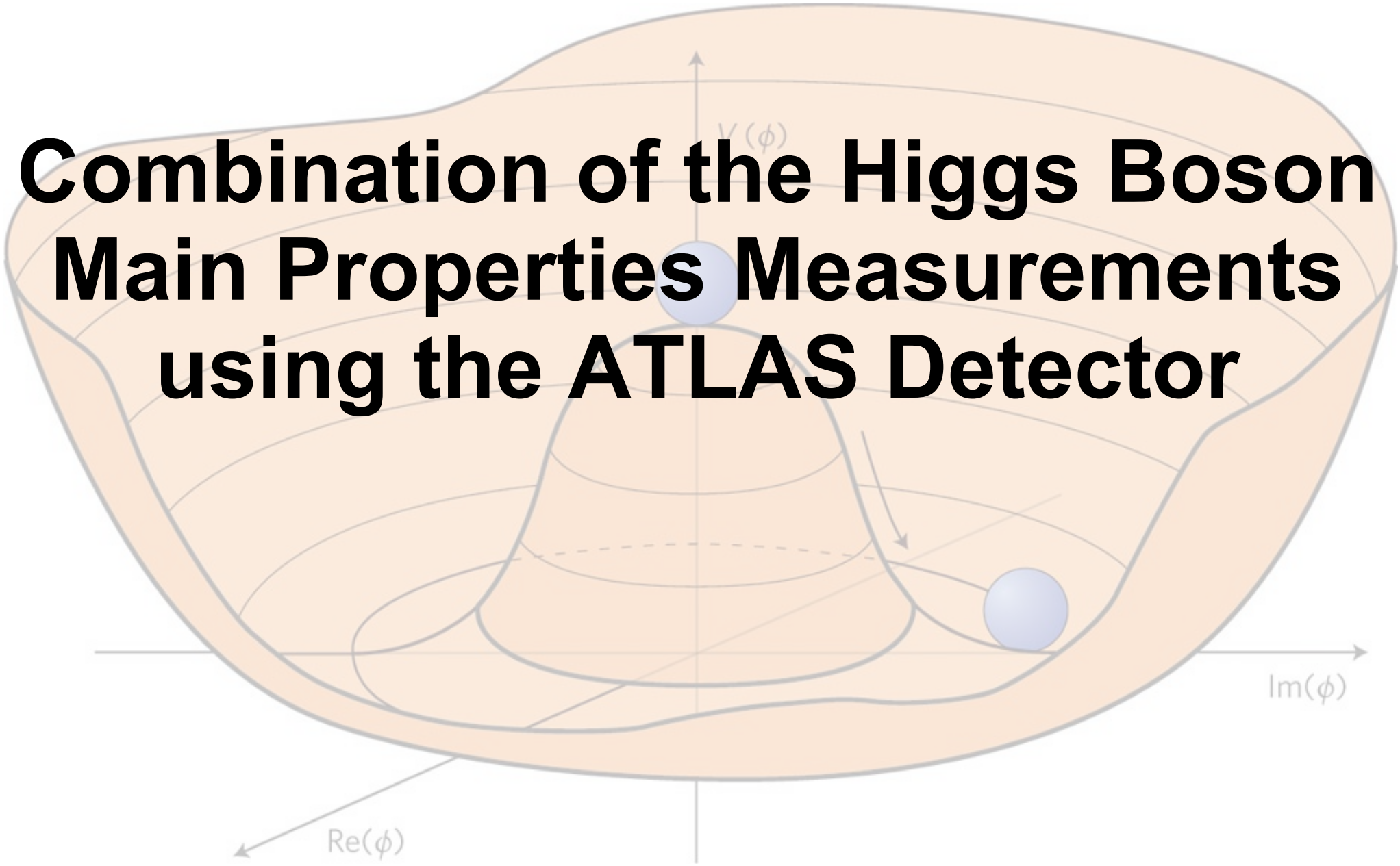
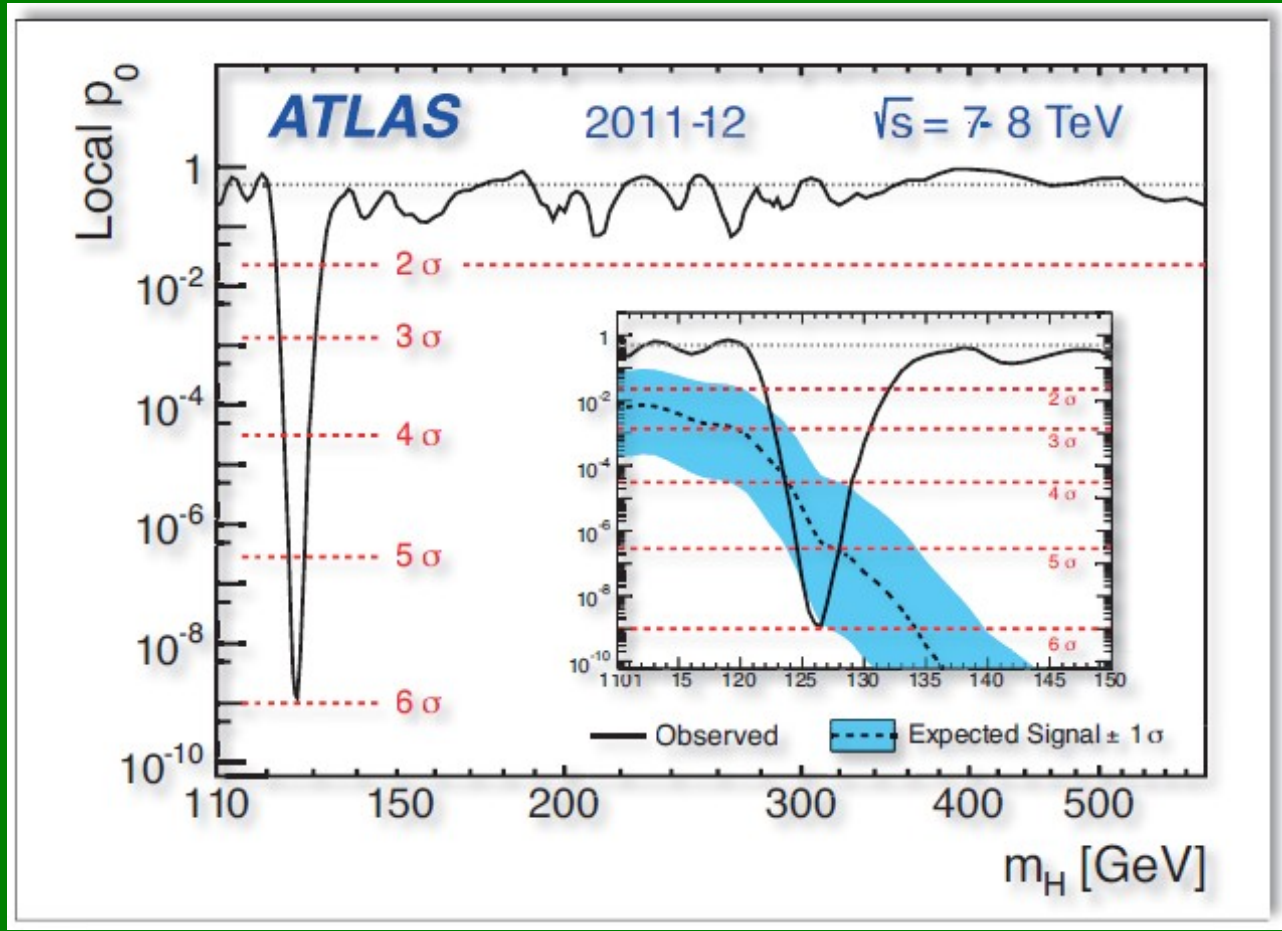


Combination of the Higgs Boson Main Properties Measurements using the ATLAS Detector

Michael Duehrssen
for the ATLAS collaboration
EPS HEP 2013 Stockholm, 19th July 2013

