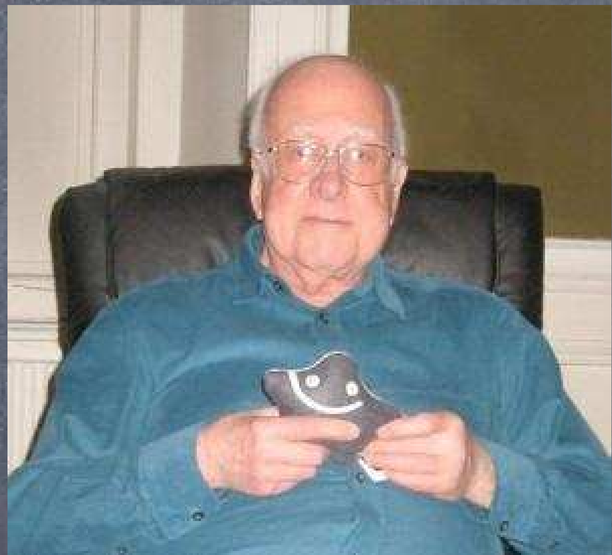
*Adam Falkowski*

# The Latest About Higgs



Buenos Aires, 13 de Mayo 2013

Based on work in collaboration with

Dean Carmi, Erik Kuflik, Francesco Riva, Alfredo Urbano, Tomer Volansky, Jure Zupan

# Plan

- What do we know from experiment?
- How to interpret that theoretically?
- State of art

# What do we know from experiment

# A Higgs particle has been discovered...

Significance in CMS, from CMS-PAS-HIG-13-005

@$m_H$ = 125.7 GeV

| Decay | Expected | Observed |
|---|---|---|
| ZZ | 7.1 σ | 6.7 σ |
| γγ | 3.9 σ | 3.2 σ |
| WW | 5.3 σ | 3.9 σ |
| bb | 2.2 σ | 2.0 σ |
| ττ | 2.6 σ | 2.8 σ |

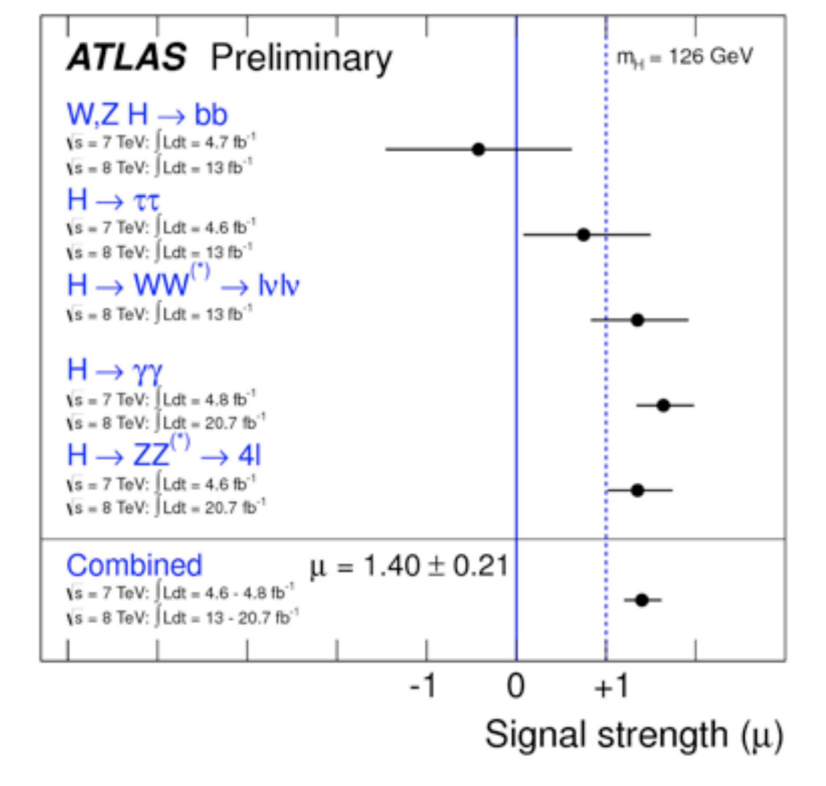
ggF, VBF, VH

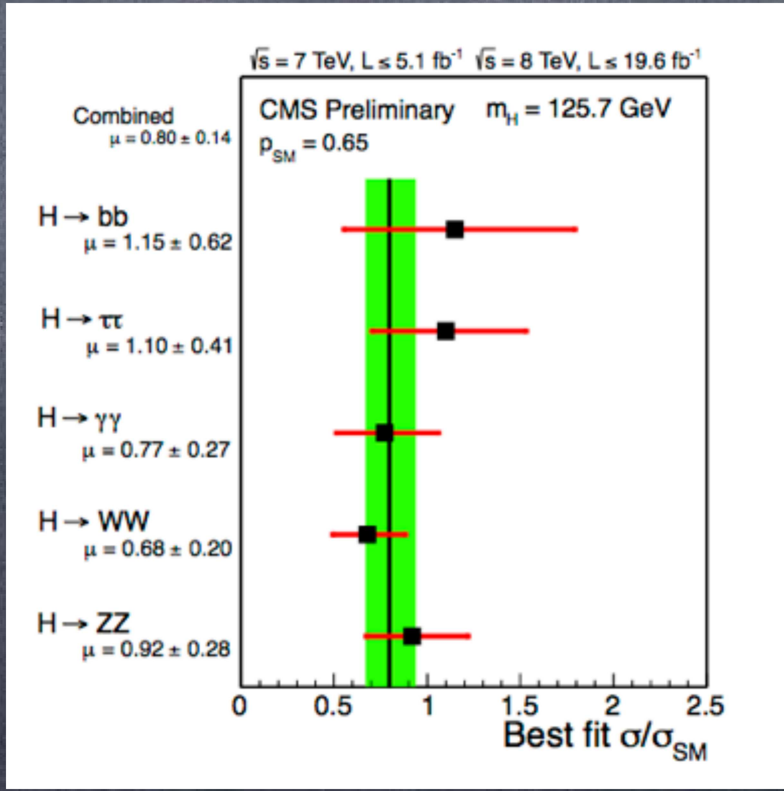
3.4 σ combined

The fact has been so firmly established that no one cares about the significance anymore ;-)

# Higgs: what do we know experimentally

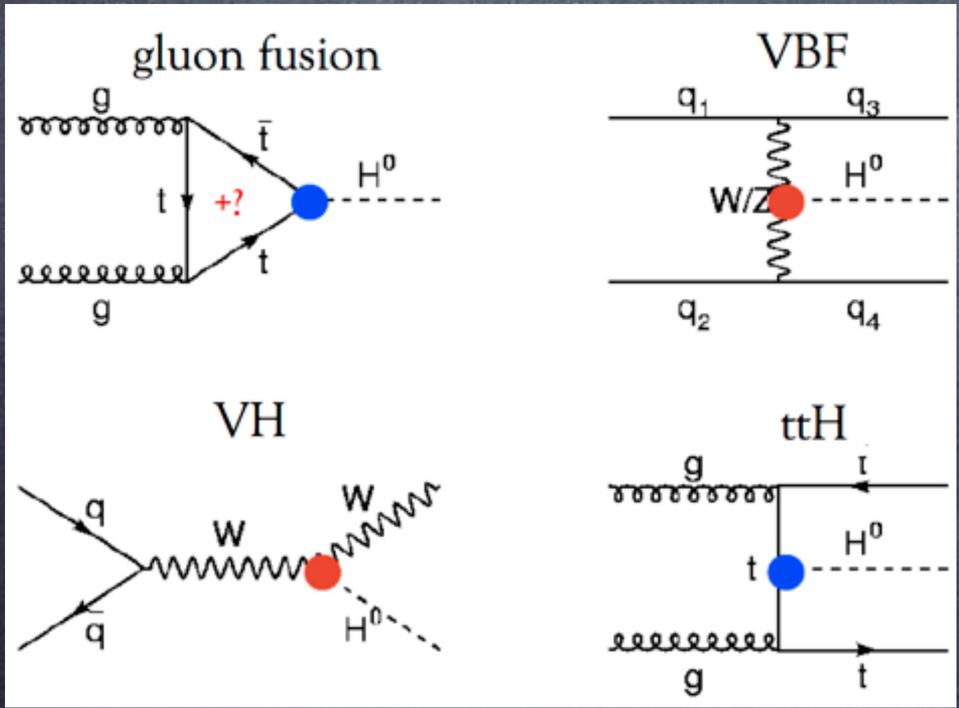
- Most transparent information about Higgs properties from measuring overall event rate in different decay channels...
- Presented as rate normalized to standard model prediction

