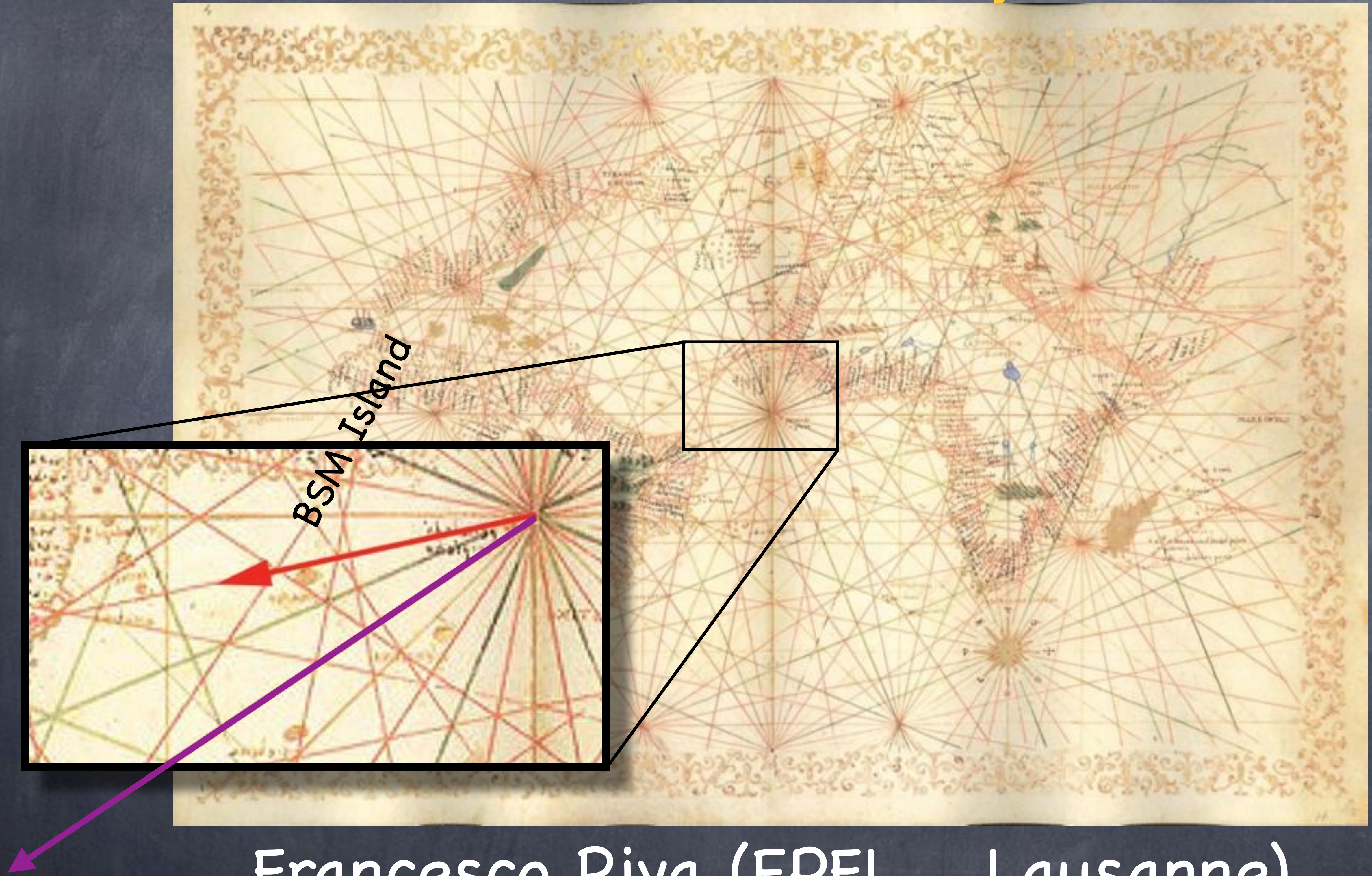
BSM Seaways

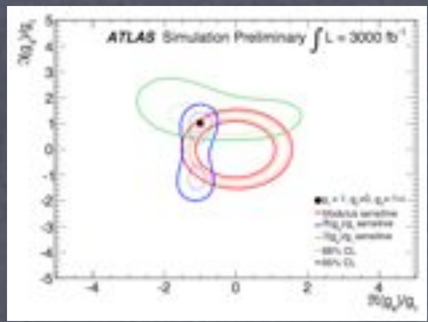


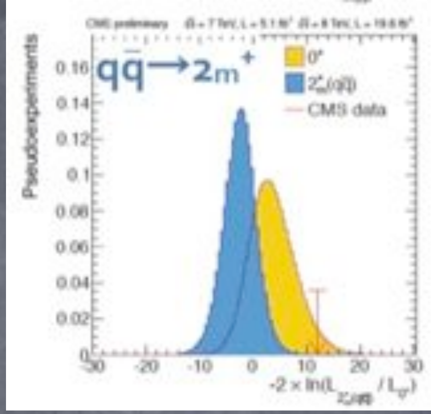
Francesco Riva (EPFL - Lausanne)

In Collaboration with: Pomarol, Gupta, Masso, Espinosa, Elias-Miro
(1308.2803 ,1308.1879, xxx)

Motivation

Searches for New Physics

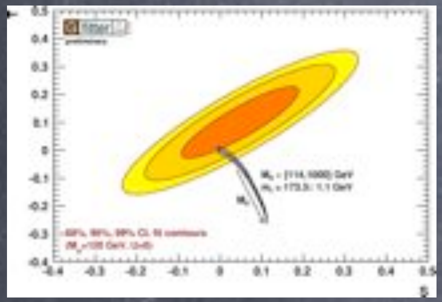


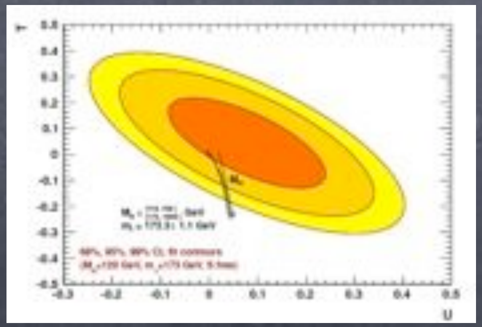


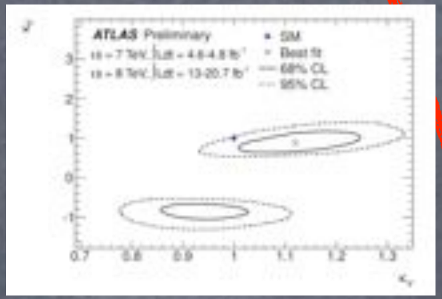
$\mathcal{L}^{SM}$

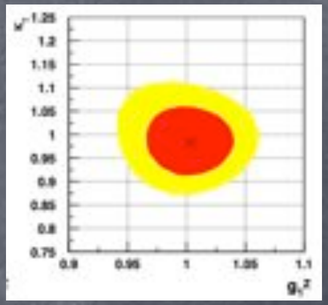
Direct

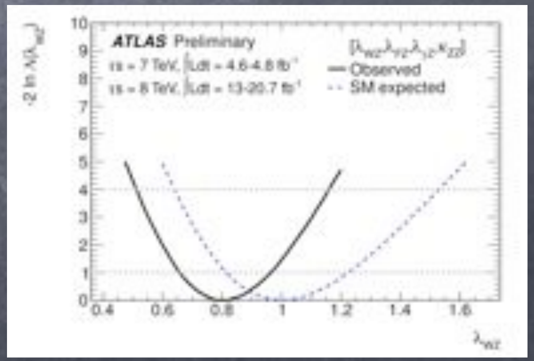
Precision

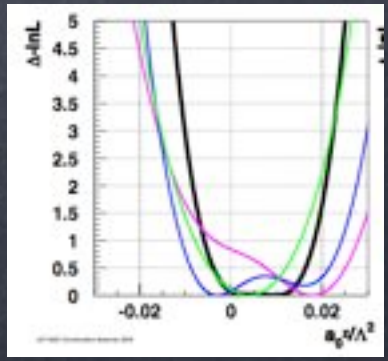












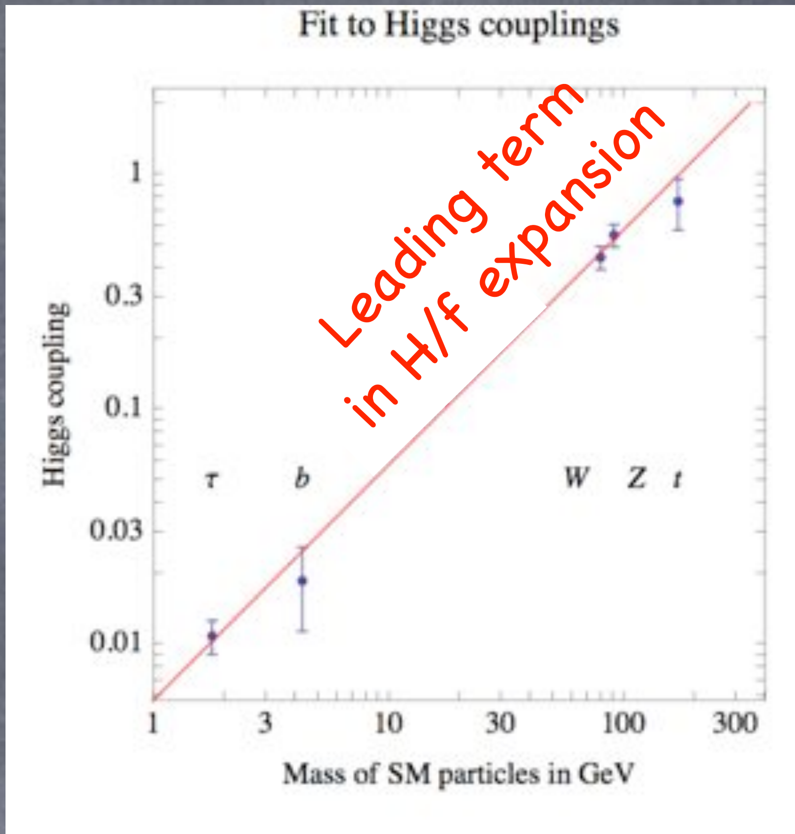
Assumptions

1) No direct findings: $M^i_{new} \sim \Lambda \gg v$

➜ Expansion in E/Λ

2) A Higgs has been found: it is the excitation around EWSB vacuum

➜ Expansion in H/f ($H \to v+h$) $\quad (f \equiv \Lambda/g_*)$



Giardino,Kannike,Masina, Raidal,Strumia'13

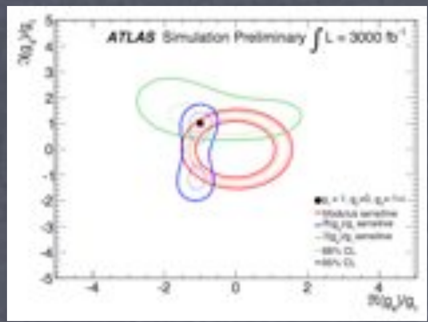
3) Minimal Flavor Violation ($U(3)^5$)