~1 year after the discovery

4th July 2012: Higgs discovery



Today:
Combination of

H→γγ	~25fb
H→ZZ	~25fb
H→WW	~25fb

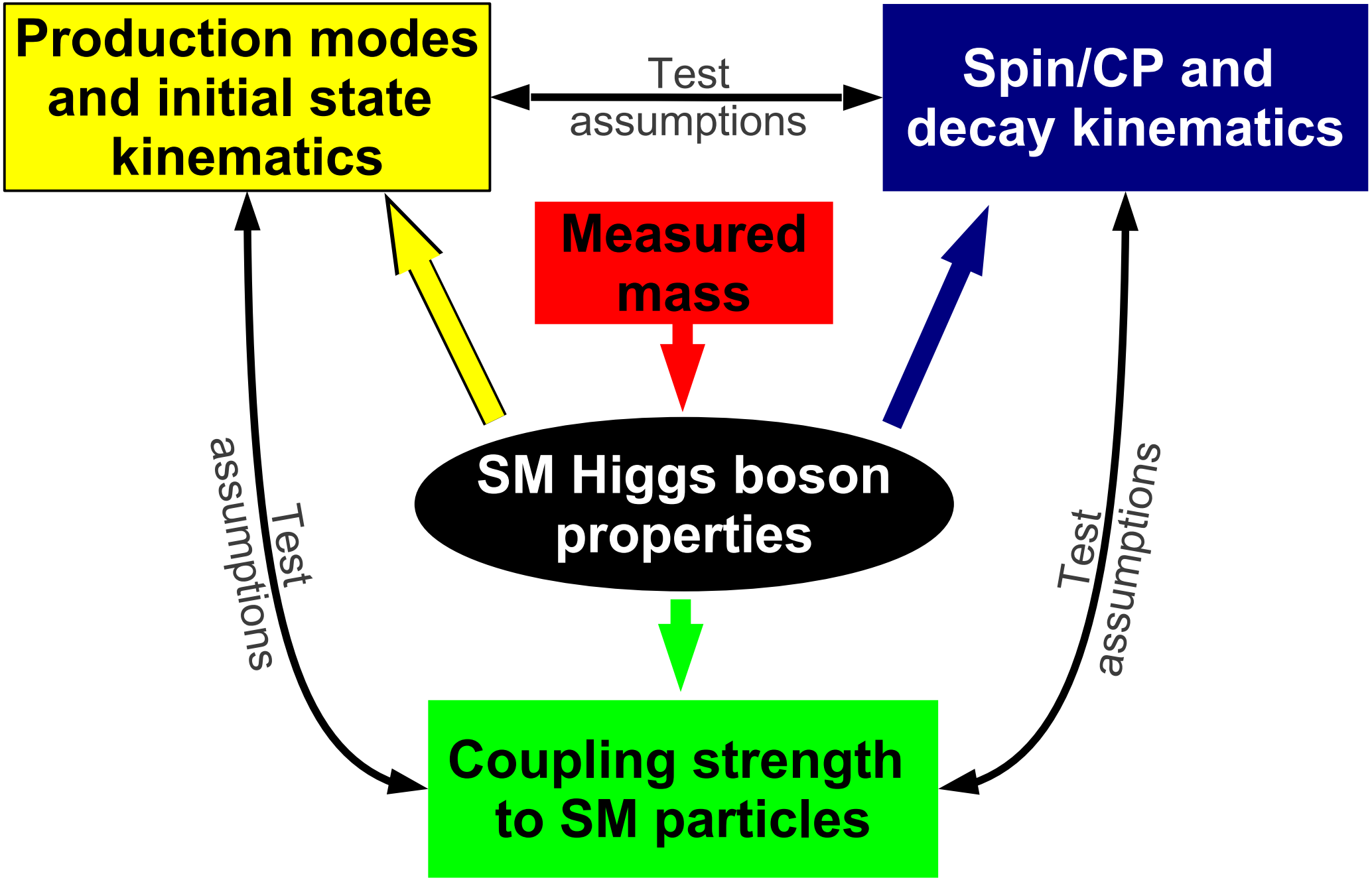
Main references :
arXiv:1307.1427 Couplings
arXiv:1307.1432 Spin/CP

Fermion channels not included yet in published combination

H→bb	~25fb
H→ττ	~18fb

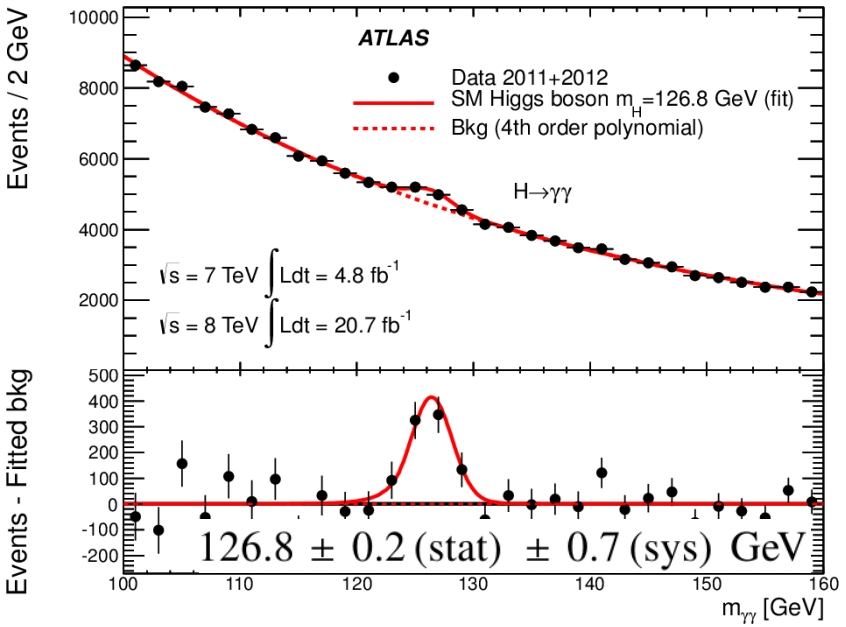
Focus of Higgs analysis after the discovery:
What are the properties of the discovered particle and do they deviate from the predictions for a SM Higgs boson?

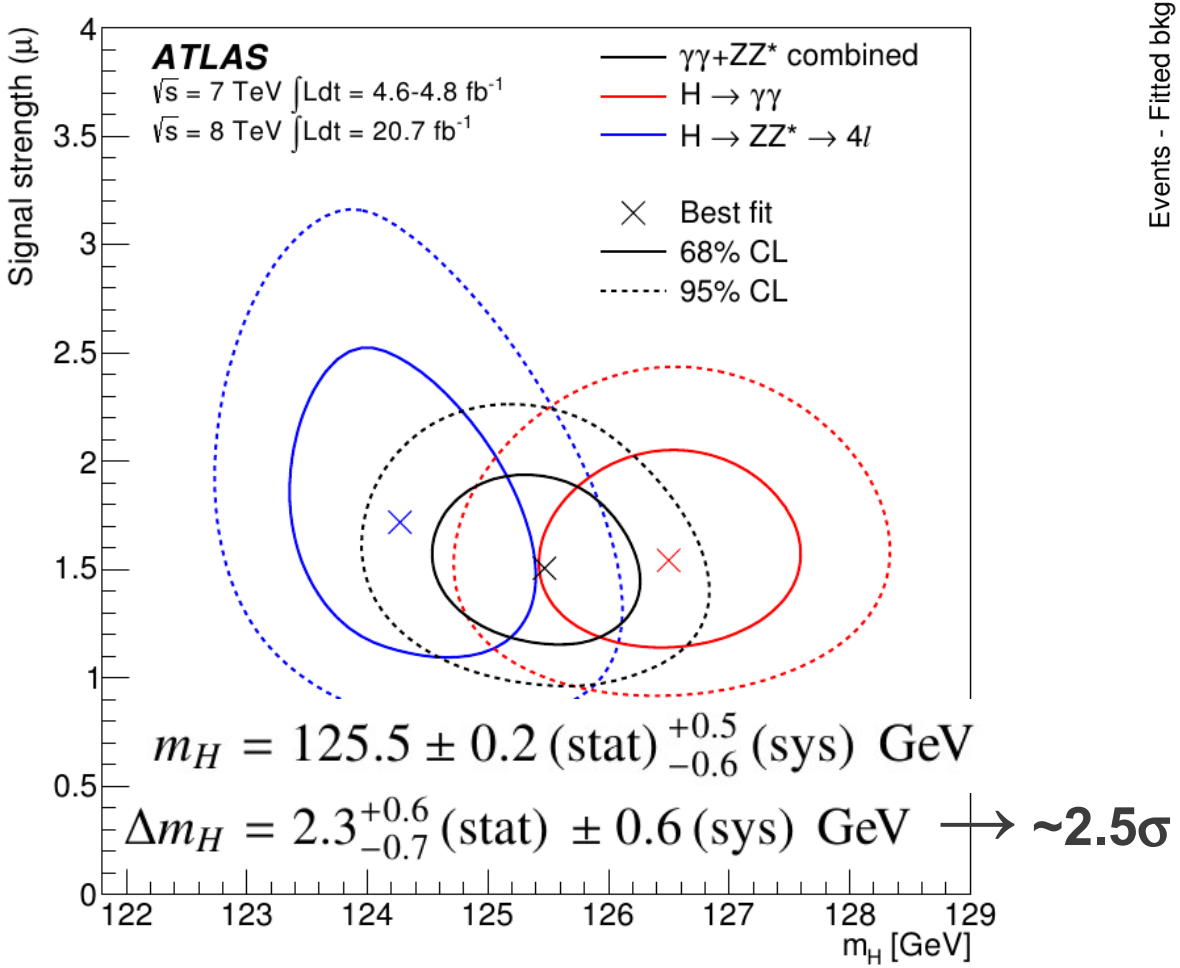
Where to look for deviations from the SM