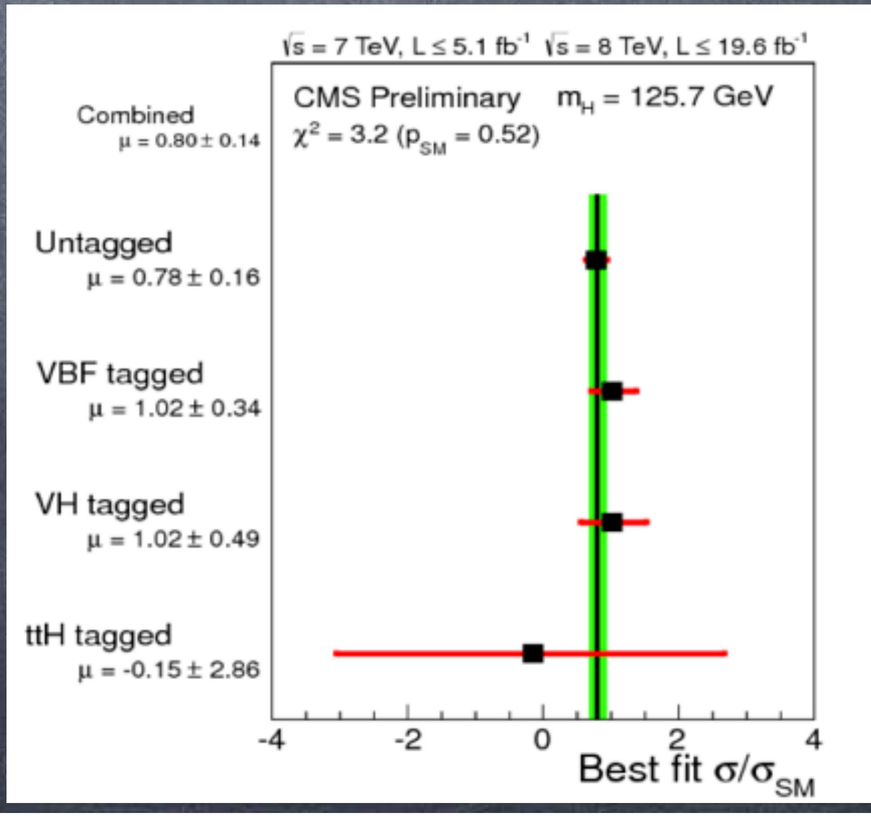


## Higgs: what do we know experimentally

- Different Higgs production processes can be, to some extent, separated by experimental cuts
- Inclusive rates dominated by gluon fusion
- But one can choose cuts that greatly enhance VBF or W/Z +h contribution while keeping the signal at observable level
- Also, first reconnaissance attacks on tth



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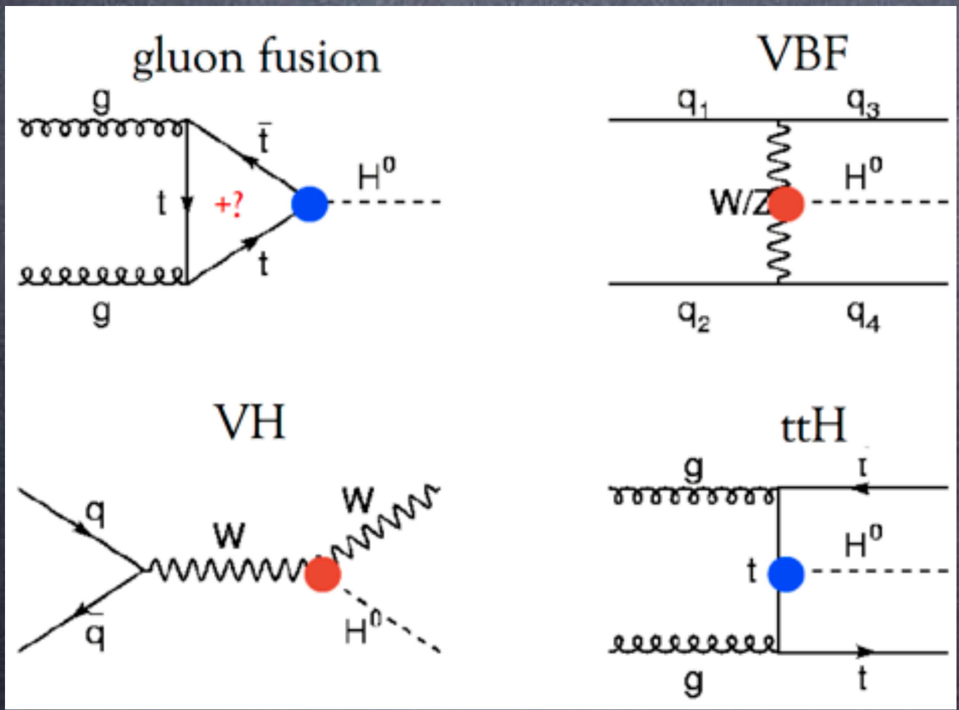
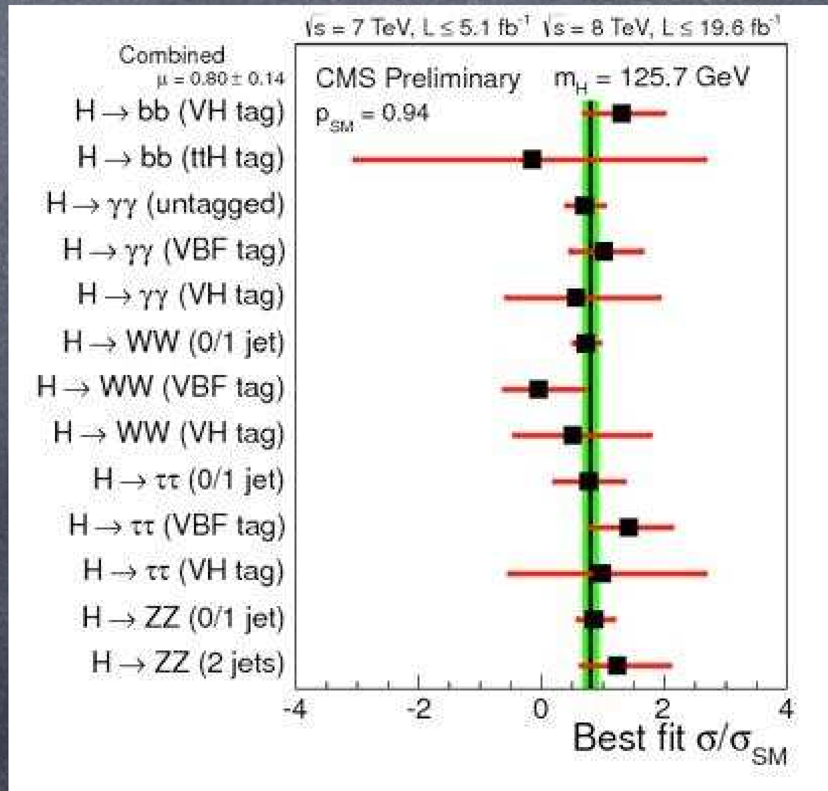
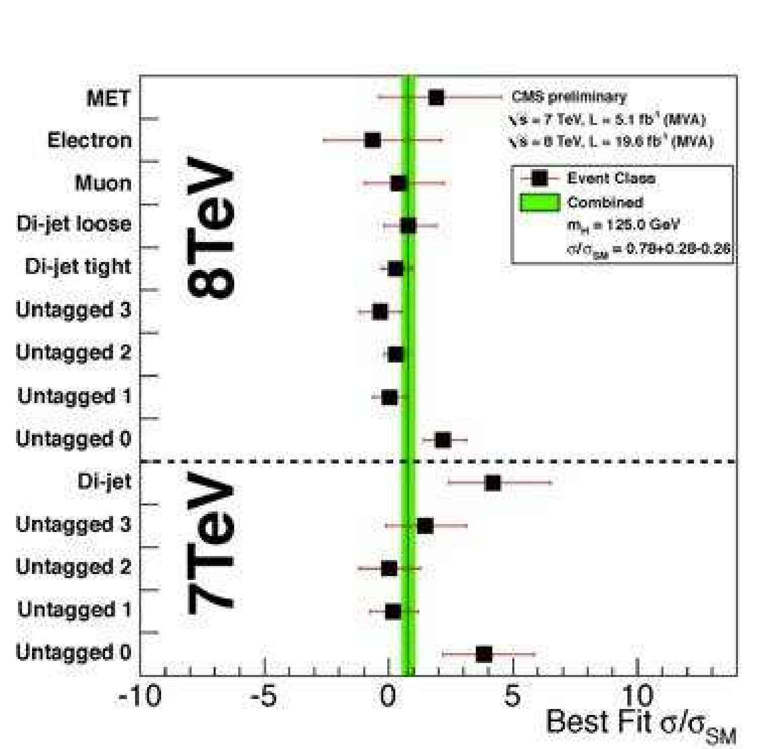


