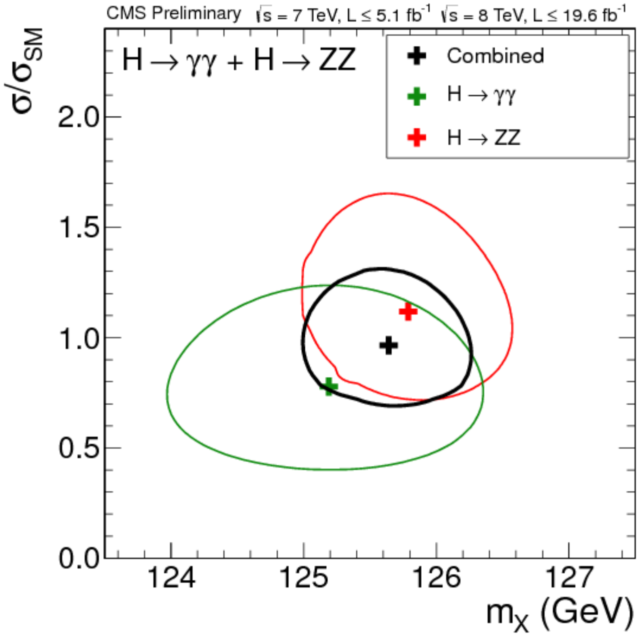


ATLAS result

$M_H = 125.5 \pm 0.2\ \mathit{(stat.)}\ ^{+0.5}_{-0.6}\ \mathit{(syst.)}$ GeV

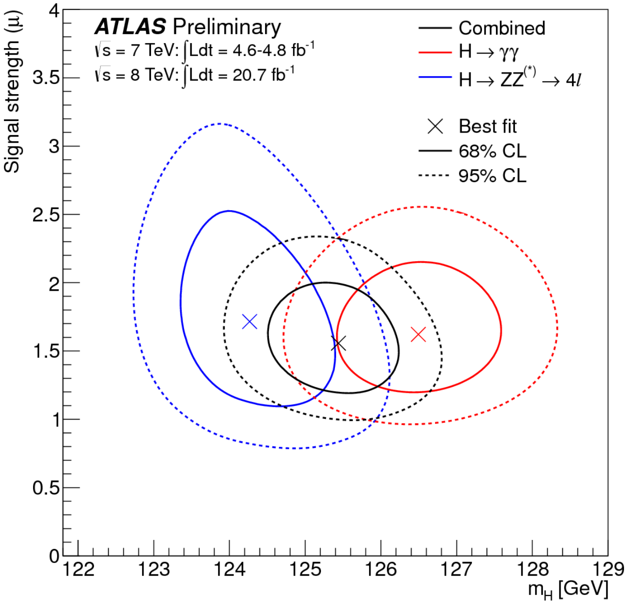
CMS result

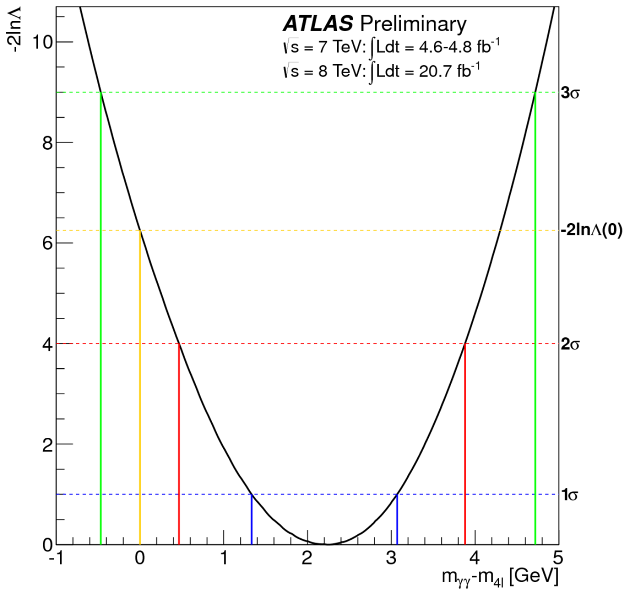
$M_H = 125.7 \pm 0.3\ \mathit{(stat.)} \pm 0.3\ \mathit{(syst.)}$ GeV



Mass and couplings to SM fields correlated in SM H. Scan L as a function of M_H and μ (fix relative signal strengths to SM value).

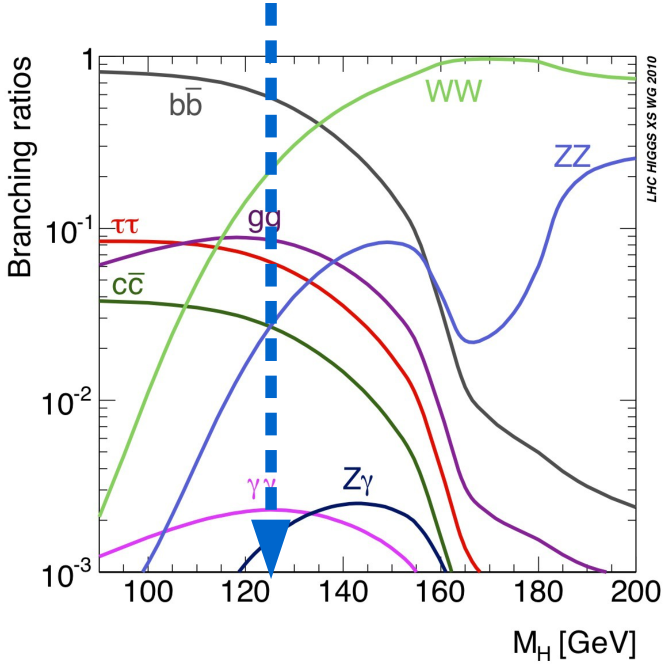
Nice compatibility across CMS channels. Difference btw ATLAS individual measurements studied in detail.





- ΔM=0 hyp. (→matching measurements) compatible with observation at 1.5%
- Sensitivity to different assumption on p.d.f. of exp. systematics, γγ vs ZZ compatibility can increase to 8%

Signal strength and couplings



Test of compatibility with SM Higgs predictions of signal strengths & couplings.

Single, narrow width, CP-even resonance.

Both experiments fix M_H to best fit value:

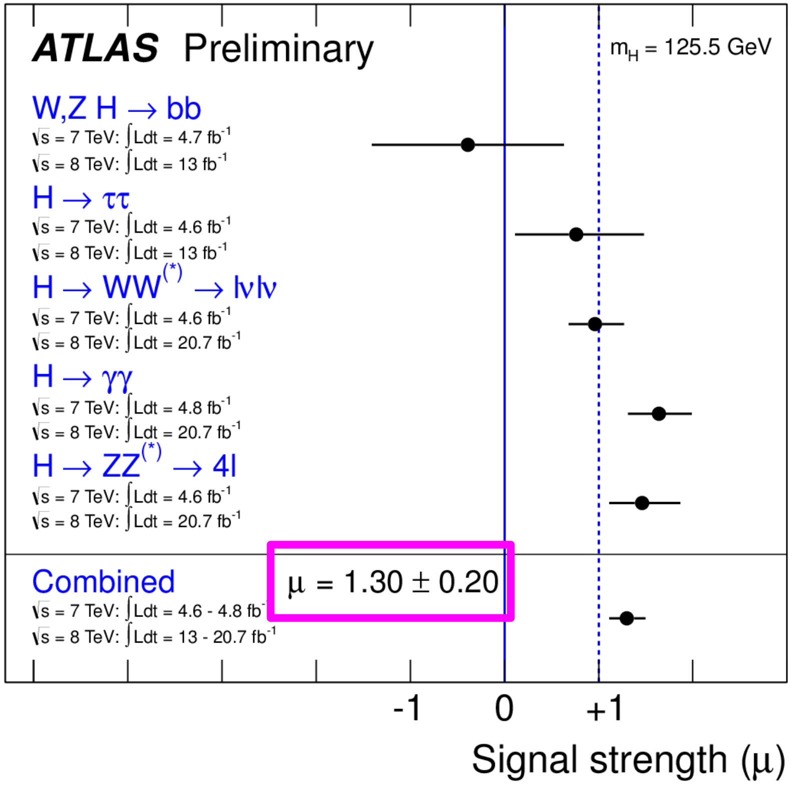
ATLAS → 125.5 GeV
CMS → 125.7 GeV

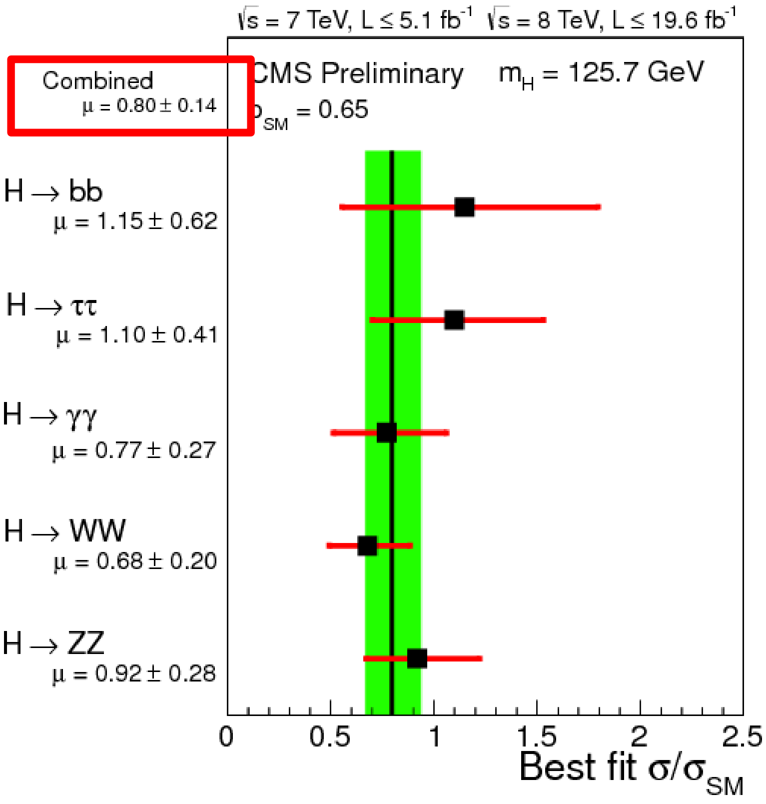
ATLAS combined channels

	Production mechanism				Luminosity [fb^{-1}]	
Channel	ggH	VBF	VH	ttH	7TeV	8TeV
$H \to \gamma\gamma$	●	●	●		4.8	20.7
$H \to ZZ \to 4l$	●	●	●		4.6	20.7
$H \to WW \to l\nu l\nu$	●	●			--	20.7
$H \to bb$			●		4.7	13.0
$H \to \tau\tau$		●	●		4.6	13.0

CMS combined channels

	Production mechanism				Luminosity [fb^{-1}]	
Channel	ggH	VBF	VH	ttH	7TeV	8TeV
$H \to \gamma\gamma$	●	●	●		5.1	19.6
$H \to ZZ \to 4l$	●	●	●		5.1	19.6
$H \to WW \to l\nu l\nu$	●	●	●		4.9	19.6
$H \to bb$			●	●	5.0	19.6
$H \to \tau\tau$	●	●	●		5.0	19.6





Good internal consistency for both experiments.

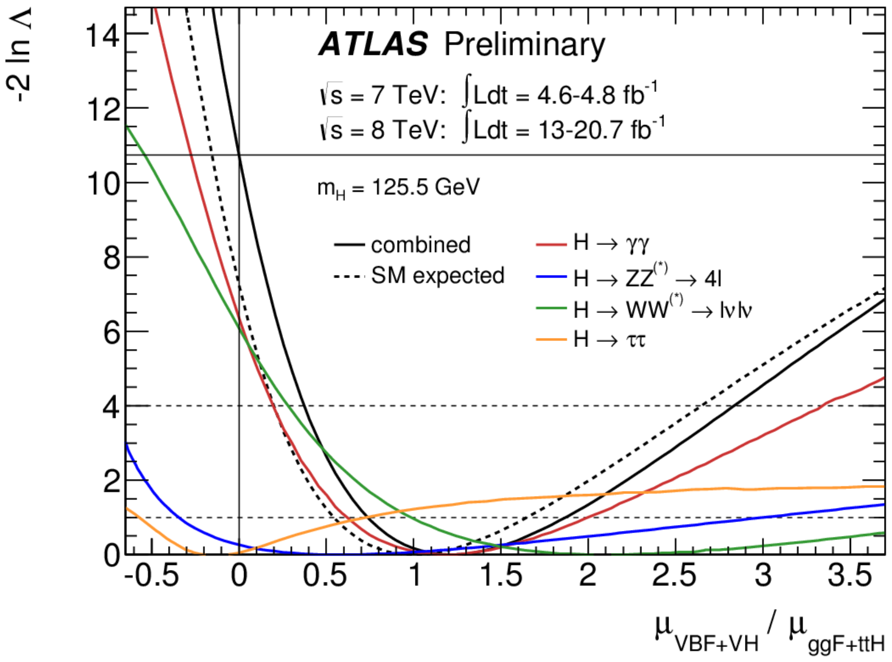
ATLAS consistent with SM at 9% (but ~40% with flat pdfs for theory unc)

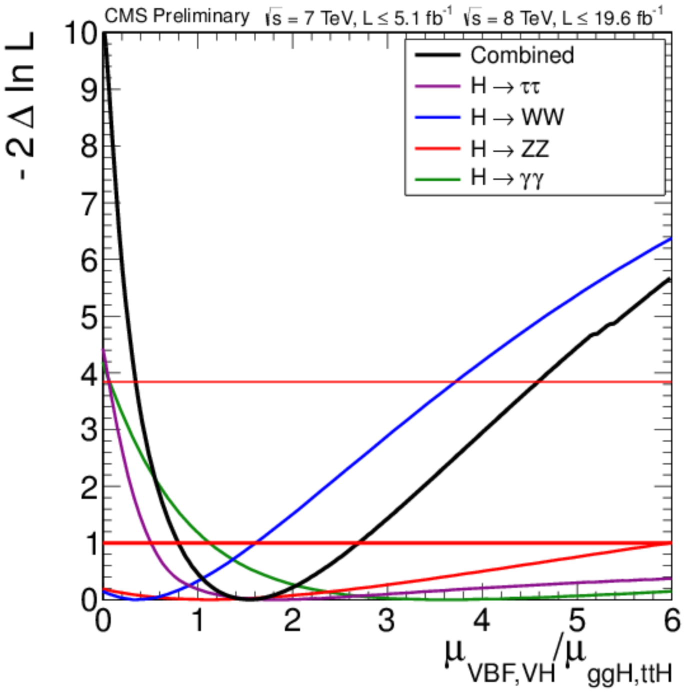
CMS consistent with SM at 16%

VBF+VH fraction

Combine signal strength of exp. channels sensitive to VBF and VH production process, compare against gg-Fusion (ggH) + ttH:

- scan ratio $\mu_{VBF+VH} / \mu_{ggH+ttH}$ while profiling $\mu_{ggF+ttH}$
- ATLAS excludes $\mu_{VBF+VH} / \mu_{ggH+ttH}=0$ at 3.3σ C.L.
- CMS excludes $\mu_{VBF+VH} / \mu_{ggH+ttH}=0$ at 3.2σ C.L.





