# Towards the fit of Higgs couplings with early LHC data

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# The usual warning

- **The Higgs is not discovered yet !**
- **From the CMS SM Higgs talk yesterday: 'peaks' come and go**

- **As long as the Higgs is not discovered we ultimately measure only the properties of a fluctuation – saying anything else would be very inconsistent. We should try to stay unbiased!**

- **BUT: all agree that we also need to be prepared.**
  **If a peak is confirmed we will be asked to provide information on the new particle – mass, width, coupling strength, spin, CP, …**

- **Last cautious remark for this summer: whatever we write for the update of European Strategy for Particle Physics on Higgs properties should stay valid. Making too strong claims and then seeing the peak disappear with the full 2012 data could be bad for the strategy evaluation early 2013**

# Measuring the Higgs couplings

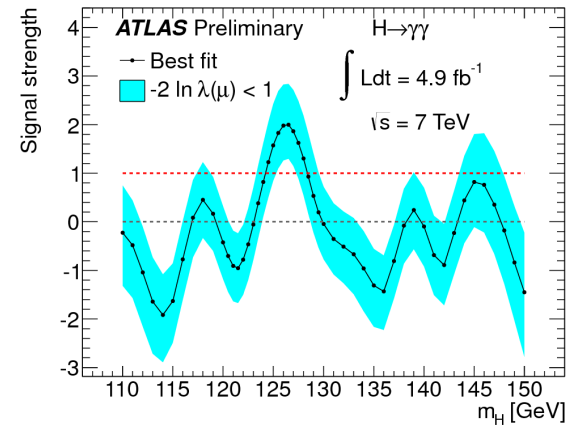
- **Discover Higgs**
  **→ make sure we don't measure the properties of fluctuations**

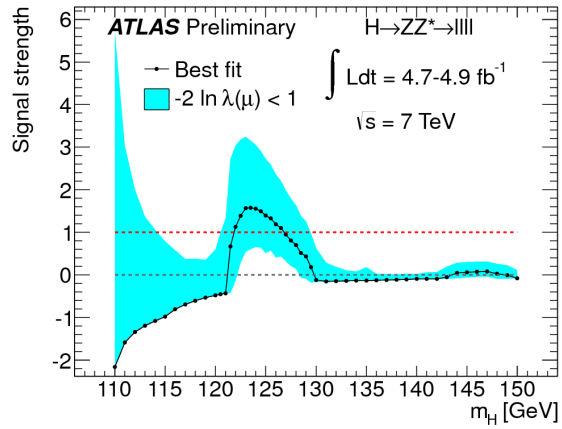
- **Measure Higgs mass (width)**
  **→ theory has strong $m_H$ dependence**
  **→ because of fluctuations also the experimental results have a strong $m_H$ dependence**
  **→ using the wrong mass as input to measurements will give a bias**

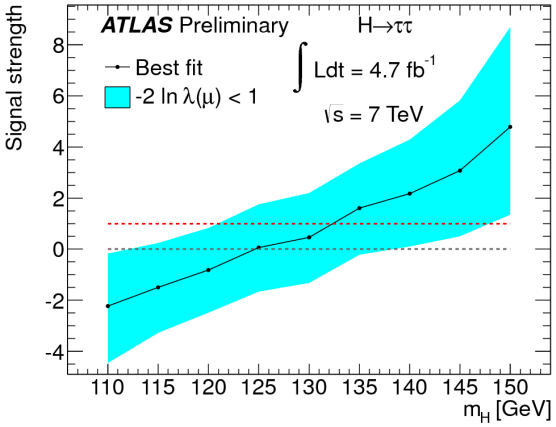
- **Measure Higgs coupling properties**
  **→ coupling strength to SM particles: W, Z, $\gamma$, t, b, $\tau$, gluon (,$\mu$)**
  **→ spin and CP (or in general tensor structure of couplings)**
  **→ self coupling (not with standard LHC)**

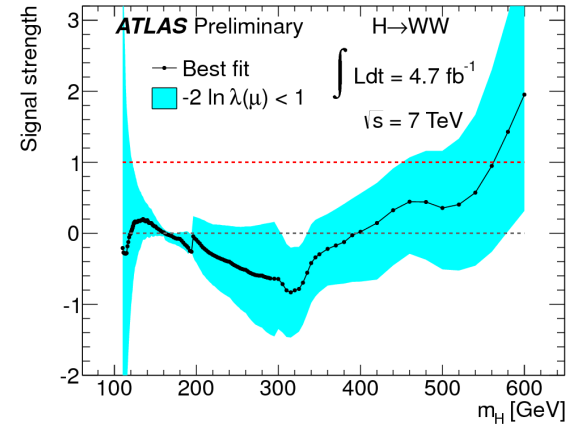
- **Correct for any wrong assumptions that might have entered earlier measurements**