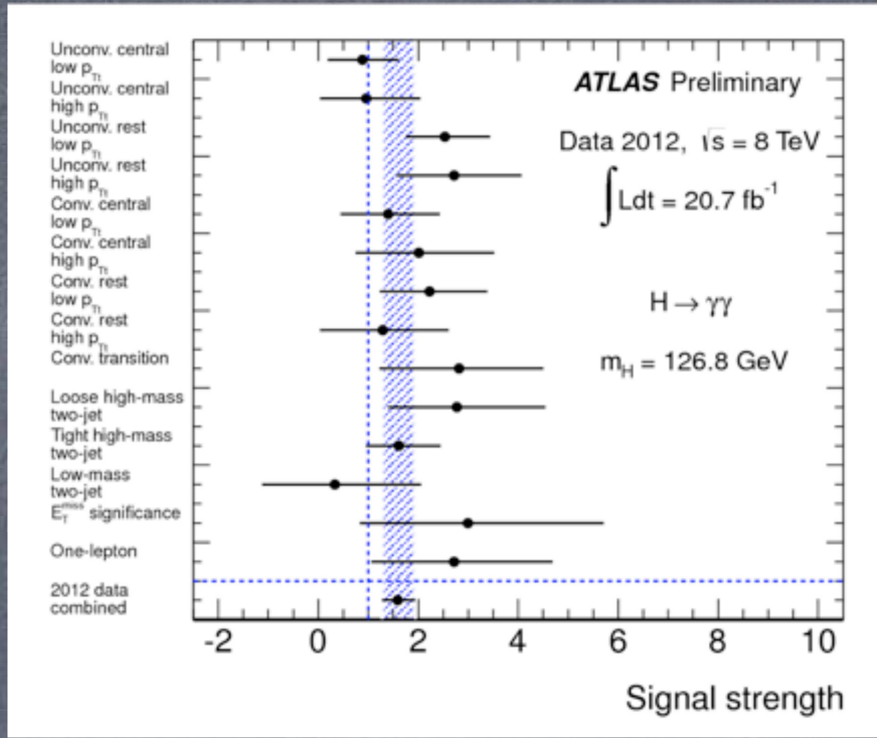
# Higgs: what do we know experimentally

- Currently, 2 most sensitive Higgs channels are $h \to \gamma\gamma$ and $h \to ZZ^* \to 4l$
- Most favorable from the point of view of S/B ($5\sigma$ discovery in $h \to \gamma\gamma$ alone in ATLAS and $h \to ZZ^* \to 4l$ alone in CMS)
- In both channels, kinematics can be fully reconstructed, and mass can be measured with ~1 GeV precision

# Higgs: what do we know experimentally




γγ




- Small deficit of inclusive rate:

  $\mu = 0.77 \pm 0.27$
- Interesting excess in 7 TeV data in not borne out in 8 TeV
- Mass measured at:

  $m_h = 125.0 \pm 0.7$ GeV

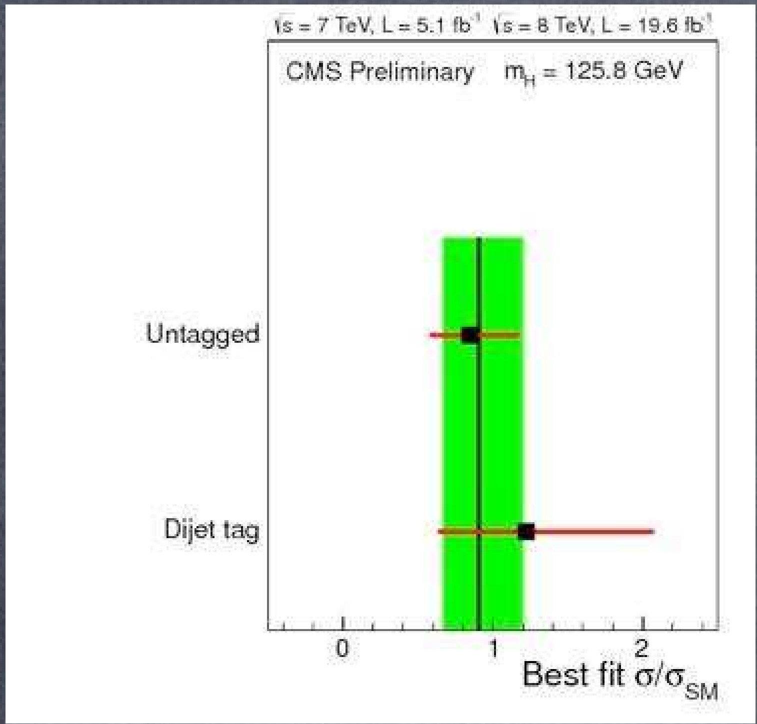
Larger rate and slightly smaller mass for cut based analysis

- ~2σ excess of inclusive rate:

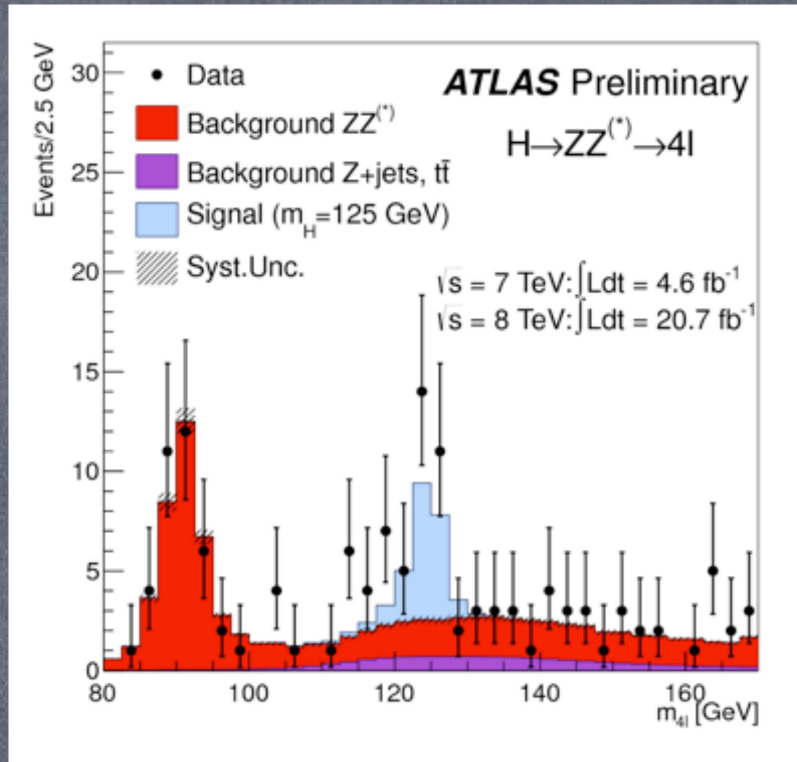
  $\mu = 1.65 \pm 0.32$
- Excess quite stable from 7 to 8 TeV
- Mass measured at:

  $m_h = 126.8 \pm 0.2 \pm 0.7$ GeV

# HIGGS: WHAT DO WE KNOW EXPERIMENTALLY




ZZ




- Rate in good agreement with SM:

  $\mu = 0.92 \pm 0.28$

- Mass measured at:

  $m_h = 125.8 \pm 0.6$ GeV

- Rate in decent agreement with SM

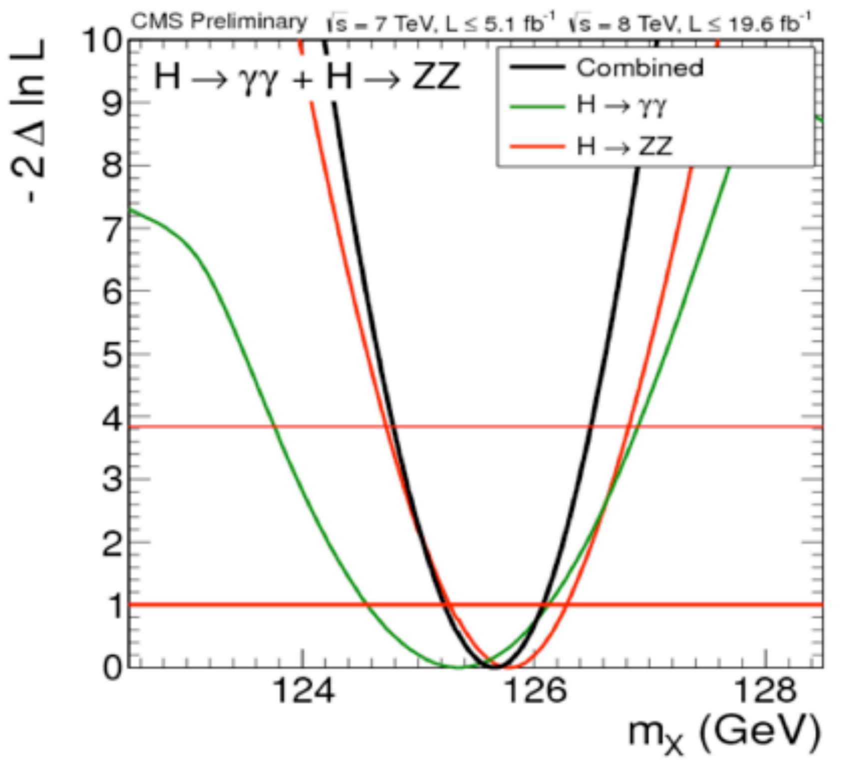
  $\mu = 1.7 \pm 0.4$

(for mh=124.3 GeV, and 1.5 for mh = 125.5 GeV)

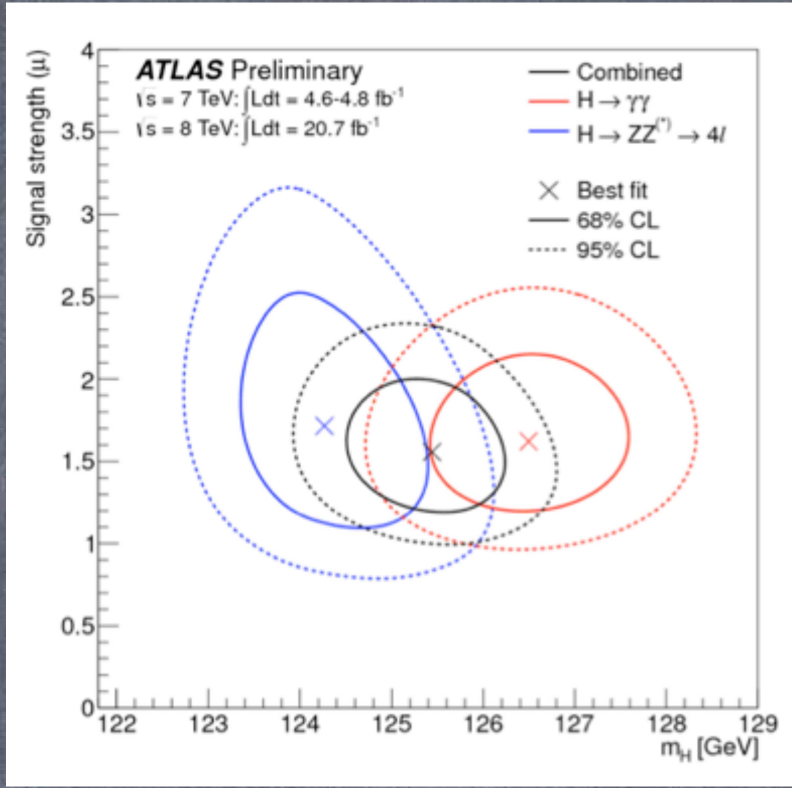
- Mass measured at:

  $m_h = 124.3 \pm 0.7$ GeV

# Higgs: what do we know experimentally




$m_h$




Systematic error? Fluctuation? Anyway, less worrying than last year...

Mass combination:

$m_h$ = 125.7 ± 0.4 GeV

Mass combination:

$m_h$ = 125.5 ± 0.6 GeV

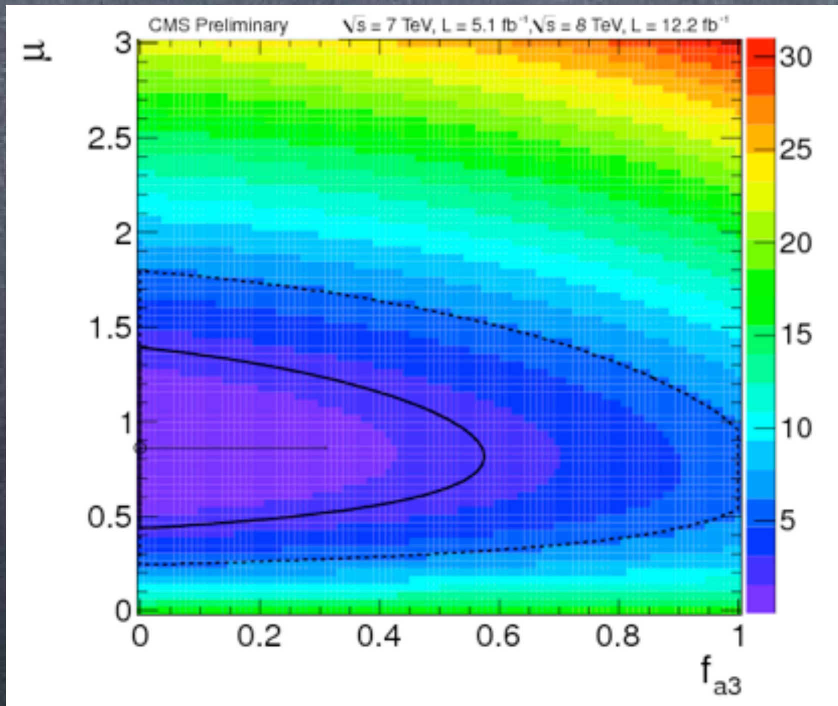
In spite of some jitters in ATLAS, experiments agree that $m_h$ is likely between 125 and 126 GeV

In this talk $m_h$ = 126 GeV

# Besides,

- Evidence for Higgs in $WW^* \to 2l2\nu$ channel from both experiments, with rate in good agreement with SM
- Almost evidence in $h \to \tau\tau$ channel from CMS
- bb+W/Z channel not conclusive yet
- A few more exotic channels ($h \to Z\gamma$, $h \to \mu\mu$, $Zh \to$ invisible)

- Besides, experiments start probing differential distributions of Higgs production direction and Higgs decay products
- Results presented in the context of "spin and parity measurements", but often relevant in a wider context



# How to interpret that theoretically

# Some different approaches

- Interpret the Higgs data in the context of an effective theory: systematic expansion of interactions of a Higgs-like scalar with the SM matter in powers of h/v and D^2/New physics scale^2

Default approach in this talk

- Interpret the Higgs data in the context of concrete model beyond the SM (MCHM5, MCHM14, LstH, MSSM, CMSSM,..., NMSSM,...)

Note than every particular BSM model is almost certainly wrong ;-)

# Effective Higgs Lagrangian

[see also Contino et al., note for LHC HXSWG]

## Assumptions

- There is no new particles with m≲mh and significant coupling to the Higgs

Crucial assumption for effective theory to be valid

Double expansion:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\partial^0} + \mathcal{L}_{\partial^2} + \ldots$$

Derivative expansion

$$\mathcal{L}_{\partial^n} = \mathcal{L}^{(0)}_{\partial^n} + \mathcal{L}^{(1)}_{\partial^n} + \ldots$$

h/v expansion

Since currently (and for looong time) no experimental access to terms with 2 and more Higgs fields, only lowest non-trivial order (1) in h/v expansion considered here

Technicalities, that can be easily relaxed

- Higgs is a scalar particle (spin-0, positive parity)
- Higgs has no flavor-violating coupling (within generations of up quarks, down quarks, and leptons, couplings ratio scale with mass)
- Custodial symmetry (couplings to WW, ZZ, Zγ and γγ not independent)

# Effective Higgs Lagrangian

- Infinite number of parameters but for a given process at a given precision level only finite number of parameters enter
- Given QCD/PDF uncertainties, unlikely we'll ever need to go beyond 2-derivatives
- Unitary gauge (but trivial to integrate the Goldstone bosons back)
- SM limit:
  -all 0-derivative couplings equal 1,
  -all 2-derivative couplings equal 0

$$\mathcal{L}^{(1)}_{\partial^0} = \frac{h}{v}\left\{ c_V 2m_W^2 W^+_\mu W^-_\mu + c_V m_Z^2 Z_\mu Z_\mu + \sum_{q=u,d,l}\sum_{i=1\ldots3} c_q m_{q_i}\bar{q}_i q_i \right\}$$