Framework for measurement of couplings

- Measurement of couplings: test of SM and way to spot hints of BSM
- CP-even and narrow width boson : $\sigma * BR = \sigma\ * \Gamma/\Gamma_H$
- $\mathbf{k_i}$: factor to apply to SM couplings in order to best describe data (should be all 1 assuming SM)
- Ratios of yields in different production and decay channels sensitive to different combinations of couplings.
- <u>Limited statistics</u> → **assumptions** on other couplings when measuring a ratio

LHC H XS WG report:
arXiv:1209.0040

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma^{\mathrm{SM}}_{\mathrm{ggH}}} = \begin{cases} \kappa_{\mathrm{g}}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, m_{\mathrm{H}}) \\ \kappa_{\mathrm{g}}^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma^{\mathrm{SM}}_{\mathrm{VBF}}} = \kappa_{\mathrm{VBF}}^2(\kappa_{\mathrm{W}}, \kappa_{\mathrm{Z}}, m_{\mathrm{H}})$$

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

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

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

Detectable decay modes

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

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

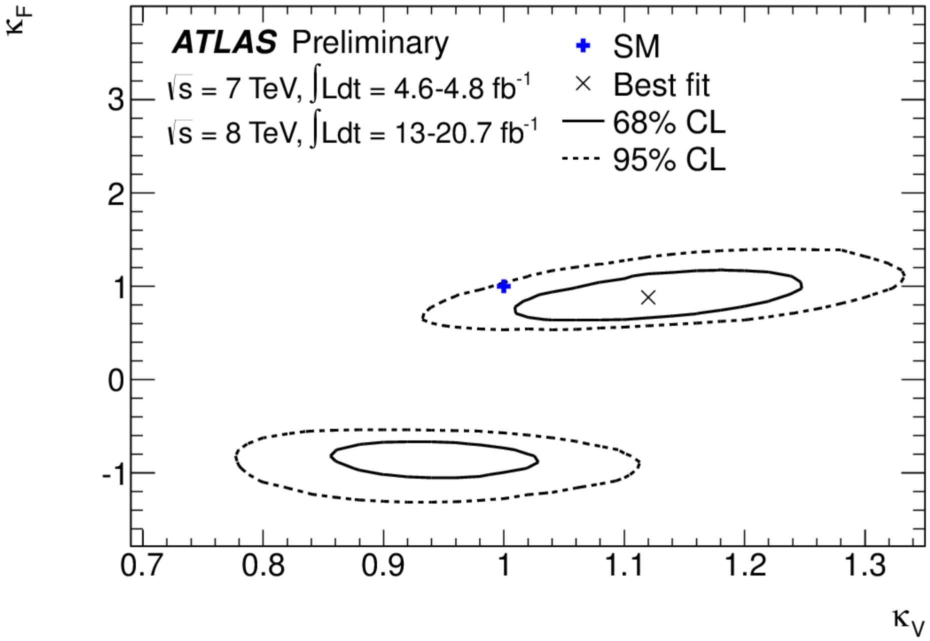
$$\frac{\Gamma_{\mathrm{b\bar{b}}}}{\Gamma^{\mathrm{SM}}_{\mathrm{b\bar{b}}}} = \kappa_{\mathrm{b}}^2$$

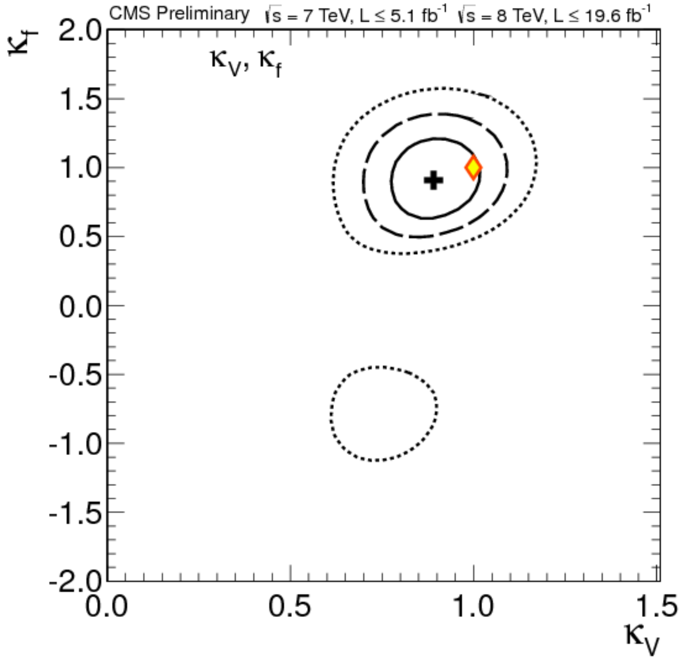
$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{\mathrm{SM}}_{\tau^-\tau^+}} = \kappa_{\tau}^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\gamma\gamma}} = \begin{cases} \kappa_{\gamma}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa_{\gamma}^2 \end{cases}$$

$$\frac{\Gamma_{\mathrm{Z}\gamma}}{\Gamma^{\mathrm{SM}}_{\mathrm{Z}\gamma}} = \begin{cases} \kappa_{(\mathrm{Z}\gamma)}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa_{(\mathrm{Z}\gamma)}^2 \end{cases}$$

k_V / k_F



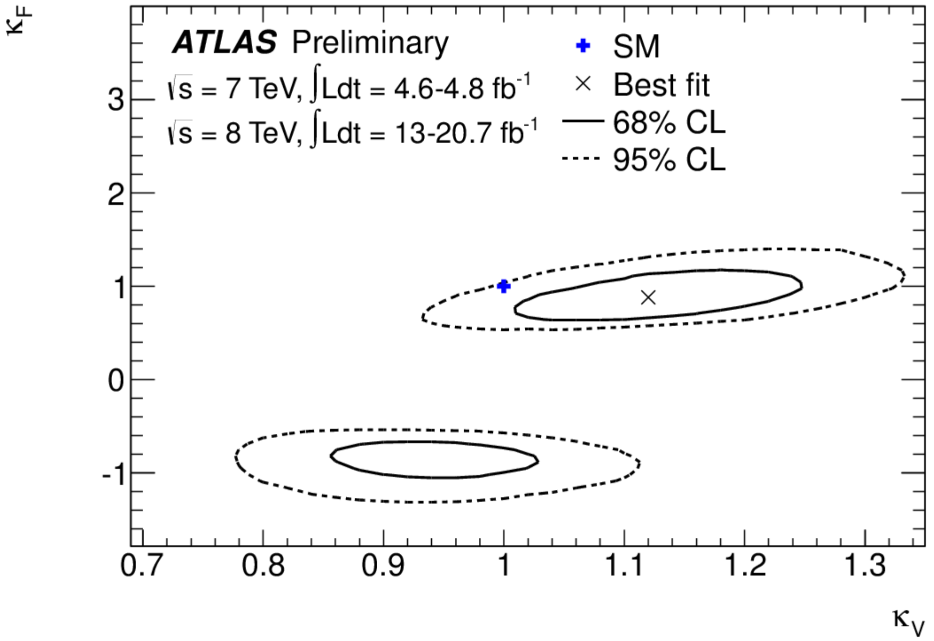


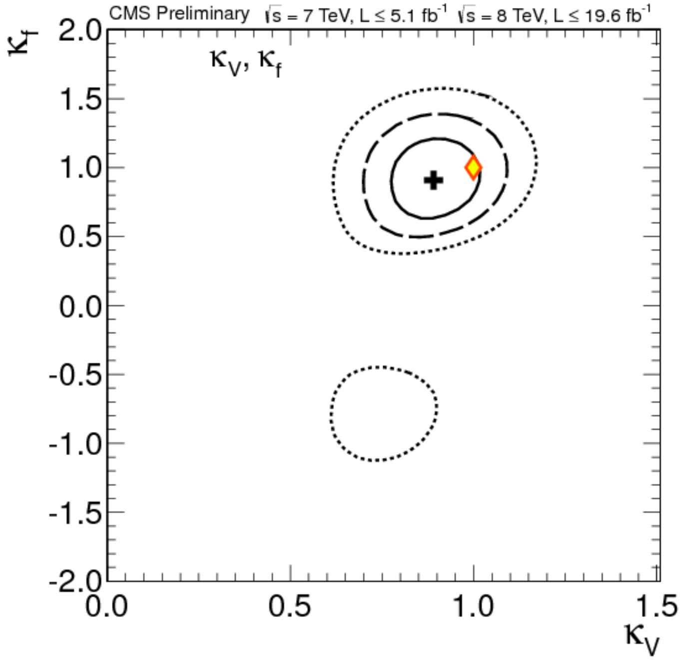
Check that the H candidate couples with fermions and gauge bosons according to SM.

Several assumptions (always needed until we don't have heaps of data):

- $\mathbf{k_V} = k_W = k_Z$
- $\mathbf{k_F} = k_t = k_b = k_\tau = k_g$
- $k_H^2 = 0.75\, k_F^2 + 0.25\, k_V^2$ → H couples only to SM fields !

k_V / k_F





Relative sign between k_F and k_V arbitrary in SM (2 out 4 quadrants).

Over-fluctuation in ATLAS Hγγ obs yields allows negative k_F (t-loop enters in γγ-decay with negative sign).

95% CL region of CMS all in positive k_F.

Both ATLAS and CMS compatible with SM.

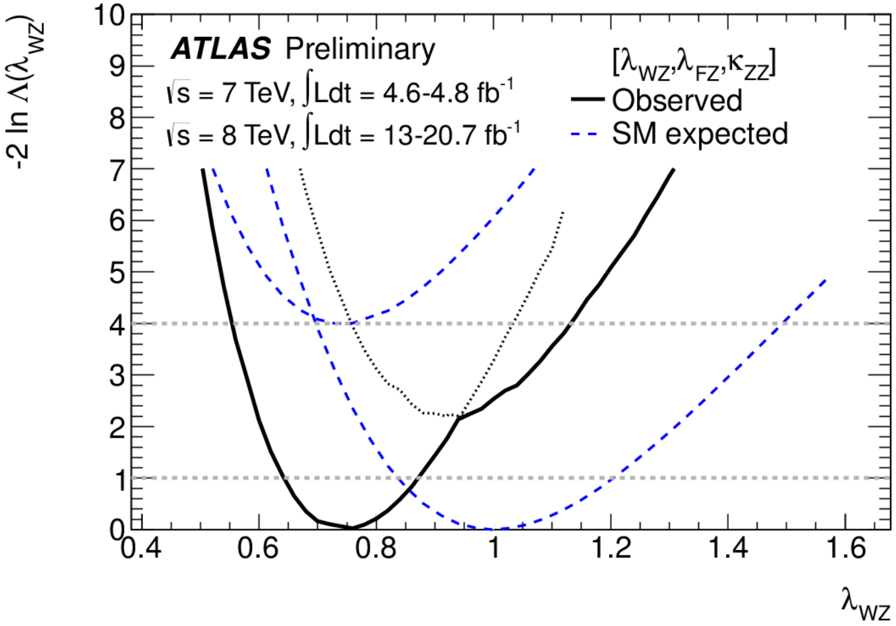
Custodial symmetry

From $SU(2)_{L+R}$ symmetry of Higgs sector + LEP tests

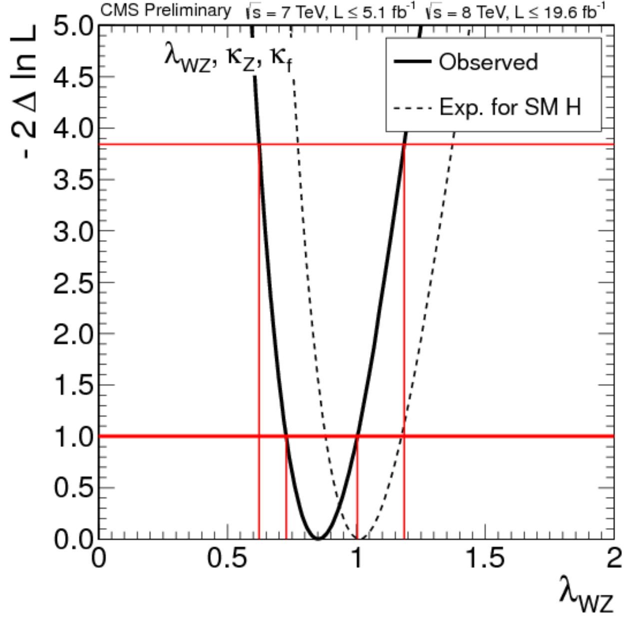
→ identical scale factors of H to W and Z.