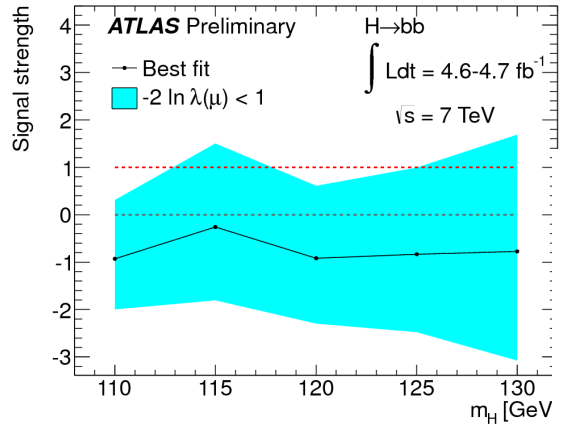
# Moriond 2012 status

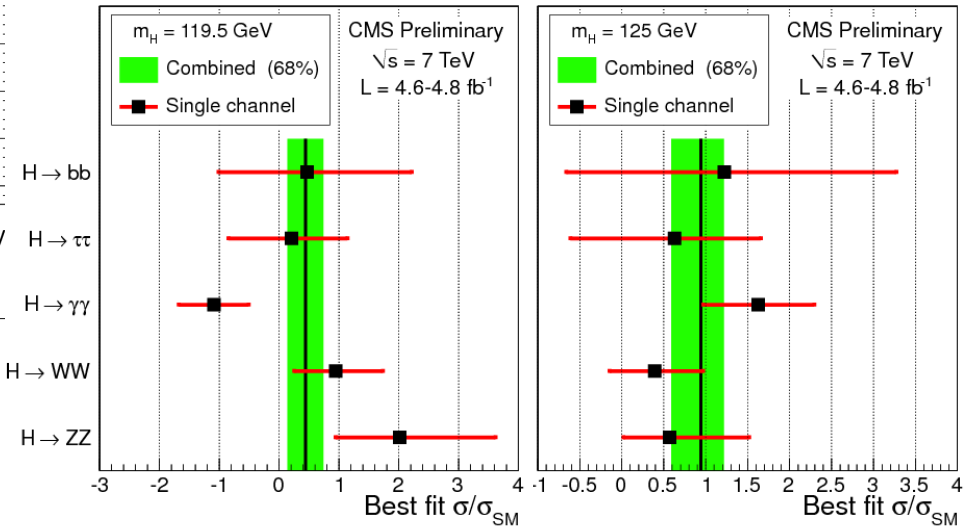


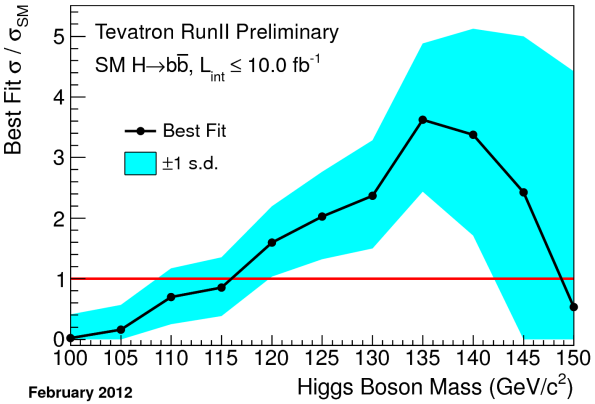



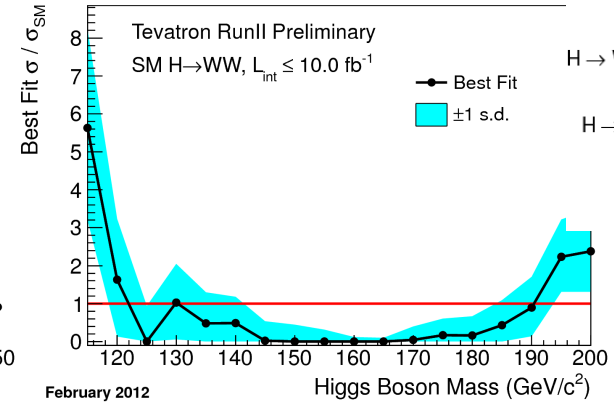



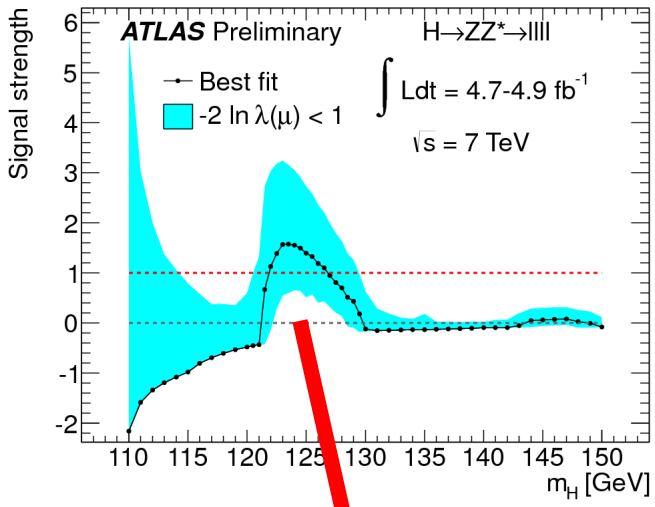



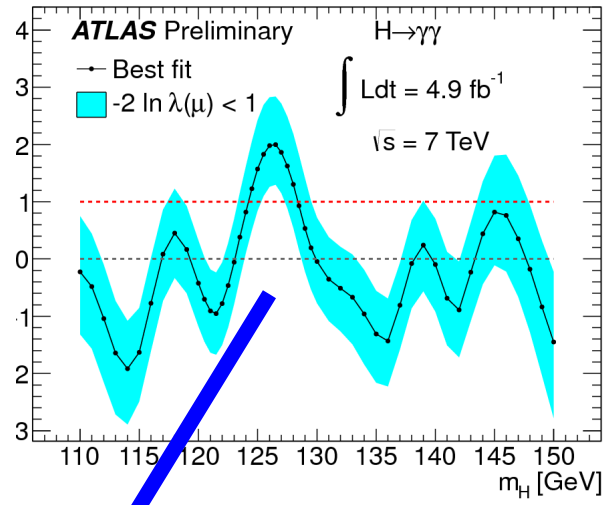



# Available coupling related information

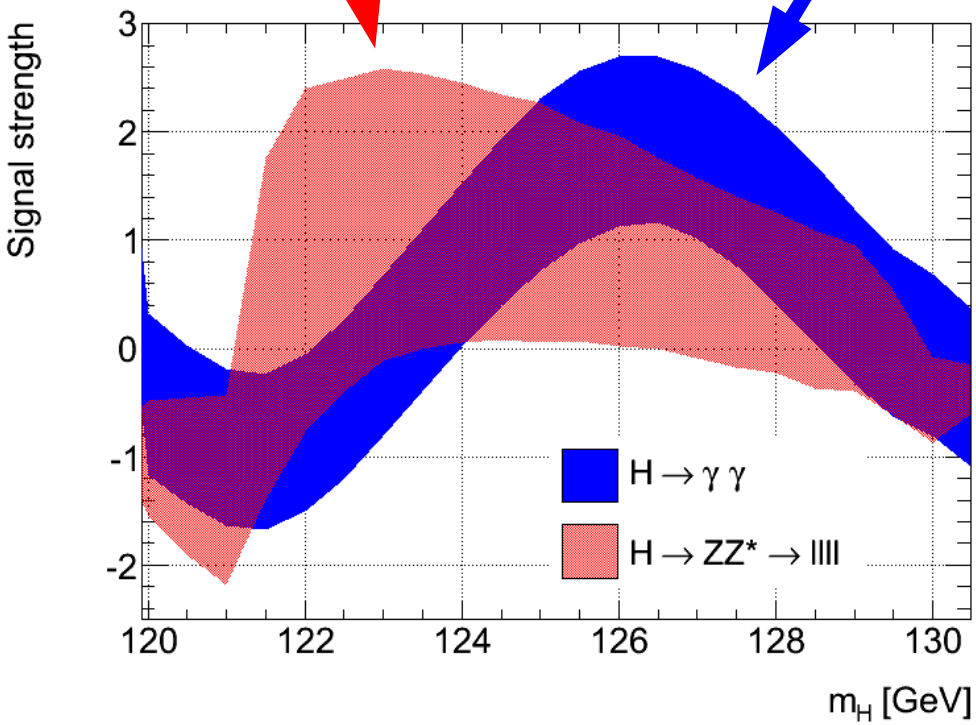
- So far only "best fit" $\mu$-results are available from experiments
- However, this is already close to a measurement of the Higgs **scalar** coupling strength to other SM particles
- The current Higgs combination fits have all needed information: the really hard work is done. Only a "few" changes are needed:
  - Provide one independent $\mu_X$ for each possible $X=\sigma*BR$
  - Disentangle in every analysis signal contributions from $gg\rightarrow H$, VBF, WH, … and $H\rightarrow WW$, $H\rightarrow ZZ$, $H\rightarrow\tau\tau$, …
  - Understand implication of fit conditions like $\mu_X>0$
  - Understand that (some) analysis assume spin 0, CP even
  - Understand that the conditions above already make assumptions on the number of Higgs bosons (=1), $m_H$ and width (narrow width approximation)
- Express the $\mu_X$ as function of more fundamental Higgs coupling parameters → more later
- Deal with multiple degenerate minima for some parameter choices

