Combination of all searches and extraction of properties of the Higgs boson (ATLAS and CMS)

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July 4th, 2012 : the discovery

In the search for the Higgs boson, ATLAS and CMS reported evidence for a new resonance,
decaying as:

$$H \to \gamma\gamma$$
$$H \to ZZ^* \to 4\ell$$
$$H \to WW^* \to \ell\nu\ell\nu$$

with a mass $m_H \simeq 125\ \mathrm{GeV}$

F.Gianotti R.Heuer J.Incandela

"We have a discovery!"

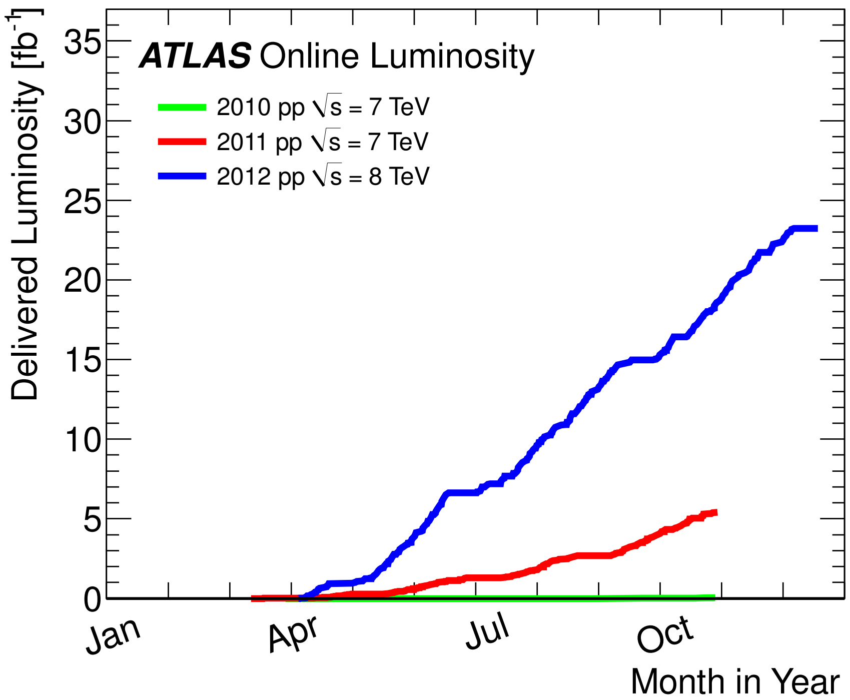
Is the new particle indeed the Higgs boson?

If yes, it should have some typical "fingerprints":

- it should have spin=0 and even parity: $J^P = 0^+$
- it should have couplings proportional to the masses of the decay products

Contents

The "LHC run-1" ended in December 2012
Overall integrated luminosity :
$\int L\, dt \sim 5\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 7\ \mathrm{TeV}$
$\int L\, dt \sim 20\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 8\ \mathrm{TeV}$

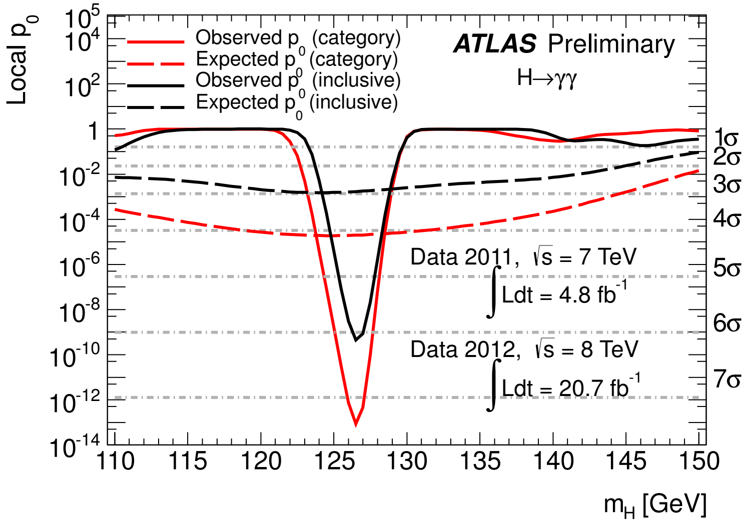


ATLAS and CMS analysed the complete data sets for the $\gamma\gamma$, ZZ^* , WW^* decay channels

In this talk:

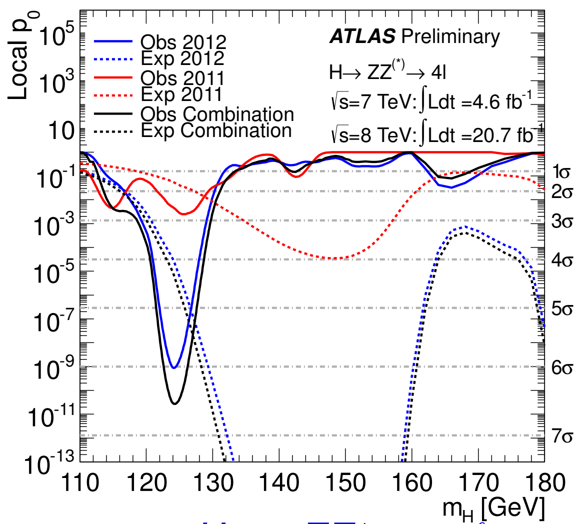
- observation in the bosonic decay channels
- mass measurements from $\gamma\gamma, ZZ^*$ combination
- signal strength (by channel and combined)
- effective couplings (from combination of decay channels)
- spin and parity (by channel and combined)

Observations of the new boson: at ATLAS . . .



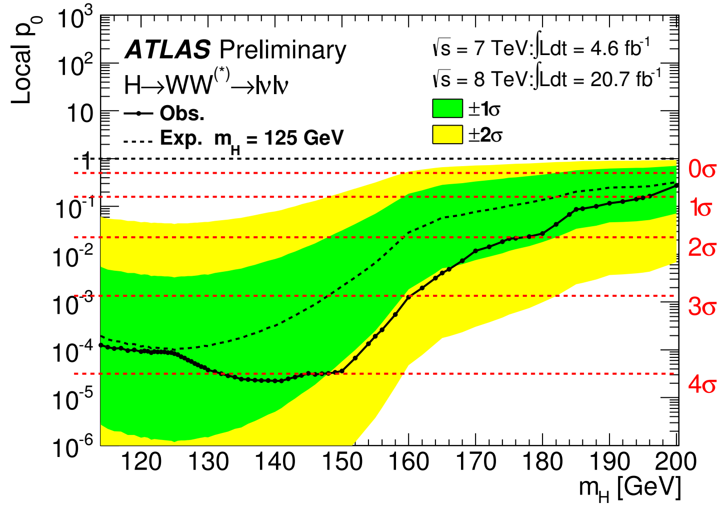
$H \to \gamma\gamma$

(ATLAS-CONF-2013-012)



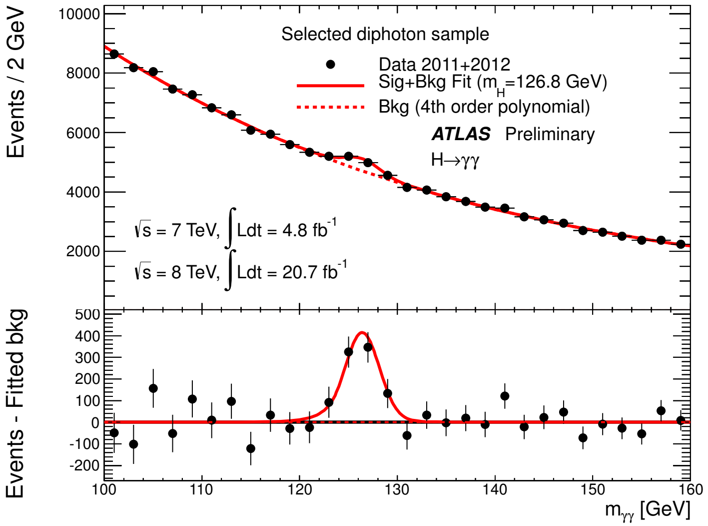
$H \to ZZ^* \to 4\ell$

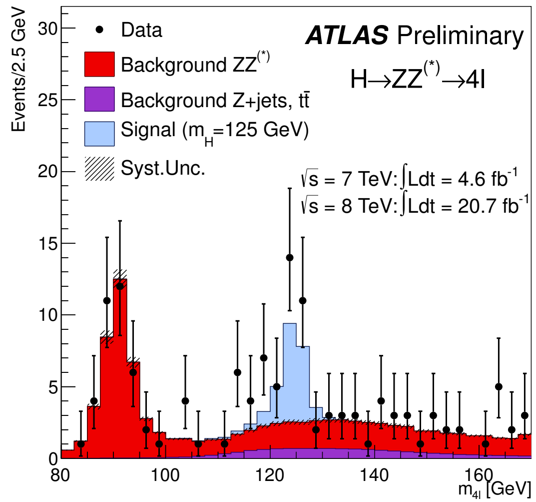
(ATLAS-CONF-2013-013)



$H \to WW^* \to \ell^+\nu\ell^-\bar{\nu}$

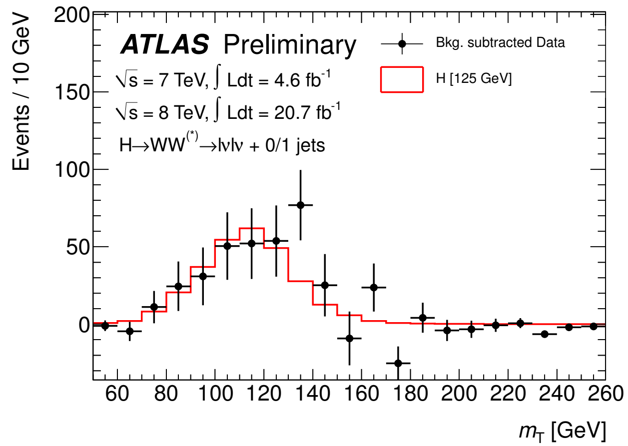
(ATLAS-CONF-2013-030)



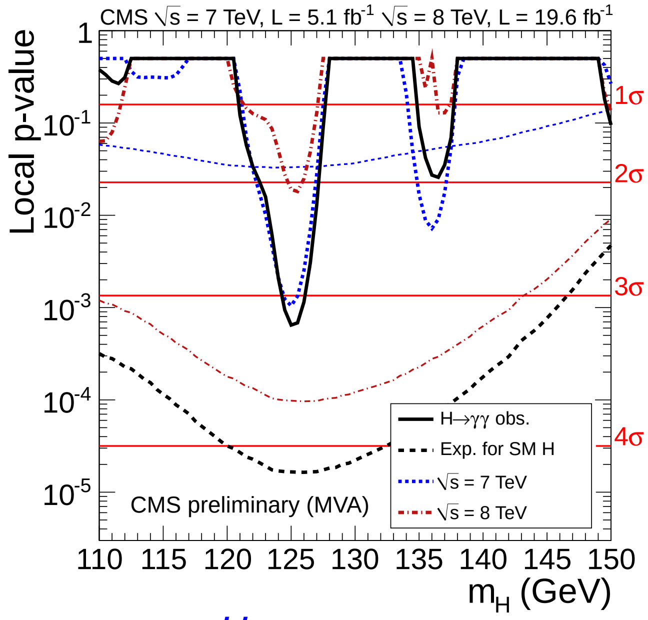


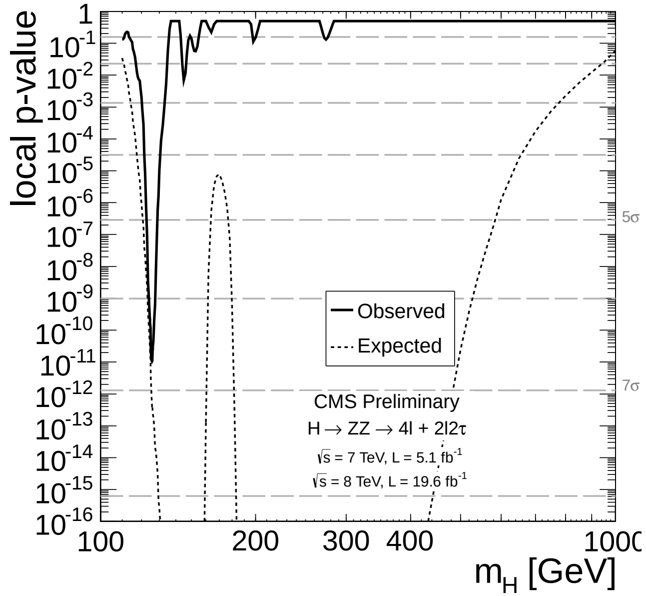
$$m_T = \sqrt{(E_T^{\ell\ell} + \not{E}_T)^2 - (\vec{p}_T^{\,\ell\ell} + \vec{\not{P}}_T)^2}$$