Custodial

Flavor

$$\tilde{\mathcal{L}}^{(1)}_{\partial^0} = \frac{h}{v} i\bar{q}\gamma_5 q + \ldots$$

parity

$$\mathcal{L}^{(1)}_{\partial^2} = -\frac{h}{4v}\Big\{ -c_{gg}\, G^a_{\mu\nu}G^a_{\mu\nu} + c_{\gamma\gamma}\, A_{\mu\nu}A_{\mu\nu} + 2c_{Z\gamma}\, Z_{\mu\nu}A_{\mu\nu}$$
$$+2\left(c_{\gamma\gamma} + \frac{g_L}{g_Y}c_{Z\gamma}\right) W^+_{\mu\nu}W^-_{\mu\nu} + \left(c_{\gamma\gamma} + \frac{g_L^2 - g_Y^2}{g_L g_Y}c_{Z\gamma}\right) Z_{\mu\nu}Z_{\mu\nu}$$
$$+\kappa_V (W^+_\mu \partial_\nu W^-_{\mu\nu} + \mathrm{h.c.}) + \kappa_V Z_\mu \partial_\nu Z_{\mu\nu} + \frac{g_L}{g_Y}\kappa_V Z_\mu \partial_\nu \gamma_{\mu\nu}\Big\} + \ldots$$

(fermions)

Custodial

$$\tilde{\mathcal{L}}^{(1)}_{\partial^2} = \frac{h}{v} Z_{\mu\nu}\tilde{Z}_{\mu\nu} + \ldots$$

parity

# Effective Higgs Lagrangian

## Possible Extensions

- Add parity-violating interactions

e.g. $\Delta\mathcal{L} = \sum_{\psi\in u,d,l} \tilde{c}_\psi \bar{\psi}\gamma_5\psi \frac{h}{v} + \frac{\alpha_{\rm em}}{8\pi}\tilde{c}_{\gamma\gamma}\frac{h}{v}\gamma_{\mu\nu}\tilde{\gamma}_{\mu\nu} + \ldots$

- Add invisible particle coupled to Higgs, so as to allow for invisible Higgs width

e.g. $\Delta\mathcal{L} = c_\chi \frac{h}{v}\bar{\chi}\chi$

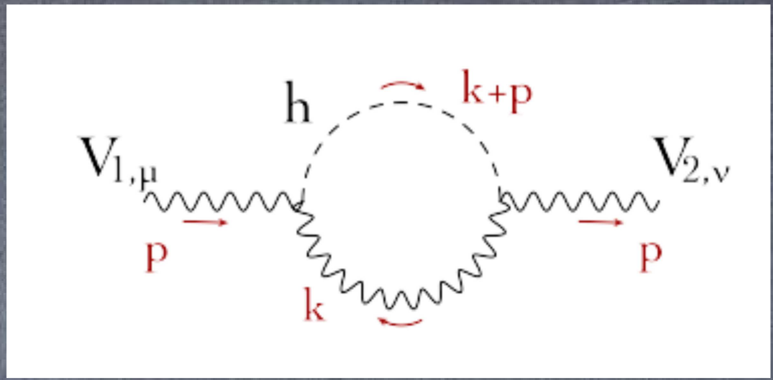
- Drop custodial symmetry assumptions

e.g. $\Delta\mathcal{L} = \Delta c_V \frac{h}{v} m_Z^2 Z_\mu Z_\mu + \ldots$

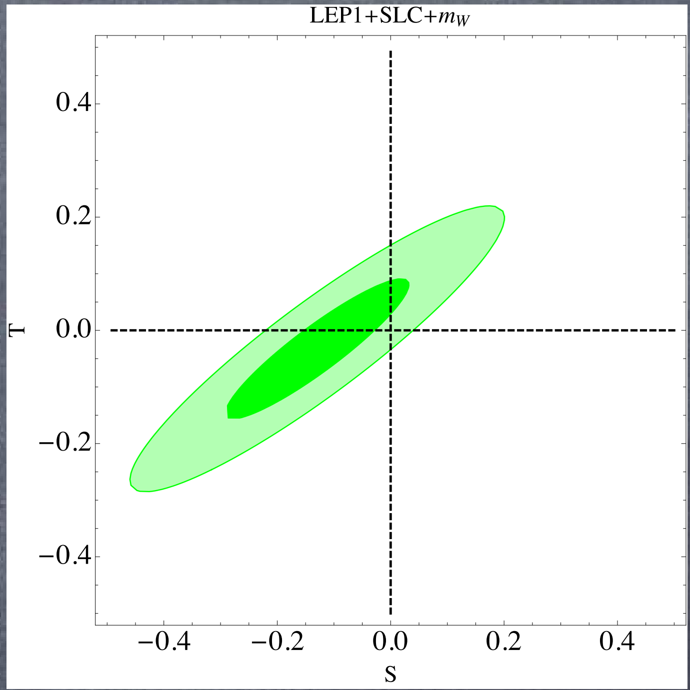
Quadratic divergences to T/U parameters - use with caution!

- If they discover a new particle at the LHC, I'll be delighted to add it to the effective lagrangian ;-)

# Not anything goes




- Higgs contributes to 2-point functions of electroweak gauge bosons, whose physical combinations (summarized into oblique parameters S,T,....) are well measured at LEP
- In the SM, Higgs+SM loop contributions to oblique parameters are finite
- But when Higgs has non-standard couplings (or coupling values) corrections to oblique parameters become divergent
- If no custodial symmetry, quadratic or even quartic (when κ-couplings present) divergent corrections to T parameter
- But even with custodial symmetry quadratic divergences may arise if κV≠0
  Hence κV must be tiny and irrelevant for Higgs phenomenology unless we allow fine-tuning




$$\Delta S = \frac{g_Y^2}{g_L^2 + g_Y^2} \frac{\kappa_V (6c_V + 9c_{WW} + 17\kappa_V)}{48\pi^2 v^2} \Lambda^2 + \ldots$$

In the following we set κV=0

# Simpler effective theory keeping the leading order parameters relevant for experimentally probed Higgs processes

$$\mathcal{L}_{eff} = c_V \frac{2m_W^2}{v} h\, W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h\, Z_\mu Z_\mu$$

$$- c_t \sum_{u,c,t} \frac{m_q}{v} h\, \bar{u}_i u_i - c_b \sum_{d,s,b} \frac{m_q}{v} h\, \bar{d}_i d_i - c_\tau \sum_{e,\mu,\tau} \frac{m_q}{v} h\, \bar{l}_i l_i$$

$$- \frac{h}{4v} \left( c_{\gamma\gamma} A_{\mu\nu} A_{\mu\nu} + 2 c_{Z\gamma} Z_{\mu\nu} A_{\mu\nu} + c_{ZZ} Z_{\mu\nu} Z_{\mu\nu} + 2 c_{WW} W_{\mu\nu} W^*_{\mu\nu} - c_{gg} G^a_{\mu\nu} G^a_{\mu\nu} \right)$$

$$c_{ZZ} = c_{\gamma\gamma} + \frac{g_L^2 - g_Y^2}{g_L g_Y} c_{Z\gamma} \qquad c_{WW} = c_{\gamma\gamma} + \frac{g_L}{g_Y} c_{Z\gamma}$$

- Simpler effective theory with 7 free parameters
- Standard Model limit: $c_V = c_f = 1$, $c_{gg} = c_{\gamma\gamma} = c_{Z\gamma} = 0$

# Effective theory and EWPT

Even with these restrictions divergent (but only log) corrections from Higgs to oblique parameters

$$\alpha T \approx \frac{3g_Y^2}{32\pi^2}\left(c_V^2-1\right)\log(\Lambda/m_Z)\,,$$

When coupling to mass deviates from SM

$$\alpha S \approx \frac{g_L g_Y}{48\pi^2(g_L^2+g_Y^2)}\left\{2g_L g_Y\left(1-c_V^2\right)+6c_V\left[2g_L g_Y c_{\gamma\gamma}+c_{Z\gamma}(g_L^2-g_Y^2)\right]\right.$$
$$\left.+3\left[g_L g_Y(c_{Z\gamma}^2-c_{\gamma\gamma}^2)-(g_L^2-g_Y^2)c_{\gamma\gamma}c_{Z\gamma}\right]\right\}\log(\Lambda/m_Z)\,,$$

$$\alpha W \approx \frac{g_L^2}{192\pi^2}\left(c_{\gamma\gamma}+\frac{g_L}{g_Y}c_{Z\gamma}\right)^2\log(\Lambda/m_Z)\,,$$

$$\alpha Y \approx \frac{g_L^2}{192\pi^2}\left(c_{\gamma\gamma}-\frac{g_Y}{g_L}c_{Z\gamma}\right)^2\log(\Lambda/m_Z)\,,$$