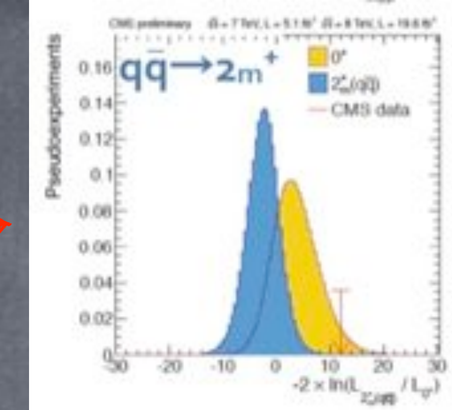
➜ Expansion in Y_U, Y_D, Y_E

D'ambrogio,Giudice, Isidori,Strumia'02

4) B,L conserved at this level of precision: $\Lambda_{\not B}, \Lambda_{\not L} \gg \Lambda$

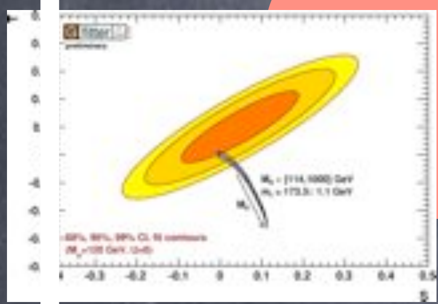
Motivation

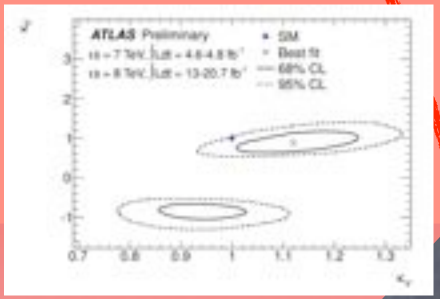


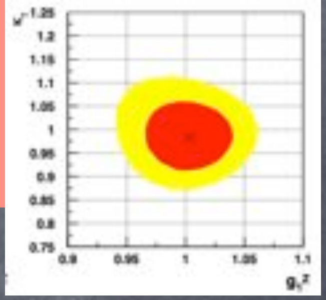


$\mathcal{L}^{SM} \equiv \mathcal{L}^4$ Many accidental Symmetries/Relations:
$m_W = m_Z \cos\theta_W$
$g_{h\bar{f}f} = m_f/v$
...

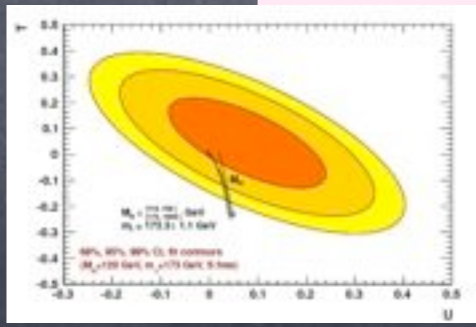
$\mathcal{L}^6$ What accidental Symmetries/Relations?

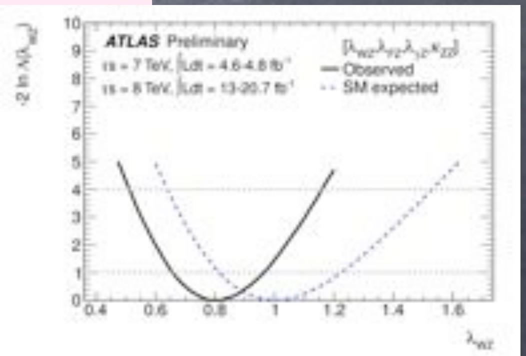


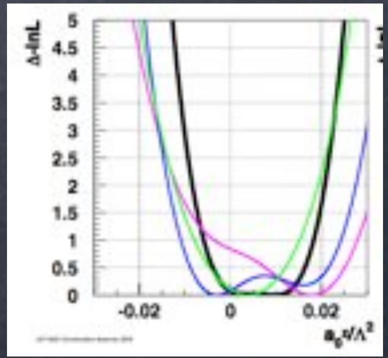




$\mathcal{L}^8$







$\mathcal{L}^{UV}$

Expansion

1) E/Λ

2) H/f

3) Y_U, Y_D, Y_E

Plan

1) Take the BSM Lagrangian $\mathcal{L}^6$ from Alex

(and rewrite it with gauge-invariant operators)

→ accidental relations

2) Compare with Experiments

→ understand implications for h-physics

3) Compare with BSM Theories

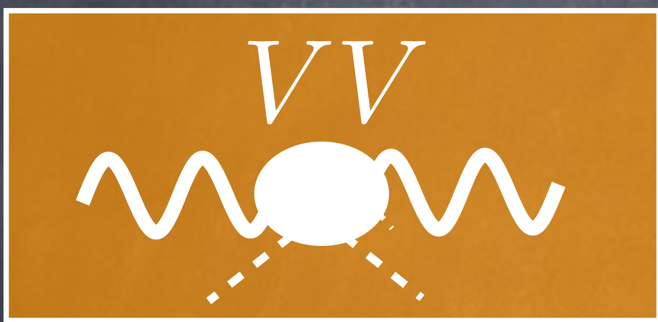
1) Expanding the Lagrangian

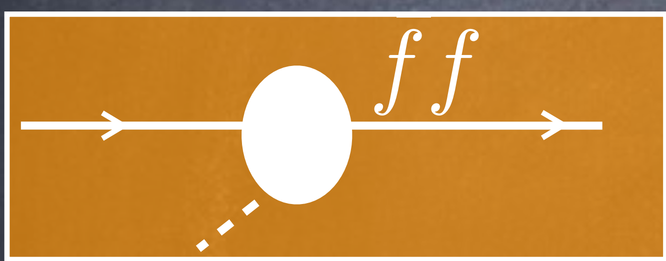
$$\mathcal{L}_{\rm eff} = \frac{\Lambda^4}{g_*^2}\mathcal{L}\left(\frac{D_\mu}{\Lambda}\,,\,\frac{g_* H}{\Lambda}\,,\,\frac{g_* f_{L,R}}{\Lambda^{3/2}}\,,\,\frac{g F_{\mu\nu}}{\Lambda^2}\right) \simeq \mathcal{L}_4 + \mathcal{L}_6 + \cdots\,,$$

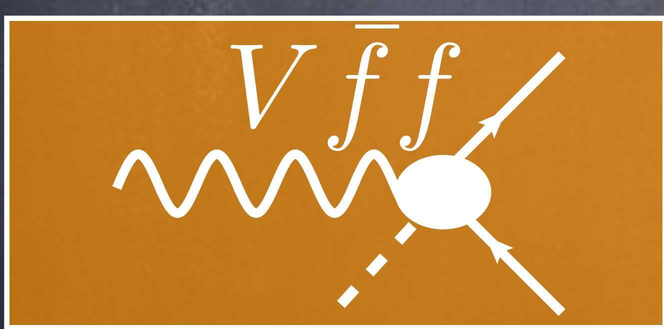
What are the relevant operators to include for studying Higgs physics?

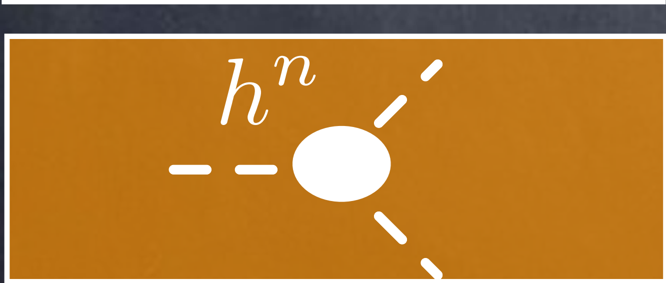
Buchmuller,Wyler'86;
Grzadkowski,Iskrzynski,Misiak,Rosiek'10

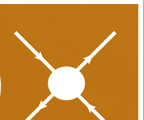
Dimension-6 Operators











	~~$SU(2)_L$~~	$SU(2)_L$
VV	$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$ $\mathcal{O}_{WB} = g' g H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{BB} = g'^2 \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$ $\mathcal{O}_{GG} = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$ $\mathcal{O}_{WW} = g^2 \lvert H\rvert^2 W^a_{\mu\nu} W^{\mu\nu\, a}$ $\mathcal{O}_r = \lvert H\rvert^2 D_\mu H^\dagger D_\mu H$
ff		$\mathcal{O}_{y_f} = y_f \lvert H\rvert^2 \bar{f}_L H f_R$ $f = L, U, D$
$V\bar{f}f$	$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$ $\mathcal{O}_L^l = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu L_L)$ $\mathcal{O}_L^{(3)\,l} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu \sigma^a L_L)$ + 4 for quarks	
h^n		$\mathcal{O}_6 = \lambda \lvert H\rvert^6$
Other (non-H)		

Giudice,Grojean,Pomarol,Rattazzi'07
Low,Rattazzi,Vichi'09
Elias-Miro,Espinosa,Masso,Pomarol'13
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Equivalent Bases

Grzadkowski,Iskrzynski,Misiak,Rosiek'10
Skiba,Han,'05
Jenkins,Manohar,Trott'13

~~$SU(2)_L$~~	$SU(2)_L$
$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$	$\mathcal{O}_{BB} = g'^2 \lvert H\rvert^2 B_{\mu\nu}B^{\mu\nu}$
	$\mathcal{O}_{GG} = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu}G^{A\mu\nu}$
$\mathcal{O}_{WB} = g' g H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{WW} = g^2 \lvert H\rvert^2 W^a_{\mu\nu} W^{\mu\nu\, a}$
	$\mathcal{O}_r = \lvert H\rvert^2 D_\mu H^\dagger D_\mu H$
	$\mathcal{O}_{y_f} = y_f \lvert H\rvert^2 \bar{f}_L H f_R$ $f = L, U, D$
$\mathcal{O}^e_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$	
$\mathcal{O}^l_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu L_L)$	
$\mathcal{O}^{(3)\,l}_L = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu \sigma^a L_L)$	
+ 4 for quarks	
	$\mathcal{O}_6 = \lambda \lvert H\rvert^6$

