Higgs Boson properties @ CMS

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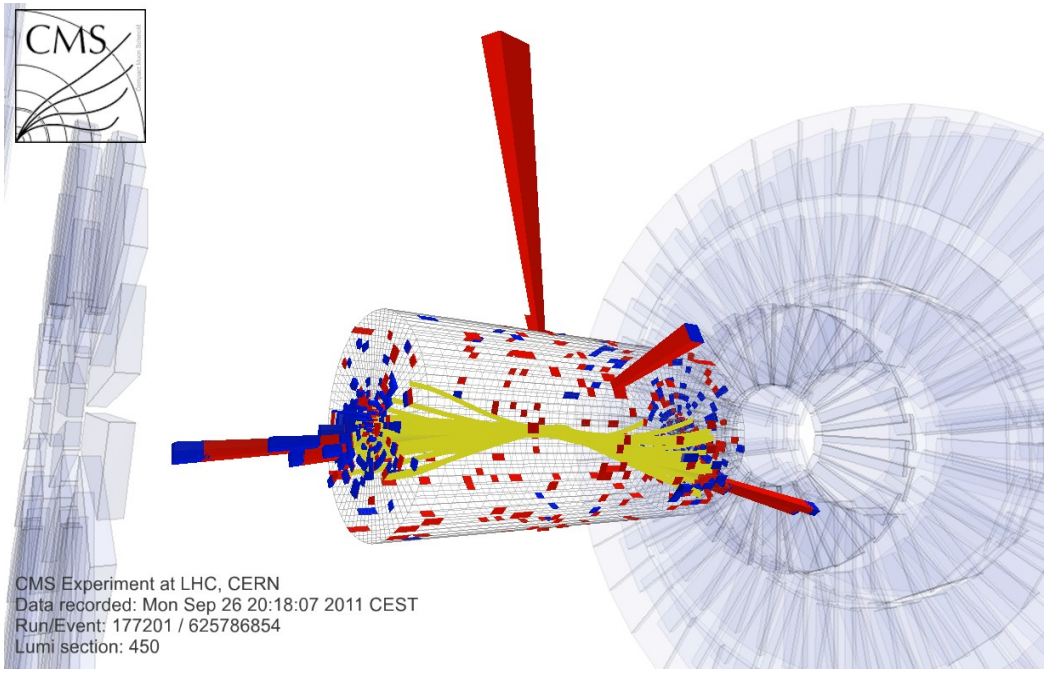
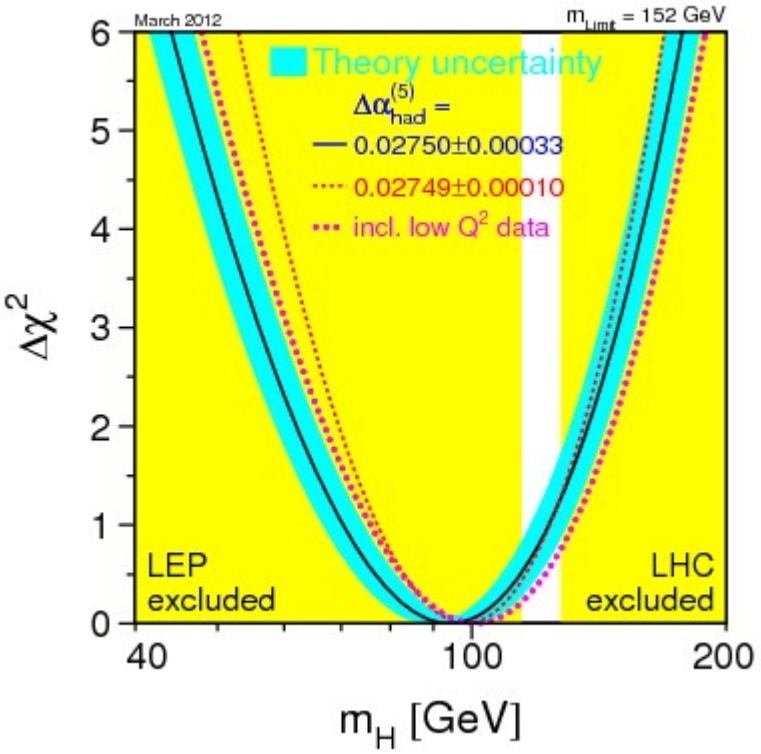
On behalf of the CMS collaboration



Higgs properties: SM predictions

- Post Higgs discovery question: Is it the SM Higgs boson?
  - SM predictions for Higgs boson:
    - mass not predicted
    - width at 125 GeV: ~4 MeV
    - couplings to fermions and bosons
    - spin and charge 0
    - parity +1