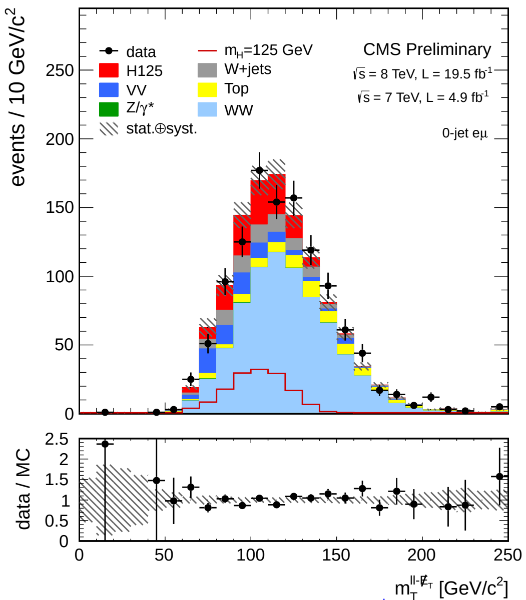
(background subtracted)



. . . and at CMS



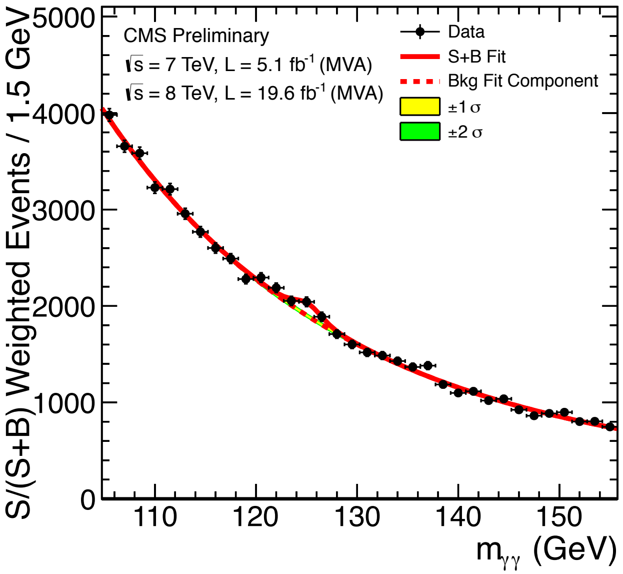


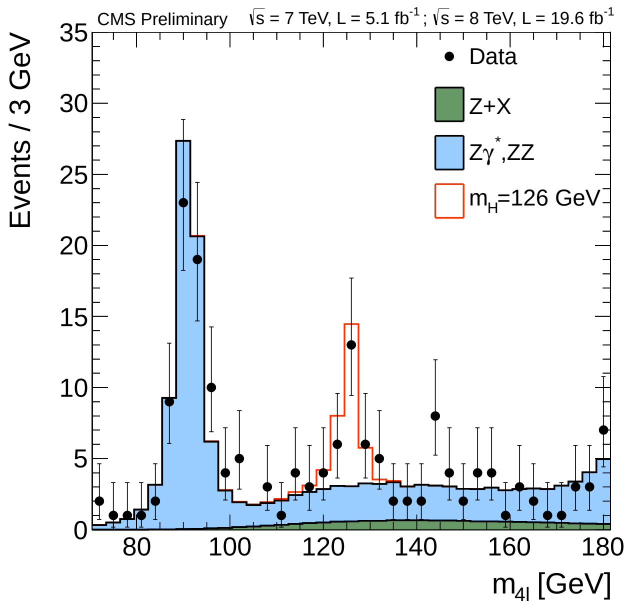


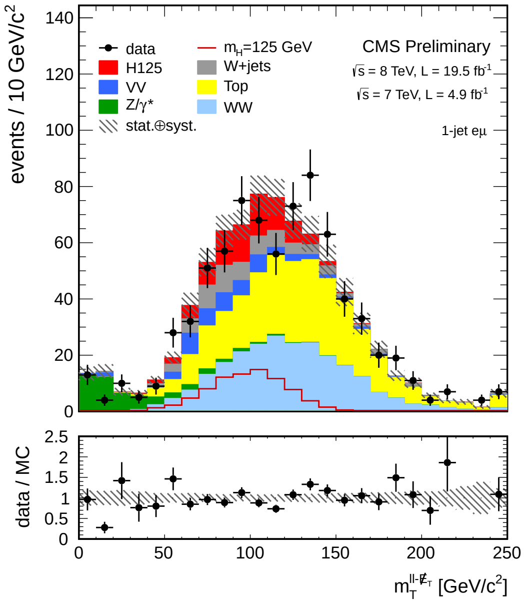
$H \to \gamma\gamma$ **(CMS PAS HIG-13-001)**

$H \to ZZ^* \to 4\ell$ **(CMS PAS HIG-13-002)**

$H \to WW^* \to \ell^+\nu\ell^-\bar{\nu}$ **(CMS PAS HIG-13-003)**







If it is indeed the Standard Model Higgs boson. . .

$$V(\phi) = \lambda \left(\phi^\dagger \phi\right)^2 - \mu^2 \left(\phi^\dagger \phi\right)$$

. . . it would be the last missing piece of the Standard Model;
. . . its mass m_H would be the last unknown parameter of the model

VEV: $v = \mu/\sqrt{\lambda} = 2m_W/g$
mass: $m_H = \sqrt{2} \cdot \mu$

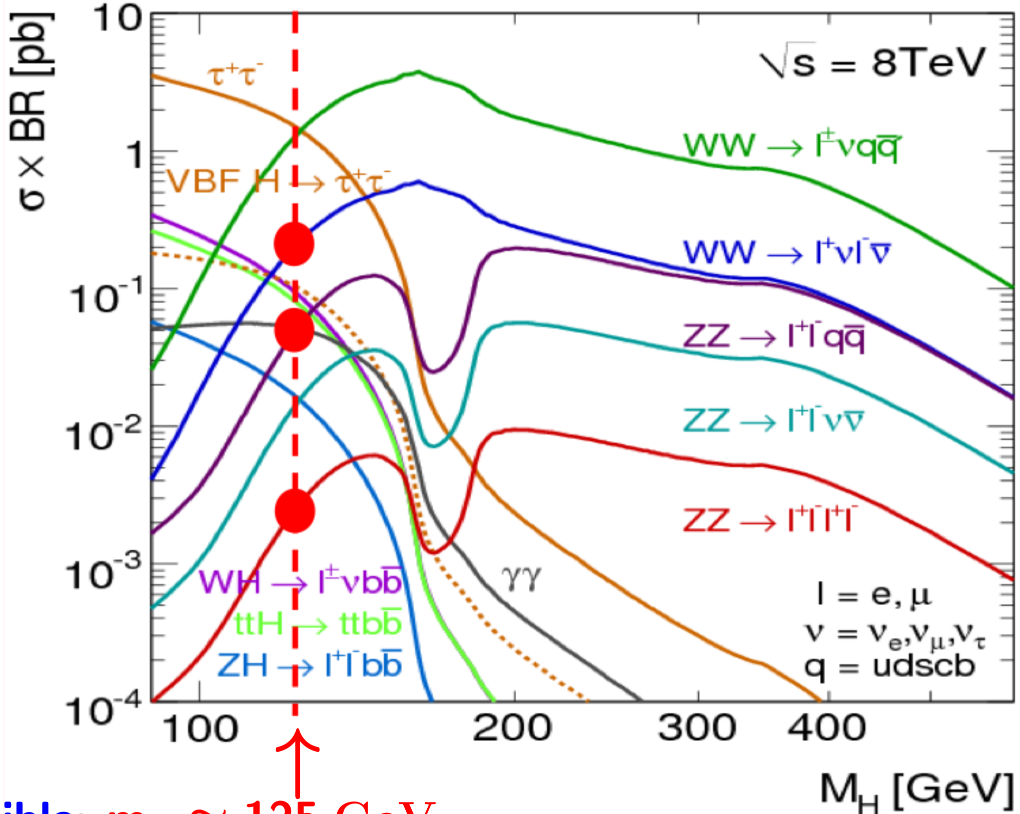
All the other properties would become calculable:

- couplings to the electroweak gauge bosons:

$$g m_W \cdot (HWW) \; + \; \frac{g m_Z}{2\cos\theta_W} \cdot (HZZ)$$

- Yukawa couplings to all fermions

$$\frac{m_f}{v} \cdot (H\bar{f}f)$$



at the observed mass many decay modes are accessible: $\mathbf{m_H \approx 125\ GeV}$

Statistical models used in measurements

Extended likelihood function: $\mathcal{L}(\vec{\alpha};\vec{\nu})$:

$$-\ln\mathcal{L}(\vec{\alpha};\vec{\nu}) = (n_s+n_b) - \sum_e \left[\overbrace{n_s \cdot f_s\left(\vec{x}_e|\vec{\alpha},\vec{\nu}_s\right)}^{\text{signal pdf}} + \overbrace{n_b \cdot f_b\left(\vec{x}_e|\vec{\nu}_b\right)}^{\text{background pdf}} \right]$$

$$- \overbrace{\sum_k \ln \pi_k(\nu_k)}^{\text{ancillary pdfs}}$$

n_s, n_b: signal / background yields
$\vec{x}$: observables
f_s, f_b: signal / background pdfs
$\vec{\alpha}$: parameters of interest
(e.g.: mass, cross-section, spin, ...)
$\vec{\nu}$: "nuisance parameters"
(shape parameters, systematics, ...)
π_k: pdfs obtained from auxiliary measurements

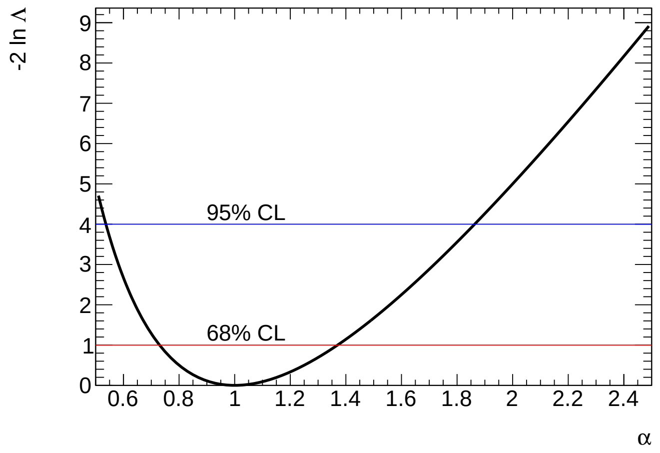
Test statistic: "Profiled Likelihood Ratio" (PLR)

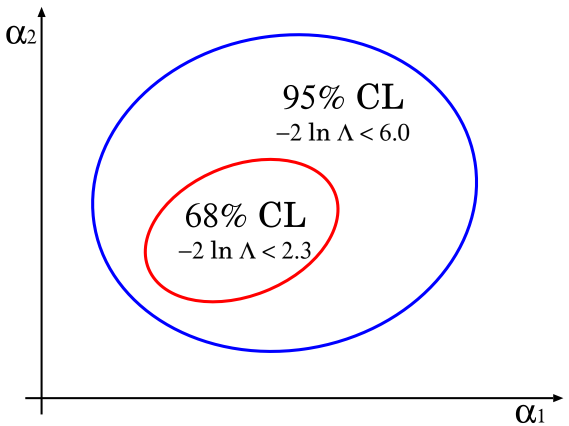
$$q_{\vec{\alpha}} = -2\ln\Lambda(\vec{\alpha}) = -2\ln\frac{\mathcal{L}(\vec{\alpha};\hat{\hat{\vec{\nu}}}(\vec{\alpha}))}{\mathcal{L}(\hat{\vec{\alpha}};\hat{\vec{\nu}})}$$

$\leftarrow \mathcal{L}(\vec{\alpha};\hat{\hat{\vec{\nu}}}(\vec{\alpha}))$: likelihood for fixed $\vec{\alpha}$ and "profiled" $\vec{\nu}$
$\leftarrow \mathcal{L}(\hat{\vec{\alpha}};\hat{\vec{\nu}})$: maximum likelihood for free $\vec{\alpha},\vec{\nu}$

Wilks' theorem : *if $\vec{\alpha} = \vec{\alpha}^{true}$, then $q_{\vec{\alpha}}$ follows a χ^2_D distribution, with D being the number of parameters of interest $\vec{\alpha}$*

$\Rightarrow$ compute confidence intervals for $\vec{\alpha}$





Mass measurement

(ATLAS-CONF-2013-014 ; CMS PAS HIG-13-005)

