Higgs couplings and Electroweak Precision data

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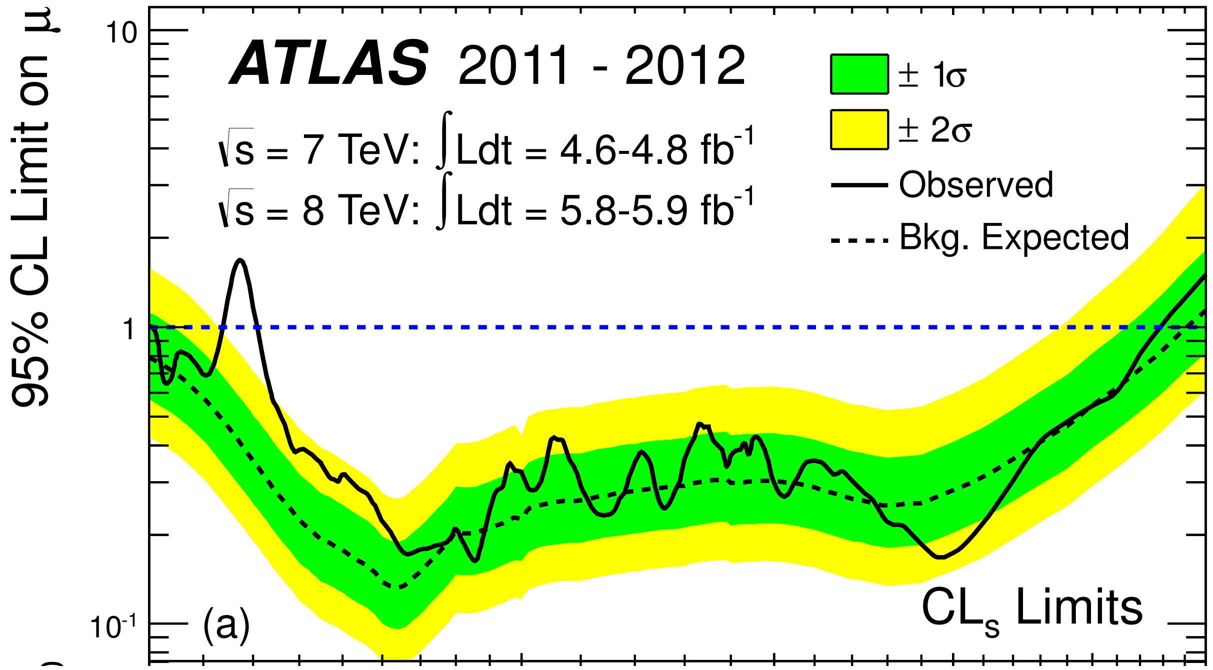
