Combination of results on the Higgs in ATLAS

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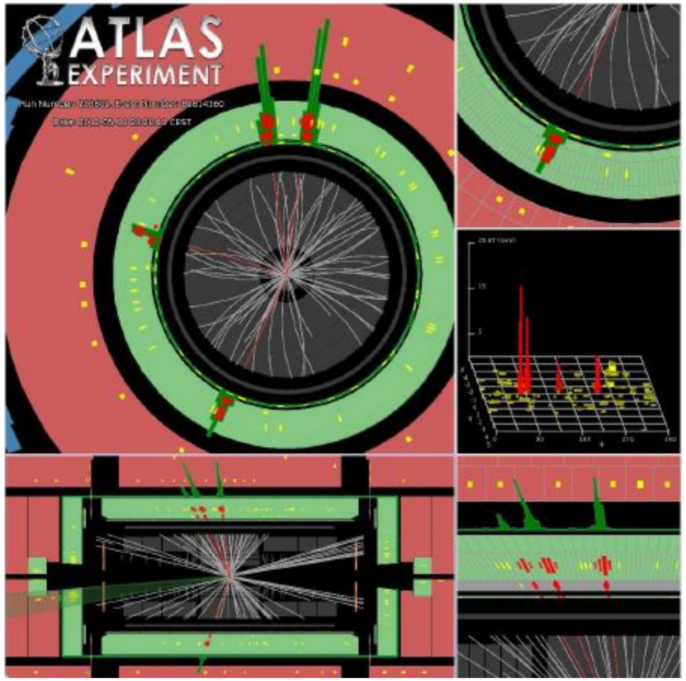
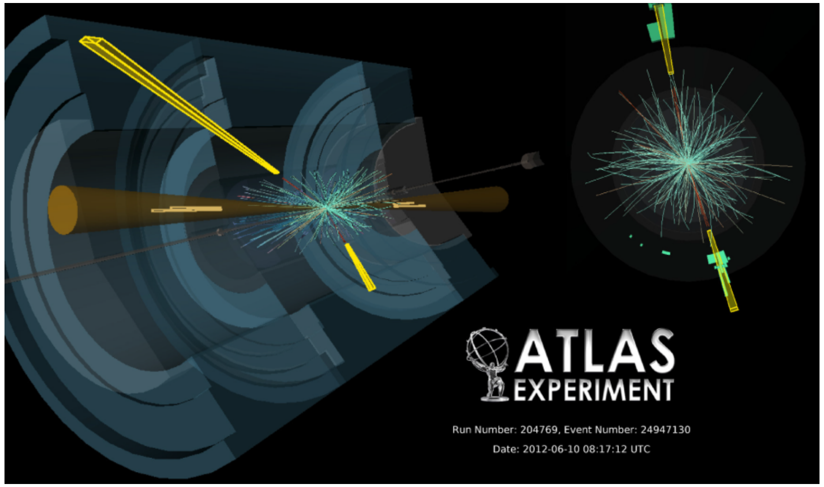
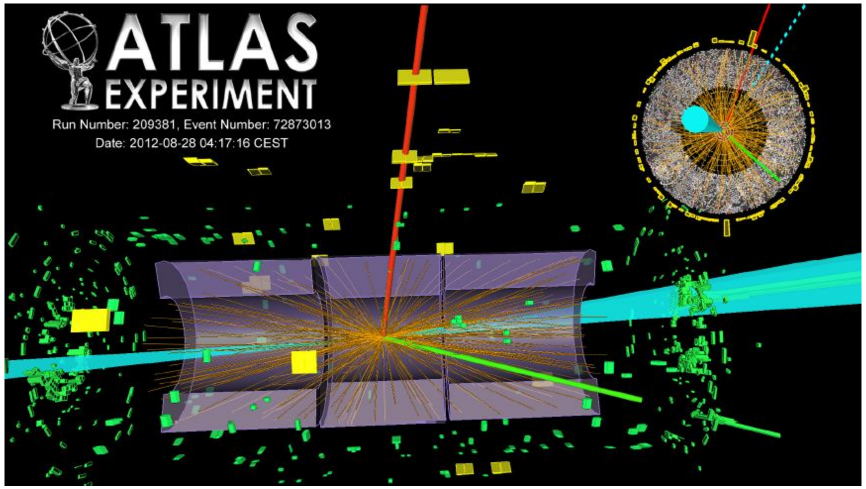
On behalf of the ATLAS collaboration







Contents

- **m_H from m(γγ) and m(4 leptons)**
- **Signal strength with respect to SM : global (μ), per channel (μ_i)**
- **Production modes: Vector Boson Fusion (+ VH) / gluon fusion (+ tt)**
- **Higgs couplings**

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Statistical method

- **All results from profiled likelihood method**

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

μ : parameter(s) of interest
θ : nuisance parameters

$L(\hat{\mu}, \hat{\theta})$ **global likelihood maximum: μ and θ adjusted for max L**

$L(\mu, \hat{\hat{\theta}}(\mu))$ **tested μ point : θ adjusted for max L *at this μ point***

- ***−2 Ln Λ(μ)*** **follows χ^2 distribution with n d.o.f. ($\mu_{1\ldots n}$) => P(χ^2 > x)…**

- **Nuisance parameters θ prob.dist.functions. : Gauss, LogNormal, Poisson …**
  - **Also explored: cases with a « rectangular » pdf for some systematic uncertainties**

Mass systematic uncertainties: 4 leptons and $\gamma\gamma$

- **4 leptons**
  - **Dominated by 4 muons (best resolution, less background)**
    - Muon momentum-scale uncertainty : 0.2% (from Z, $J/\psi \rightarrow \mu\mu$)
  - **electron E-scale = > see below**

- $\gamma\gamma$
  - **Per category systematic uncertainties:**
    - method ~ 0.3 % : *(mainly from $Z \rightarrow ee$ MC/data)*
    - material in front of calorimeter: ~ 0.3%, up to 0.7%
    - relative calibration presampler/calorimeter : ~ 0.1%

    In each of the above: extrapolation in E $\oplus$ transfer from e to γ

  - **Additional (global) syst uncertainties:**
    - E1/E2, linearity, lateral leakage, conversion fraction … 0.32%

