« Electroweak Breaking After First Three Years at the LHC »

Aspects of Higgs rate fits

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Based on arXiv:1210.3977 (will be updated tuesday)

& Work in progress with ***A. Djouadi***

Warsaw

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Outline

A - Focusing on new fermions

I) The Higgs fits with Extra-Fermions

II) Constraining single Extra-Fermions

B – The interests of rate ratios

I) Get rid of the theoretical uncertainty

II) Fitting ratios of signal strengths

A - Focusing on new fermions

I) The Higgs fits with Extra-Fermions

Today : The LHC has **discovered** a resonance of ~ 125.5 GeV

➡ *it is probably the B.E.Higgs boson => **EWSB** mechanism*

\+ Tevatron and LHC provide **58** measurements of the Higgs rates

= new precious source of indirect information on BSM physics

➡ *nature of the EWSB : within the **SM** or a **BSM** context !?*

On the theoretical side:

New fermions arise in most (all?) of the SM extensions,

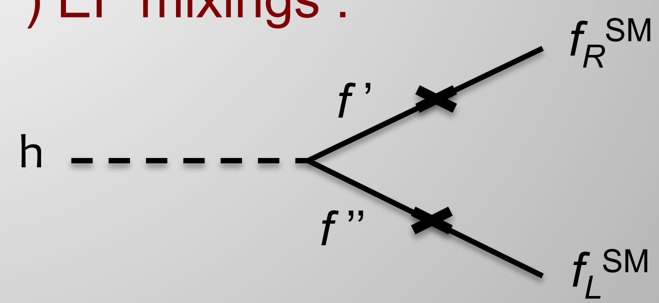
- little Higgs *[fermionic partners]*
- supersymmetry *[gauginos / higgsinos]*
- composite Higgs *[excited bounded states]*
- extra-dimensions *[Kaluza-Klein towers]*
- 4*th* generations *[new families]*
- GUT *[multiplet components]*
- etc…

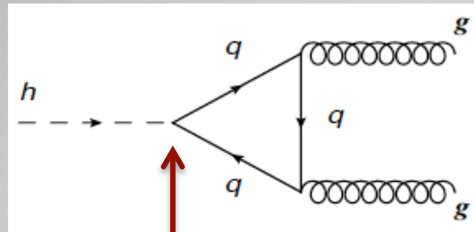
➡ *What are the present **constraints on extra-fermions** from all the experimental Higgs boson results ?*

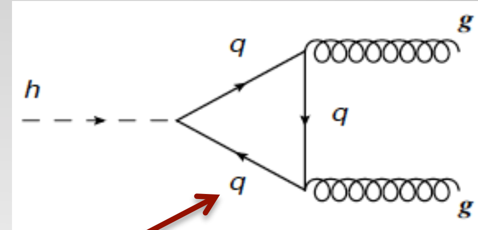
Effective approach : Corrections on the Higgs couplings from **any** extra-fermions *(via mixing, new loops)*

$$\mathcal{L}_h = - c_t Y_t \, h \, \bar{t}_L \, t_R - c_b Y_b \, h \, \bar{b}_L \, b_R - c_\tau Y_\tau \, h \, \bar{\tau}_L \, \tau_R + C_{h\gamma\gamma} \frac{\alpha}{\pi v} \, h \, F^{\mu\nu} F_{\mu\nu} + C_{hgg} \frac{\alpha_s}{12\pi v} \, h \, G^{a\mu\nu} G^a_{\mu\nu} + \text{h.c.}$$

Modifications of Y_f Yukawa couplings via (f') EF mixings :

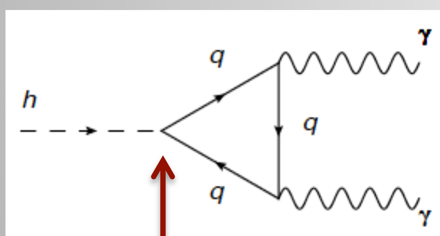


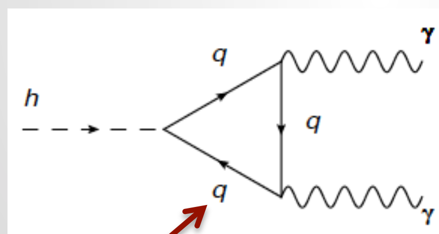




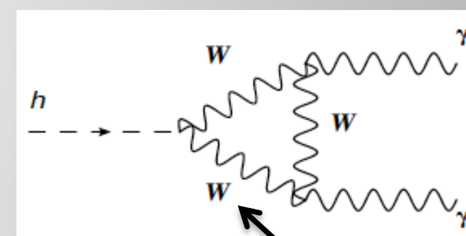
b' , $q_{5/3}$, …

$$C_{hgg} \;=\; 2C(t)\; A[\tau(m_t)]\; (c_t + c_{gg}) \;+\; 2C(b)\; A[\tau(m_b)]\; c_b \;+\; 2C(c)\; A[\tau(m_c)]$$





b' , $q_{5/3}$, …



$$C_{h\gamma\gamma} \;=\; \frac{N_c^t}{6} Q_t^2 A[\tau(m_t)]\; (c_t + c_{\gamma\gamma}) + \frac{N_c^b}{6} Q_b^2 A[\tau(m_b)]\; c_b + \frac{N_c^c}{6} Q_c^2 A[\tau(m_c)] + \frac{N_c^\tau}{6} Q_\tau^2 A[\tau(m_\tau)]\; c_\tau + \frac{1}{8} A_1[\tau(m_W)]$$

Higgs production cross sections over their SM expectations :

$$\frac{\sigma_{\mathrm{gg}\to\mathrm{h}}}{\sigma^{\mathrm{SM}}_{\mathrm{gg}\to\mathrm{h}}} \simeq \frac{\left|(c_t + c_{gg})A[\tau(m_t)] + c_b A[\tau(m_b)] + A[\tau(m_c)]\right|^2}{\left|A[\tau(m_t)] + A[\tau(m_b)] + A[\tau(m_c)]\right|^2} \qquad \frac{\sigma_{\mathrm{h\bar{t}t}}}{\sigma^{\mathrm{SM}}_{\mathrm{h\bar{t}t}}} \simeq |c_t|^2$$

Higgs partial decay widths over the SM predictions (no new channels) :

$$\frac{\Gamma_{\mathrm{h}\to\gamma\gamma}}{\Gamma^{\mathrm{SM}}_{\mathrm{h}\to\gamma\gamma}} \simeq \frac{\left|\frac{1}{4}A_1[\tau(m_W)] + (\frac{2}{3})^2(c_t + c_{\gamma\gamma})A[\tau(m_t)] + (-\frac{1}{3})^2 c_b A[\tau(m_b)] + (\frac{2}{3})^2 A[\tau(m_c)] + \frac{1}{3}c_\tau A[\tau(m_\tau)]\right|^2}{\left|\frac{1}{4}A_1[\tau(m_W)] + (\frac{2}{3})^2 A[\tau(m_t)] + (-\frac{1}{3})^2 A[\tau(m_b)] + (\frac{2}{3})^2 A[\tau(m_c)] + \frac{1}{3}A[\tau(m_\tau)]\right|^2}$$

$$\frac{\Gamma_{\mathrm{h}\to\mathrm{\bar{b}b}}}{\Gamma^{\mathrm{SM}}_{\mathrm{h}\to\mathrm{\bar{b}b}}} \simeq |c_b|^2 \qquad \frac{\Gamma_{\mathrm{h}\to\bar{\tau}\tau}}{\Gamma^{\mathrm{SM}}_{\mathrm{h}\to\bar{\tau}\tau}} \simeq |c_\tau|^2$$