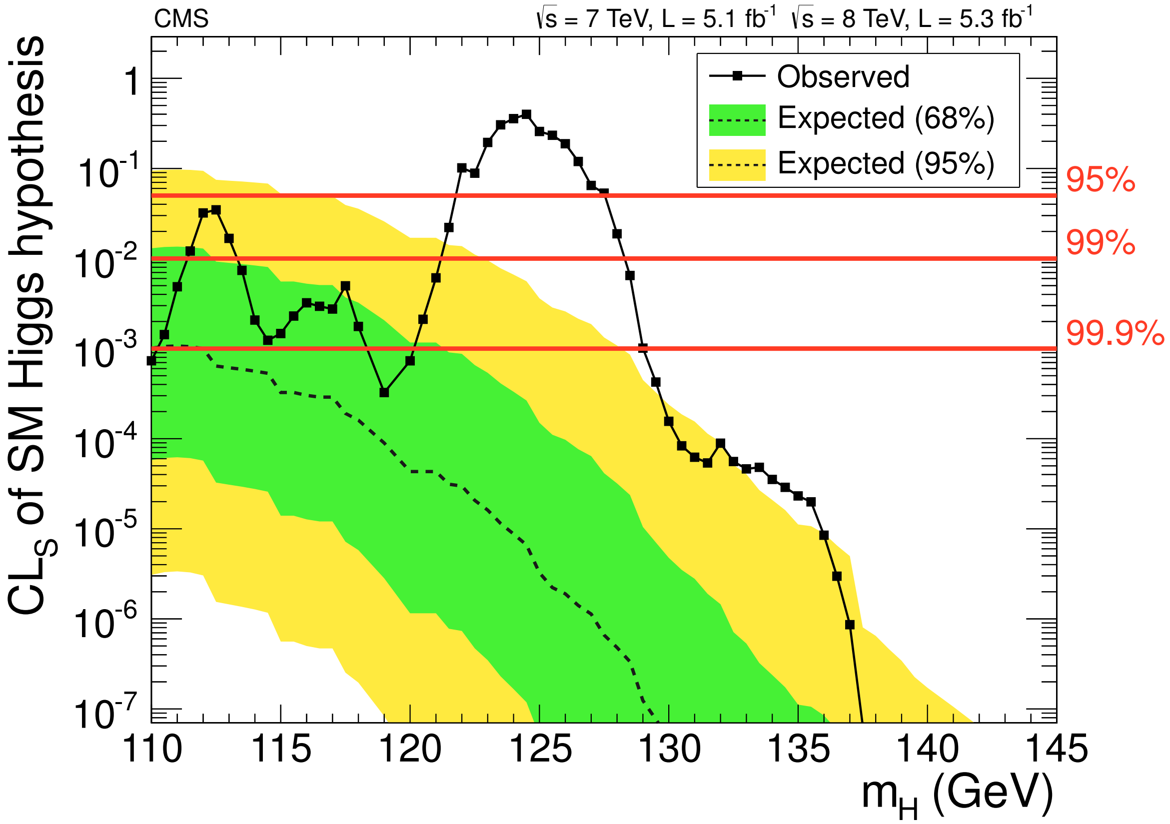
with Brian Batell and Stefania Gori
arXiv:1209.6382

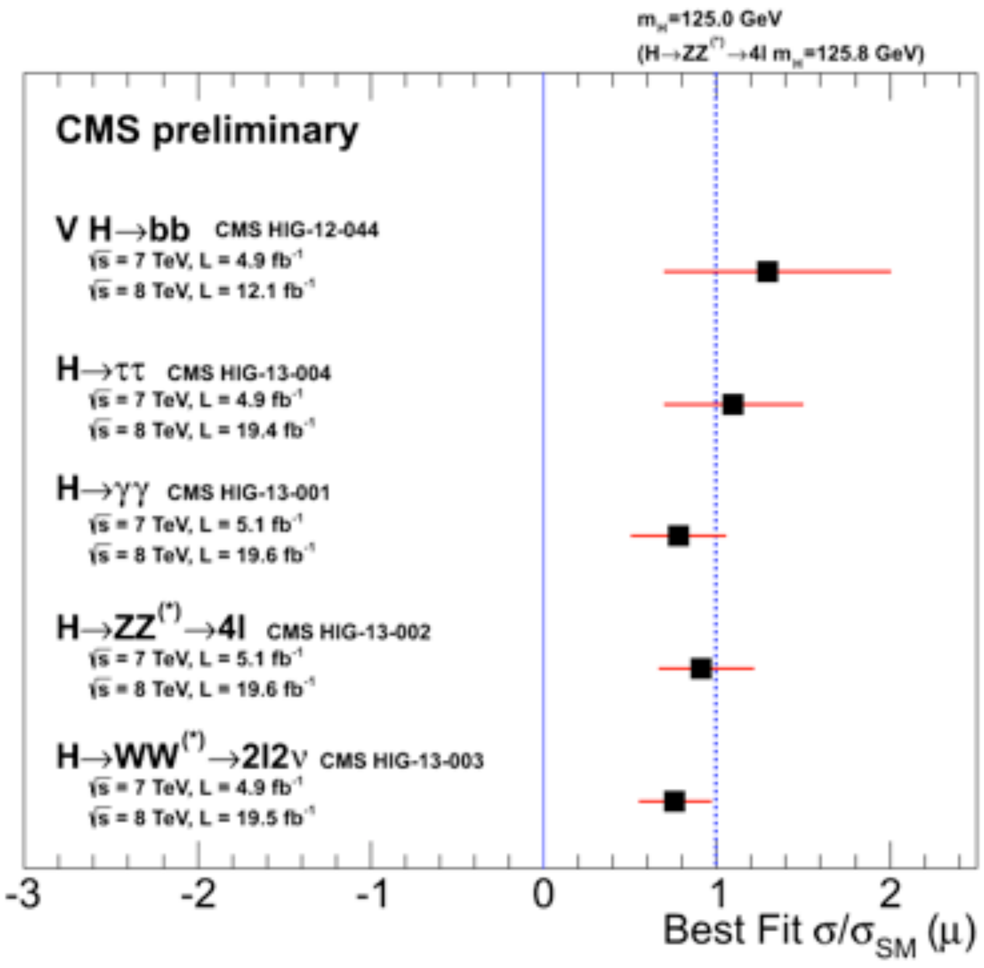
Beauty 2013, Bologna, Italy.

