Vanilla New Physics facing the Higgs boson

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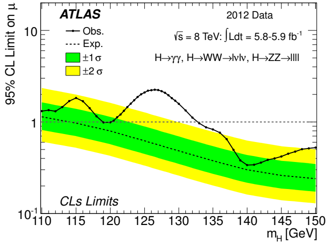
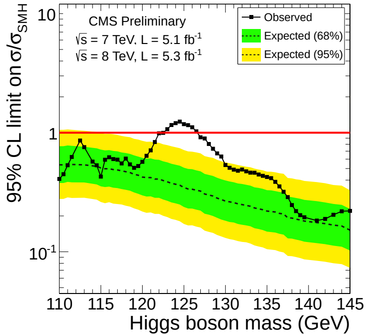
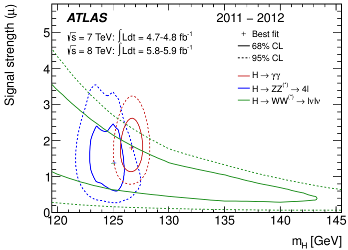
July 4^{th}, celebration day

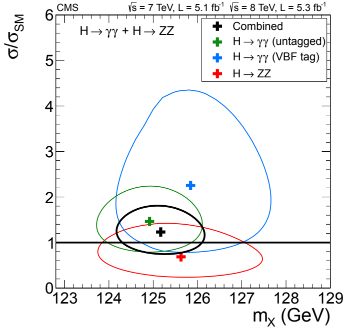




Next step: what's the shape of the Higgs?

Some interesting hints that something may be going on:



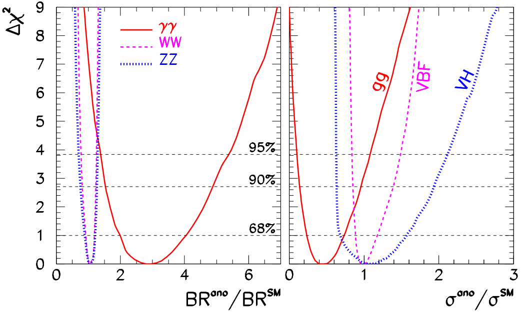


Consistent with SM at 95% C.L., but...

Fits to σ/σ_{SM} and BR/BR_{SM}

Many fits roughly in agreement

(Corbett et al., Giardino et al., Espinosa et al., Plehn et al, Montull et al.)



Corbett et al., 2012

Overall picture emerging

Everything compatible with SM, but best fit points hint to:

- WW, ZZ: $\simeq 1$
- GG: $\lesssim 1$
- $\gamma\gamma$: $\gtrsim 1$

at loop level in SM

is it new physics manifesting itself?

Useful way to see things

Key quantities:

$$R_{\gamma\gamma} = \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{SM}} \simeq \left| 1 + \sum_i \delta_C^i + \sum_j \delta_{NC}^j \right|^2$$

$$R_{GG} = \frac{\sigma(GG \to h)}{\sigma(GG \to h)_{SM}} \simeq \left| 1 - 9.7 \sum_i \frac{t_c^i}{N_c^i Q_i^2} \delta_C^i \right|^2$$

where

Loop function

$$\delta_{C,NC}^i = \frac{N_c^i Q_i^2 \frac{2 g_{hii}}{m_i} A_i\left(\frac{m_h^2}{4 m_i^2}\right)}{\mathcal{A}_W + \mathcal{A}_t}$$

-0.096 $\qquad$ 0.021

Useful way to see things 2

Since

$$\mathcal{A}_W + \mathcal{A}_t \simeq -0.075$$

if we want to increase $h \to \gamma\gamma$ we need $\delta_{C,NC} < 0$.
Possibilities:

	$\frac{2g_{hii}}{m_i}$	$A_i\left(\frac{m_h^2}{4m_i^2}\right)$
scalar	-	$+$
fermion	-	$+$
vector	$+$	-

with

$$A_{vector} \simeq -5A_{fermion}, \quad A_{fermion} \simeq (2-4)A_{scalar}$$

A closer look to $2g_{hii}/m_i$

Ellis et al. 76, Shifman et al. 79:

$$\frac{2g_{hii}}{m_i} = \frac{\partial}{\partial v}\lambda_i^2(v)$$

eigenvalues of $M^\dagger M$

Conclusion:
eigenvalues repulsion with vev-dependent mixing can do the job

Example: $M = \begin{pmatrix} m_1 & cv \\ cv & m_2 \end{pmatrix}$

$$\Rightarrow \quad \lambda_{1,2}^2 = \frac{m_1^2 + m_2^2 + 2c^2v^2 \mp (m_1+m_2)\sqrt{(m_1-m_2)^2 + 4c^2v^2}}{2}$$

Additional fermions

SM + (uncolored/colored) fermions

A chiral fourth generation?

Does not decouple from Higgs system, production ~ 9 times larger than in SM

Mixing with SM fermions?

Possible, but better be small so to avoid problems with precision measurements and flavor

In this talk

SM

$+$

(uncolored/colored)

vector-like fermions

not mixed with SM

in their smallest $SU(2)_L$ representations

Analysis of effects on

- Higgs decays

	$R_{\gamma\gamma}$	R_{GG}	
Uncolored	✓	✗	Almeida, B, Machado, Zukanovich-Funchal, 1207:5254
Colored	✓	✓	B, Machado, Zukanovich-Funchal, 1209:6359

- EWPM (S, T, U)

Models considered

$\mathrm{SU(2)_L}$		$\mathrm{U(1)_Y}$	$SU(3)_c$
$2+1$	$3+2$		
$D_{L,R}=2$	$T_{L,R}=3$	$\hat{y}=y-\frac{1}{2}$	**1**, **3**, **6**, **8**
$S_{L,R}=1$	$D_{L,R}=2$	y	**1**, **3**, **6**, **8**

with lagrangian

$$-\mathcal{L}^{2+1} = c\,\overline{D}_R\,HS_L + c\,\overline{D}_L HS_R + m_1\overline{D}_R D_L + m_2\overline{S}_R S_L + \mathrm{h.c.}$$

$$-\mathcal{L}^{3+2} = c\overline{D}_R\,T_L H + c\overline{D}_L\,T_R H + m_1\,\overline{T}_L T_R + m_2\,\overline{D}_L D_R + \mathrm{h.c.}$$

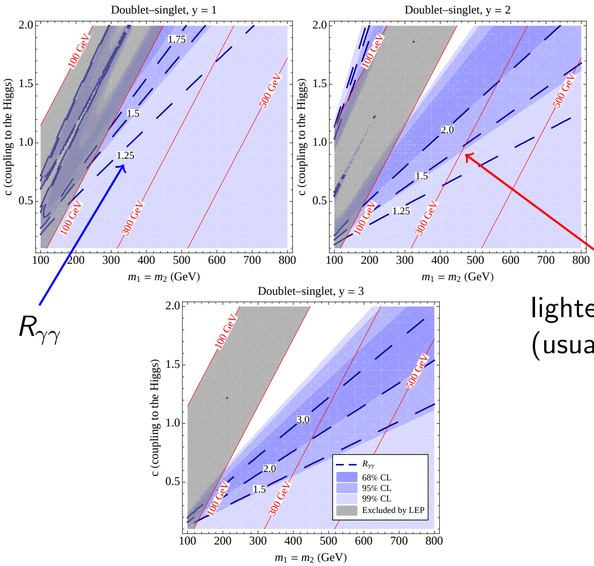
Models considered

$\mathrm{SU(2)_L}$		$\mathrm{U(1)_Y}$	$SU(3)_c$
$2+1$	$3+2$		
$D_{L,R}=2$	$T_{L,R}=3$	$\hat{y}=y-\frac{1}{2}$	$\mathbf{1}$, $\mathbf{3}$, $\mathbf{6}$, $\mathbf{8}$
$S_{L,R}=1$	$D_{L,R}=2$	y	$\mathbf{1}$, $\mathbf{3}$, $\mathbf{6}$, $\mathbf{8}$

Particle content:

	Q coupled to h	Q not coupled to h
$2+1$	(y,y)	$y-1$
$3+2$	$(y+1/2, y+1/2)$ $+$ $(y-1/2, y-1/2)$	$y-3/2$