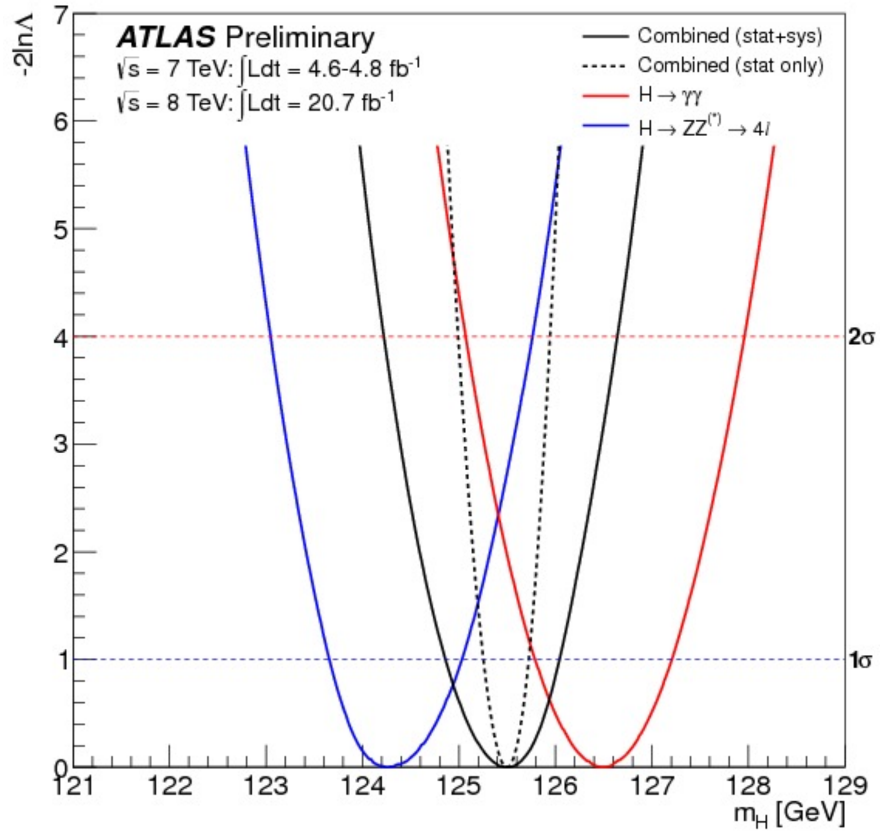
  - **Global mass systematic uncertainty: 0.55% = 0.7 GeV**

Mass measurement from γγ and 4 leptons

- $\mu_{\gamma\gamma}$ and μ_{4l} treated as independent nuisance parameters

- m_H : parameter of interest

- Full data sample :
  2011 (4.8 fb^{-1}) + 2012 (20.7 fb^{-1})

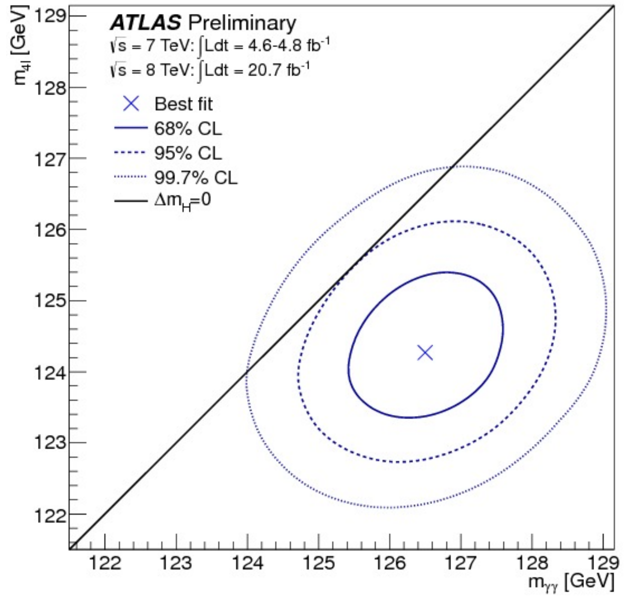


- Result: $m_H = 125.5 \pm 0.2\ (stat)\ ^{+0.5}_{-0.6}\ (sys)$ GeV

Council Dec 2012 : $m_H = 125.2 \pm 0.3\ (stat) \pm 0.6\ (sys)$ GeV (4.7 fb^{-1} + 13 fb^{-1})

Mass difference: $m_{\gamma\gamma}$ / m_{4l}

- **Parameters of interest: $m_{\gamma\gamma}$, m_{4l} (independent)**
- **Small correlation due to the common EM-scale in $\gamma\gamma$ and ee in 4 leptons**
  - *in 4 leptons: m_{4e} = 126.2 ± 1.5, $m_{4\mu}$ = 123.8 ± 0.8*
    pulls EM-scale down by 0.3 %
    => $m_{\gamma\gamma}$ here 0.4 GeV lower than single channel value

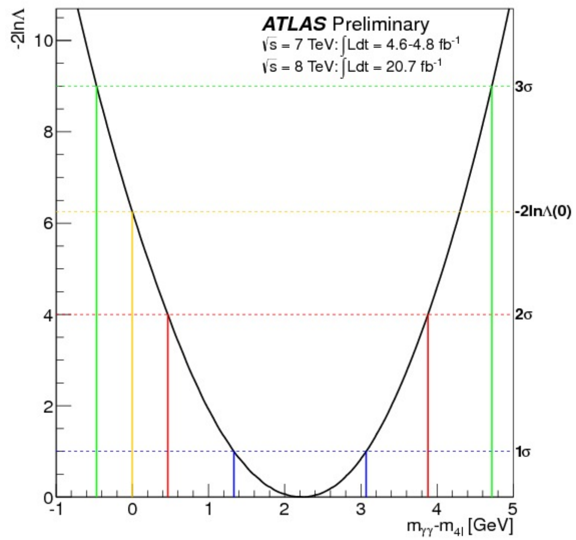


Quantify consistency:

- **parameter of interest: $\Delta m_H = m_{gg} - m_{4l}$**

$\Rightarrow$ $\Delta m_H = 2.3\ ^{+0.6}_{-0.7}$ (stat) ± 0.6 (sys) GeV

2.4 σ from $\Delta m_H = 0$ (p = 1.5%)



Also: set E-scale, e/γ pdf's to rectangular *[± 1 σ]*
(material models, calo samplings calibration…)