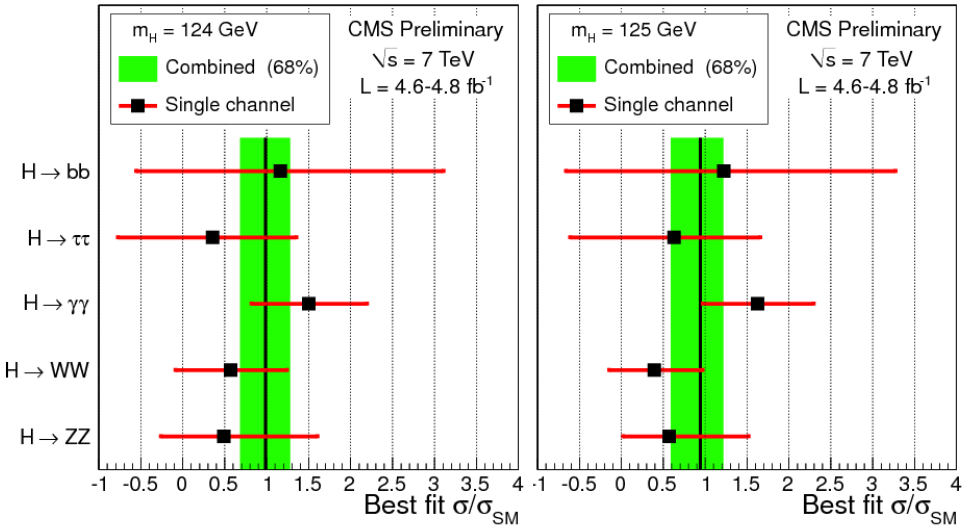
# Mass sensitivity




- ~2 GeV change in $m_H$ can give a ~1σ change
- If there is real signal, its modulated with fluctuations
- Fluctuations don't care about $m_H$. The real mass might not be 125 GeV



# Available channels for coupling measurements

- With some sensitivity we have access to the following SM channels: $\mu_X = \sigma * BR(AA \rightarrow H \rightarrow BB)$ for $m_H < 130$ GeV
  - $gg \rightarrow H \rightarrow \gamma\gamma$ (uncertainty <50% possible)
  - VBF $H \rightarrow \gamma\gamma$ (also WH, ZH)
  - $gg \rightarrow H \rightarrow ZZ^* \rightarrow ll\ ll$ (uncertainty <50% possible)
  - $gg \rightarrow H \rightarrow WW^* \rightarrow l\nu\ l\nu$ (uncertainty <50% possible)
  - VBF $H \rightarrow WW^* \rightarrow l\nu\ l\nu$ (also WH, ZH)
  - $gg \rightarrow H \rightarrow \tau\tau$
  - VBF $H \rightarrow \tau\tau$ (also WH, ZH)
  - $WH(H \rightarrow bb)$ (+Tevatron: uncertainty <50% possible)
  - $ZH(H \rightarrow bb)$ (+Tevatron: uncertainty <50% possible)
- Any combination of these could be the most sensitive to a specific aspects of a model → Important to keep all correlations in a fit
- Because of fluctuations: Even for the SM expect >1-2$\sigma$ deviation from the SM if one picks an extreme combination
- Don't select only the channels with highest **observed** significance → a coupling fit might be biased by upward fluctuations

