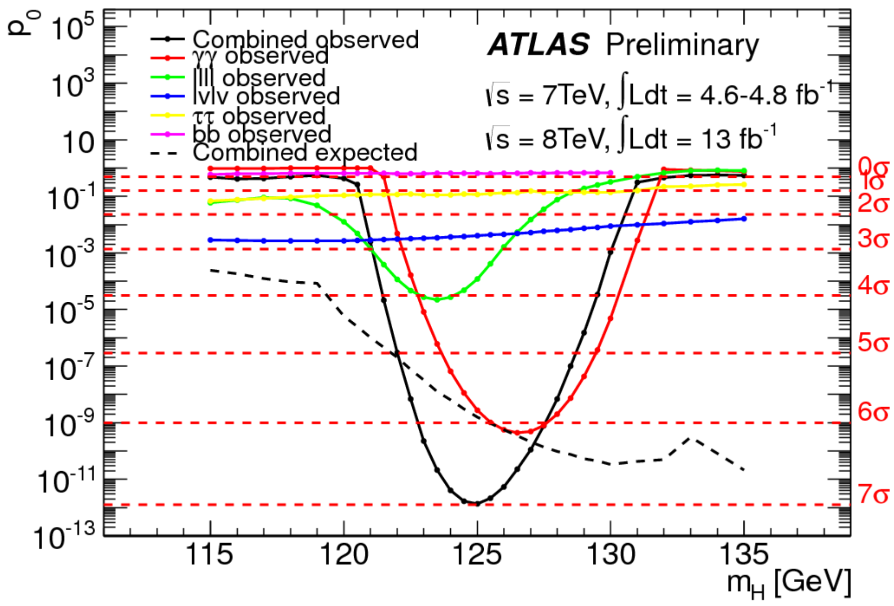
Higgs couplings after Moriond EW

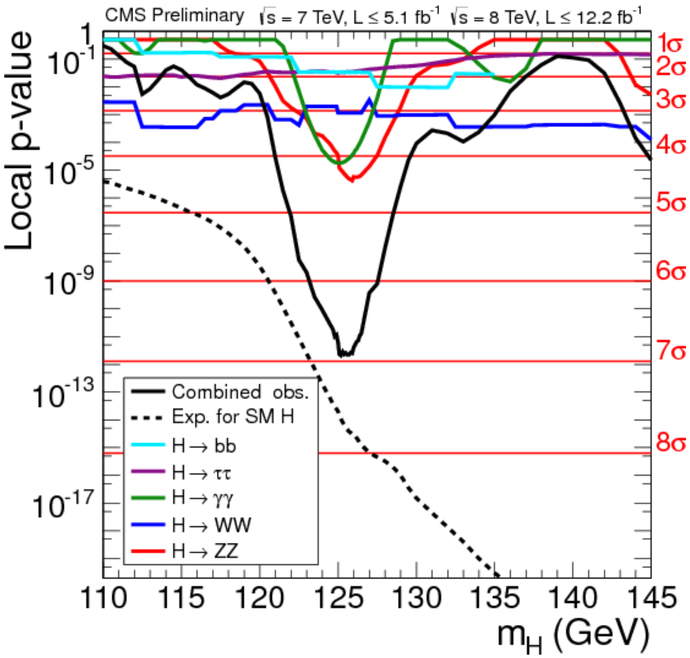
Béranger Dumont (LPSC Grenoble)

based on:
G. Belanger, BD, U. Ellwanger, J. F. Gunion, and S. Kraml
[JHEP02(2013)053, arXiv:1212.5244] and [arXiv:1302.5694]

Rencontres de Moriond – QCD and High Energy Interactions
March 14, 2013

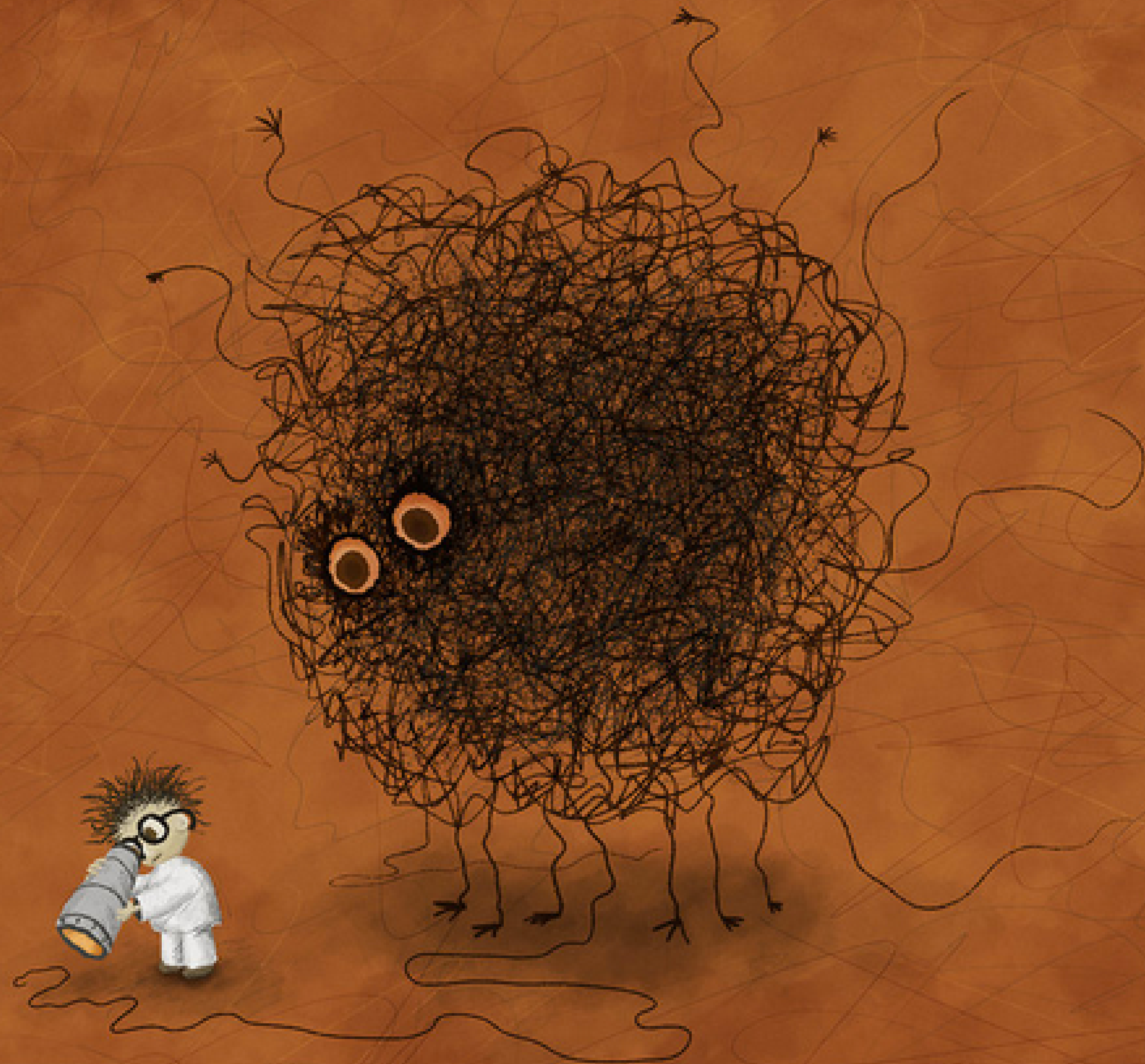
The Higgs boson has been found





- previous updates at HCP2012 in Kyoto (in November) and at the open session of the CERN Council (in December)
- and now Moriond!
- Tevatron is very competitive for H→bb and results are not yet final

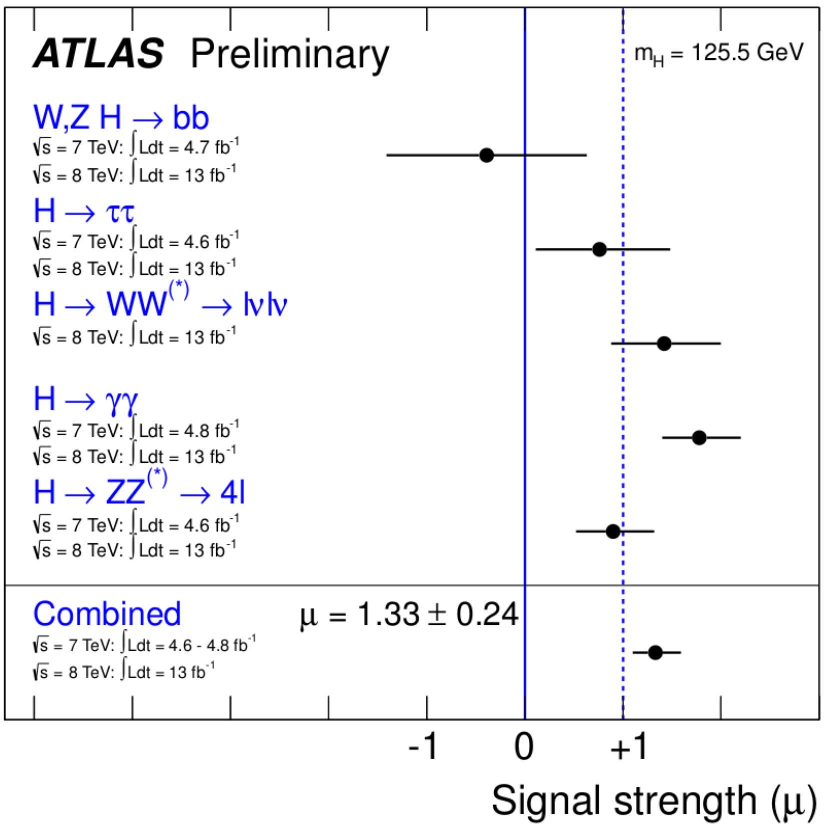
Standard Model Higgs... or New Physics?