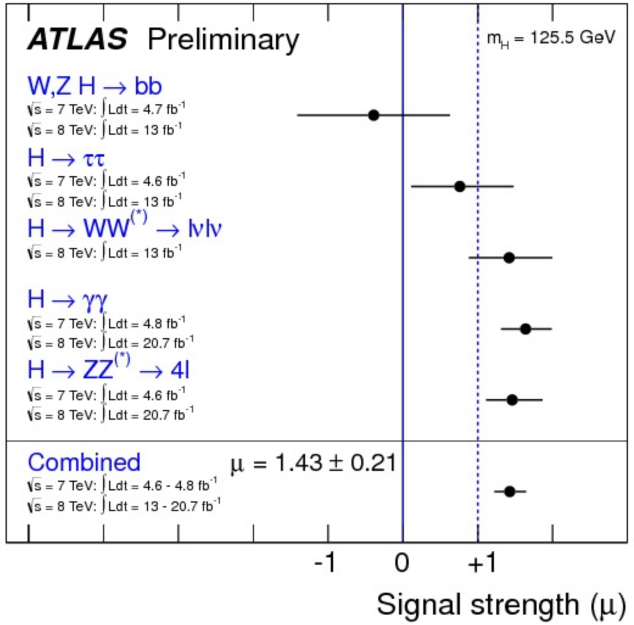
$\Rightarrow$ p = 8%

Signal strength

- **Parameter of interest : μ (global)**

⇒ $\mu = 1.43 \pm 0.16$ (stat) ± 0.14 (sys)

Council Dec 2012 $\mu = 1.35 \pm 0.19$ (stat) ± 0.15 (sys)

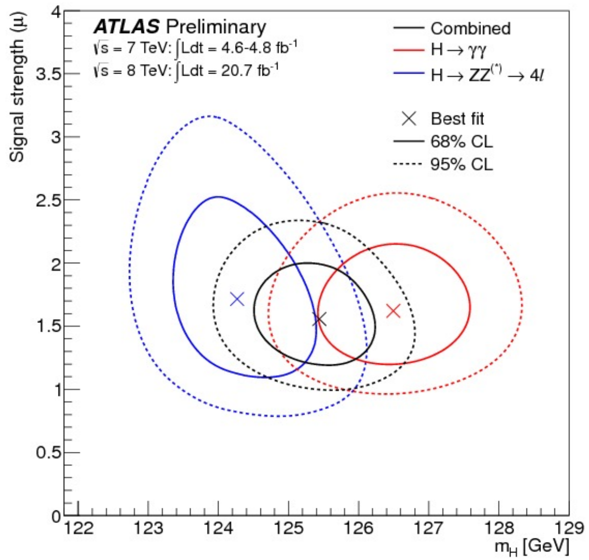


at $m_H = 125.5$

[124.5-126.5]:
$\mu \pm 4\%$

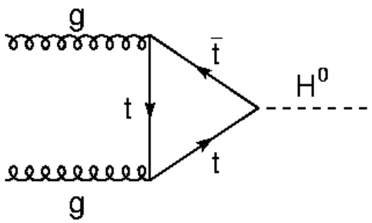
- **Consistency tests**
  - **global μ with SM: 3%**
    - 11% with rectangular QCD scale and parton dist functions
  - **5 μ_i with SM: 8%**
  - **5 μ_i with 1.43: 32%**

- **μ, m_H contours**
  - **γγ**
  - **4l**
  - **combined**

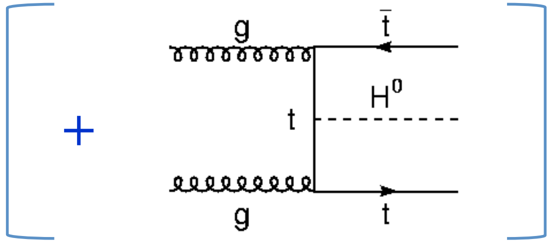


Higgs production modes

- **Through t coupling**
  - **fermion masses…**

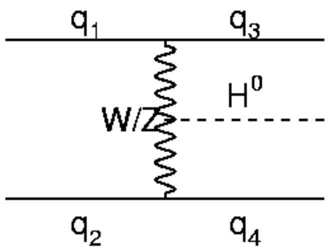


g g F

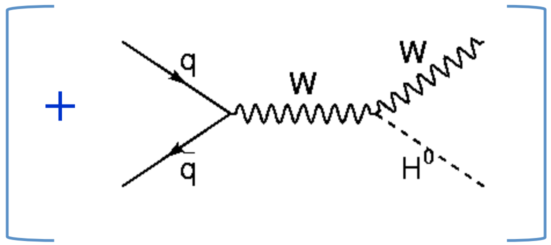


t t H

- **Through W/Z coupling**
  - **W/Z masses…**
  - **unitarity of SM**



VBF



VH

Can be tested for all modes with VBF sensitivity

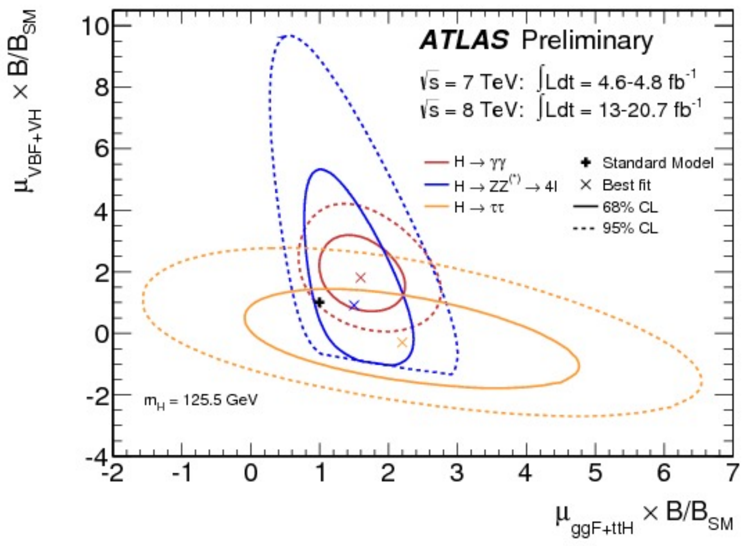
Here : $\gamma\gamma$, ZZ (4.8 + 21 fb^{-1}) , $\tau\tau$ (4.6 + 13 fb^{-1})