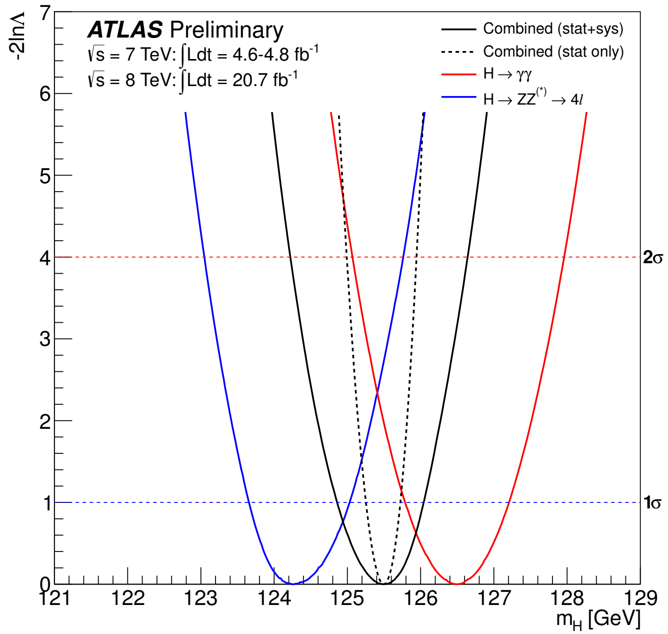
Mass measurements

ATLAS

Measurements from separate decay channels:

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

$m_H^{4\ell} = 124.3^{+0.6}_{-0.5}(stat)^{+0.5}_{-0.3}(syst)$ GeV



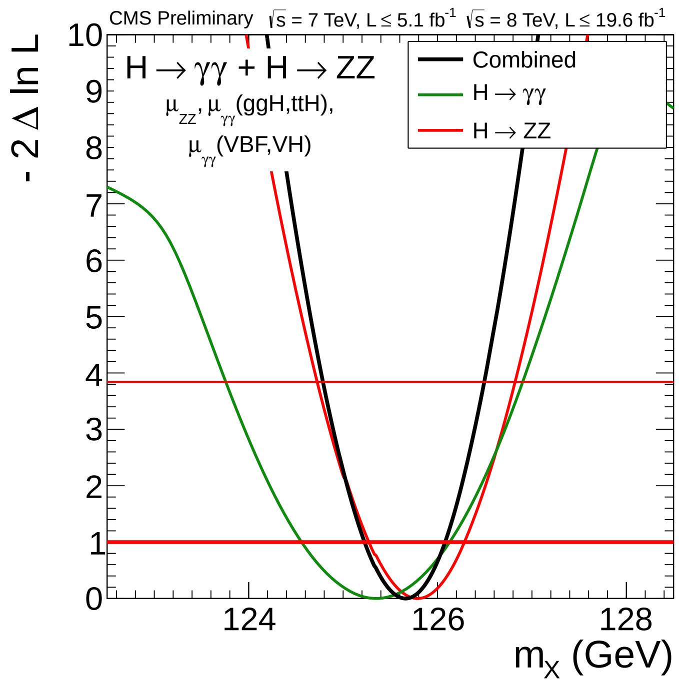
$\hat{m}_H = 125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(syst)$ GeV

CMS

Measurements from separate decay channels:

$m_H^{\gamma\gamma} = 125.4 \pm 0.5(stat) \pm 0.6(syst)$ GeV

$m_H^{4\ell} = 125.8 \pm 0.5(stat) \pm 0.2(syst)$ GeV



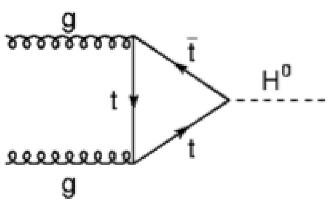
$\hat{m}_H = 125.7 \pm 0.3(stat) \pm 0.3(syst)$ GeV

(e, μ energy scales from $J/\psi, \Upsilon, Z \rightarrow \ell\ell$; γ energy scale from $Z \rightarrow e^+e^-$ and $e \rightarrow \gamma$ extrapolation)

Couplings measurements

(ATLAS-CONF-2013-034 , CMS PAS HIG-13-005)

Production modes and categories



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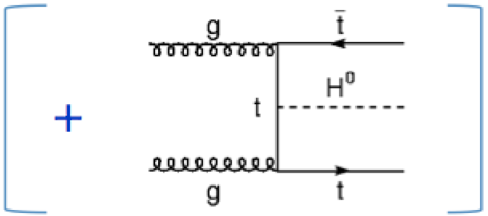

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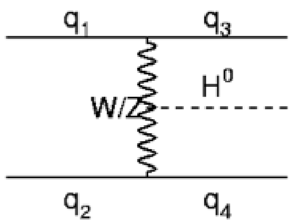
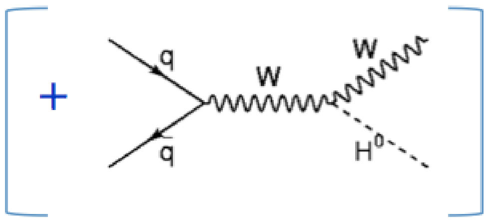
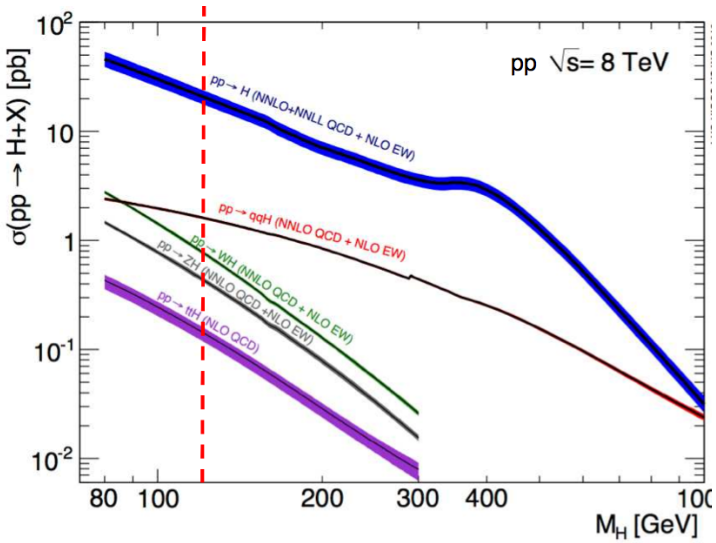


VBF



VH



More exclusive channels have a better signal-to-background ratio ⇒ introduce categories

Moreover, this provides sensitivity to production modes (therefore to fermion/vector couplings)
Possible "production tags":

- two hard jets with large $|\eta|$ and large m_{jj} ⇒ VBF mode
- two jets with small m_{jj} ⇒ VH mode with V→ jj
- identified lepton (e, μ) ⇒ VH mode with V→ $\ell(\ell)$
- missing transverse energy ⇒ ZH mode with Z→ $\nu\nu$
- "untagged" ⇒ mainly ggF
  (divide in more categories according to e.g. photons' η and conversion status)

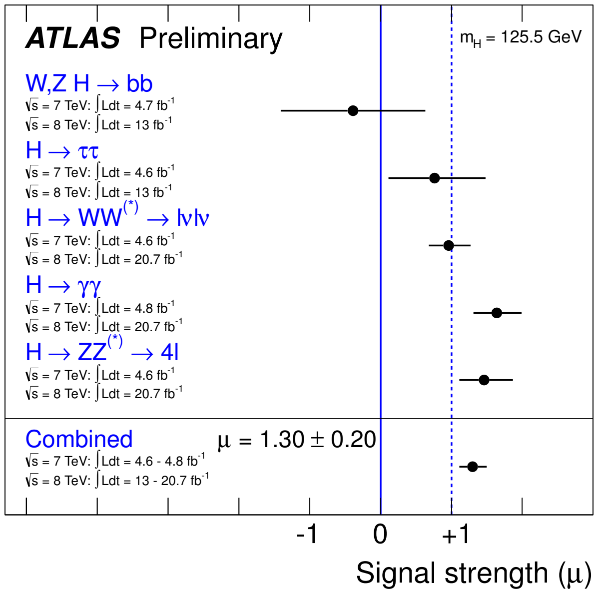
CAVEAT: "prod tags" are enriched by specific production modes, but are not pure samples

Signal strengths

By definition, $\mu = \dfrac{\sigma^{\text{obs}}}{\sigma_{SM}}$ ($\mu \simeq 1$ means compatibility with SM Higgs boson signal)

ATLAS

by decay channel

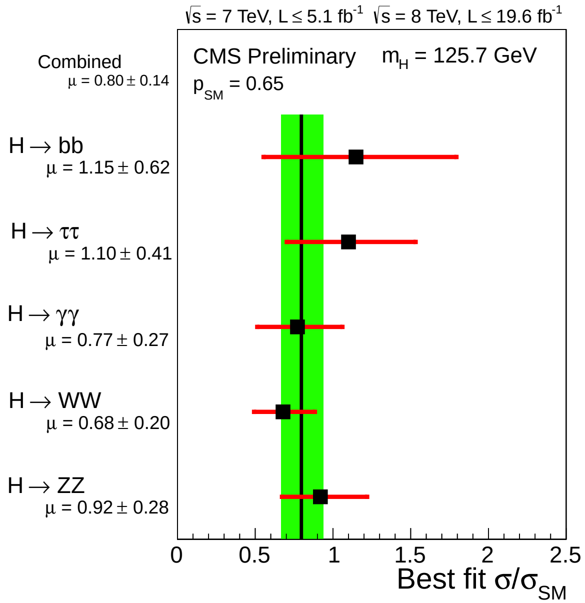


$\hat{\mu} = 1.30 \pm 0.13(stat) \pm 0.14(syst)$

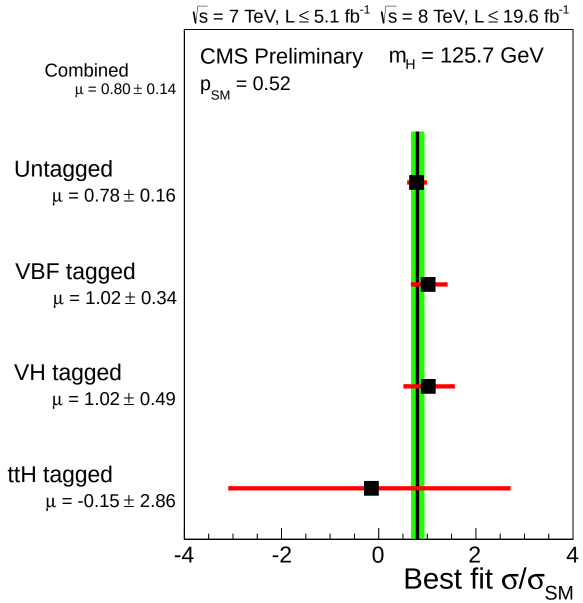
13% compatibility among channels
9% compatibility with SM

CMS

by decay channel



by prod tag

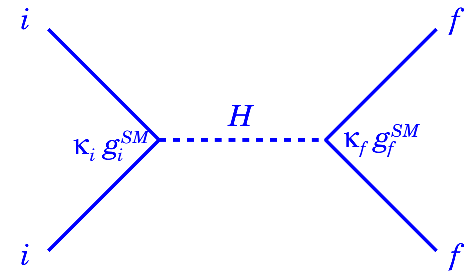


$\hat{\mu} = 0.80 \pm 0.14$

50% compatibility among decay channels
37% compatibility among production tags

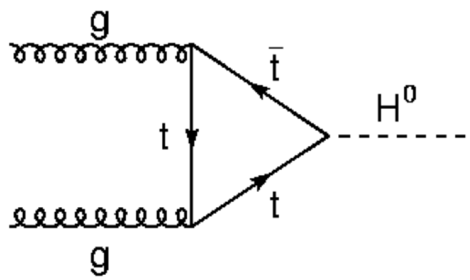
Effective couplings

Assume a tree-level model for a process $ii \to H \to ff$ with effective couplings:



$$\sigma(ii \to H) \times BR(H \to ff) = \frac{\sigma_{ii}\Gamma_{ff}}{\Gamma_H} = \overbrace{\sigma_{SM}(ii \to H) \times BR_{SM}(H \to ff)}^{\text{SM prediction}} \times \left[\frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}\right]$$

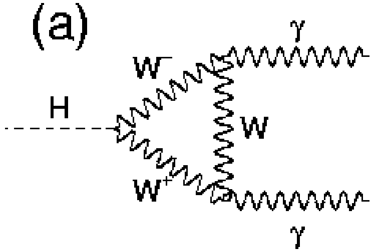
$\kappa_{i,f}$ are scale factors wrt Standard Model couplings $g_{i,f}^{SM}$
($\kappa_{i,f} \simeq 1$ means compatibility with SM Higgs boson)