When 2-derivative couplings are present

Using STUVWXYZ parametrization of Barbieri et al from hep-ph/0405040:

$$\alpha S = -4\frac{g_L g_Y}{g_L^2+g_Y^2}\delta\Pi_{3B}^{(2)}, \quad \alpha T = \frac{\delta\Pi_{11}^{(0)}-\delta\Pi_{33}^{(0)}}{m_W^2}, \quad \alpha U = \frac{4g_Y^2}{g_L^2+g_Y^2}\left(\delta\Pi_{11}^{(2)}-\delta\Pi_{33}^{(2)}\right)$$

$$\alpha V = m_W^2\left(\delta\Pi_{11}^{(4)}-\delta\Pi_{33}^{(4)}\right), \quad \alpha W = -m_W^2\delta\Pi_{33}^{(4)}, \quad \alpha X = -m_W^2\delta\Pi_{3B}^{(4)}, \quad \alpha Y = -m_W^2\delta\Pi_{BB}^{(4)}. \quad \alpha Z = -m_W^2\Pi_{gg}^{(4)}$$

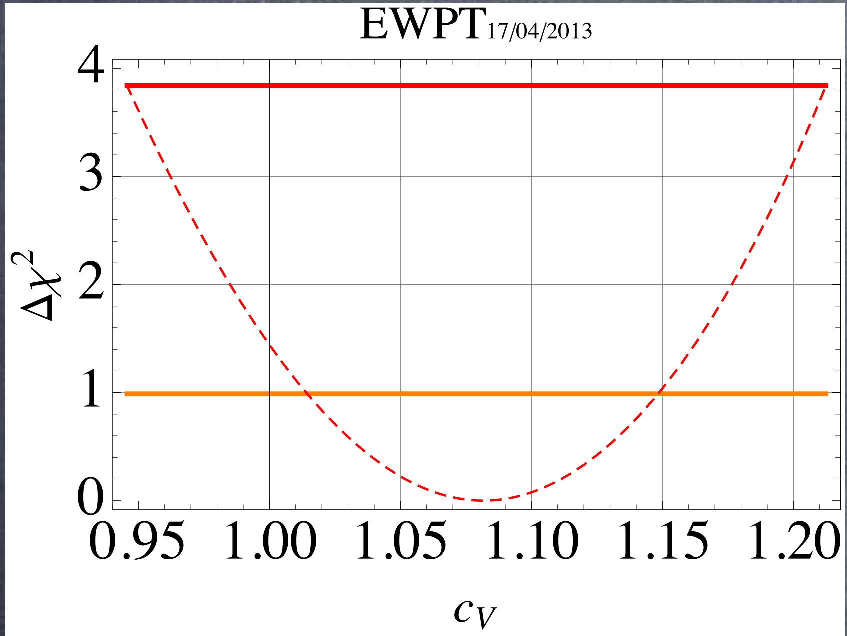
STWY are singled out because they correspond to dimension-6 BSM operators:

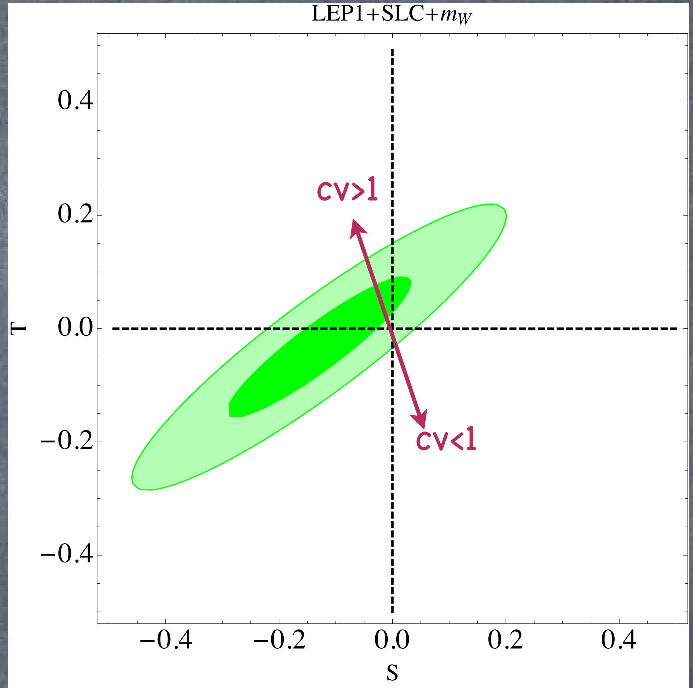
$$\frac{\alpha S(g_L^2+g_Y^2)}{4v^2 g_L g_Y}(H^\dagger\sigma^a H)W_{\mu\nu}^a B_{\mu\nu} - \frac{2\alpha T}{v^2}|H^\dagger D_\mu H|^2 - \frac{\alpha W}{4m_W^2}(D_\rho W_{\mu\nu}^a)^2 - \frac{\alpha Y}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$$

# Effective theory and EWPT

cV<1 is like heavier Higgs
cV>1 is like lighter Higgs
Stringent limits on cV from EWPT alone:

Barbieri,Bellazzini,Rychkov,Varagnolo, 0706.0432




Unless tuned against other significant contributions to S and T

# Effective theory and EWPT

2-derivative couplings also constrained by EWPT, though less strongly

$$\alpha T \approx \frac{3g_Y^2}{32\pi^2}\left(c_V^2 - 1\right)\log(\Lambda/m_Z)\,,$$

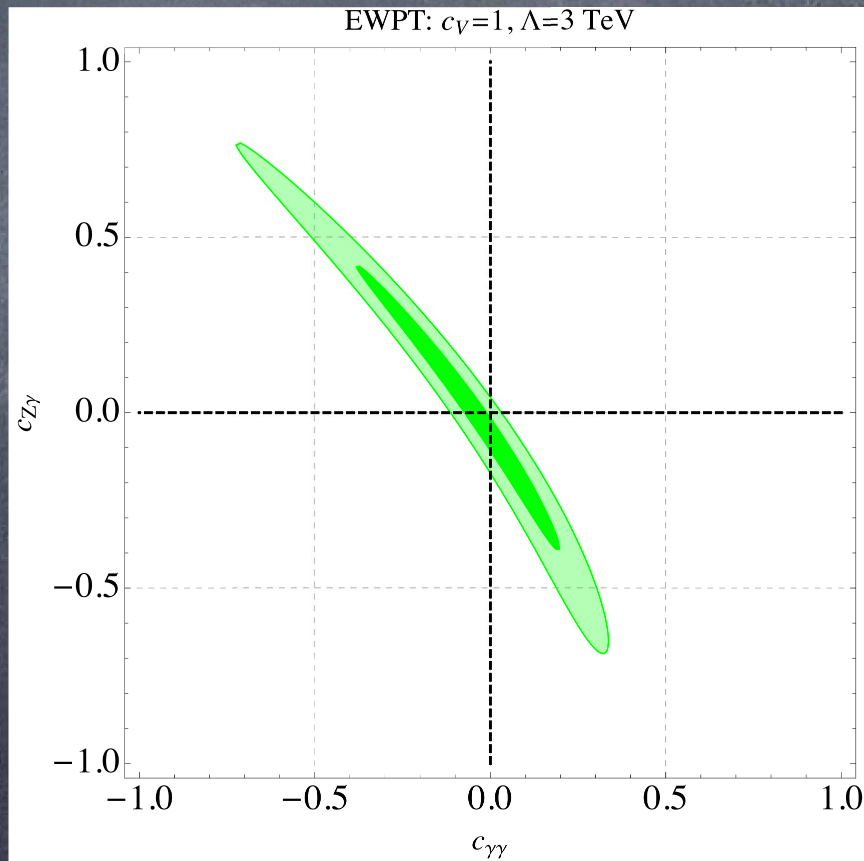
$$\alpha S \approx \frac{g_L g_Y}{48\pi^2(g_L^2+g_Y^2)}\Big\{2g_L g_Y\left(1-c_V^2\right) + 6c_V\left[2g_L g_Y c_{\gamma\gamma} + c_{Z\gamma}(g_L^2-g_Y^2)\right]$$
$$+3\left[g_L g_Y(c_{Z\gamma}^2 - c_{\gamma\gamma}^2) - (g_L^2 - g_Y^2)c_{\gamma\gamma}c_{Z\gamma}\right]\Big\}\log(\Lambda/m_Z)\,,$$

This combination enters linearly (when cV=1) and therefore is strongly constrained

$$\alpha W \approx \frac{g_L^2}{192\pi^2}\left(c_{\gamma\gamma} + \frac{g_L}{g_Y}c_{Z\gamma}\right)^2\log(\Lambda/m_Z)\,,$$