Production modes: VBF+VH / ggF +ttH

- μ_{VBF+VH} versus $\mu_{ggF+ttH}$

  includes Branching Ratio

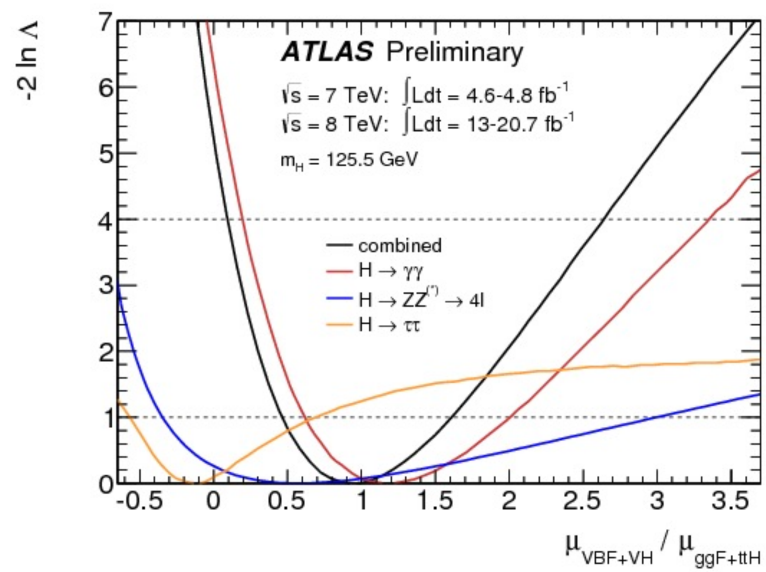
  (which might be different in each case)



- Ratio independent of B.R.:

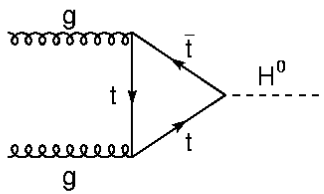
  can be combined

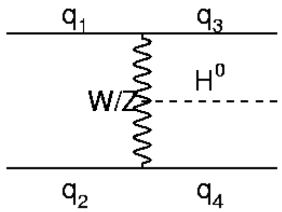
=> μ_{VBF+VH} / $\mu_{ggF+ttH}$ = $0.9^{+0.7}_{-0.4}$



Higgs couplings

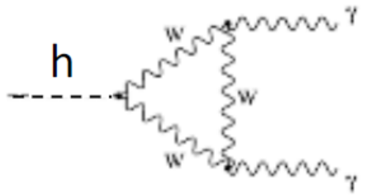
- **For each observed final state, production and decay involve several couplings**
- **Best example: γγ**
  - **Production**

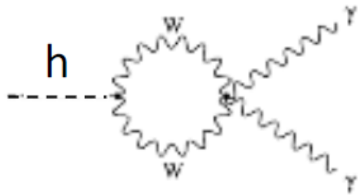


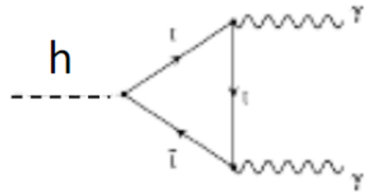


$\sim \kappa_g^2 \ (\kappa_t, \kappa_{b,} \ m_H)$ + $\sim \kappa_W^2$

  - **Decay**







Decay width : $\sim (\kappa_W - 0.2\ \kappa_t)^2$ ***[note: interference]***

- **Need consistent parametrization => LHC-XS-WG**
- **Ideally: use all production and decay modes to measure all κ's**
- **Reality: some modes are statistically limited, or even invisible (κ_c, κ_μ...?)**

=> Group some κ's in order to test salient/important features

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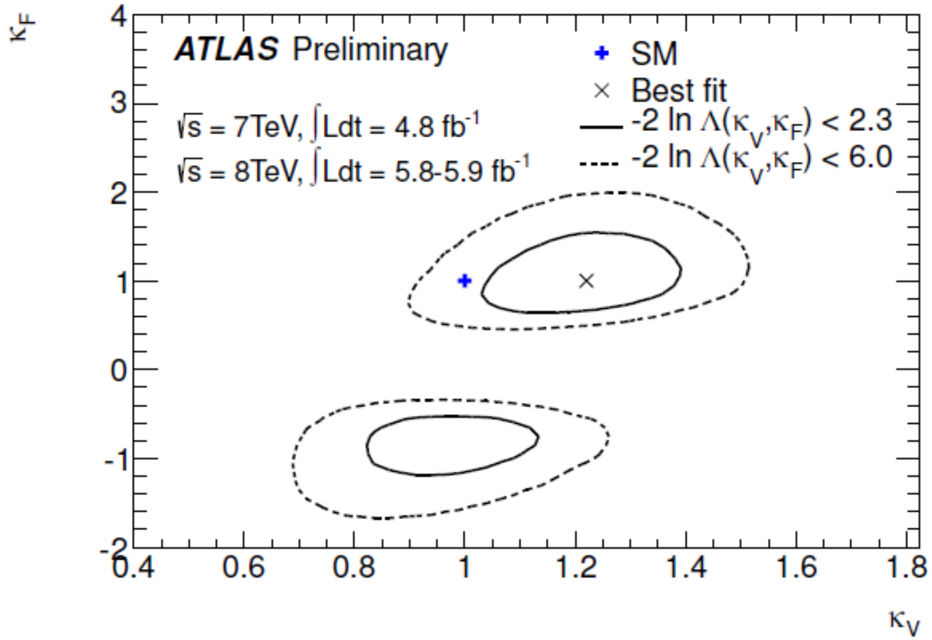
Fermion versus Vector couplings

- **Group couplings : $\kappa_V = \kappa_W = \kappa_Z$; $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$**
- **Assume:**
  - **gg → H and H → γγ only through SM particles**
  - **only SM particles contribute to decay** ***(relaxing this assumption => backup)***

sensitivity to relative sign:
only from
interference term in H → γγ



  - **compatibility with SM: 21%**

- **With these data, sensitivity to κ_F is mostly through top in loops. Will be better with ττ, bb…**

W and Z couplings ('custodial symmetry')