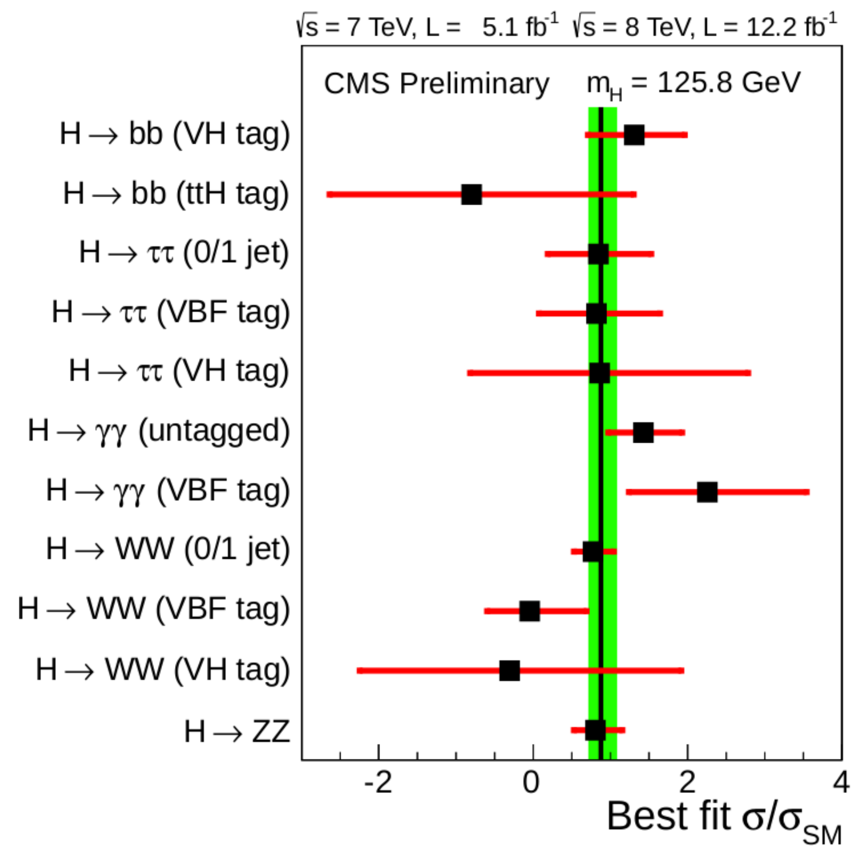


(taken from Alexey Drozdetskiy's talk at HCP2012)

What we know about it before Moriond

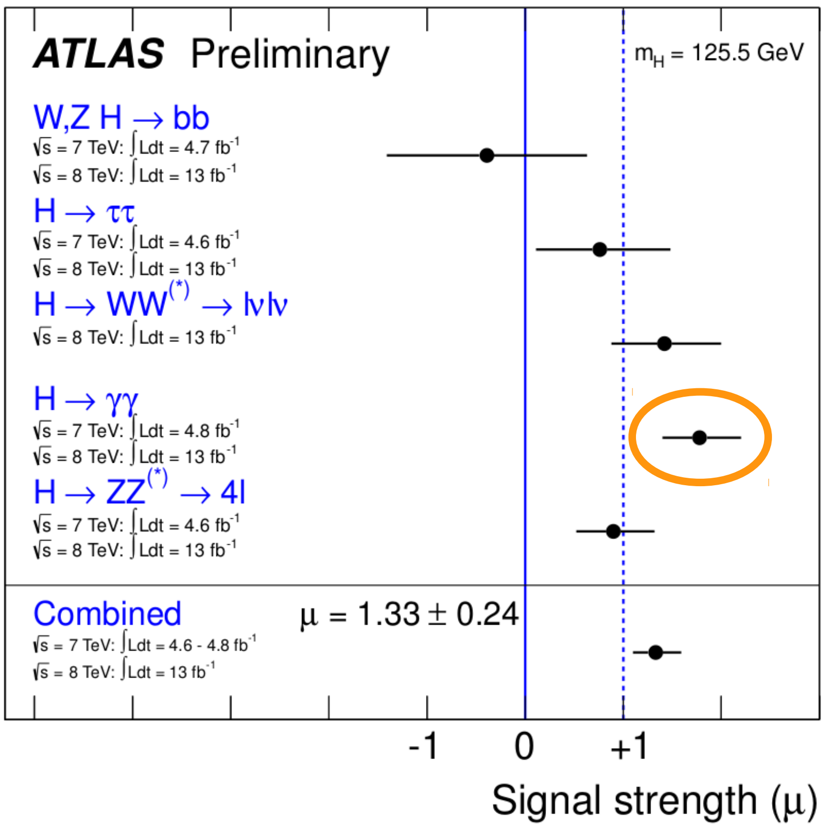
$$\mu_i = \frac{\left[\sum_j \sigma_{j\to h} \times \mathrm{Br}(h \to i)\right]_{observed}}{\left[\sum_j \sigma_{j\to h} \times \mathrm{Br}(h \to i)\right]_{SM}}$$

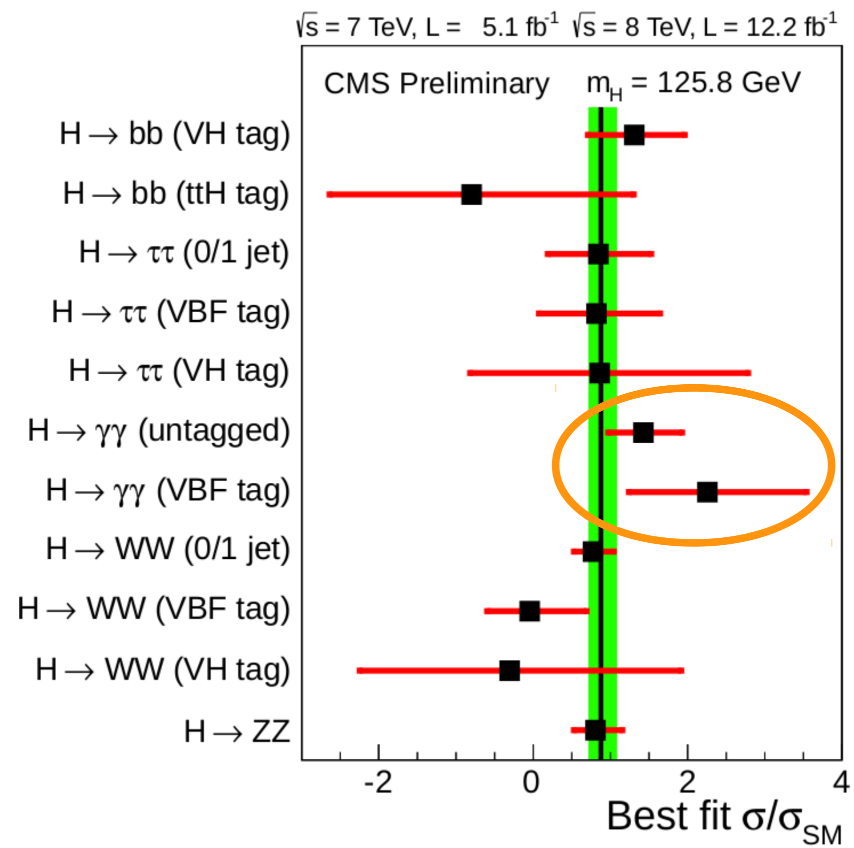




What we know about it before Moriond

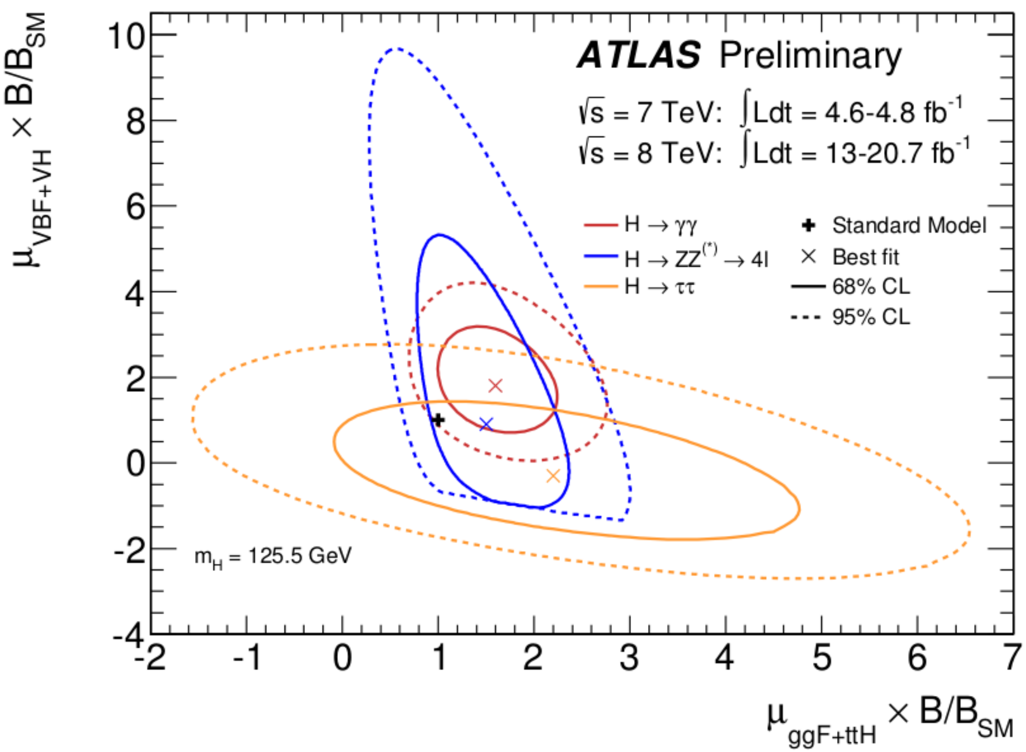
$$\mu_i = \frac{[\sum_j \sigma_{j\to h} \times \mathrm{Br}(h \to i)]_{observed}}{[\sum_j \sigma_{j\to h} \times \mathrm{Br}(h \to i)]_{SM}}$$