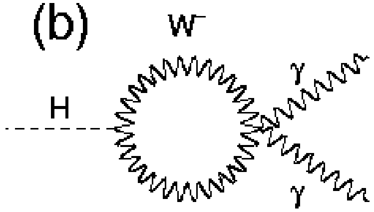
Some assumptions

- universality of κ's for fermions and for gauge bosons:
  $\kappa_t = \kappa_b = \kappa_\tau = \kappa_F$ and $\kappa_W = \kappa_Z = \kappa_V$
- gg-fusion $gg \to H$ mediated by a top loop as in SM
  $\Rightarrow \kappa_g = \kappa_F$
- $H \to \gamma\gamma$ decay mediated by W and top loops
  $\Rightarrow \kappa_\gamma^2 = (1.26 \cdot \kappa_V - 0.26 \cdot \kappa_F)^2$ (at $m_H = 125.5$)
  (sensitive to relative sign between κ_F, κ_V)
- in SM $BR(H \to f\bar{f}, gg) = 0.75$
  $\Rightarrow \kappa_H^2 = 0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2$ (at $m_H = 125.5$)

(a)



(b)



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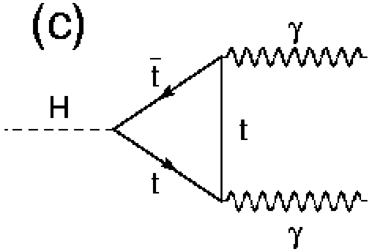
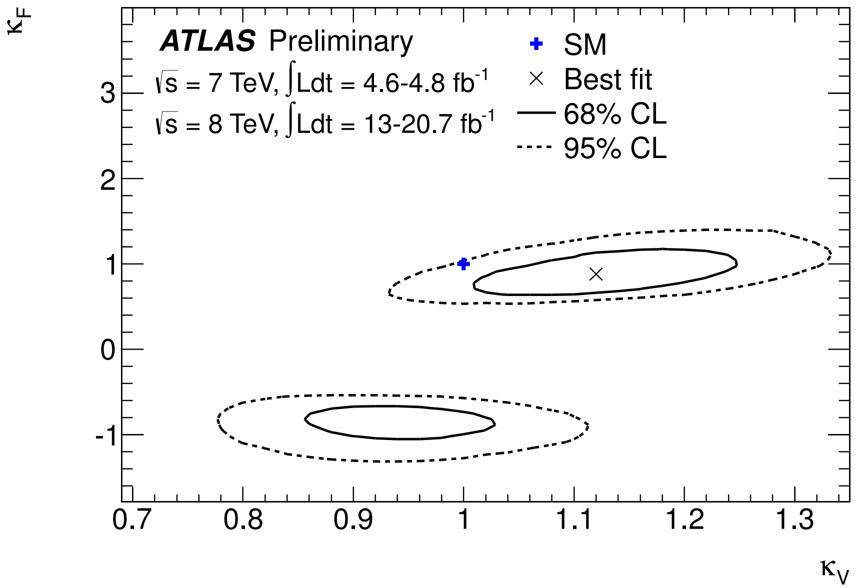
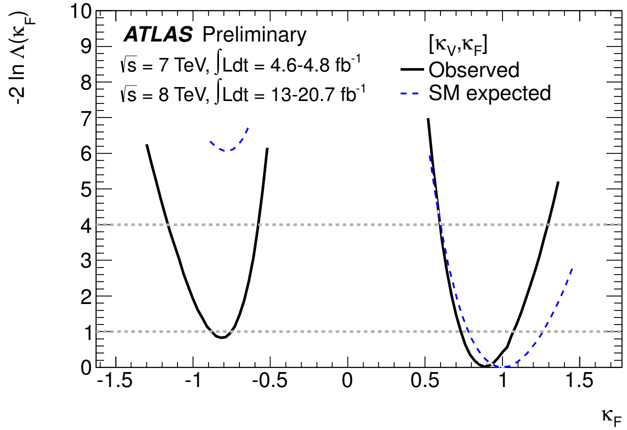


Fermion vs gauge boson couplings factors

ATLAS

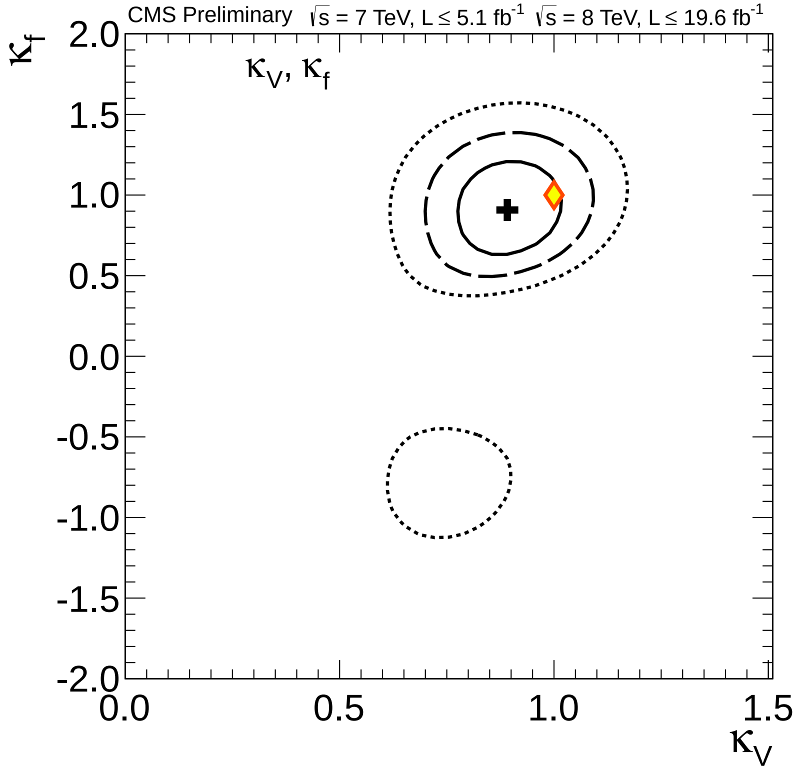




Two minima, but fit prefers same-sign κ_F, κ_V

8% compatibility with SM

CMS



$\kappa_V > 0$ by convention ; $\pm\kappa_F$ asymmetry due to $\gamma\gamma$:
$\kappa_\gamma^2 = (1.26 \cdot \kappa_V - 0.26 \cdot \kappa_F)^2$

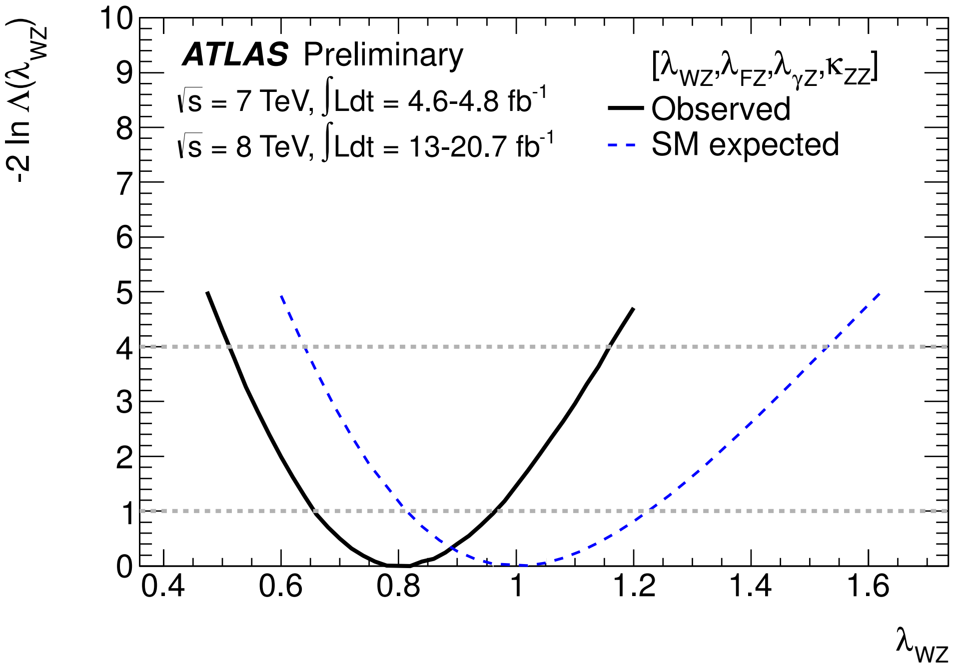
$\Rightarrow$ **Evidence for both fermion and vector couplings**

The difference between ATLAS and CMS is due to the large $H \to \gamma\gamma$ yield observed by ATLAS

Testing the custodial symmetry

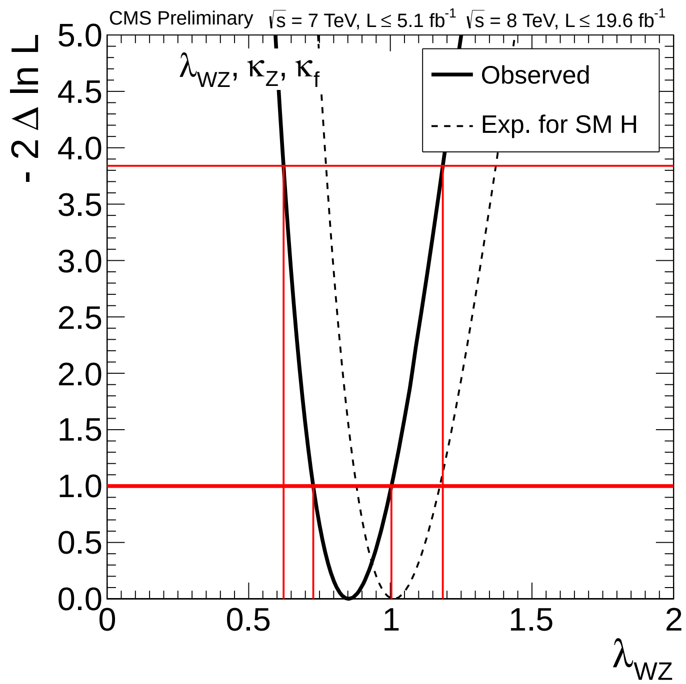
Assume κ_W, κ_Z independent, test $\lambda_{WZ} \stackrel{\text{def}}{=} \frac{\kappa_W}{\kappa_Z}$