- $\lambda_{WZ} = k_W / k_Z$ (POI, must be 1 in SM)
- $\mathbf{k_F} = k_t = k_b = k_\tau = k_g$
- k_F and k_Z profiled

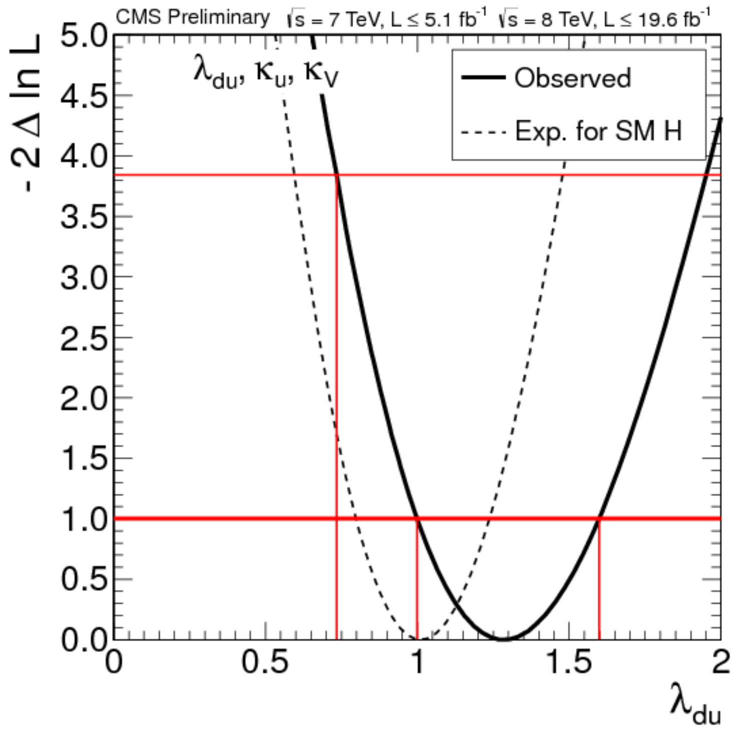
ATLAS: $\lambda_{WZ} \in [0.64, 0.87]$ (68% CL)



CMS: $\lambda_{WZ} \in [0.62, 1.19]$ (95% CL)

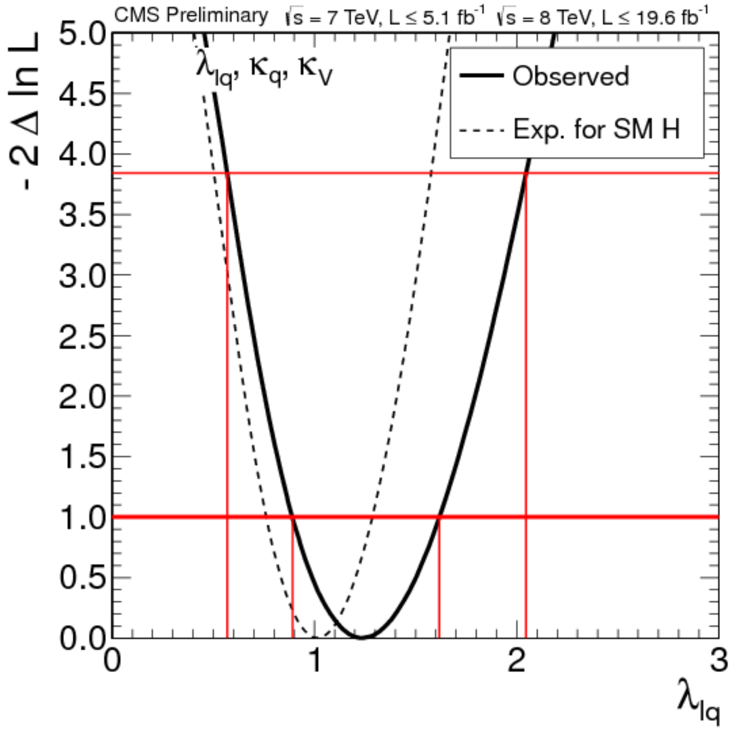


Test of fermion universality



Up quark vs Down quark scale factors, k_d and k_u ; $\lambda_{du} = k_d / k_u$

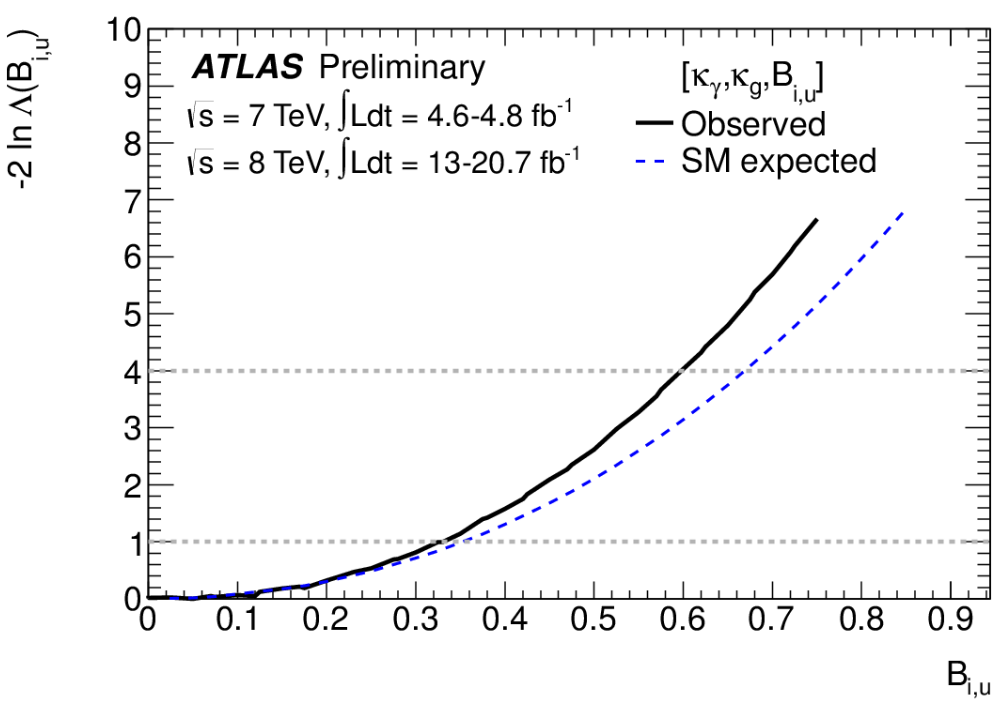
- k_u and k_v profiled
- k_u and k_v constrained to be >0

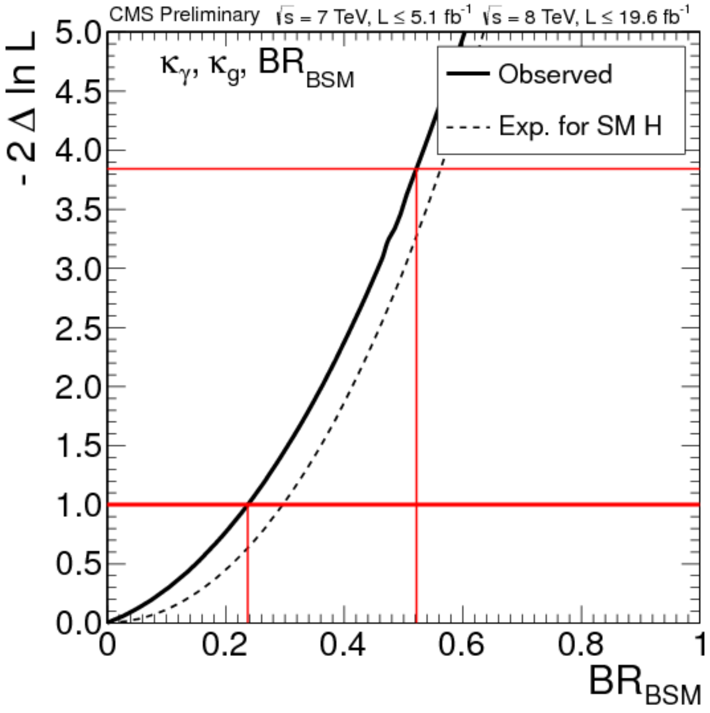


Lepton vs Quark scale factors, k_l and k_q ; $\lambda_{lq} = k_l / k_q$

- k_q and k_v profiled
- k_q and k_v constrained to be >0

BSM contributions



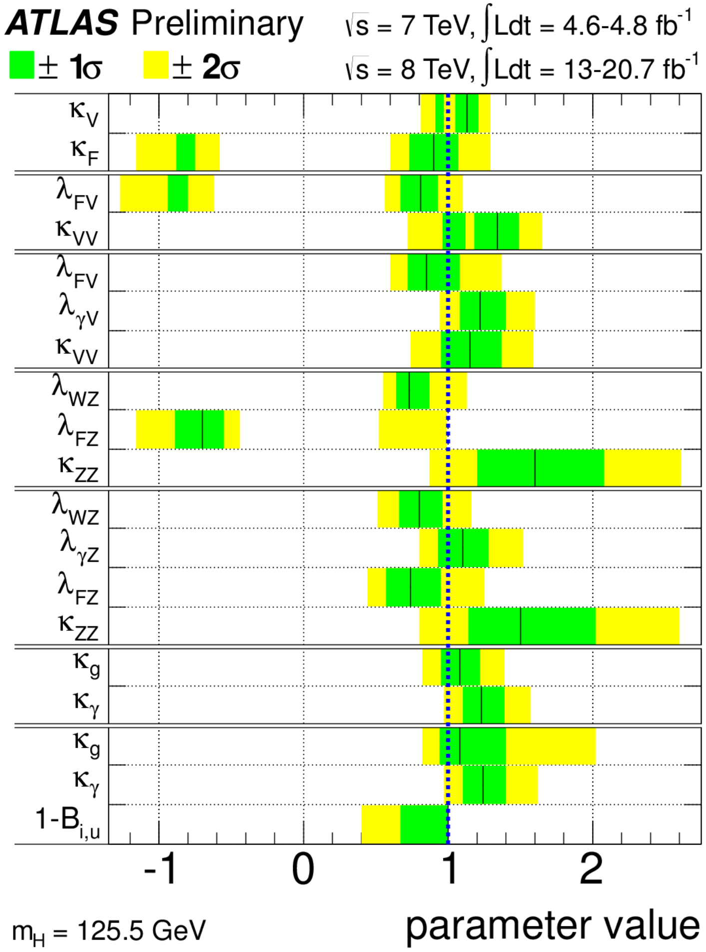


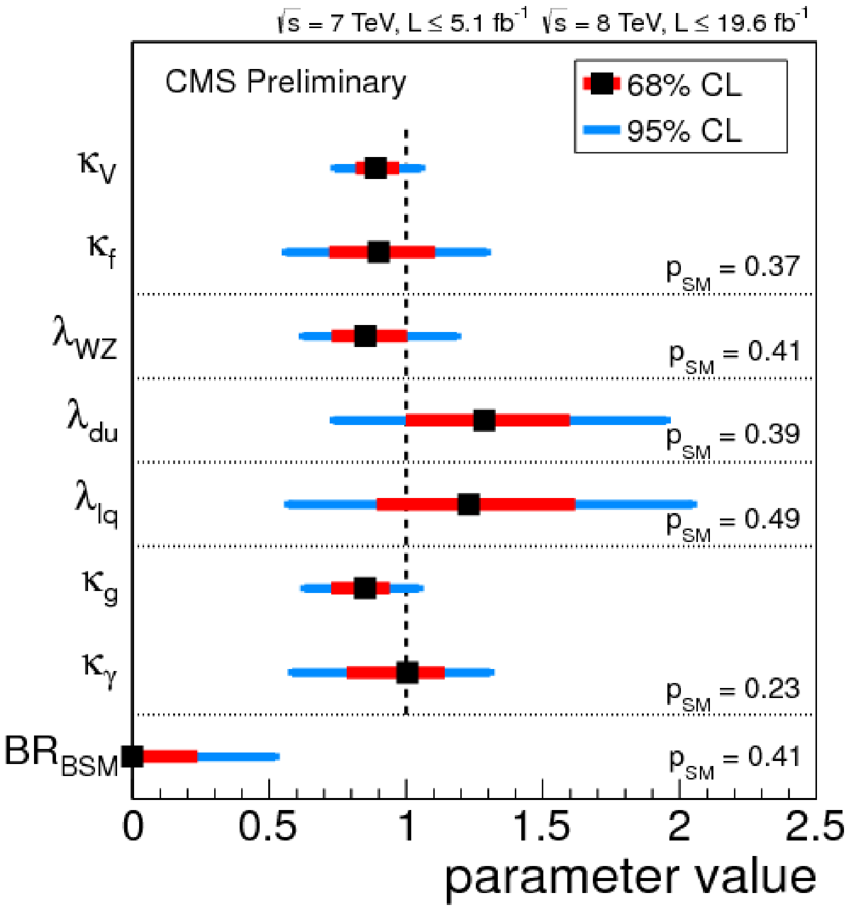
- Target: new physics in $\gamma\gamma H$ and ggH loops, not detectable in experiments
- H width modified from SM by a factor BR_{BSM}
- k_γ and k_g profiled , k_F and k_V fixed to 1 (→ SM)

ATLAS: $BR_{BSM} < 0.60$ (95% C.L.)

CMS : $BR_{BSM} < 0.52$ (95% C.L.)

Overview





Many tests for compatibility to SM, no significant deviation

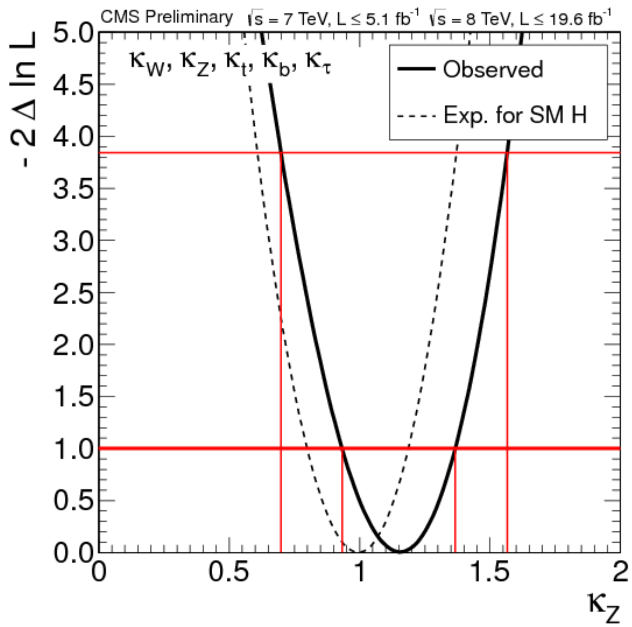
C6 model

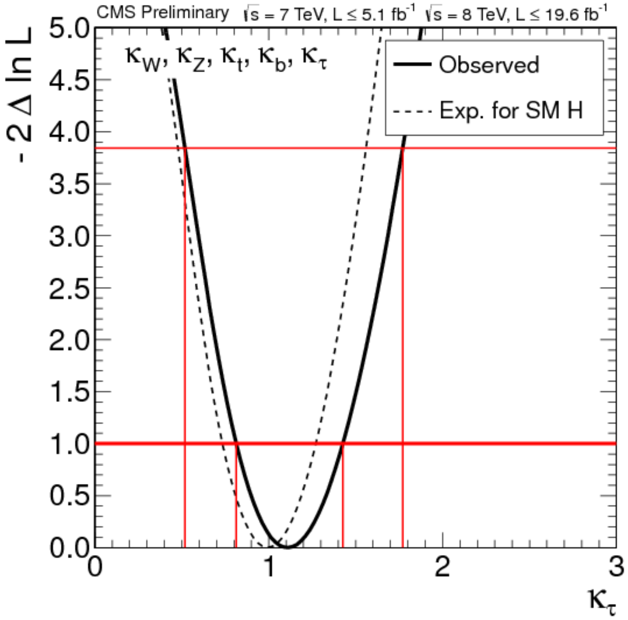
C6 model studied by CMS:

- same scale factor k_V for W and Z
- same scale factors for 3 fermion generations
- effective couplings for γγH and ggH, scaled independently
- no contributions from BSM : $\Gamma_{BSM}=0$

