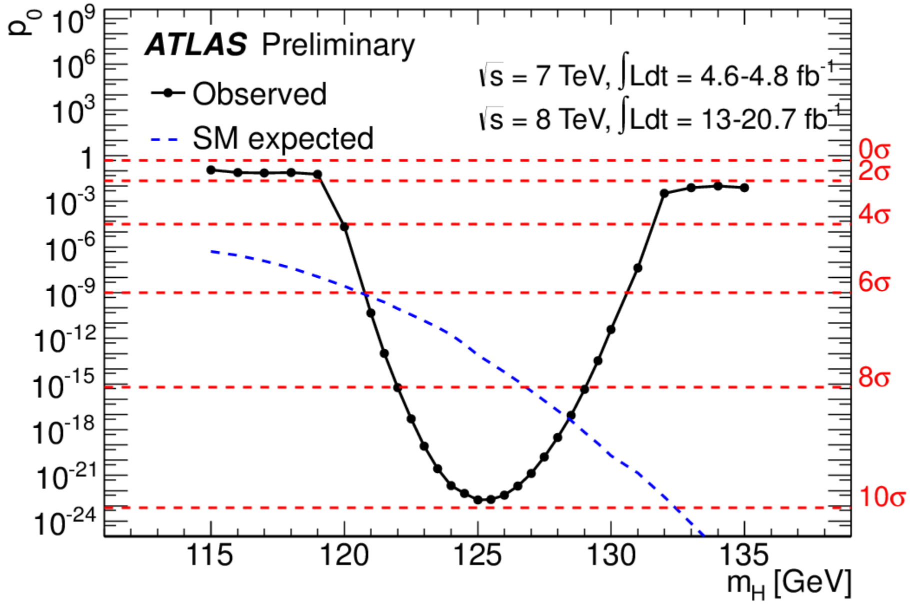
Higgs couplings after Moriond

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]
(update in preparation)

HEFTI Higgs workshop
April 22, 2013

The Higgs boson has been found

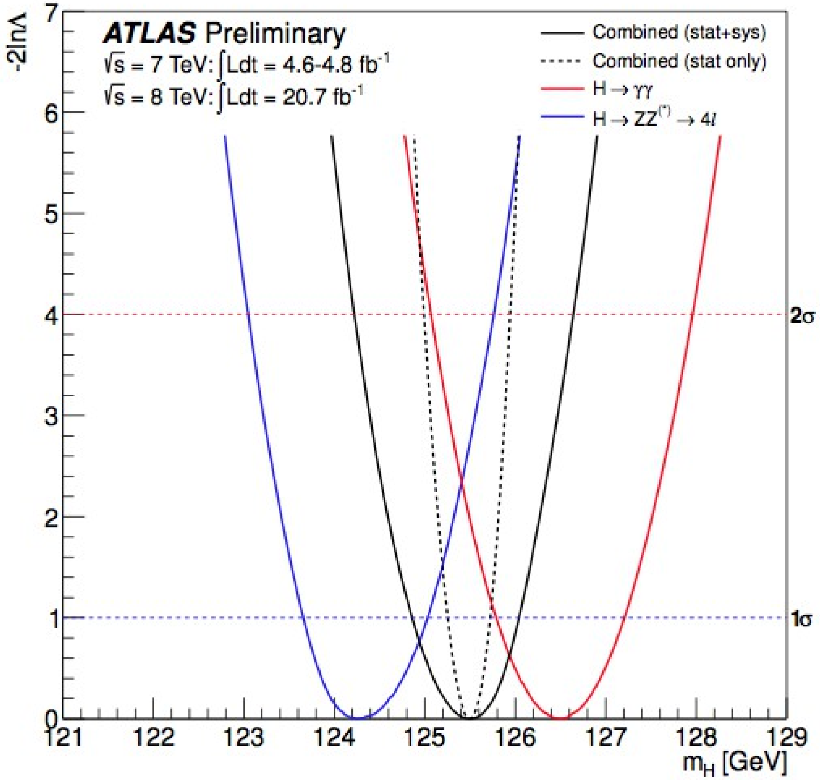


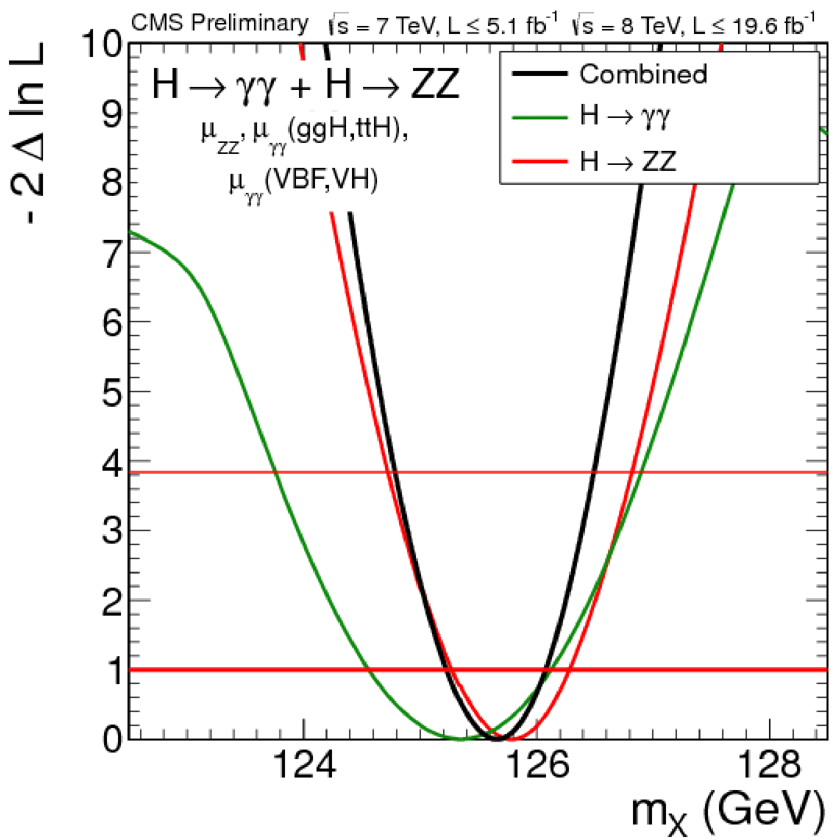
CMS preliminary

Decay mode	Expected (σ)	Observed (σ)
ZZ	7.1	6.7
$\gamma\gamma$	3.9	3.2
WW	5.3	3.9
bb	2.2	2.0
$\tau\tau$	2.6	2.8

- previous update in Moriond (in March)
  → almost all bosonic channels have been updated with full luminosity
- also, final results from Tevatron! (arXiv:1303.6346)
  very competitive for H→bb

What we know about it
its mass





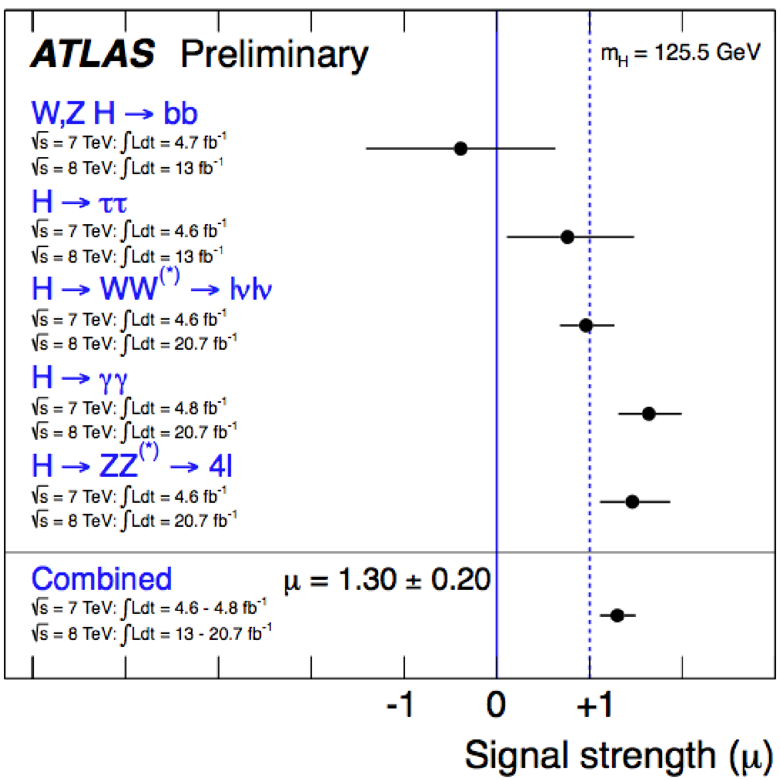
$$m_H = 125.5 \pm 0.6 \text{ GeV}$$

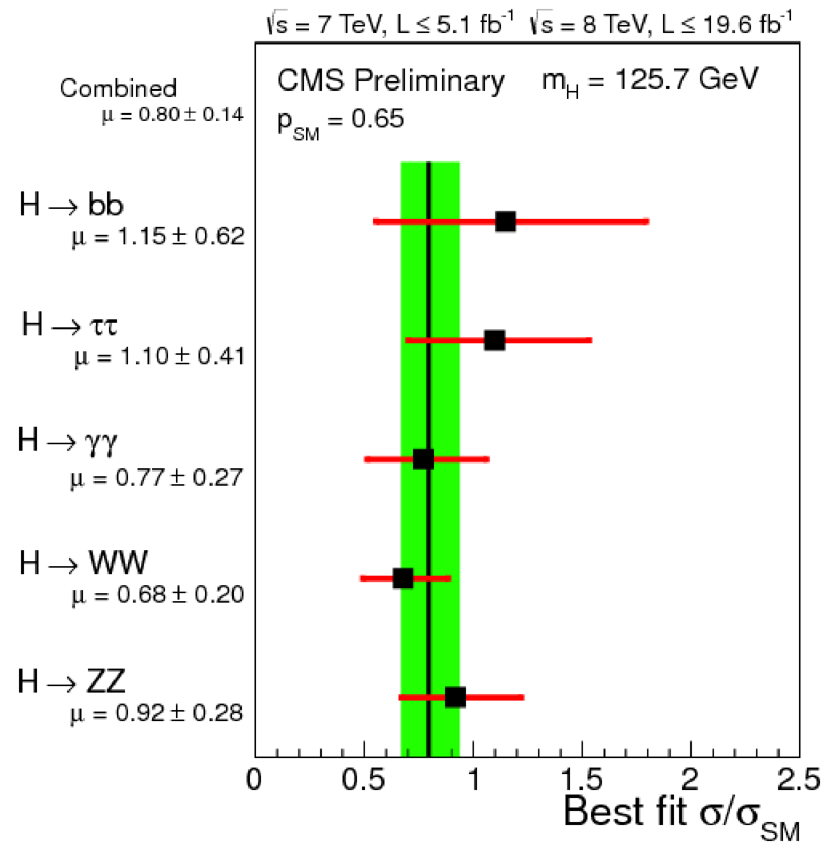
$$m_H = 125.7 \pm 0.4 \text{ GeV}$$

naive average: $m_H = 125.6 \pm 0.3 \text{ GeV}$

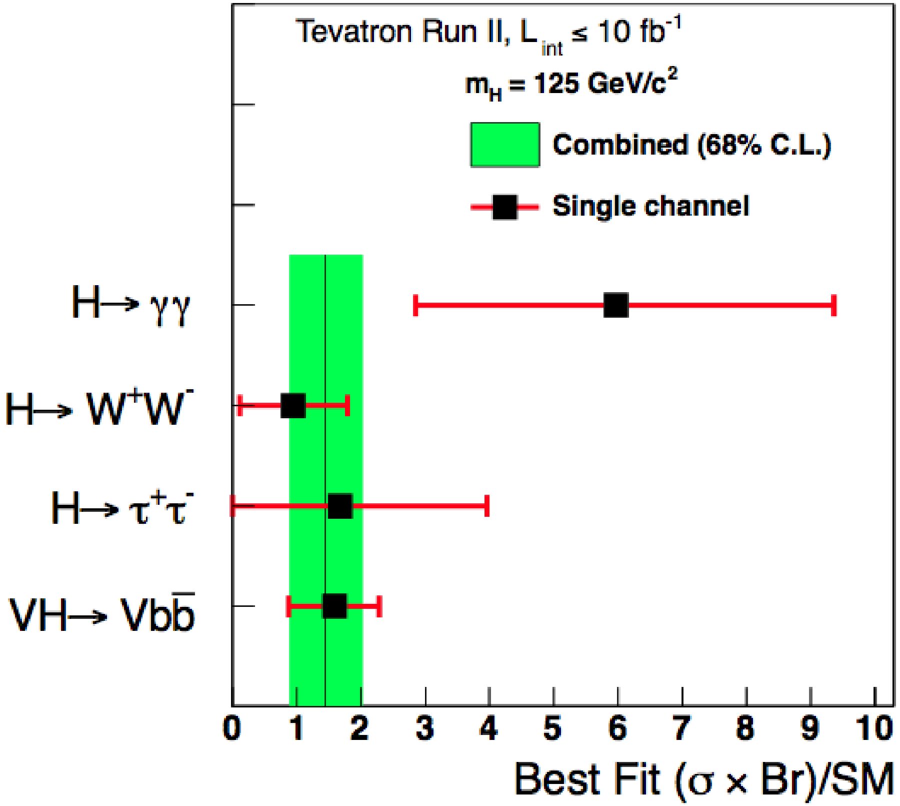
What we know about it
signal strengths

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





What we know about it
signal strengths



...but New Physics modify not only the Higgs decays but also its production

how can we use the experimental information in a correct way?

One example: ATLAS H→γγ

What do we have in the conf note? [ATLAS-CONF-2013-012]

Abstract

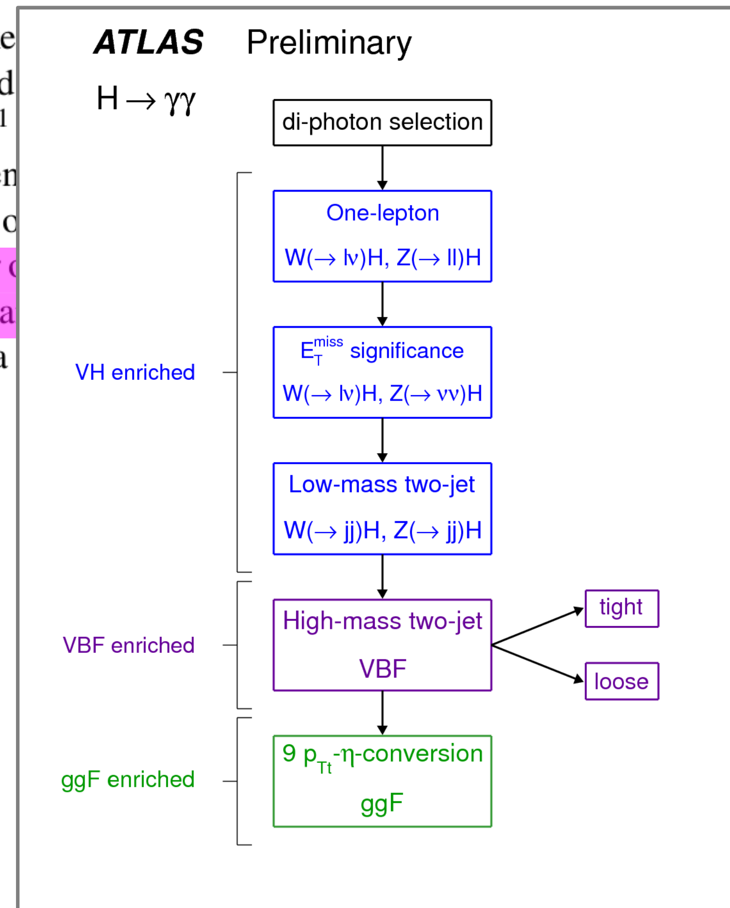
Measurements of the mass and couplings of the Higgs-like boson in the two photon decay channel with the ATLAS detector at the LHC are presented. The proton-proton collision datasets used correspond to integrated luminosities of 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV and 20.7 fb^{-1} collected at $\sqrt{s} = 8$ TeV. The updated measurements benefit from an increased data sample and an improved analysis. The measured value of the mass of the Higgs-like boson is $126.8 \pm 0.2(\text{stat}) \pm 0.7(\text{syst})$ GeV and the fitted number of signal events is found to be $1.65 \pm 0.24(\text{stat})^{+0.25}_{-0.18}(\text{syst})$ times the value predicted by the Standard Model. Measurements of the signal strengths in different production processes and a fiducial cross section for the observed particle are also presented.