- group $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$

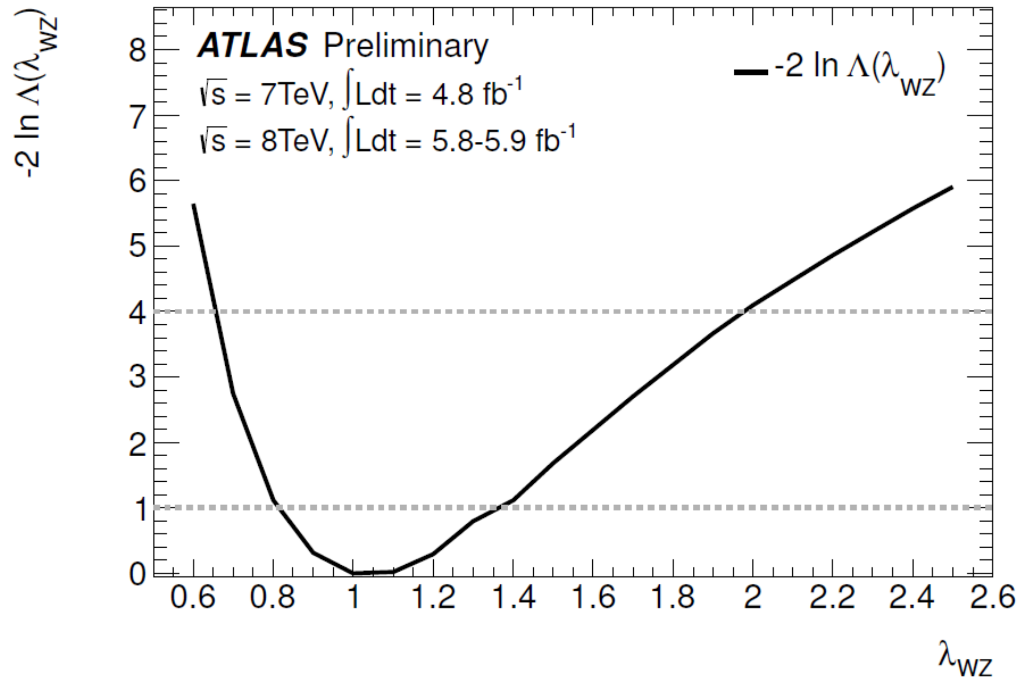
  un-group κ_W , κ_Z

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

$\Rightarrow \lambda_{WZ} = 1.07\ ^{+0.35}_{-0.27}$

Direct contribution: WW and ZZ

Indirect: $\gamma\gamma$ (through W loop)



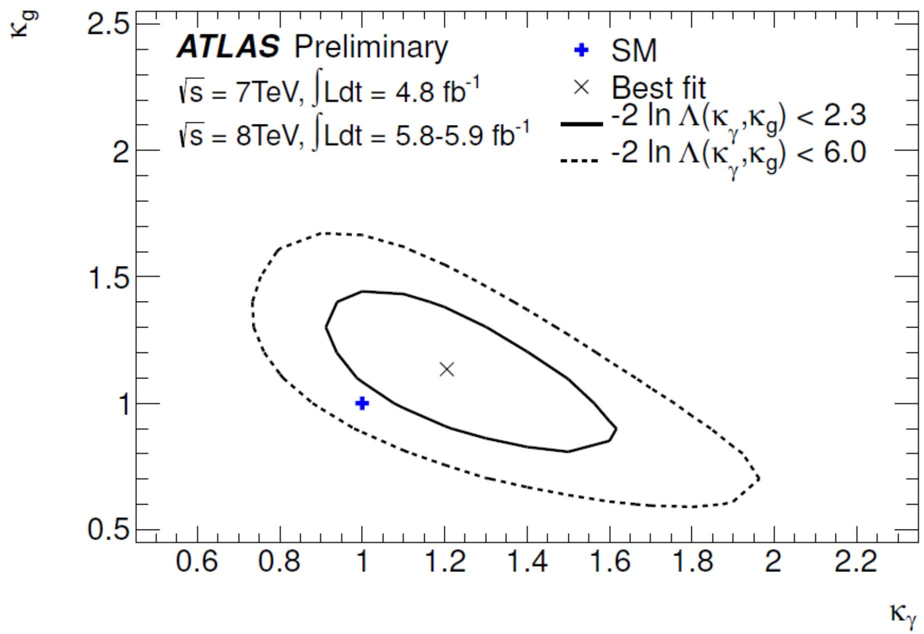
Contributions from non-SM particles

- Assume all couplings to SM particles $\kappa_i = 1$
- Introduce effective κ_g, κ_γ, *independent* (allow additional contributions to loops)

- Assume no contributions to the total width in undetected modes
  (relaxing this assumption => backup)

$\kappa_g = 1.1^{+0.2}_{-0.3}$; $\kappa_\gamma = 1.2^{+0.3}_{-0.2}$

SM hypothesis : 18%



Conclusion: ATLAS-Higgs status today

- **New high resolution channels γγ and 4 leptons (full 2011 + 2012 data)**

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

  $\mu = 1.43 \pm 0.16\ (\text{stat}) \pm 0.14\ (\text{sys})$

- **Signal strengths => =>**

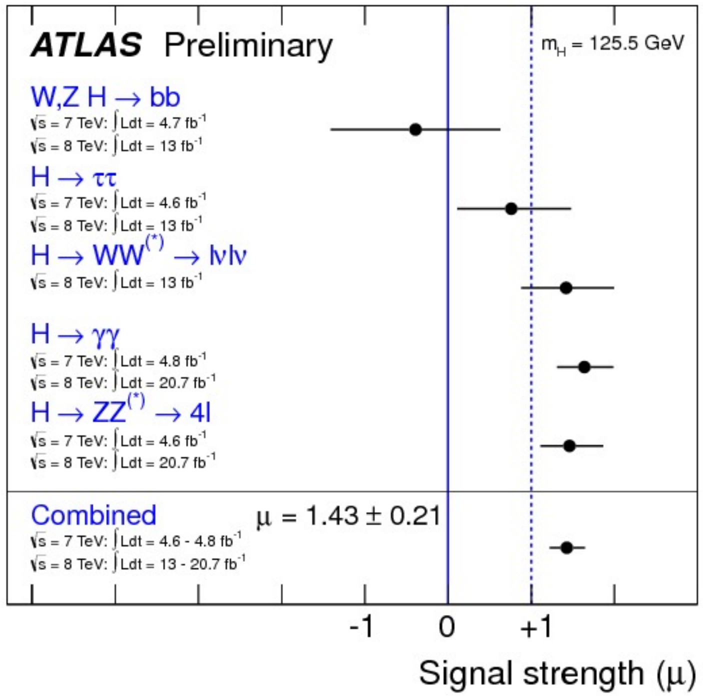
- **Production mode (from γγ, ZZ, τ τ):**