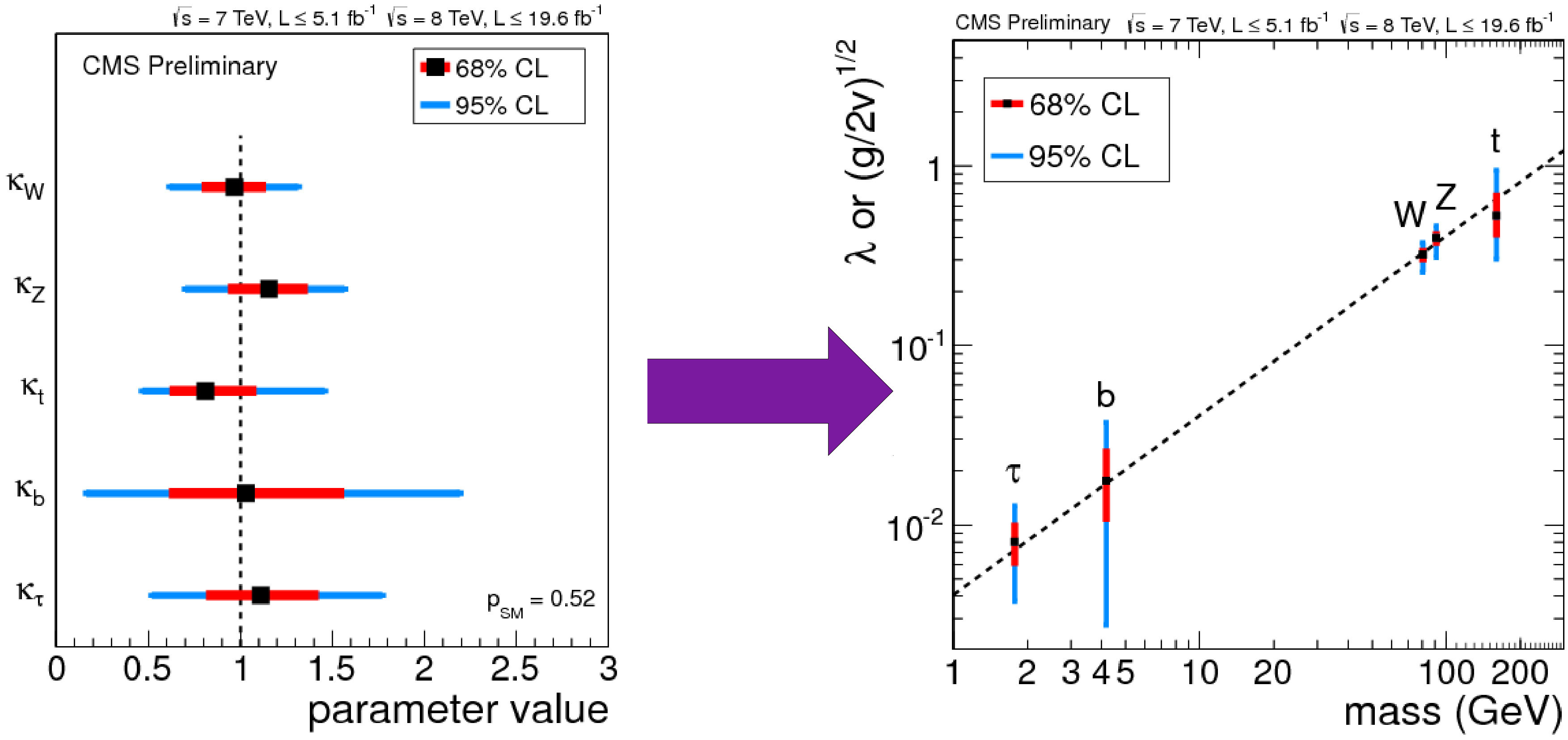
→ six independent parameters:
$k_V, k_b, k_t, k_\tau, k_\gamma, k_g$

Likelihood scan one scale factor at a time, profiling the other five. **No significant deviation from SM**.





C5 model



Similar to C6: k_W and k_Z independent, k_γ and k_g as a function of others.

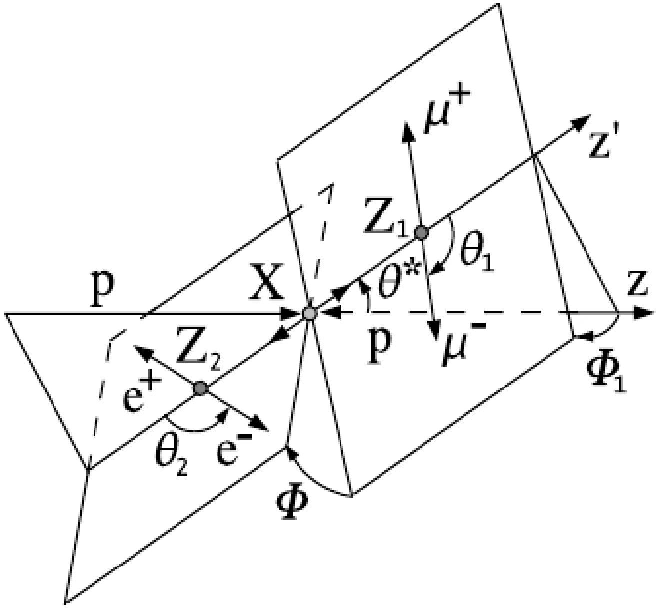
No significant deviation from SM.

Same result, re-interpreted as a function of mass of SM particle shows nicely Yukawa couplings (dashed line is SM, not a fit!)

Spin and parity

Three channels used for J^P analysis:

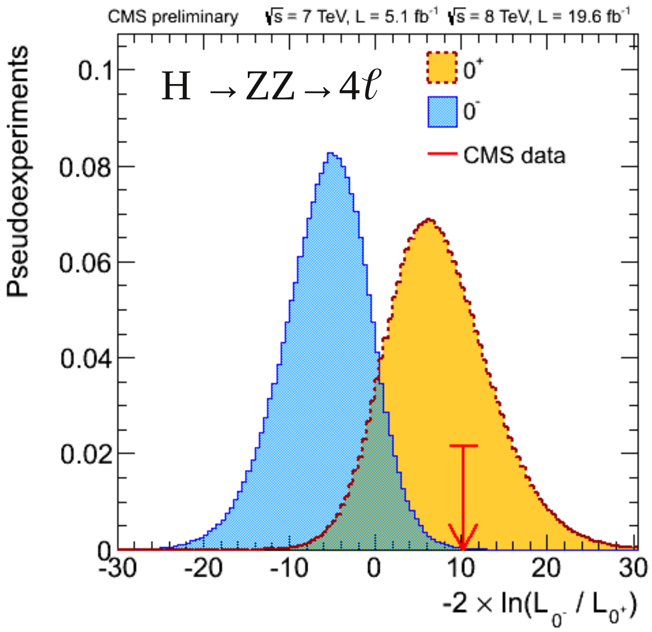
- $H \rightarrow ZZ \rightarrow 4\ell$: full reco, excellent angular res, sensitive to broad range of J^P scenarios
- $H \rightarrow WW \rightarrow 2\ell 2\nu$: partial reco, used only for spin-0 vs spin-2
- $H \rightarrow \gamma\gamma$: full reco, but no measure of photon polarization possible, used only for spin-0 vs spin-2 (spin-1 forbidden by Landau-Yang theorem)

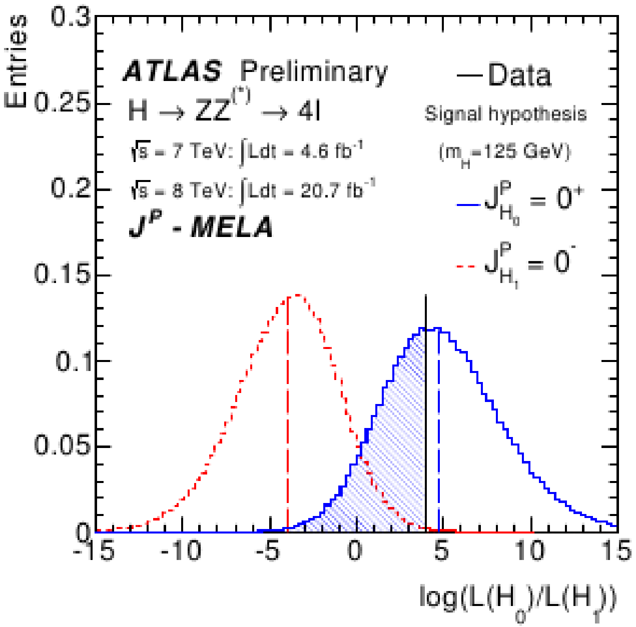


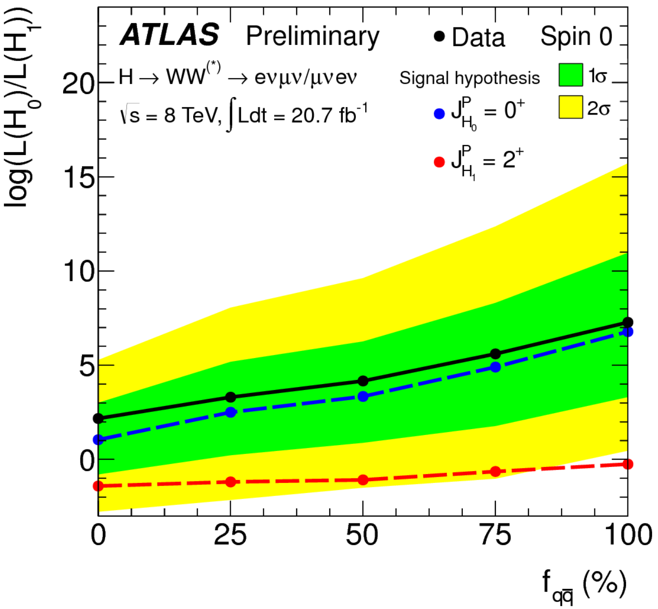
Minimize changes respect to baseline analysis (used for mass and couplings).

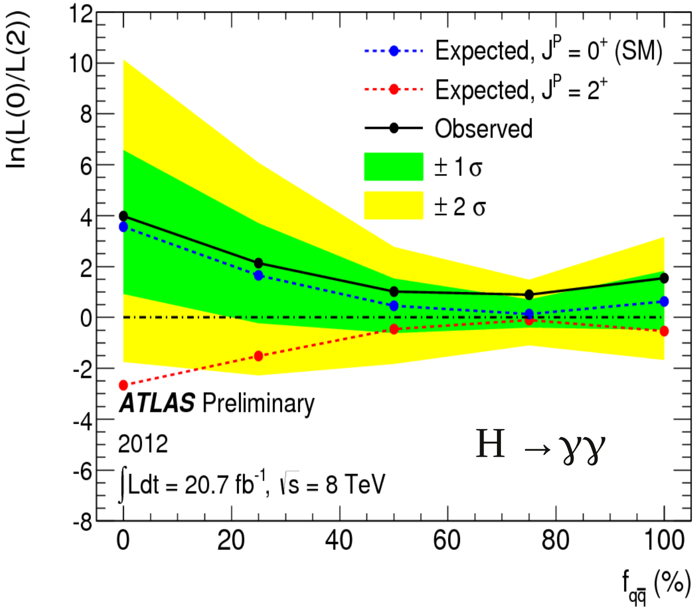
Spin analyses use reconstructed production and helicity angles for discriminating between J^P:

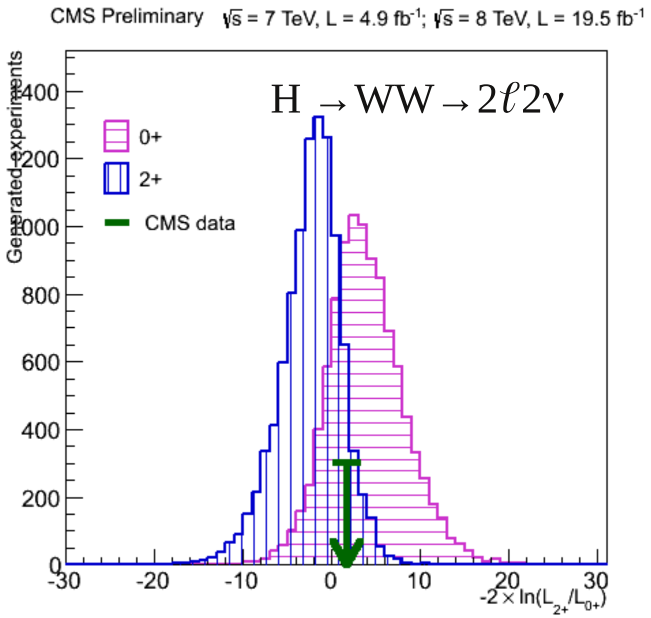
- HWW based on $M_{\ell\ell}$ and M_T
- $H\gamma\gamma$ exploits only θ^* in Collins-Soper frame
- HZZ uses also masses of Z bosons