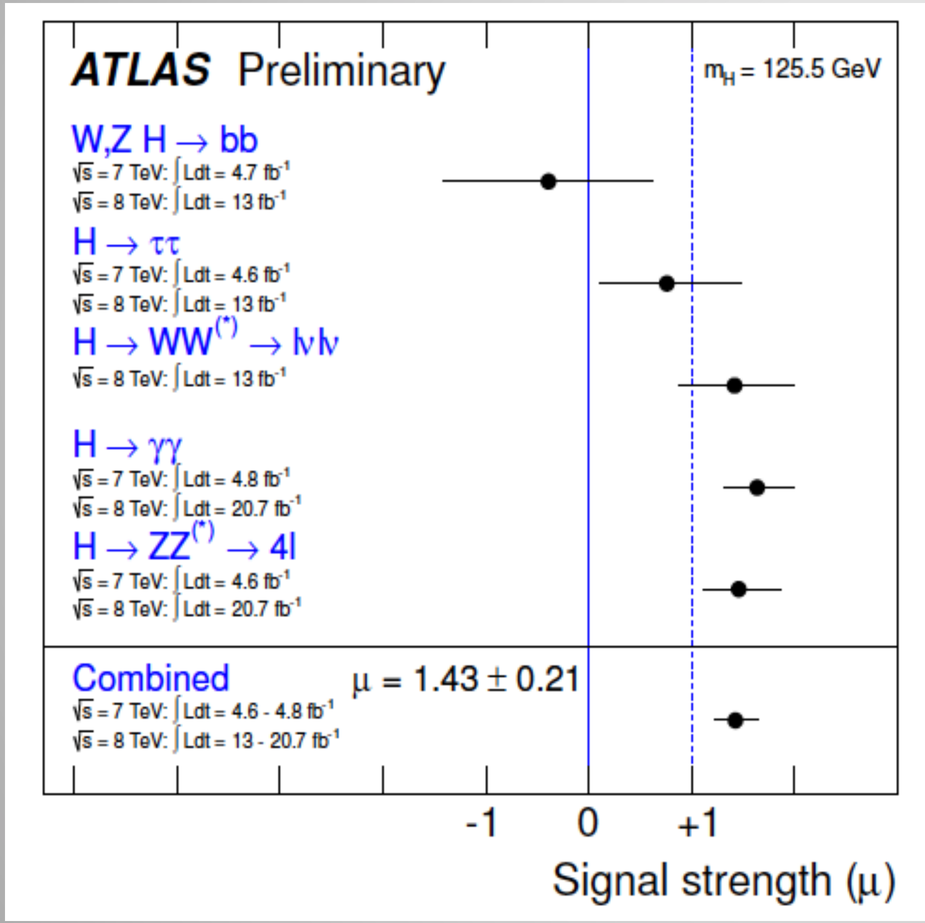
Measured signal strengths all of the form (exp. selection efficiencies) :

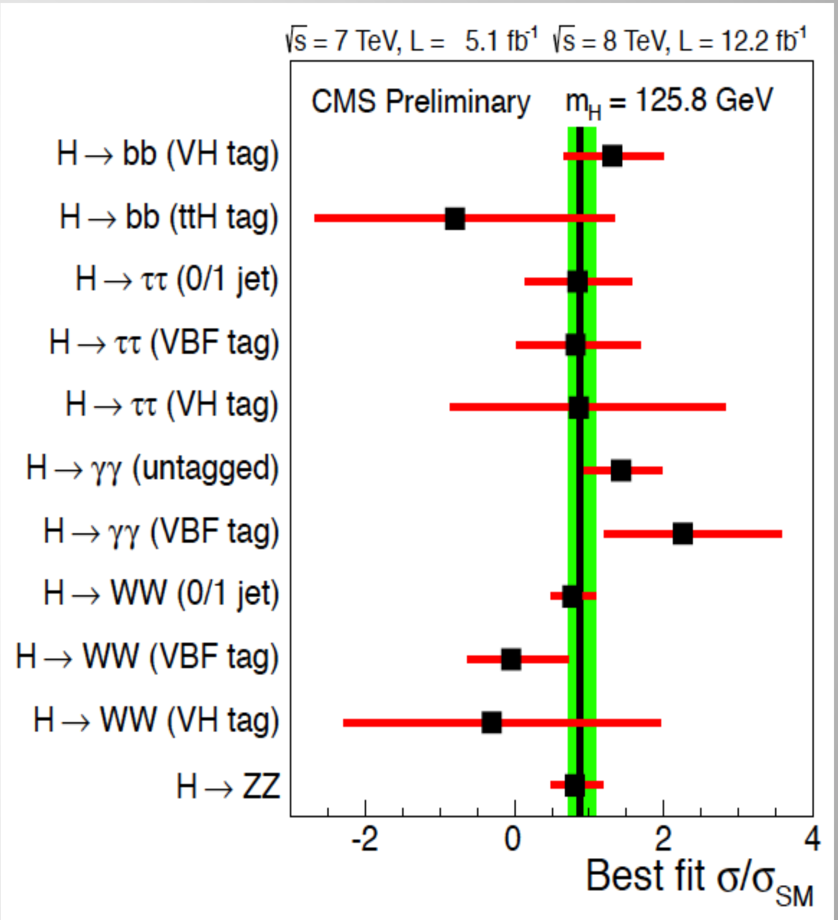
$$\mu^p_{s,c,i} \simeq \frac{\sigma_{gg\to h}\big|_s + \frac{\epsilon_{hqq}}{\epsilon_{gg\to h}}\Big|^p_{s,c,i} \sigma^{SM}_{hqq}\big|_s + \frac{\epsilon_{hV}}{\epsilon_{gg\to h}}\Big|^p_{s,c,i} \sigma^{SM}_{hV}\big|_s + \frac{\epsilon_{h\bar{t}t}}{\epsilon_{gg\to h}}\Big|^p_{s,c,i} \sigma_{h\bar{t}t}\big|_s}{\sigma^{SM}_{gg\to h}\big|_s + \frac{\epsilon_{hqq}}{\epsilon_{gg\to h}}\Big|^p_{s,c,i} \sigma^{SM}_{hqq}\big|_s + \frac{\epsilon_{hV}}{\epsilon_{gg\to h}}\Big|^p_{s,c,i} \sigma^{SM}_{hV}\big|_s + \frac{\epsilon_{h\bar{t}t}}{\epsilon_{gg\to h}}\Big|^p_{s,c,i} \sigma^{SM}_{h\bar{t}t}\big|_s} \frac{B_{h\to XX}}{B^{SM}_{h\to XX}}$$

For the fit analysis, we define a function $\chi^2(c_t, c_b, c_\tau, c_{gg}, c_{\gamma\gamma})$:

$$\chi^2 = \sum_{p,s,c,i} \frac{(\mu^p_{s,c,i} - \mu^p_{s,c,i}|_{exp})^2}{(\delta\mu^p_{s,c,i})^2}$$