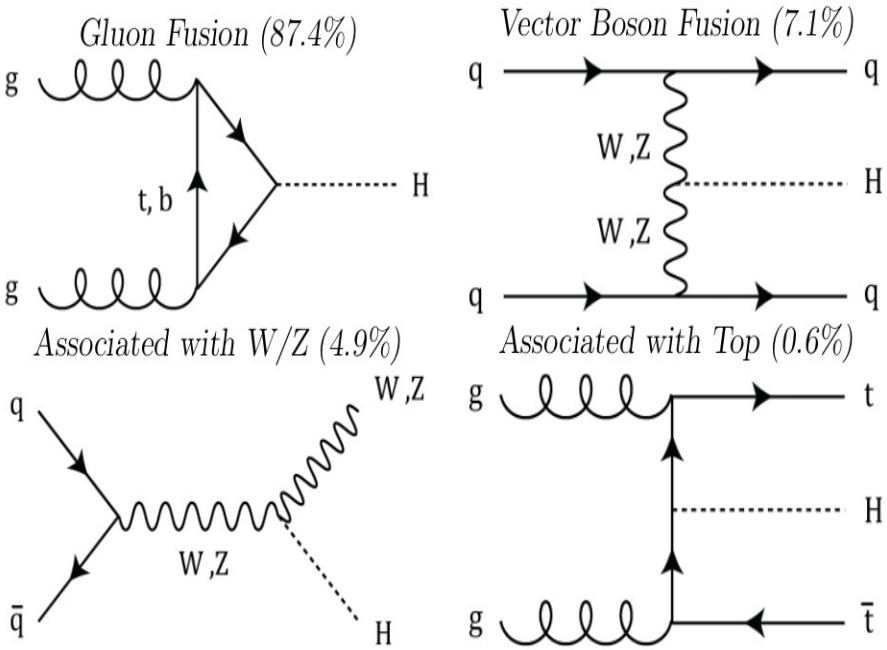


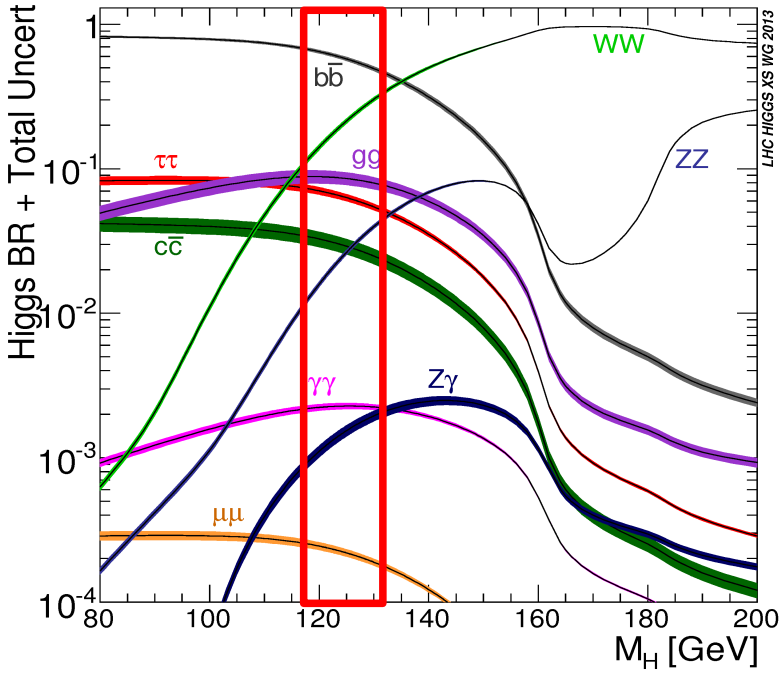
95% CL upper limit from EW fit = 152 GeV

- <u>Tests of consistency with SM are mandatory</u>

Higgs boson production and decays

- At the LHC, the main Higgs production mechanism in the SM is gluon fusion, followed by VBF and associated production with W, Z or tt
- m_H = 125 GeV → several decay channels accessible: γγ, ZZ, WW, ττ, bb



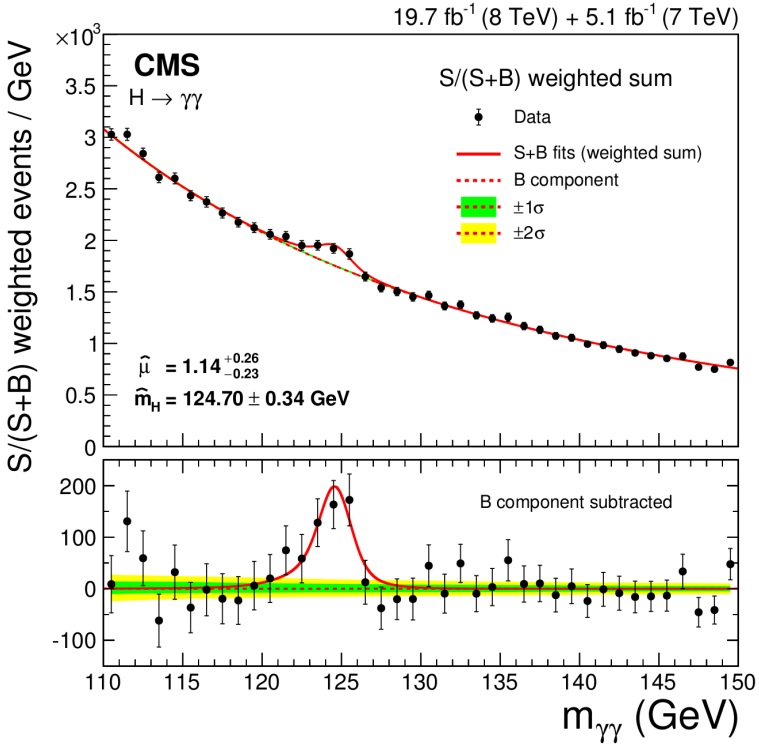


Decay	BR @125 GeV
bb	57%
WW	21%
ττ	6.4%
ZZ	2.6%
γγ	0.2%

Higgs boson mass

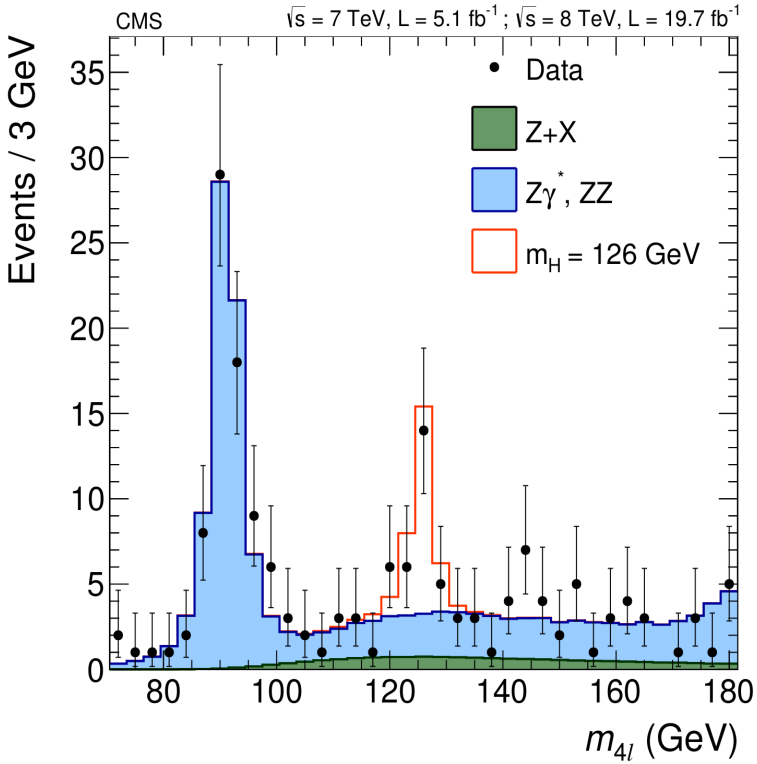
Channels with very good mass resolution (~1%) used to determine the Higgs boson mass: H→γγ and H→ZZ→4l

EPJC 74(2014)3076



H→γγ

PRD 89 (2014) 092007



H→ZZ→4l (4μ,2e2μ,4e)