One example: ATLAS H→γγ

What do we have in the conf note? [ATLAS-CONF-2013-012]

Abstract

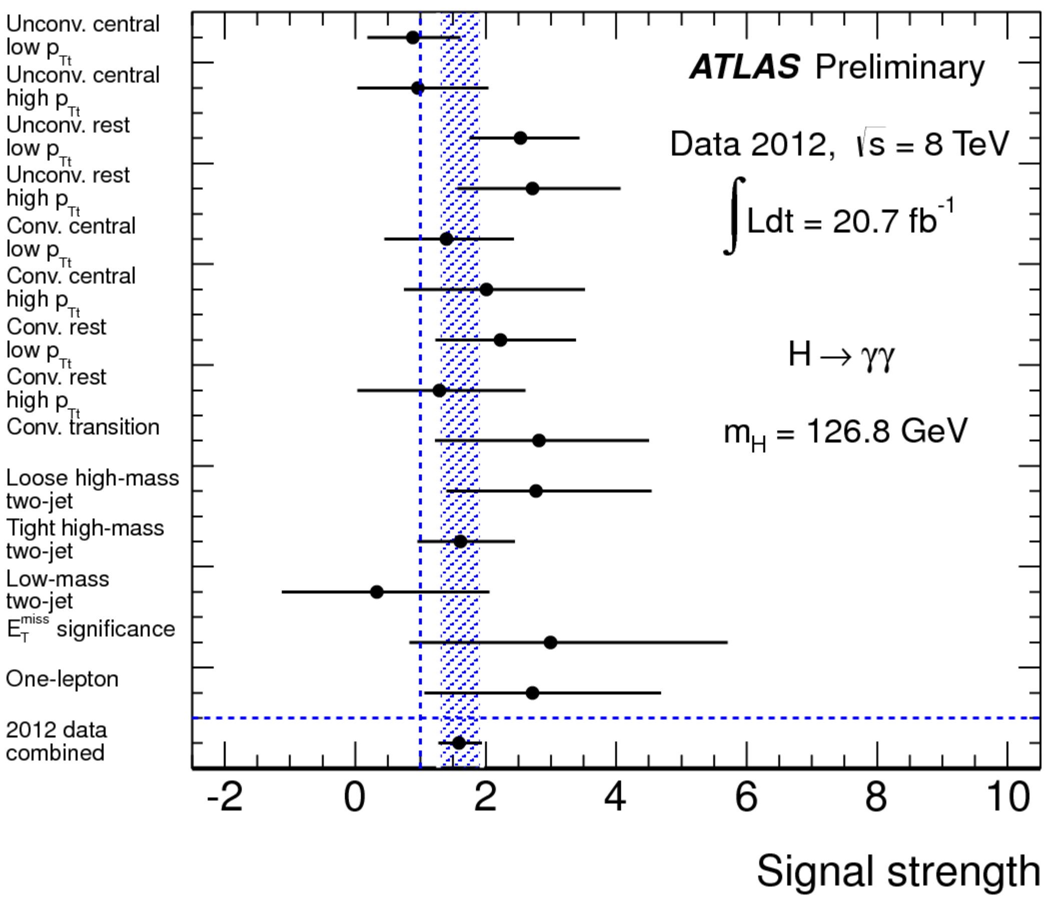
Measurements of the mass and couplings of the Higgs-like
cay channel with the ATLAS detector at the LHC are presented
datasets used correspond to integrated luminosities of 4.8 fb^{-1}
20.7 fb^{-1} collected at $\sqrt{s}$ = 8 TeV. The updated measuremen
data sample and an improved analysis. The measured value o
boson is 126.8±0.2(stat)±0.7(syst) GeV and the fitted number o
$1.65 \pm 0.24(stat)^{+0.25}_{-0.18}(syst)$ times the value predicted by the Sta
of the signal strengths in different production processes and a
observed particle are also presented.



...but this is the combination of several sub-categories with different sensitivity to the various production mechanisms

One example: ATLAS H→γγ

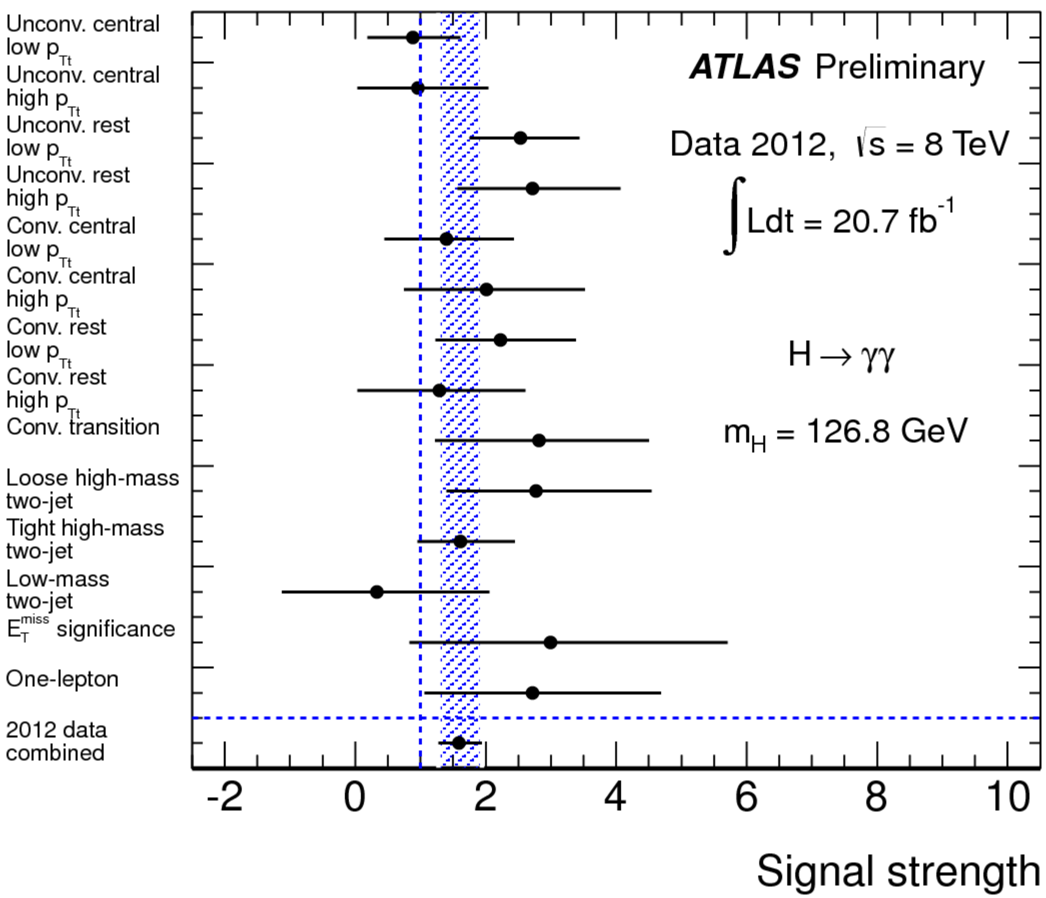
Ok, so let's have a look at the 14 sub-categories! [ATLAS-CONF-2013-012]



$\sqrt{s}$	8 TeV						
Category	N_D	N_S	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
Unconv. central, low p_{Tt}	10900	51.8	93.7	4.0	1.4	0.8	0.2
Unconv. central, high p_{Tt}	553	7.9	79.3	12.6	4.1	2.5	1.4
Unconv. rest, low p_{Tt}	41236	107.9	93.2	4.0	1.6	1.0	0.1
Unconv. rest, high p_{Tt}	2558	16.0	78.1	13.3	4.7	2.8	1.1
Conv. central, low p_{Tt}	7109	33.1	93.6	4.0	1.3	0.9	0.2
Conv. central, high p_{Tt}	363	5.1	78.9	12.6	4.3	2.7	1.5
Conv. rest, low p_{Tt}	38156	97.8	93.2	4.1	1.6	1.0	0.1
Conv. rest, high p_{Tt}	2360	14.4	77.7	13.0	5.2	3.0	1.1
Conv. transition	14864	40.1	90.7	5.5	2.2	1.3	0.2
Loose high-mass two-jet	276	5.3	45.0	54.1	0.5	0.3	0.1
Tight high-mass two-jet	136	8.1	23.8	76.0	0.1	0.1	0.0
Low-mass two-jet	210	3.3	48.1	3.0	29.7	17.2	1.9
E_T^{miss} significance	49	1.3	4.1	0.5	35.7	47.6	12.1
One-lepton	123	2.9	2.2	0.6	63.2	15.4	18.6
All categories (inclusive)	118893	395.0	88.0	7.3	2.7	1.5	0.5

One example: ATLAS H→γγ

Ok, so let's have a look at the 14 sub-categories! [ATLAS-CONF-2013-012]



$\sqrt{s}$	8 TeV						
Category	N_D	N_S	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]
Unconv. central, low p_{Tt}	10900	51.8	93.7	4.0	1.4	0.8	0.2
Unconv. central, high p_{Tt}	553	7.9	79.3	12.6	4.1	2.5	1.4
Unconv. rest, low p_{Tt}	41236	107.9	93.2	4.0	1.6	1.0	0.1
Unconv. rest, high p_{Tt}	2558	16.0	78.1	13.3	4.7	2.8	1.1
Conv. central, low p_{Tt}	7109	33.1	93.6	4.0	1.3	0.9	0.2
Conv. central, high p_{Tt}	363	5.1	78.9	12.6	4.3	2.7	1.5
Conv. rest, low p_{Tt}	38156	97.8	93.2	4.1	1.6	1.0	0.1
Conv. rest, high p_{Tt}	2360	14.4	77.7	13.0	5.2	3.0	1.1
Conv. transition	14864	40.1	90.7	5.5	2.2	1.3	0.2
Loose high-mass two-jet	276	5.3	45.0	54.1	0.5	0.3	0.1
Tight high-mass two-jet	136	8.1	23.8	76.0	0.1	0.1	0.0
Low-mass two-jet	210	3.3	48.1	3.0	29.7	17.2	1.9
E_T^{miss} significance	49	1.3	4.1	0.5	35.7	47.6	12.1
One-lepton	123	2.9	2.2	0.6	63.2	15.4	18.6
All categories (inclusive)	118893	395.0	88.0	7.3	2.7	1.5	0.5

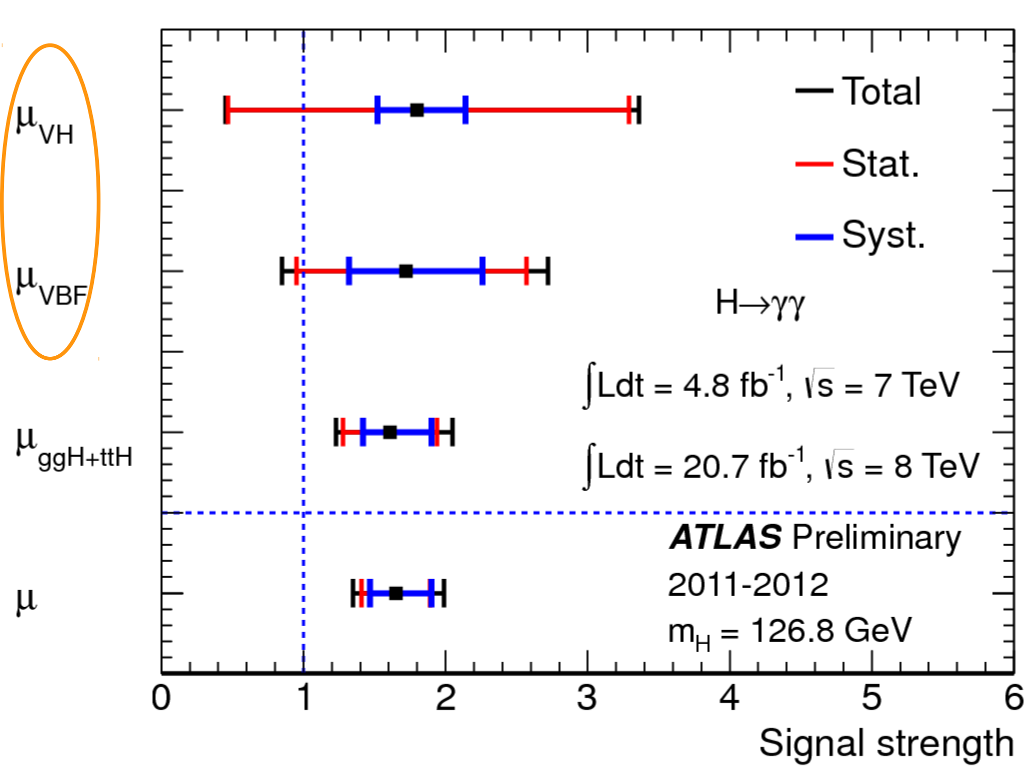
…but what about the correlations between sub-channels? (not given by the experiments)

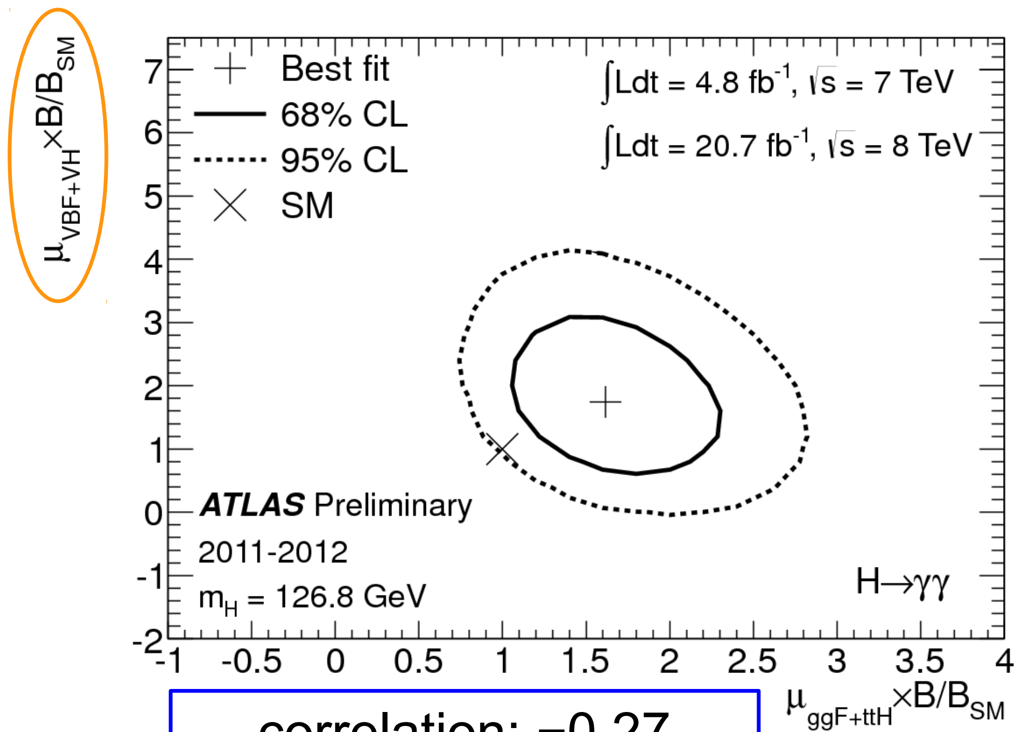
can we safely neglect them? probably not...