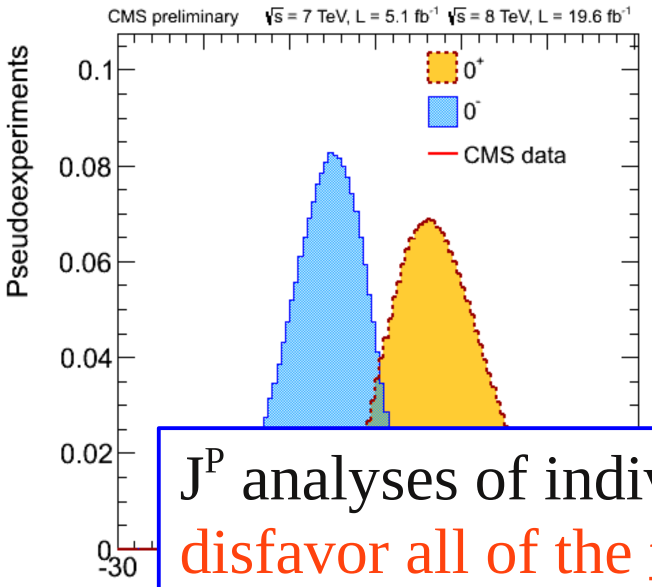


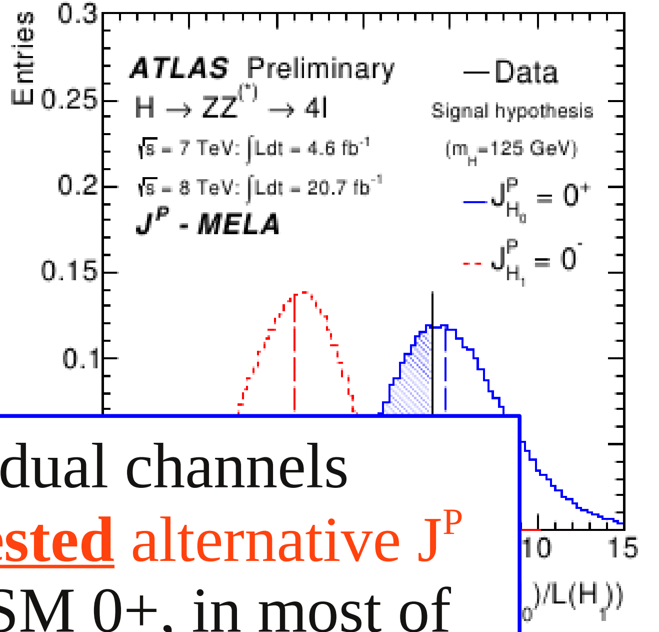


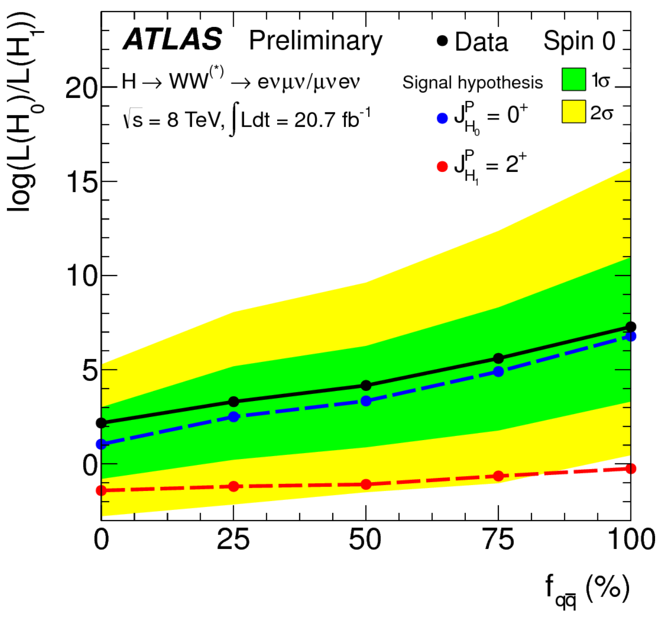




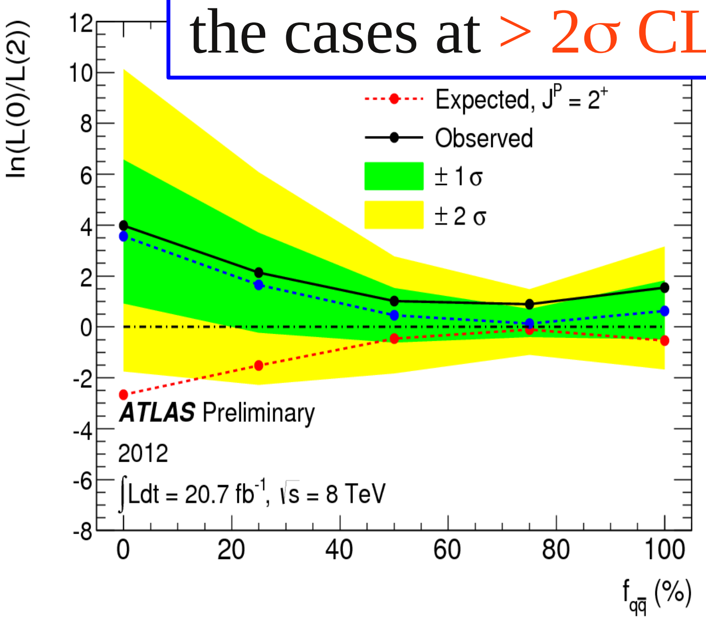
Refer to talks with individual channels for more details on the analyses.

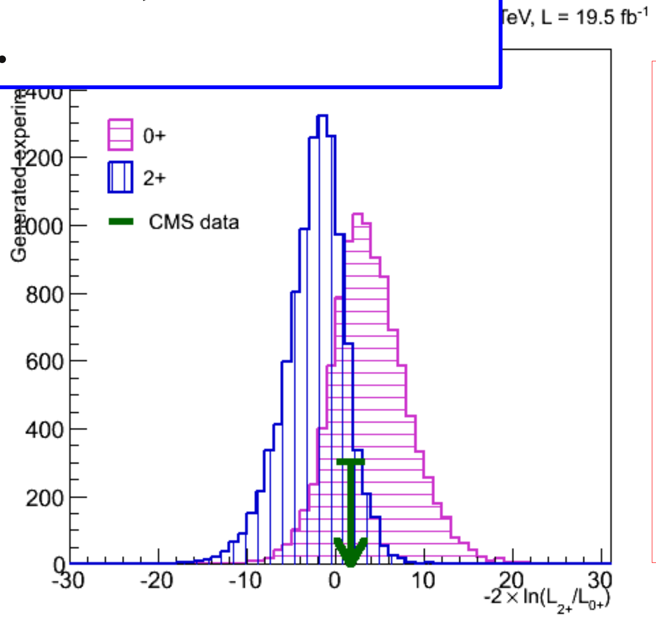






J^P analyses of individual channels disfavor all of the ***tested*** alternative J^P hypotheses against SM 0+, in most of the cases at > 2σ CL.





Reminder: these are tests between two J^P hypotheses, not a measurement of J^P !
Probed only specific admixture of spin-2 models, param phase space much larger.
Fit to anomalous couplings parameters needs far more data than what available now.

Combination done only for spin-2 where all channels have sensitivity.

$$n_i = \varepsilon\ n_{i,SM} + (1-\varepsilon)\, n_{i,ALT} + b_i$$

POI ε tells how much of observed yield in i-th channel comes from SM or ALT JP hypothesis.

$$q = \frac{L(\varepsilon=1\ ;\hat{\theta}_{\varepsilon=1})}{L(\varepsilon=0\ ;\hat{\hat{\theta}}_{\varepsilon=0})}$$

Likelihood ratio between SM (ε=1) and ALT hyp (ε=0). Total L from product of individual L_i (except for correlated syst.). Signal strength modifiers μ_i profiled independently as a nuisance parameters.

For alternative J^P, assume:

- same line shape of SM H
- same cross section of SM H (but correct for different detector acc.)

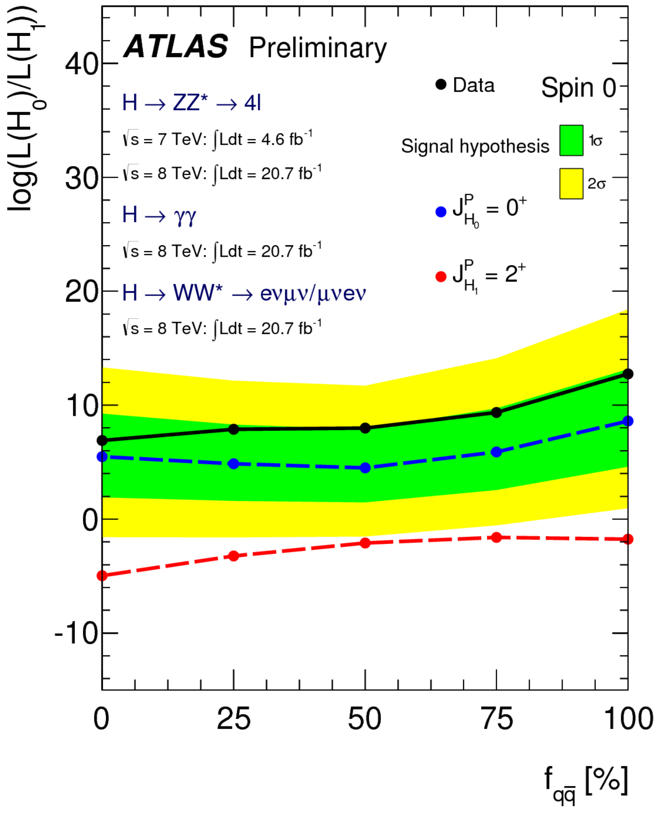
➔ use only info from decay products for discriminating between J^P (yields still important as they can enhance the sensitivity of the test)

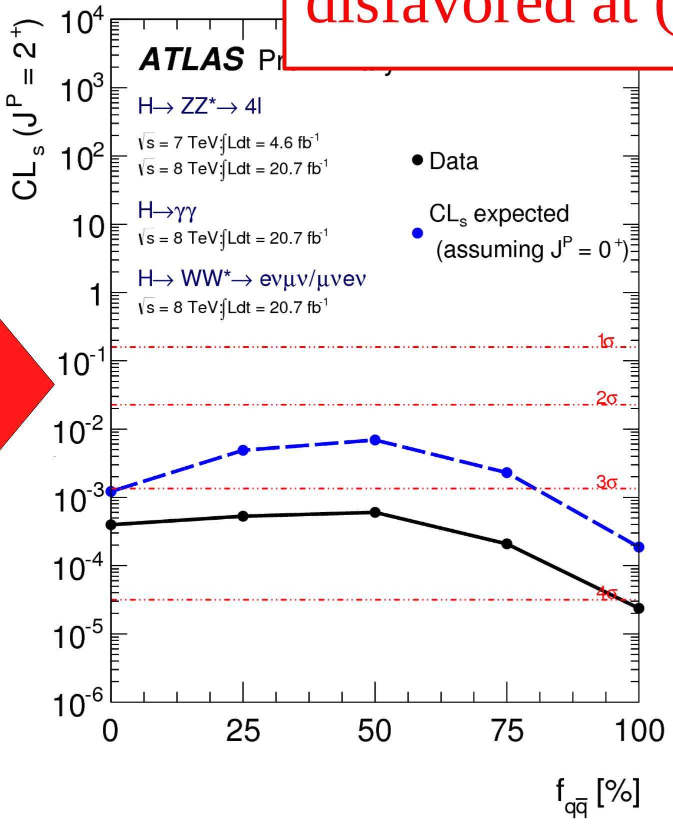
ATLAS combines all $H\gamma\gamma$ + HWW + HZZ.

Test SM vs spin-2 minimal couplings, with different admixture of qq- and gg-induced production.

Scan vs f_{qq} of separation of 0^+ vs 2^+_{min}.

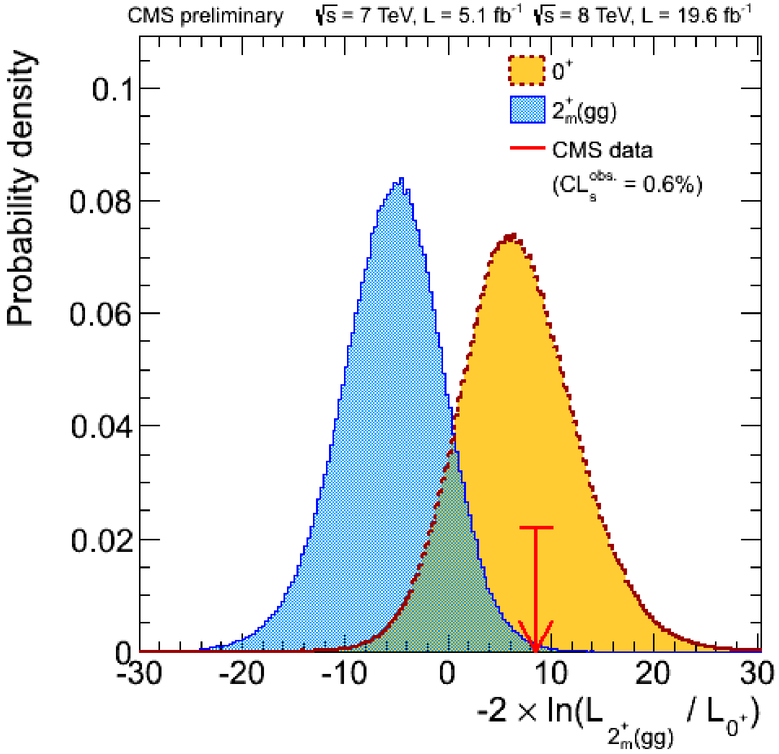
Spin-2 (minimal couplings) disfavored at (1- CL_S) > 99.9%

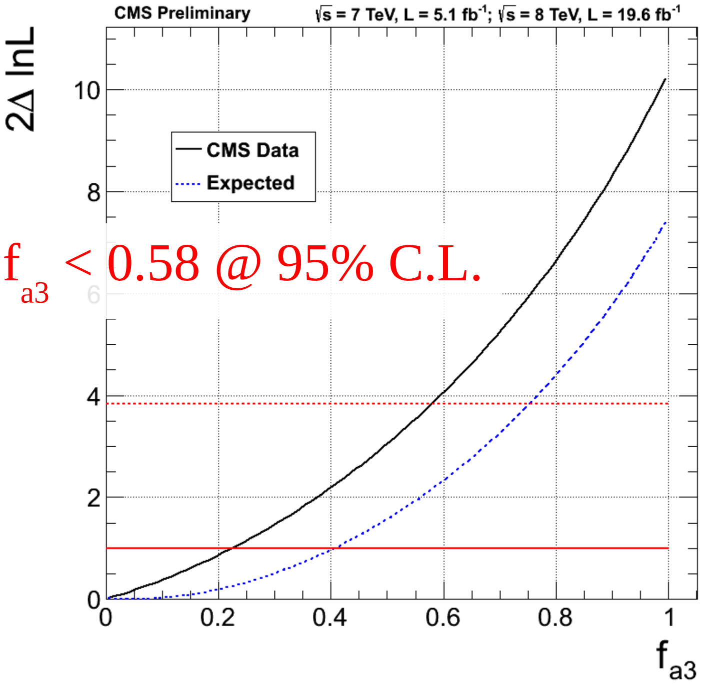




CMS combination of HZZ+HWW for testing 0^+ vs $2^+_{\rm min}$

- only for production 100% in gg-fusion channel of the spin-2
- Non-SM hyp excluded at 99.4% (CL_S criterion)
- Driven mostly from >2σ excess in HZZ





$f_{a3} < 0.58$ @ 95% C.L.

First attempt of measuring anomalous couplings in HZZ

$$A = v^{-1}\epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(a_1 g_{\mu\nu} m_H^2 + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta\right) = A_1 + \cancel{A_2} + A_3$$

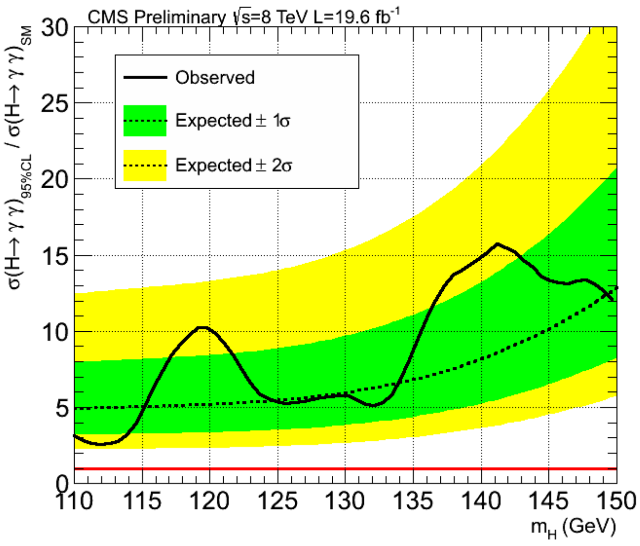
$$f_{a3} \propto \frac{|A_3|^2}{|A_1|^2 + |A_3|^2 + interf.} \approx \frac{N_{PS}}{N_{SM} + N_{PS}}$$

What's next

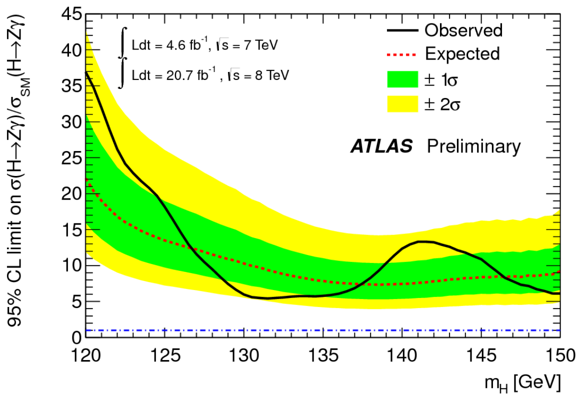
- Repeat analyses with full stats and final detector calibrations
- More analyses based on 2011-2012 data, prelim. or in preparation: ttH (several final states), $gg \rightarrow H \rightarrow Z\gamma$, $ZH \rightarrow$ inv. , $H \rightarrow \mu\mu$

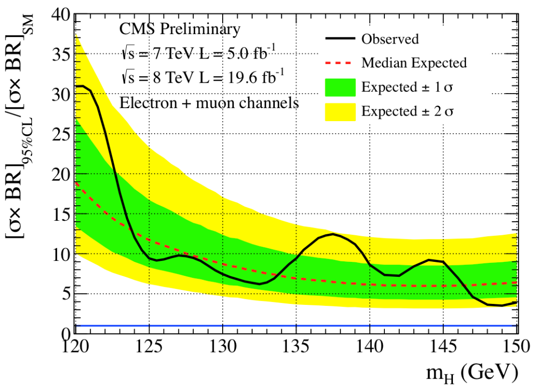
→ more inputs to include in combination !