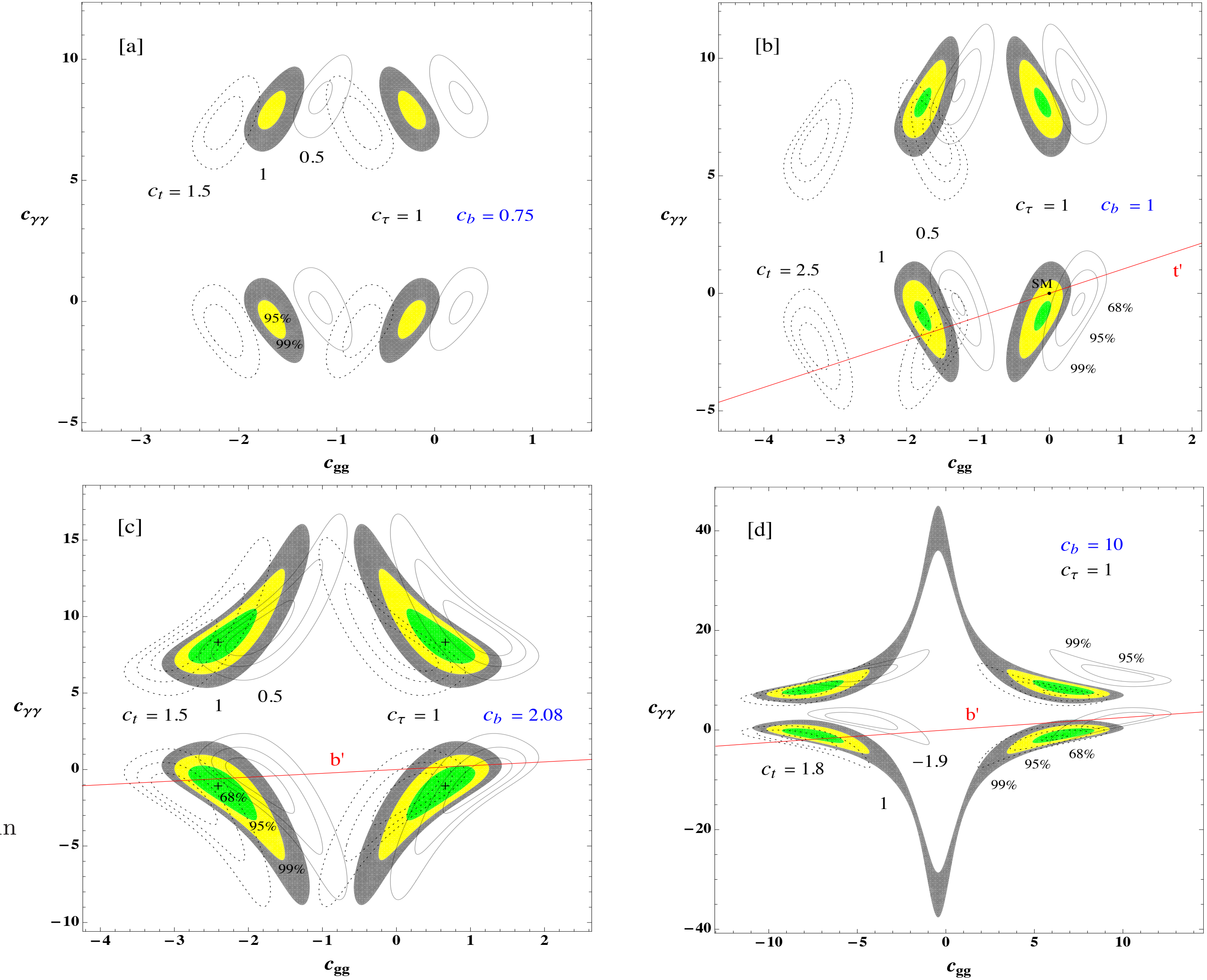
Taking the latest experimental results…





Higgs fit results :

(3 free param.)



$$\Delta\chi^2 = \chi^2 - \chi^2_{\min}$$

$$\chi^2_{\min} = 52.36$$

« 3 conclusions for this first fit... »

* The SM point ($\chi^2_{\rm SM} = 57.10$) does not belong to the 1**σ** region

* Determination of c_{gg} and $c_{\gamma\gamma}$ ***relies*** on the knowledge of $\mathbf{Y_t^{EF}}$ (c_t)

* $\mathbf{Y_b^{EF}}$ (c_b) ↗ B(h → VV) ↘ compensated by $\boldsymbol{\sigma}_{gg\to h}$ ↗ i.e. c_{gg} ↗

➡ $\mathbf{Y_b}$ **cannot** be determined by the (previous) Higgs fit

suggestion : avoid compensations by measuring

$$\bar{\rm q}{\rm q} \to {\rm h}\bar{\rm b}{\rm b} \text{ and } {\rm gg} \to {\rm h}\bar{\rm b}{\rm b} \qquad {\rm h} \to \bar{\rm b}{\rm b}$$

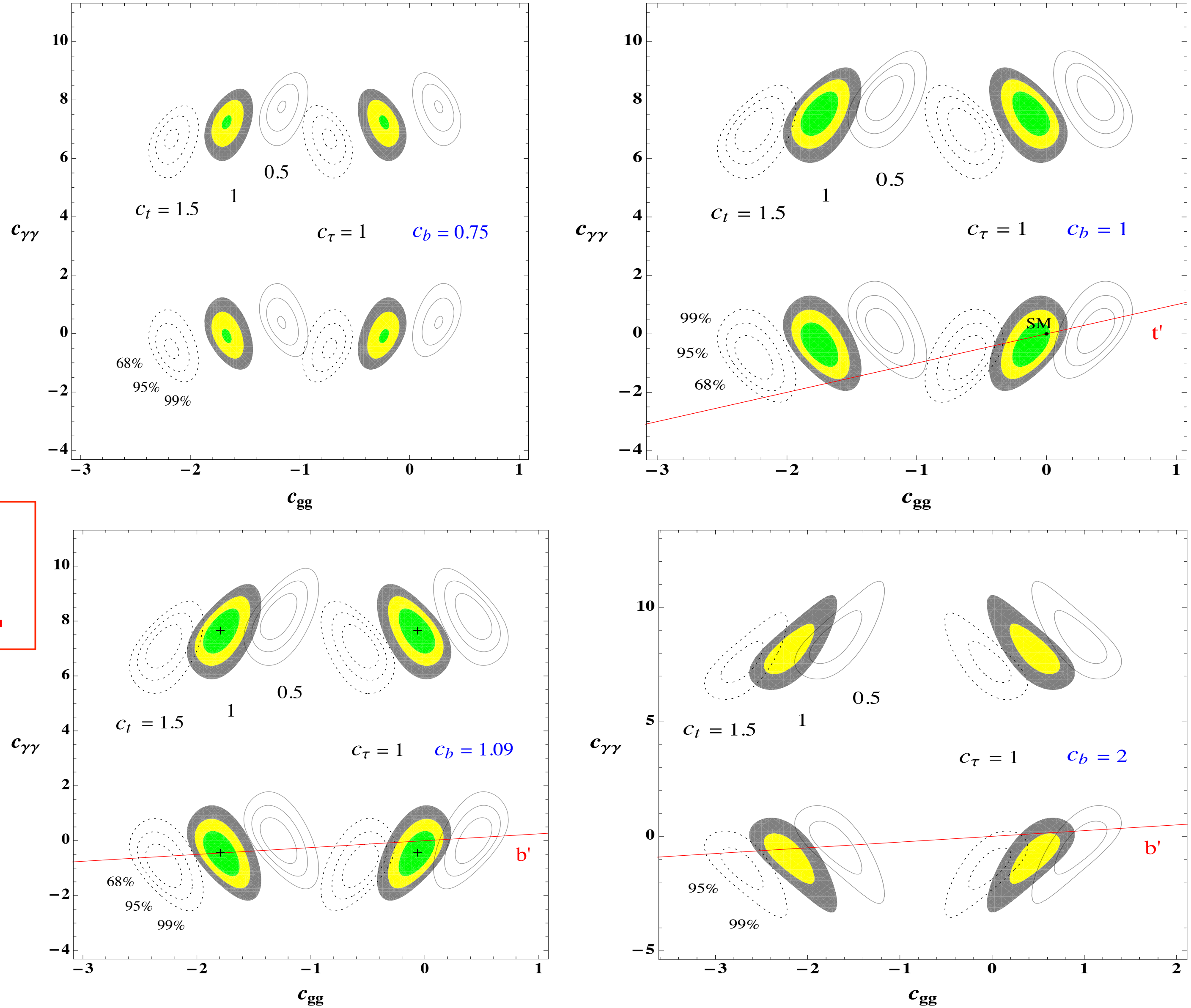
Higgs fit results :

(3 free param.)

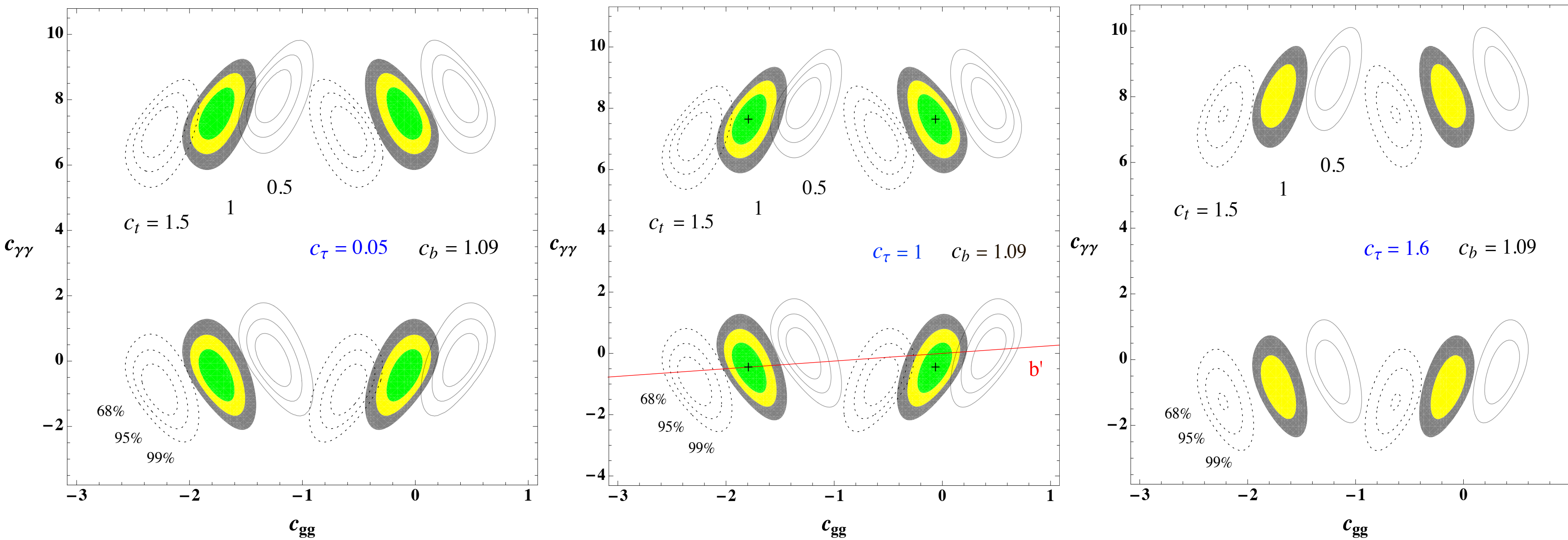
AFTER MORIOND...