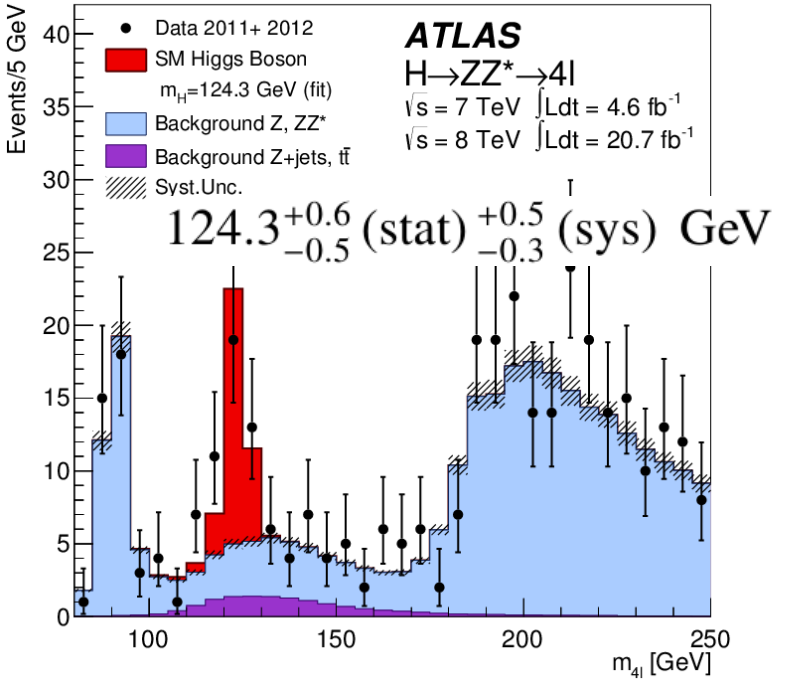
Higgs boson mass m_H

- **For any statement on the SM nature of H, we first need m_H**
- **The two most sensitive channels are H→γγ and H→ZZ→4l**



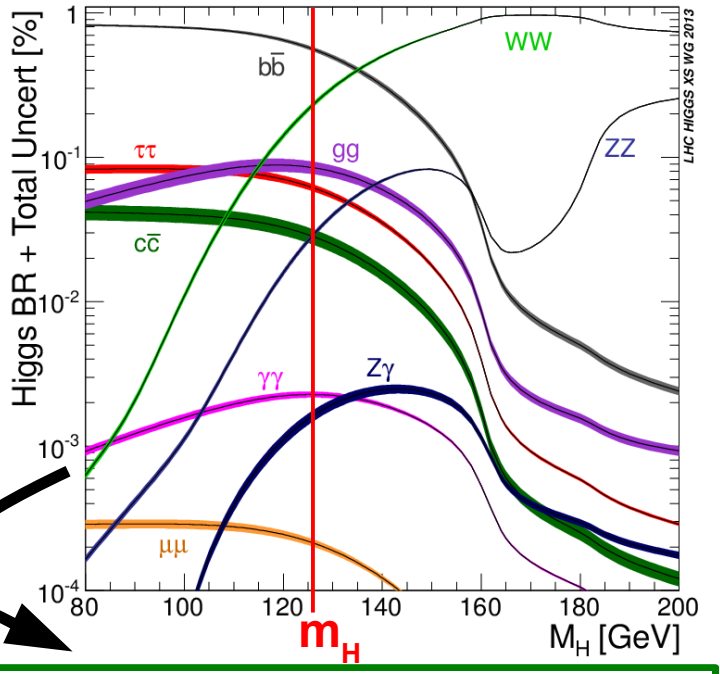


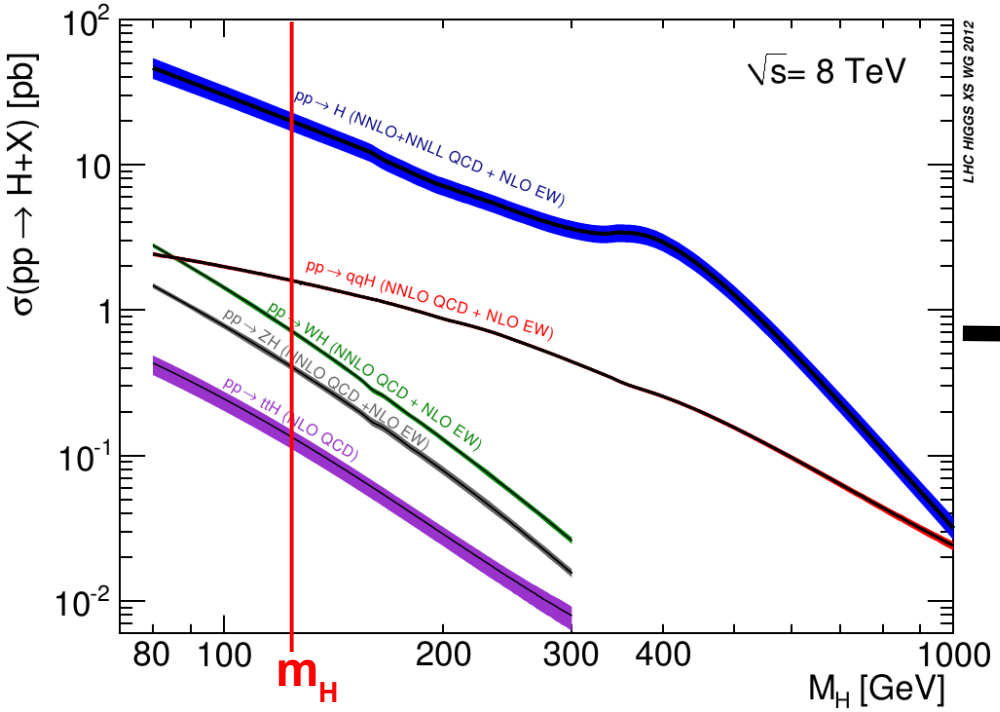
→ ~2.5σ

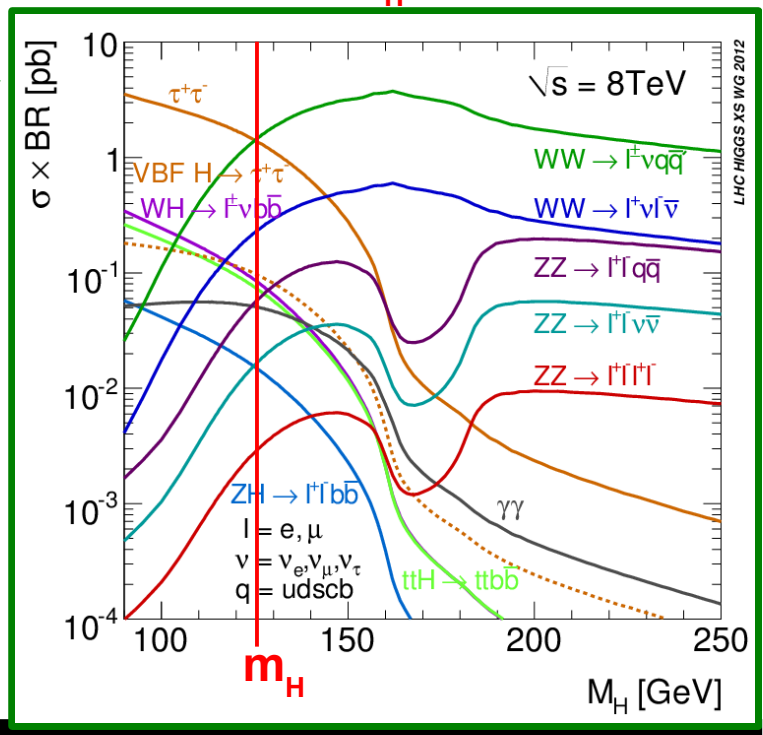


Properties of a SM Higgs boson

- **Once the mass is known, all properties of a SM Higgs boson are fixed and predictable**
- **This gives a very special pattern of observable signal rates in the different production and decay modes**
- **Observing such a pattern is a strong indication for a Higgs!**