$2 + 1$ Uncolored

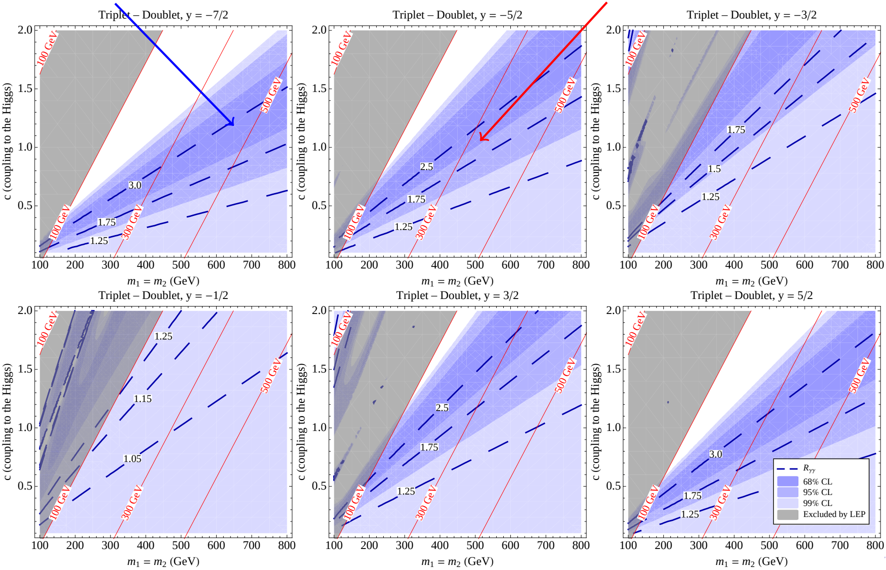


$R_{\gamma\gamma}$

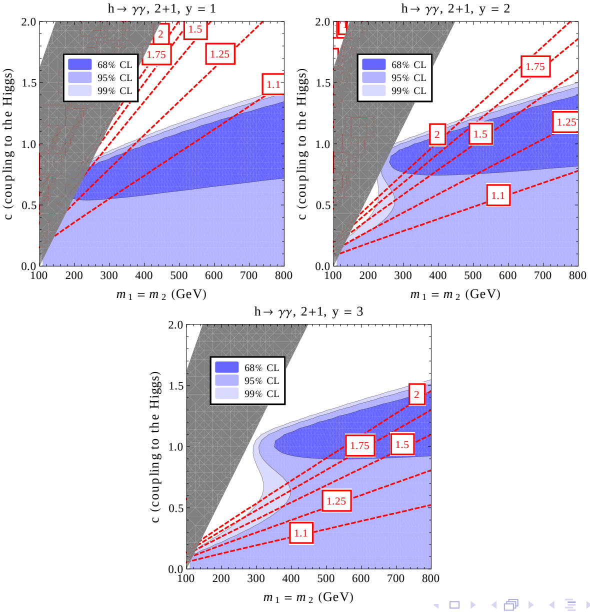
lightest mass (usually $Q = y$)

3 + 2 Uncolored

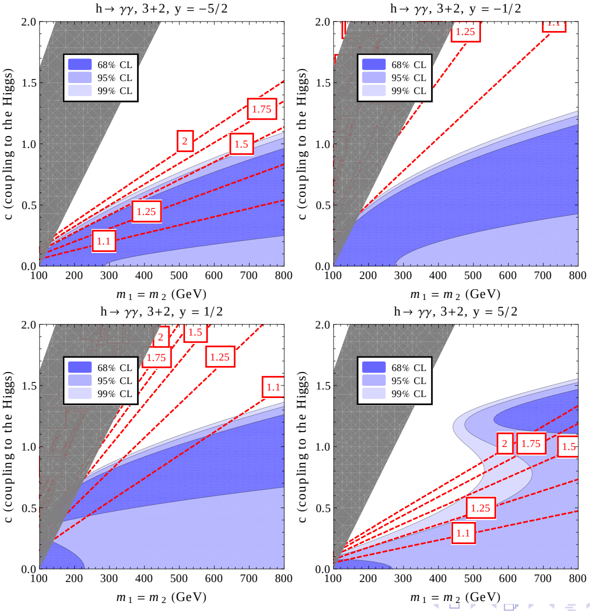
$R_{\gamma\gamma}$ lightest mass (usually $Q = y + 1/2$)



Constraints from oblique parameters: $2+1$ case



Constraints from oblique parameters: $3 + 2$ case



What changes turning on color?