ATLAS



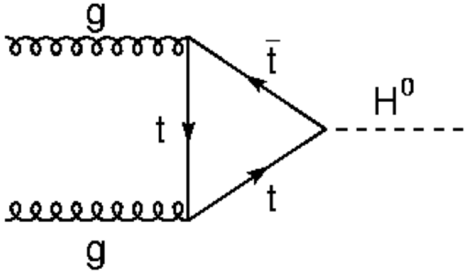
$\lambda_{WZ} = 0.80 \pm 0.15$

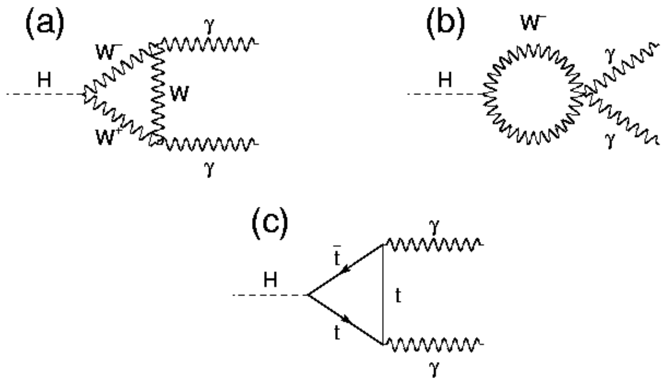
CMS



$\lambda_{WZ} \in [\ 0.73\ ;\ 1.00\ ]$

Testing possible new physics in loops

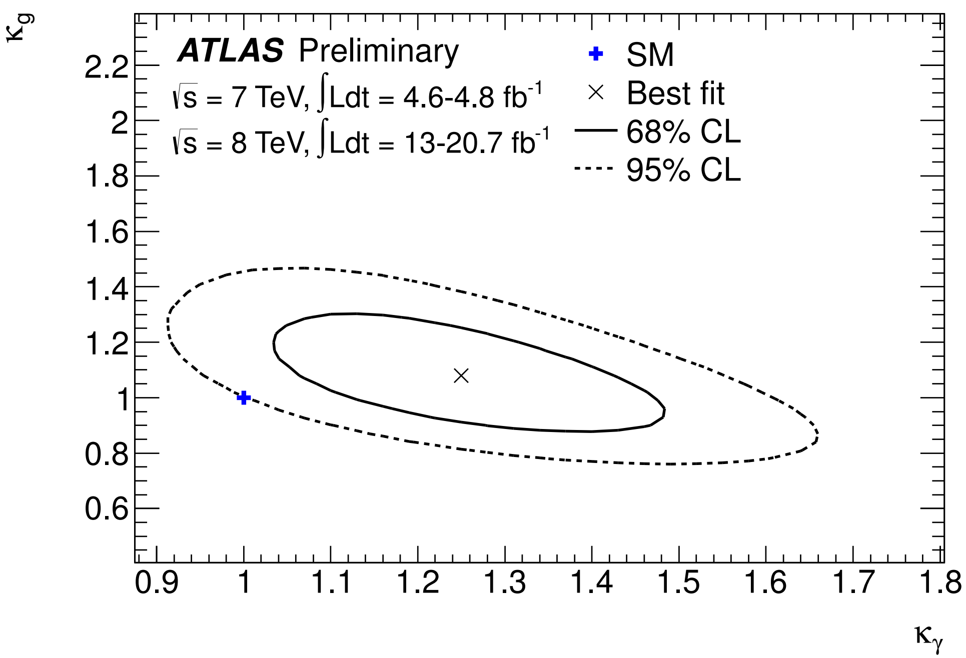




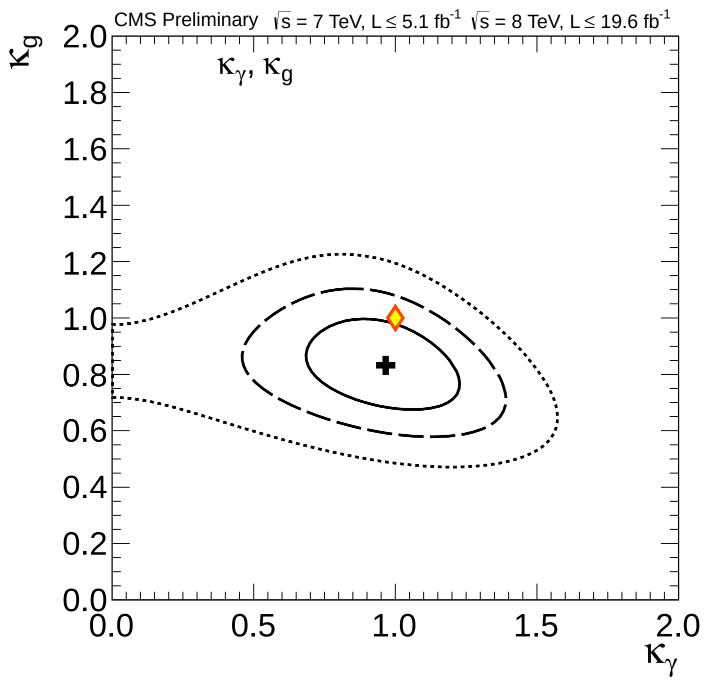
ggH and $H\gamma\gamma$ interactions in the SM are mediated by loops
$\Rightarrow$ particularly sensitive to new physics beyond SM

Assume all $\kappa = 1$ except κ_γ and κ_g left free

ATLAS



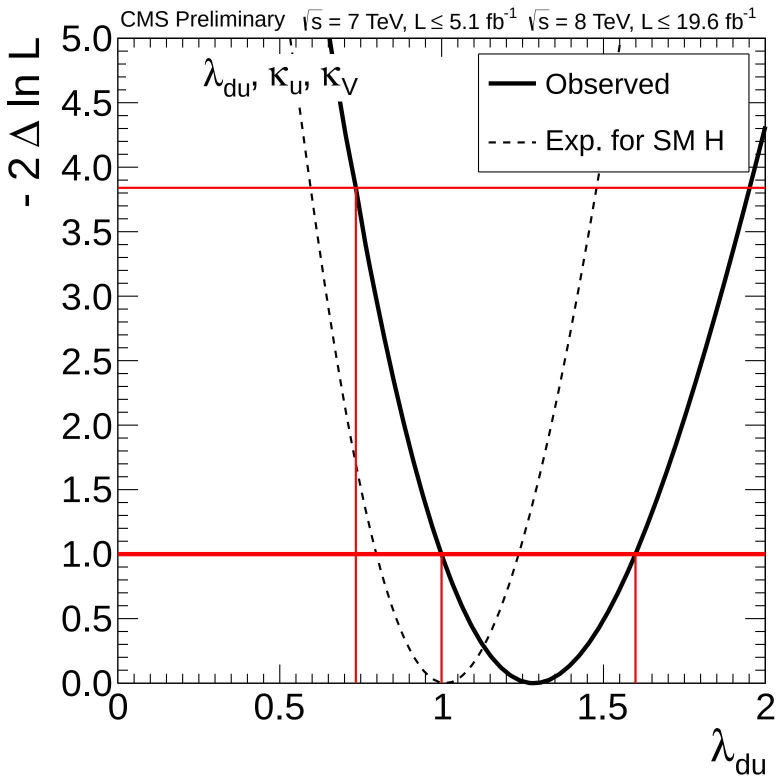
CMS



Testing alternative Higgs models (CMS)

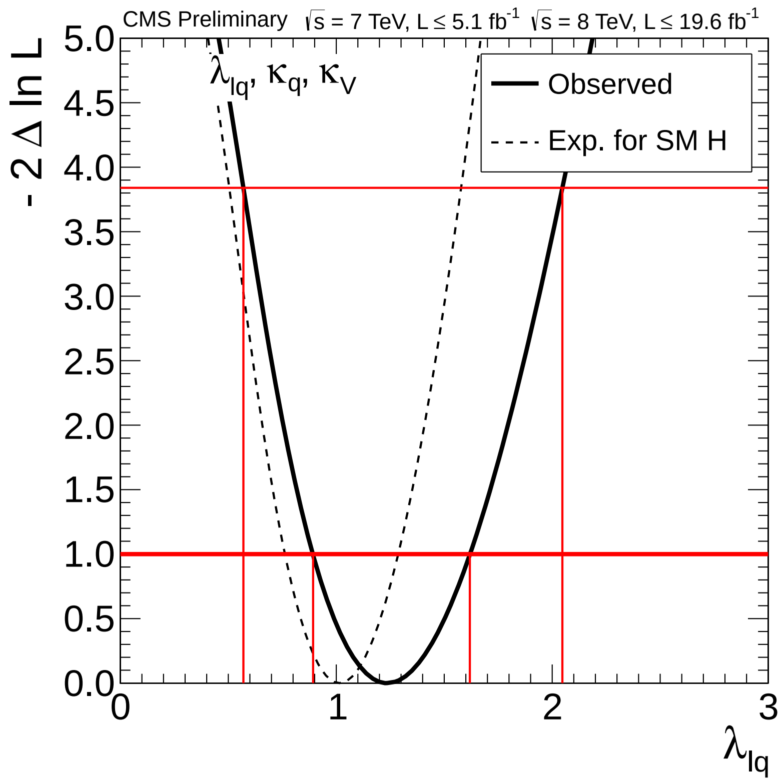
In some two-doublet models (2HDM) up-type and down-type fermions couple to different Higgs fields
. . . or leptons and quarks may have different couplings

Probing up/down fermion couplings



$$\lambda_{du} \stackrel{\text{def}}{=} \frac{\kappa_d}{\kappa_u} \in [1.00; 1.60]$$

Probing quark/lepton couplings



$$\lambda_{\ell q} \stackrel{\text{def}}{=} \frac{\kappa_\ell}{\kappa_q} \in [0.89; 1.62]$$

Spin and parity measurements

(ATLAS-CONF-2013-029 , ATLAS-CONF-2013-031 , ATLAS-CONF-2013-013 , ATLAS-CONF-2013-040)

(CMS PAS HIG-13-002 , CMS PAS HIG-13-003 , CMS PAS HIG-13-005)

Spin measurements: introduction

The observed decays into $\gamma\gamma$, ZZ^*, WW^* imply integer spin
The decay into $\gamma\gamma$ excludes the spin-1 possibility (Landau-Yang theorem)

A Standard Model Higgs boson must have $J^P = 0^+$
$\Rightarrow$ the interesting alternative hypotheses are 0^- , $2^\pm$ (but $1^\pm$ are also investigated)

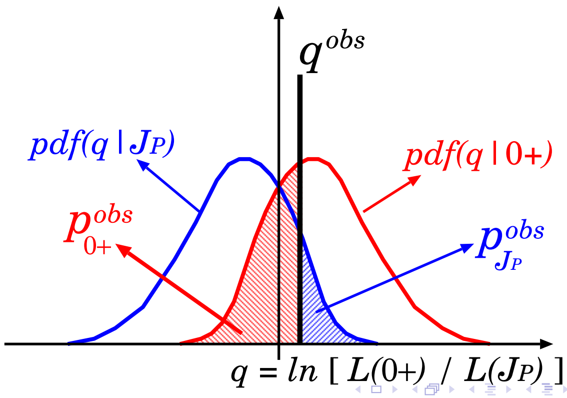
In practice, the most generic lagrangian for a spin-2 particle contains many free parameters, and it would impossible to exclude it in the most general case.
$\Rightarrow$ we chose the "minimal coupling" scenario, 2^+_m — inspired by a graviton model.

Moreover, the production mechanisms $gg \to (2^+_m)$ and $q\bar{q} \to (2^+_m)$ give rise to different polarization states, hence different angular distributions.
CMS tests both production modes. ATLAS explores several possible "mixtures":

$$f_{q\bar{q}} \stackrel{\text{def}}{=} \frac{\sigma(q\bar{q} \to 2^+_m)}{\sigma(q\bar{q} \to 2^+_m) + \sigma(gg \to 2^+_m)} \in \{ 0.00 , 0.25 , 0.50 , 0.75 , 1.00 \}$$

Test statistic: here we compare alternative hypotheses $\mathcal{H}_{0^+}, \mathcal{H}_{J^P_{alt}}$

$\Rightarrow$ use Ratio of Profiled Likelihoods (RPL) $q = \ln \dfrac{\mathcal{L}(\mathcal{H}_{0^+}; \hat{\hat{\nu}}(\mathcal{H}_{0^+}))}{\mathcal{L}(\mathcal{H}_{J^P_{alt}}; \hat{\hat{\nu}}(\mathcal{H}_{J^P_{alt}}))}$

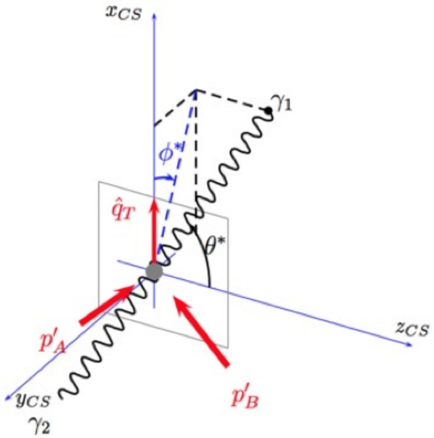


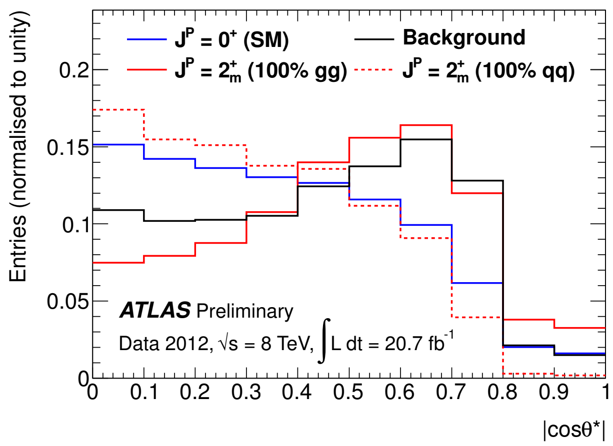
Spin measurement in the $H \to \gamma\gamma$ channel (ATLAS)

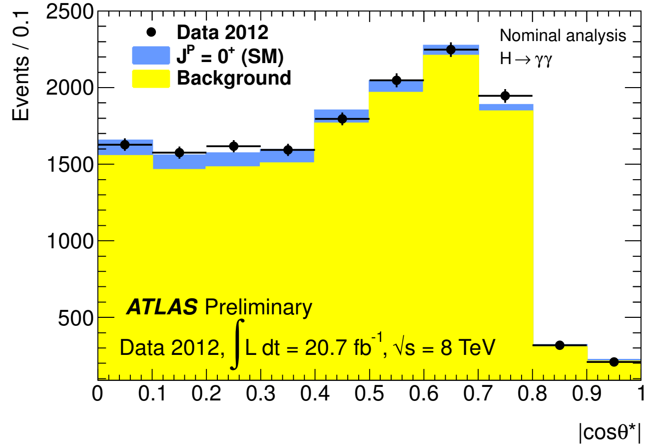
Observable: photons' production angle θ^* in $\gamma\gamma$ center-of-mass frame