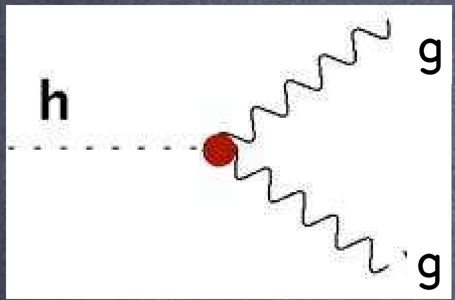
$$\alpha Y \approx \frac{g_L^2}{192\pi^2}\left(c_{\gamma\gamma} - \frac{g_Y}{g_L}c_{Z\gamma}\right)^2\log(\Lambda/m_Z)\,,$$

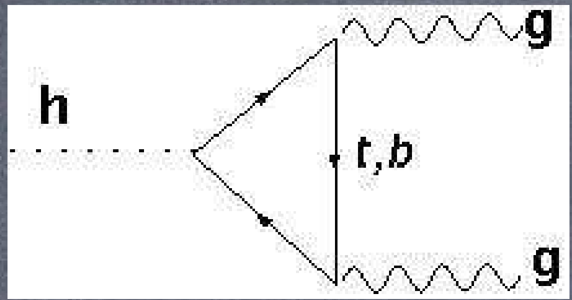
Orthogonal combination of cγγ and cZγ enters quadratically, and therefore is less constrained



# Effective theory: decay

$$\frac{\Gamma_{VV^*}}{\Gamma_{VV^*}^{SM}} \simeq |c_V|^2 \qquad \frac{\Gamma_{bb}}{\Gamma_{bb}^{SM}} = |c_b|^2 \qquad \frac{\Gamma_{\tau\tau}}{\Gamma_{\tau\tau}^{SM}} = |c_\tau|^2$$



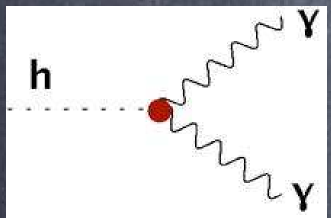



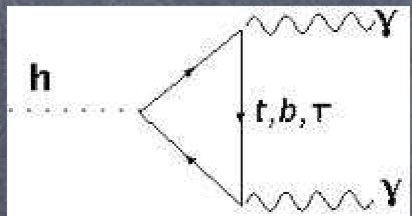

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{SM}} \simeq \frac{|\hat{c}_{gg}|^2}{|\hat{c}_{gg,SM}|^2}$$

$$\hat{c}_{gg} = c_{gg} + 10^{-2}\,[1.28\,c_t - (0.07 - 0.1\,i)\,c_b]$$

$$|\hat{c}_{gg,SM}| \simeq 0.012$$

Naive one-loop results

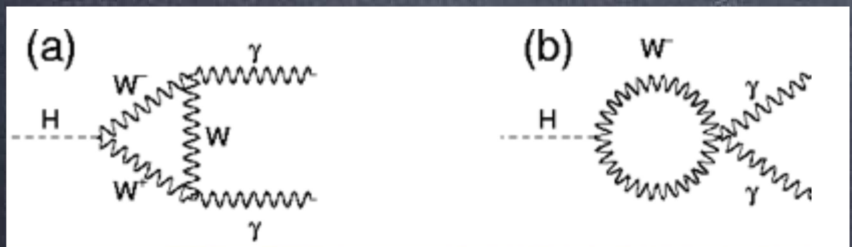



$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} \simeq \frac{|\hat{c}_{\gamma\gamma}|^2}{|\hat{c}_{\gamma\gamma,SM}|^2}$$

$$\hat{c}_{\gamma\gamma} = c_{\gamma\gamma} + 10^{-2}\,(0.97\,c_V - 0.21\,c_t)\,,$$

$$|\hat{c}_{\gamma\gamma,SM}| \simeq 0.0076,$$



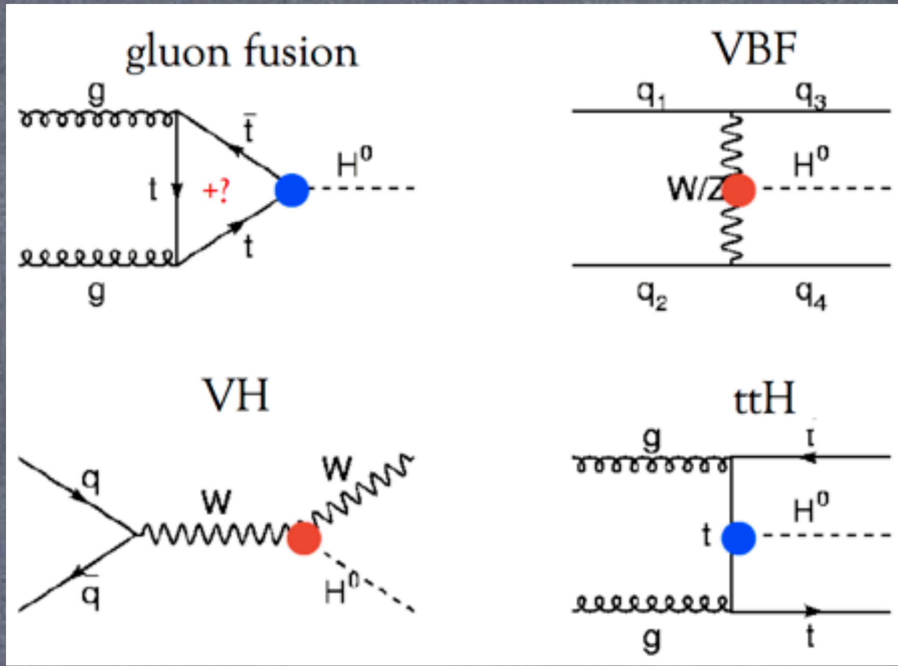

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} \simeq \frac{|\hat{c}_{Z\gamma}|^2}{|\hat{c}_{Z\gamma,SM}|^2}$$

$$\hat{c}_{Z\gamma} = c_{Z\gamma} + 10^{-2}\,(1.49\,c_V - 0.09\,c_t)\,,$$

$$|\hat{c}_{Z\gamma,SM}| \simeq 0.014$$

# Effective theory: production

- **Gluon fusion** (ggF), *gg→h+jets*
- Vector boson fusion (VBF), *qq→hqq+jets*
- Vector boson associated production (VH), *$q\bar{q}$→hV+jets*
- Top quark associated production (tth), *gg→tth+jets*




Production rates: $\frac{\sigma_{\rm ggF}}{\sigma^{\rm SM}_{\rm ggF}} = \frac{|\hat{c}_{gg}|^2}{|\hat{c}_{gg,\rm SM}|^2}$ $\quad \frac{\sigma_{\rm VBF}}{\sigma^{\rm SM}_{\rm VBF}} \simeq |c_V|^2$ $\quad \frac{\sigma_{\rm tth}}{\sigma^{\rm SM}_{\rm tth}} = |c_t|^2$

Significant effect of 2-derivative couplings on VH production modes:

$$\frac{\sigma_{WH}}{\sigma^{\rm SM}_{WH}} \simeq c_V^2 - 7.0\, c_V c_{Z\gamma} - 3.6\, c_V c_{\gamma\gamma} + 20.4\, c_{Z\gamma}^2 + 5.5\, c_{\gamma\gamma}^2 + 21.2\, c_{Z\gamma} c_{\gamma\gamma},$$

$$\frac{\sigma_{ZH}}{\sigma^{\rm SM}_{ZH}} \simeq c_V^2 - 5.7\, c_V c_{Z\gamma} - 3.4\, c_V c_{\gamma\gamma} + 14.9\, c_{Z\gamma}^2 + 4.3\, c_{\gamma\gamma}^2 + 15.0\, c_{Z\gamma} c_{\gamma\gamma}$$

# Effective theory: rates

Observables are rates in various Higgs channels, which are convolution of production, partial decay and total decay width
e.g.

$$\hat{\mu}^{ggF}_{\gamma\gamma} \simeq \frac{|\hat{c}_{gg}|^2}{|\hat{c}_{gg,\mathrm{SM}}|^2} \frac{|\hat{c}_{\gamma\gamma}|^2}{|\hat{c}_{\gamma\gamma,\mathrm{SM}}|^2} \frac{1}{C^2_{\mathrm{tot}}}$$

$$|C_{\mathrm{tot}}|^2 = \frac{\Gamma_{\mathrm{tot}}}{\Gamma_{\mathrm{tot,SM}}} \approx 0.56c_b^2 + 0.03c_t^2 + 0.06c_\tau^2 + 0.26c_V^2 + 0.09\frac{|\hat{c}_{gg}|^2}{|\hat{c}_{gg,\mathrm{SM}}|^2}$$