One step back:

$$R_{\gamma\gamma} = \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{SM}} = |1 + \sum_i \delta^i_C + \sum_j \delta^j_{NC}|^2$$

$$R_{GG} = \frac{\sigma(GG \to h)}{\sigma(GG \to h)_{SM}} = |1 - 9.7 \sum_i \frac{t^i_c}{N^i_c Q^2_i} \delta^i_C|^2$$

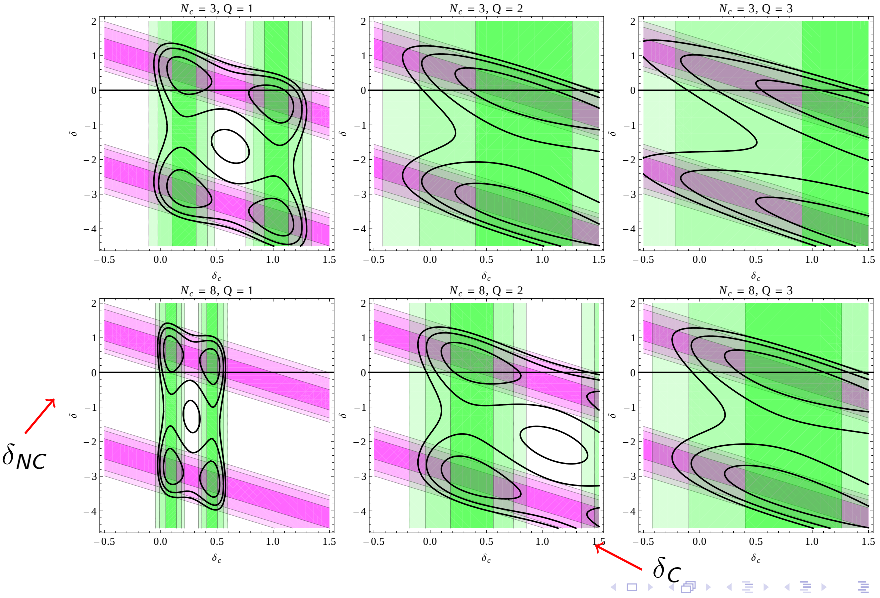
where

$$\delta^i_{C,NC} = \frac{N^i_c Q^2_i \frac{2 g_{hii}}{m_i} A_i \left(\frac{m_h^2}{4 m_i^2}\right)}{\mathcal{A}_W + \mathcal{A}_t}$$

Loop function

-0.096 0.021

General expectation



Strategy

In principle,

SM+ colored vector-like fermions

should be able to accommodate both $GG \to h$ & $h \to \gamma\gamma$.

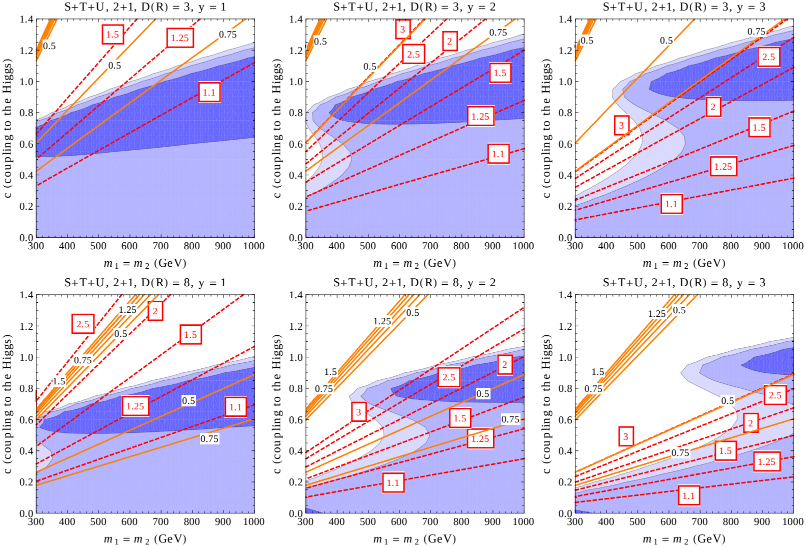
Again: consider SM $+ (2+1)$ or $(3+2)$ colored vector-like fermions:

effect on S, T and U?