$\Rightarrow$ isotropic distribution for spin-0 (uniform $\cos\theta^*$) before kinematic cuts

$$\Rightarrow \frac{d\sigma(gg \to (2^+_m) \to \gamma\gamma)}{d(\cos\theta^*)} \propto (1 + 6\cos^2\theta^* + \cos^4\theta^*) \quad ; \quad \frac{d\sigma(q\bar{q} \to (2^+_m) \to \gamma\gamma)}{d(\cos\theta^*)} \propto (1 - \cos^4\theta^*)$$

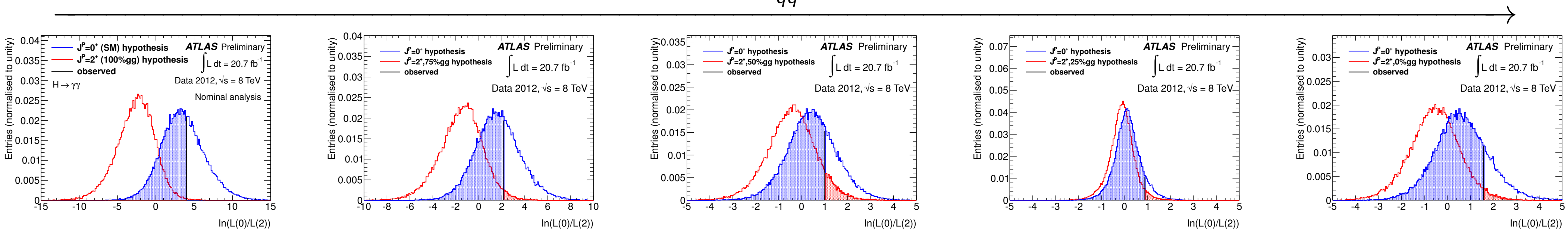






Low S/B ratio, $\approx 3\%$ $\Rightarrow$ crucial to have good understanding of the background shape and normalization (extracted from data sidebands) $\Rightarrow$ use $\cos\theta^*$ and $m_{\gamma\gamma}$ as observables

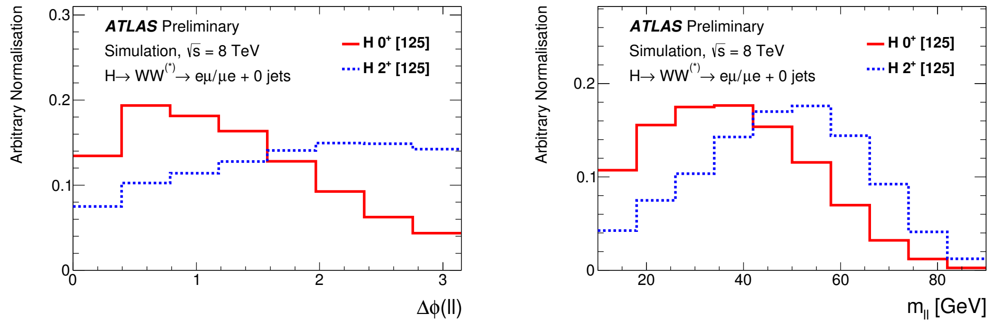
0 $\quad f_{q\bar{q}} \quad$ 1

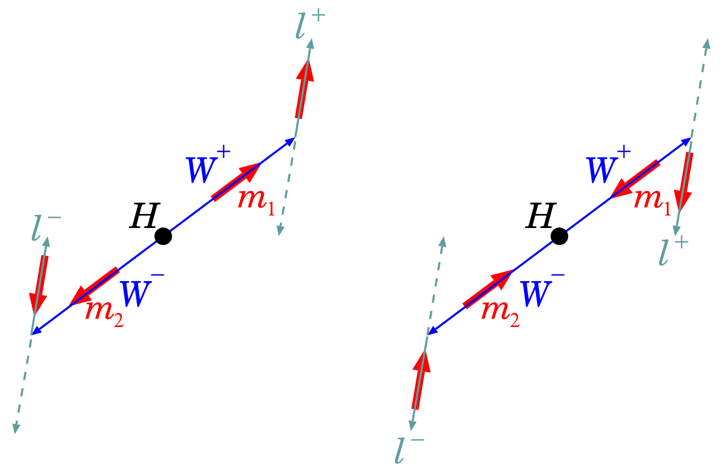


data always favour 0^+ hypothesis

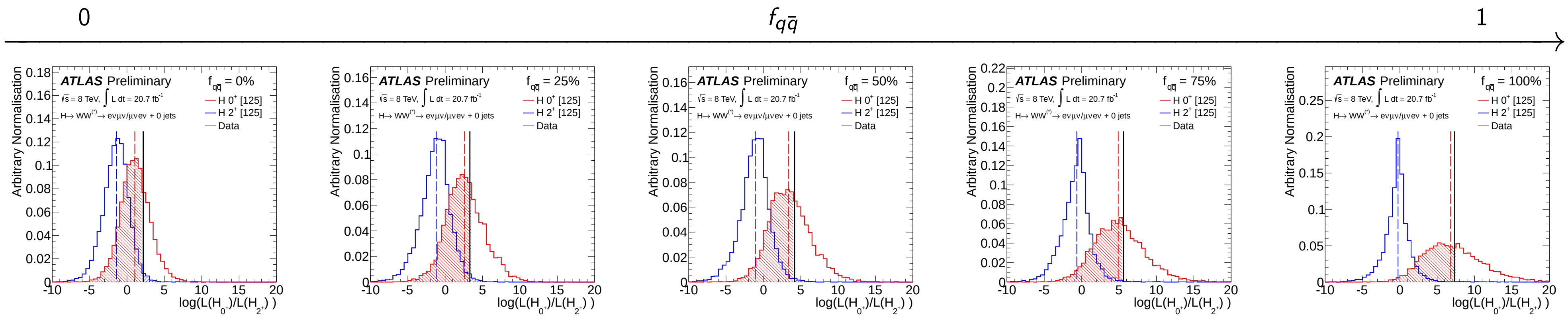
Spin measurement in the $H \to WW^* \to e\nu\mu\nu$ channel

For spin-0 the two leptons tend to be close in angle
(correlation between $W^\pm$ helicities and $V - A$ decay)





from ATLAS: (CMS results in backup material)



data always favour 0^+ hypothesis

(Note the opposite trend vs $f_{q\bar{q}}$ wrt $\gamma\gamma$)

Spin measurement in the $\mathrm{H} \to ZZ^* \to 4\ell$ channel

The complete reconstruction of the final state gives access to the polarization of the resonance and of the Z bosons

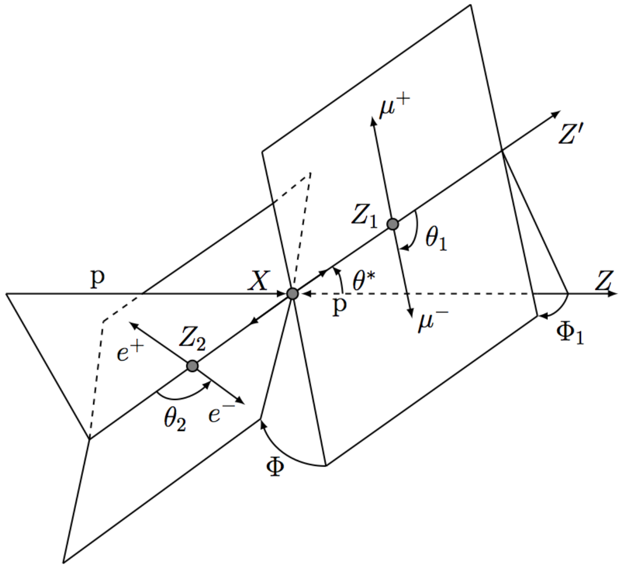
Sensitive observables:

- 2 invariant masses m_{12} , m_{34} (from $Z \to \ell_1\ell_2$ and $Z^* \to \ell_3\ell_4$)
- 5 angles θ^* , Φ_1 , Φ , θ_1 , θ_2

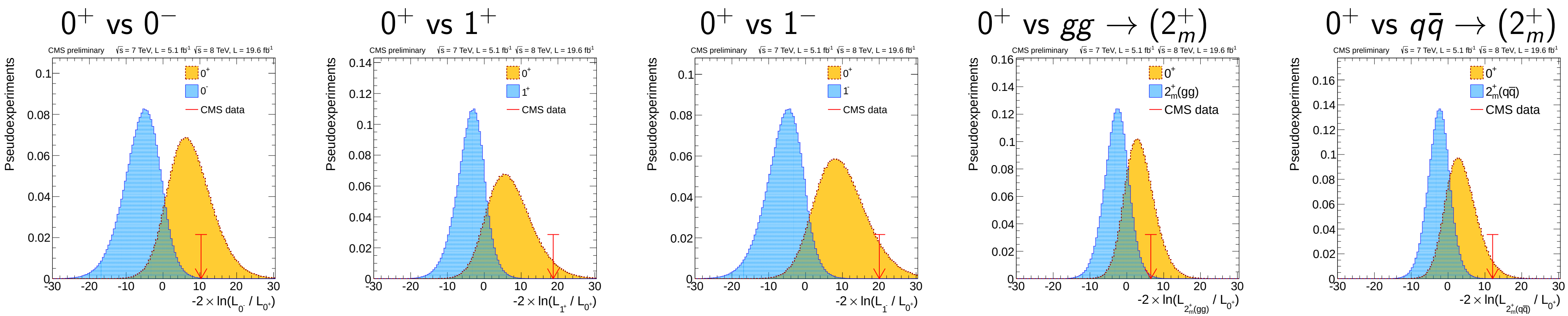
Cases $J^P = 0^\pm$: isotropic in $\cos\theta^*$, Φ_1 ; Φ , $\theta_{1,2}$, m_{34} sensitive to parity

Cases $J^P = 1^\pm, 2^\pm_m$: all variables are discriminant

$\Rightarrow$ multivariate analysis



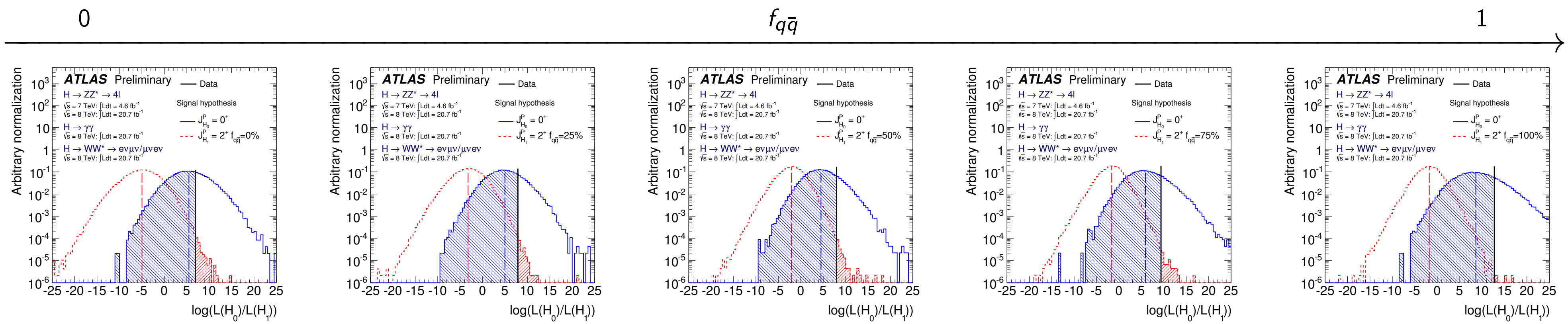
from CMS: (ATLAS results in backup material)

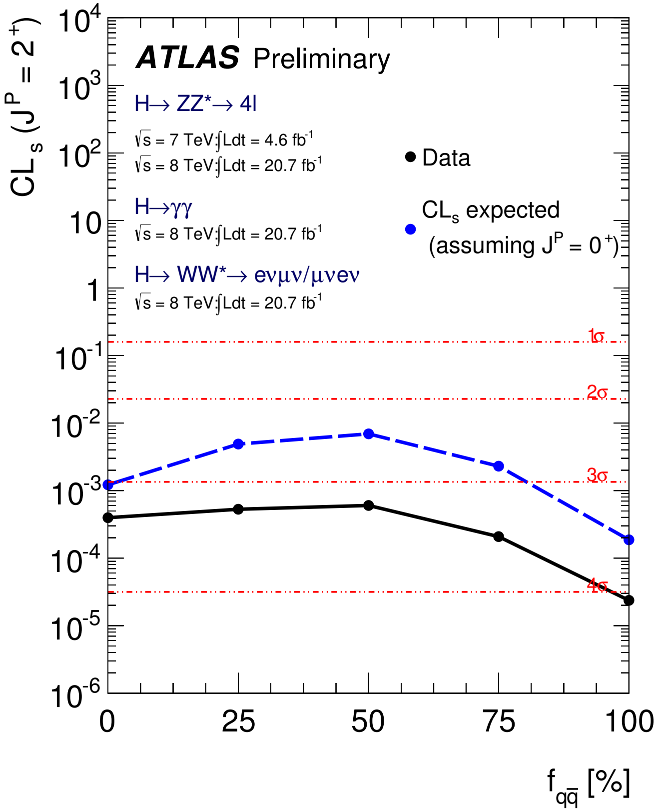


data always favour 0^+ hypothesis

Test of $J^P = 2^+_m$: combination

Combination of $\gamma\gamma$, $ZZ^* \to 4\ell$, $WW^* \to e\nu\mu\nu$ decay channels (from ATLAS)