  $\mu_{VBF+VH} / \mu_{ggF+ttH} = 0.9\ ^{+0.7}_{-0.4}$

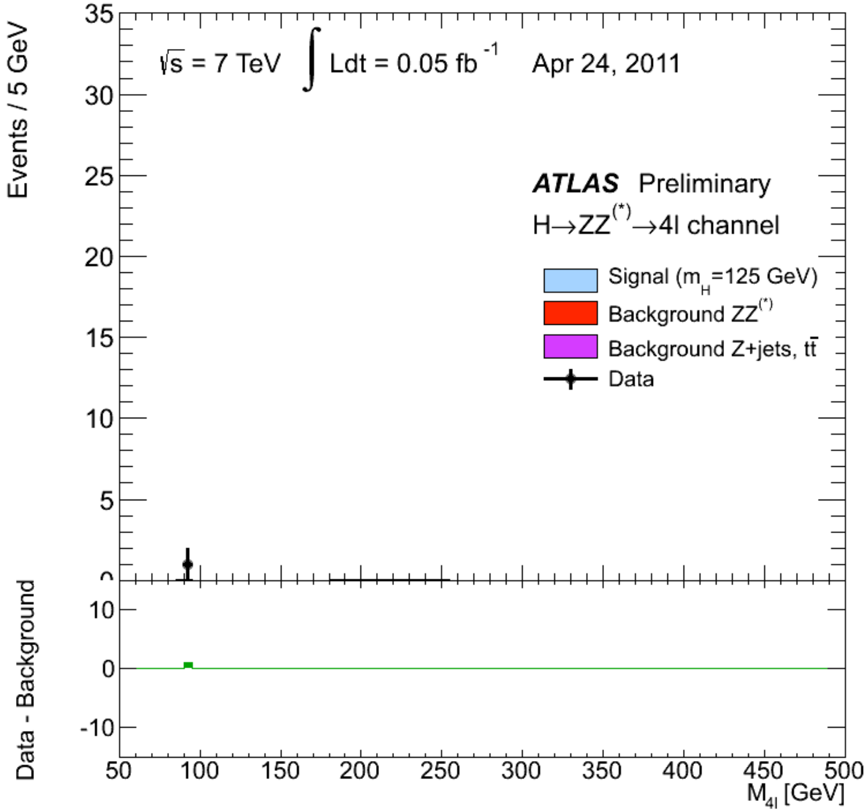
- **Higgs couplings (partial dataset)**

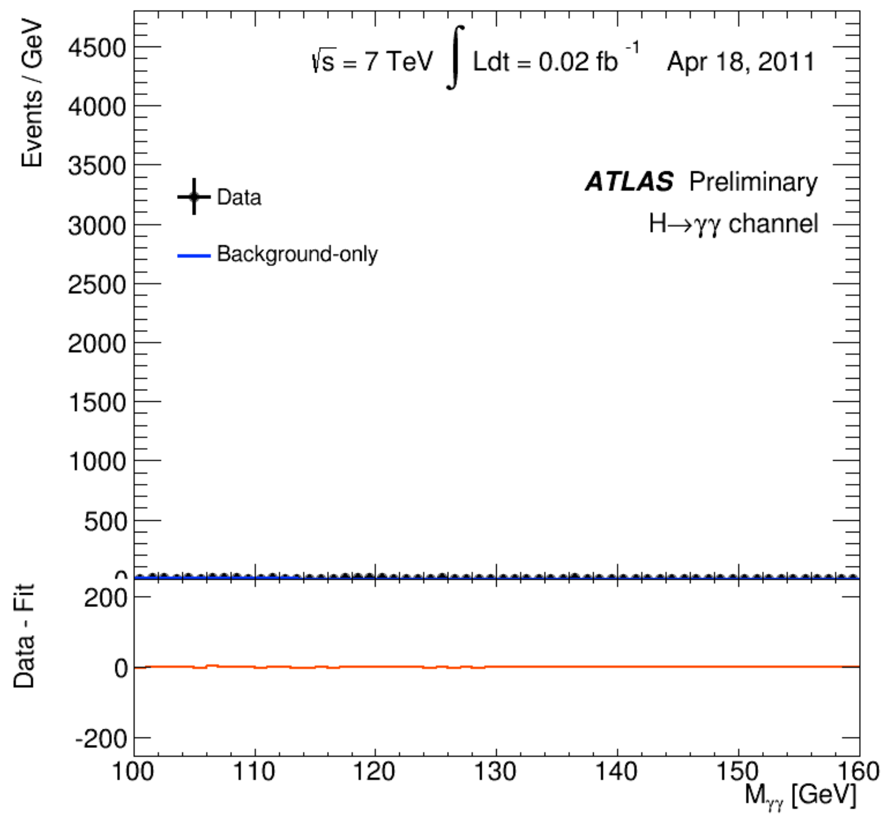
  Compatible with SM hypothesis.