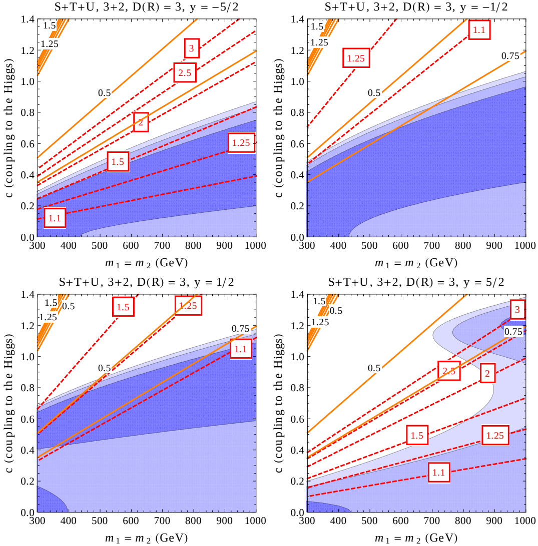
Effect of color

- R_{GG} depends on $t_c = \mathrm{tr}(T^A T^B) = 1/2\ (\mathbf{3}),\ 5/2\ (\mathbf{6}),\ 3\ (\mathbf{8})$
- $R_{\gamma\gamma} = |1 + \delta_c|^2$ with $\delta_c \propto N_c$
- $S,\ T,\ U \propto N_c$

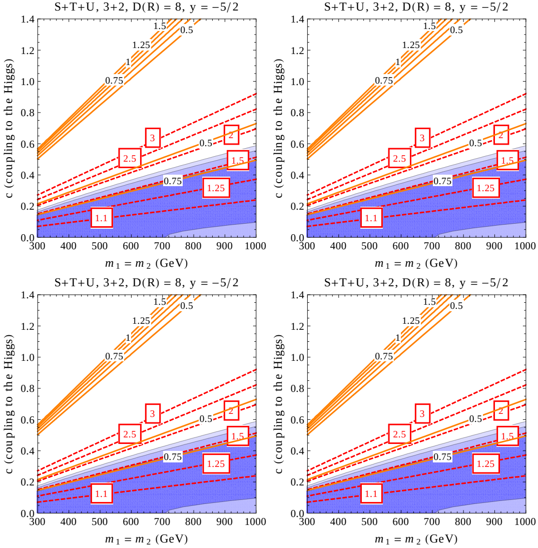
$2 + 1$ with colored **3** and **8**



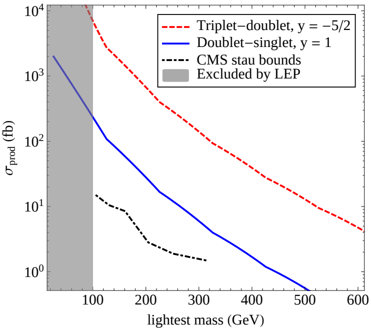
3 + 2 with colored **3**



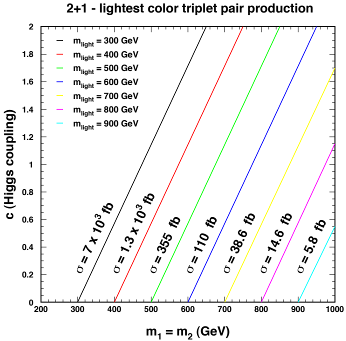
$3 + 2$ with colored **8**



LHC



Triplet−doublet, y = −5/2
Doublet−singlet, y = 1
CMS stau bounds
Excluded by LEP
σ_{prod} (fb)
lightest mass (GeV)