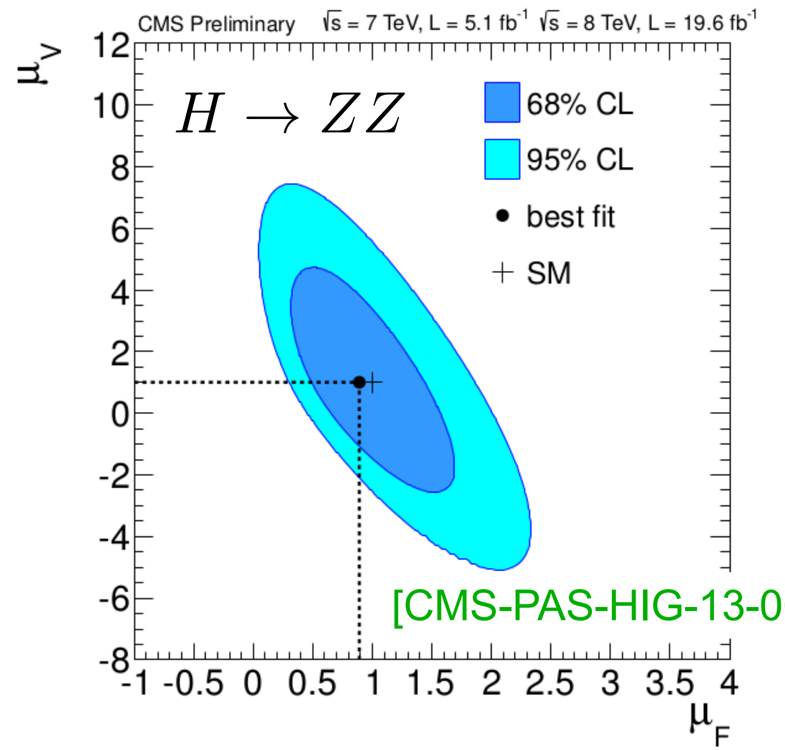
What we know about it after Moriond EW

ATLAS



[ATLAS-CONF-2013-012]
[ATLAS-CONF-2013-013]
[ATLAS-CONF-2013-014]

CMS



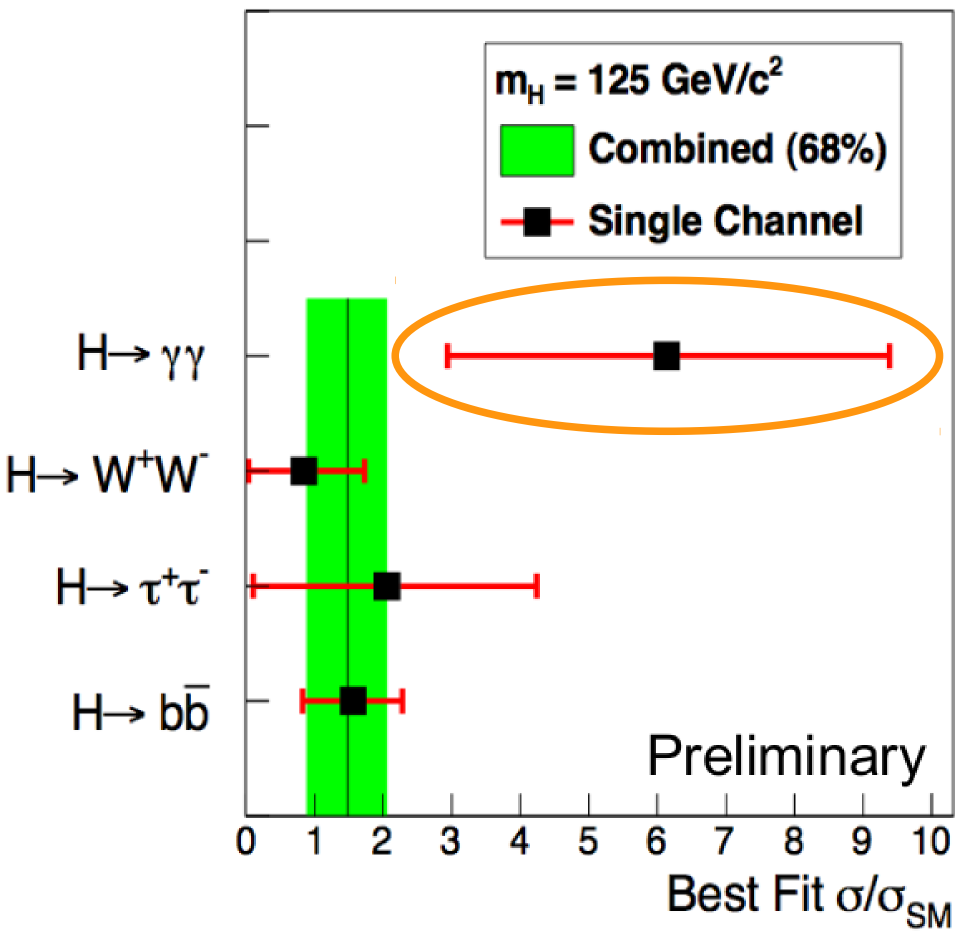
[CMS-PAS-HIG-13-002]

WW 0/1-jet: $\mu = 0.76 \pm 0.21$

[CMS-PAS-HIG-13-003]

Tevatron results

Tevatron (HCP2012)



How can we go beyond this information to understand what is in the data?

How well do we know the Higgs couplings?

Deviations from the SM Higgs

- We first need to specify a Lagrangian. Our choice:

$$\mathcal{L} = g\left[C_V\left(m_W W_\mu W^\mu + \frac{m_Z}{\cos\theta_W} Z_\mu Z^\mu\right) - C_U \frac{m_t}{2m_W}\bar{t}t - C_D \frac{m_b}{2m_W}\bar{b}b - C_D \frac{m_\tau}{2m_W}\bar{\tau}\tau\right] H$$

Scaling factors C parametrize deviations from the SM

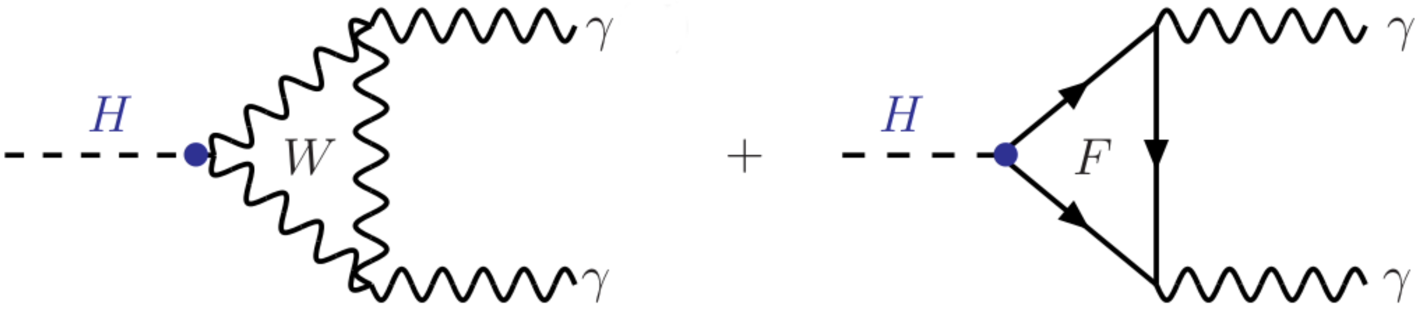
- We calculate $\overline{C}_g$ (for gluon-gluon fusion) and $\overline{C}_\gamma$ (for H→γγ) from C_U, C_D, C_V and we allow for additional particles in the loop: ΔC_g and ΔC_γ
  → $C_g = \overline{C}_g + \Delta C_g$ and $C_\gamma = \overline{C}_\gamma + \Delta C_\gamma$

- Total Higgs width: a priori not accessible at the LHC
  → we can in general only determine ratio of couplings
  ... or fix an invisible/undetected Higgs width

Fitting procedure

- simple χ^2 fit: $\chi^2 = \sum_k \frac{(\mu_k - \mu_k^{\exp})^2}{\Delta\mu_k^2}$
- when we use ($\mu_{ggF+ttH}$, μ_{VBF+VH}) information we take into account correlations
- μ_k: rescaling of the SM prediction (given by the LHC Higgs XS WG)
- we take into account the different efficiencies for the various production mechanisms
- when showing contours of $\Delta\chi^2$:
  we profile the likelihood over the unseen parameters

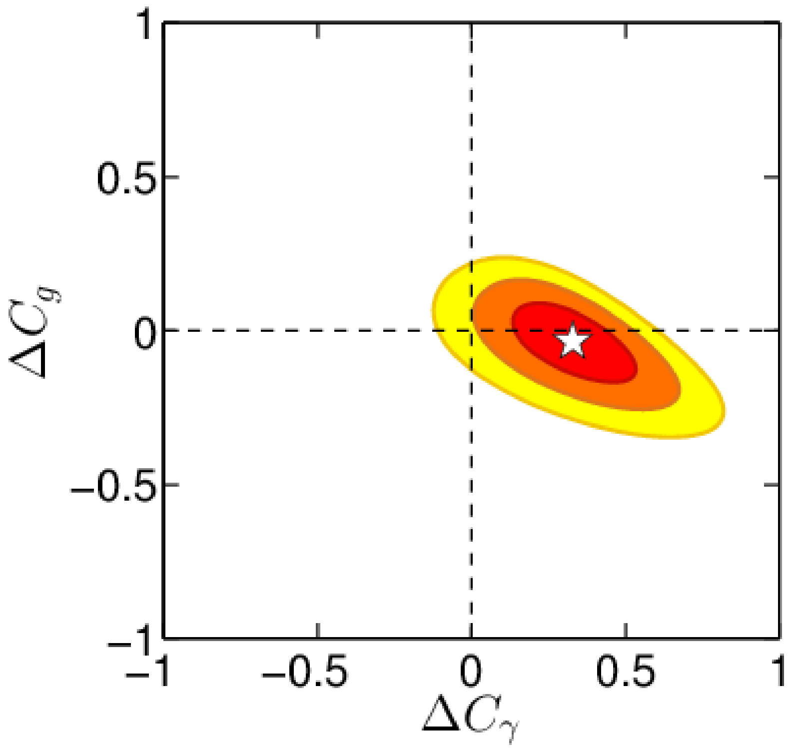
A word on H→γγ



- contribution from the W is 5 times larger than from the top quark and with opposite sign
- small contributions from bottom and lighter quarks
- new particles in the loop could change the Hγγ rate (e.g. charged Higgses, charginos, staus, ...)