One example: ATLAS H→γγ

Hmm... is there anything else in this conf note? [ATLAS-CONF-2013-012]

In a second step, signal strength parameters for different Higgs boson production modes are introduced to characterise their contributions to the observed excess. To further enhance the sensitivity, the

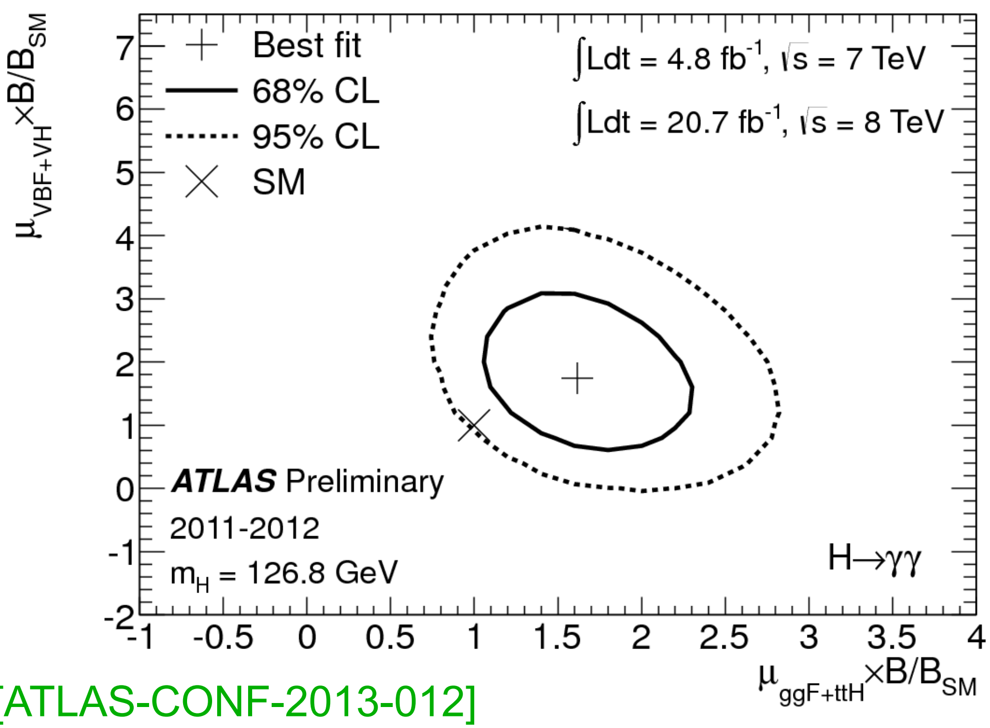




correlation: −0.27
(−0.48 in CMS H→γγ)

One example: ATLAS $H\to\gamma\gamma$

- grouping VBF and VH=(WH,ZH): usually OK (custodial symmetry)
- grouping ggF and ttH: OK for now (ttH is not precisely probed yet)



[ATLAS-CONF-2013-012]

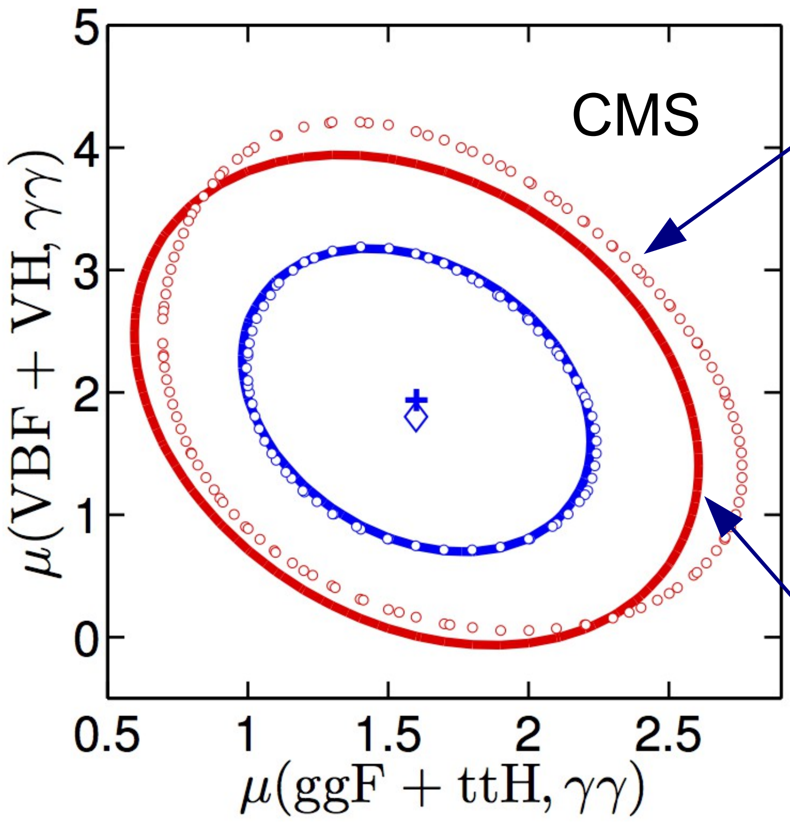
but we only have contours...

simplest option: fit Gaussian measurements from one contour

is it a good approximation?

One example: ATLAS H→γγ

- grouping VBF and VH=(WH,ZH): usually OK (custodial symmetry)
- grouping ggF and ttH: OK for now (ttH is not precisely probed yet)



experimental 95% CL contour

but we only have contours...

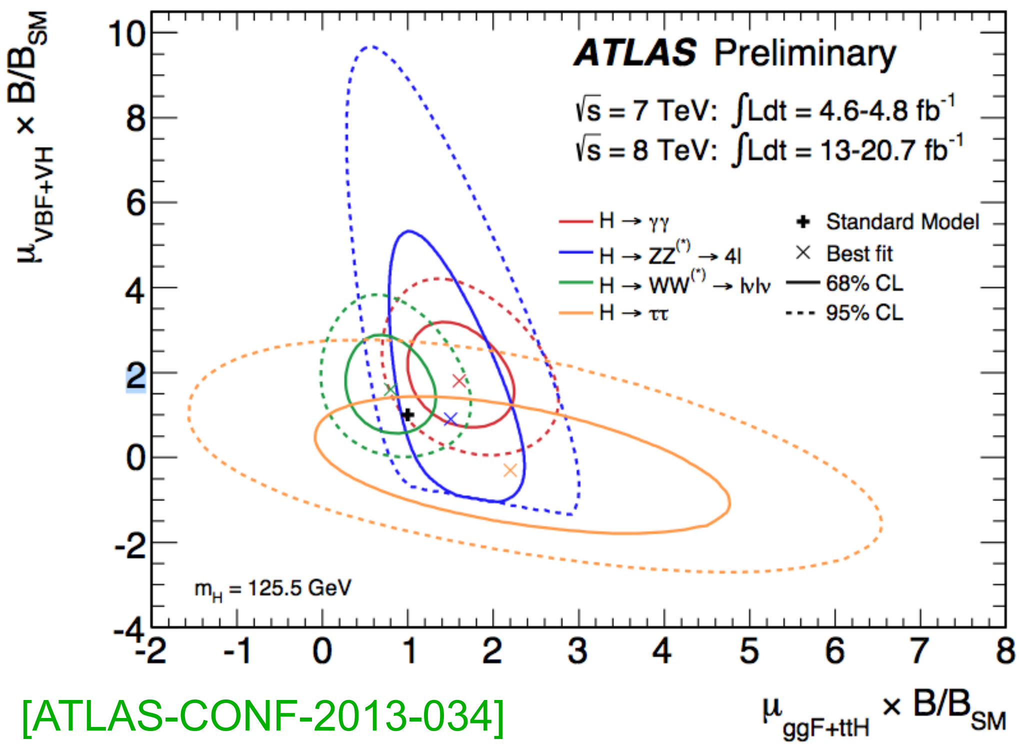
simplest option: fit Gaussian measurements from one contour

is it a good approximation?
✓ seems fairly good

extrapolated 95% CL contour

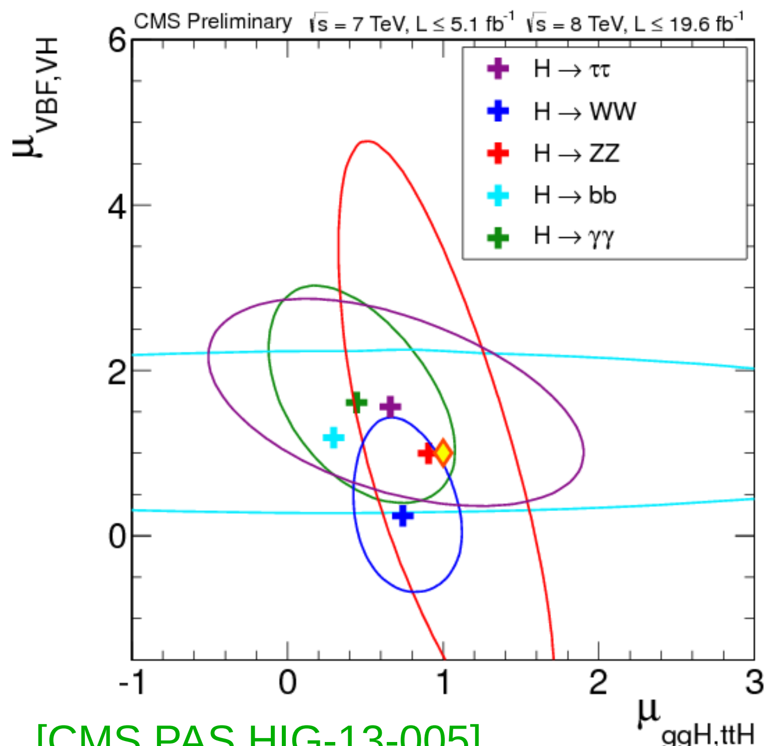
2D μ plots from ATLAS and CMS

ATLAS



[ATLAS-CONF-2013-034]

CMS



[CMS PAS HIG-13-005]

whenever possible, we check the validity of the Gaussian approximation
→ usually fairly good (see backup slides!)

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 + 20.7 fb^{-1} at 8 TeV) [1, 2]						
$\mu(\text{ggF}+\text{ttH},\gamma\gamma)$	1.60 ± 0.41	125.5	100%	–	–	–
$\mu(\text{VBF}+\text{VH},\gamma\gamma)$	1.94 ± 0.82	125.5	–	60%	40%	–
$H \to ZZ$ (4.6 fb^{-1} at 7 TeV + 20.7 fb^{-1} at 8 TeV) [3, 2]						
$\mu(\text{ggF}+\text{ttH},ZZ)$	1.50 ± 0.50	125.5	100%	–	–	–
$\mu(\text{VBF}+\text{VH},ZZ)$	1.50 ± 2.52	125.5	–	60%	40%	–
$H \to WW$ (4.6 fb^{-1} at 7 TeV + 20.7 fb^{-1} at 8 TeV) [4, 5]						
$\mu(\text{ggF}+\text{ttH},WW)$	0.79 ± 0.35	125.5	100%	–	–	–
$\mu(\text{VBF}+\text{VH},WW)$	1.71 ± 0.76	125.5	–	60%	40%	–
$H \to b\bar{b}$ (4.7 fb^{-1} at 7 TeV + 13.0 fb^{-1} at 8 TeV) [6, 2]						
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) [2]						
$\mu(\text{ggF}+\text{ttH},\tau\tau)$	2.31 ± 1.61	125.5	100%	–	–	–
$\mu(\text{VBF}+\text{VH},\tau\tau)$	-0.20 ± 1.06	125.5	–	60%	40%	–

Table 1: ATLAS results, as employed in this analysis. The following correlations are included in the fit: $\rho_{\gamma\gamma} = -0.27$, $\rho_{ZZ} = -0.46$, $\rho_{WW} = -0.18$, $\rho_{\tau\tau} = -0.49$.