$$\Delta\chi^2 = \chi^2 - \chi^2_{\min}$$

$$\chi^2_{\min} = 52.36$$



Varying the last parameter : c_τ



II) Constraining single Extra-Fermions

Single extra-fermion (starting approximation) => new loop-contributions :

$$c_{gg} = \frac{1}{C(t)A[\tau(m_t)]/v}\left[-C(t')\frac{Y_{t'}}{m_{t'}}A[\tau(m_{t'})] - C(q_{5/3})\frac{Y_{q_{5/3}}}{m_{q_{5/3}}}A[\tau(m_{q_{5/3}})] + \ldots\right]$$

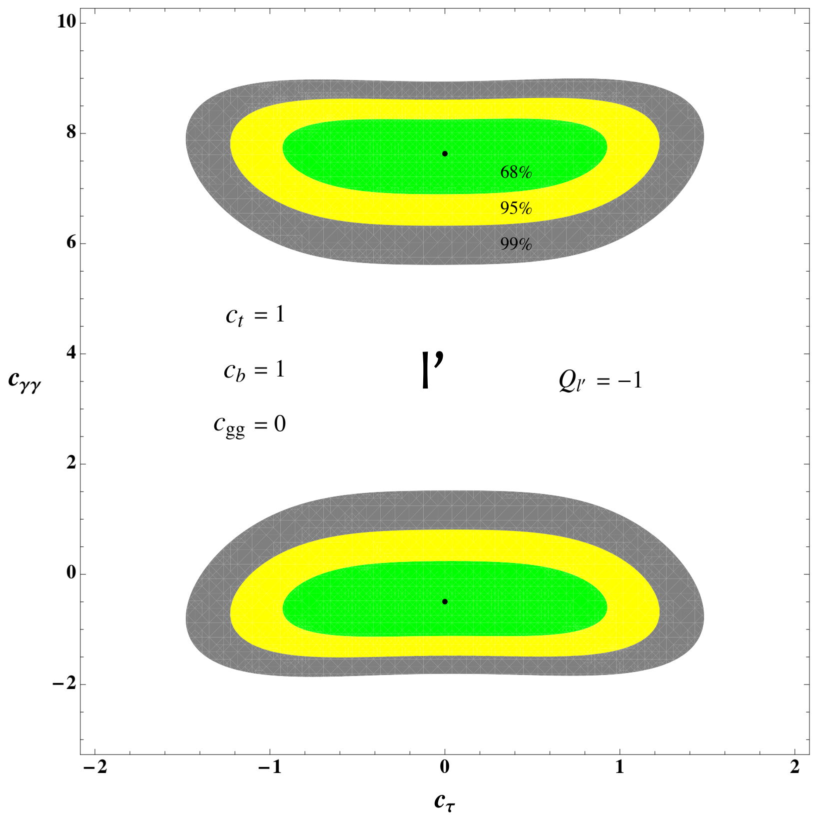
$$c_{\gamma\gamma} = \frac{1}{N_c^t Q_t^2 A[\tau(m_t)]/v}\left[-3\left(\frac{2}{3}\right)^2\frac{Y_{t'}}{m_{t'}}A[\tau(m_{t'})] - N_c^{q_{5/3}}\left(\frac{5}{3}\right)^2\frac{Y_{q_{5/3}}}{m_{q_{5/3}}}A[\tau(m_{q_{5/3}})] - Q_{\ell'}^2\frac{Y_{\ell'}}{m_{\ell'}}A[\tau(m_{\ell'})] + \ldots\right]$$

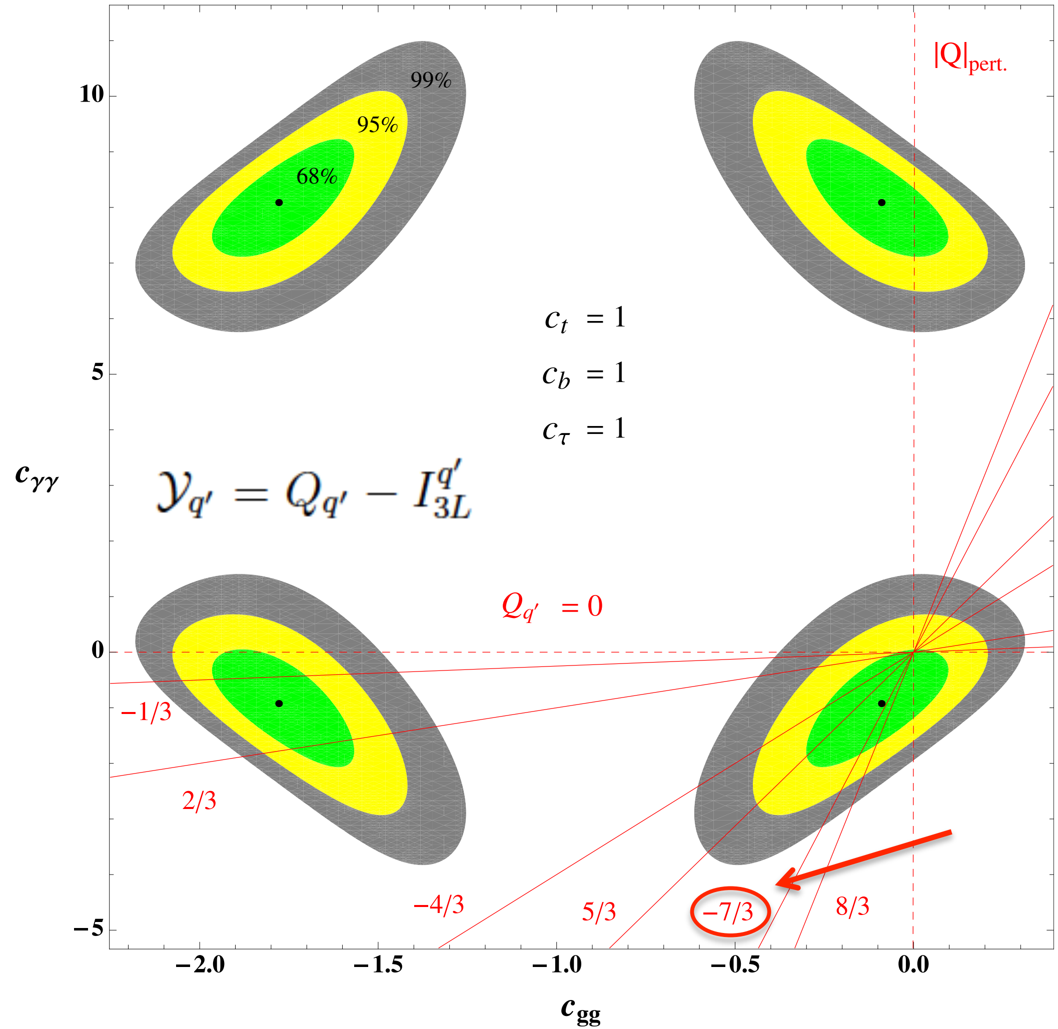
➡ $$\left.\frac{c_{\gamma\gamma}}{c_{gg}}\right|_{q'} = \frac{Q_{q'}^2}{(2/3)^2}$$

(same color repres. as the top)

independently of $Y_{q'}$, masses, $SU(2)_L$ repres.