Only Flavor diagonal part

$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$

$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$

$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$

$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$

$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right) \partial^\nu B_{\mu\nu}$

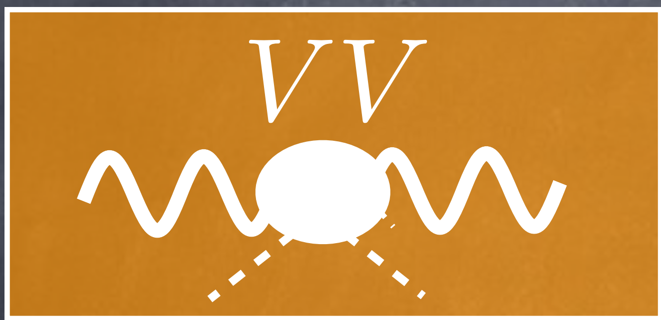
2) Confronting with Experiments

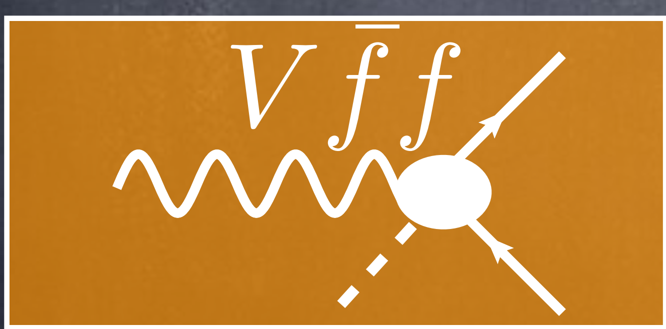
EFT predictive when
#parameters < #observables

Which Experiments?

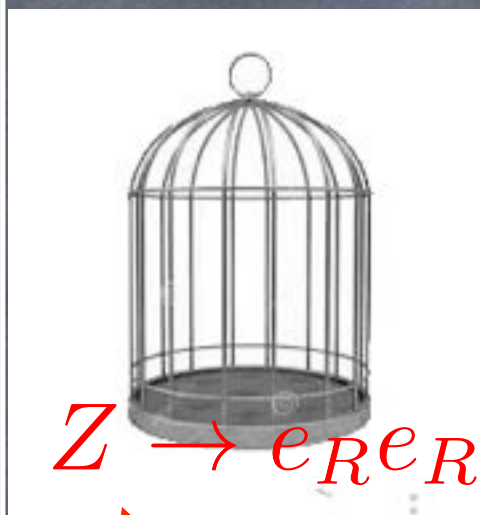
Affect Higgs physics ONLY!

Can be measured ALSO in th VACUUM h=v! (better...)





~~$SU(2)_L$~~	$SU(2)_L$



$Z \to e_R e_R$

$h \to Z e_R e_R$

$\cdots$

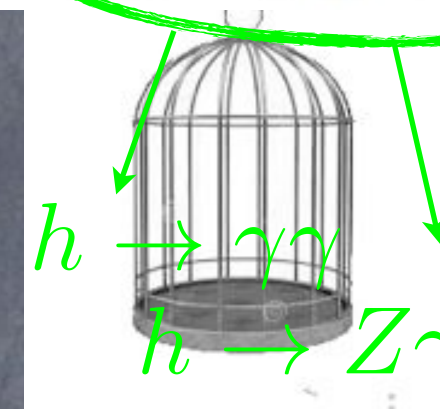
$$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$$

$$\mathcal{O}_L^l = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu L_L)$$

$$\mathcal{O}_L^{(3)\,l} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu \sigma^a L_L)$$

$$\mathcal{O}_{BB} = g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu}$$

$$\mathcal{O}_{WW} = g^2 |H|^2 W^a_{\mu\nu} W^{\mu\nu\,a}$$



$h \to \gamma\gamma$

$h \to Z\gamma$

$h \to ZZ^*$

$h \to WW^*$

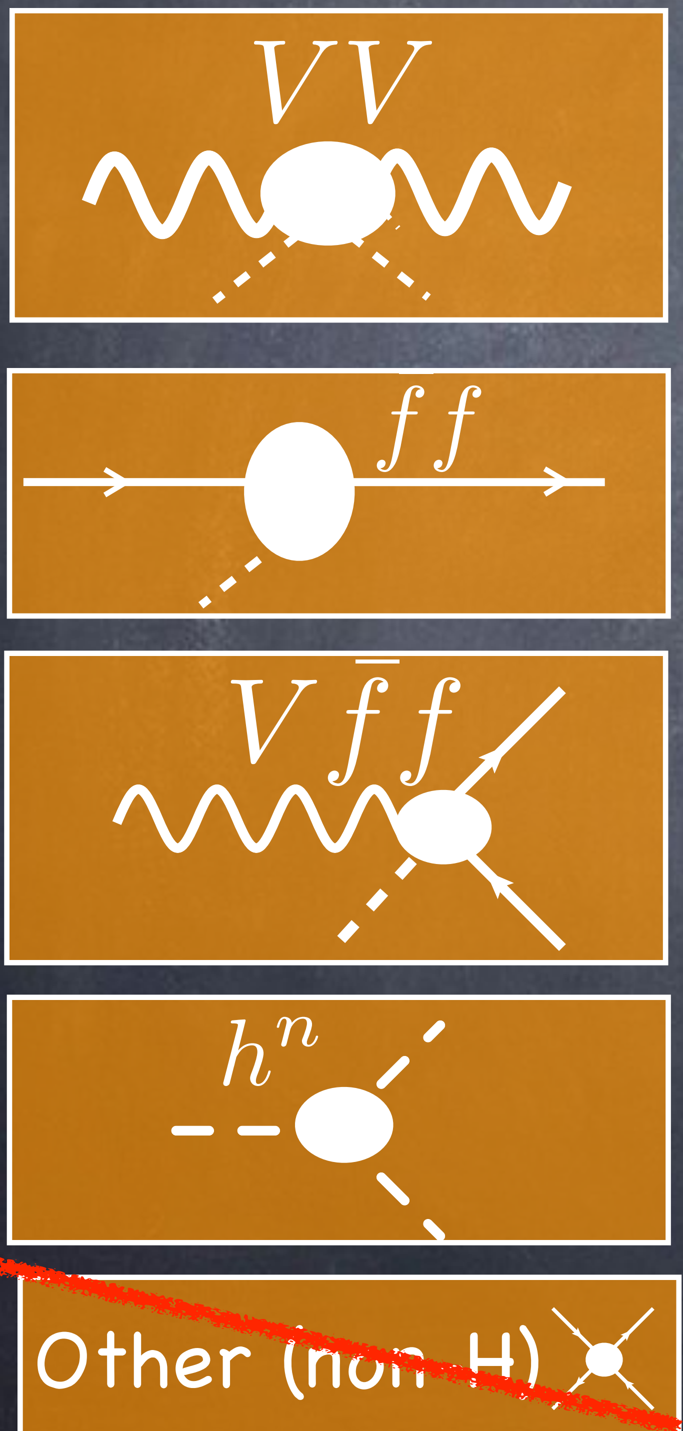
$WW \to hh$

$\cdots$

Use strongest experiment to constrain direction

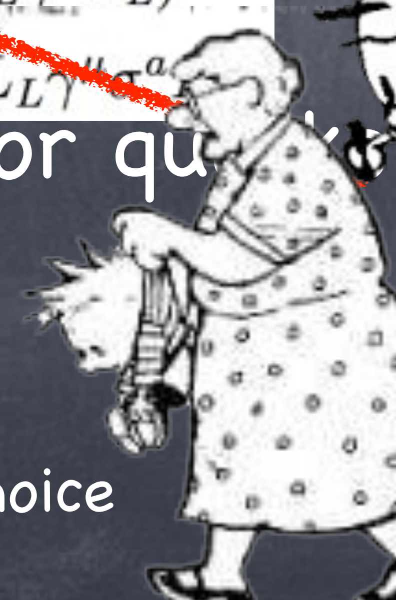
→ Make predictions for other (Higgs) physics

LEP 1: ‰ constraints



~~$SU(2)_L$~~	$SU(2)_L$
~~$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$~~ ~~$\mathcal{O}_{WB} = g'gH^\dagger\sigma^a H W^a_{\mu\nu}$~~ ~~$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R\gamma^\mu e_R)$~~ ~~$\mathcal{O}_L^l = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L\gamma^\mu L_L)$~~ ~~$\mathcal{O}_L^{(3)\,l} = (iH^\dagger\sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L\gamma^\mu\sigma^a$~~ + 4 for qu (requires intelligent choice of input parameters)	How many parameters can LEP1 constrain? 7 $\Gamma(Z\to l_Ll_L, l_Rl_R, \nu\nu)$ $\Gamma(Z\to u_{L,R}u_{L,R}, d_{L,R}d_{L,R})$ In this case SILH basis more transparent $\{\mathcal{O}_W+\mathcal{O}_B, \mathcal{O}_T, \mathcal{O}_R^e, \mathcal{O}_R^u, \mathcal{O}_R^d, \mathcal{O}_L^q, \mathcal{O}_L^{(3)q}\}$