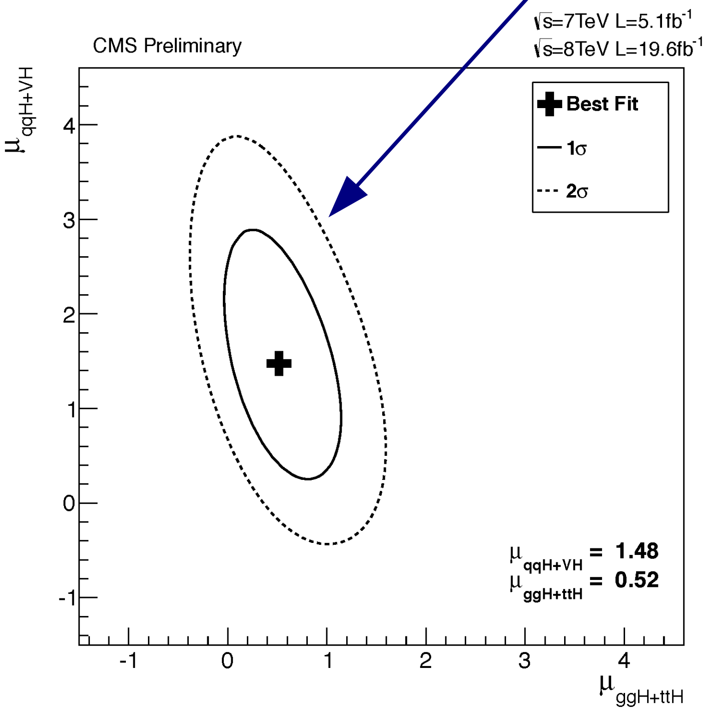
Experimental data we use CMS

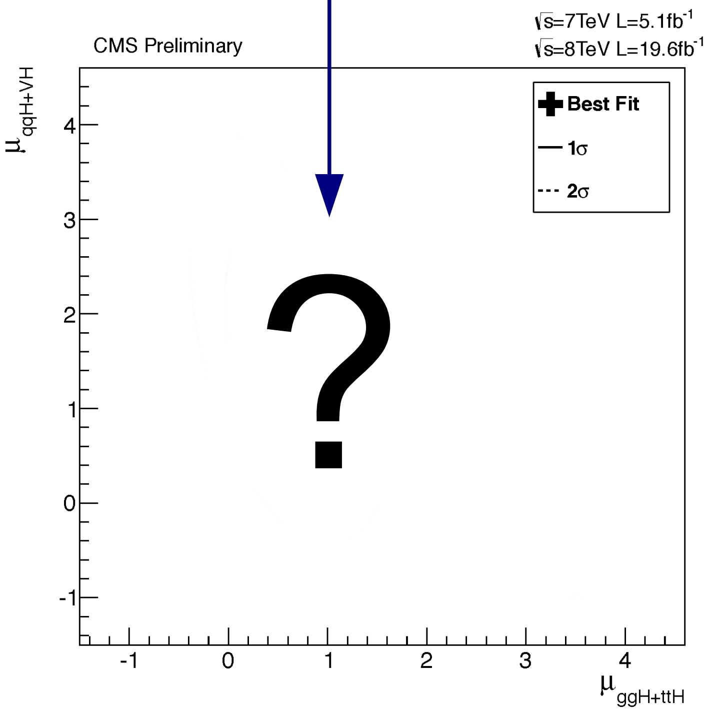
Channel	Signal strength μ	m_H (GeV)	Production mode			
			ggF	VBF	VH	ttH
$H \to \gamma\gamma$ (5.1 fb^{-1} at 7 TeV + 19.6 fb^{-1} at 8 TeV) [7, 8]						
$\mu(\text{ggF} + \text{ttH}, \gamma\gamma)$	0.46 ± 0.40	125.7	100%	–	–	–
$\mu(\text{VBF} + \text{VH}, \gamma\gamma)$	1.68 ± 0.87	125.7	–	60%	40%	–
$H \to ZZ$ (5.1 fb^{-1} at 7 TeV + 19.6 fb^{-1} at 8 TeV) [9]						
$\mu(\text{ggF} + \text{ttH}, ZZ)$	0.98 ± 0.46	125.8	100%	–	–	–
$\mu(\text{VBF} + \text{VH}, ZZ)$	1.07 ± 2.37	125.8	–	60%	40%	–
$H \to WW$ (up to 4.9 fb^{-1} at 7 TeV + 19.5 fb^{-1} at 8 TeV) [10, 11, 12, 8]						
$\mu(\text{ggF} + \text{ttH}, WW)$	0.78 ± 0.23	125.7	100%	–	–	–
$\mu(\text{VBF} + \text{VH}, WW)$	0.33 ± 0.70	125.7	–	60%	40%	–
$H \to b\bar{b}$ (up to 5.0 fb^{-1} at 7 TeV + 12.1 fb^{-1} at 8 TeV) [13, 14, 8]						
VH tag	$1.31^{+0.68}_{-0.61}$	125.7	–	–	100%	–
ttH tag	$-0.15^{+2.82}_{-2.90}$	125.7	–	–	–	100%
$H \to \tau\tau$ (4.9 fb^{-1} at 7 TeV + 19.4 fb^{-1} at 8 TeV) [15, 8]						
$\mu(\text{ggF} + \text{ttH}, \tau\tau)$	0.67 ± 0.79	125.7	100%	–	–	–
$\mu(\text{VBF} + \text{VH}, \tau\tau)$	1.59 ± 0.83	125.7	–	60%	40%	–

Table 2: CMS results, as employed in this analysis. The following correlations are included in the fit: $\rho_{\gamma\gamma} = -0.48$, $\rho_{ZZ} = -0.73$, $\rho_{WW} = -0.21$, $\rho_{\tau\tau} = -0.47$.

A word on CMS H→γγ

	MVA analysis (at m_H=125 GeV)	cut-based analysis (at m_H=124.5 GeV)
7 TeV	$1.69^{+0.65}_{-0.59}$	$2.27^{+0.80}_{-0.74}$
8 TeV	$0.55^{+0.29}_{-0.27}$	$0.93^{+0.34}_{-0.32}$
7 + 8 TeV	$0.78^{+0.28}_{-0.26}$	$1.11^{+0.32}_{-0.30}$





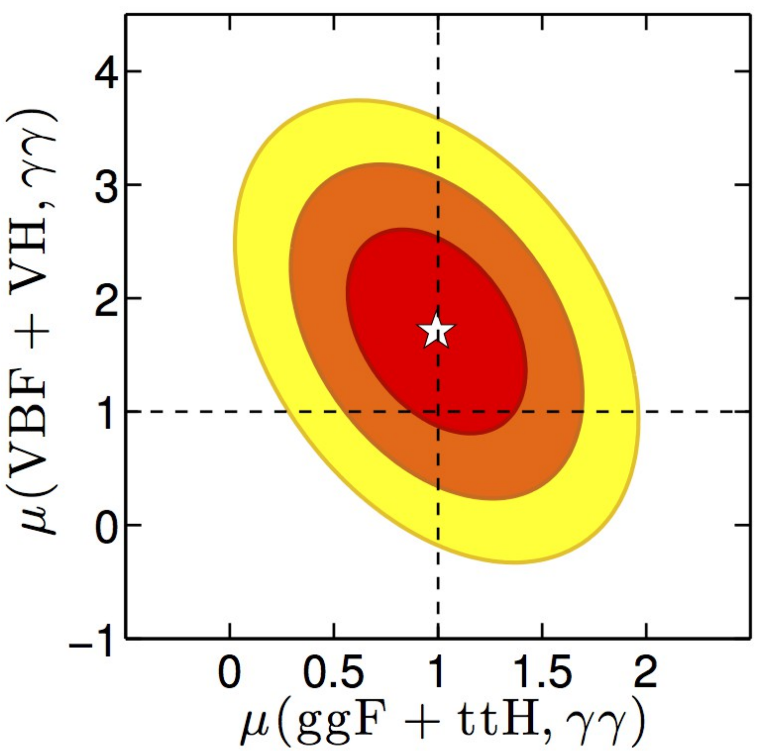
Experimental data we use
Tevatron

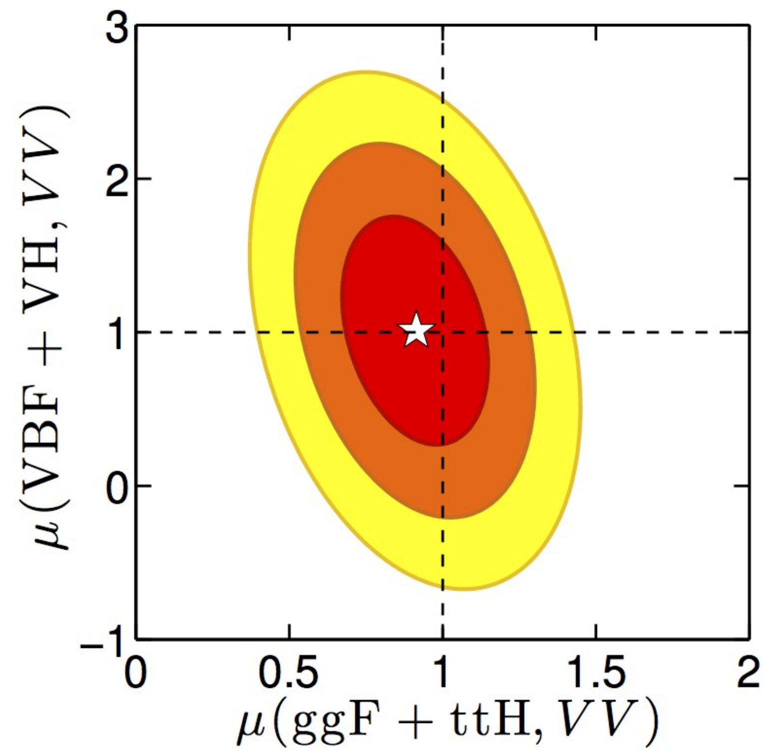
Channel	Signal strength μ	m_H (GeV)	Production mode			
			ggF	VBF	VH	ttH
$H \to \gamma\gamma$ [17]						
Combined	$5.97^{+3.39}_{-3.12}$	125	78%	5%	17%	–
$H \to WW$ [17]						
Combined	$0.94^{+0.85}_{-0.83}$	125	78%	5%	17%	–
$H \to b\bar{b}$ [17]						
VH tag	$1.59^{+0.69}_{-0.72}$	125	–	–	100%	–

Table 3: Tevatron results for up to 10 fb^{-1} at $\sqrt{s} = 1.96$ TeV, as employed in this analysis.

- Tevatron H→ττ is omitted (large uncertainties)
- H→γγ and H→WW are approximated as inclusive searches (ratio of inclusive cross sections for p$\bar{\text{p}}$ collisions at 2 TeV)

Combined 2D μ plots bosonic channels

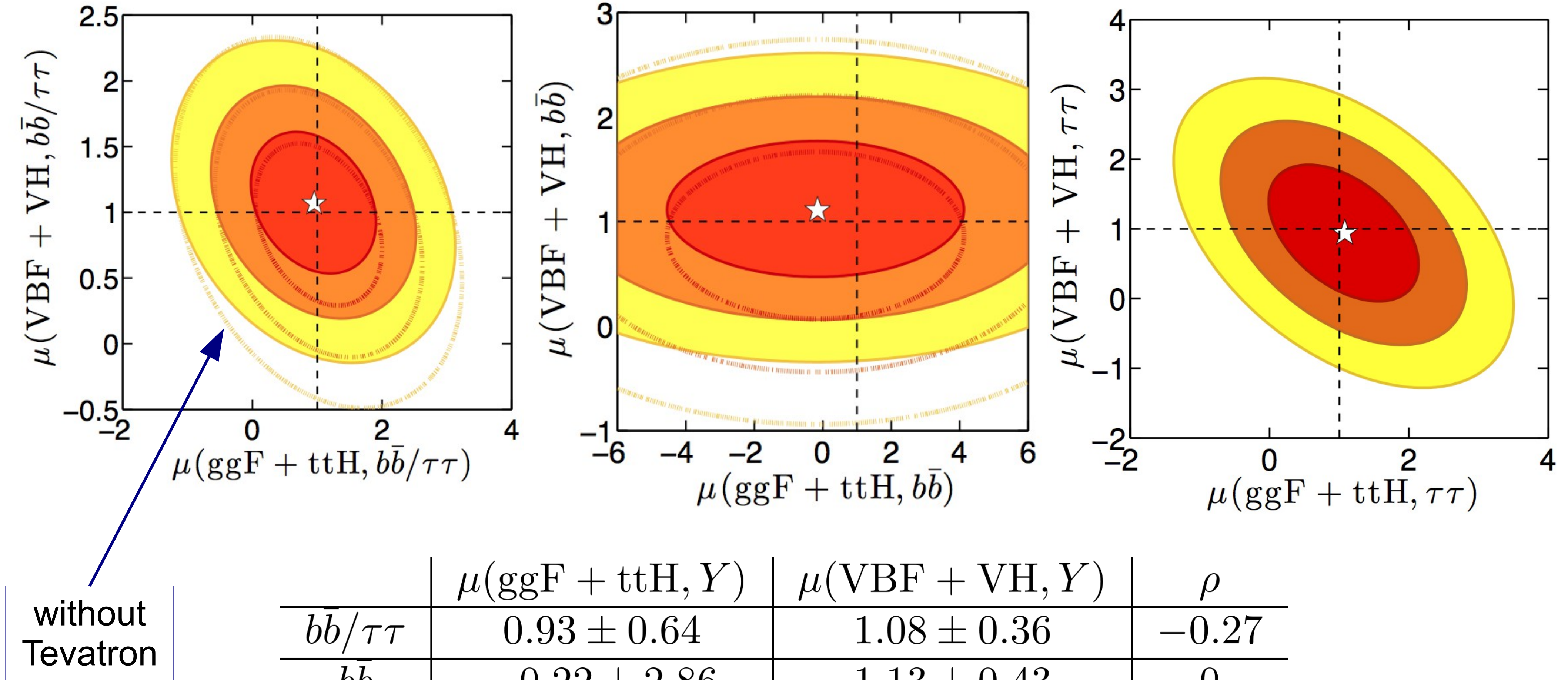




	$\mu(\mathrm{ggF} + \mathrm{ttH}, Y)$	$\mu(\mathrm{VBF} + \mathrm{VH}, Y)$	ρ
$\gamma\gamma$	0.99 ± 0.28	1.71 ± 0.59	-0.38
VV	0.91 ± 0.16	1.01 ± 0.49	-0.30

identical with or without Tevatron!

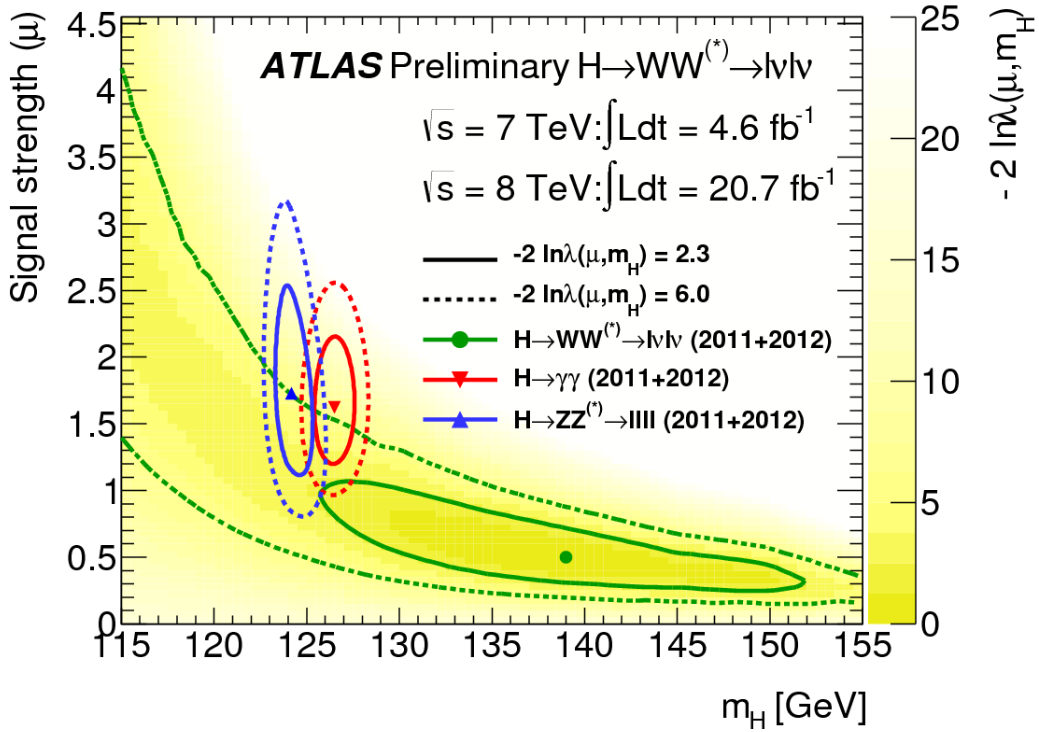
Combined 2D μ plots fermionic channels

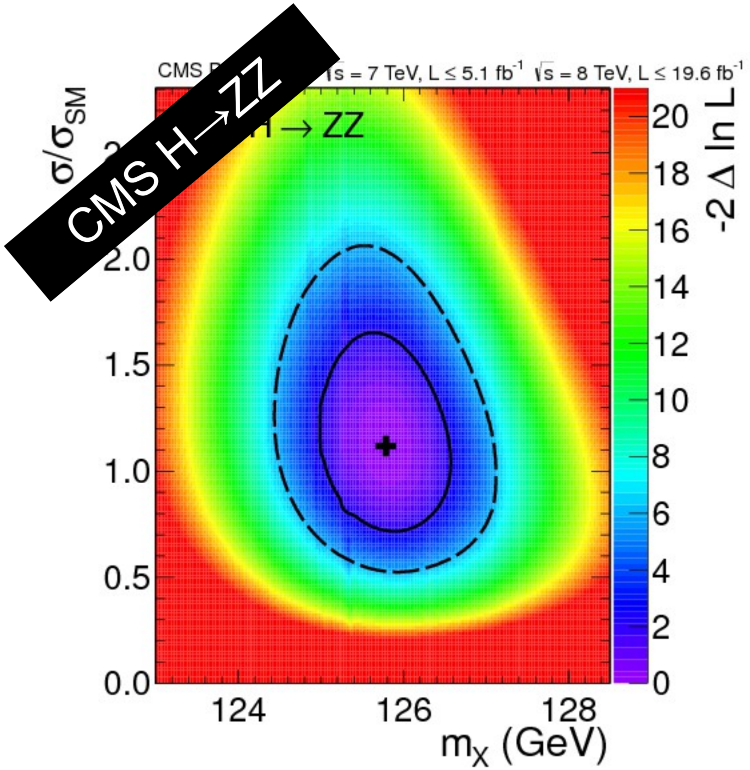


	$\mu(\mathrm{ggF+ttH}, Y)$	$\mu(\mathrm{VBF+VH}, Y)$	ρ
$b\bar{b}/\tau\tau$	0.93 ± 0.64	1.08 ± 0.36	-0.27
$b\bar{b}$	-0.22 ± 2.86	1.13 ± 0.43	0
$\tau\tau$	1.07 ± 0.71	0.94 ± 0.65	-0.47