# Fundamental coupling parameter choices

- Assume exactly one narrow Higgs: $\sigma$*BR(AA $\rightarrow$ H $\rightarrow$ BB)=$\Gamma_A * \Gamma_B / \Gamma_H$
- Disentangling production A and decay B
  - $\Gamma_W / \sqrt{\Gamma_H}$ ; $\Gamma_Z / \sqrt{\Gamma_H}$ (could be combined $\rightarrow$ SU2 symmetry)
  - $\Gamma_\tau / \sqrt{\Gamma_H}$ ; $\Gamma_b / \sqrt{\Gamma_H}$ (could be combined $\rightarrow$ down type fermion symmetry)
  - $\Gamma_g / \sqrt{\Gamma_H}$ ; $\Gamma_\gamma / \sqrt{\Gamma_H}$
  - Because always a product of parameters is fitted to one observable, strong (anti-)correlations are induced
  - If all correlations are kept, all ratios not involving $\Gamma_H$ can be derived
- Disentangling the total width $\Gamma_H$ (too narrow for direct measurement)
  - $\Gamma_H = \sum \Gamma_i + \Gamma_{inv} + \Gamma_{undet}$ (inv=invisible; undet=undetectable, e.g jets)
  - Absolute measurements of $\Gamma_i$ and $\Gamma_H$ possible with some assumptions on only one of $\Gamma_i$, $\Gamma_H$, $\Gamma_{inv} + \Gamma_{undet}$ (many choices possible)
- Disentangling loops $\rightarrow$ measuring (Yukawa) couplings $Y_i$
  - Gluon Fusion : $\Gamma_g = \Gamma(Y_t, Y_b) \pm \Gamma_g$(new) ; H$\rightarrow\gamma\gamma$ : $\Gamma_\gamma = \Gamma(Y_W, Y_t) \pm \Gamma_\gamma$(new)
  - For all others: $\Gamma_i \sim Y_i^2$
- All choices can be freely combined for different model tests

# Planning ahead : NLO and interference

- In narrow width approximation
  → partial decay width $\Gamma_i$ is well defined
- BUT: looking close at (Yukawa) couplings
  → $\Gamma_i \sim Y_i^2$ is only that simple in LO (and for fermions)
  → Already at NLO $\Gamma_i$ function of (almost) all $Y_k$. Is that well defined?
  Also experimentally well defined? Many almost degenerate solutions!
  → Perhaps not a problem for 20-50% measurements this year,
  but eventually for ultimate precision
  → Without narrow width approximation the same applies to $\sigma$*BR
  → Is it possible to get all $\sigma$*BR as functional (analytic or tabulated)
  expressions of identical defined parameters $Y_k$?
- BUT: looking at interference with SM processes
  - Interference terms of gg→H→AA and gg→AA exist and can contribute at the % level (the same for VBF: WW→WW)
  - Unfortunately these SM processes are small. Otherwise this would be a nice way of measuring the Higgs couplings

**Summary:** make sure theory and experiment speak the same language

# Planning ahead : tensor structure

- So far fundamental coupling parameters assumed spin 0, CP even
  - This is the "easy" case
    → a change in couplings changes only signal xsec, not acceptance
  - Nature could be more complicated. Example for general VV→Φ tensor (with spin 1, 2, … even more complicated)

$$T^{\mu\nu}(q_1,q_2) = a_1(q_1,q_2)\, g^{\mu\nu} + a_2(q_1,q_2)\,[q_1\cdot q_2 g^{\mu\nu} - q_2^{\mu} q_1^{\nu}] + a_3(q_1,q_2)\,\varepsilon^{\mu\nu\rho\sigma} q_{1\rho} q_{2\sigma}$$

$a_1$=const : SM  $a_2$ : CP-even  $a_3$ : CP-odd

  - This would also imply a change in the signal acceptance. Current analysis might no longer be sensitive to these signals
  - Tensor structure is not necessarily a general particle property: each coupling tensor could be different
  - For a measurement of this structure signal significance in several bins of tensor structure sensitive variables is needed
- Dedicated analysis needed, but only few realistic with ~10fb$^{-1}$
  - Distinguish some cases of spin 0, 2 in H→γγ
  - Distinguish some spin/CP cases in H→ZZ* and H→WW
  - Perhaps distinguish CP with ΔΦ(tagjets) in VBF channels