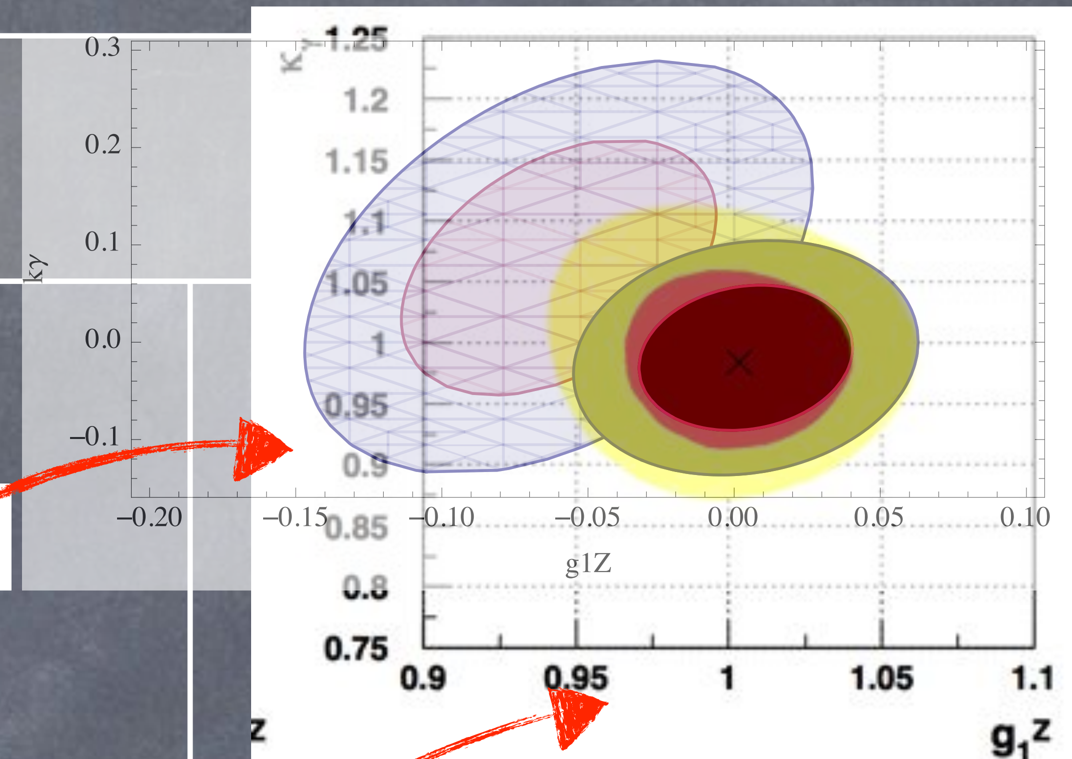




2+8 Directions after LEP1

~~$SU(2)$~~$_L$

$$\mathcal{O}_{WB} = g' g H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$$



LEP2

$$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$$

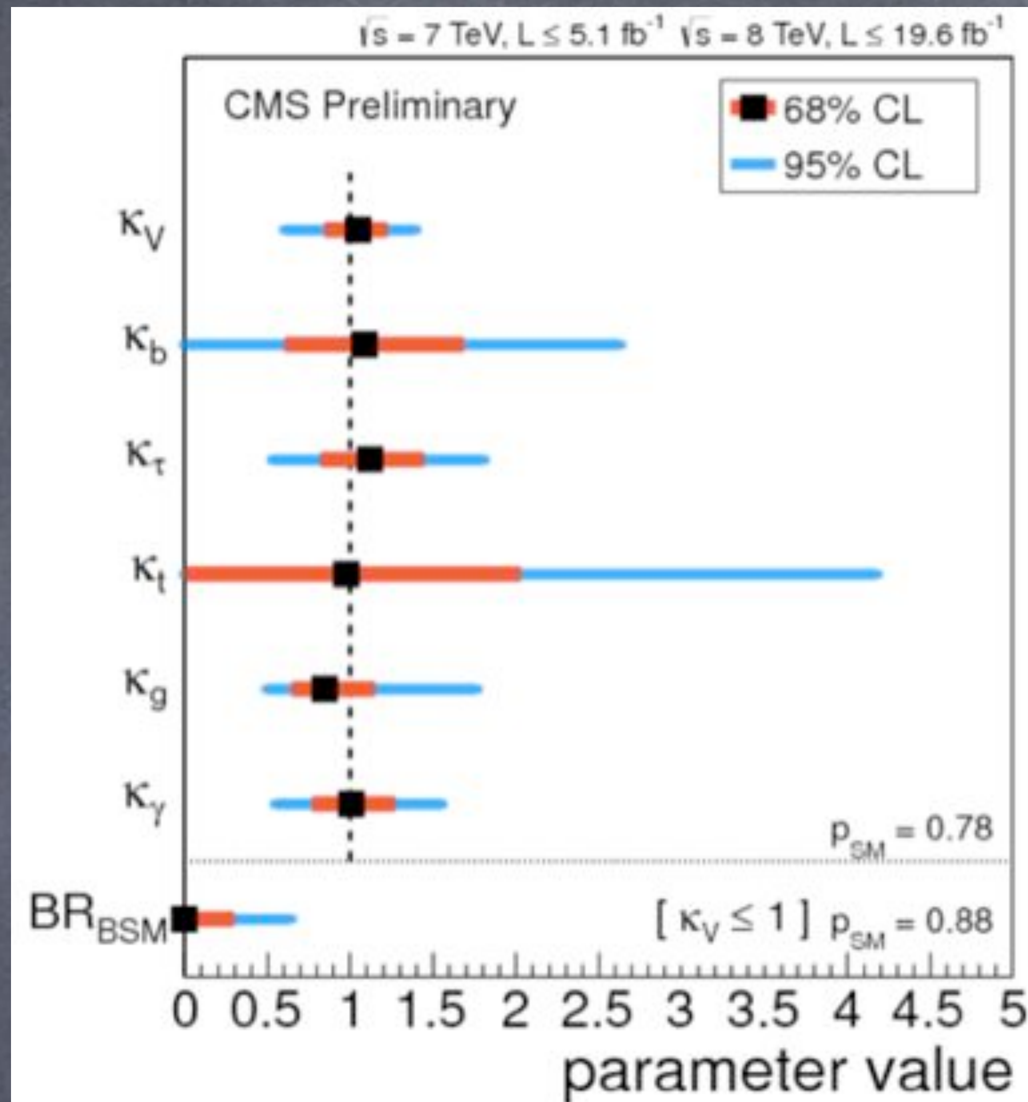
$$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$$

$$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_{\mu} W^b_{\nu\rho} W^{c\,\rho\mu}$$

Parameter	68% C.L.	95% C.L.	Correlations Δg_1^Z	λ_γ	$\Delta\kappa_\gamma$
Δg_1^Z	$-0.060^{+0.031}_{-0.030}$	$[-0.118, \ +0.002]$	1.0	−0.55	−0.41
λ_γ	$0.038^{+0.031}_{-0.032}$	$[-0.027, \ +0.099]$	−0.55	1.0	−0.04
$\Delta\kappa_\gamma$	$0.077^{+0.070}_{-0.070}$	$[-0.050, \ +0.218]$	−0.41	−0.04	1.0

Delphi

2+8 Directions after LEP1



$SU(2)_L$

$$\mathcal{O}_{BB} = g'^2|H|^2 B_{\mu\nu}B^{\mu\nu}$$
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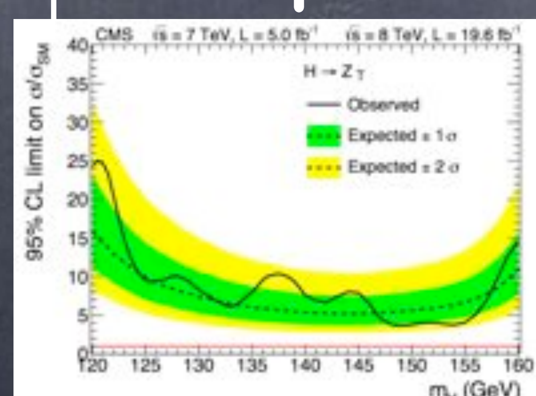
$$\mathcal{O}_{WW} = g^2|H|^2 W^a_{\mu\nu}W^{\mu\nu\, a}$$
$$\mathcal{O}_r = |H|^2 D_\mu H^\dagger D_\mu H$$

$$\mathcal{O}_{y_f} = y_f|H|^2 \bar{f}_L H f_R$$
$$f = L, U, D$$

+



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h^3?

$$\mathcal{O}_6 = \lambda|H|^6$$

All operators already constrained*

- Look at implications for other observables!

*= Although not measured, h^3 doesn't affect arguments

Implications 1

Custodial Symmetry in h decays λ_{WZ}

Related to constrained dim-6 operators...
which ones?

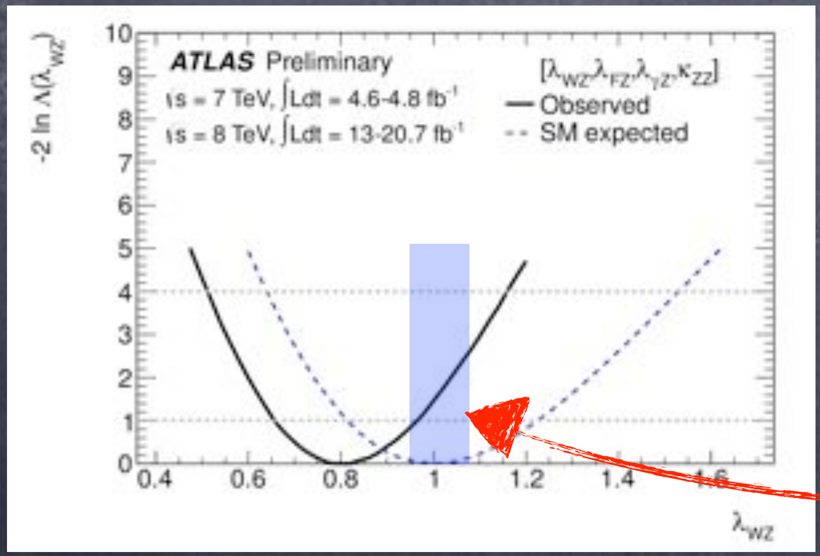
LEP 1

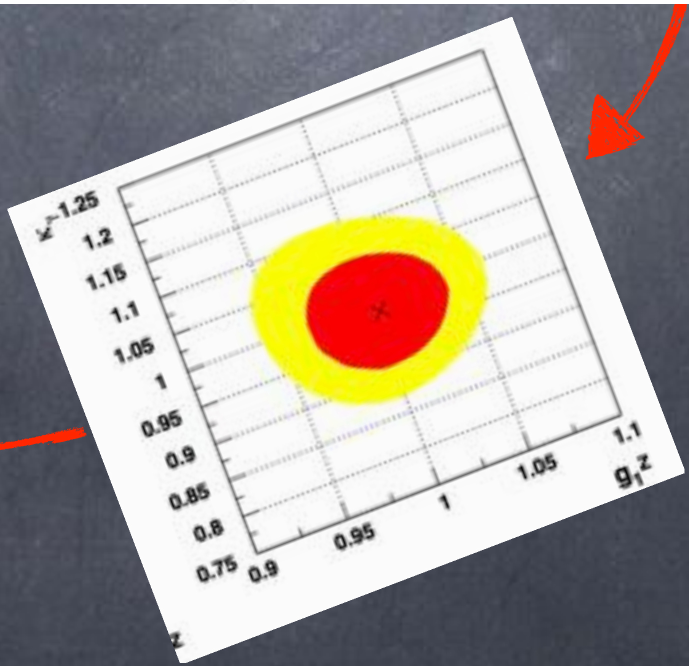
- ~~$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$~~ affects only $h \to ZZ$
- $\mathcal{O}_W - \mathcal{O}_B$ through:

Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

$$\frac{\Gamma(h \to W^{(*)}W^{*})}{\Gamma(h \to W^{(*)}W^{*})_{SM}} \simeq 1 + 2.2\,\bar{c}_W\,,$$

$$\frac{\Gamma(h \to Z^{(*)}Z^{*})}{\Gamma(h \to Z^{(*)}Z^{*})_{SM}} \simeq 1 + 2.0\left(\bar{c}_W + \tan^2\theta_W\,\bar{c}_B\right)$$





Pomarol,FR'13

- Bounds from LEP2 (through relations in $\mathcal{L}^6$), stronger than direct bounds

Implications 2

Deviations in different. distr. of $h \to Z\bar{f}f$ or $h \to W\bar{f}f$

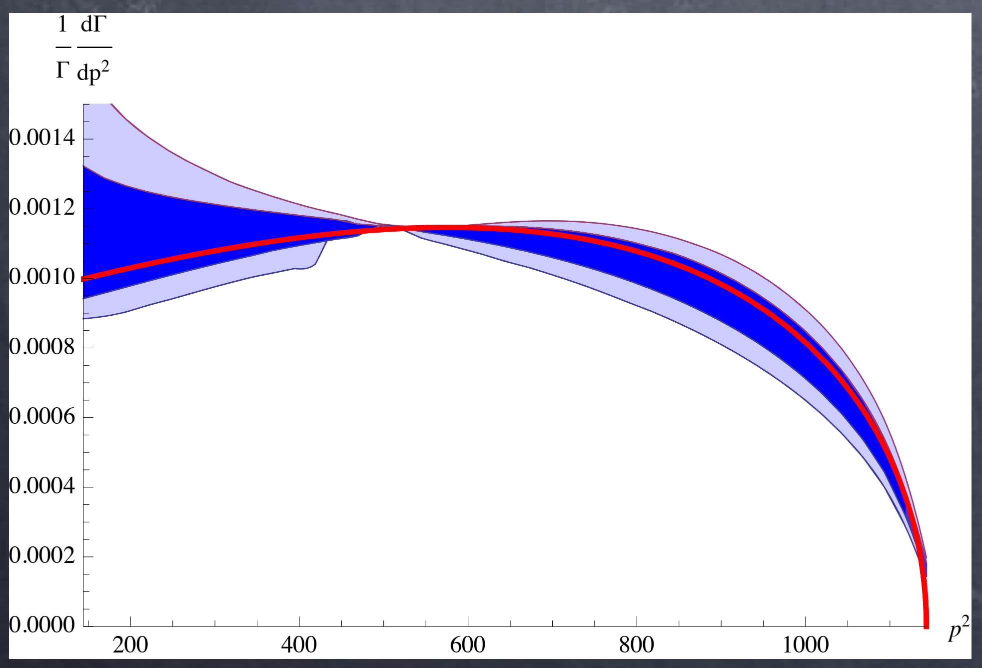
Related to constrained dim-6 operators... See e.g. Isidori,Manohar,Trott'13

which ones?

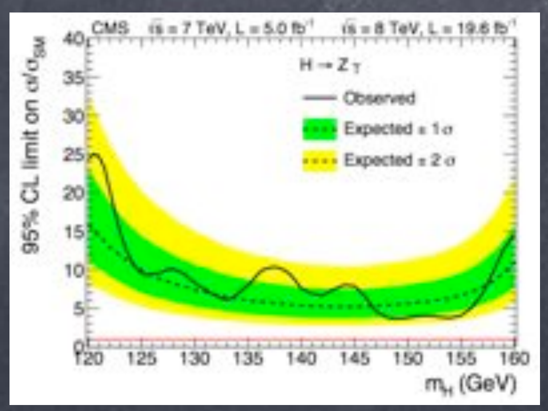
LEP 1

- ~~$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R\gamma^\mu e_R)$~~
  ~~$\mathcal{O}_L^l = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L\gamma^\mu L_L)$~~
  ~~$\mathcal{O}_L^{(3)\,l} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{L}_L\gamma^\mu \sigma^a L_L)$~~

- $\mathcal{O}_W - \mathcal{O}_B$ → Related with Triple Gauge Coupling
- $\mathcal{O}_{WW}, \quad \mathcal{O}_{BB}$ Related with $h \to Z\gamma, \gamma\gamma$



Pomarol,FR'13



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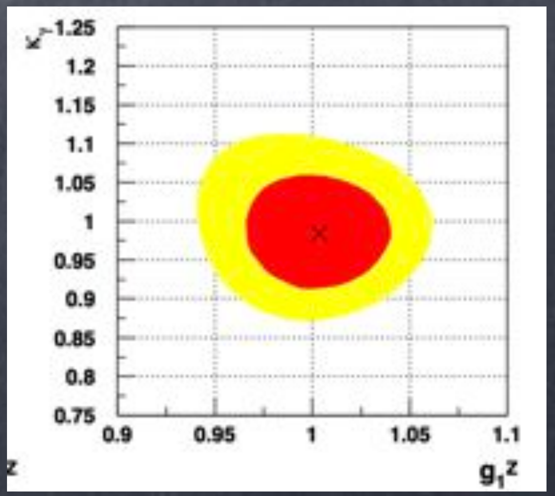

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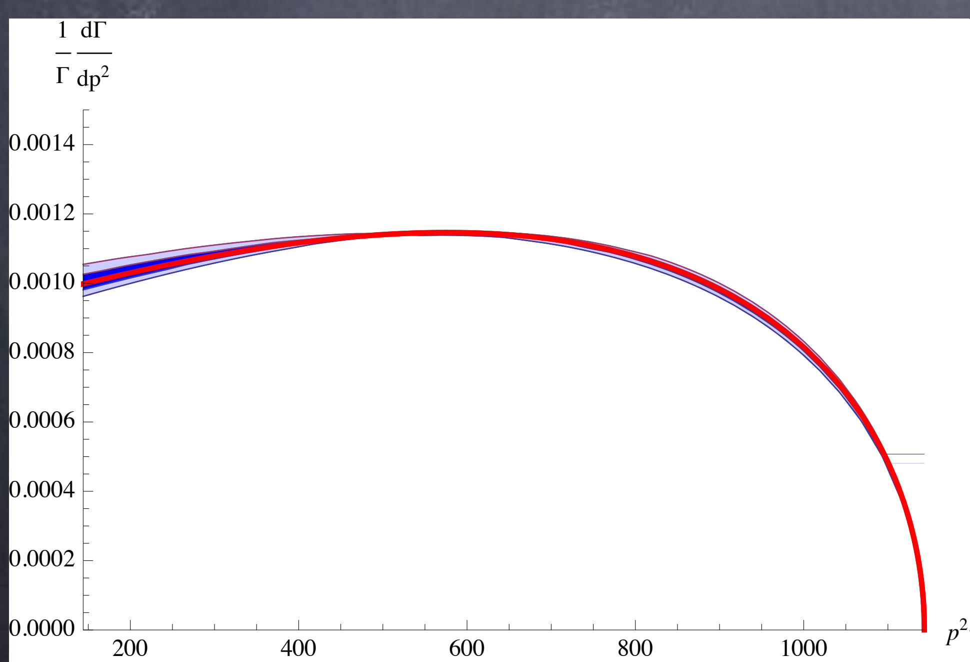
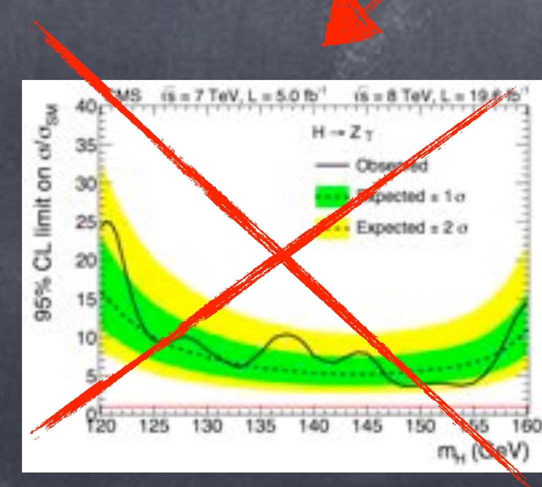


Pomarol,FR'13



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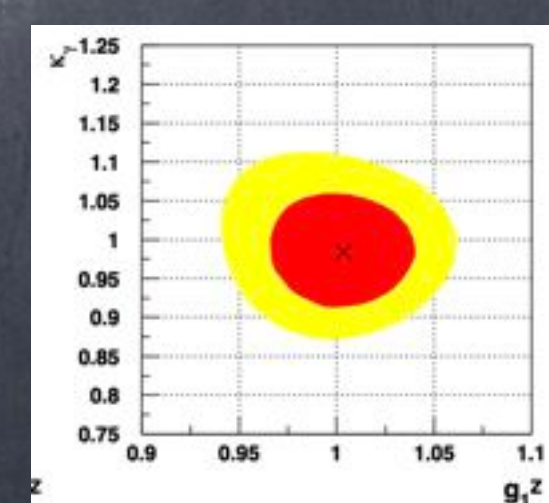


3) Comparison with Theory

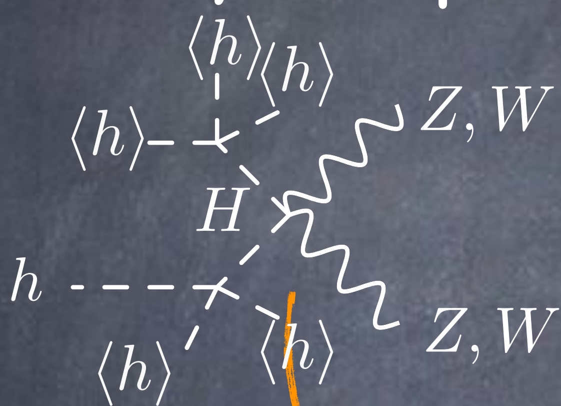
- (N)MSSM
- Composite Higgs

Explicit Examples

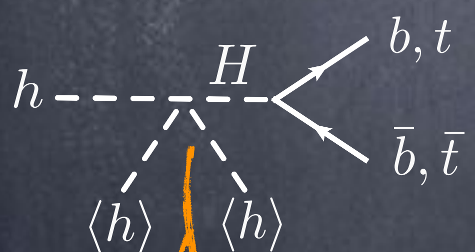
MSSM

R-Parity: no tree-level contributions from sparticles (only H_2)