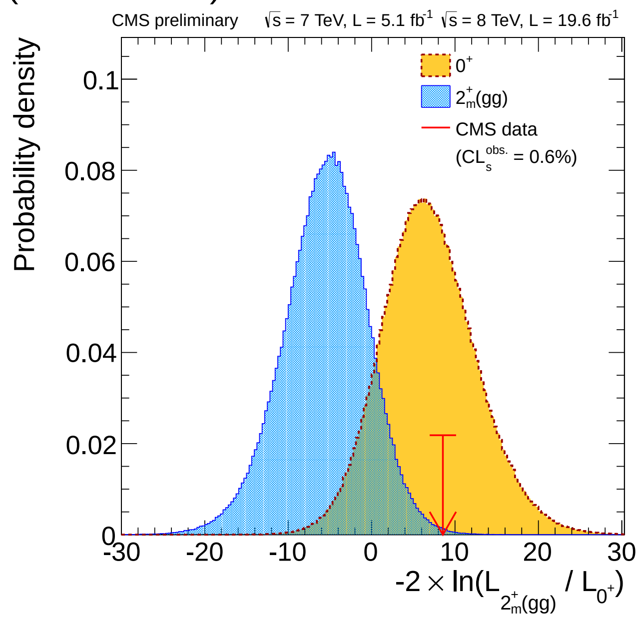




⇒ **Data favour 0^+ state**

⇒ **2^+_m excluded at $> 99.9\%$ CL**

ZZ^* , WW^* combination, 100% ggF (from CMS)



Summary

The state of the art

ATLAS and CMS have analysed all LHC run-1 data for $\gamma\gamma$, $ZZ^* \to 4\ell$, $WW^* \to \ell\nu\ell\nu$ channels
($\sim 5\ \mathrm{fb}^{-1}$ @ $\sqrt{s} = 7\ \mathrm{TeV}$ $+$ $\sim 20\ \mathrm{fb}^{-1}$ @ $\sqrt{s} = 8\ \mathrm{TeV}$)
$\gamma\gamma$ and ZZ^* channels have now $> 5\sigma$ evidence each, at least from one experiment — WW^* channel reaches $\sim 4\sigma$
$b\bar{b}$ and $\tau^+\tau^-$ not yet well established

The "new particle" has a mass measured as: $\begin{cases} m_H^{ATLAS} = 125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(syst)\ \mathrm{GeV} \\ m_H^{CMS} = 125.7 \pm 0.3(stat) \pm 0.3(syst)\ \mathrm{GeV} \end{cases}$

It is compatible with a state $J^P = 0^+$.
Alternative state 2^+ is disfavoured at $> 99.9\%$ CL. States 0^- , $1^\pm$ are disfavoured at $> 99\%$ CL

All couplings' measurements do not show any significant deviation from the Standard Model predictions
— but measurements are precise at $\gtrsim 20\%$ (at best!)

"New results indicate that particle discovered at CERN is a Higgs boson" — CERN press release

Geneva, 14 March 2013. At the Moriond Conference today, the ATLAS and CMS collaborations at CERN's Large Hadron Collider (LHC) presented preliminary new results that further elucidate the particle discovered last year. [. . .] The new particle is looking more and more like a Higgs boson [. . .] It remains an open question, however, whether this is the Higgs boson of the Standard Model of particle physics, or possibly the lightest of several bosons predicted in some theories that go beyond the Standard Model. [. . .] To characterize all of the decay modes will require much more data from the LHC.

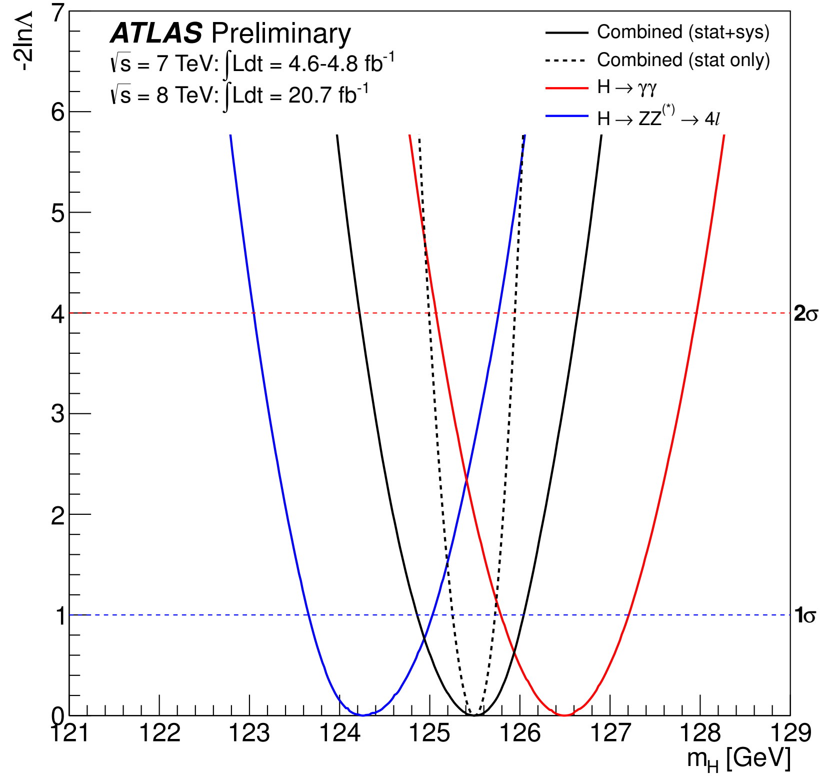
More material

Mass measurement at ATLAS

Measurements from separate decay channels:

$H \to \gamma\gamma \Rightarrow m_H^{\gamma\gamma} = 126.8 \pm 0.2(stat) \pm 0.7(syst)$ GeV

$H \to 4\ell \Rightarrow m_H^{4\ell} = 124.3^{+0.6}_{-0.5}(stat)^{+0.5}_{-0.3}(syst)$ GeV



Systematics:

- muon energy scale (dominant for $H \to 4\ell$):
  (calibrated on $Z \to \mu^+\mu^-$, $\Upsilon \to \mu^+\mu^-$)
  $\Rightarrow$ 0.2% on $m_{4\mu}$
- electromagnetic scale (especially for $H \to \gamma\gamma$)
  - scale from $Z \to e^+e^-$ and $e \to \gamma$ extrapolation : 0.3%
  - material in front of the calorimeter : 0.3% – 0.7%
  - presampler/calorimeter relative calibration : 0.1%
  - E_1/E_2, linearity, lateral leakage, ...: 0.32%

  $\Rightarrow$ overall 0.55% on $m_{\gamma\gamma}$ ($\Rightarrow$ 0.7 GeV)

Combined mass value:

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

Compatibility between $\gamma\gamma$ and 4ℓ channels: 2% to 8% (depending on the choice of the ancillary pdfs for EM scales and material in front of the calorimeter)

Mass measurement at CMS

Measurements from separate decay channels:

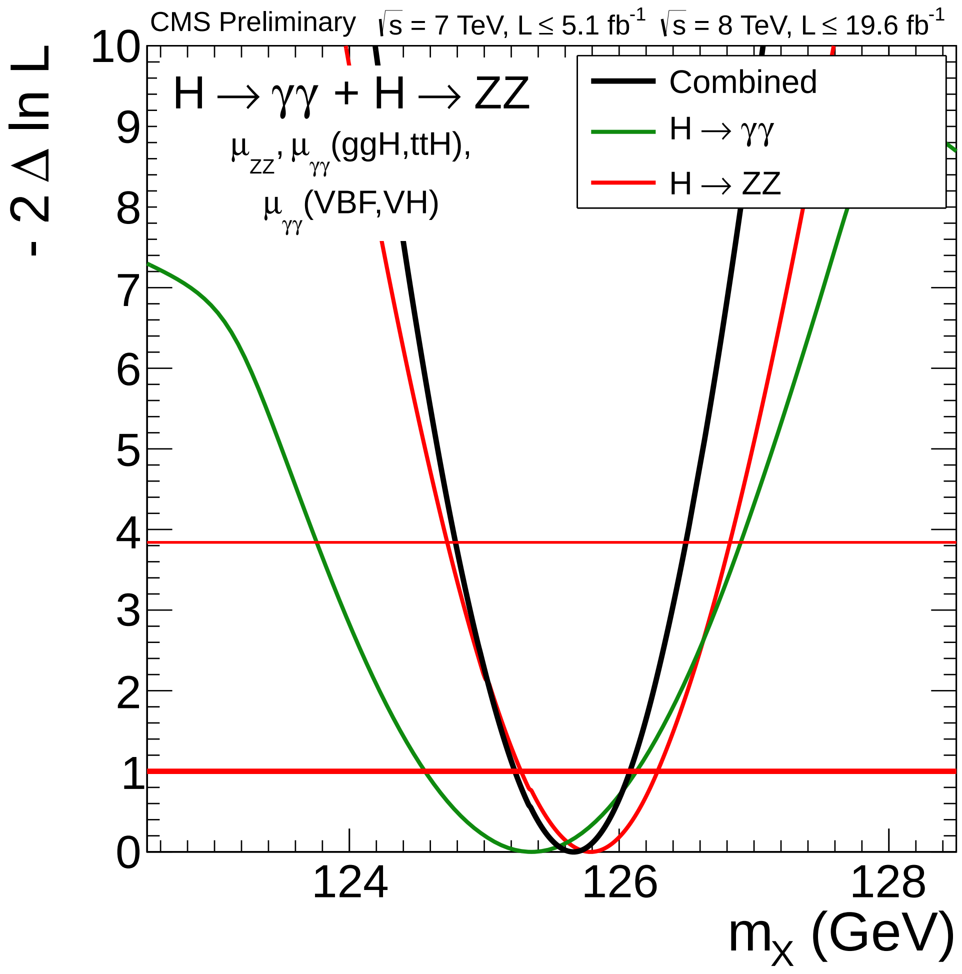
$H \to \gamma\gamma \Rightarrow m_H^{\gamma\gamma} = 125.4 \pm 0.5(stat) \pm 0.6(syst)$ GeV

$H \to 4\ell \Rightarrow m_H^{4\ell} = 125.8 \pm 0.5(stat) \pm 0.2(syst)$ GeV

Mass resolution assigned individually to each event before fitting

Systematics:

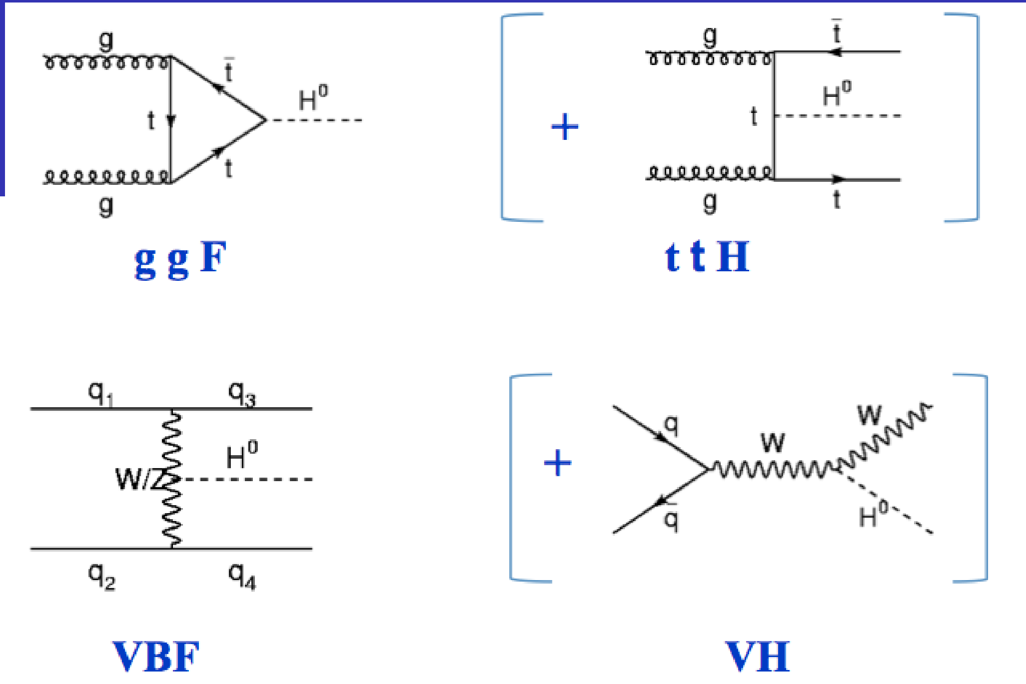
- electron and muon energy scale: assessed from $J/\psi, \Upsilon, Z \to \ell\ell$ $\Rightarrow$ 0.1% on $m_{4\mu}$ and 0.3% on m_{4e}
- photon energy scale: $Z \to e^+e^-$ plus $e \to \gamma$ extrapolation $\Rightarrow$ overall 0.47% on $m_{\gamma\gamma}$