- **BR(H→inv.) < 65% (95% C.L.)**



The birth of a particle



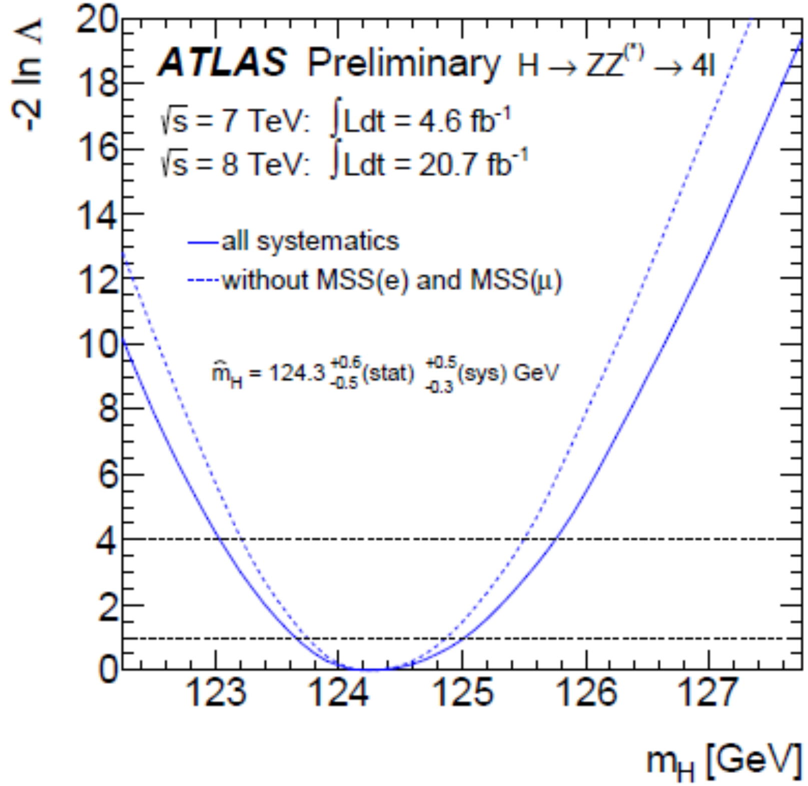


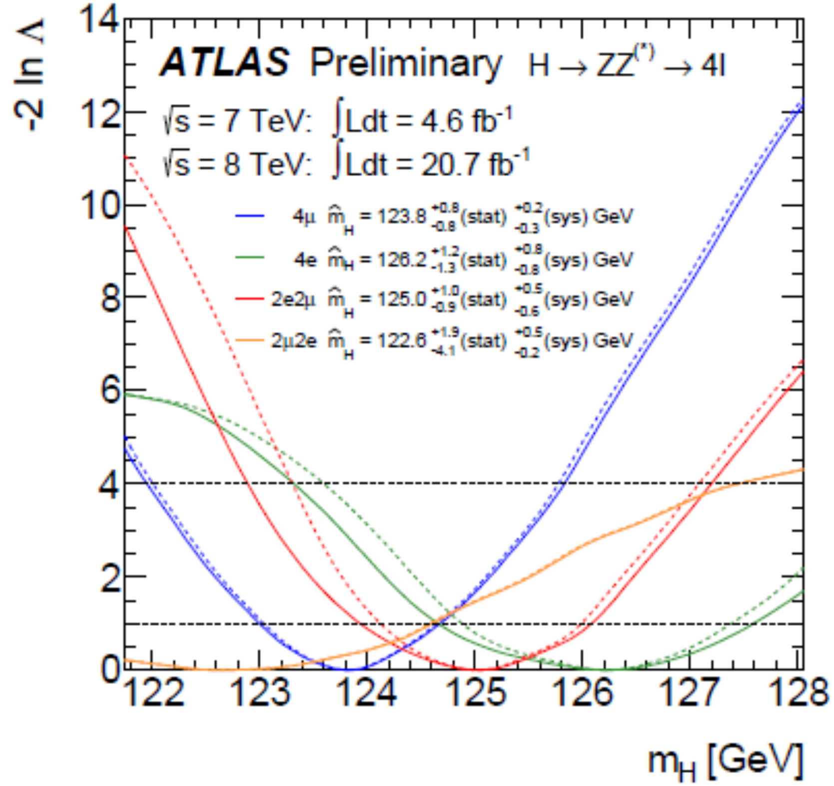
- *A big thank you to all my ATLAS colleagues since the beginning…*

Back-up

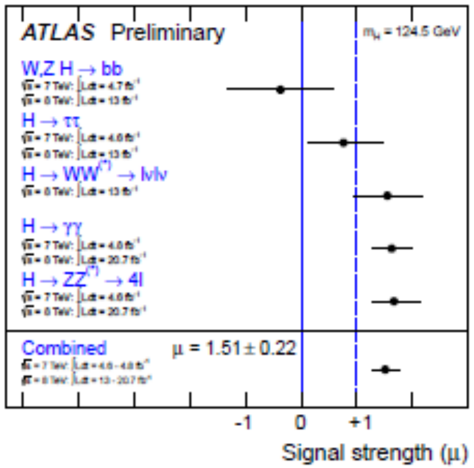
- **Most recent documentation**
  - ***γγ : ATLAS-CONF-2013-012***
  - ***ZZ : ATLAS-CONF-2013-013***
  - ***WW, ττ, bb: ATLAS-CONF-2012-162***
  - ***Previous combination:ATLAS-CONF-2012-170***
  - ***Couplings: ATLAS-CONF-2012-127***