Dependence on m_H

- we would like to treat the Higgs mass as a nuisance parameter
- a priori important for the two high resolution channels ($H \to ZZ$ and $H \to \gamma\gamma$)





- unfortunately impossible to use together with the 2D μ information

Higgs couplings

How can we use this information to constrain the couplings of the 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

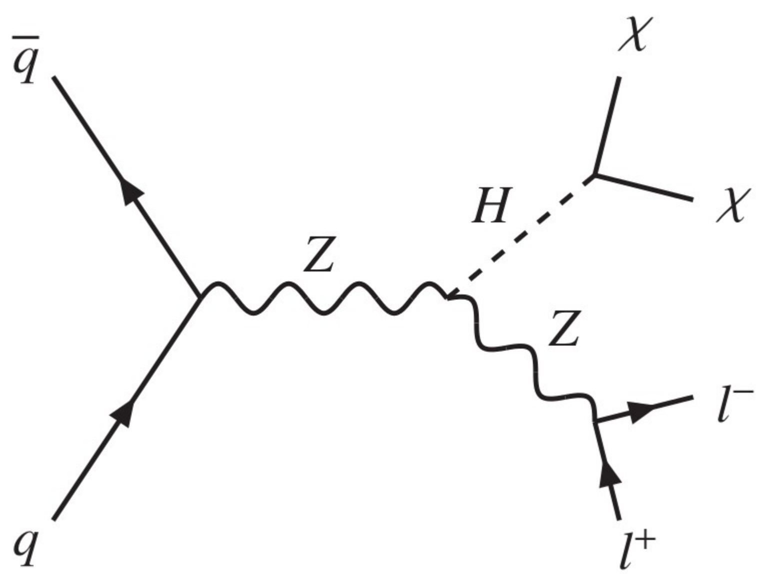
- We calculate $\overline{C}_g$ (for gluon-gluon fusion) and $\overline{C}_\gamma$ (for $H\rightarrow\gamma\gamma$) from C_U, C_D, C_V and we allow for additional particles in the loop: ΔC_g and ΔC_γ
$\rightarrow C_g = \overline{C}_g + \Delta C_g$ and $C_\gamma = \overline{C}_\gamma + \Delta C_\gamma$

- Total Higgs width: not accessible at the LHC. 2 possibilities:
1) assume that BR($H\rightarrow$invisible/undetected) = 0
2) allow for $H\rightarrow$invisible/undetected

Searches for invisible decays of the Higgs boson

ATLAS

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



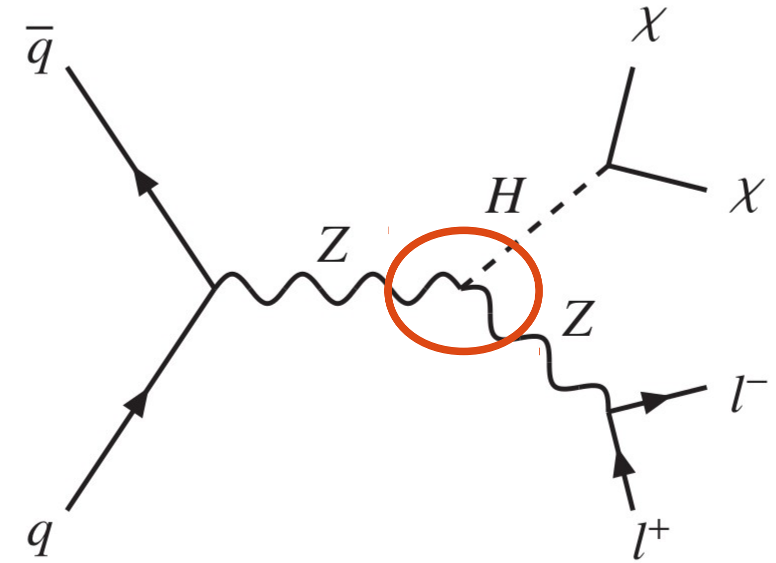
[ATLAS-CONF-2013-011]

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

Searches for invisible decays of the Higgs boson

ATLAS

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



[ATLAS-CONF-2013-011]

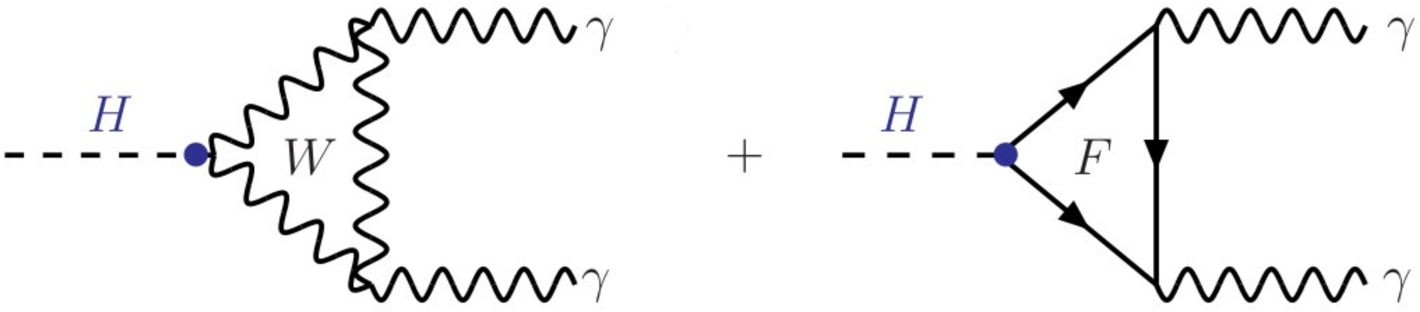
$$C_V^2\, \mathcal{B}(H \to \text{inv.}) < 0.65 \text{ at } 95\% \text{ CL}$$

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

Fitting procedure

- simple χ^2 fit: $\chi^2 = \sum_k \frac{(\mu_k - \mu_k^{\text{exp}})^2}{\Delta\mu_k^2}$
- ATLAS 95% CL limit on BR(H→invisible) implemented as a hard cut
- μ_k: rescaling of the SM prediction (given by the LHC Higgs XS WG)
- when showing contours of $\Delta\chi^2$:
  we profile the likelihood over the unseen parameters

A word on H→γγ

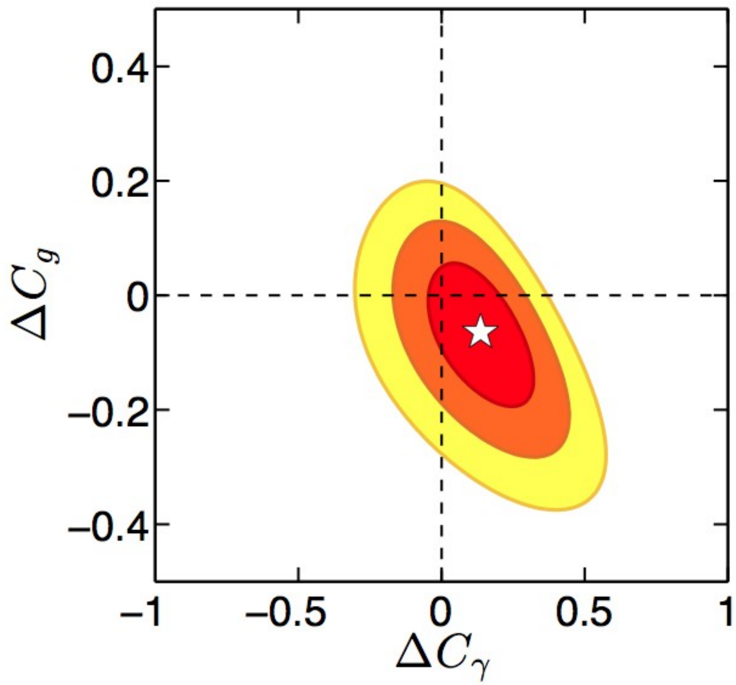


- contribution from the W is 5 times larger than from the top quark and with opposite sign
- small contributions from bottom and lighter quarks
- new particles in the loop could change the Hγγ rate (e.g. charged Higgses, charginos, staus, ...)

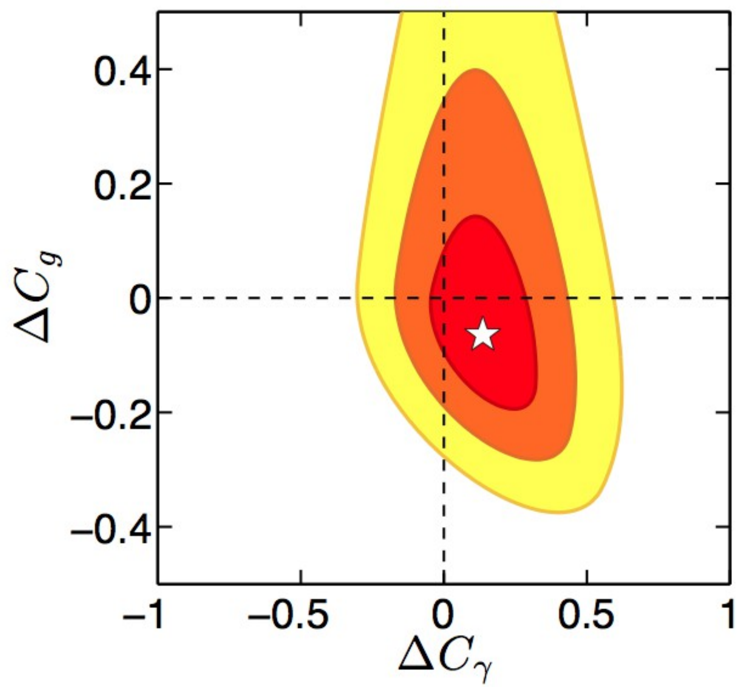
I) ΔC_g , ΔC_γ fit

- 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, ...

BR(H→invisible/undetected) = 0



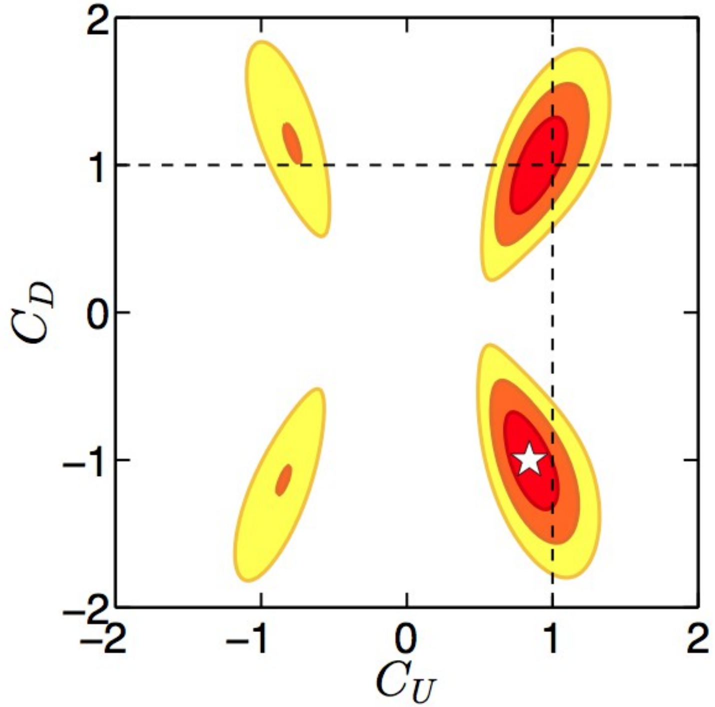
BR(H→invisible/undetected) free



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^+)

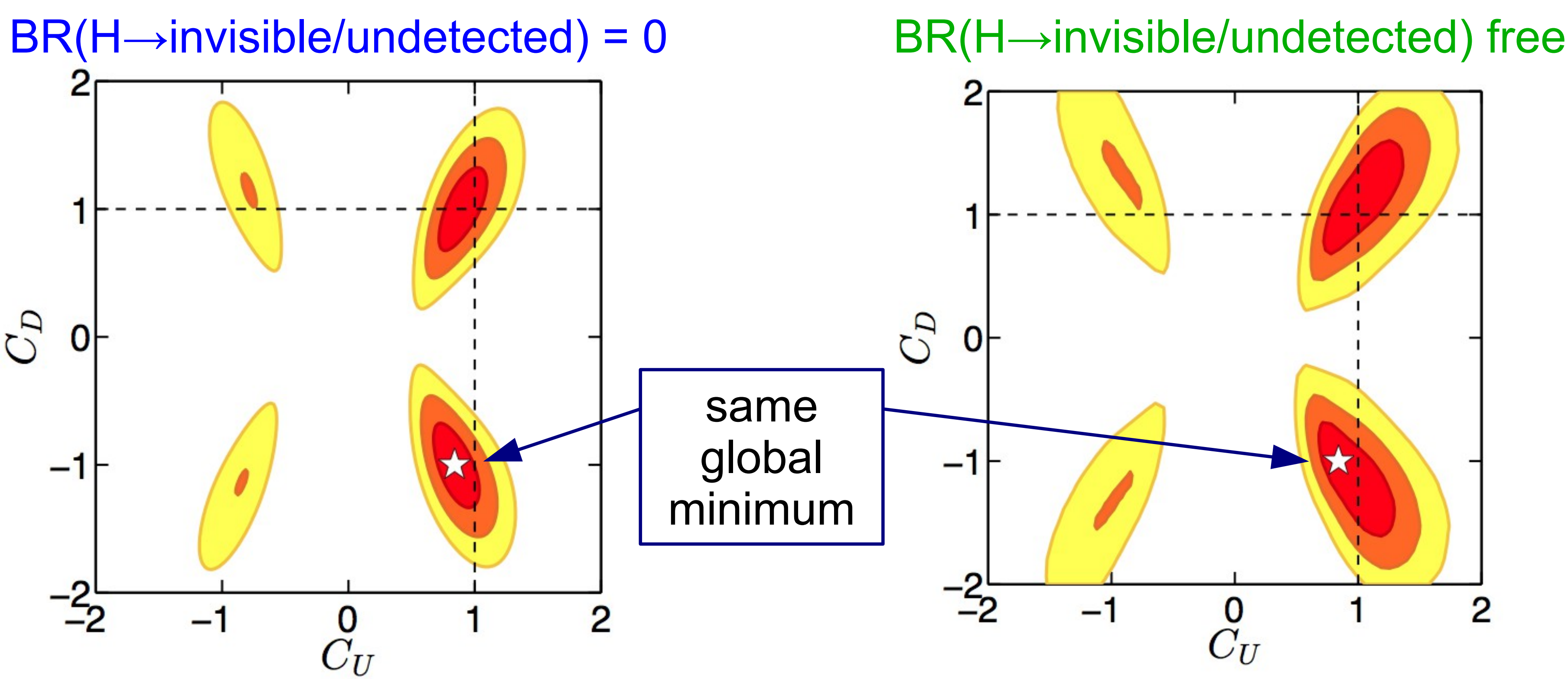
BR(H→invisible/undetected) = 0



- $C_U < 0$ (sign opposite to C_V): constructive interference with W disfavored at the level of 2.4σ
- minimum with $C_D > 0$ and $C_D < 0$ are practically equivalent