$ttH \rightarrow \gamma\gamma$



$H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$





… plus heaps of data to come in Run II !!!!

Summary

- Properties of the Higgs-like boson studied more and more in detail: mass, couplings to SM, J^P
- So far, no significant deviations from SM prediction, our good old friend still resists.
- Lots of more data to come, precision of the characterization will further increase
  - more channels (ttH, Zγ)
  - better control on systematics
  - dominant systematics from theory (ggH predictions in particular)

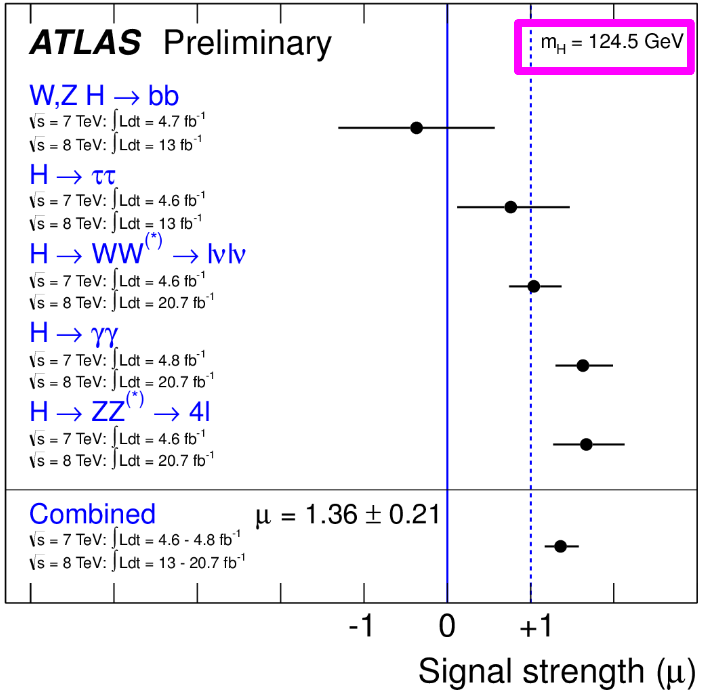
The siege to SM continues!

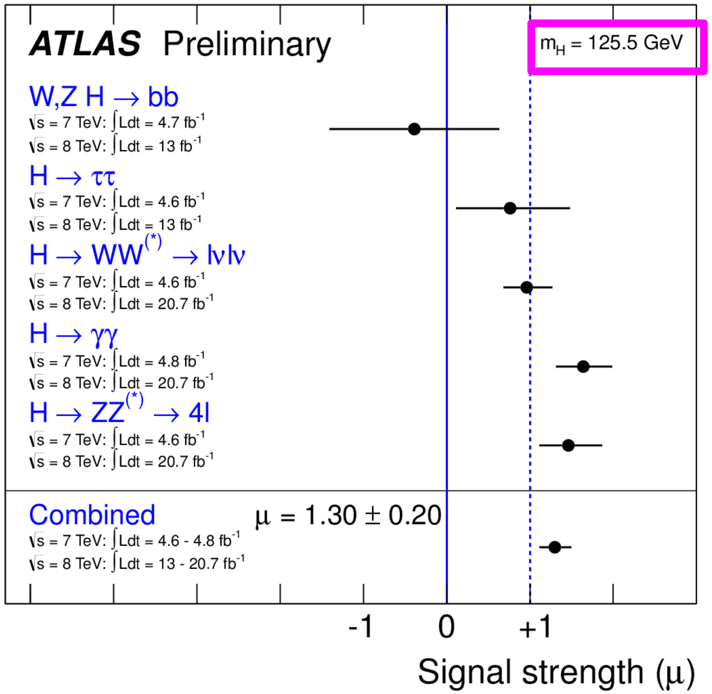
Combination of channels will keep playing a key role

References

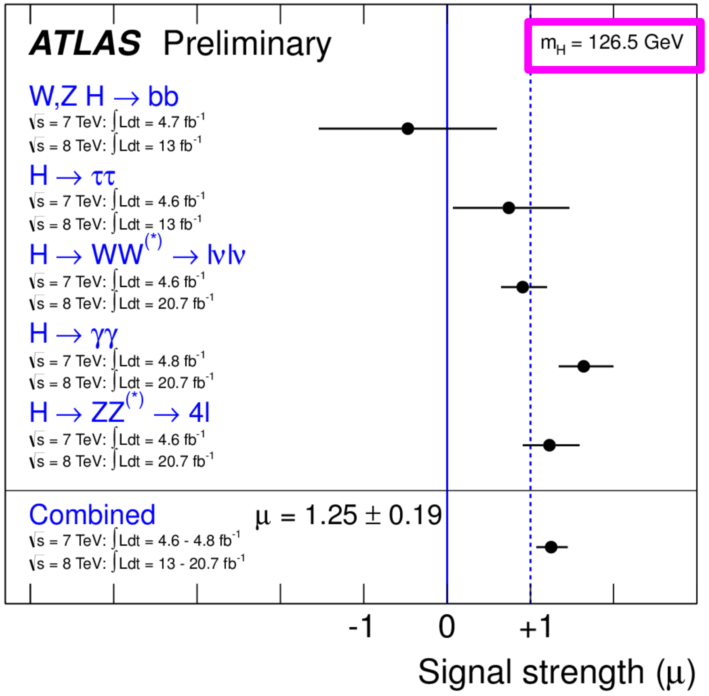
- CMS/ATLAS Common statistical framework: link to CDS record
- LHC H XS WG interim report : arXiv:1209.0040
- ATLAS Higgs combination (Winter 2013 preliminary results):
  - ATLAS-CONF-2013-014 (combination of mass measurements)
  - ATLAS-CONF-2013-034 (combination of couplings measurements)
  - ATLAS-CONF-2013-040 (combination of spin measurements)
- CMS Higgs combination (Winter 2013 preliminary results):
  - CMS-PAS-HIG-13-005 (combination of mass, couplings and spin)

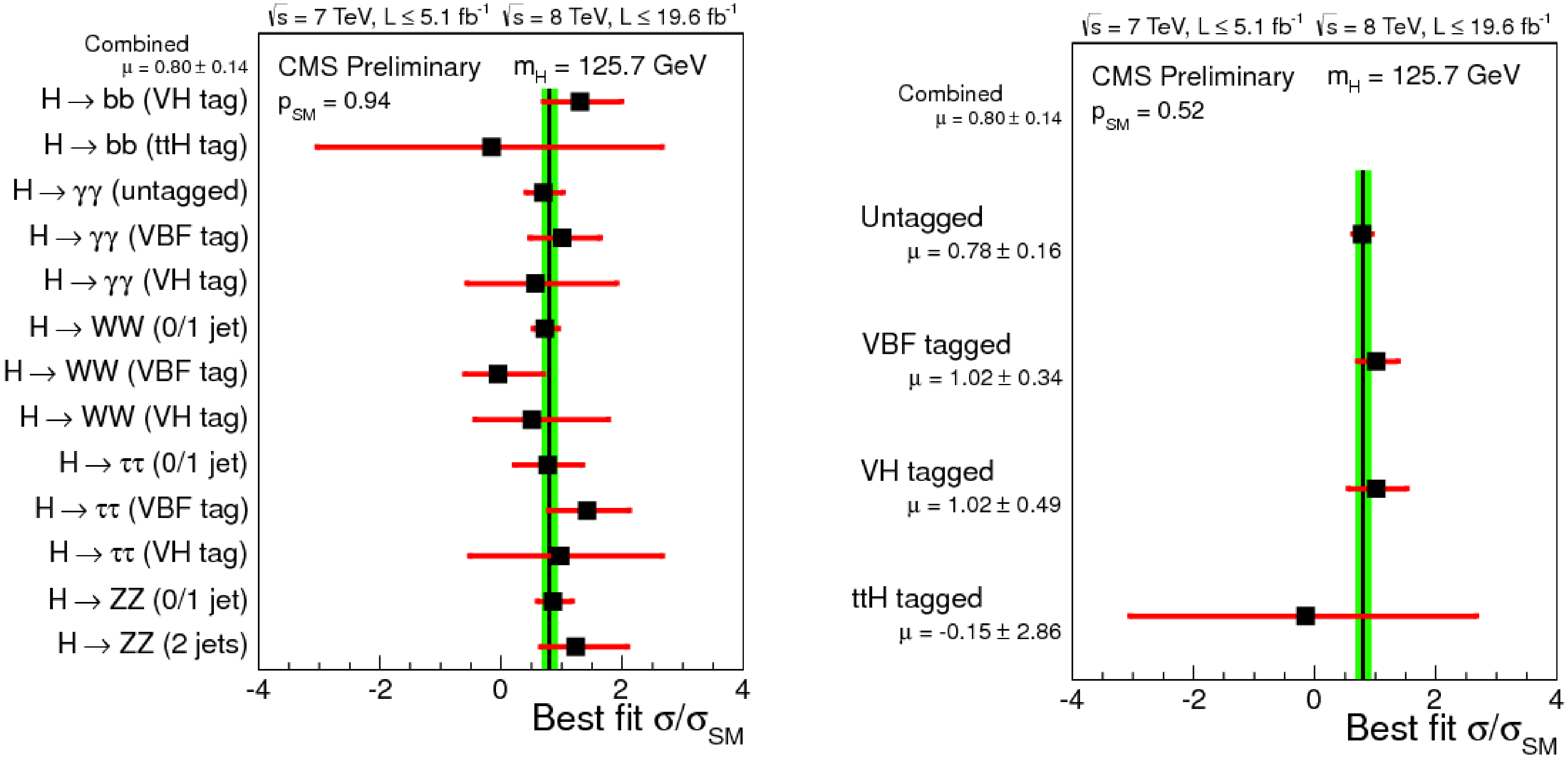
Additional material





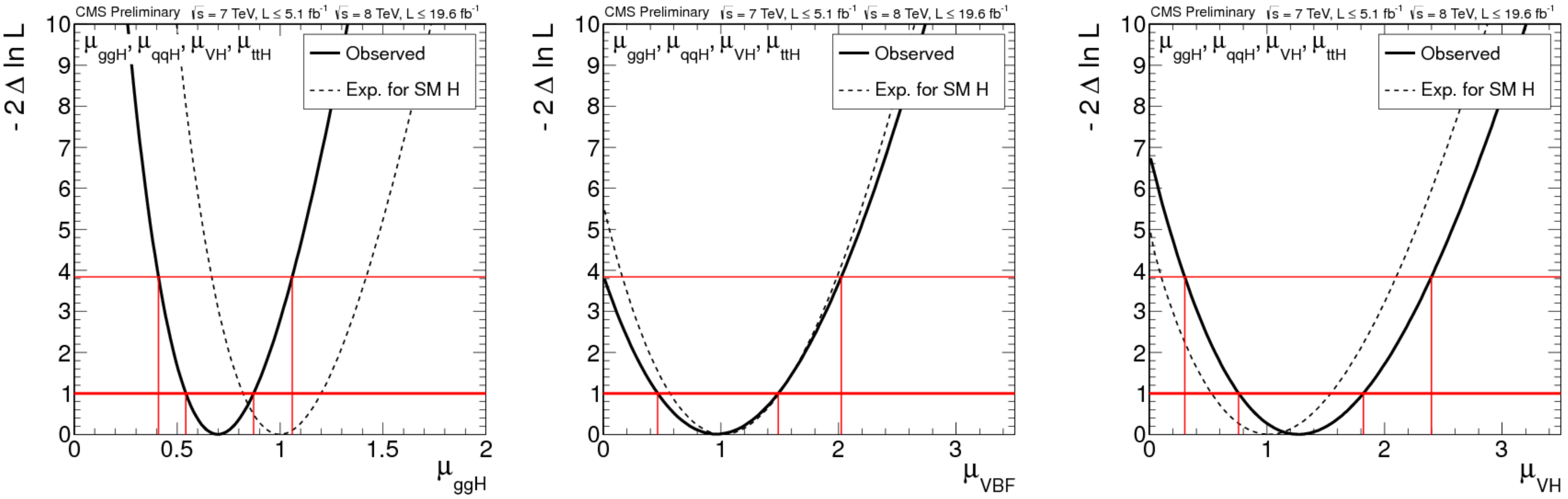
Scan of μ_i as a function of the value of M_H fixed in the combination done by ATLAS.





Signal strengths measured by CMS, presented broken down by individual analysis channel and production mechanism.

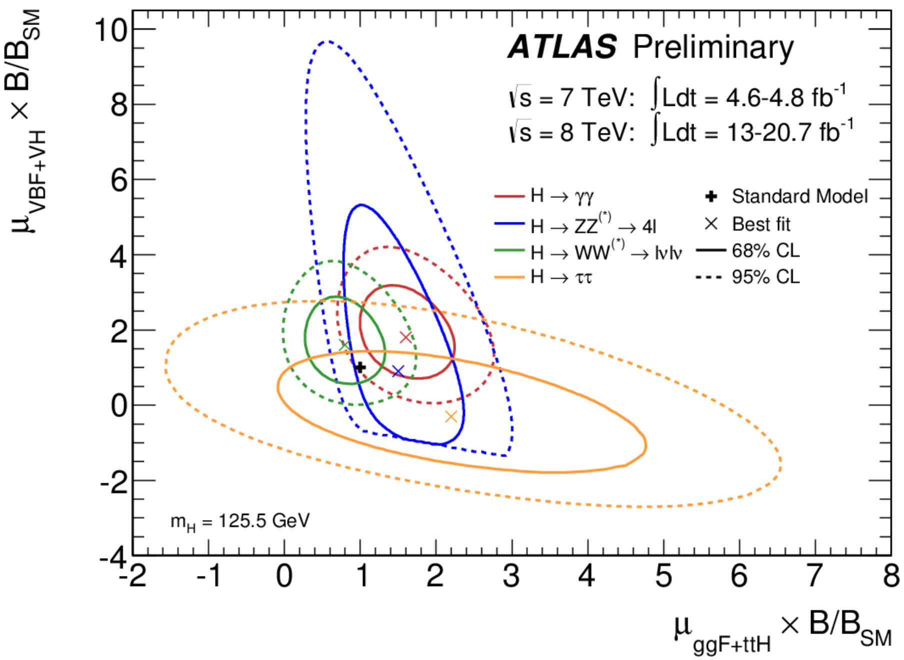
Signal strengths by prod channel



Scan of $q(\mu_i)$ test statistics, profiling all other μ.