Per-channel masses in H to 4l

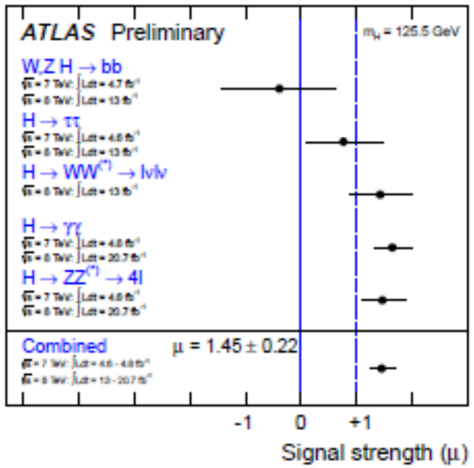




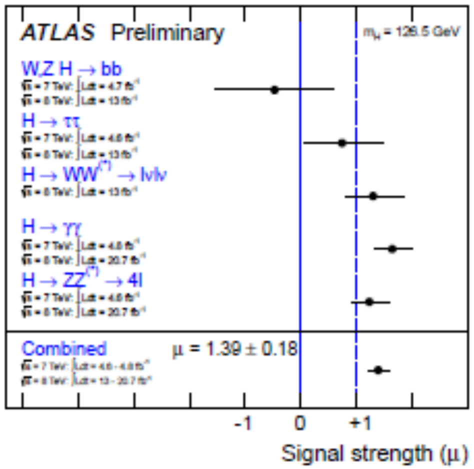
μ_i dependence on assumed m_H



$m_H = 124.5$



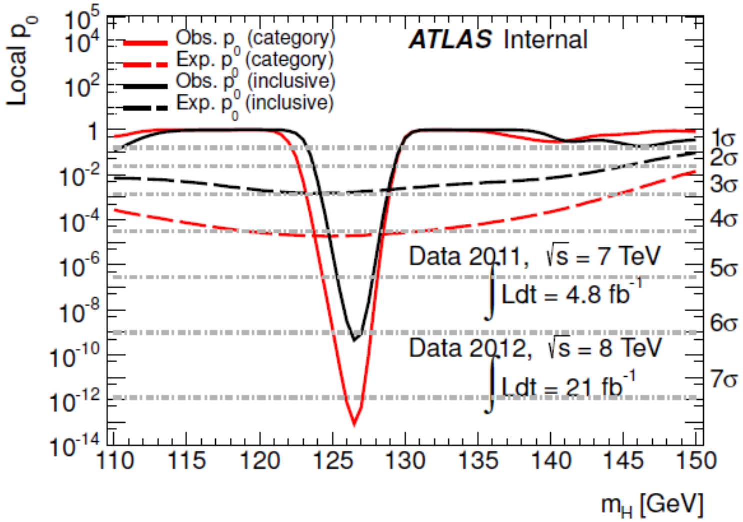
$m_H = 125.5$

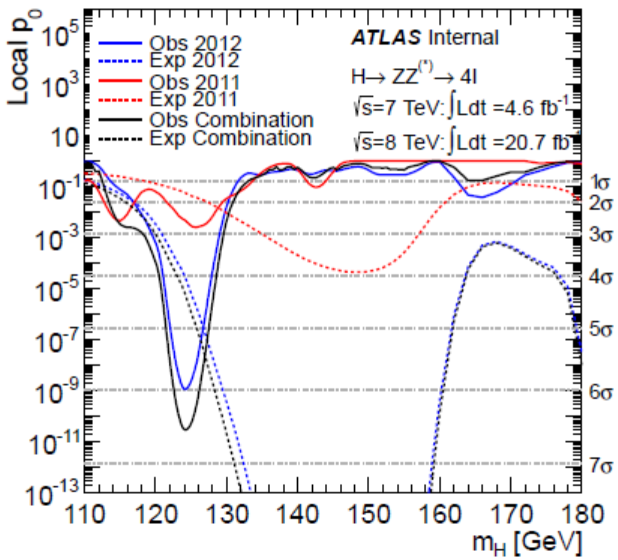


$m_H = 126.5$

p_0 plots

- **Full 2011 and 2012 statistics:**





Z

- **Previous combination**

  γγ : 6.1 σ ⊕ ZZ : 4.1 σ => global : 7.0 σ

  Present combination

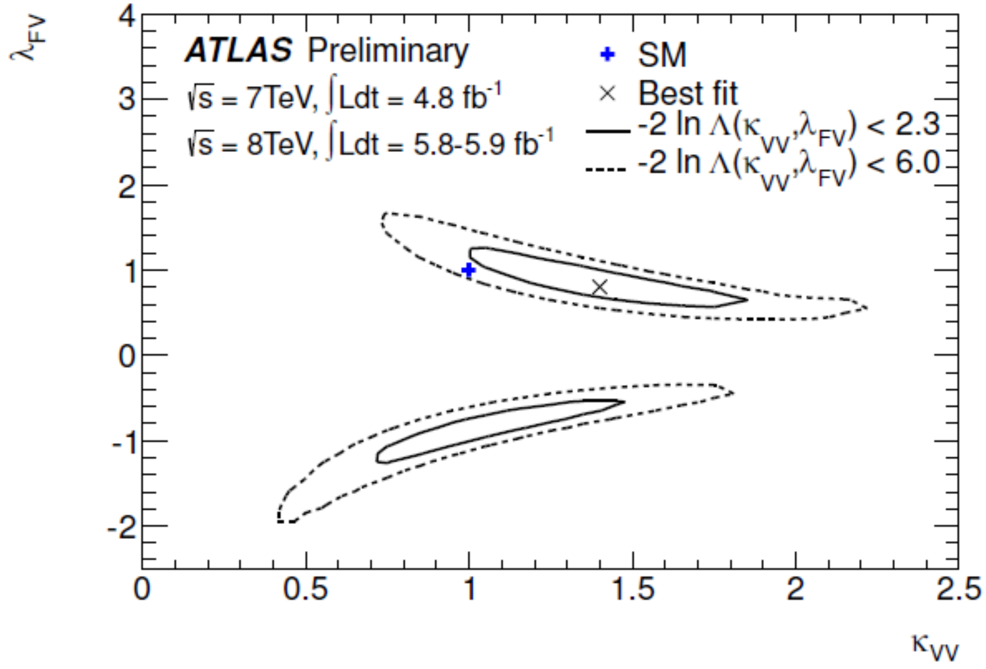
  γγ : 7.4 σ ⊕ ZZ : 6.6 σ => global : ? (> 9 σ)

Fermion versus Vector couplings (2)

- **Group couplings : $\kappa_V = \kappa_W = \kappa_Z$; $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$**
  - **Assume: gg → H and H → γγ only through SM particles**

- **No assumption on total width:**

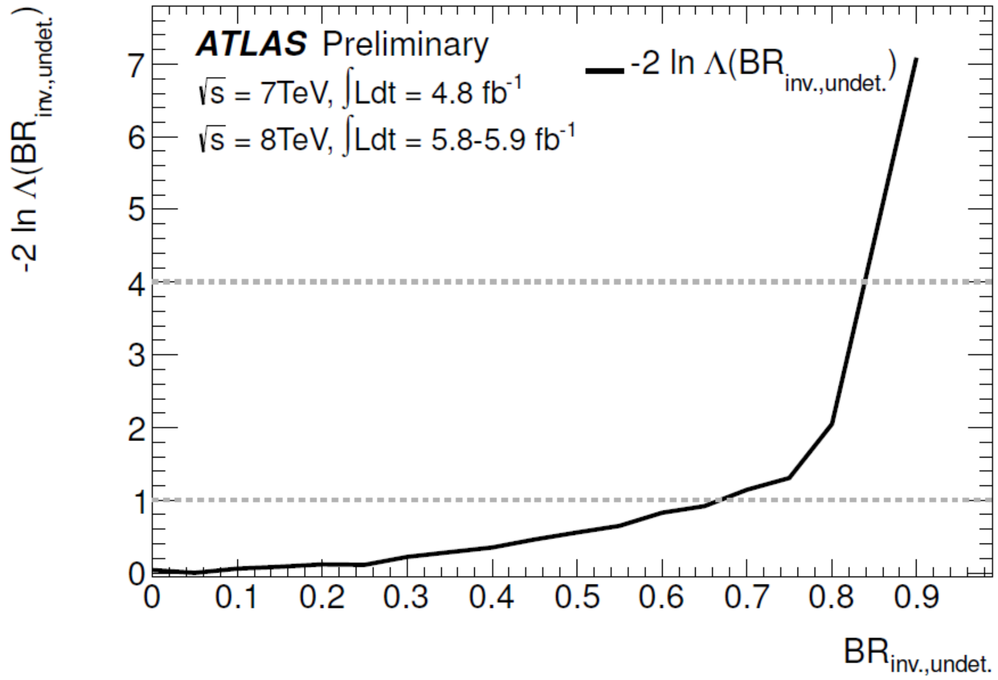
$$\lambda_{FV} = \kappa_F / \kappa_V \; ; \quad \kappa_{VV} = \kappa_V \kappa_V / \kappa_H$$



Contributions from non-SM particles (2)

- Assume all couplings to SM particles $\kappa_i = 1$
- Introduce effective κ_g, κ_γ, *independent* (allow additional contributions to loops)

- Allowing possible $BR_{inv,\ undet}$ to undetected modes



$BR_{inv,\ undet} < 0.68$ (68% CL)
< 0.84 (95% CL)

SM hypothesis : 35%