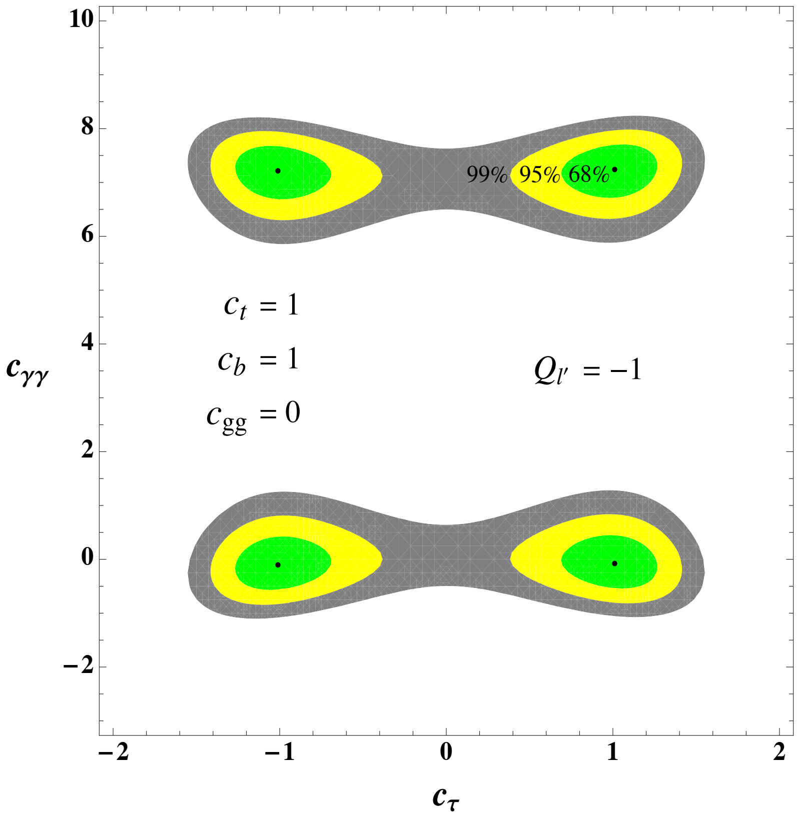
(2 free parameters)



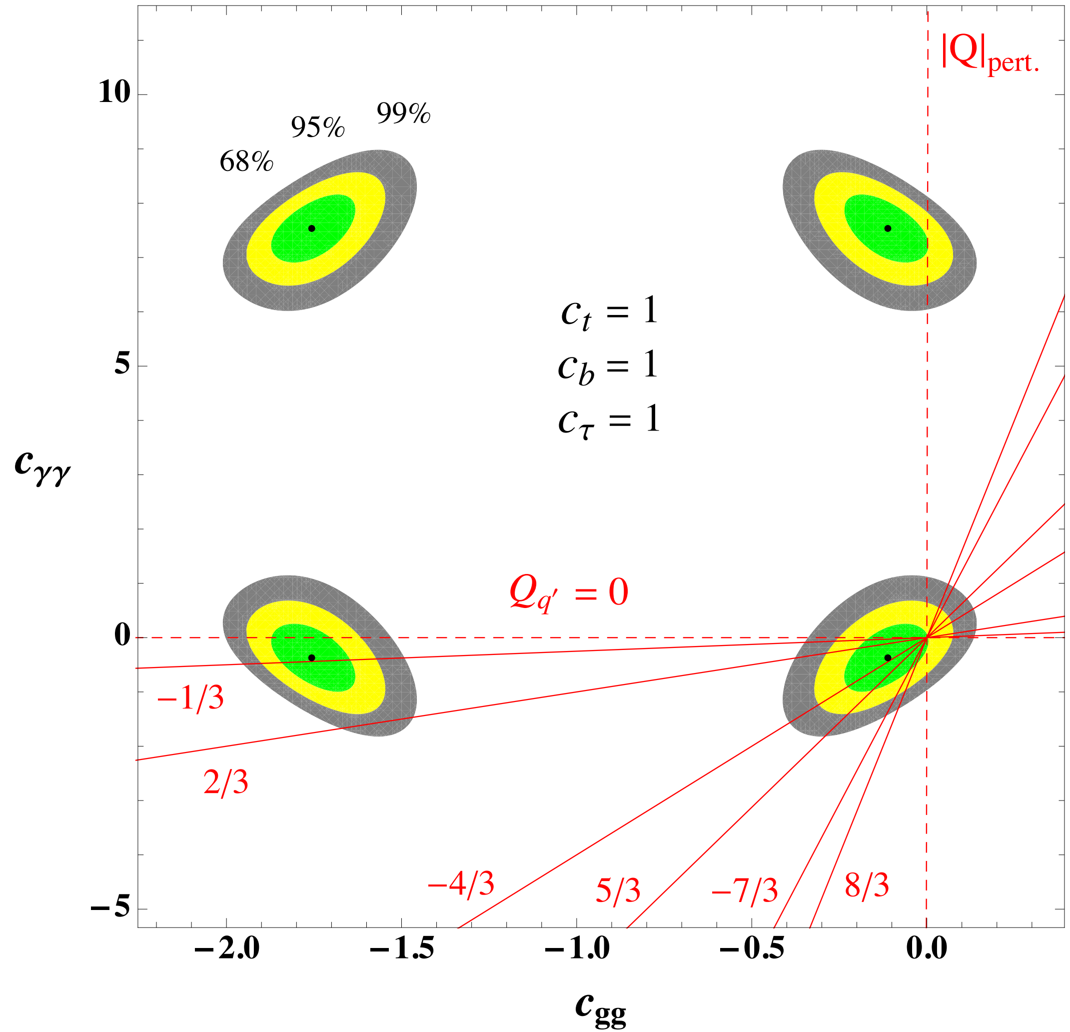


AFTER MORIOND...

(2 free parameters)



independently of $Y_{q'}$, masses, $SU(2)_L$ repres.



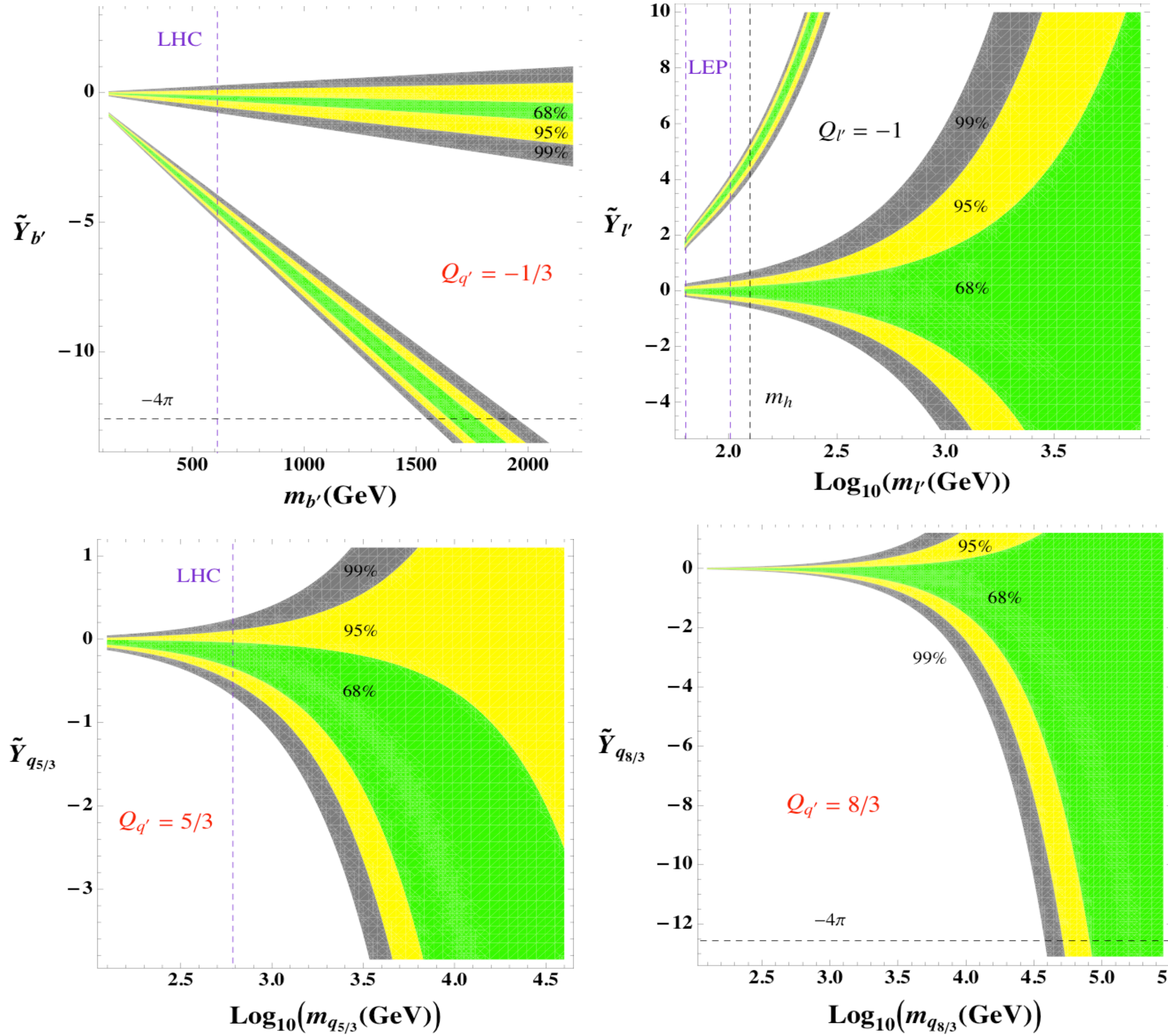
(1 free param.)