I) ΔC_g , ΔC_γ fit

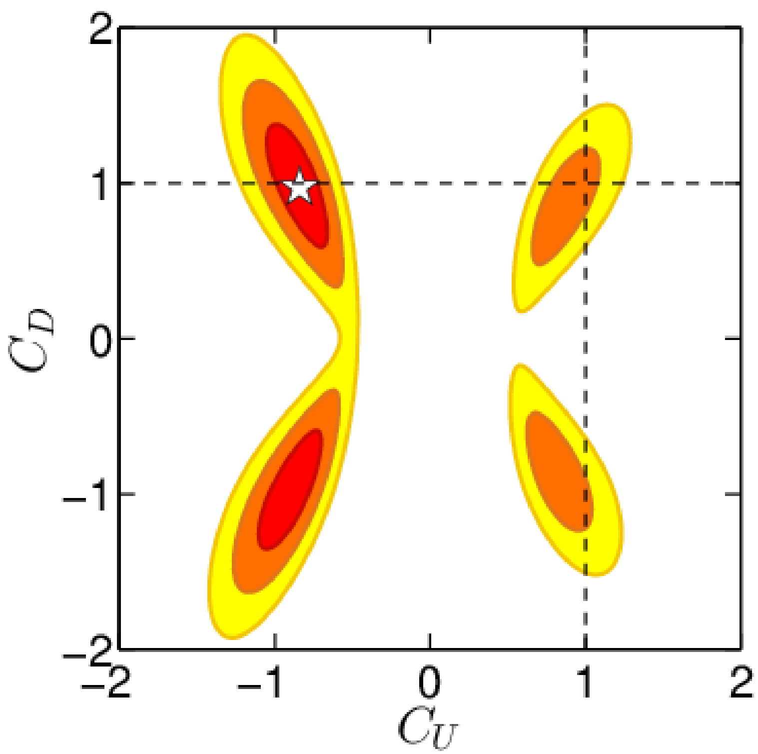
- we assume $C_U = C_D = C_V = 1$ — ΔC_g and ΔC_γ are free to vary
  → new physics as additional particles in the loops
- relevant in the context of Universal Extra Dimensions, VLQ, ...



- SM: 2.2σ away from best fit due to the excess in $H \to \gamma\gamma$
- Observed gluon-gluon fusion rate well compatible with the SM

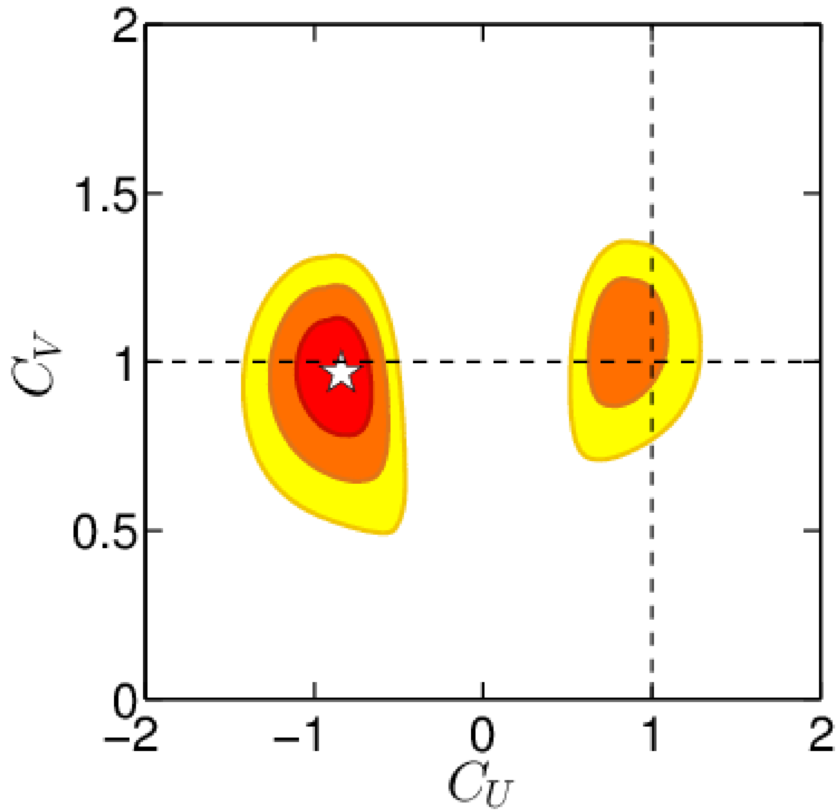
II) C_U , C_D , C_V fit

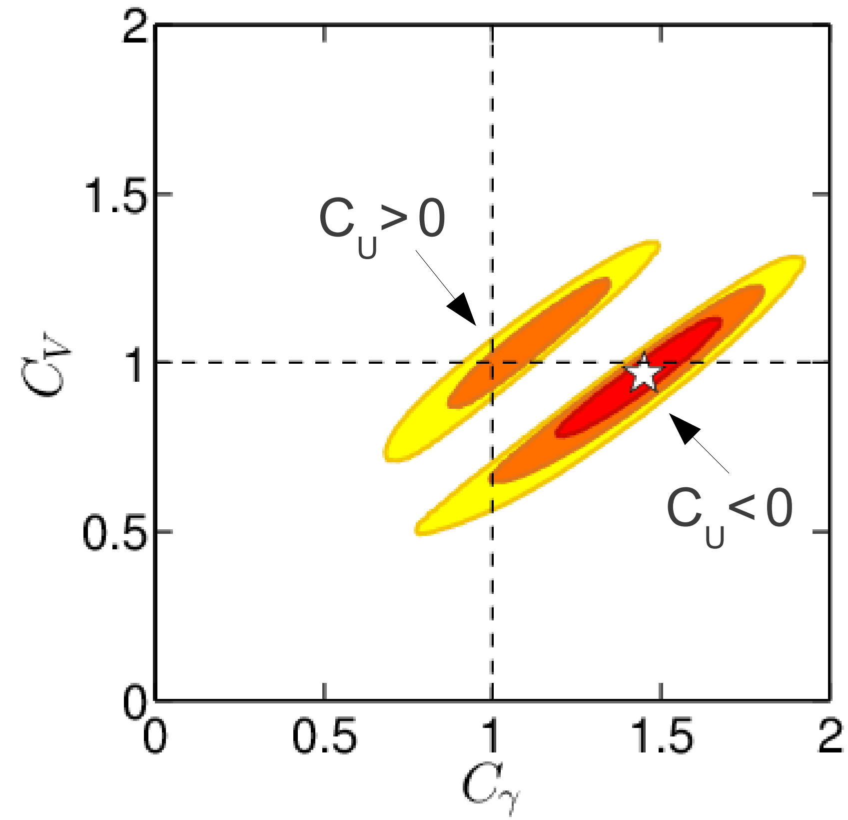
- we assume $\Delta C_g = \Delta C_\gamma = 0$ — C_U , C_D and C_V are free to vary
  → modified Higgs sector + no new particles in the loops
- can arise with extended Higgs sectors (e.g. 2HDM with heavy H^+)



- SM: 1.6σ away from best fit due to the excess in $H \to \gamma\gamma$
- $C_U < 0$ (sign opposite to C_V)
  ⇒ constructive interference with W preferred at the level of 1.8σ
- C_D compatible with the SM (up to a minus sign)