Weakly coupled: loop effects small unless sparticles very light



$$c_H \sim \frac{m_Z^4}{m_H^4}$$



$$c_{y_t} \sim \frac{m_Z^2}{m_H^2} \cot\beta$$

$$c_{y_{d,e}} \sim \frac{m_Z^2}{m_H^2} \tan\beta$$

~~$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$~~	~~$\mathcal{O}_{BB} = g'^2 \lvert H\rvert^2 B_{\mu\nu}B^{\mu\nu}$~~
[redacted]	~~$\mathcal{O}_{GG} = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu}G^{A\mu\nu}$~~
$\mathcal{O}_6 = \lambda \lvert H\rvert^6$	~~$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$~~
~~$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$~~	~~$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$~~
[redacted]	~~$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_{\mu} W^b_{\nu\rho} W^{c\,\rho\mu}$~~

~~$\mathcal{O}_{y_u} = y_u \lvert H\rvert^2 \bar{Q}_L \tilde{H} u_R + \text{h.c.}$~~	$\mathcal{O}_{y_d} = y_d \lvert H\rvert^2 \bar{Q}_L H d_R + \text{h.c.}$	$\mathcal{O}_{y_e} = y_e \lvert H\rvert^2 \bar{L}_L H e_R + \text{h.c.}$
[redacted]		[redacted]

Gupta,Montull,FR'12

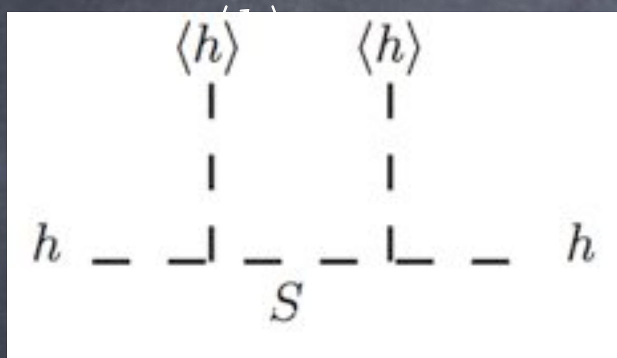
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Explicit Examples

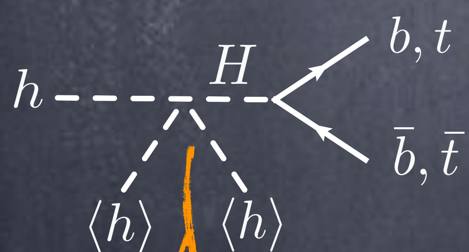
NMSSM

R-Parity: no tree-level contributions from sparticles (only H_2)

Weakly coupled: loop effects small unless sparticles very light



$$c_H \sim \frac{m_Z^2}{m_S^2}$$



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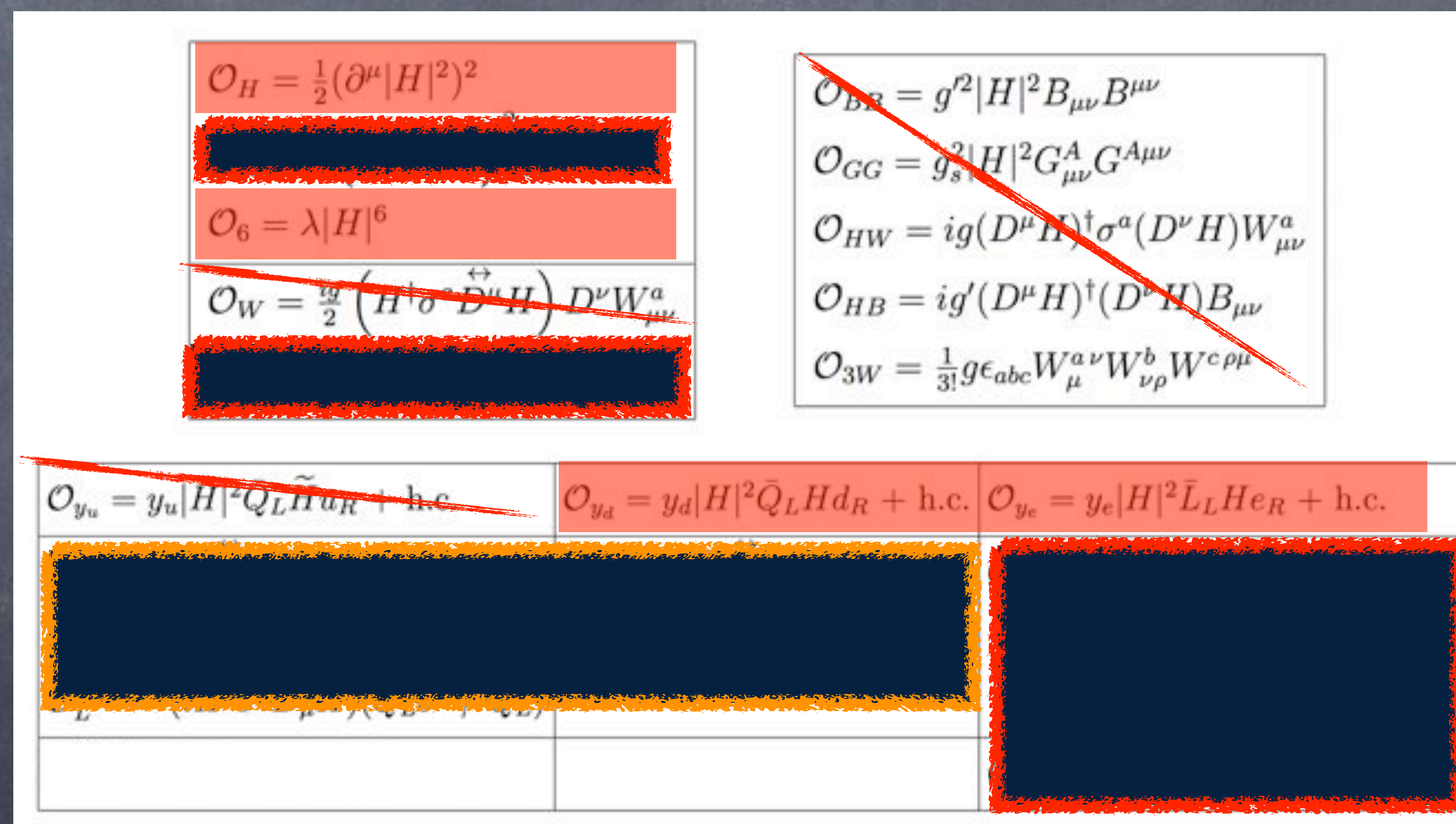

$\mathcal{O}_H = \frac{1}{2}(\partial^\mu |H|^2)^2$

[redacted]

$\mathcal{O}_6 = \lambda |H|^6$

$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$

[redacted]

$\mathcal{O}_{BB} = g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu}$

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[redacted]	[redacted]	[redacted]

Gupta,Montull,FR'12

Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Explicit Examples

Composite Higgs

Strongly coupled: powers of H enhanced by g*>1 w.r.t. derivatives

Shift Symmetry: hgg and $h\gamma\gamma$ suppressed

$\frac{1}{f^2}$

$\frac{1}{\Lambda^2}$

$\frac{g_*^2}{16\pi^2\Lambda^2}$

$\mathcal{O}_H = \frac{1}{2}(\partial^\mu |H|^2)^2$

[redacted]

$\mathcal{O}_6 = \lambda |H|^6$

$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$

[redacted]

$\mathcal{O}_{BB} = g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu}$

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[redacted]		[redacted]

Giudice,Grojean,Pomarol,Rattazzi'07
Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Explicit Examples

Composite Higgs - with LR symmetry ($gW \leftrightarrow g'B$)

Strongly coupled: powers of H enhanced by g*>1 w.r.t. derivatives

Shift Symmetry: hgg and $h\gamma\gamma$ suppressed

$$\frac{g_*^2}{16\pi^2\Lambda^2}$$

$$\frac{1}{f^2}$$

$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$
[redacted]
$\mathcal{O}_6 = \lambda \lvert H\rvert^6$
$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger\sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$
[redacted]

~~$\mathcal{O}_{BB} = g'^2 \lvert H\rvert^2 B_{\mu\nu}B^{\mu\nu}$~~
~~$\mathcal{O}_{GG} = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu}G^{A\mu\nu}$~~
$\mathcal{O}_{HW} + \mathcal{O}_{HB}$
~~$\mathcal{O}_{3W} = \frac{1}{3!} g\epsilon_{abc} W^{a\nu}_{\mu} W^b_{\nu\rho} W^{c\rho\mu}$~~

$$\frac{1}{\Lambda^2}$$

$\mathcal{O}_{y_u} = y_u \lvert H\rvert^2 \bar{Q}_L \widetilde{H} u_R + \text{h.c.}$	$\mathcal{O}_{y_d} = y_d \lvert H\rvert^2 \bar{Q}_L H d_R + \text{h.c.}$	$\mathcal{O}_{y_e} = y_e \lvert H\rvert^2 \bar{L}_L H e_R + \text{h.c.}$
[redacted]		[redacted]

→ No modifications in $h \to Z\gamma$

Giudice,Grojean,Pomarol,Rattazzi'07

Contino,Ghezzi,Muhlleitner,Grojean,Spira'13

Conclusions

- How many operators need to be included to study Higgs physics?