2+1 - lightest color triplet pair production
m_{light} = 300 GeV
m_{light} = 400 GeV
m_{light} = 500 GeV
m_{light} = 600 GeV
m_{light} = 700 GeV
m_{light} = 800 GeV
m_{light} = 900 GeV
$\sigma = 7 \times 10^3$ fb
$\sigma = 1.3 \times 10^3$ fb
σ = 355 fb
σ = 110 fb
σ = 38.6 fb
σ = 14.6 fb
σ = 5.8 fb
c (Higgs coupling)
$m_1 = m_2$ (GeV)

A model building disclaimer

RGE for the Higgs quartic: $\dfrac{\mathrm{d}\lambda}{\mathrm{d}\log\mu} = -\dfrac{N_c}{8\pi^2}c^4$

λ driven negative at a scale $\Lambda \sim 3m_{light}$

Arkani-Hamed et al 2012, Reece 2012

$\Downarrow$

new fields should enter at this scale to postpone vacuum instability (i.e. new scalars, but their effect on $R_{\gamma\gamma}$ and R_{GG} should be small)

In our case, in most of parameter space $m_{heavy} \lesssim (2-2.5)m_{light}$

(No) Conclusions

- We have a new particle, it looks like the SM Higgs boson
- Some interesting hints that something may be going on in the loops (but right now everything consistent with SM at 95% C.L.)
- Addition of new particles to the SM:
  - Scalars: (relatively) small effect, mixing with Higgs
  - Fermions: mixed, unmixed (this talk)
  - Vectors: ?
  - Spin 2: Urbano 2012

(No) Conclusions II

General message:

- Uncolored Fermions:
  - Increasing $R_{\gamma\gamma}$ up to $\gtrsim 2$ requires large electric charges $Q \gtrsim 2$
  - A modest increase (up to $\sim 20\%$) not too problematic even with $Q \sim 1$ and light $\sim 200 - 300\ \mathrm{GeV}$ particles
- Colored Fermions:
  - $R_{GG} \sim 0.5$ simpler with octects, but more difficult to pass S, T and U
  - $R_{\gamma\gamma}$ approximately as in the uncolored case (but more difficult to pass EWPM according to the number of colors)

BACK UP

New Gfitter result

$$
\begin{aligned}
\alpha(M_Z^2)\, S^{\rm NP} &= \frac{4s_W^2 c_W^2}{M_Z^2}\left[\Pi^{\rm NP}_{ZZ}(M_Z^2) - \Pi^{\rm NP}_{ZZ}(0) - \Pi^{\rm NP}_{\gamma\gamma}(M_Z^2) - \frac{c_W^2 - s_W^2}{c_W s_W}\, \Pi^{\rm NP}_{\gamma Z}(M_Z^2)\right], \\
\alpha(M_Z^2)\, T^{\rm NP} &= \frac{\Pi^{\rm NP}_{WW}(0)}{M_W^2} - \frac{\Pi^{\rm NP}_{ZZ}(0)}{M_Z^2}, \\
\alpha(M_Z^2)\, U^{\rm NP} &= 4s_W^2\left[\frac{\Pi^{\rm NP}_{WW}(M_W^2) - \Pi^{\rm NP}_{WW}(0)}{M_W^2} - c_W^2\left(\frac{\Pi^{\rm NP}_{ZZ}(M_Z^2) - \Pi^{\rm NP}_{ZZ}(0)}{M_Z^2}\right)\right. \\
&\qquad \left. -2s_W c_W\, \frac{\Pi^{\rm NP}_{\gamma Z}(M_Z^2)}{M_Z^2} - s_W^2\, \frac{\Pi^{\rm NP}_{\gamma\gamma}(M_Z^2)}{M_Z^2}\right],
\end{aligned}
$$

$$
\begin{aligned}
\Delta S &= S - S_{\rm SM} = 0.03 \pm 0.10 \\
\Delta T &= T - T_{\rm SM} = 0.05 \pm 0.12 \\
\Delta U &= U - U_{\rm SM} = 0.03 \pm 0.10
\end{aligned}
\qquad
V = \begin{pmatrix} 1 & +0.89 & -0.54 \\ +0.89 & 1 & -0.83 \\ -0.54 & -0.83 & 1 \end{pmatrix}
$$