II) C_U , C_D , C_V fit



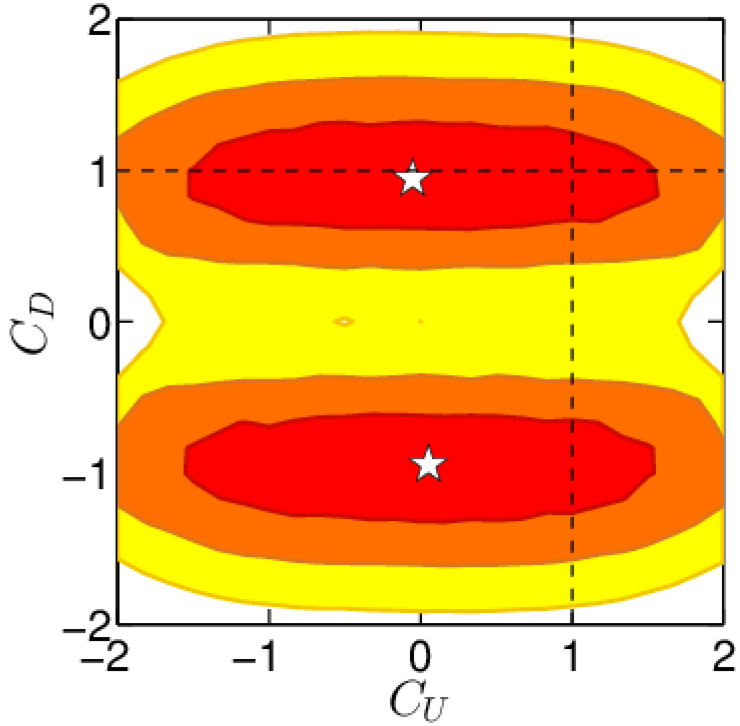


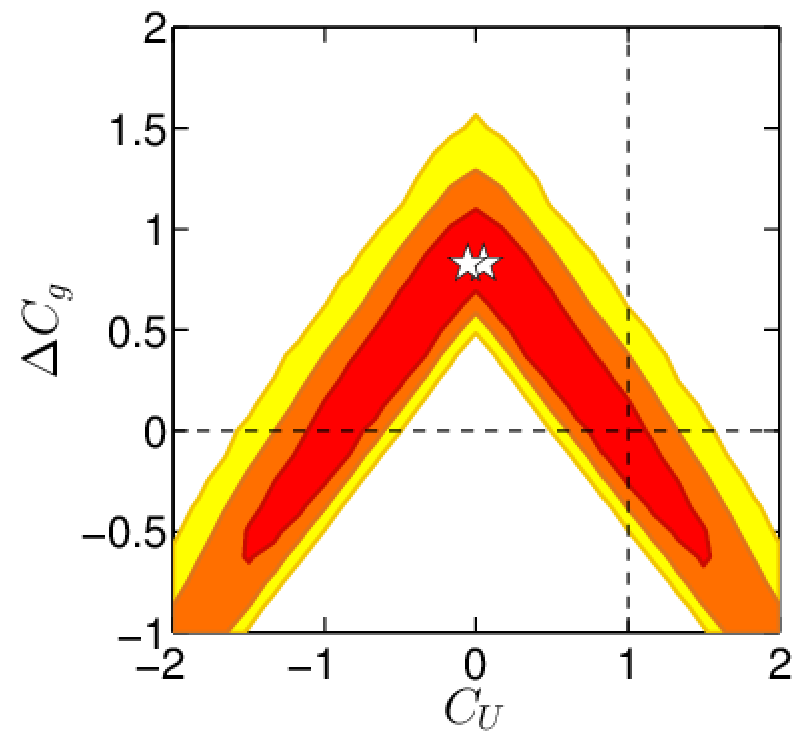
- C_V tend to be larger for $C_U > 0$
- Strong correlation between C_γ and C_V

Single top production in association with a Higgs boson could soon discriminate $C_U > 0$ and $C_U < 0$ [Biswas, Gabrielli and Mele '12; Farina et al. '12]

III) C_U , C_D , C_V , ΔC_g , ΔC_γ fit

- general case: C_U, C_D, C_V, ΔC_g and ΔC_γ are free to vary
- encompasses a very broad class of models (incl. Higgs sector made of any number of doublets + singlets)



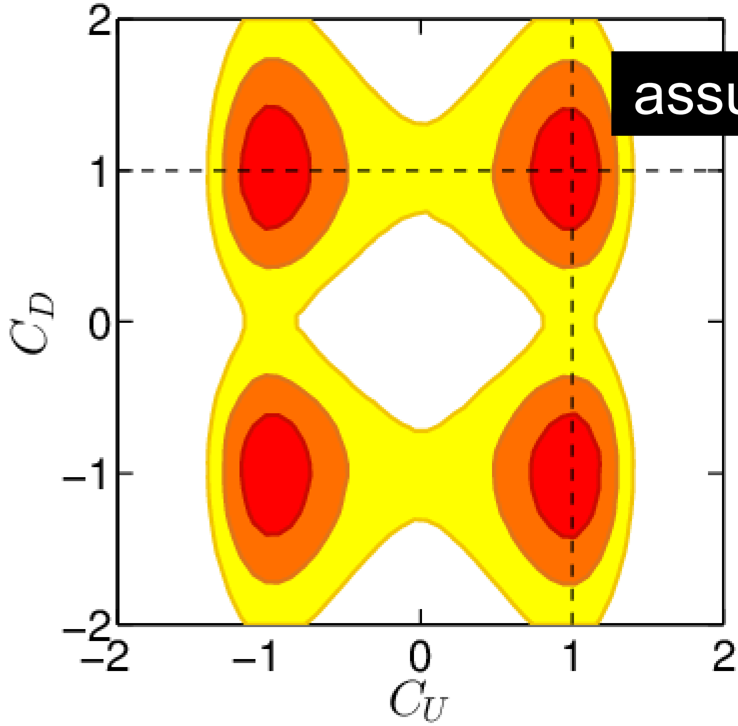


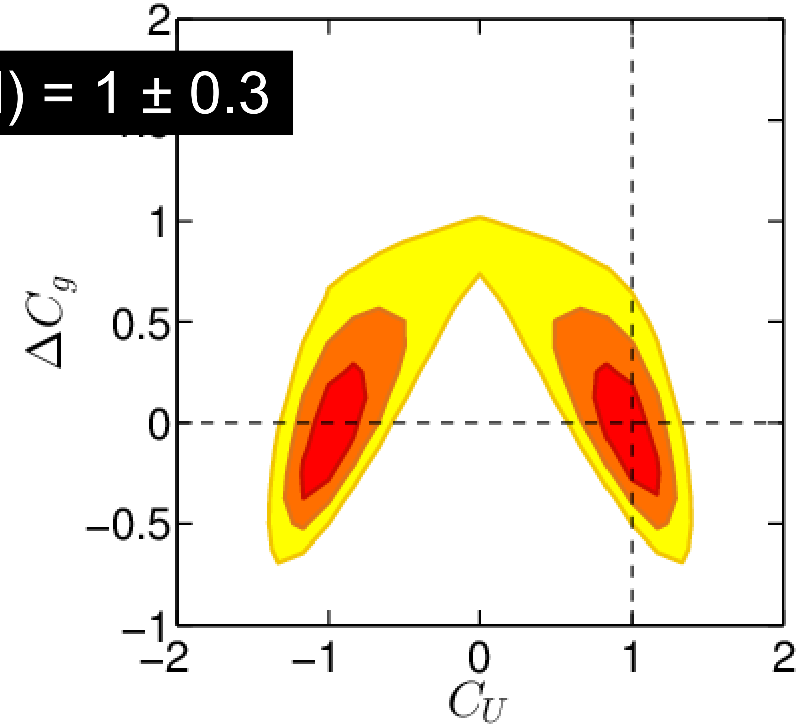
- $C_\gamma > 1$ is achieved with $\Delta C_\gamma > 0$
- anticorrelation between C_U and ΔC_g

III) C_U , C_D , C_V , ΔC_g , ΔC_γ fit

- general case: C_U, C_D, C_V, ΔC_g and ΔC_γ are free to vary
- encompasses a very broad class of models (incl. Higgs sector made of any number of doublets + singlets)

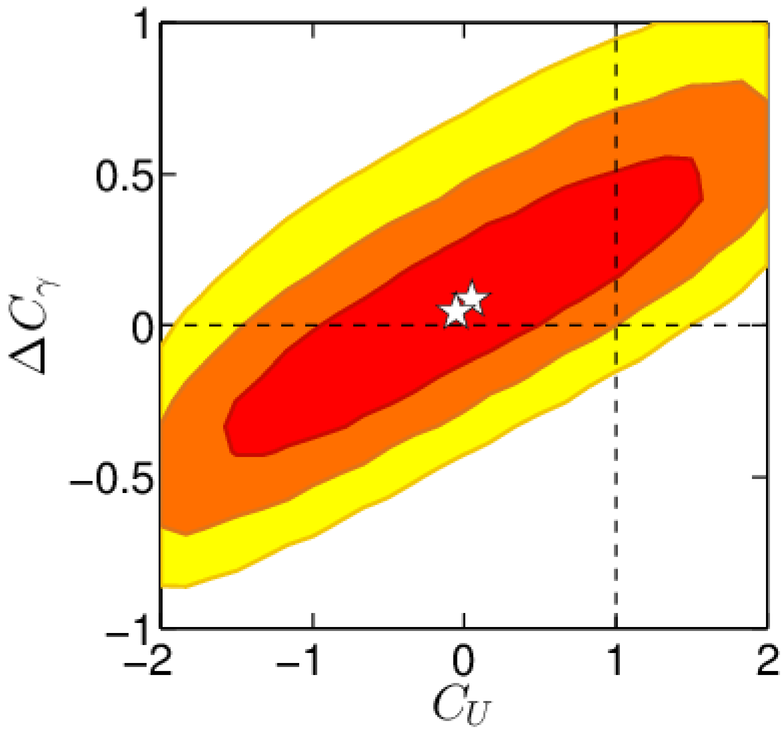
assuming μ(ttH) = 1 ± 0.3

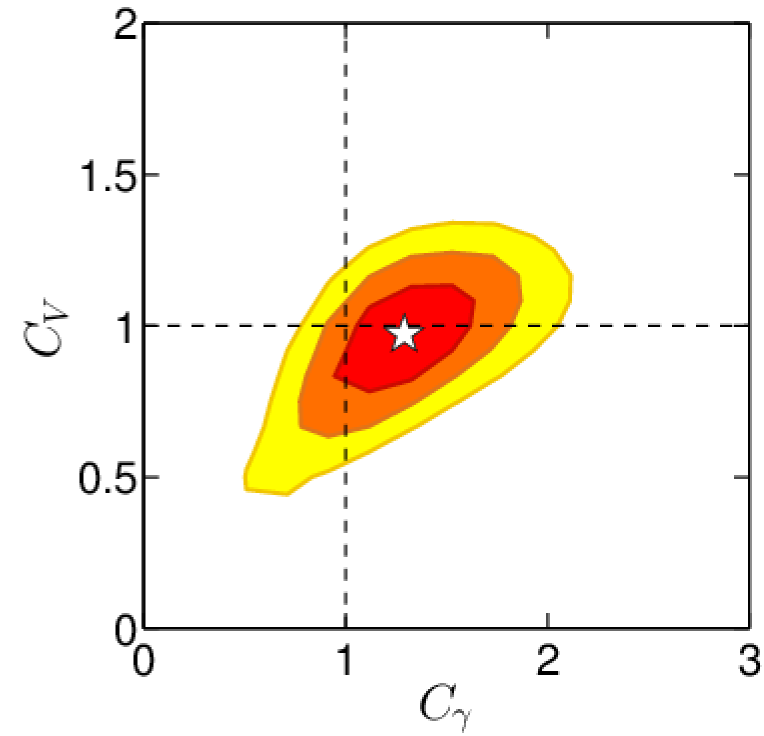




- $C_\gamma > 1$ is achieved with $\Delta C_\gamma > 0$
- anticorrelation between C_U and ΔC_g