M_H = 124.70±0.31(stat.)±0.15(syst.) GeV

M_H = 125.6±0.4(stat.)±0.2(syst.) GeV

Combined measurement of the mass

- The mass measurements with H→γγ and H→ZZ→4l data are combined assuming a single state
- Production rates and decay ratios left free in the m_H fit

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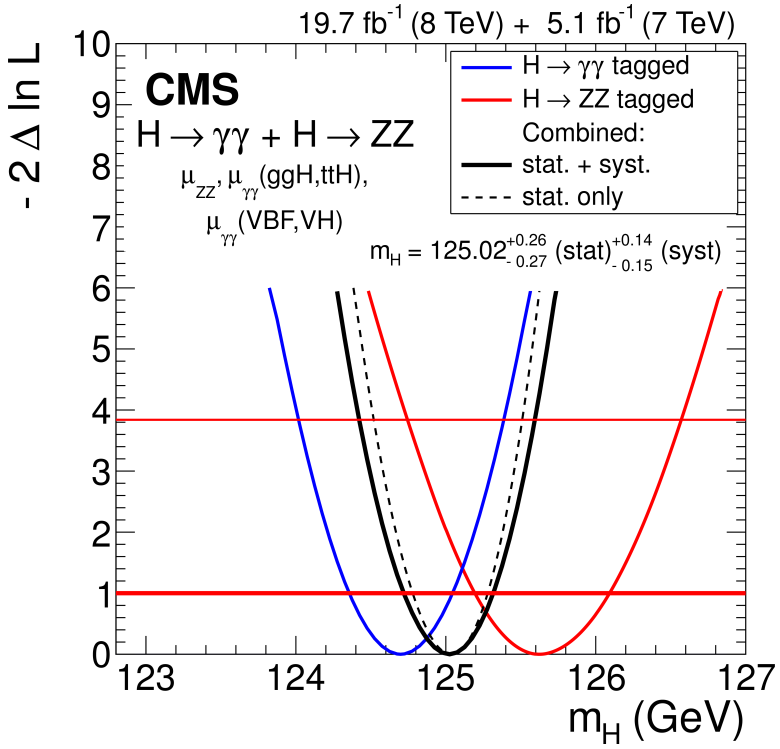

$M_H = 125.02 \pm 0.27$ (stat.) ± 0.15 (syst.) GeV

Combined measurement of the mass

- The mass measurements with H→γγ and H→ZZ→4l data are combined assuming a single state
- Production rates and decay ratios left free in the m_H fit

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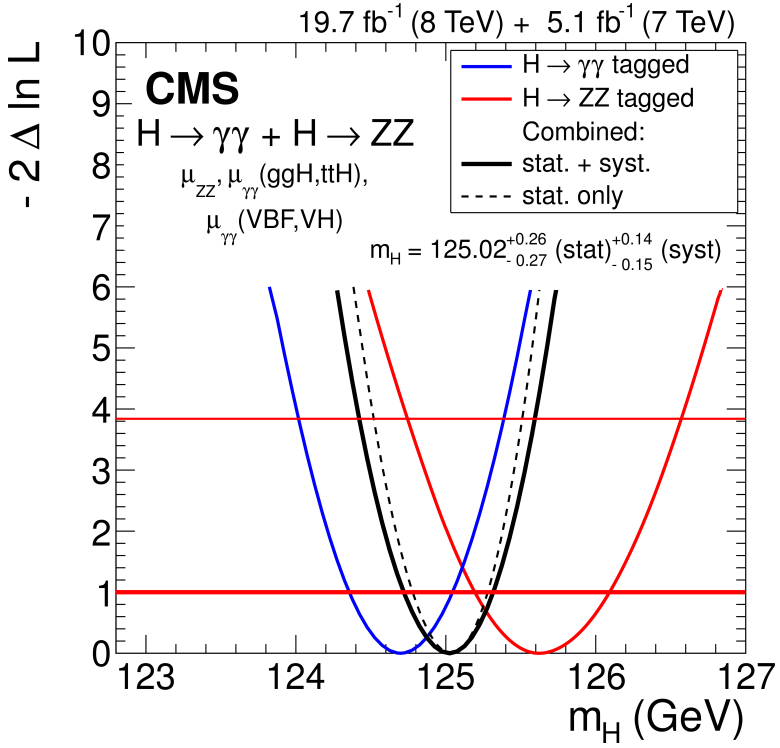
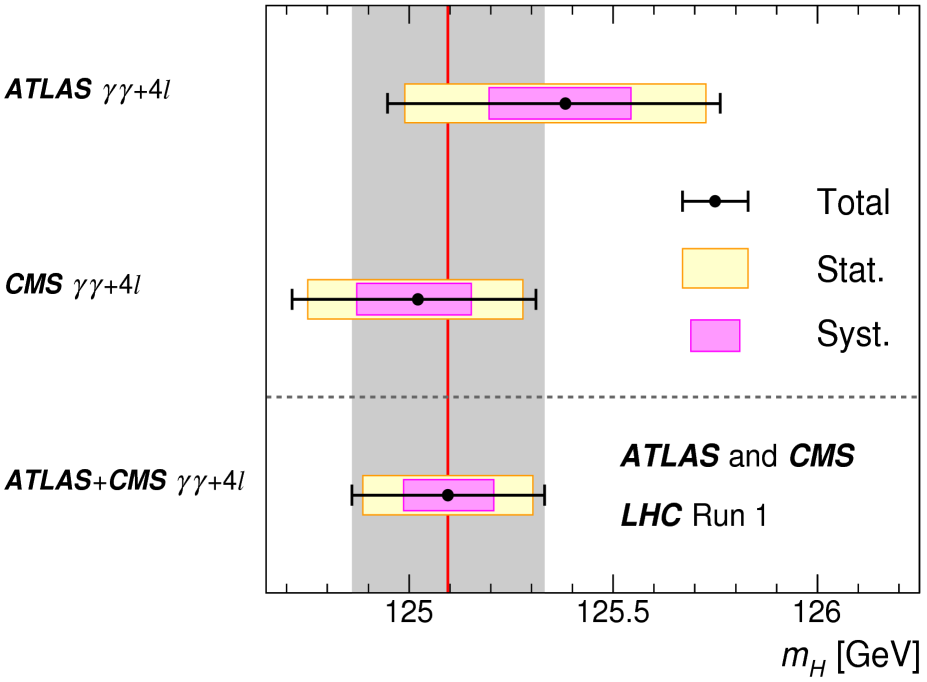