Furthermore, rates measured by experiment typically depend on different production modes (sometimes event different decay channels)
e.g.

$$\hat{\mu}^{THM2J}_{\gamma\gamma} = \epsilon^{THM2J}_{\mathrm{ggF}}\hat{\mu}^{ggF}_{\gamma\gamma} + \epsilon^{THM2J}_{\mathrm{VBF}}\hat{\mu}^{VBF}_{\gamma\gamma} + \epsilon^{THM2J}_{\mathrm{VH}}\hat{\mu}^{VH}_{\gamma\gamma} + \epsilon^{THM2J}_{\mathrm{ttH}}\hat{\mu}^{ttH}_{\gamma\gamma}$$

24% 76% 0.1% 0.1%

Thus, effectively, each observable depends on all parameters of effective theory

# State of Art

Disclaimer: similar or exactly the same fits done independently by numerous theorist groups;
too many to cite them all, so in this talk no references at all, so as not to miss someone ;-)

# Global fits

- We fit couplings of the effective theory to available ATLAS, CMS, and Tevatron data and EW precision tests from LEP, SLC, Tevatron
- Starting with unconstrained 7 parameter, than moving to constrained 2 parameter fits motivated by new physics models
- Assuming errors in different channels are Gaussian and uncorrelated (except in EW precision tests)
- But taking into account the efficiencies of various subchannels to different Higgs production processes, whenever available

# Global fits

| CMS | | | |
|---|---|---|---|
| | Category | $\hat{\mu}$ | Ref. |
| $\gamma\gamma$ | VBF+VH/ggF | $0.77^{+0.29}_{-0.26}$ | [4] |
| $WW$ | 0/1j | $0.73^{+0.22}_{-0.20}$ | [8] |
| | VBF | $-0.05^{+0.75}_{-0.56}$ | |
| | VH | $0.51^{+1.26}_{-0.94}$ | |
| $ZZ$ | untag. | $0.86^{+0.32}_{-0.26}$ | [5] |
| | dijet | $1.24^{+0.85}_{-0.58}$ | |
| $Z\gamma$ | incl. | $-1.8^{+5.6}_{-5.6}$ | [9] |
| $\tau\tau$ | $0/1j$ | $0.77^{+0.58}_{-0.55}$ | [7] |
| | VBF | $1.42^{+0.70}_{-0.64}$ | |
| | VH | $0.98^{+1.68}_{-1.50}$ | |
| $bb$ | $ZH(l^+l^-)$ | $1.52^{+1.20}_{-1.082}$ | [30] |
| | $ZH(\nu\nu)$ | $1.76^{+1.12}_{-1.00}$ | |
| | $WH$ | $0.64^{+0.92}_{-0.88}$ | |
| | $ttH$ | $-0.15^{+2.8}_{-2.9}$ | [8] |

| ATLAS | | | |
|---|---|---|---|
| | Category | $\hat{\mu}$ | Ref. |
| $\gamma\gamma$ | UnCe, low $p_{Tt}$ | $(0.5^{+1.4}_{-1.4})0.87^{+0.73}_{-0.70}$ | [13] |
| | UnCe, high $p_{Tt}$ | $(0.2^{+2.0}_{-1.9})0.96^{+1.07}_{-0.95}$ | |
| | UnRe, low $p_{Tt}$ | $(2.5^{+1.7}_{-1.7})2.50^{+0.92}_{-0.77}$ | |
| | UnRe, high $p_{Tt}$ | $(10.4^{+3.7}_{-3.7})2.69^{+1.35}_{-1.17}$ | |
| | CoCe, low $p_{Tt}$ | $(6.1^{+2.7}_{-2.7})1.39^{+1.01}_{-0.95}$ | |
| | CoCe, high $p_{Tt}$ | $(-4.4^{+1.8}_{-1.8})1.98^{+1.54}_{-1.26}$ | |
| | CoRe, low $p_{Tt}$ | $(2.7^{+2.0}_{-2.0})2.23^{+1.14}_{-1.01}$ | |
| | CoRe, high $p_{Tt}$ | $(-1.6^{+2.9}_{-2.9})1.27^{+1.32}_{-1.23}$ | |
| | CoTr | $(0.3^{+3.6}_{-3.6})2.78^{+1.72}_{-1.57}$ | |
| | L2j(high mass) | $2.75^{+1.78}_{-1.38}$ | |
| | T2j (high mass) | $1.61^{+0.83}_{-0.67}$ | |
| | 2j (low mass) | $(2.7^{+1.9}_{-1.9})0.32^{+1.72}_{-1.44}$ | |
| | $E_T^{\rm miss}$ | $2.97^{+2.71}_{-2.15}$ | |
| | 1l | $2.69^{+1.97}_{-1.66}$ | |
| $WW$ | VBF+VH/ggF | $1.35^{+0.57}_{-0.53}$ | [14] |
| $ZZ$ | incl. | $1.35^{+0.39}_{-0.34}$ | [16] |
| $Z\gamma$ | incl. | $2.6^{+6.5}_{-6.5}$ | [11] |
| $\tau\tau$ | VBF+VH/ggF | $0.74^{+0.76}_{-0.67}$ | [31] |
| $bb$ | VH | $-0.41^{+1.02}_{-1.04}$ | [32] |

Table 2: The LHC Higgs data included in our fit [4]-[16], [30]-[32]. The rates are normalized to the SM rate; when data for 7 and 8 TeV are separately provided, we write the former in brackets. We also include the latest combined Tevatron measurements: $\hat{\mu}_{\gamma\gamma} = 6.2^{+3.2}_{-3.2}$, $\hat{\mu}_{WW} = 0.9^{+0.9}_{-0.8}$, $\hat{\mu}^{VH}_{bb} = 1.62^{+0.77}_{-0.77}$, $\hat{\mu}_{\tau\tau} = 2.1^{+2.2}_{-2.0}$ [33]. For the ATLAS $WW$ and $\tau\tau$ and CMS $\gamma\gamma$ channels we include in our fit the two-dimensional likelihood correlations of the signal strengths for the ggF+ttH and VBF+VH production modes.

# Effective Theory Parameter Fits

$$\mathcal{L}_{eff} = c_V \frac{2m_W^2}{v} h\, W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h\, Z_\mu Z_\mu$$
$$- c_t \sum_{u,c,t} \frac{m_q}{v} h\, \bar{u}_i u_i - c_b \sum_{d,s,b} \frac{m_q}{v} h\, \bar{d}_i d_i - c_\tau \sum_{e,\mu,\tau} \frac{m_q}{v} h\, \bar{l}_i l_i$$
$$- \frac{h}{4v} \left( c_{\gamma\gamma}\, A_{\mu\nu} A_{\mu\nu} + 2 c_{Z\gamma}\, Z_{\mu\nu} A_{\mu\nu} + c_{ZZ}\, Z_{\mu\nu} Z_{\mu\nu} + 2 c_{WW}\, W_{\mu\nu} W^*_{\mu\nu} - c_{gg}\, G^a_{\mu\nu} G^a_{\mu\nu} \right)$$

## Why fit?

- Because it's fun
- Because it may gives hints what kind of new physics could be realized in nature and prompt new theoretical directions
- For example: fits to early Higgs data were suggesting cV > 1, and prompted studies of Higgs sectors with triplets where it's possible
- For example: fits to early Higgs data suggesting large new contributions to cγγ prompted more in-depth studies (collider pheno, stability, etc.) of theories with light charged particles strongly coupled to the Higgs
- Ultimately, to prove it's just the SM in a model independent and prejudice free fashion :-(((

# Effective Theory Parameter Fits

$$\mathcal{L}_{eff} = c_V \frac{2m_W^2}{v} h\, W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h\, Z_\mu Z_\mu$$
$$- c_t \sum_{u,c,t} \frac{m_q}{v} h\, \bar{u}_i u_i - c_b \sum_{d,s,b} \frac{m_q}{v} h\, \bar{d}_i d_i - c_\tau \sum_{e,\mu,\tau} \frac{m_q}{v} h\, \bar{l}_i l_i$$
$$- \frac{h}{4v} \left( c_{\gamma\gamma} A_{\mu\nu} A_{\mu\nu} + 2 c_{Z\gamma} Z_{\mu\nu} A_{\mu\nu} + c_{ZZ} Z_{\mu\nu} Z_{\mu\nu} + 2 c_{WW} W_{\mu\nu} W^*_{\mu\nu} - c_{gg} G^a_{\mu\nu} G^a_{\mu\nu} \right)$$

## Should theorists fit?

- Asymptotically, no...
- Theorists cannot properly take into account all systematics and correlations
- OK as long as the errors are dominated by statistics, but we're close to the point where they are not

# Comparison of naive and professional fits

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