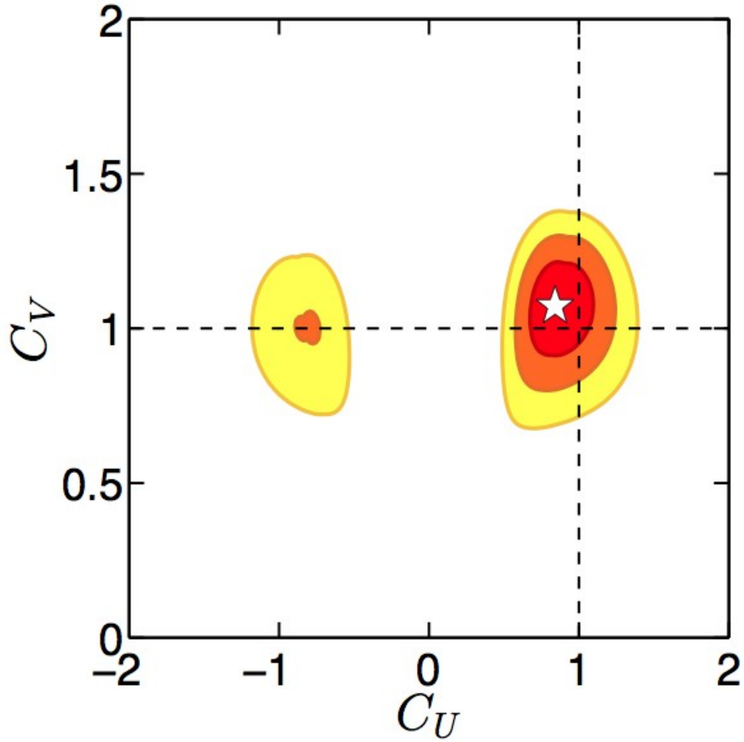
II) C_U , C_D , C_V fit

- 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^+)



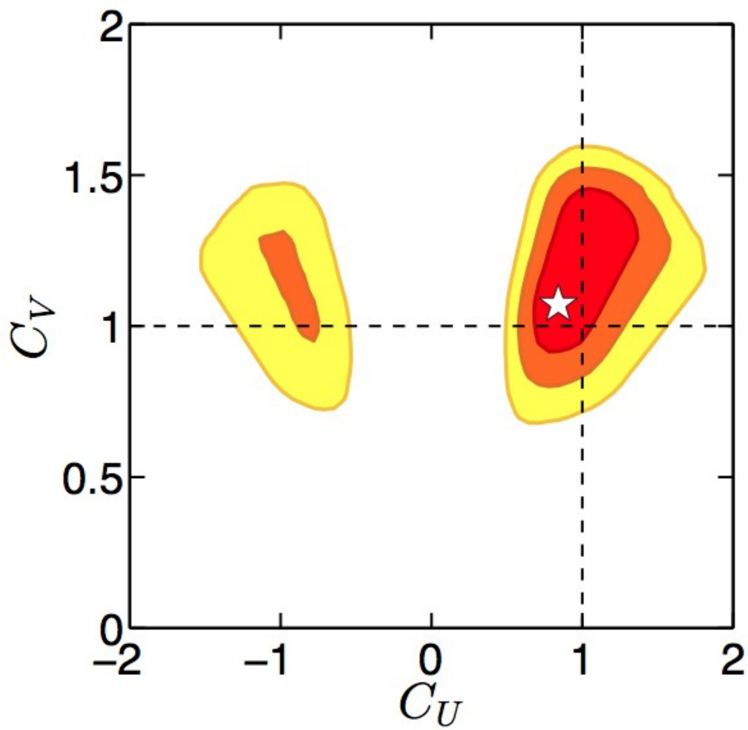
II) C_U , C_D , C_V fit

BR(H→invisible/undetected) = 0



- C_V tend to be larger for $C_U > 0$

BR(H→invisible/undetected) free

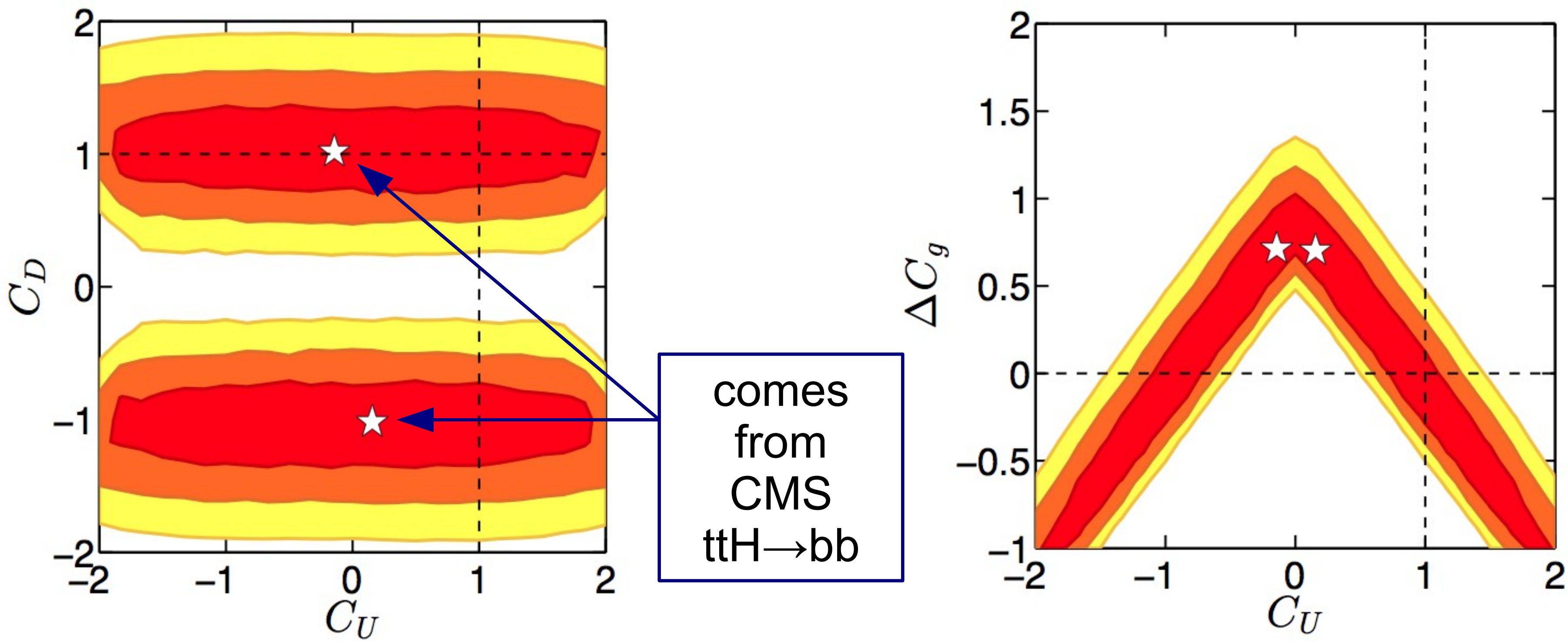


- common increase of C_U , C_D and C_V

Single top production in association with a Higgs boson could help discriminate between $C_U > 0$ 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

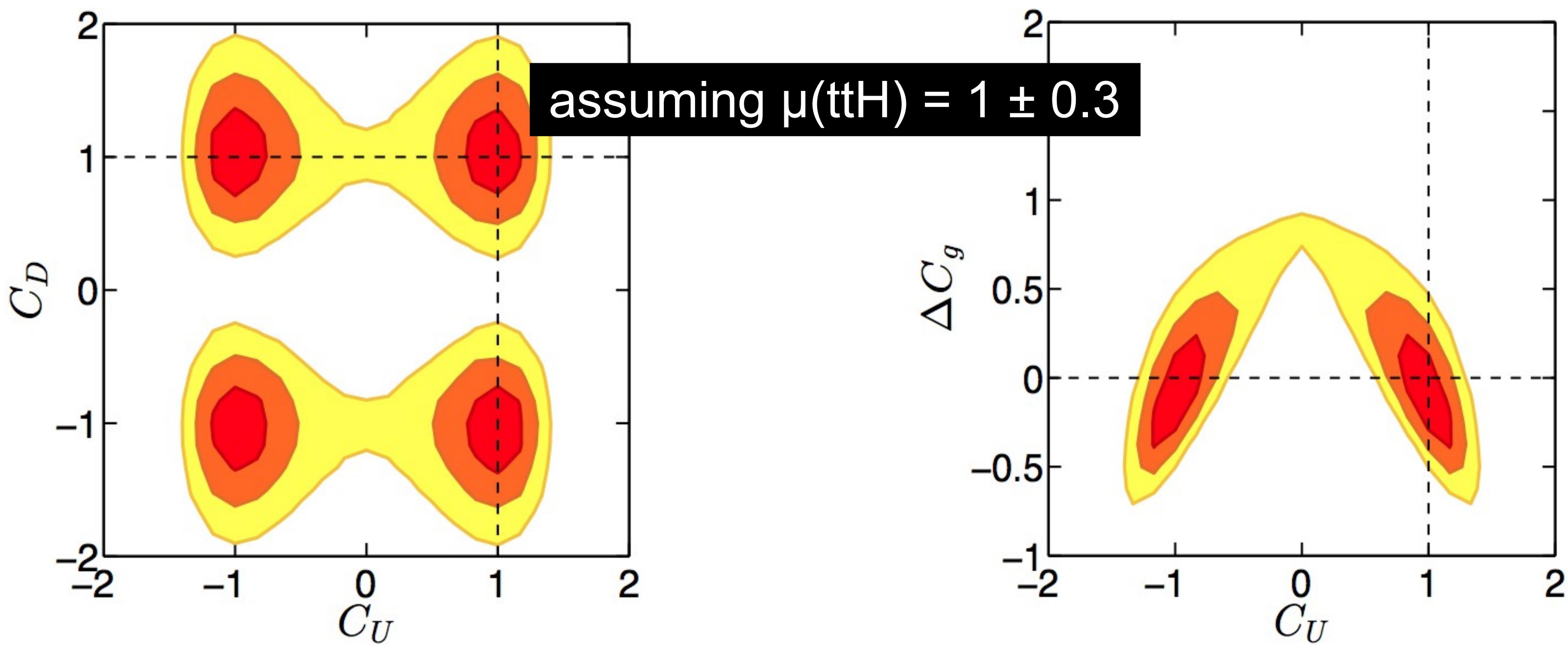
- general case: C_U, C_D, C_V, ΔC_g and ΔC_γ are free to vary (but no invisible)
- encompasses a very broad class of models



- determination of C_D is robust
- anticorrelation between C_U and ΔC_g

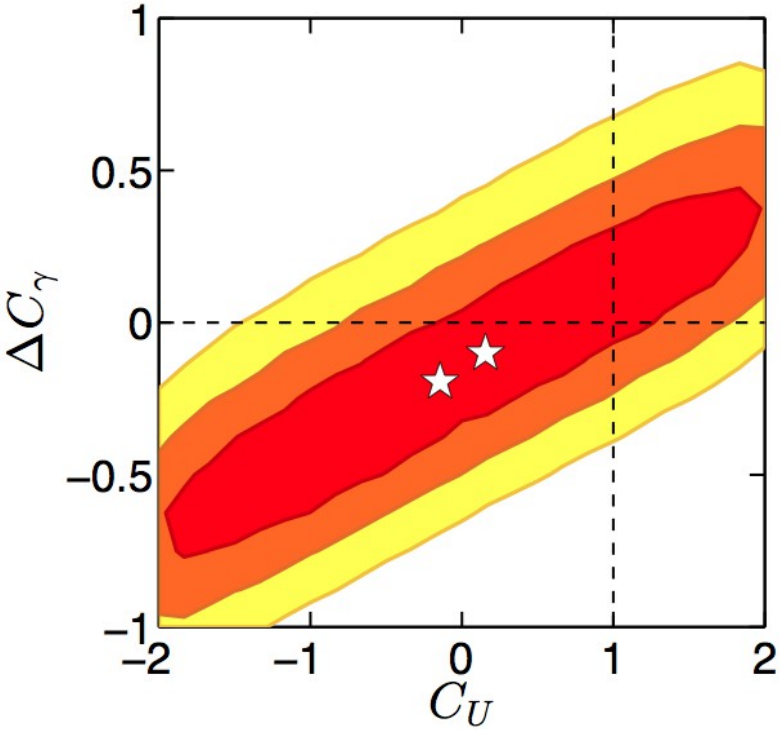
III) C_U , C_D , C_V , ΔC_g , ΔC_γ fit

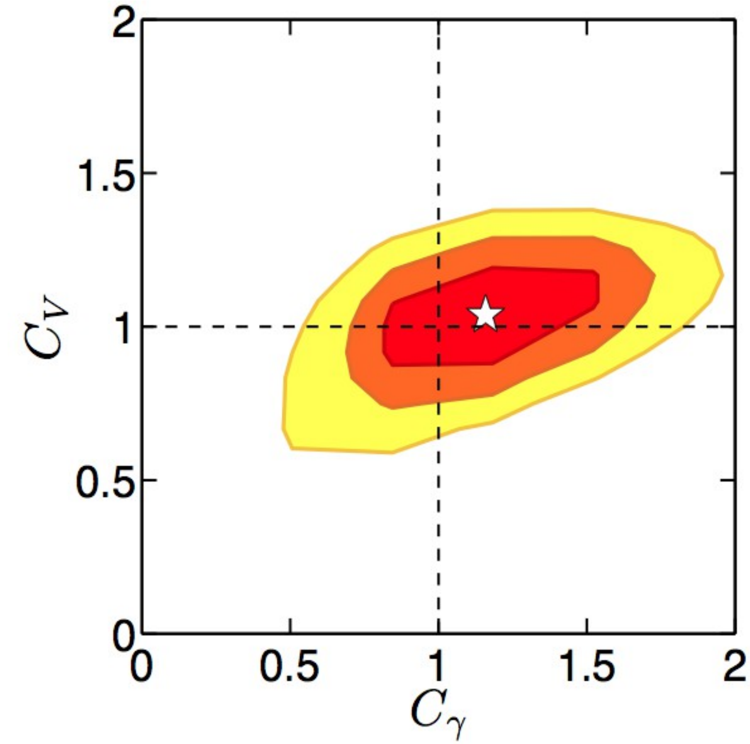
- general case: C_U, C_D, C_V, ΔC_g and ΔC_γ are free to vary (but no invisible)
- encompasses a very broad class of models