M_H = 125.02 ± 0.27 (stat.) ± 0.15 (syst.) GeV

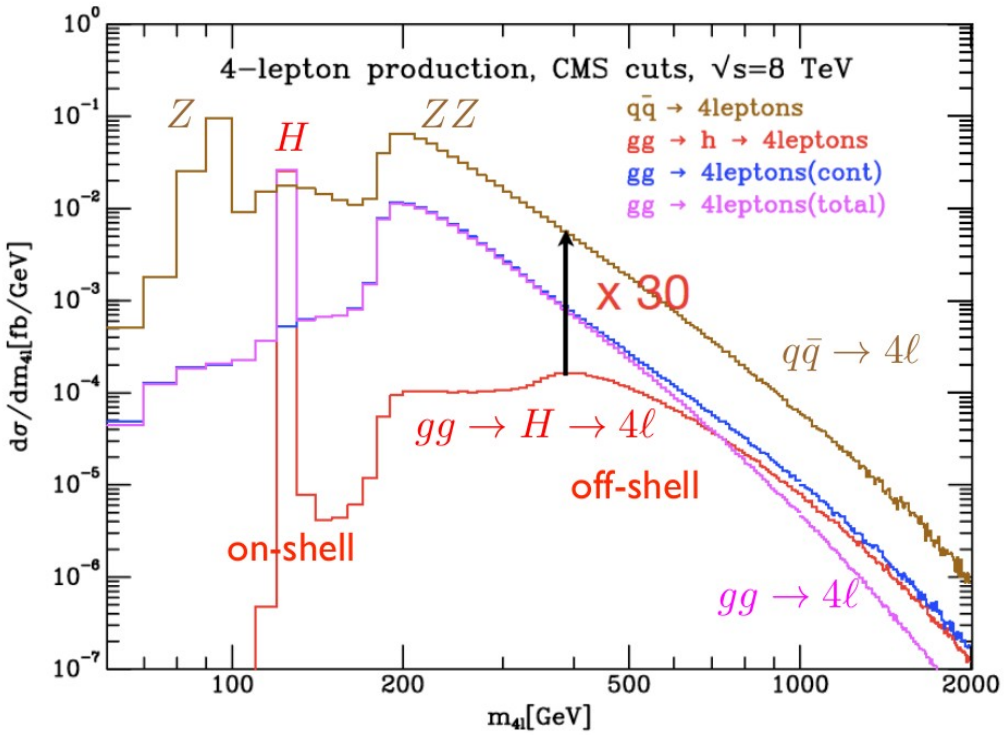
ATLAS+CMS combined result:
125.09 ± 0.21 (stat.) ± 0.11 (syst.) GeV

Higgs boson width

- The width of the SM Higgs boson expected to be **~ 4 MeV**
- Upper limits on the width can be obtained through direct measurement from the mass peak, but limited by experimental resolution (**~1 GeV**)
- **Possibility:** use off/on-shell mass ratio (although generic assumptions, still model-dependent)

$$\frac{\mathrm{d}\sigma_{gg\to H\to ZZ}}{\mathrm{d}m^2_{ZZ}} \sim \frac{g^2_{ggH} g^2_{HZZ}}{(m^2_{ZZ} - m^2_H)^2 + m^2_H \Gamma^2_H}$$

$$\frac{\sigma^{\text{off-shell}}_{gg\to H\to ZZ}}{\sigma^{\text{on-shell}}_{gg\to H\to ZZ}} \sim \Gamma_H$$



Assumption: evolution of ggH and HZZ couplings as a function of the mass is the SM one

Higgs boson width

direct

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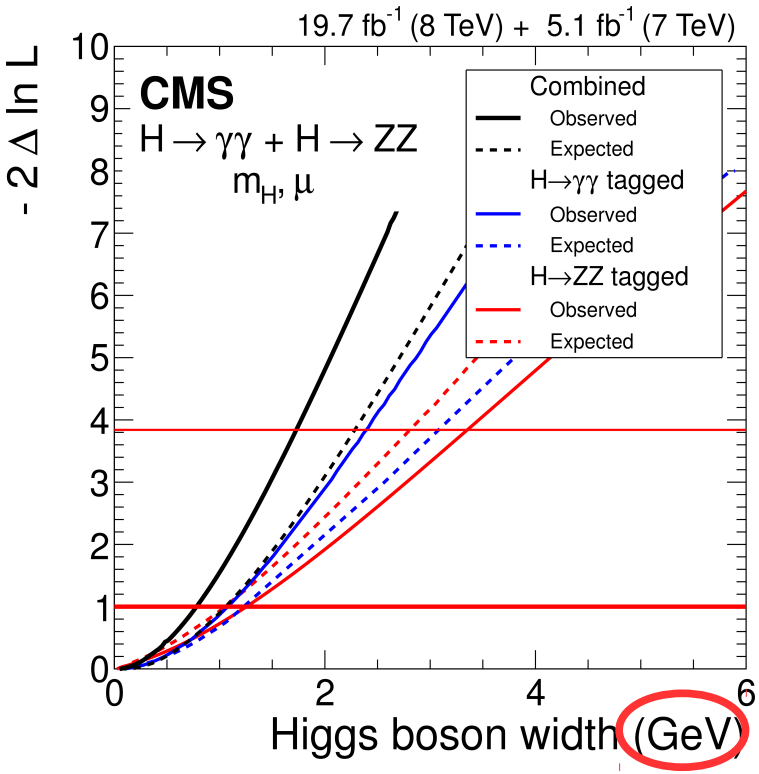
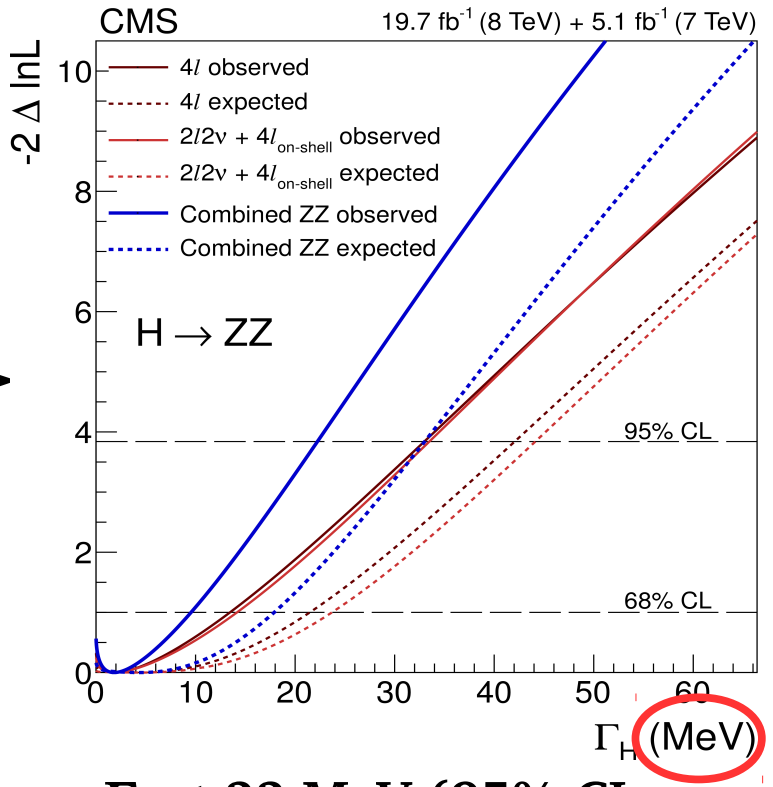