For low-charge q', *Extra-dysfermiophilia* :

$$\mathrm{sign}\left(\frac{-Y_{q'}}{m_{q'}}\right) < 0$$

…increasing the diphoton rates.

$$q_{5/3} \to tW^+$$
$$q_{8/3} \to tW^+W^+$$



Conclusions (A)

- Already ***non-trivial*** & **generic constraints** on extra-fermions from the Higgs rate fit :

- Potentially stringent constraints on extra-quark electric charges **independently** of the *Yukawa's, masses, $SU(2)_L$ representations*

- ***Extra-dysfermiophilia*** for low-charge single q' (colored as the top)

- The obtained plots can be used for any scenario with new fermions

+ *Difficult* and *correlated* determinations of some Yukawa couplings and parameters for the new loop-contributions to hgg , hγγ.

B – The interests of rate ratios

I) Get rid of the theoretical uncertainty

The QCD uncertainty *(PDF, α_s^2 @ LO, scale dependence)* on the inclusive Higgs production cross section reaches ~ 15-20% [LHCHWG]

..it affects the μ's fit

$$\mu_{XX}|_{\rm exp} = \frac{\mathrm{N}^{\rm evts.}(pp \to H \to XX)}{\sum_i \epsilon_i^X \sigma_i(H)\ \mathrm{BR}(H \to XX)|_{\rm SM} \times \mathcal{L}}$$

$$\mu_{XX}|_{\rm th} = \frac{\sum_i \epsilon_i^X \sigma_i(H)\ \mathrm{BR}(H \to XX)}{\sum_i \epsilon_i^X \sigma_i(H)\ \mathrm{BR}(H \to XX)|_{\rm SM}}$$

Numerator of $\mu_{XX}|_{\rm exp}$ → $\delta_{\rm exp}$

Denominator of $\mu_{XX}|_{\rm exp}$ and numerator of $\mu_{XX}|_{\rm th}$ → $\delta_{\rm th}$

Taking μ ratios can allow to suppress the QCD error :

δ_{exp}

$$\left.\frac{\mu_{XX}}{\mu_{YY}}\right|_{\text{exp}} = \frac{\text{N}^{\text{evts.}}(pp \to H \to XX)}{\text{N}^{\text{evts.}}(pp \to H \to YY)} \frac{\sum_i \epsilon_i^Y \sigma_i(H)|_{\text{SM}}}{\sum_i \epsilon_i^X \sigma_i(H)|_{\text{SM}}} \frac{\text{BR}(H \to YY)|_{\text{SM}}}{\text{BR}(H \to XX)|_{\text{SM}}}$$

can cancel out !

$$\left.\frac{\mu_{XX}}{\mu_{YY}}\right|_{\text{th}} = \frac{\epsilon_{gg}^X \sigma(gg \to H) + \epsilon_{\text{VBF}}^X \sigma(qq \to Hqq) + \epsilon_{HV}^X \sigma(q\bar{q} \to VH) + \epsilon_{t\bar{t}H}^X \sigma(gg \to t\bar{t}H)}{\epsilon_{gg}^Y \sigma(gg \to H) + \epsilon_{\text{VBF}}^Y \sigma(qq \to Hqq) + \epsilon_{HV}^Y \sigma(q\bar{q} \to VH) + \epsilon_{t\bar{t}H}^Y \sigma(gg \to t\bar{t}H)}$$

$$\times \frac{\sum_i \epsilon_i^Y \sigma_i(H)|_{\text{SM}}}{\sum_i \epsilon_i^X \sigma_i(H)|_{\text{SM}}} \frac{\frac{\Gamma(H \to XX)}{\Gamma(H \to XX)|_{\text{SM}}}}{\frac{\Gamma(H \to YY)}{\Gamma(H \to YY)|_{\text{SM}}}}$$

$D_{XY}(c_f, c_V)$

II) Fitting ratios of signal strengths

Usual fits of the Higgs rates :

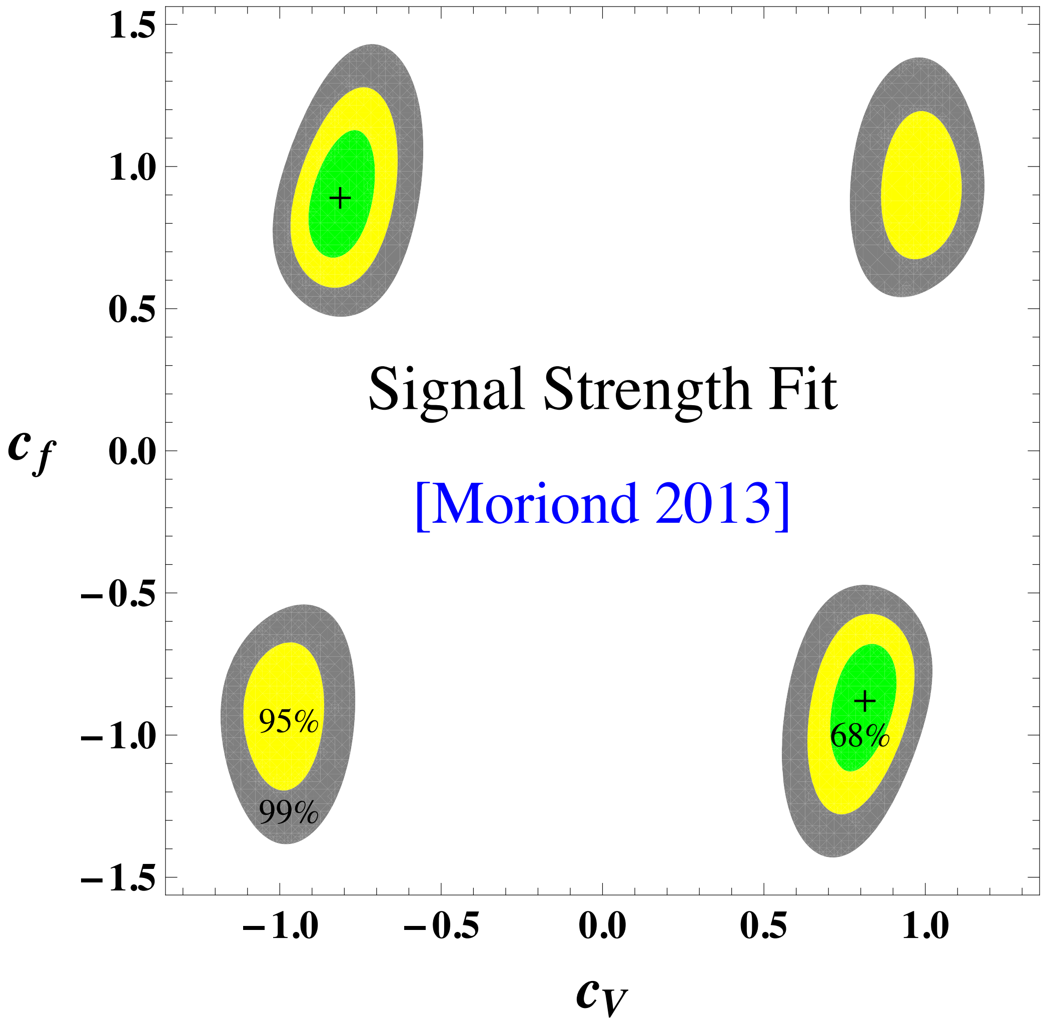
$$\mathcal{L}_h = c_W \, g_{HWW} \, H \, W^+_\mu W^{-\mu} + c_Z \, g_{HZZ} \, H \, Z^0_\mu Z^{0\mu}$$
$$- c_t Y_t \, H \, \bar{t}_L \, t_R - c_c Y_c \, H \, \bar{c}_L \, c_R - c_b Y_b \, H \, \bar{b}_L \, b_R - c_\tau Y_\tau \, H \, \bar{\tau}_L \, \tau_R + \text{h.c.}$$