III) C_U , C_D , C_V , ΔC_g , ΔC_γ fit





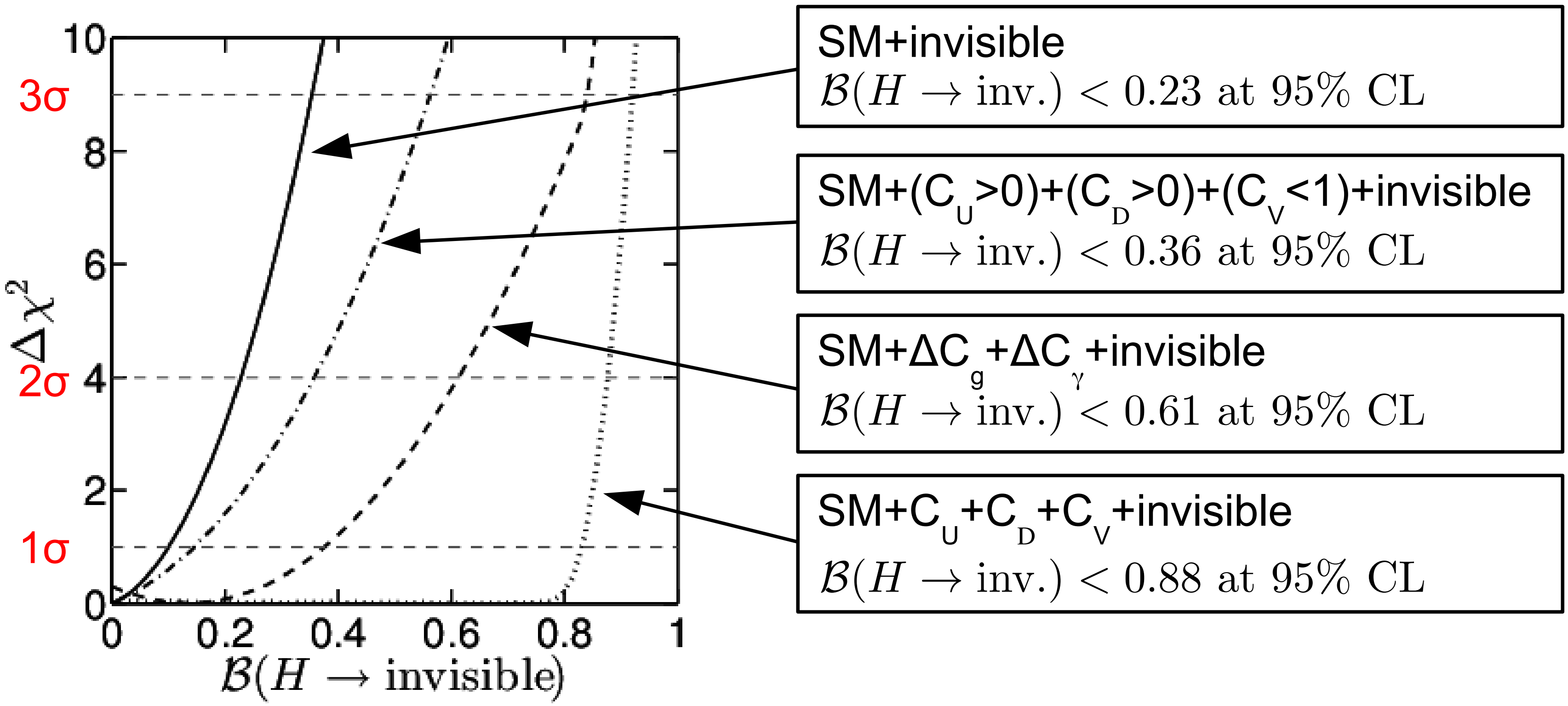
- SM: 1.4σ away from best fit due to the excess in $H \rightarrow \gamma\gamma$
- balance between C_U and ΔC_γ
- the determination of C_V is robust

Goodness-of-fit

Fit	Standard Model	ΔC_γ, ΔC_g	C_U, C_D, C_V	C_U, C_D, C_V, ΔC_γ, ΔC_g
$\chi^2_{\rm min}$	22.1	15.1	16.2	14.4
$\chi^2_{\rm min}$/d.o.f.	0.96	0.72	0.81	0.80
dominant contributions to $\chi^2_{\rm min}$	ATLAS $\gamma\gamma$ CMS $\gamma\gamma$ Tevatron $\gamma\gamma$	ATLAS ZZ CMS WW VBF Tevatron $\gamma\gamma$	ATLAS ZZ Tevatron $\gamma\gamma$ CMS $\gamma\gamma$	ATLAS ZZ CMS WW VBF Tevatron $\gamma\gamma$

- significant improvement of χ^2/d.o.f. (hence the *p*-value) when allowing for an enhanced $H\gamma\gamma$ rate
- no amelioration of the fit from 2 to 5 parameters

Invisible decays of the Higgs boson before Moriond EW

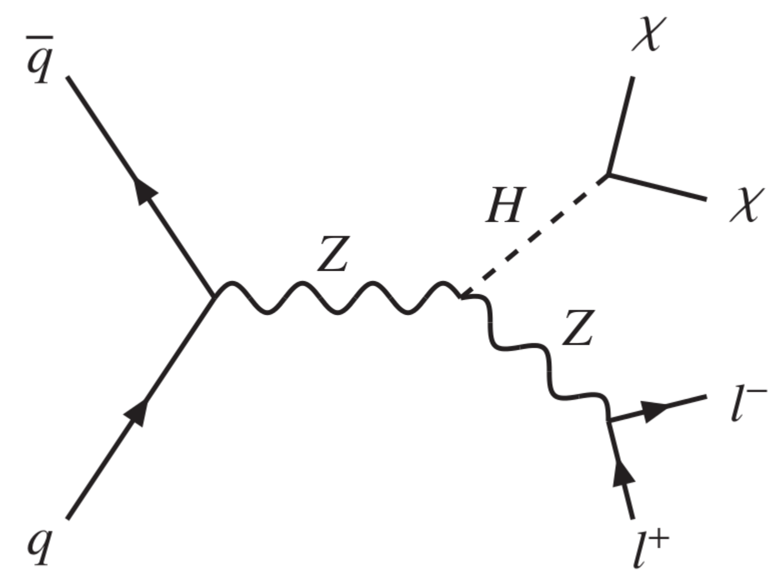


it needs to be updated with the Moriond results already shown, but not only...

Searches for invisible decays of the Higgs boson

ATLAS

$ZH \to \ell\ell + \text{invisible}$



[ATLAS-CONF-2013-011]

$$\mathcal{B}(H \to \text{inv.}) < 0.65 \text{ at } 95\% \text{ CL}$$

Searches for invisible decays of the Higgs boson

ATLAS

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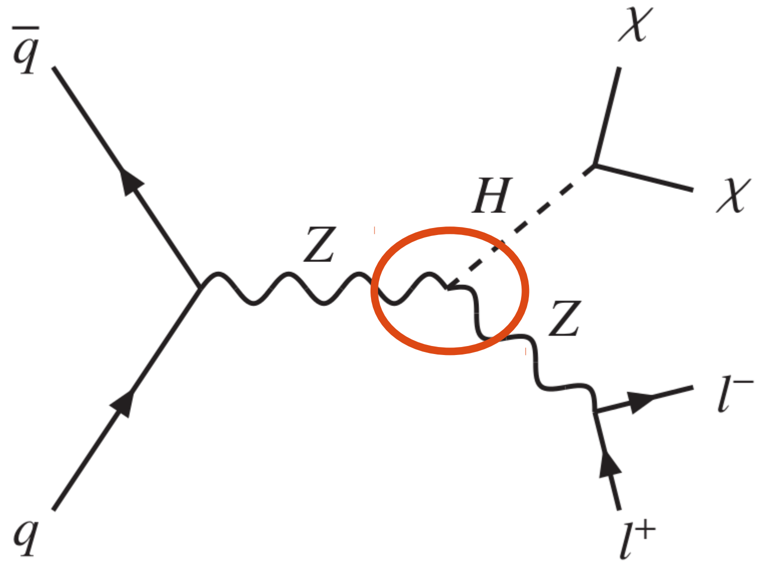
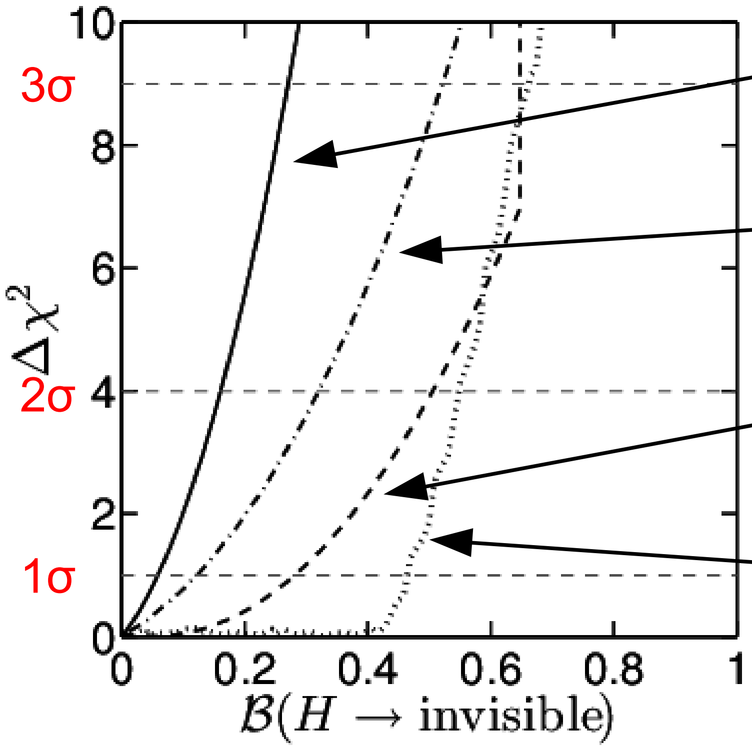