$\Gamma_H \leq$ 1.7 GeV (95% CL)

indirect

PLB 736 (2014) 64



$\Gamma_H \leq$ 22 MeV (95% CL – exp. 33 MeV)

Compatibility with SM: Signal strength

Higgs boson signal strength $\mu = \sigma/\sigma_{SM}$

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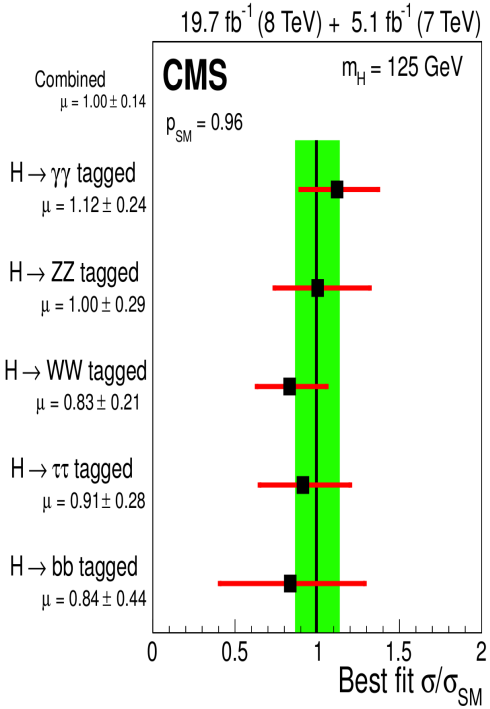
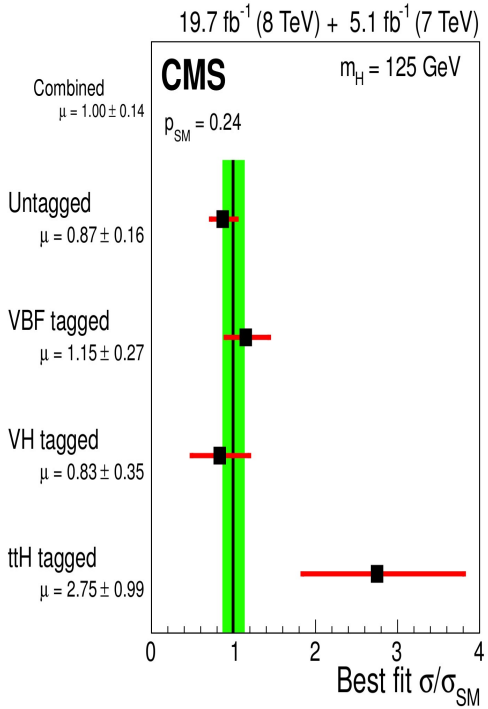
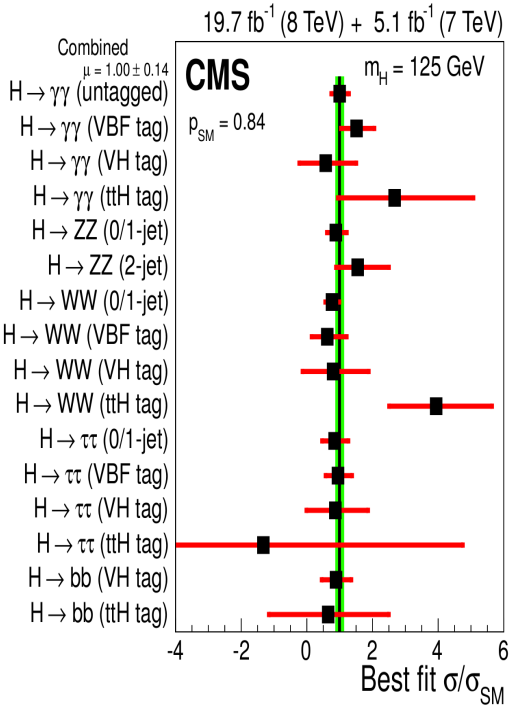
By final state

By production mechanism







$$\mu = 1.00 \pm 0.09(\text{stat}) \pm 0.08(\text{theo}) \pm 0.07(\text{syst})$$

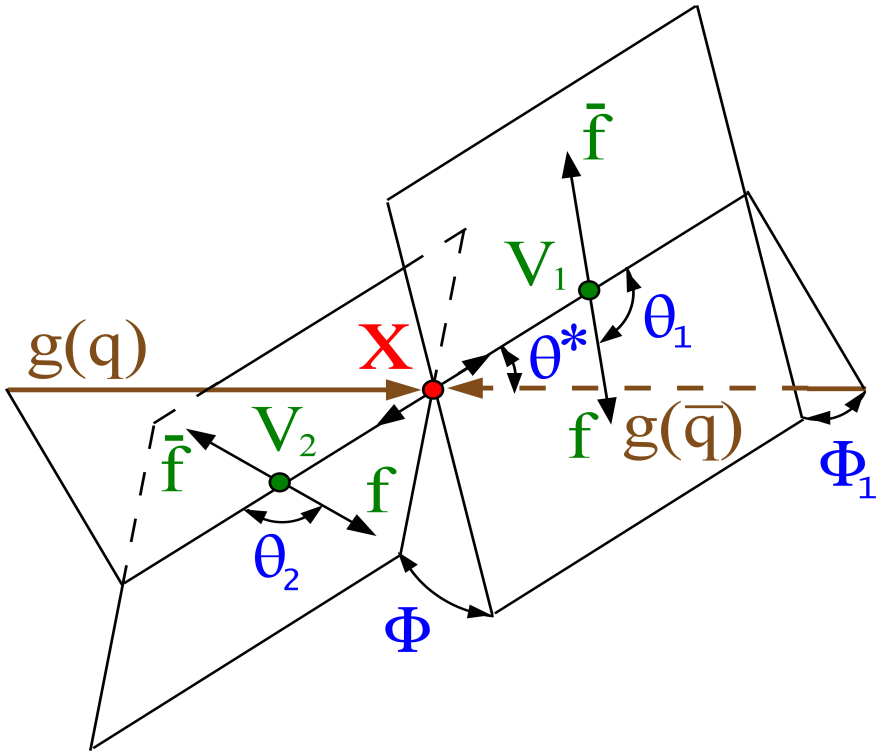
Spin-Parity measurement

- Able to test some reasonable **benchmark models for alternative J^{CP} hypotheses**
- Use mainly **angular distributions**, **bosonic channels** are the most sensitive:

- **ZZ→4l** system fully reconstructed. Use of a Matrix Element Likelihood Approach (polarisation derived from kinematics of decay products)

- **WW** not fully reconstructed but kinematic variables (M_{ll} and M_T) sensitive to Higgs spin/CP

- **γγ** can be used for spin determination through p_T and $\cos\theta^*$. **γγ excludes spin-1**



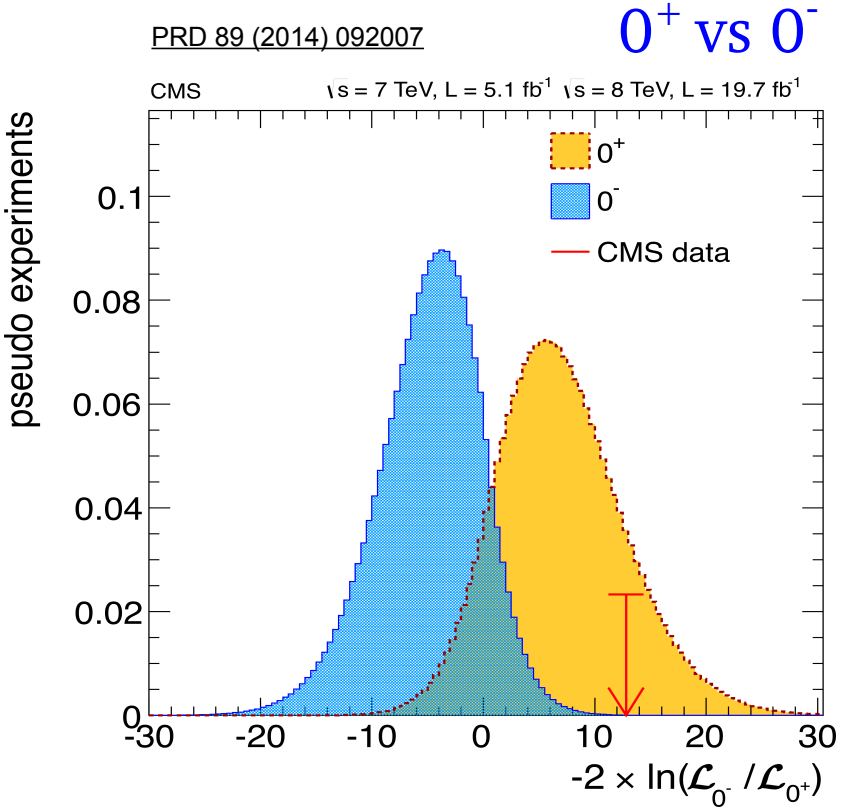
Spin-Parity measurement

Most general expression for HVV scattering amplitude:

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q^2_{\mathrm{V1}} + \kappa_2^{\mathrm{VV}} q^2_{\mathrm{V2}}}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} \right] m^2_{\mathrm{V1}} \epsilon^*_{\mathrm{V1}} \epsilon^*_{\mathrm{V2}} + a_2^{\mathrm{VV}} f^{*(1)}_{\mu\nu} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f^{*(1)}_{\mu\nu} \tilde{f}^{*(2),\mu\nu}$$