Combined mass value:

$$\hat{m}_H = 125.7 \pm 0.3(stat) \pm 0.3(syst) \text{ GeV}$$

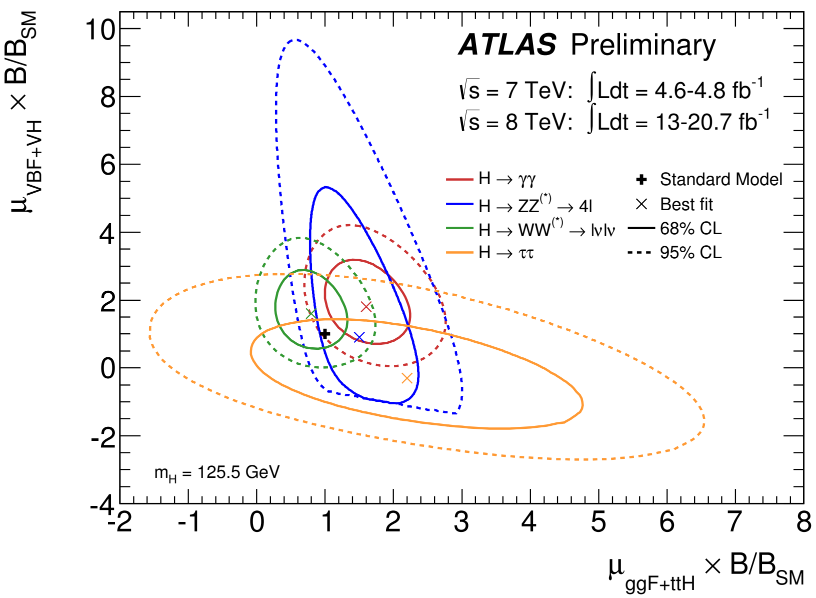
Signal strength by production mechanisms



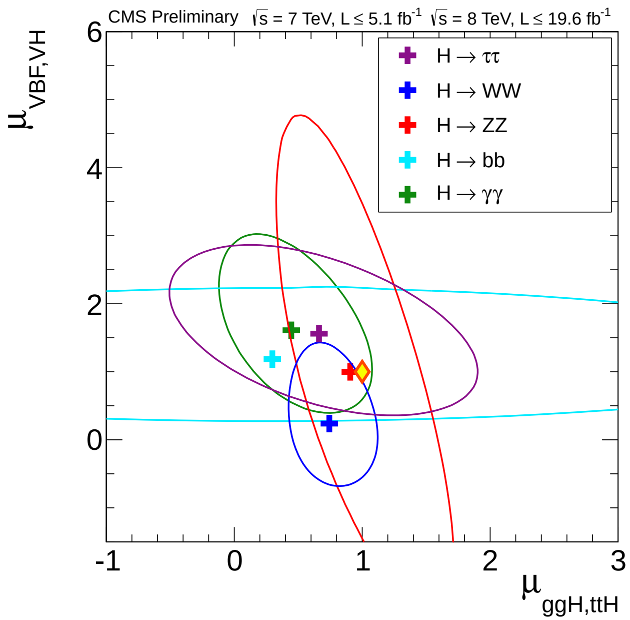
We define two signal strengths, relative to different production mechanisms:

- $\mu_{ggF+ttH}$ for productions mediated by couplings to fermions (especially the ttH vertex)
- μ_{VBF+VH} for productions mediated by couplings to gauge bosons (WWH and ZZH vertices)

ATLAS



CMS

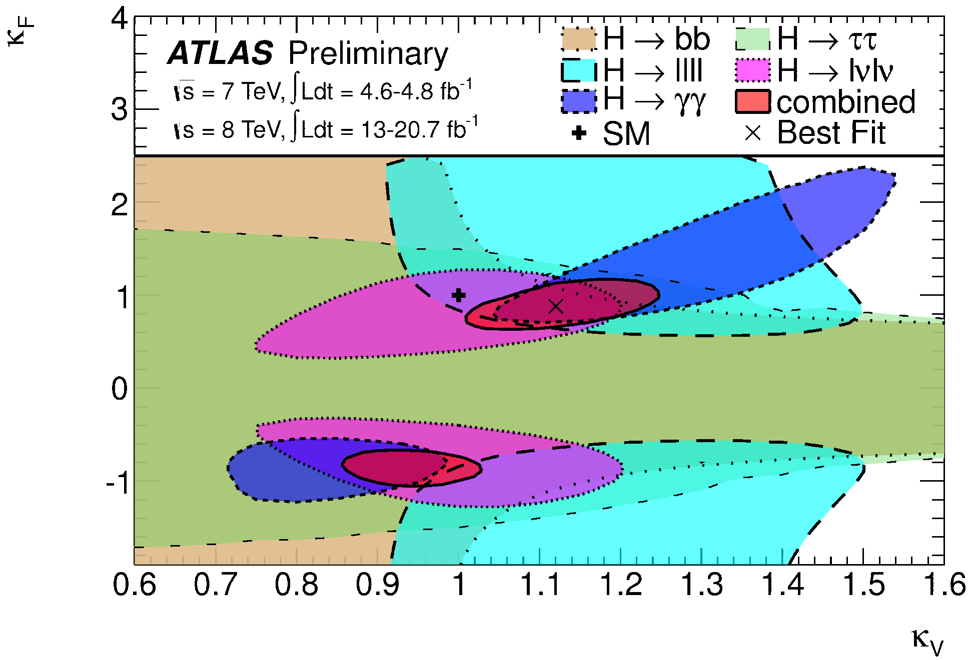


$\Rightarrow$ 3σ evidence for VBF production

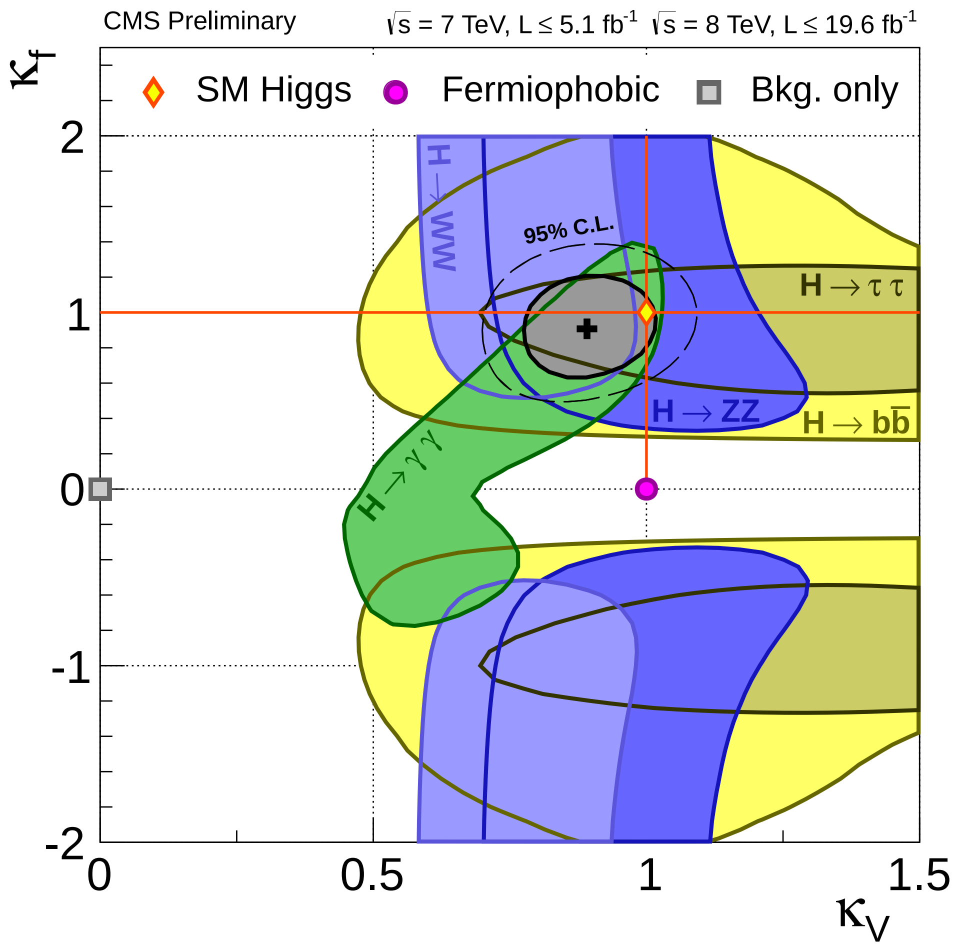
Fermion vs gauge boson couplings factors (by channels)

(the contributions from different decay channels)

ATLAS



CMS

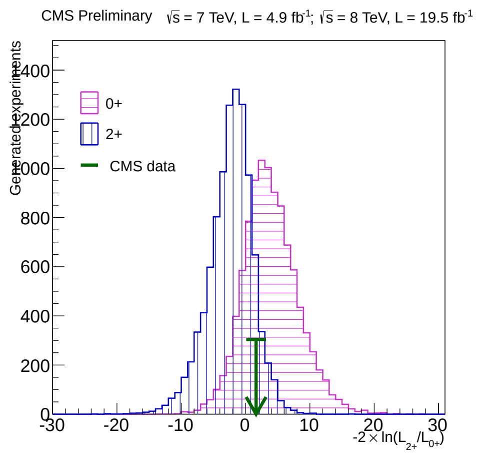


Most general model for spin 2

$$
\begin{aligned}
A(X \to VV) = \Lambda^{-1} \Big[& 2g_1 t_{\mu\nu} f^{*1,\mu\alpha} f^{*2,\nu\alpha} + 2g_2 t_{\mu\nu} \frac{q_\alpha q_\beta}{\Lambda^2} f^{*1,\mu\alpha} f^{*2,\nu\alpha} \\
& + g_3 \frac{\tilde{q}^\beta \tilde{q}^\alpha}{\Lambda^2} t_{\beta\nu} \left(f^{*1,\mu\nu} f^{*2}_{\mu\alpha} + f^{*2,\mu\nu} f^{*1}_{\mu\alpha} \right) + g_4 \frac{\tilde{q}^\nu \tilde{q}^\mu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} f^{*(2)}_{\alpha\beta} \\
& + m_V^2 \left(2g_5 t_{\mu\nu} \epsilon_1^{*\mu} \epsilon_2^{*\nu} + 2g_6 \frac{\tilde{q}^\mu q_\alpha}{\Lambda^2} t_{\mu\nu} \left(\epsilon_1^{*\nu} \epsilon_2^{*\alpha} - \epsilon_1^{*\alpha} \epsilon_2^{*\nu} \right) + g_7 \frac{\tilde{q}^\mu \tilde{q}^\nu}{\Lambda^2} t_{\mu\nu} \epsilon_1^* \epsilon_2^* \right) \\
& + g_8 \frac{\tilde{q}_\mu \tilde{q}_\nu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} \tilde{f}^{*(2)}_{\alpha\beta} + g_9 t_{\mu\alpha} \tilde{q}^\alpha \epsilon_{\mu\nu\rho\sigma} \epsilon_1^{*\nu} \epsilon_2^{*\rho} q^\sigma \\
& + \frac{g_{10} t_{\mu\alpha} \tilde{q}^\alpha}{\Lambda^2} \epsilon_{\mu\nu\rho\sigma} q^\rho \tilde{q}^\sigma \left(\epsilon_1^{*\nu} (q \epsilon_2^*) + \epsilon_2^{*\nu} (q \epsilon_1^*) \right) \Big],
\end{aligned}
$$

More spin results in WW*, ZZ* channels

from WW* — CMS



(assuming $gg \to (2^+_m)$)

from ZZ* — ATLAS

0^+ vs 0^- $\quad$ 0^+ vs 1^+ $\quad$ 0^+ vs 2^+_m