[ATLAS-CONF-2013-011]

$$C_V^2\,\mathcal{B}(H \to \text{inv.}) < 0.65 \text{ at } 95\% \text{ CL}$$

see also earlier studies based on e.g. monojet searches [Djouadi *et al.* '12]

Invisible decays of the Higgs boson after Moriond EW



SM+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.16$ at 95% CL

SM+(C_U>0)+(C_D>0)+(C_V<1)+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.32$ at 95% CL

SM+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.51$ at 95% CL

SM+C_U+C_D+C_V+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.55$ at 95% CL

if invisible = dark matter:
interplay between direct searches and H → invisible
(see backup)

Conclusion/Outlook

- better fit to the data are possible with enhanced $H\to\gamma\gamma$
  ... future will tell us whether it is a fluke or New Physics

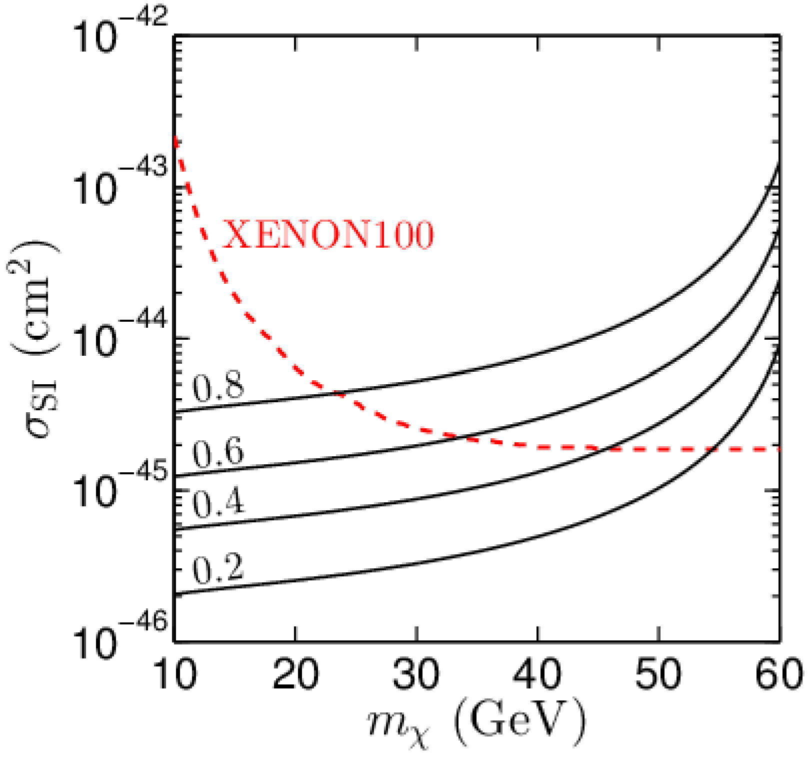
- enhanced $H\to\gamma\gamma$ can be accommodated with:
  - $C_U \approx -C_V$ (difficult to achieve in a realistic model)
  - $\Delta C_\gamma > 0$ (light non-SM electrically charged particles)

- results from this morning have to be taken into account
  (effect of CMS $H\to\gamma\gamma$ on the excess?)

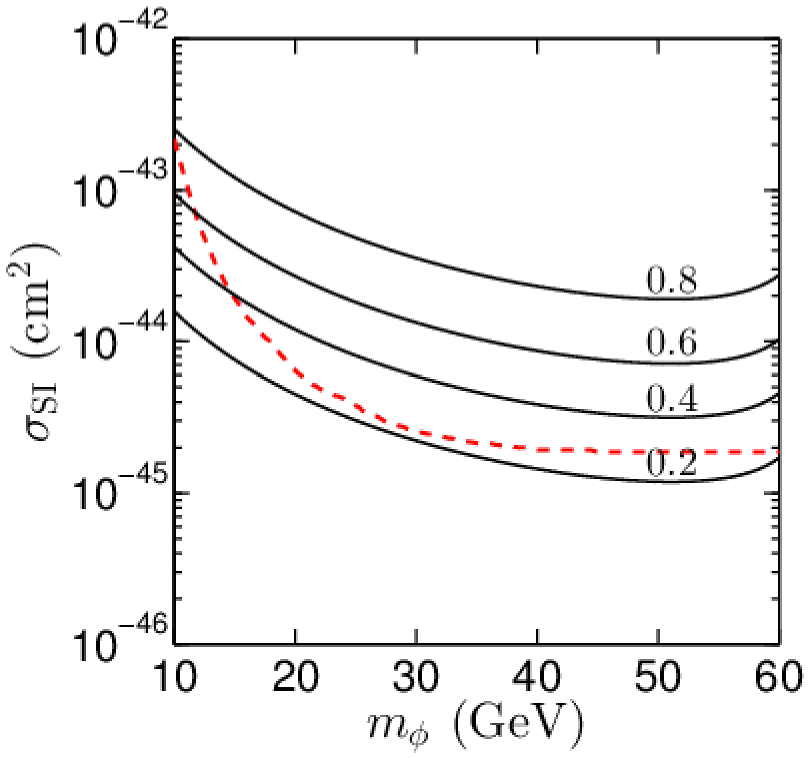
- many New Physics models to explore in light of what we learned on the 125 GeV Higgs boson!