~~7~~

2 $\{g_1^Z, \kappa_\gamma\}$

8 $\{\kappa_g, \kappa_\gamma, \kappa_V, \kappa_t, \kappa_b, \kappa_\tau, \kappa_{Z\gamma}, \kappa_{h^3}\}$

BACKUP

CP-Odd Terms?

$$\mathcal{O}_{B\widetilde{B}} = g'^2|H|^2 B_{\mu\nu}\widetilde{B}^{\mu\nu}\,, \qquad \mathcal{O}_{G\widetilde{G}} = g_s^2|H|^2 G^A_{\mu\nu}\widetilde{G}^{A\mu\nu}$$

$$\mathcal{O}_{H\widetilde{W}} = ig(D^\mu H)^\dagger\sigma^a(D^\nu H)\widetilde{W}^a_{\mu\nu}\,, \qquad \mathcal{O}_{H\widetilde{B}} = ig'(D^\mu H)^\dagger(D^\nu H)\widetilde{B}_{\mu\nu}$$

$$\mathcal{O}_{3\widetilde{W}} = \frac{1}{3!}g\epsilon_{abc}W^{a\,\nu}_{\mu}W^b_{\nu\rho}\widetilde{W}^{c\,\rho\mu}\,,$$

Counting similar to CP-even:

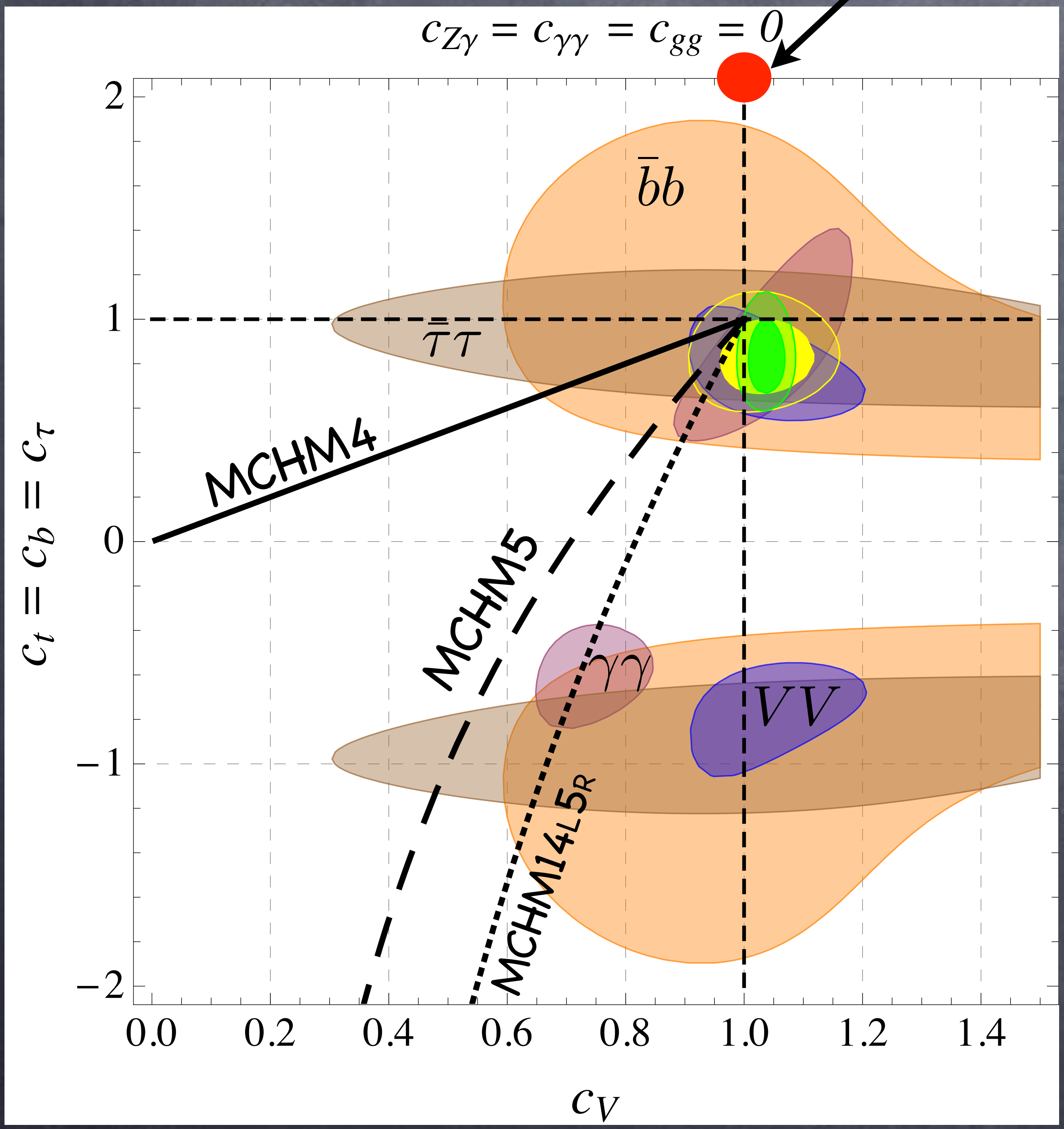
- 2 deformations in TGCs $\tilde{\kappa}_\gamma \quad \tilde{\lambda}_\gamma$
- 3 deformations in Higgs physics $h \to \gamma\gamma$, $gg \to h$, $h \to Z\gamma$

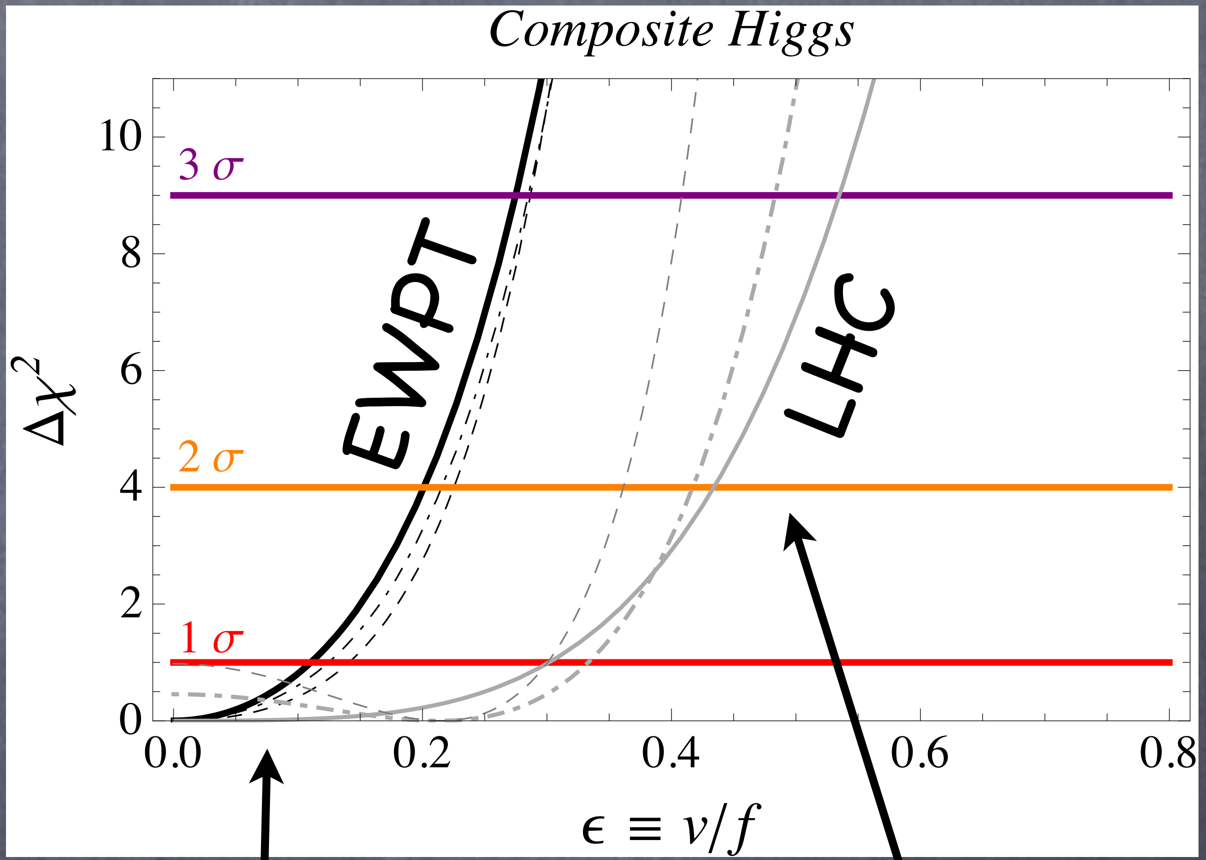
No interference with SM, nor with dim-6 CP-even

→ Need other experiments

NGBHiggs couplings to SM fields

$m \neq 0$ excluded





Strong sector contributions can weaken this bound

(not this)

Giudice,Grojean,Pomarol,Rattazzi '07;Barbieri,Bellazzini,Rychkov,Varagnolo'07; Pomarol,FR,'12; Falkowski,FR,Urbano,'13; many more...

Two Higgs Doublets Models, SUSY

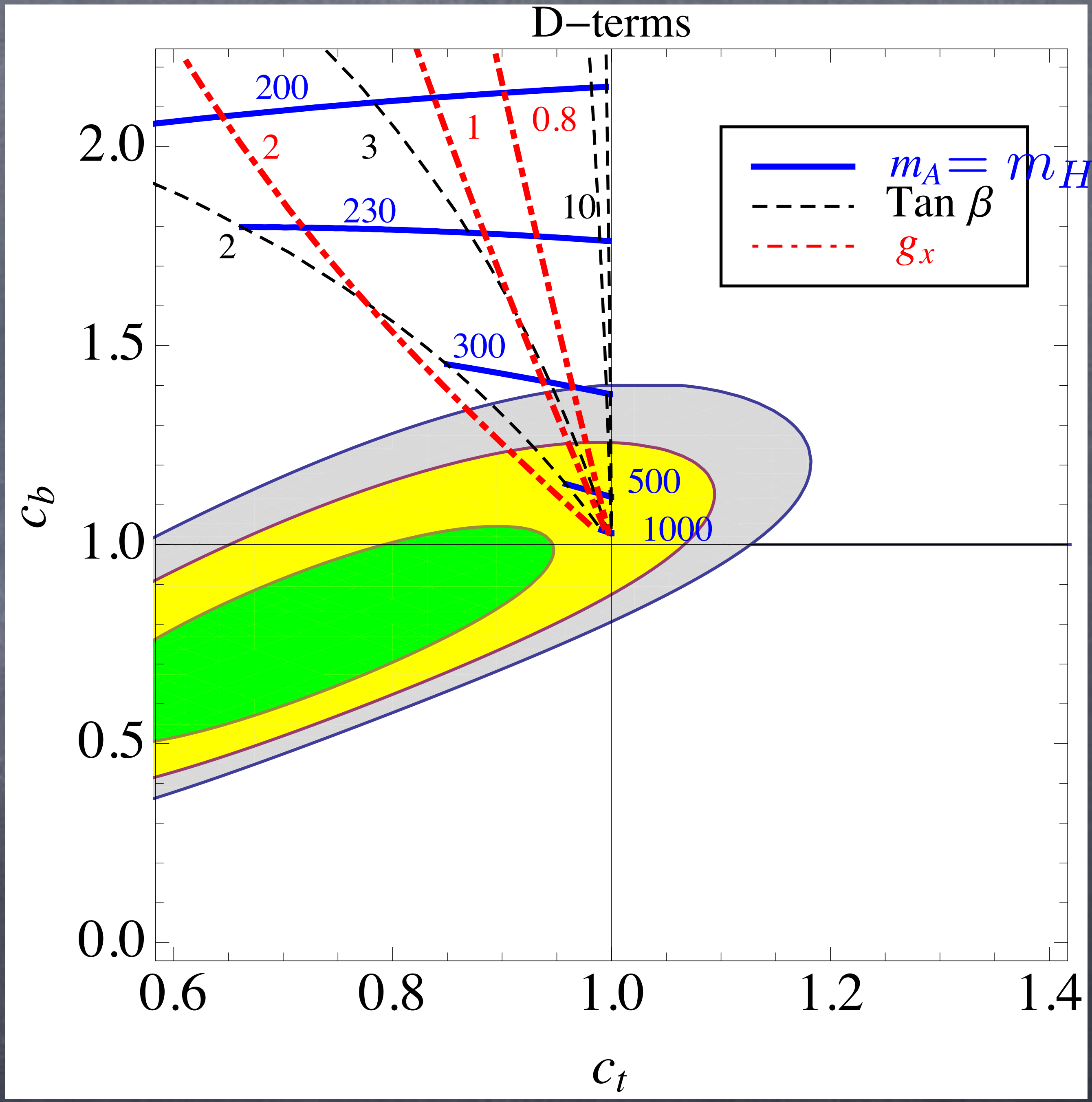
$$m_h^2 \approx m_Z^2 + 16\delta_\lambda v^2$$