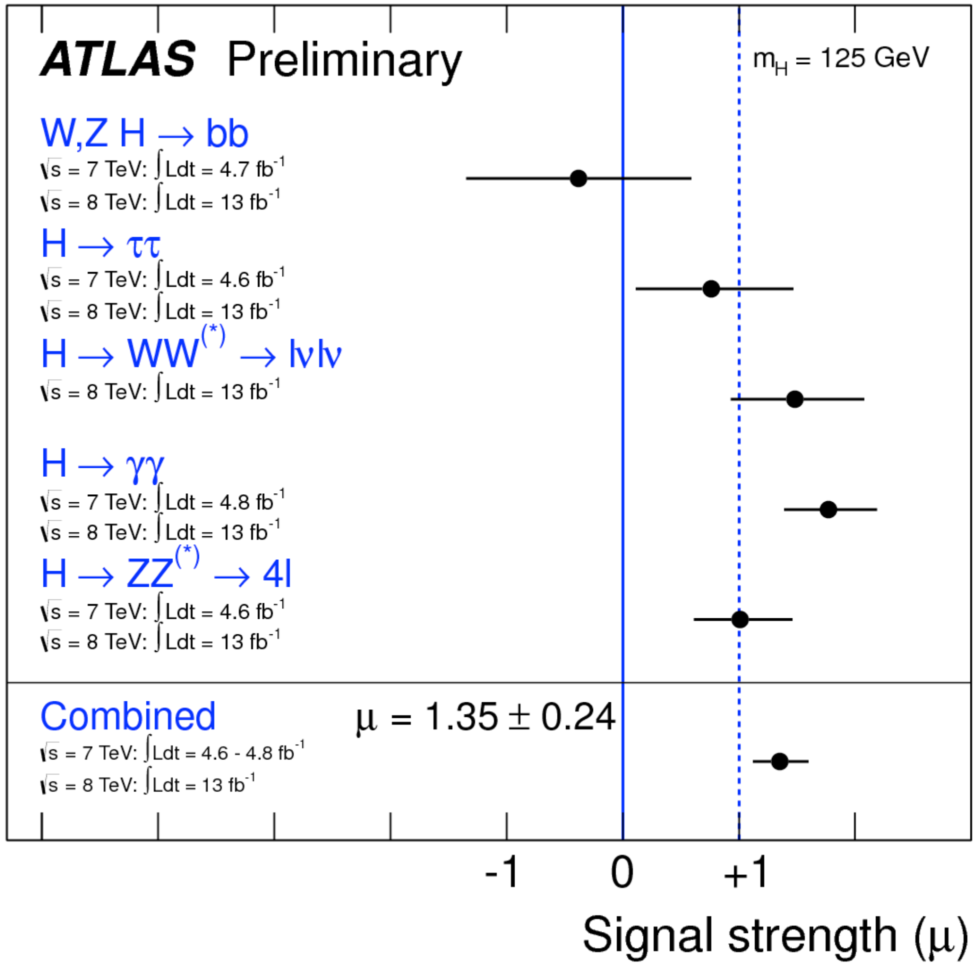
Much celebrated discovery!