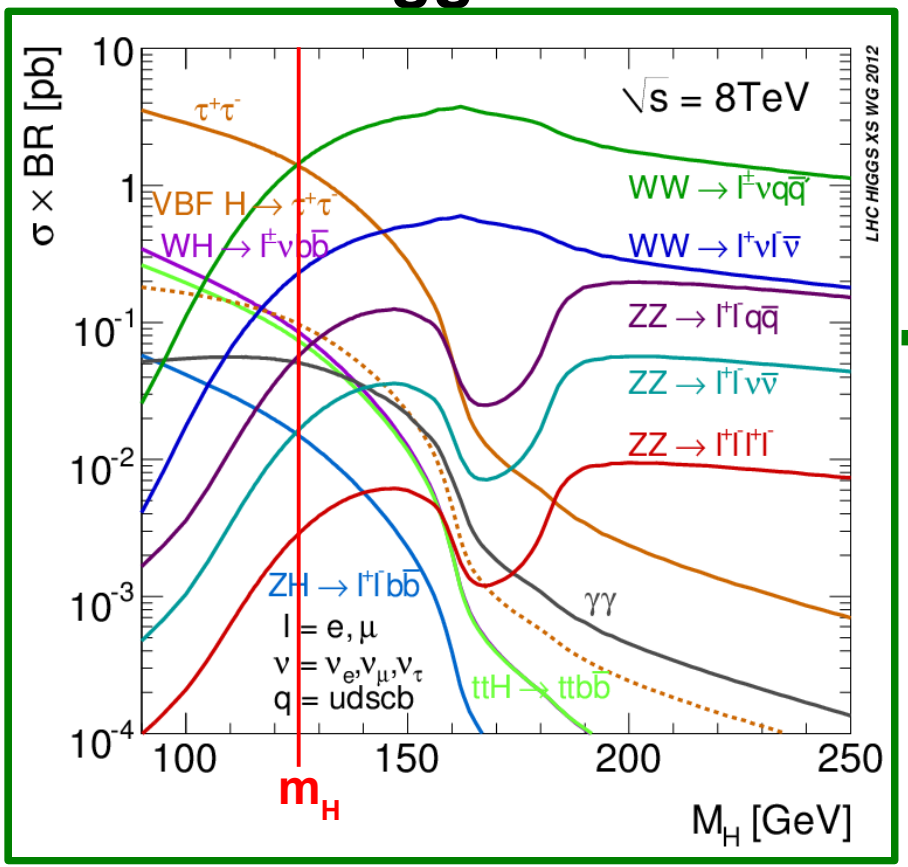


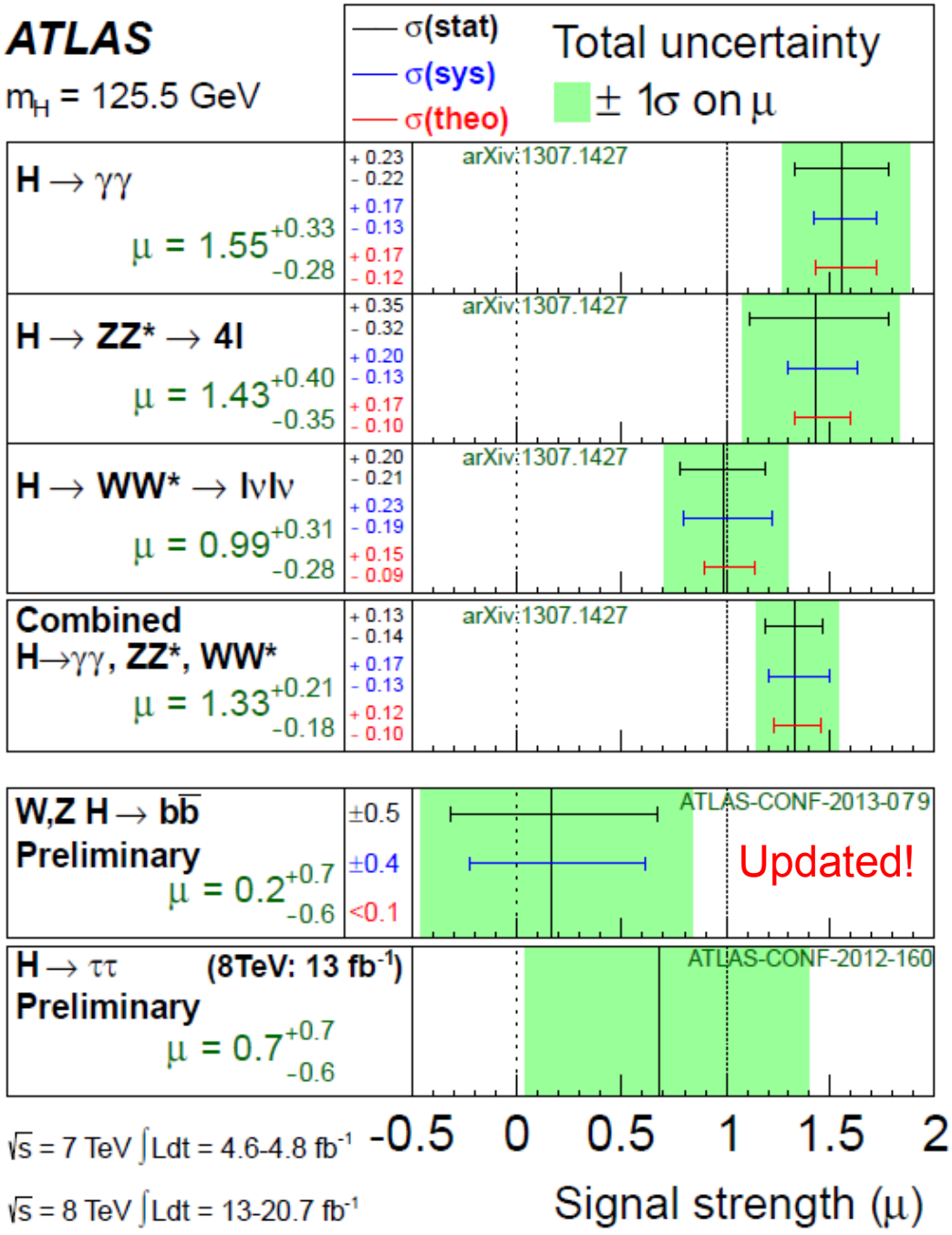




Measuring the signal strength

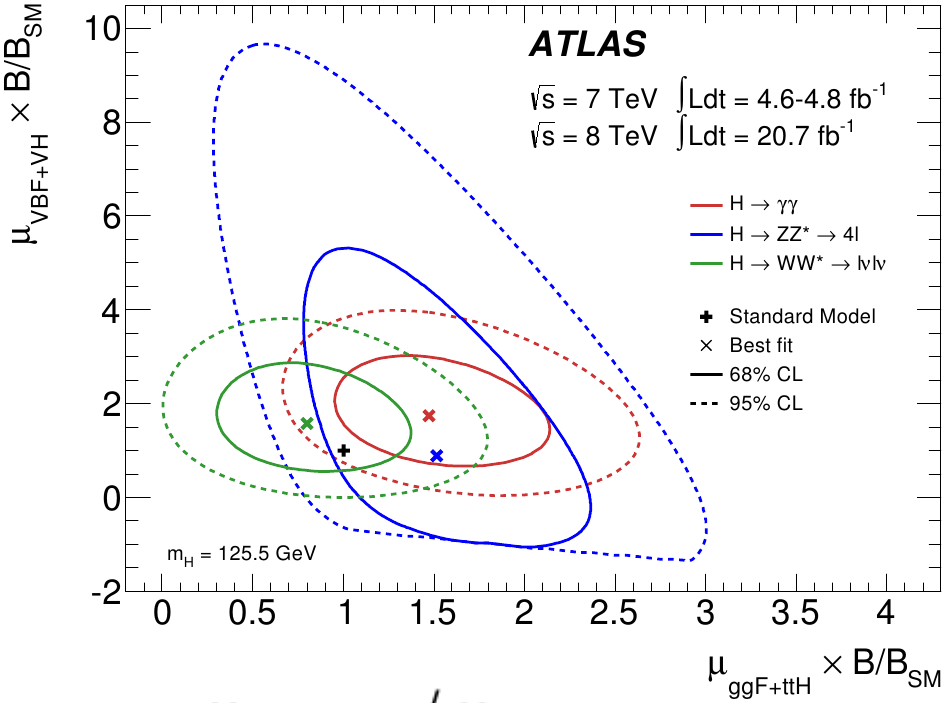
- **Measure the ratio μ between the observed rate and the SM expectation for σ x BR**
- **Result consistent with μ=1: Pattern matches the footprint of a SM Higgs boson!**