- determination of C_D is robust
- anticorrelation between C_U and ΔC_g

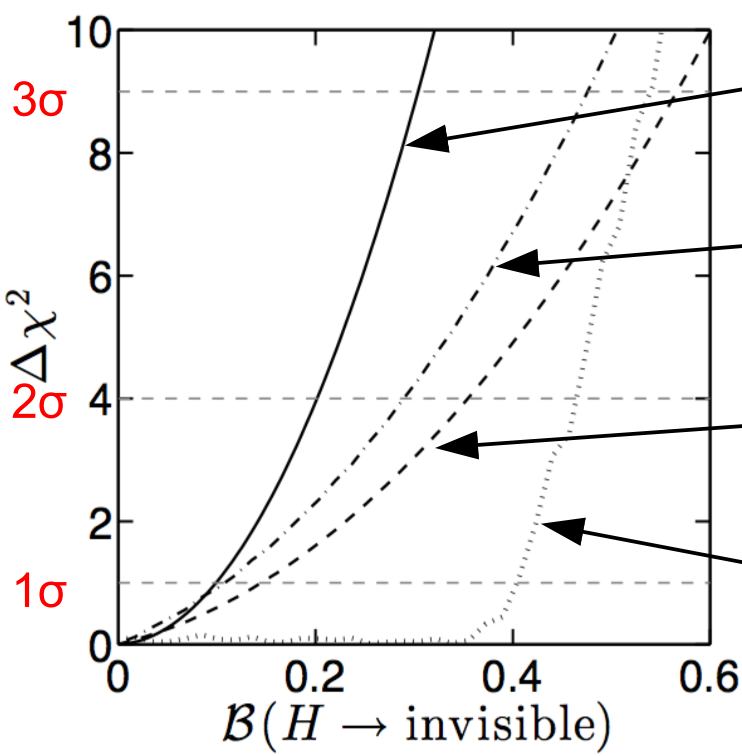
III) C_U , C_D , C_V , ΔC_g , ΔC_γ fit





- balance between C_U and ΔC_γ
- the determination of C_V is robust

Invisible decays of the Higgs boson



SM+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.20$ at 95% CL

SM+(C_U>0)+(C_D>0)+(C_V<1)+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.29$ at 95% CL

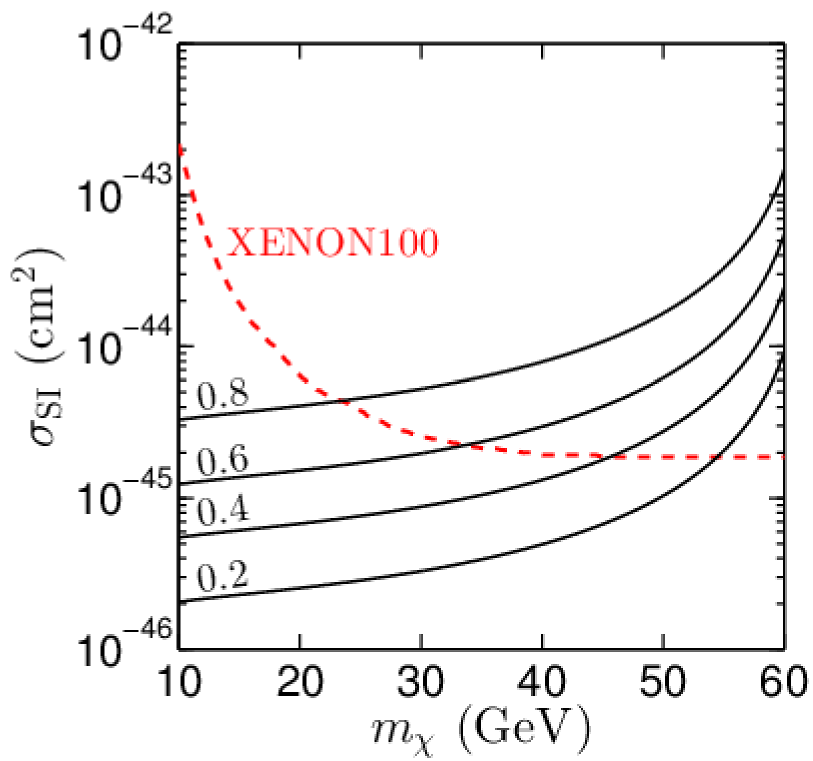
SM+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.35$ at 95% CL

SM+C_U+C_D+C_V+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.46$ at 95% CL

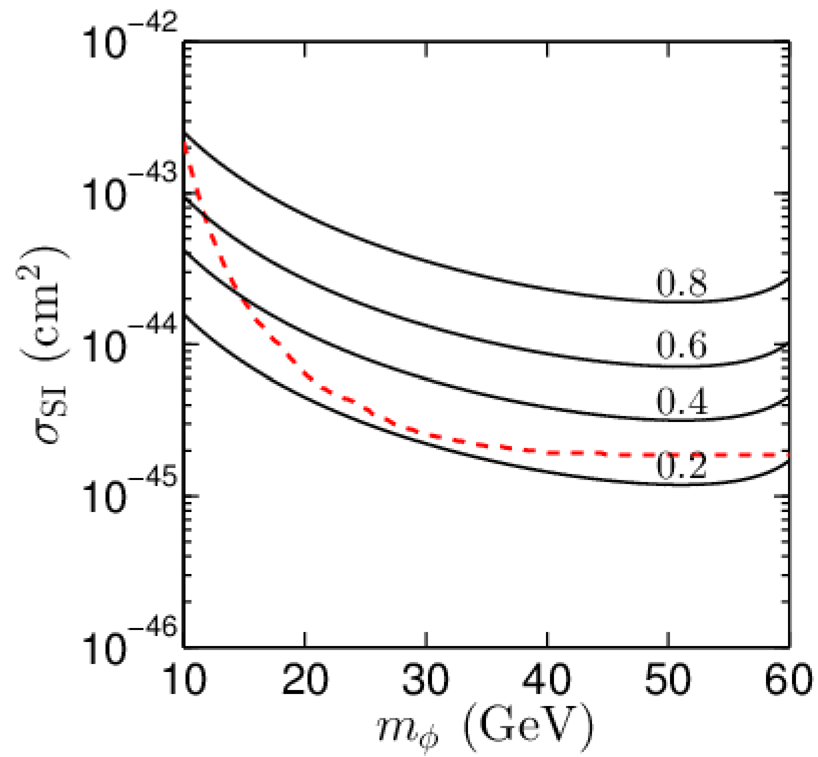
Invisible decays of the Higgs boson and dark matter

if invisible = dark matter:
interplay between direct searches and H→invisible

Majorana dark matter



scalar dark matter



Goodness-of-fit

Fit	Standard Model	$\Delta C_\gamma, \Delta C_g$	C_U, C_D, C_V	$C_U, C_D, C_V, \Delta C_\gamma, \Delta C_g$
$\chi^2_{\rm min}$ $\chi^2_{\rm min}$/d.o.f.	19.0 0.86	17.6 0.88	17.6 0.93	17.2 1.01
dominant contributions to $\chi^2_{\rm min}$	ATLAS $\gamma\gamma$ Tevatron $\gamma\gamma$ CMS WW	CMS $\gamma\gamma$ ATLAS $\gamma\gamma$ Tevatron $\gamma\gamma$	ATLAS $\gamma\gamma$ CMS WW Tevatron $\gamma\gamma$	CMS $\gamma\gamma$ ATLAS $\gamma\gamma$ Tevatron $\gamma\gamma$

- no improvement of χ^2/d.o.f. (hence the *p*-value) when allowing for additional freedom
- most of the tensions in the fit come from $\gamma\gamma$

Two Higgs Doublet Model

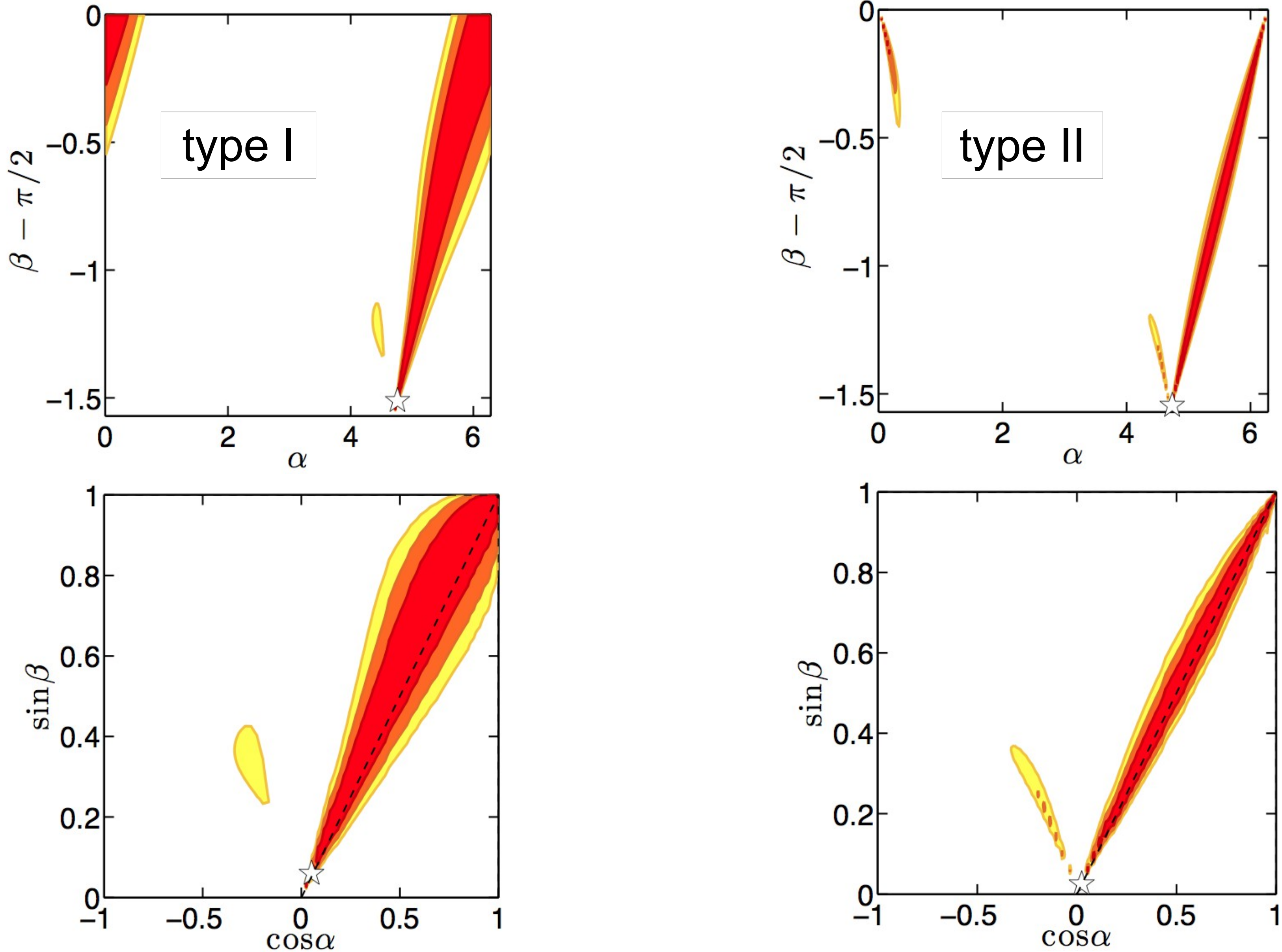
- Model-dependent study: 2HDM type I and II
- 2 parameters (angles): α and β

	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	$\cot\beta$	$-\cot\beta$	$\cot\beta$	$\tan\beta$

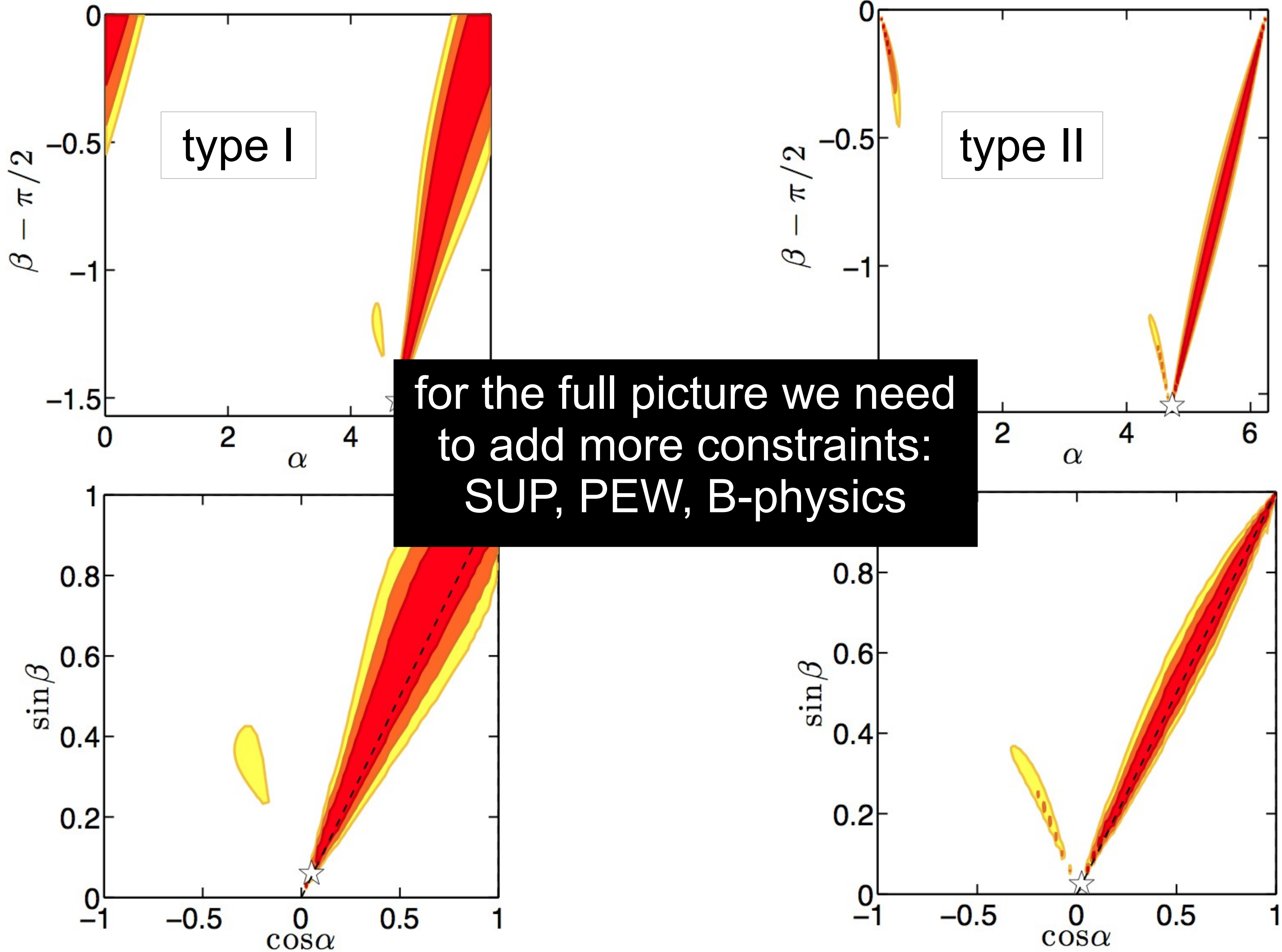
- in both cases we have:
  - $|C_V| < 1$
  - $|C_U| < 1.4$ if $\tan\beta > 1$