Good compatibility with SM prediction.

Signal strengths by prod channel (2D)



Likelihood scan as function of μ_{VBF+VH} and $\mu_{ggH+ttH}$ for individual channels.

Sharp cut in HZZ due to constraint on S+B yield > 0.

No assumption on BR of individual channels (i.e., can be ≠ from SM). Impossible to combine directly the contours. BR simplifies in ratio μ_{VBF+VH} / $\mu_{ggF+ttH}$, combination is possible in that case.

Verify that interactions of new boson with SM particles correspond to those predicted for SM Higgs. Use formalism proposed by LHC XS WG (interim report arXiV:1209.0040).

SM expression for full chain (ii → H → oo)
(for example gg → H → ZZ)

Add scaling factors, **k**,
allow deviations from SM

$$(\sigma_{SM} \cdot BR_{SM})(ii \rightarrow H \rightarrow oo) = \frac{\sigma_{ii,SM} \cdot \Gamma_{oo,SM}}{\Gamma_{H,SM}} \quad \Longrightarrow \quad (\sigma \cdot BR)(ii \rightarrow H \rightarrow oo) = \frac{\sigma_{ii,SM} \cdot \Gamma_{oo,SM}}{\Gamma_{H,SM}} \cdot \frac{k_i^2 k_o^2}{k_H^2}$$

Production modes

$$\frac{\sigma_{\mathrm{ggH}}}{\sigma_{\mathrm{ggH}}^{\mathrm{SM}}} = \begin{cases} \kappa_{\mathrm{g}}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, m_{\mathrm{H}}) \\ \kappa_{\mathrm{g}}^2 \end{cases}$$

$$\frac{\sigma_{\mathrm{VBF}}}{\sigma_{\mathrm{VBF}}^{\mathrm{SM}}} = \kappa_{\mathrm{VBF}}^2(\kappa_{\mathrm{W}}, \kappa_{\mathrm{Z}}, m_{\mathrm{H}})$$

$$\frac{\sigma_{\mathrm{WH}}}{\sigma_{\mathrm{WH}}^{\mathrm{SM}}} = \kappa_{\mathrm{W}}^2$$

$$\frac{\sigma_{\mathrm{ZH}}}{\sigma_{\mathrm{ZH}}^{\mathrm{SM}}} = \kappa_{\mathrm{Z}}^2$$

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

Detectable decay modes

$$\frac{\Gamma_{\mathrm{WW}^{(*)}}}{\Gamma_{\mathrm{WW}^{(*)}}^{\mathrm{SM}}} = \kappa_{\mathrm{W}}^2$$

$$\frac{\Gamma_{\mathrm{ZZ}^{(*)}}}{\Gamma_{\mathrm{ZZ}^{(*)}}^{\mathrm{SM}}} = \kappa_{\mathrm{Z}}^2$$

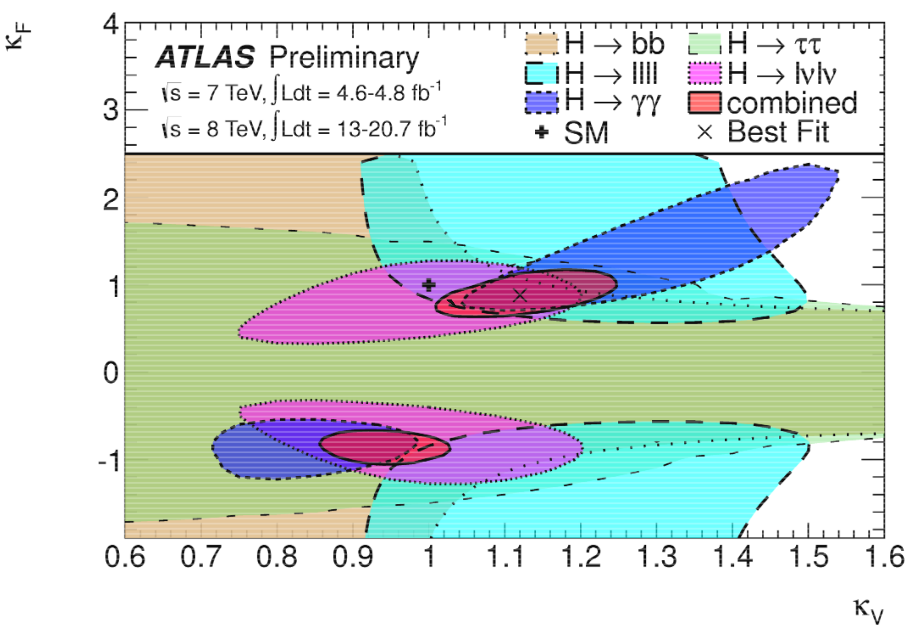
$$\frac{\Gamma_{\mathrm{b\bar{b}}}}{\Gamma_{\mathrm{b\bar{b}}}^{\mathrm{SM}}} = \kappa_{\mathrm{b}}^2$$

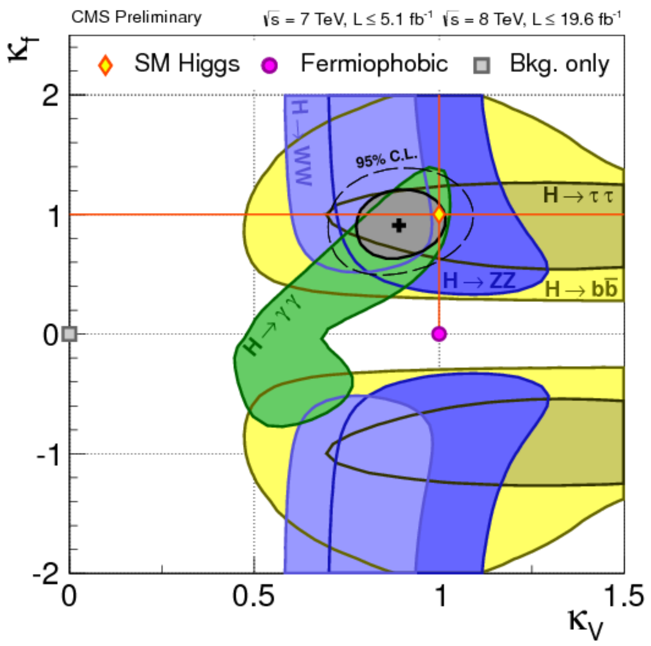
$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{\mathrm{SM}}} = \kappa_{\tau}^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{\mathrm{SM}}} = \begin{cases} \kappa_{\gamma}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa_{\gamma}^2 \end{cases}$$

$$\frac{\Gamma_{\mathrm{Z}\gamma}}{\Gamma_{\mathrm{Z}\gamma}^{\mathrm{SM}}} = \begin{cases} \kappa_{(\mathrm{Z}\gamma)}^2(\kappa_{\mathrm{b}}, \kappa_{\mathrm{t}}, \kappa_{\tau}, \kappa_{\mathrm{W}}, m_{\mathrm{H}}) \\ \kappa_{(\mathrm{Z}\gamma)}^2 \end{cases}$$

k_V / k_F



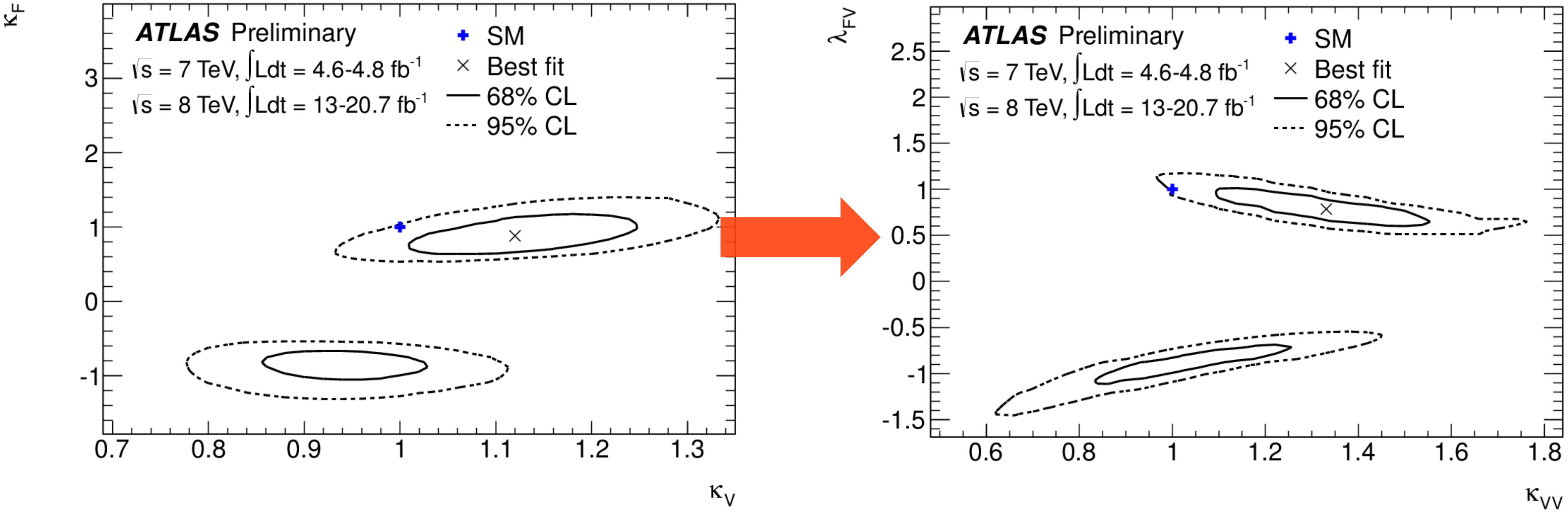


Check that the H candidate couples with fermions and gauge bosons according to SM.

Several assumptions (always needed until we don't have heaps of data):

- $\mathbf{k_V} = k_W = k_Z$
- $\mathbf{k_F} = k_t = k_b = k_\tau = k_g$
- $k_H^2 = 0.75\, k_F^2 + 0.25\, k_V^2$ → H couples only to SM fields !

k_V / k_F



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- $\mathbf{k_V} = k_W = k_Z$
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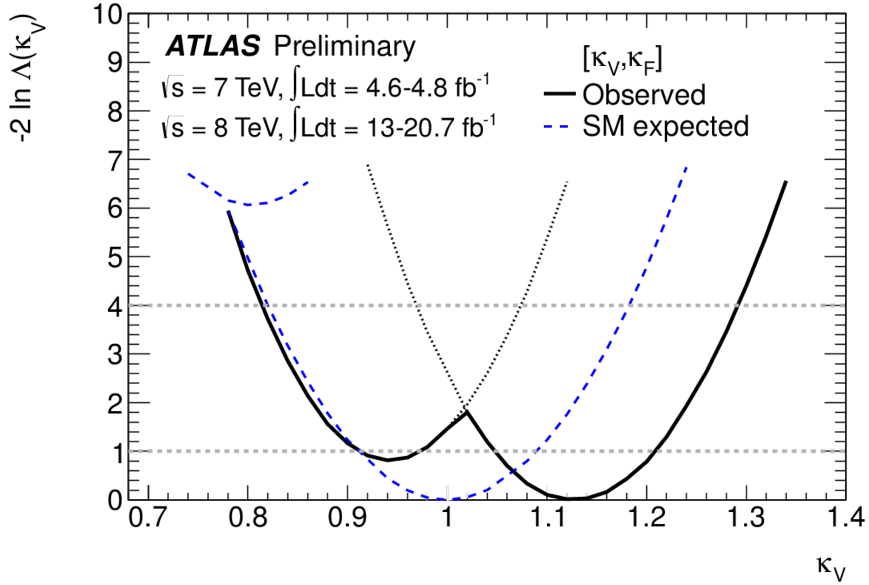
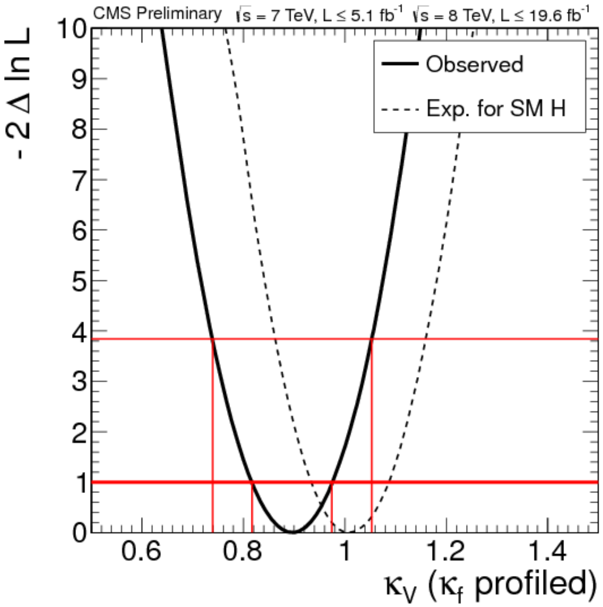
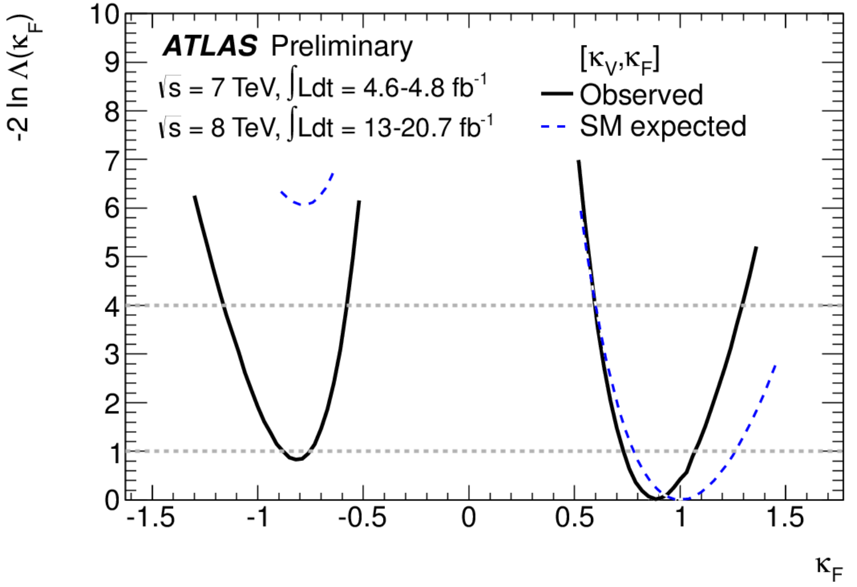
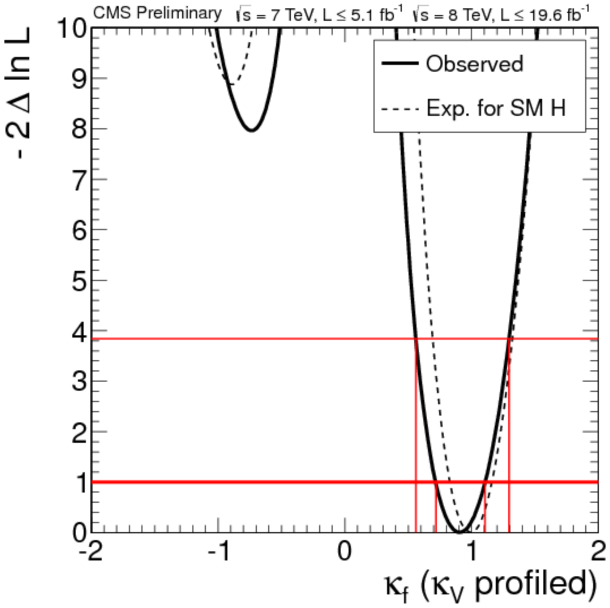
- $k_H^2 = 0.75\, k_F^2 + 0.25\, k_V^2$ → H couples only to SM fields !
- Alternatively, **drop assumption on total width k_H**, scan $\lambda_{FV} = k_F/k_V$ and $k_{VV} = k_V^2 / k_H$