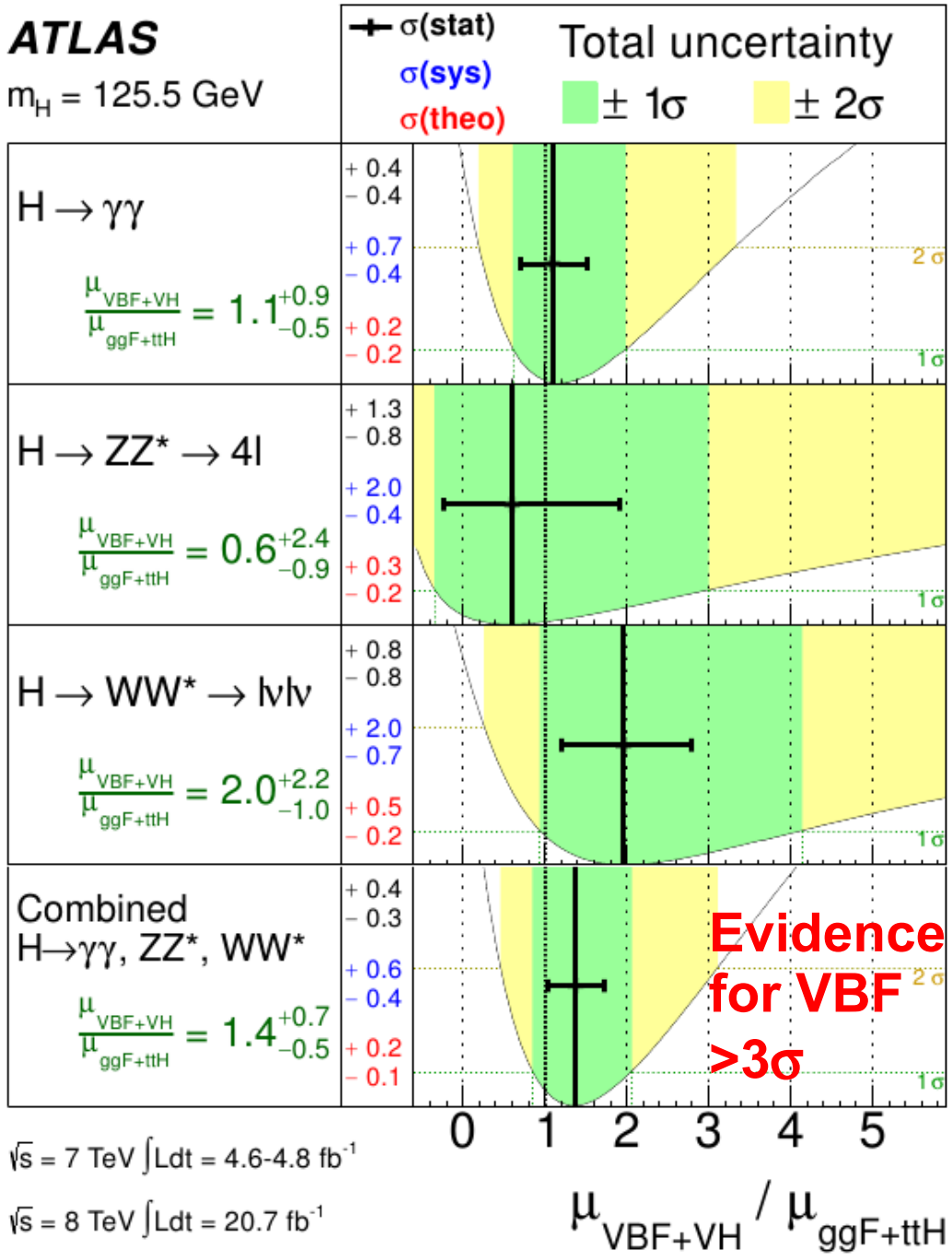


Higgs boson production

- **Measurement of μ needs some assumptions about the relative strength of production modes**
- **Test these by measuring "VBF vs. ggH" in each final state:**

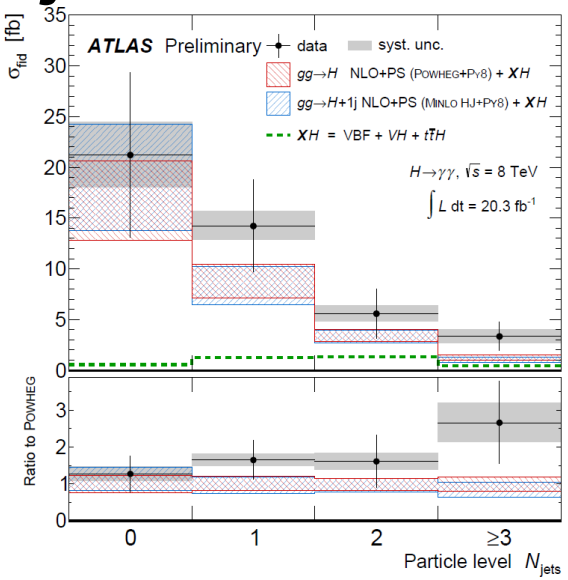


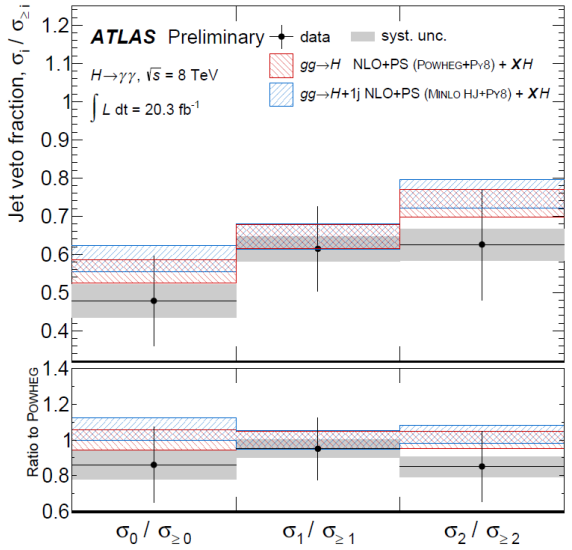
- **Ratio $\mu_{VBF+VH} / \mu_{ggF+ttH}$ is independent of new physics in BR → combine measurements**
- **Ratio consistent with SM Higgs!**

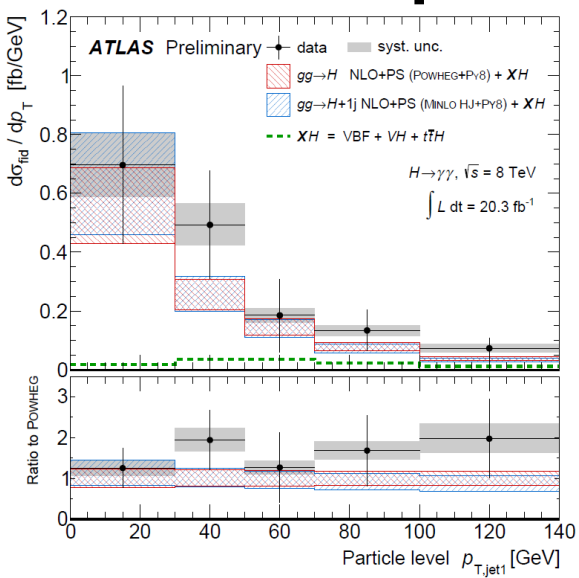


Initial state and jet kinematics

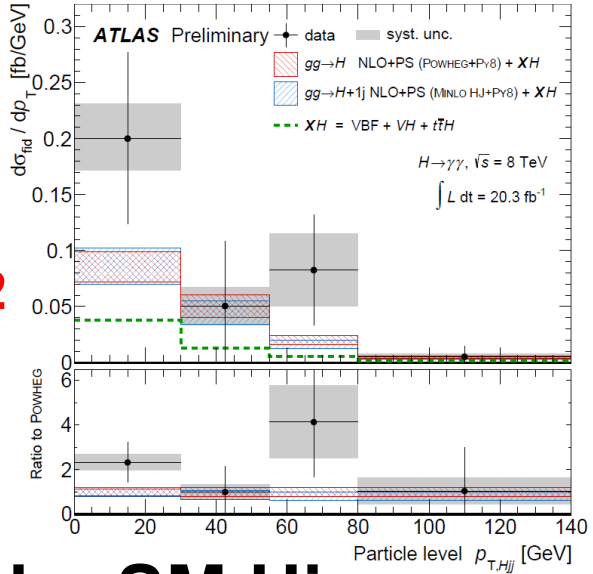
- The measurements of μ and production modes use initial state and jet kinematics of Higgs production modes as input

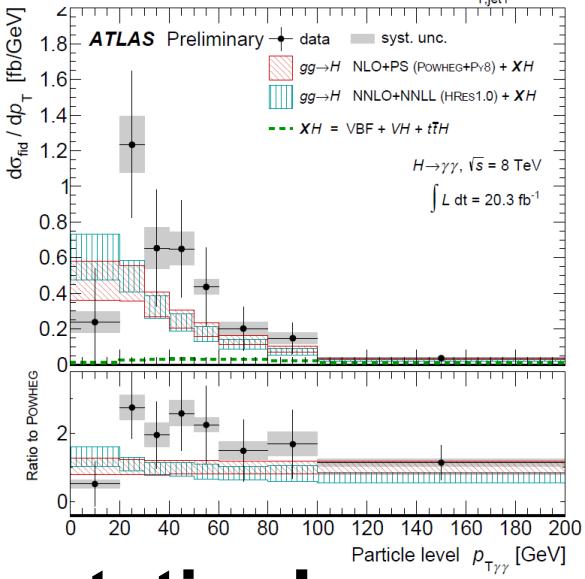






- First measurements of these inputs are available from the H→γγ channel:ATLAS-CONF-2013-072 (see yesterdays talk by J. B. de Vivie)

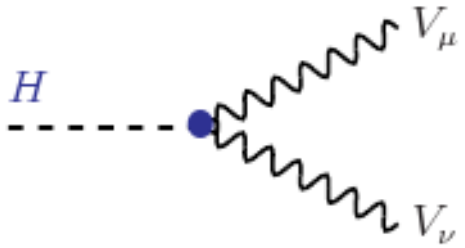




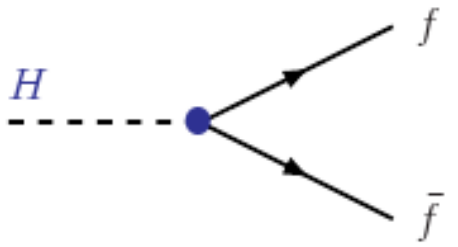
- Results consistent with the SM Higgs expectation!