scalar SM — scalar anomalous — pseudo scalar

The SM hypothesis (0^+) is tested against many alternative ones

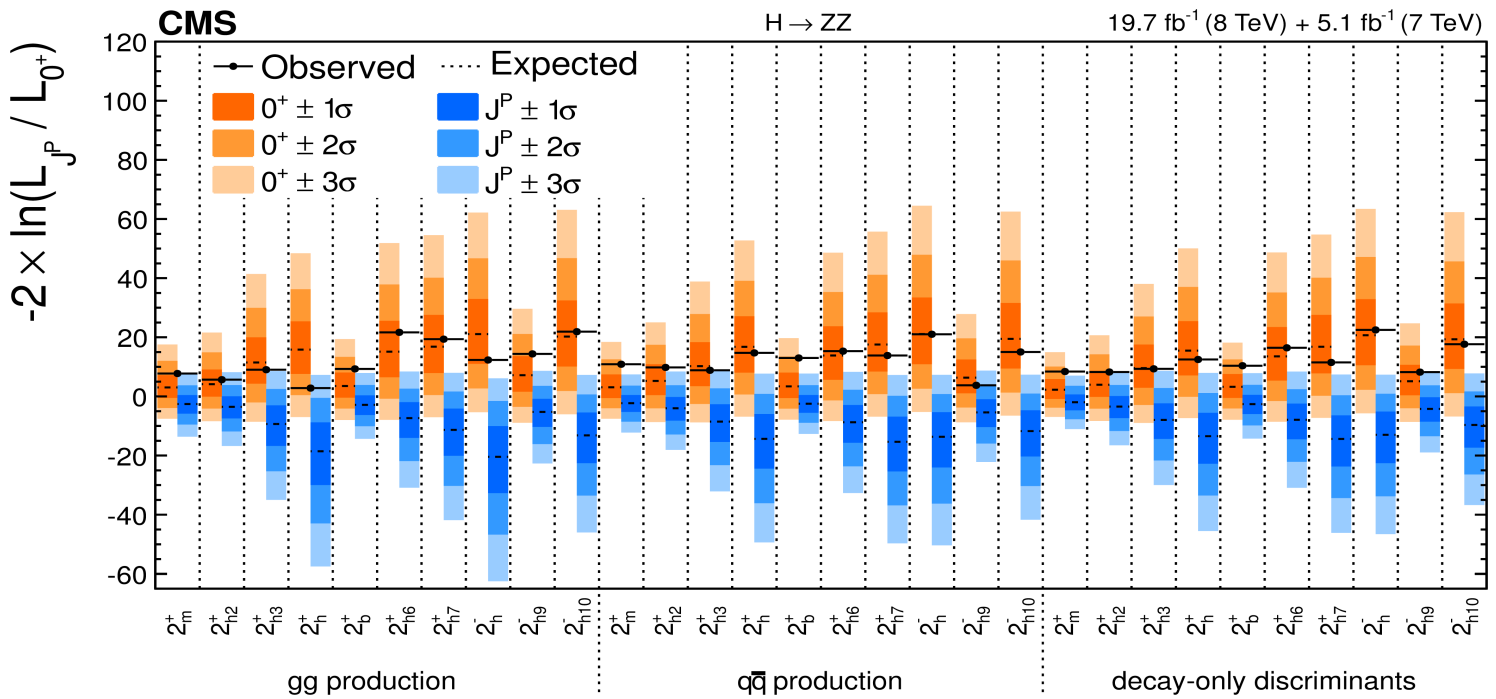


Spin-Parity measurement

The SM hypothesis (0^+) is tested against many alternative ones

0^+ vs $2^\pm$

PRD 92 (2015) 012004



- $J^P=0^-$, $1^\pm$,$2^\pm$ excluded at more than 3σ level
- The observation is well compatible with SM Higgs expectations (0^+)

Higgs couplings

Extracting Higgs couplings requires assumptions at the LHC

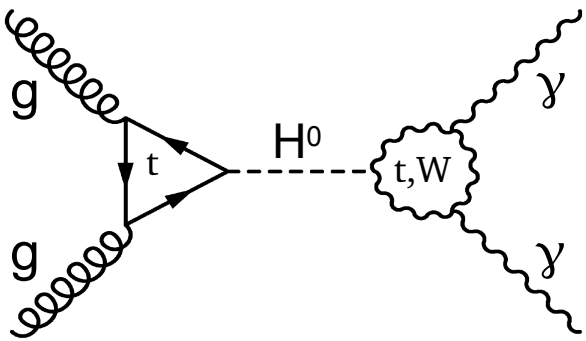
$$(\sigma\,\mathcal{B})\,(x \to \mathrm{H} \to yy) = \frac{\sigma_x\,\Gamma_{yy}}{\Gamma_{\mathrm{tot}}}$$

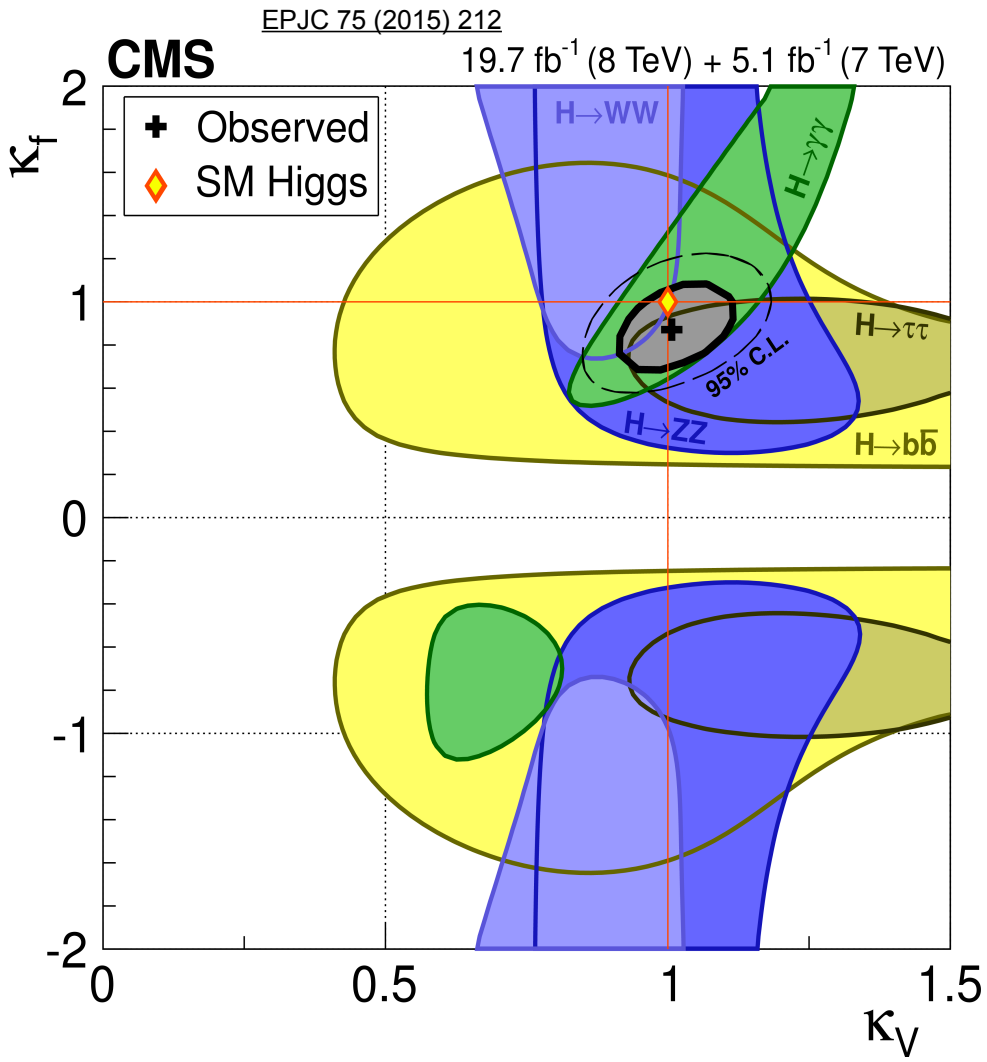
- Higgs boson couplings grouped into **Vectorial (*kV*)** and **Fermionic (*kF*)** sets

- H→γγ is the only channel sensitive to *kV* and *kF* relative sign

$\Gamma_{gg} \sim k_F^2$ $\quad$ $\Gamma_{\gamma\gamma} \sim |\alpha k_V + \beta k_F|^2$