1D scan of $q(k_V)$ and $q(k_F)$

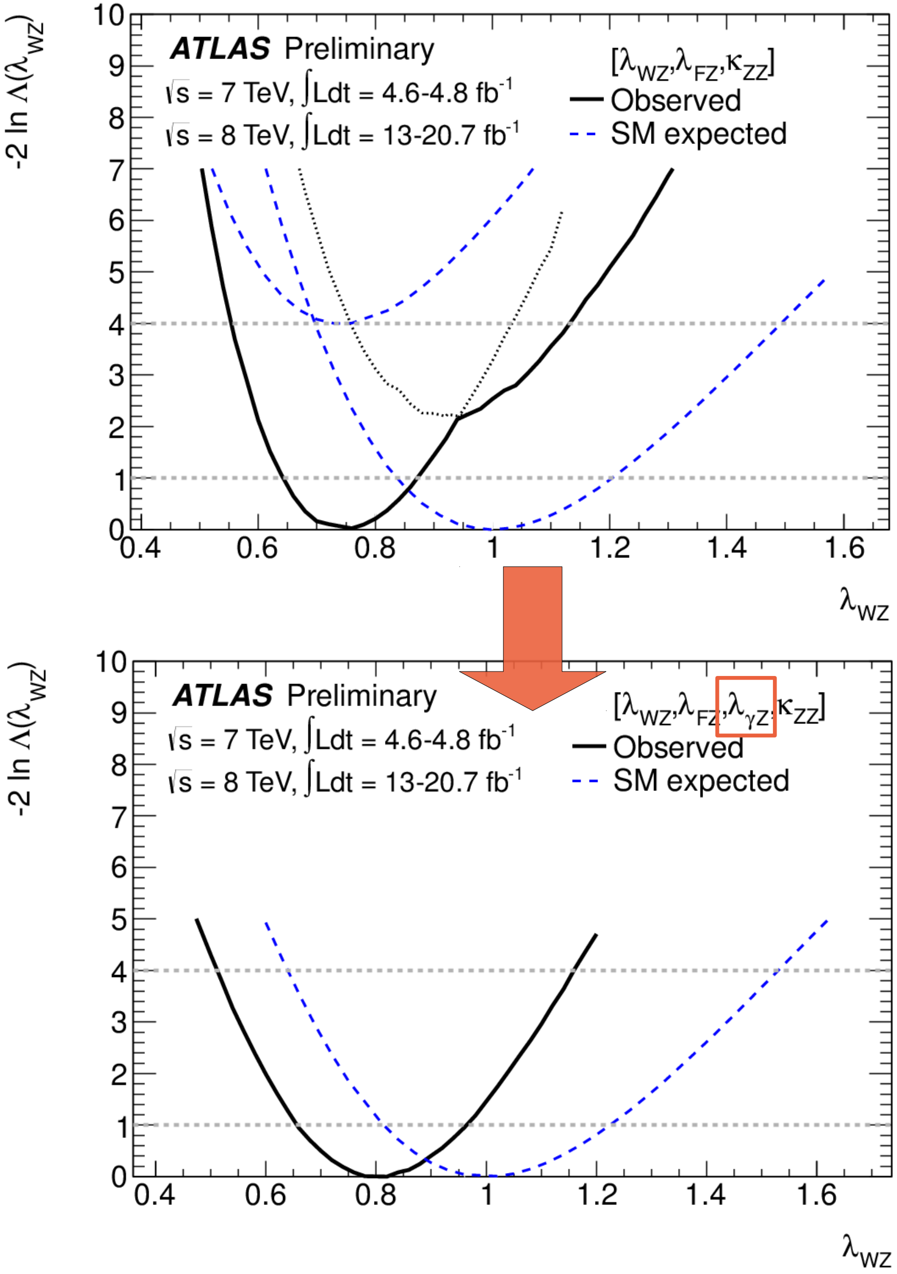








More on test of custodial symmetry

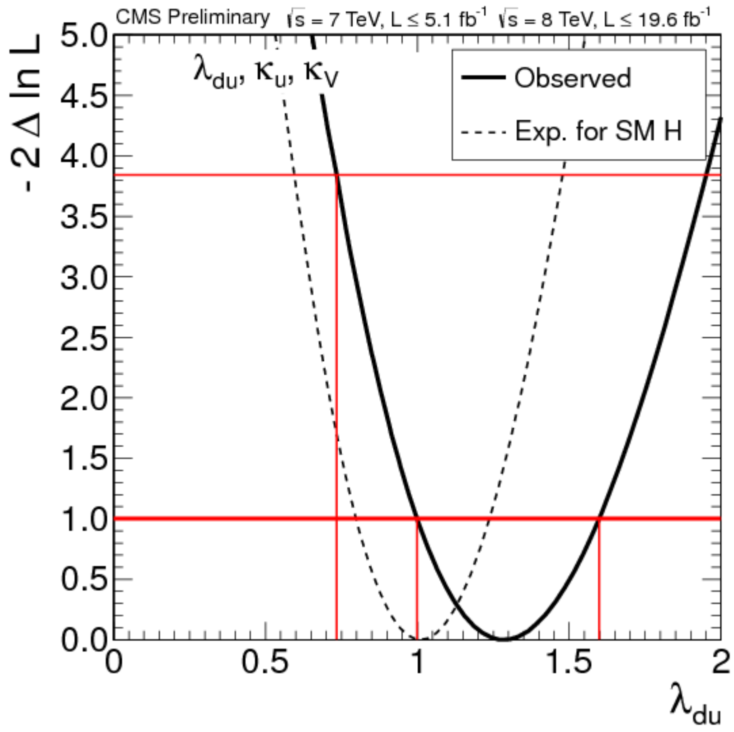


k_W sensitive to Hγγ because of W-induced loops. If BSM physics contributing to Hγγ ,would cause deviations from unity of **λ_{wz}** $= k_W / k_Z$.

Decouple Hγγ from λ_{WZ} measurement, add one more free parameter:

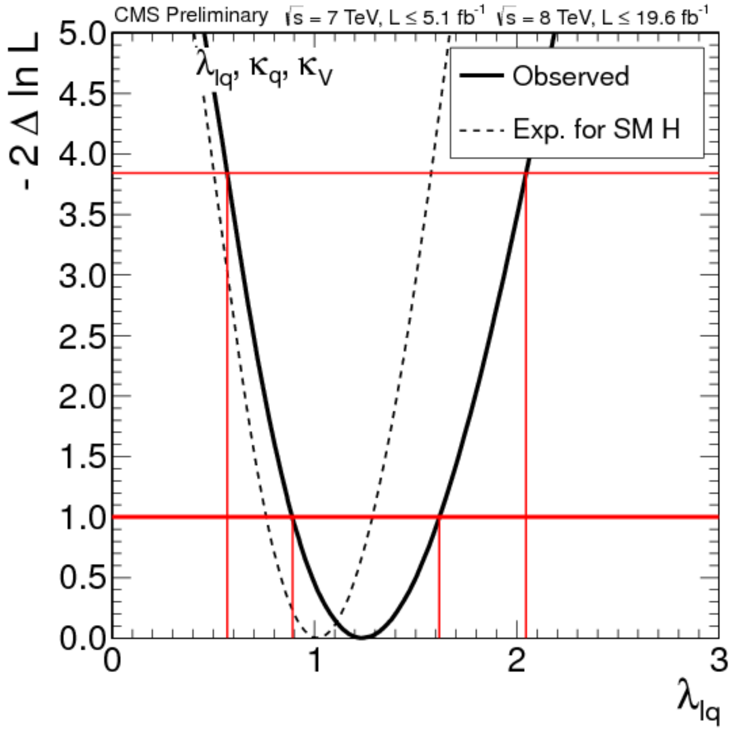
- λ_{WZ} (POI)
- $k_{ZZ} = k_Z^2 / k_H$ (profiled)
- $k_{FZ} = k_F / k_Z$ (profiled)
- $k_{\gamma Z} = k_\gamma / k_Z$ (profiled, new!)

Test of fermion universality



Up quark vs Down quark scale factors, k_d and k_u ; $\lambda_{du} = k_d / k_u$

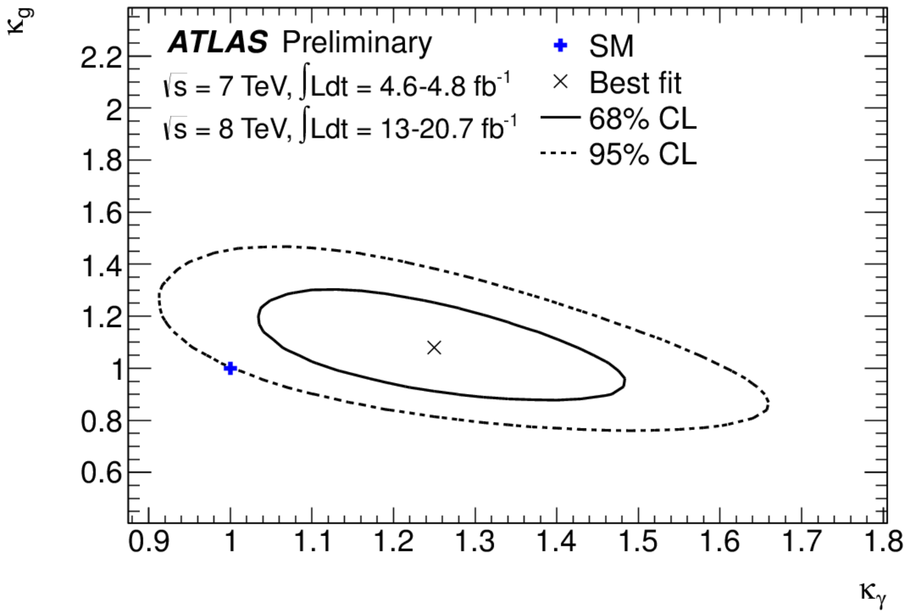
- k_u and k_v profiled
- k_u and k_v constrained to be >0

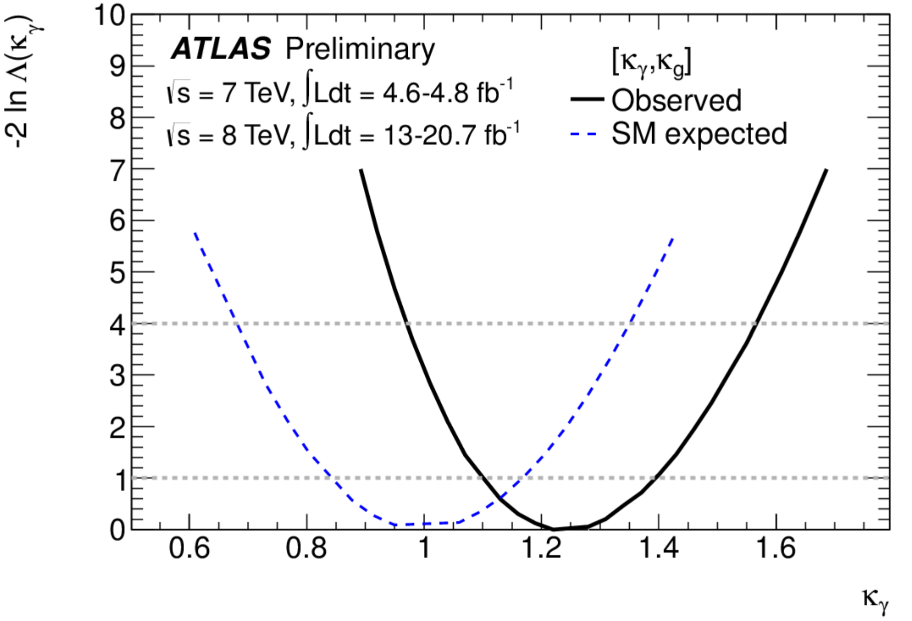


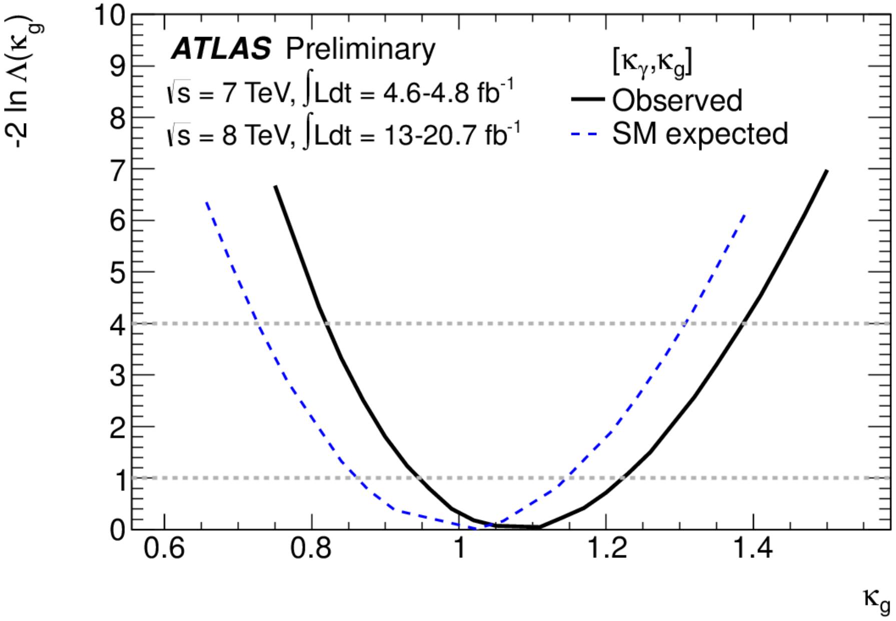
Lepton vs Quark scale factors, k_l and k_q ; $\lambda_{lq} = k_l / k_q$

- k_q and k_v profiled
- k_q and k_v constrained to be >0

k_g / k_γ scan







k_g / k_γ scan