Decay kinematics and Spin/CP

- **The SM Higgs boson is Spin 0, CP even. This gives a very distinct decay signature from the scalar coupling structure:**

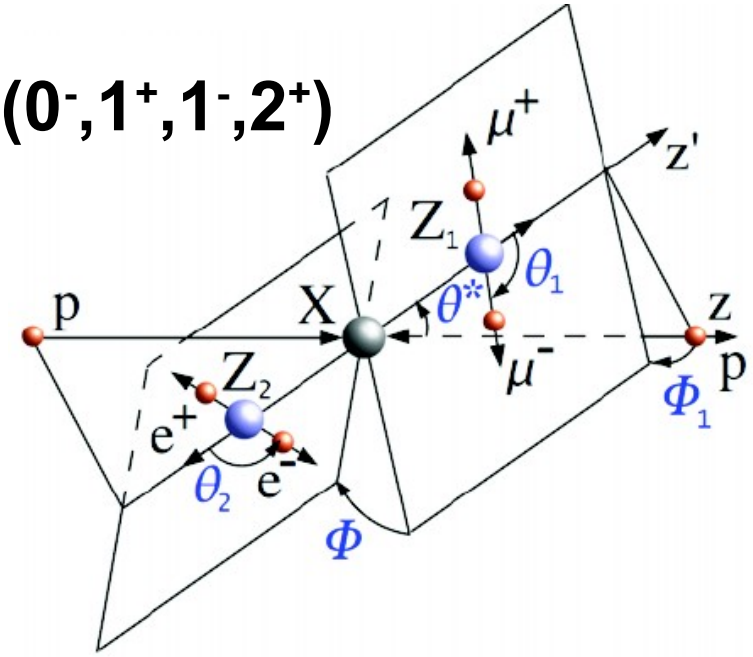


$$g_{HVV} = 2M_V^2/v = 2(\sqrt{2}G_\mu)^{1/2} M_V^2 \quad \times (-ig_{\mu\nu})$$



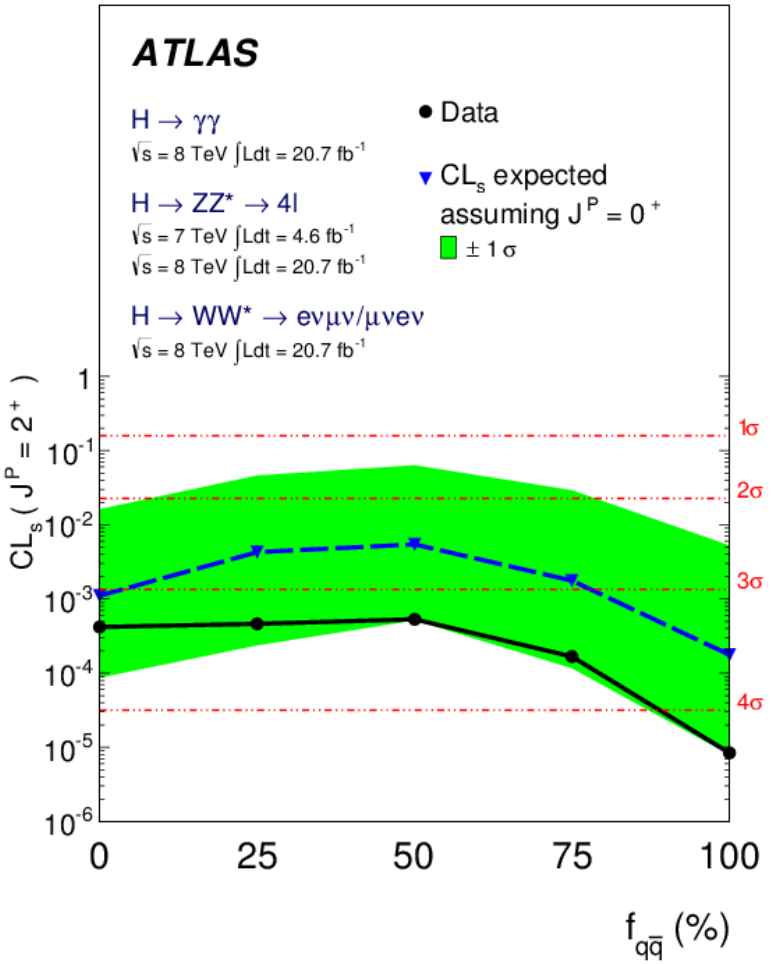
$$g_{Hff} = m_f/v = (\sqrt{2}G_\mu)^{1/2} m_f \quad \times (i)$$

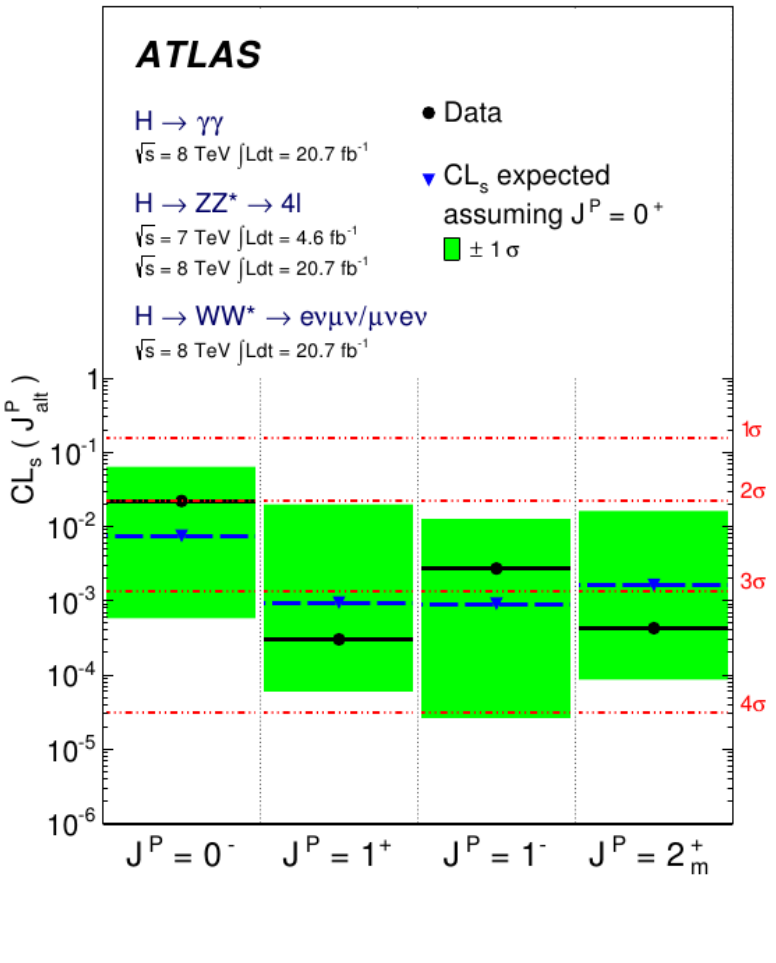
- **Test different Spin and CP hypotheses (0^-,1^+,1^-,2^+) using angular correlations**
  - **H→ZZ:** Multivariate discriminant (BDT) based on full decay kinematics
  - **H→WW:** BDT based on lepton + missing E_T kinematics
  - **H→γγ:** cos(θ*) of production angle



Decay kinematics and Spin/CP

- **Spin 2 has many potential degrees of freedom. Here test of graviton inspired Spin 2 models as function of qq/gg fraction**
- **The tested BSM Spin/CP hypotheses (0^-,1^+,1^- and 2^+ with 0%-100% qq-fraction) are all ruled out with >97.8% CL**
- **Data favors SM 0+ hypothesis**





Coupling strength "measurements"

- The coupling strength g of the Higgs to other SM particles is the most characteristic footprint. It scales with the particle mass: fermions: $g_F=\sqrt{2}\, m_F/v$, gauge bosons: $g_V=2\, m_V^2/v$
- Measure this by introducing coupling scale factors κ_i