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

Two Higgs Doublet Model
h^0 results



Two Higgs Doublet Model
h^0 results



for the full picture we need to add more constraints: SUP, PEW, B-physics

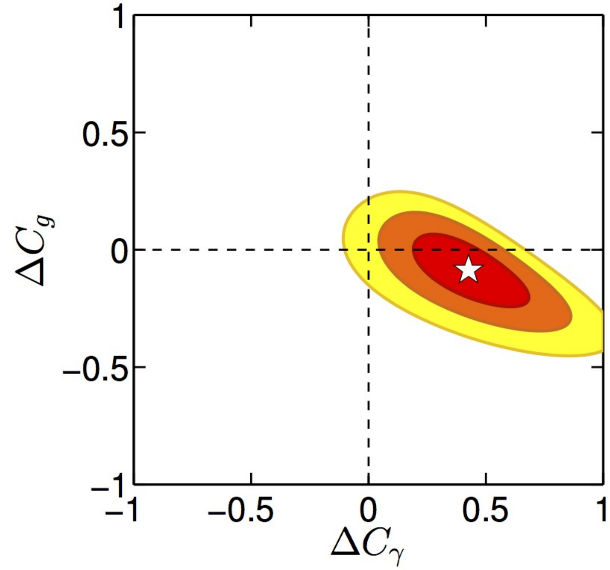
Conclusion

- previously favored $C_U < 0$ region is now disfavored at the level of 2.4σ (unless we allow for additional loop contributions to ggF)
- overall, the observed Higgs boson seems very SM-like (but still waiting for updates, especially in fermionic channels)
- first step in the study of the implications of the new boson
  → time has come to explore the consequences for BSM models

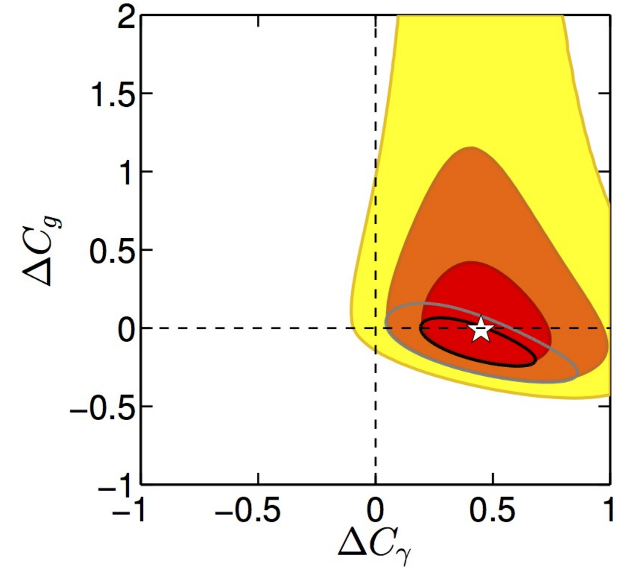
I) ΔC_g , ΔC_γ fit before and after Moriond

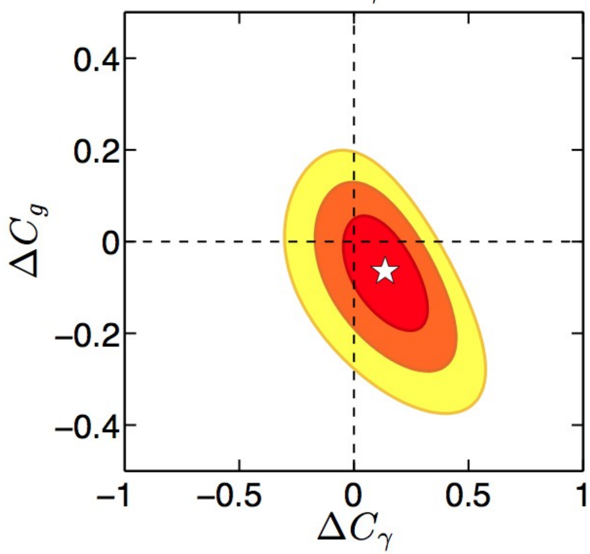
BR(H→invisible/undetected) = 0

BR(H→invisible/undetected) free

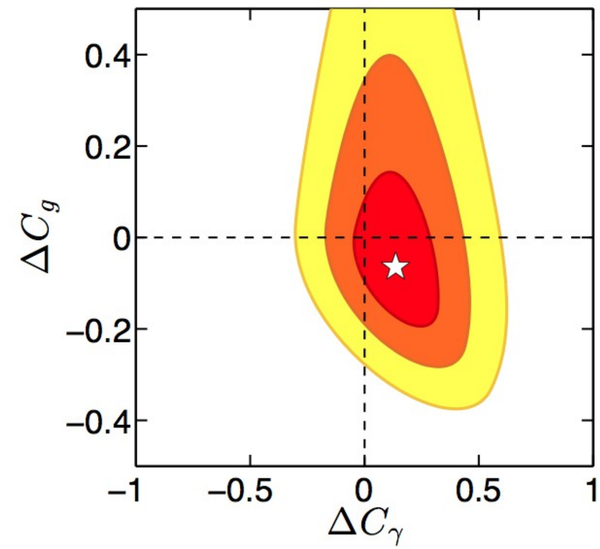


BEFORE

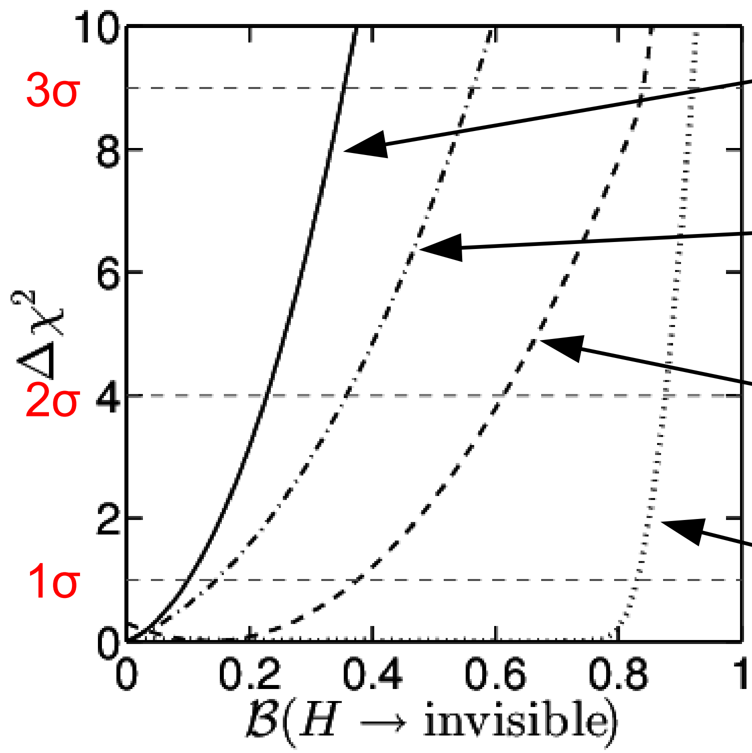




AFTER



Invisible decays of the Higgs boson before Moriond



SM+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.23$ at 95% CL

SM+(C_U>0)+(C_D>0)+(C_V<1)+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.36$ at 95% CL

SM+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.61$ at 95% CL

SM+C_U+C_D+C_V+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.88$ at 95% CL

Computation of C_g and C_γ

$$\bar{C}_g^2 = \frac{C_U^2 \sigma_{\rm ggF}^{tt} + C_D^2 \sigma_{\rm ggF}^{bb} + C_U C_D \sigma_{\rm ggF}^{tb}}{\sigma_{\rm ggF}^{tt} + \sigma_{\rm ggF}^{bb} + \sigma_{\rm ggF}^{tb}}$$

taken from HIGLU (with EW corrections switched off)

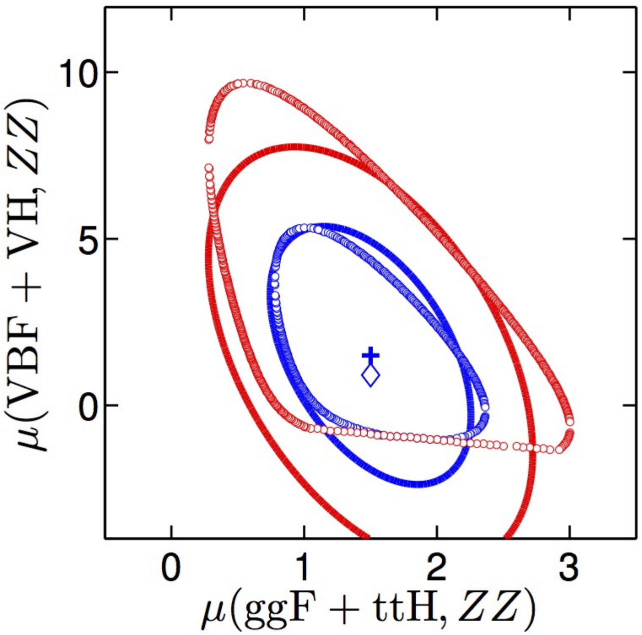
$$C_g^2 = \left(\sqrt{\bar{C}_g^2} + \Delta C_g\right)^2$$

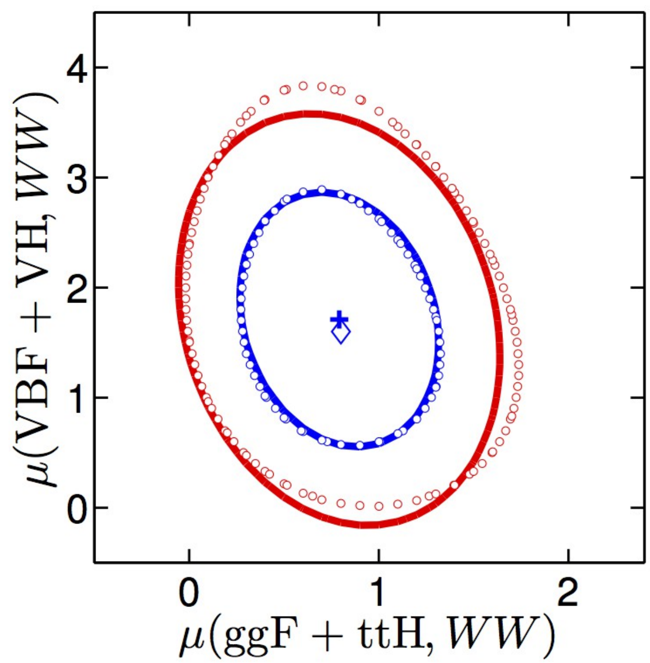
$$\bar{C}_\gamma^2 = \frac{C_V^2 \Gamma_{\gamma\gamma}^{WW} + C_U^2 \Gamma_{\gamma\gamma}^{tt} + C_D^2 \Gamma_{\gamma\gamma}^{bb} + C_D^2 \Gamma_{\gamma\gamma}^{\tau\tau} + \text{interferences}}{\Gamma_{\gamma\gamma}^{WW} + \Gamma_{\gamma\gamma}^{tt} + \Gamma_{\gamma\gamma}^{bb} + \Gamma_{\gamma\gamma}^{\tau\tau} + \text{interferences}}$$

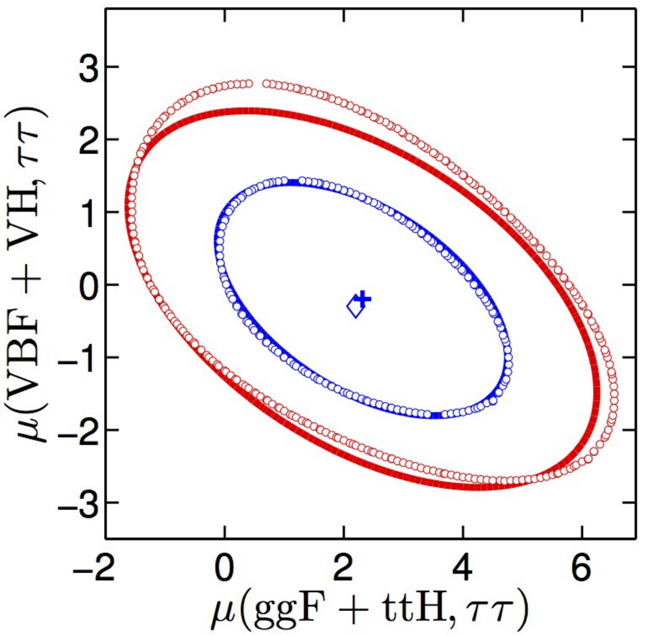
taken from HDECAY (with EW corrections switched off)

$$C_\gamma^2 = \left(\sqrt{\bar{C}_\gamma^2} + \Delta C_\gamma\right)^2$$

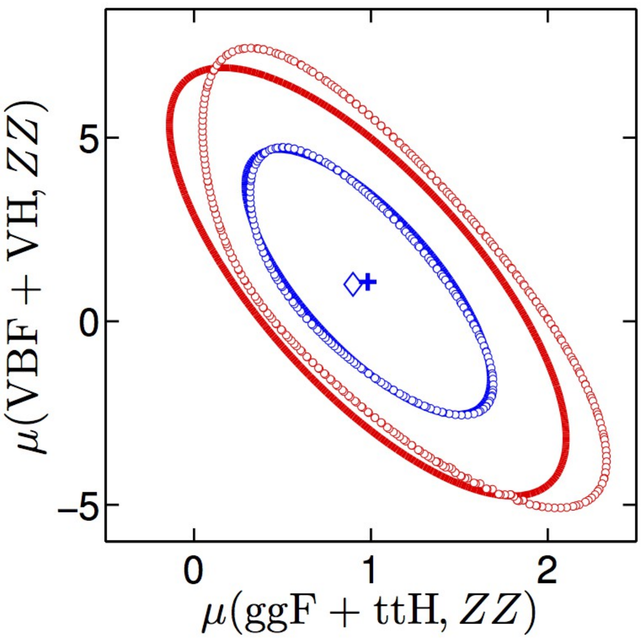
2D μ plots – ATLAS validity of the Gaussian approximation

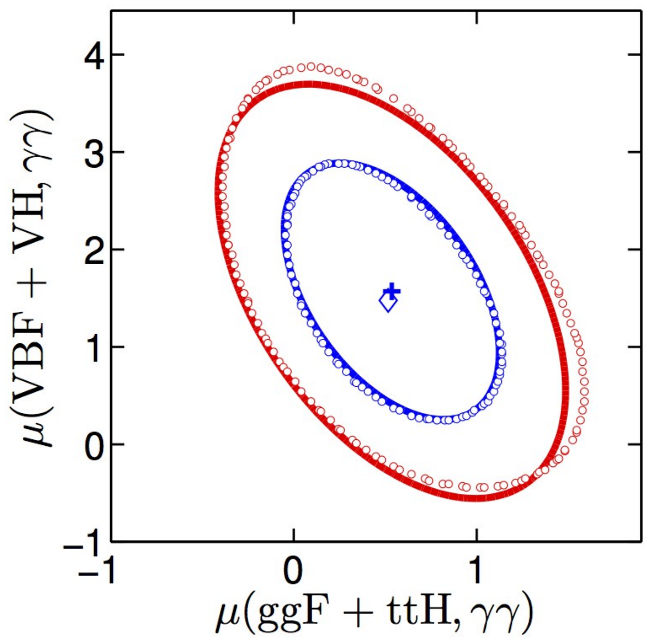






2D μ plots – CMS validity of the Gaussian approximation





only 68% CL contours are available
for CMS H→WW and H→ττ