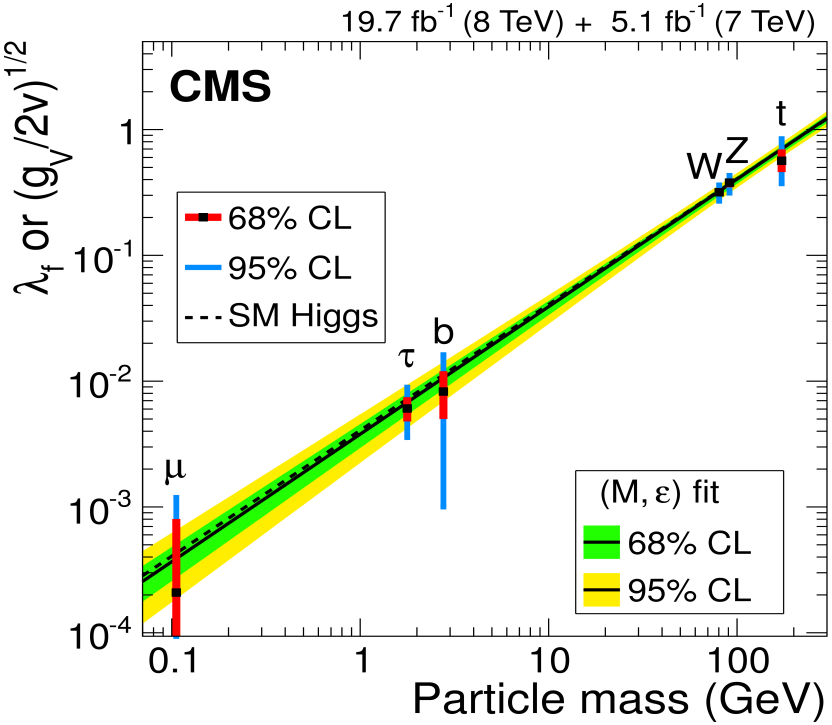
$\beta/\alpha < 0$





Conclusions

- Main results on Higgs properties with the full RUN1 statistics have been shown
- Higgs mass: $M_H = 125.09 \pm 0.21$ (stat.) ± 0.11 (syst.) GeV (ATLAS+CMS)



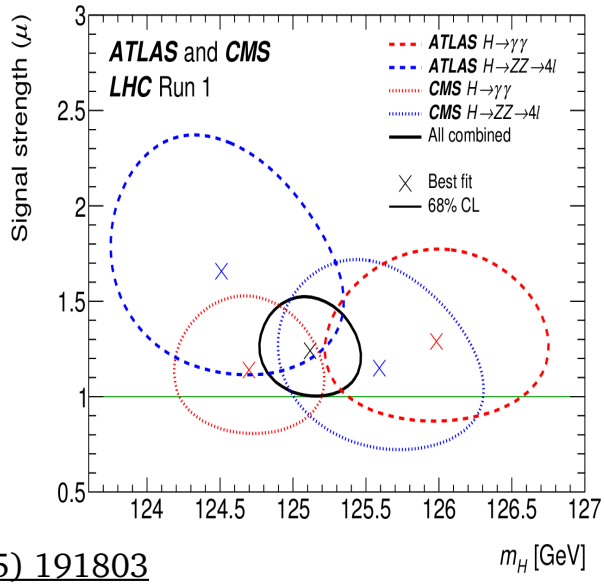
- Everything is compatible with the SM predictions
- Searches for small deviations from the SM will continue at LHC 13 TeV RUN2

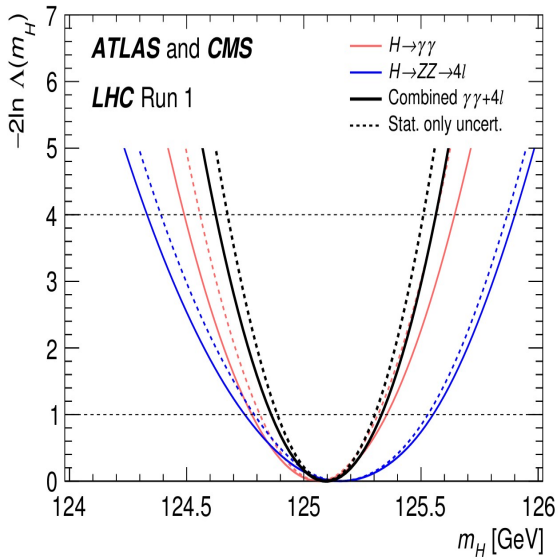
Thanks for the attention !

Backup

Combined measurement of the mass (CMS+ATLAS)

- Combination of ATLAS and CMS mass measurements with H→γγ and H→ZZ→4l data. Obtained from a simultaneous fit to the reconstructed invariant mass peaks in both channels and for both experiments





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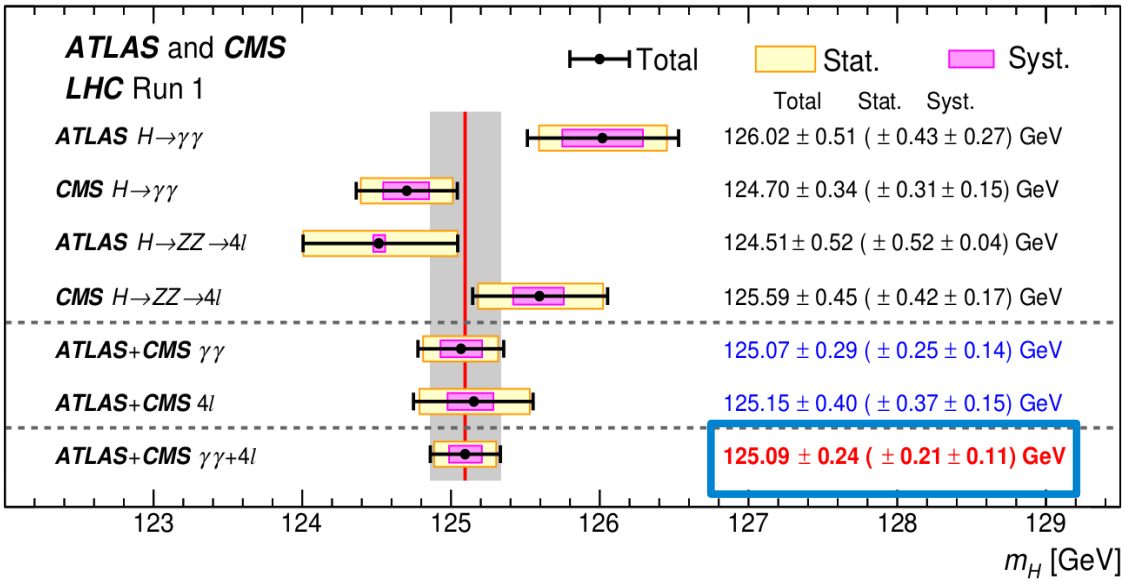

Differential measurements

- Differential measurements performed both in $H\to\gamma\gamma$ and $H\to ZZ$ channel
- Higgs pT sensitive to new contribution in the ggH loop
- 0-jet and 1-jet dominated by gluon fusion. Associated production populates higher jet multiplicity bins