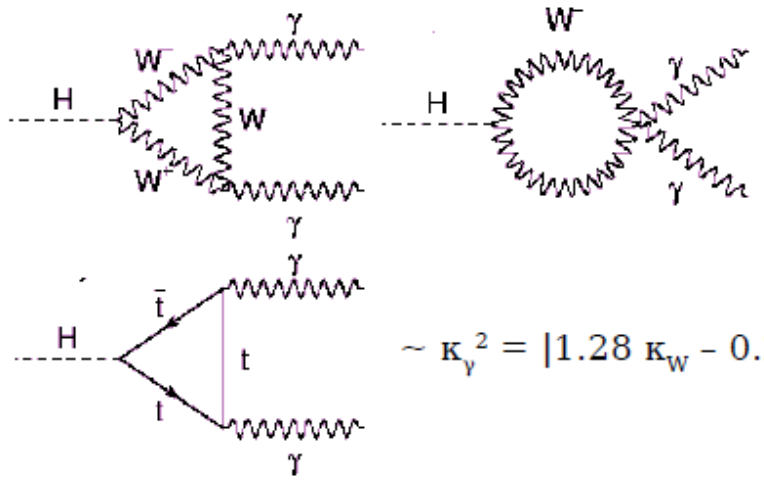
  (for fermions: $g_F=\kappa_F * \sqrt{2}\, m_F/v$, gauge bosons: $g_V=\kappa_V * 2\, m_V^2/v$)

  in a leading order motivated framework:
  - Production: $\sigma_i \sim \kappa_i^2$
  - Decay: $\Gamma_i \sim \kappa_i^2$
  - Total width: $\Gamma_H = \Sigma_i\ \kappa_i^2 \Gamma_i^{SM}$
  - Interference in $H\rightarrow\gamma\gamma$:

    → sign-ambiguity in many measurements
- Assumptions:
  - Only one Higgs
  - Spin 0, CP even: only scalar modifications of the coupling strength

Example:

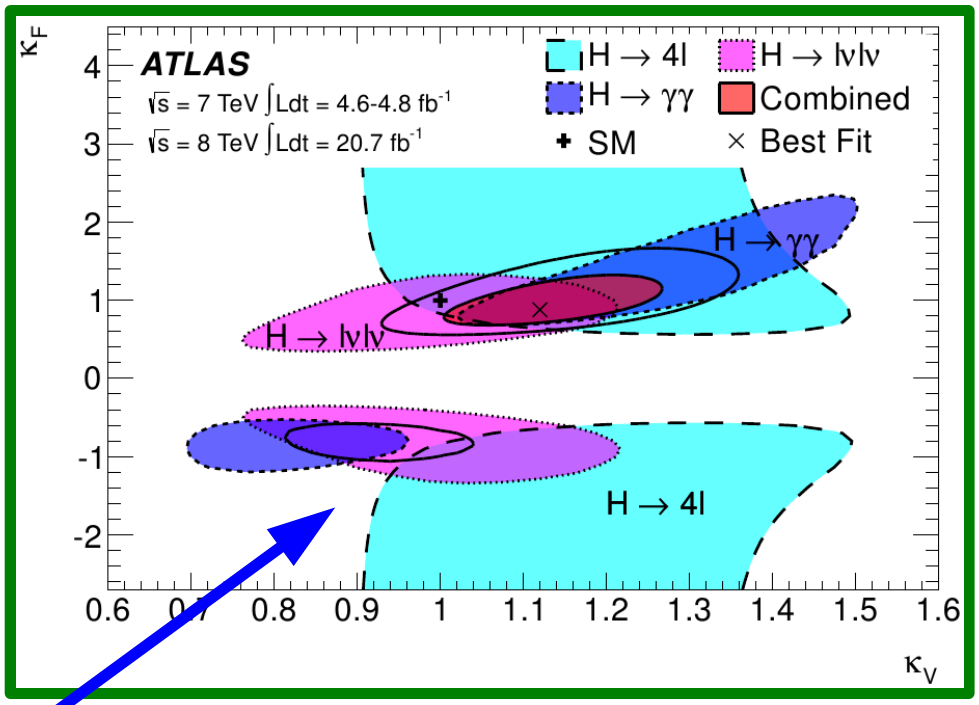
$$\frac{\sigma \cdot \mathrm{B}\,(gg \rightarrow H \rightarrow \gamma\gamma)}{\sigma_{\mathrm{SM}}(gg \rightarrow H) \cdot \mathrm{B}_{\mathrm{SM}}(H \rightarrow \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

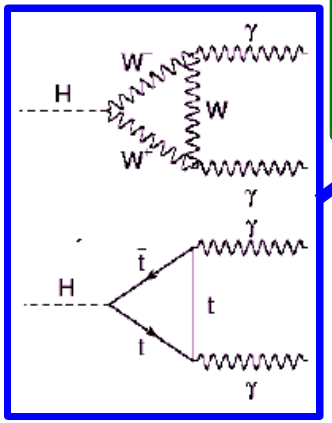


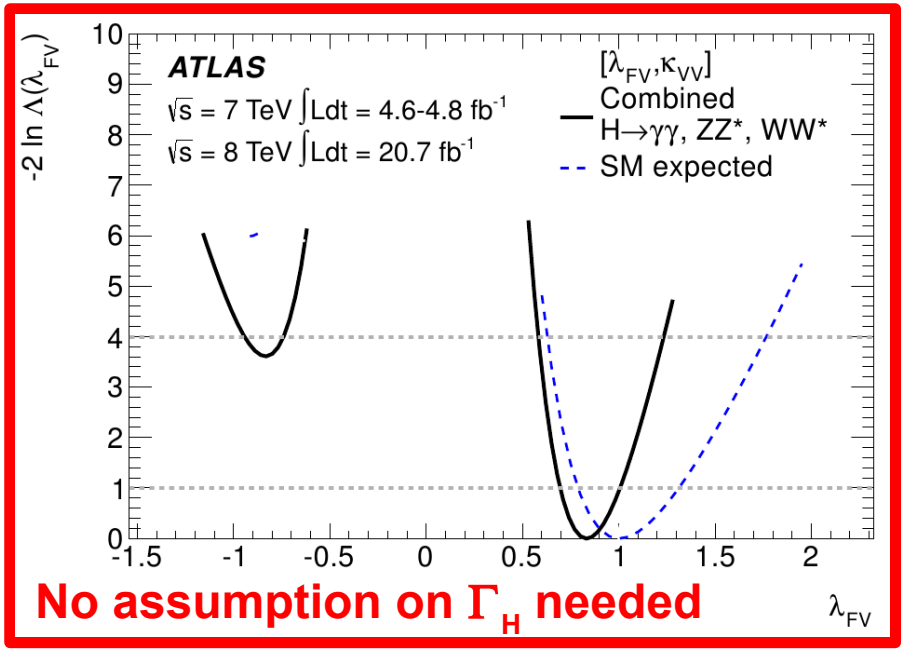
$$\sim \kappa_\gamma^2 = |1.28\ \kappa_W - 0.28\ \kappa_t|^2$$

Couplings to fermions and gauge bosons

- **Test of fundamental difference between Yukawa and gauge couplings using independent scale factors for fermions and gauge bosons: κ_F and κ_V**
- **Assume: no BSM contributions to the total width Γ_H and $H\to\gamma\gamma$ + $gg\to H$ loops**
- **κ_F sign ambiguity from interference in $H\to\gamma\gamma$: $\Gamma_\gamma \sim |1.28\kappa_W - 0.28\kappa_t|^2$**
- **Directly probe fermion/gauge coupling ratio through $\lambda_{FV}=\kappa_F/\kappa_V$**
- **Individual channels + combination compatible with the SM**