Invisible decays of the Higgs boson and dark matter

Majorana dark matter

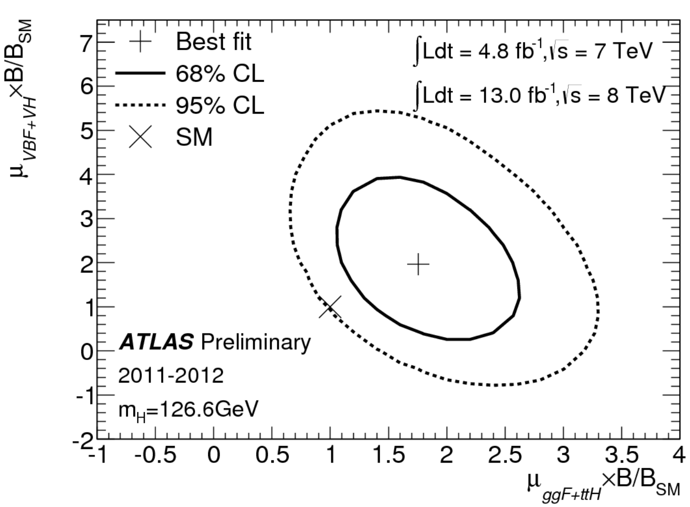


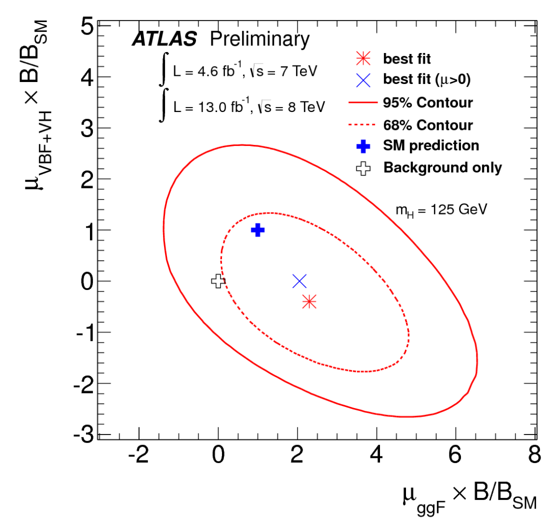
scalar dark matter



Pre-Moriond experimental data we use ATLAS

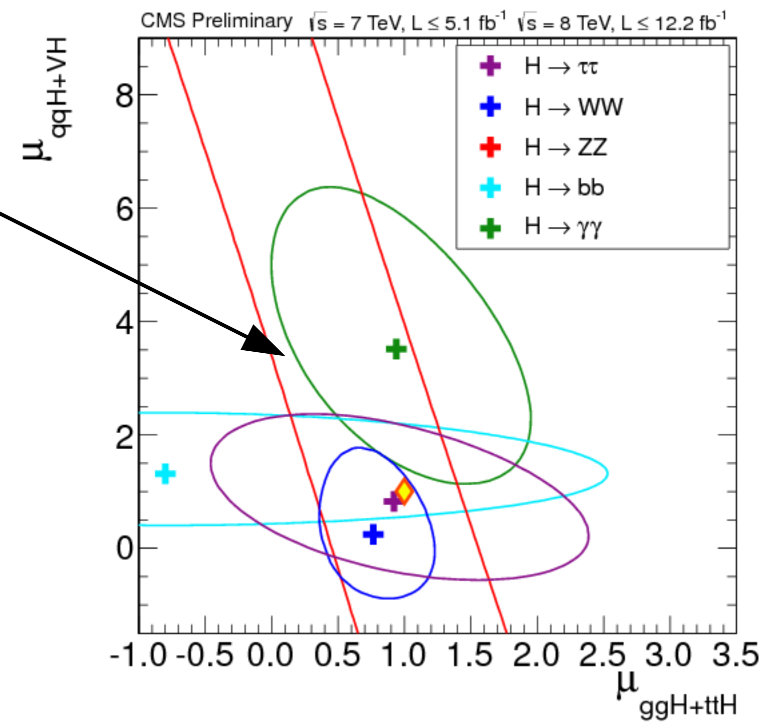
Channel	Signal strength μ	M_H (GeV)	Production mode			
			ggF	VBF	VH	ttH
$H \to \gamma\gamma$ (4.8 fb^{-1} at 7 TeV + 13.0 fb^{-1} at 8 TeV) [4]						
$\mu(\mathrm{ggF+ttH}, \gamma\gamma)$	1.85 ± 0.52	126.6	100%	–	–	–
$\mu(\mathrm{VBF+VH}, \gamma\gamma)$	2.01 ± 1.23	126.6	–	60%	40%	–
$H \to ZZ$ (4.6 fb^{-1} at 7 TeV + 13.0 fb^{-1} at 8 TeV) [6,11]						
Inclusive	$1.01^{+0.45}_{-0.40}$	125	87%	7%	5%	1%
$H \to WW$ (13.0 fb^{-1} at 8 TeV) [8,11]						
$e\nu\mu\nu$	$1.42^{+0.58}_{-0.54}$	125.5	95%	3%	2%	–
$H \to b\bar{b}$ (4.7 fb^{-1} at 7 TeV + 13.0 fb^{-1} at 8 TeV) [11,50]						
VH tag	-0.39 ± 1.02	125.5	–	–	100%	–
$H \to \tau\tau$ (4.6 fb^{-1} at 7 TeV + 13.0 fb^{-1} at 8 TeV) [51]						
$\mu(\mathrm{ggF}, \tau\tau)$	2.41 ± 1.57	125	100%	–	–	–
$\mu(\mathrm{VBF+VH}, \tau\tau)$	-0.26 ± 1.02	125	–	60%	40%	–





Pre-Moriond experimental data we use CMS

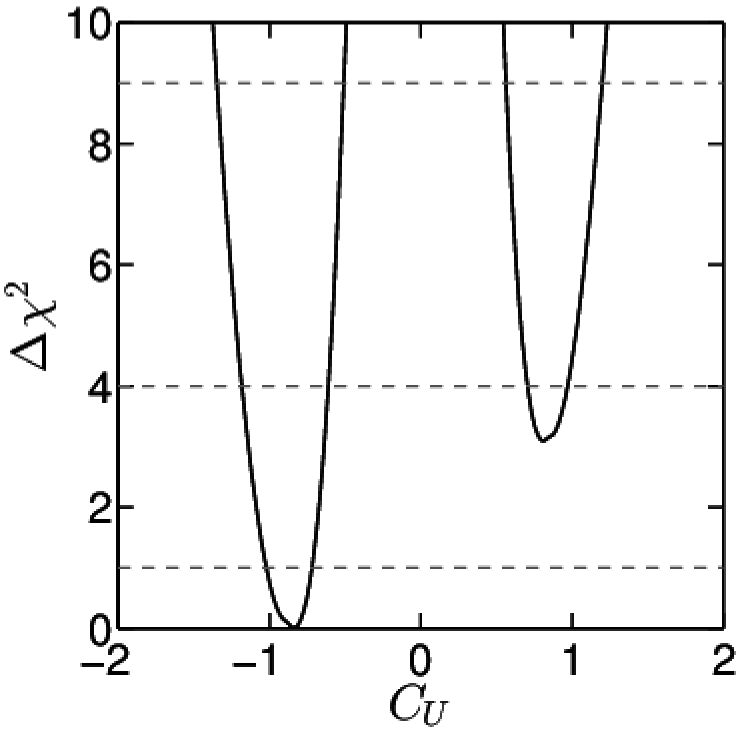
Channel	Signal strength μ	M_H (GeV)	Production mode ggF	VBF	VH	ttH
$H \to \gamma\gamma$ (5.1 fb^{-1} at 7 TeV + 5.3 fb^{-1} at 8 TeV) [2, 5, 12]						
$\mu(\text{ggF} + \text{ttH}, \gamma\gamma)$	0.95 ± 0.65	125.8	100%	–	–	–
$\mu(\text{VBF} + \text{VH}, \gamma\gamma)$	3.77 ± 1.75	125.8	–	60%	40%	–
$H \to ZZ$ (5.1 fb^{-1} at 7 TeV + 12.2 fb^{-1} at 8 TeV) [7, 12]						
Inclusive	$0.81^{+0.35}_{-0.28}$	125.8	87%	7%	5%	1%
$H \to WW$ (up to 4.9 fb^{-1} at 7 TeV + 12.1 fb^{-1} at 8 TeV) [10, 12, 52]						
0/1 jet	$0.77^{+0.27}_{-0.25}$	125.8	97%	3%	–	–
VBF tag	$-0.05^{+0.74}_{-0.55}$	125.8	17%	83%	–	–
VH tag	$-0.31^{+2.22}_{-1.94}$	125.8	–	–	100%	–
$H \to b\bar{b}$ (up to 5.0 fb^{-1} at 7 TeV + 12.1 fb^{-1} at 8 TeV) [12, 53, 54]						
VH tag	$1.31^{+0.65}_{-0.60}$	125.8	–	–	100%	–
ttH tag	$-0.80^{+2.10}_{-1.84}$	125.8	–	–	–	100%
$H \to \tau\tau$ (up to 5.0 fb^{-1} at 7 TeV + 12.1 fb^{-1} at 8 TeV) [12, 55, 56]						
0/1 jet	$0.85^{+0.68}_{-0.66}$	125.8	76%	16%	7%	1%
VBF tag	$0.82^{+0.82}_{-0.75}$	125.8	19%	81%	–	–
VH tag	$0.86^{+1.92}_{-1.68}$	125.8	–	–	100%	–

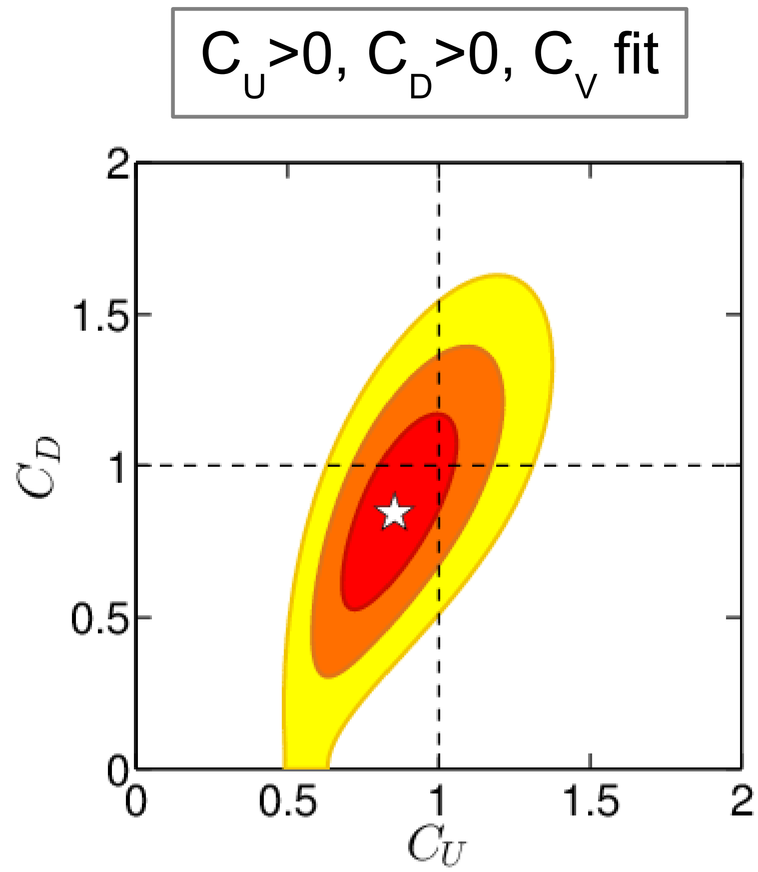


Pre-Moriond experimental data we use
Tevatron

Channel	Signal strength μ	M_H (GeV)	Production mode			
			ggF	VBF	VH	ttH
$H \to \gamma\gamma$ [59]						
Combined	$6.14^{+3.25}_{-3.19}$	125	78%	5%	17%	–
$H \to WW$ [59]						
Combined	$0.85^{+0.88}_{-0.81}$	125	78%	5%	17%	–
$H \to b\bar{b}$ [14]						
VH tag	$1.56^{+0.72}_{-0.73}$	125	–	–	100%	–

II) C_U , C_D , C_V fit





Two Higgs Doublet Model

- Model-dependent study: 2HDM type I and II
- 2 parameters (angles): α and β

	Type I and II	Type I		Type II	
Higgs	VV	up quarks	down quarks & leptons	up quarks	down quarks & leptons
h	$\sin(\beta-\alpha)$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
H	$\cos(\beta-\alpha)$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
A	0	$\cot\beta$	$-\cot\beta$	$\cot\beta$	$\tan\beta$

- in both cases we have:
  - $|C_V| < 1$
  - $|C_U| < 1.4$ if $\tan\beta > 1$

- both h and H could be the 125.5 GeV observed state

Two Higgs Doublet Model results