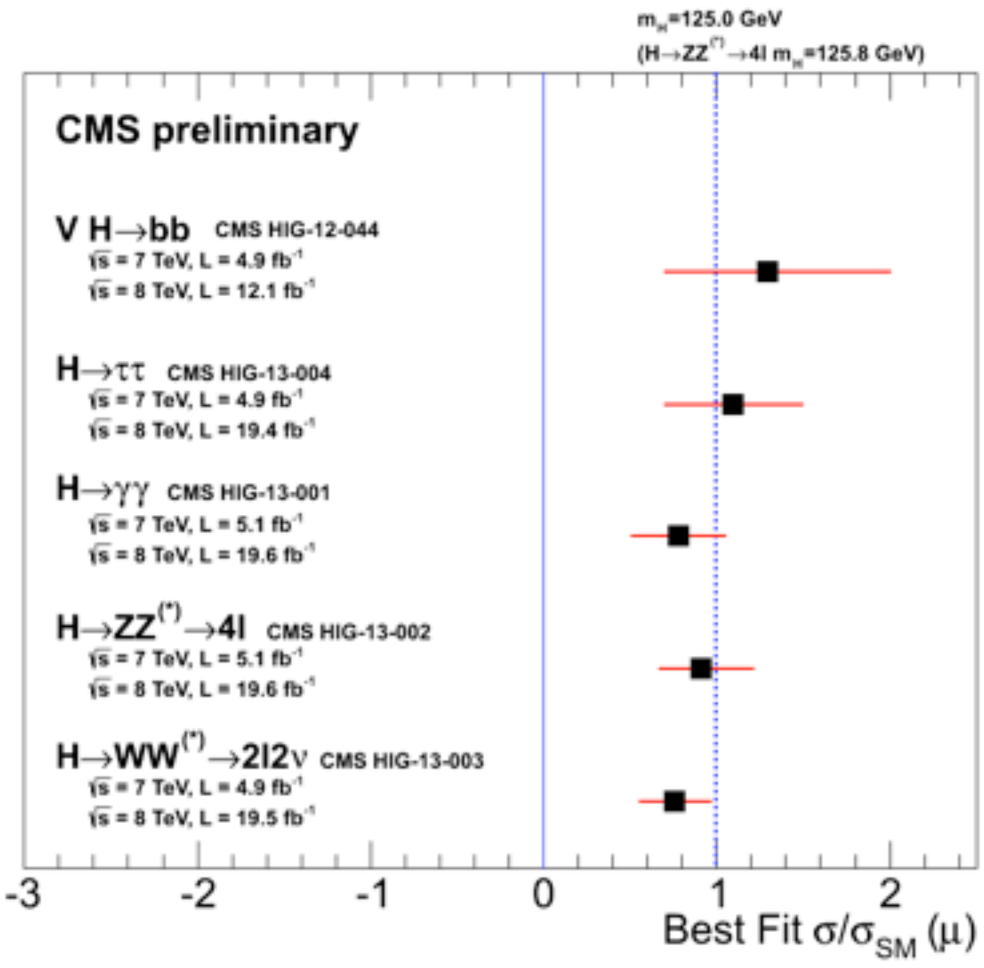


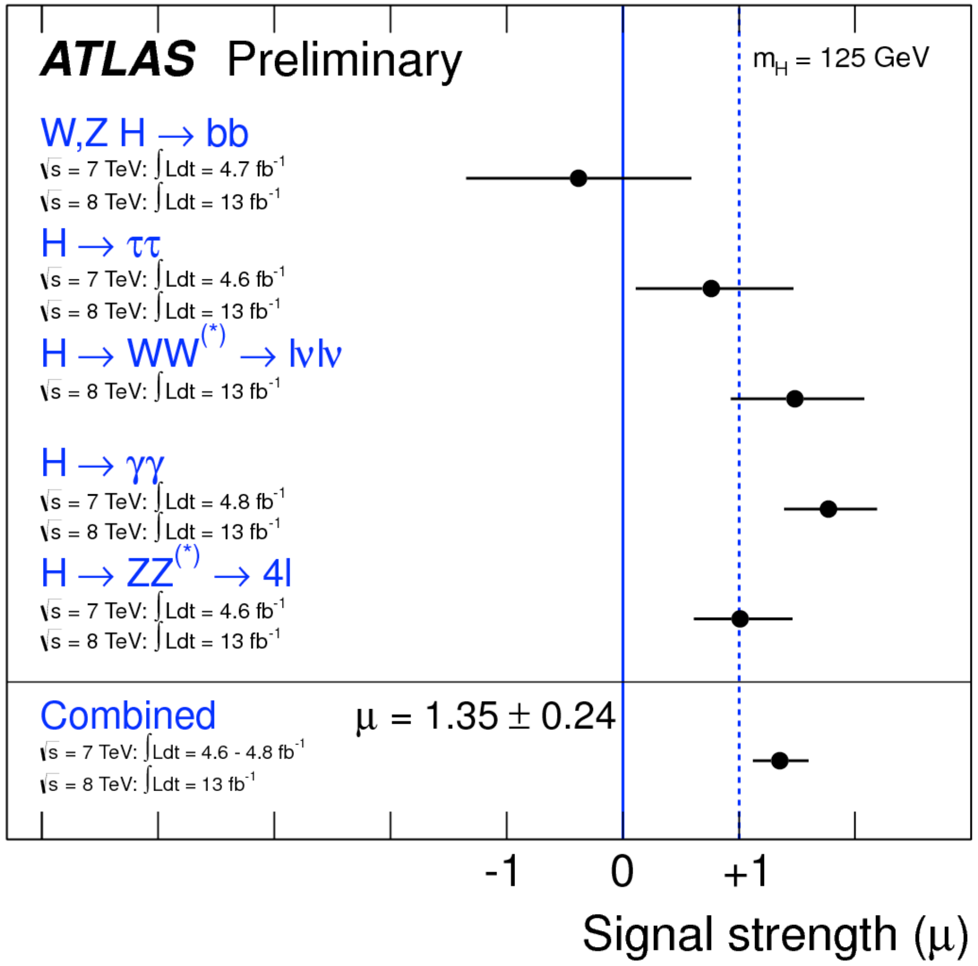
- Next step, detailed understanding its properties.