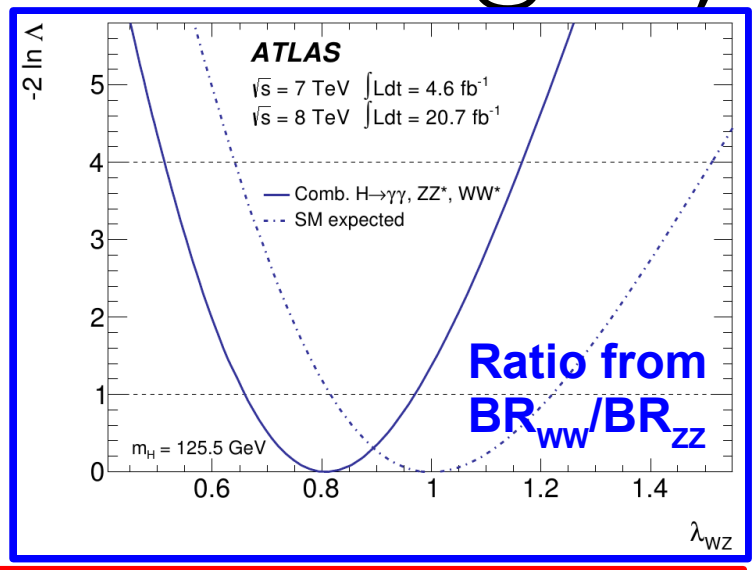


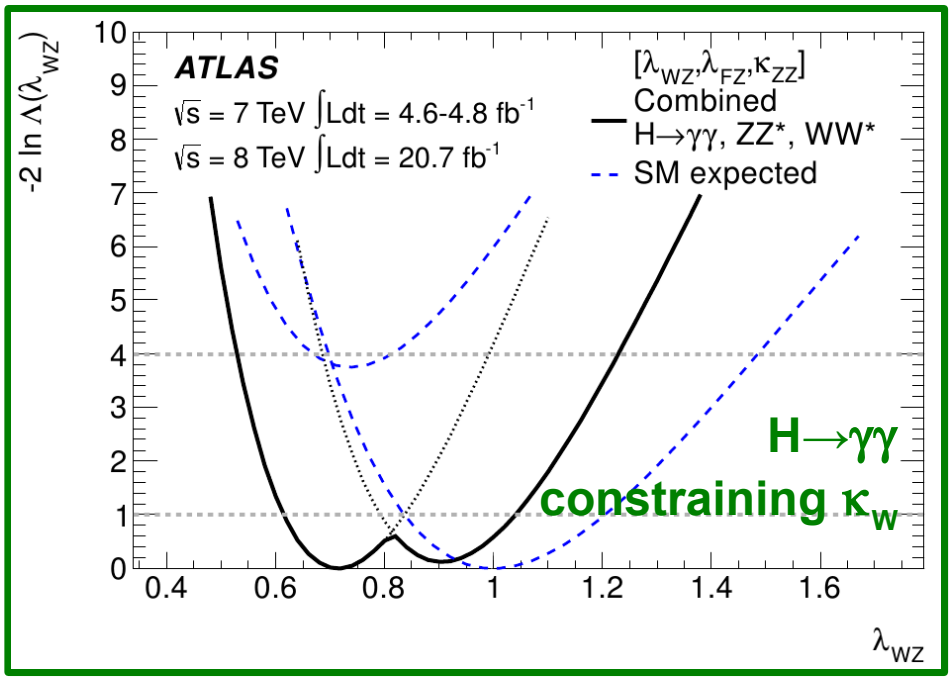


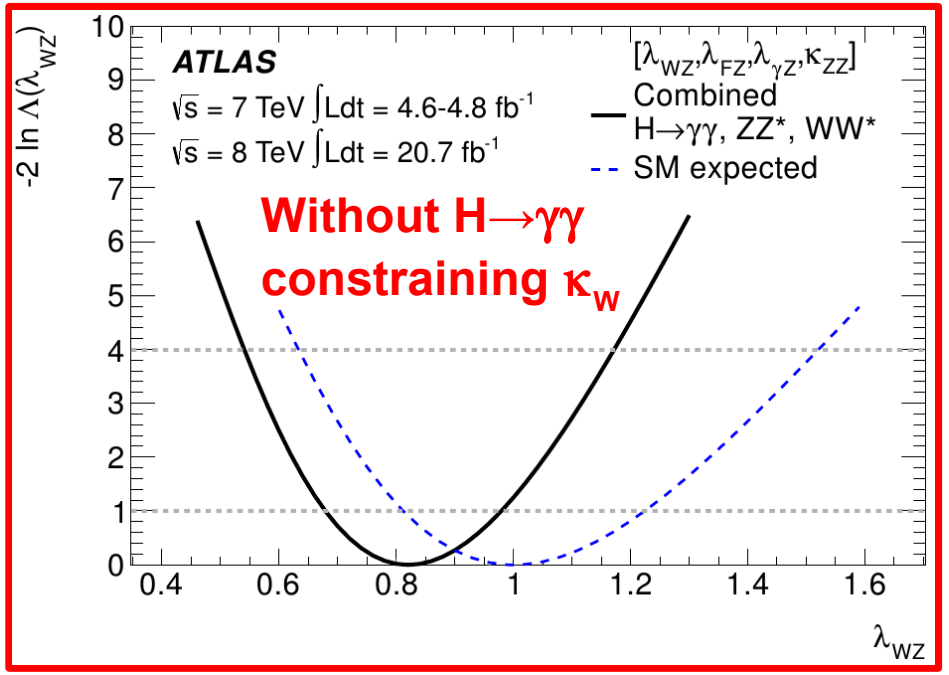


Couplings to W- and Z- bosons

- Custodial symmetry imposes the SM coupling ratio between the W and Z Higgs couplings (and ρ=1 as measured @ LEP)
- Measure coupling ratio $\lambda_{WZ}=\kappa_W/\kappa_Z$
  - From the ratio of branching ratios
  - From the ratio of coupling
  - From the ratio of coupling, but not letting $H\rightarrow\gamma\gamma$ influence κ_W
- All results consistent with the SM

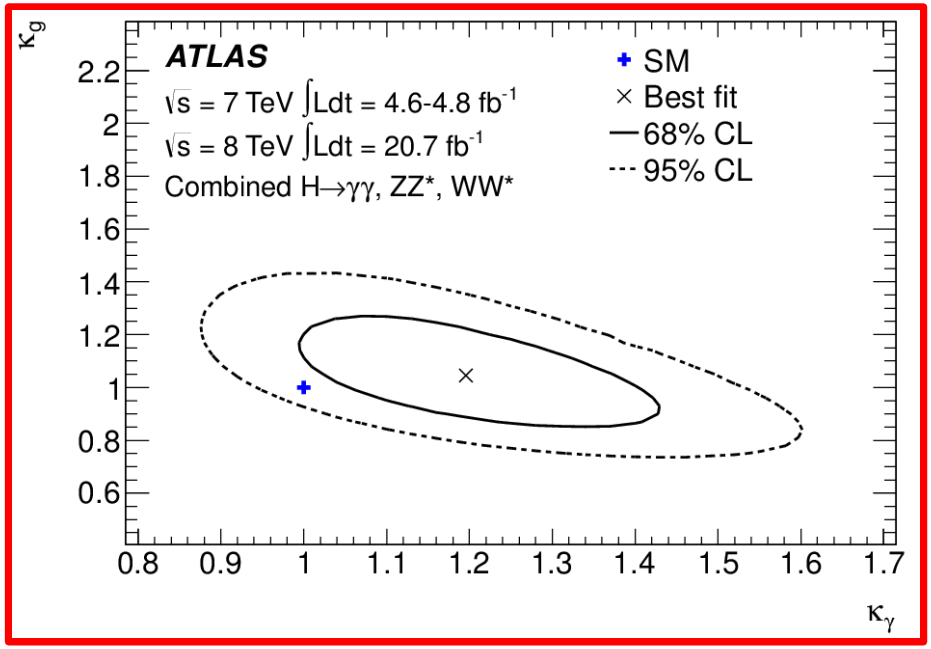


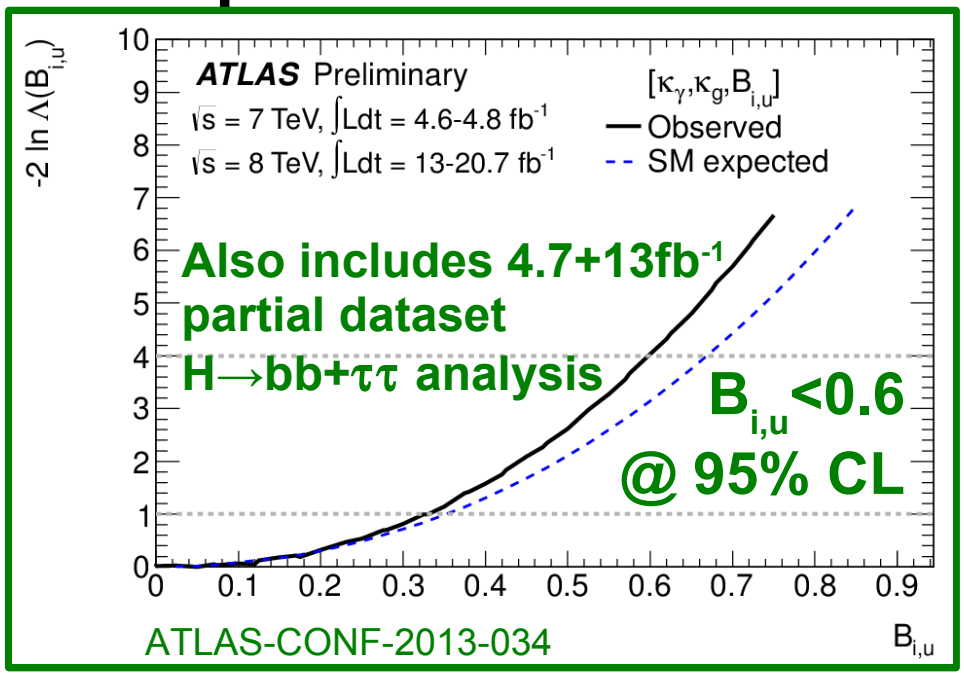




BSM contributions to gg→H and H→γγ loops

- The gg→H and H→γγ loops are especially sensitive to potential new physics.
- Determine effective coupling scale factors for these loop induced couplings: κ_g and κ_γ. Assume all other couplings as in the SM: $\kappa_i=1$
- Can in addition fit for a potential BSM Higgs branching ratio $B_{i,u}$ to invisible or undetectable final states
- All results compatible with the SM expectation





Summary

- During the last year ATLAS has done extensive property measurements for the discovered Higgs boson
- All results consistent with a SM Higgs boson
- But stay tuned – fermion and "rare" Higgs channels to be added