$$\frac{y_b}{y_b^{SM}} = 1 - 4\delta \tan\tilde{\beta}\,\frac{v^2}{m_H^2}$$

$$\frac{y_t}{y_t^{SM}} = 1 + 4\delta \cot\tilde{\beta}\,\frac{v^2}{m_H^2}$$

D-Terms: $\Delta V = \kappa\left(|H_1^0|^2 - |H_2^0|^2\right)^2$

$$\delta = -\frac{m_h^2}{2v^2}\frac{t_\beta}{t_\beta^2 - 1}$$



Blum,D'Agnolo,Fan'12; Azatov,Chang,Craig,Galloway'12
Montull,Gupta, FR, '12

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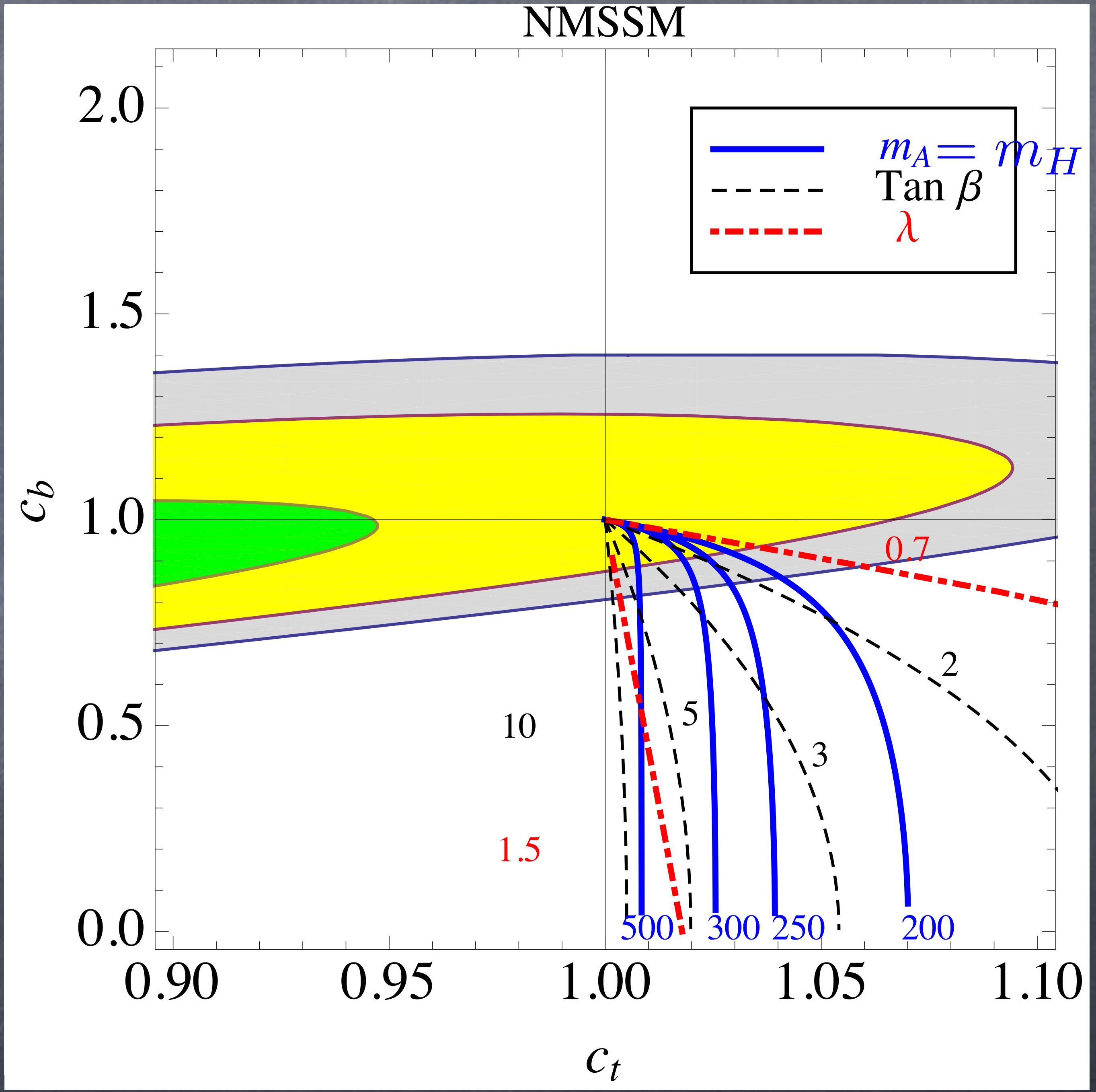


F-Terms (no mixing):

$$\Delta V = -\lambda_S^2 (H_1 H_2)^2 \frac{m_S}{M_S}$$

$$\Delta c_b \approx -t_\beta^2 (60\text{GeV}/m_H)^2$$

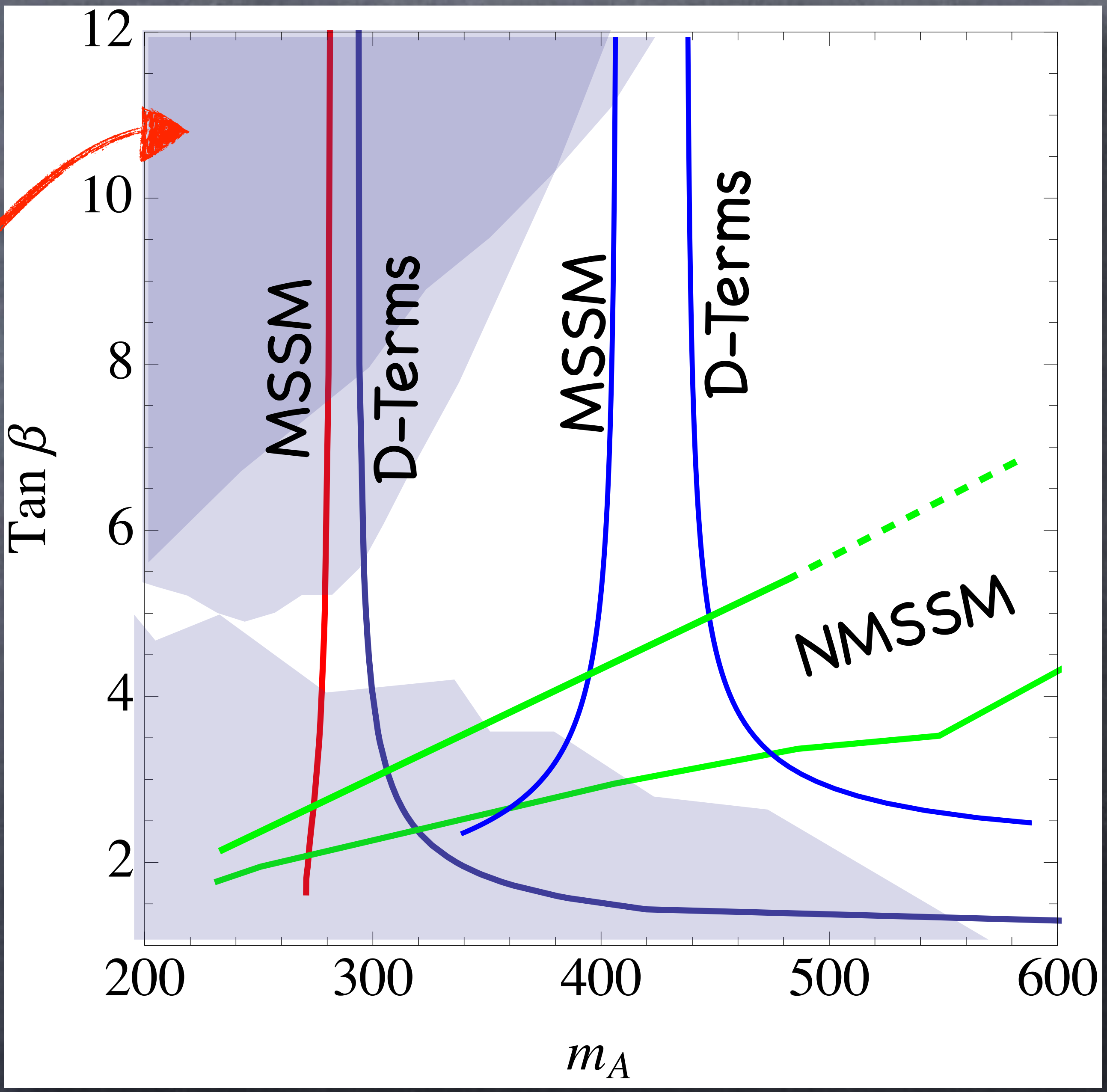
$$\Delta c_t \approx (60\text{GeV}/m_H)^2$$

Blum,D'Agnolo,Fan'12; Azatov,Chang,Craig,Galloway'12
Montull,Gupta, FR, '12

Two Higgs Doublets Models, SUSY

Nevertheless, no deviations imply:

$H \to \tau\tau$



Blum,D'Agnolo,Fan'12 ;D'agnolo,Kufflick,Zanetti'12;
Peskin'12; Linssen et al.'12; Montull,Gupta, FR, '12