$$\left(\quad Y_{t,c,b,\tau} = m_{t,c,b,\tau}/v \qquad g_{HWW} = 2m_W^2/v, \; g_{HZZ} = m_Z^2/v \quad \right)$$

$$\chi^2 = \sum_i \frac{\left[\mu_i(c_f, c_V) - \mu_i|_{\text{exp}}\right]^2}{(\delta\mu_i)^2}$$

$$\delta\mu_i = \sqrt{\delta\mu_i|^2_{\text{exp}} + \delta\mu_i|^2_{\text{th}}}$$

(2 free parameters)



(without the CMS diphoton data from Moriond QCD)

Symmetry:

$c_f \to -c_f,\ c_V \to -c_V$

Now fitting ratios of the Higgs rates :

$$\chi_r^2 = \frac{[D_{Z\gamma}^{gg}(c_f, c_V) - \frac{\mu_{ZZ}}{\mu_{\gamma\gamma}}|_{\rm exp}^{gg}]^2}{[\delta(\frac{\mu_{ZZ}}{\mu_{\gamma\gamma}})_{gg}]^2} + \frac{[D_{\tau W}^{gg}(c_f, c_V) - \frac{\mu_{\tau\tau}}{\mu_{WW}}|_{\rm exp}^{gg}]^2}{[\delta(\frac{\mu_{\tau\tau}}{\mu_{WW}})_{gg}]^2} + \frac{[D_{\tau W}^{\rm VBF}(c_f, c_V) - \frac{\mu_{\tau\tau}}{\mu_{WW}}|_{\rm exp}^{\rm VBF}]^2}{[\delta(\frac{\mu_{\tau\tau}}{\mu_{WW}})_{\rm VBF}]^2}$$

$$D_{Z\gamma}^{gg} \simeq \frac{\frac{\Gamma(H\to ZZ)}{\Gamma(H\to ZZ)|_{\rm SM}}}{\frac{\Gamma(H\to\gamma\gamma)}{\Gamma(H\to\gamma\gamma)|_{\rm SM}}} \quad , \quad D_{\tau W}^{gg} \simeq D_{\tau W}^{\rm VBF} \simeq \frac{\frac{\Gamma(H\to\tau\tau)}{\Gamma(H\to\tau\tau)|_{\rm SM}}}{\frac{\Gamma(H\to WW)}{\Gamma(H\to WW)|_{\rm SM}}}$$

$$\begin{cases} D_{Z\gamma} \simeq |c_Z|^2 \left\{ \frac{|\frac{1}{4}c_W A_1[m_W] + (\frac{2}{3})^2 c_t A[m_t] + (-\frac{1}{3})^2 c_b A[m_b] + (\frac{2}{3})^2 c_c A[m_c] + \frac{1}{3} c_\tau A[m_\tau]|^2}{|\frac{1}{4}A_1[m_W] + (\frac{2}{3})^2 A[m_t] + (-\frac{1}{3})^2 A[m_b] + (\frac{2}{3})^2 A[m_c] + \frac{1}{3}A[m_\tau]|^2} \right\}^{-1} \\ D_{\tau W} \simeq \frac{|c_\tau|^2}{|c_W|^2} \end{cases}$$

$$\left(\begin{array}{c} \tau(m) = m_H^2/4m^2 \quad A[\tau(m) \ll 1] \to 1 \\ \text{for } m_H \simeq 125 \text{ GeV}, \ A_1[\tau(m_W)] \simeq -8.3 \end{array} \right)$$

(2 free parameters)

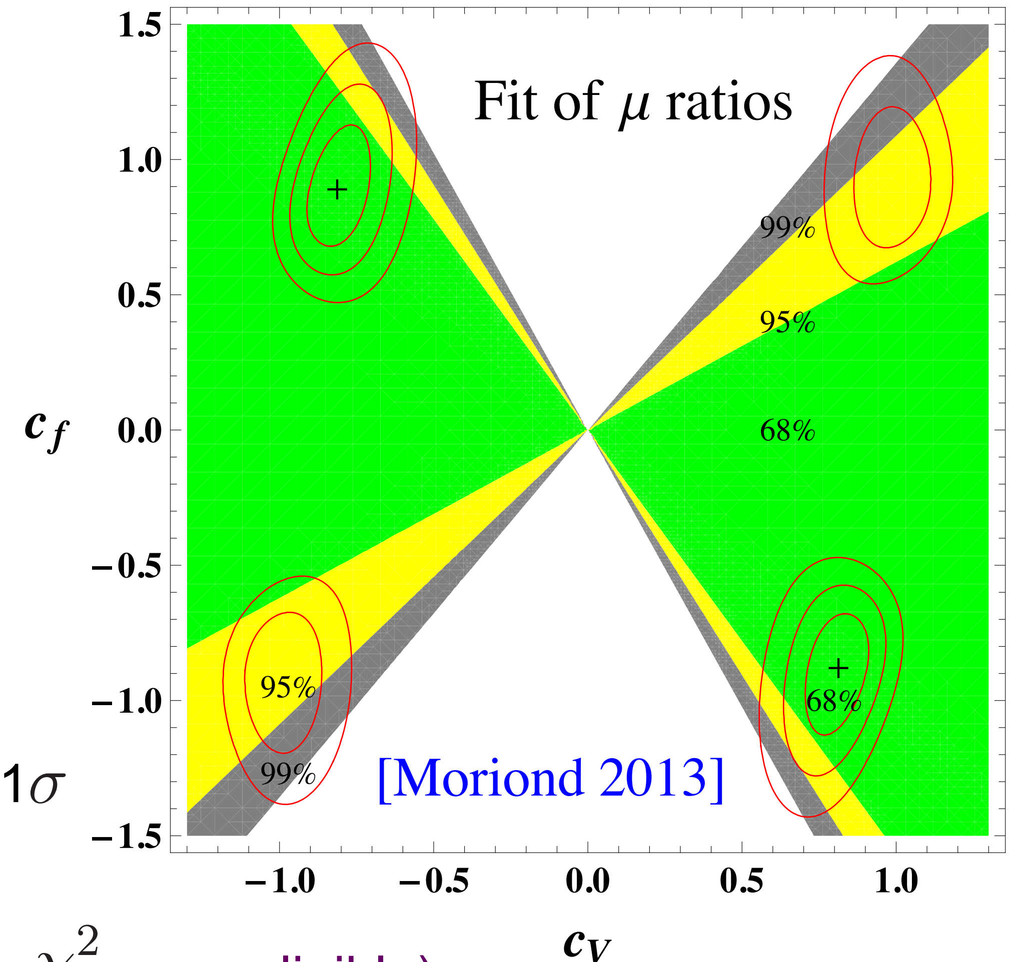
Less informations than on individual signal strengths

+

Combined Num. & Denominator experimental errors

⬇

Best-fit regions larger for ratios and containing the μ domains at 1σ



(theoretical error in quadrature for χ^2 => negligible)

(2 free parameters)

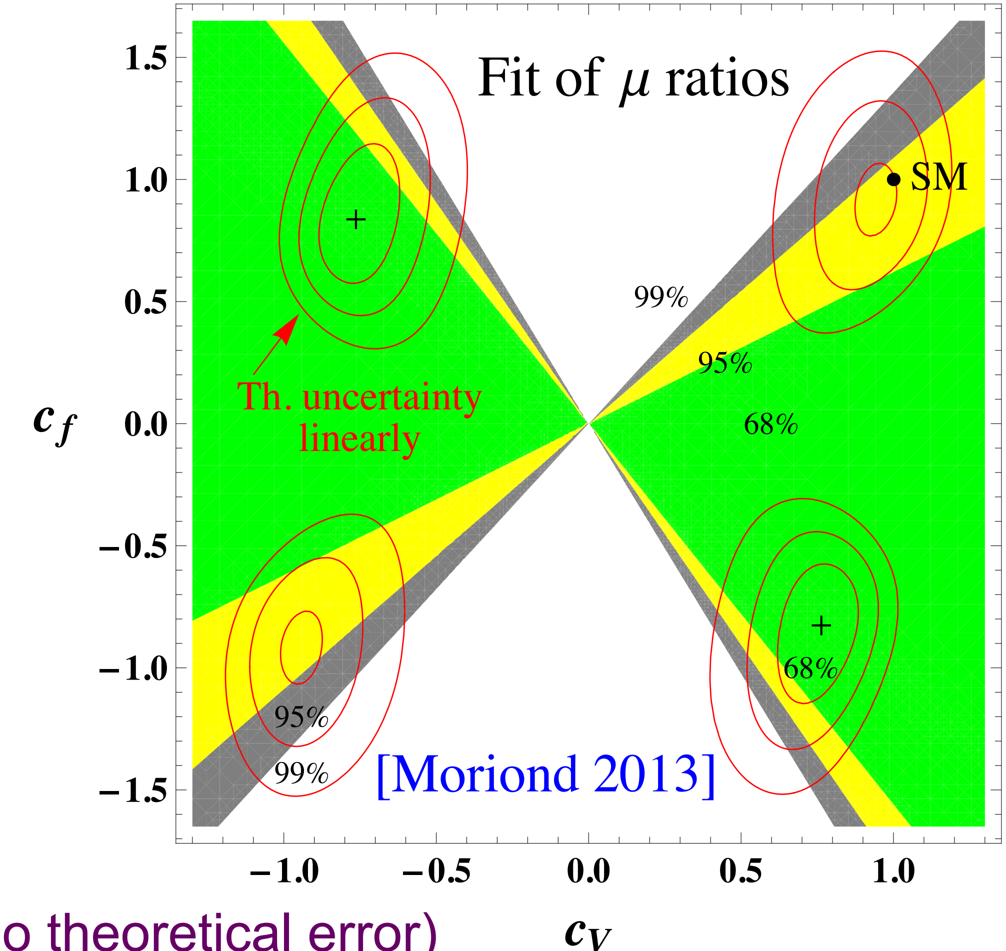
Theoretical error added linearly
(no statistical distribution)

⬇

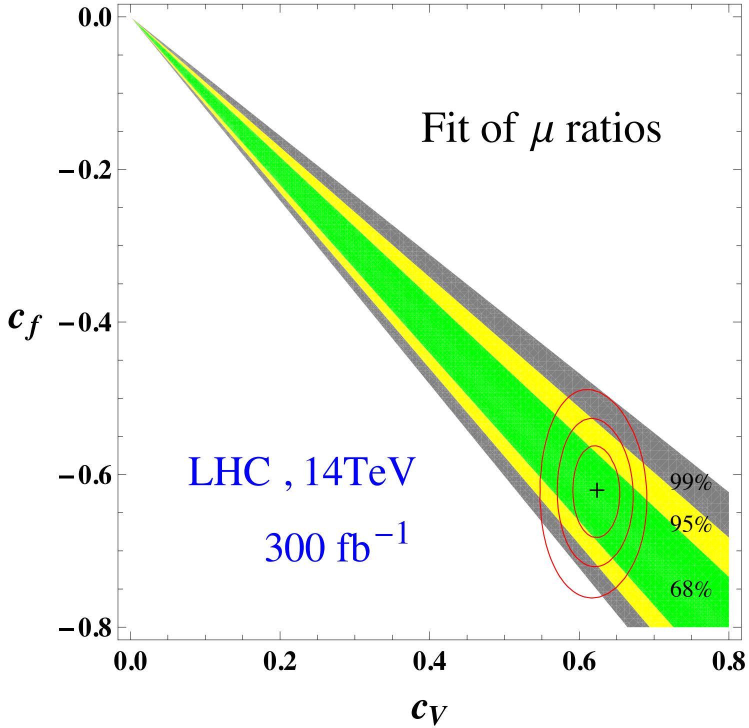
Best-fit χ^2 regions larger

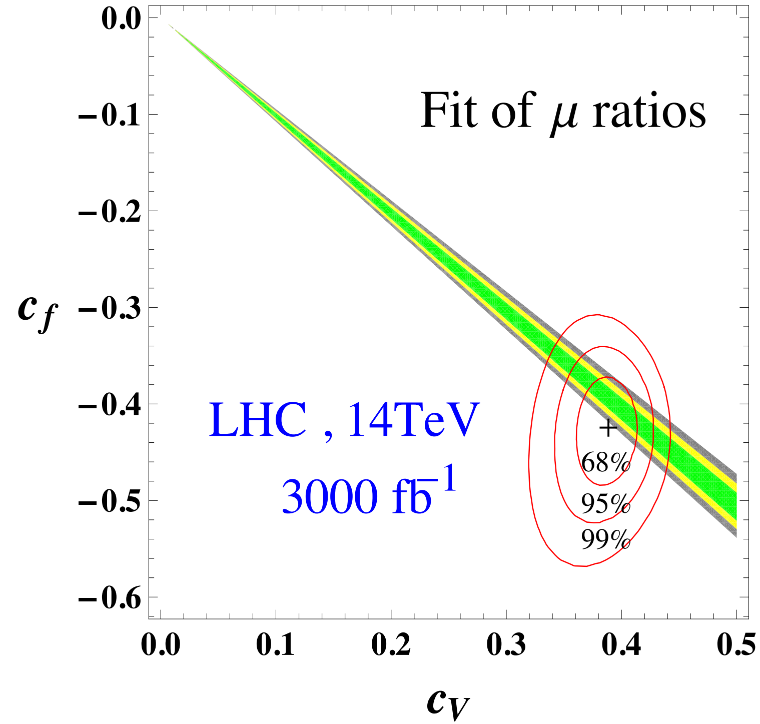
⬇

χ_r^2 domains rule out
χ^2 regions at 1σ
including the **SM** *point !*



(more constraining with χ_r^2 as no theoretical error)





Assuming the statistical error to decrease like $1/\sqrt{\sigma_i \mathcal{L}}$ we add up **14TeV LHC** results in the fits…

χ^2 dominated by $\delta_{\rm th}$ => constant region sizes
χ^2_r uncertainties decrease => more precise c's

Crucial χ^2_r rôle

Conclusions (B)

- Fitting the ratios of Higgs rates already improves the constraints on the c_f , c_V parameters (for linear combination of exp./th. uncertainties)

- *Combining the fits of the signal strengths and of their ratios can turn out to be crucial for the precise determination of the Higgs couplings @ LHC.*

Back up

$$\epsilon_t c_t = \frac{\operatorname{sign}(m_t)}{\operatorname{sign}(m_t^{\mathrm{EF}})}\, c_t = \frac{\operatorname{sign}(m_t)}{\operatorname{sign}(m_t^{\mathrm{EF}})}\, \frac{\operatorname{sign}(-Y_t^{\mathrm{EF}})}{\operatorname{sign}(-Y_t)}\, |c_t| = \frac{\operatorname{sign}(-Y_t^{\mathrm{EF}})}{\operatorname{sign}(m_t^{\mathrm{EF}})}\, |c_t| = \operatorname{sign}\left(\frac{-Y_t^{\mathrm{EF}}}{m_t^{\mathrm{EF}}}\right) \left|\frac{Y_t^{\mathrm{EF}}}{Y_t}\right|$$