- Many possible connection to other searches, measurements.
  - Focusing on EWPT here.





Coupling SM-like?





Coupling SM-like?

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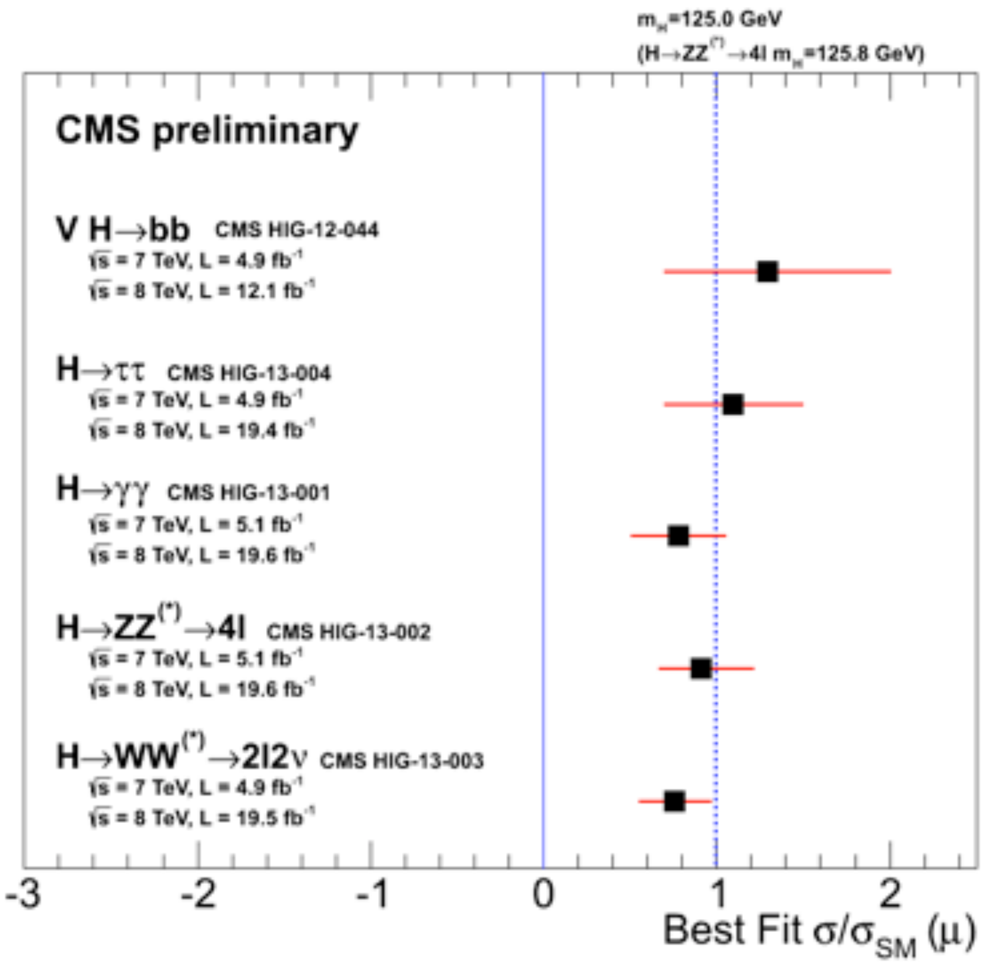
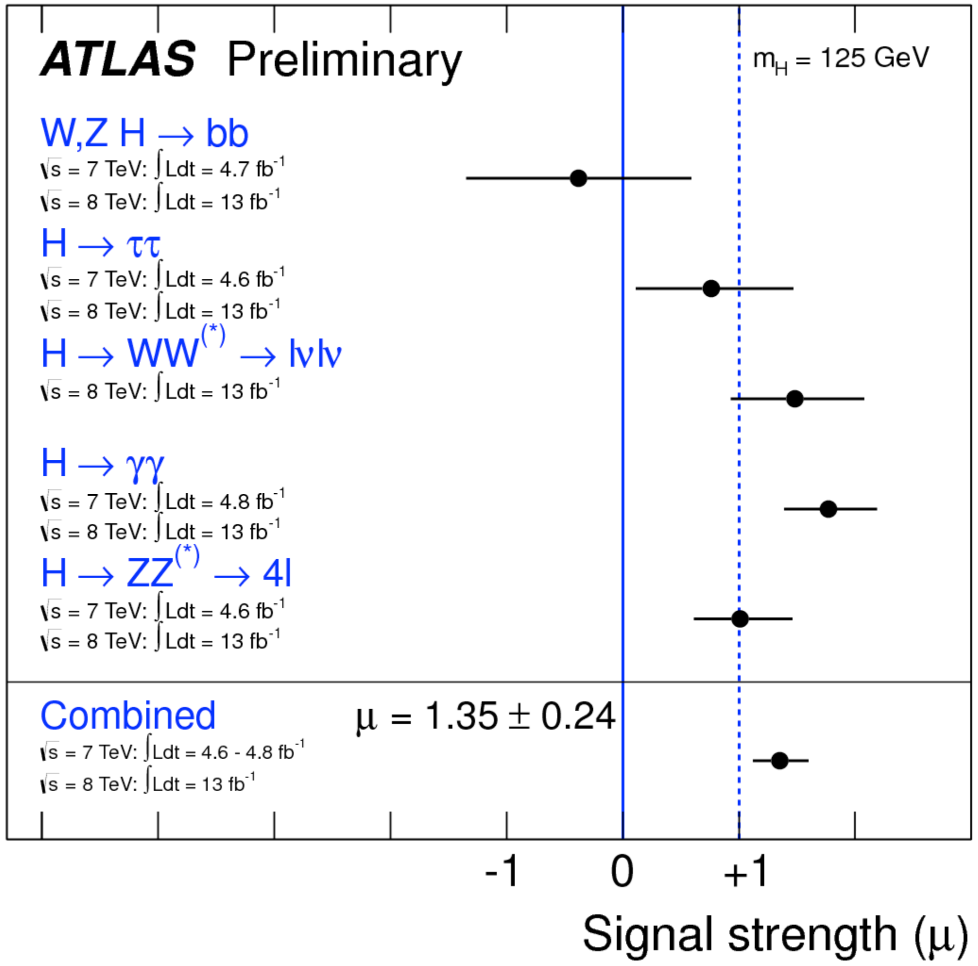
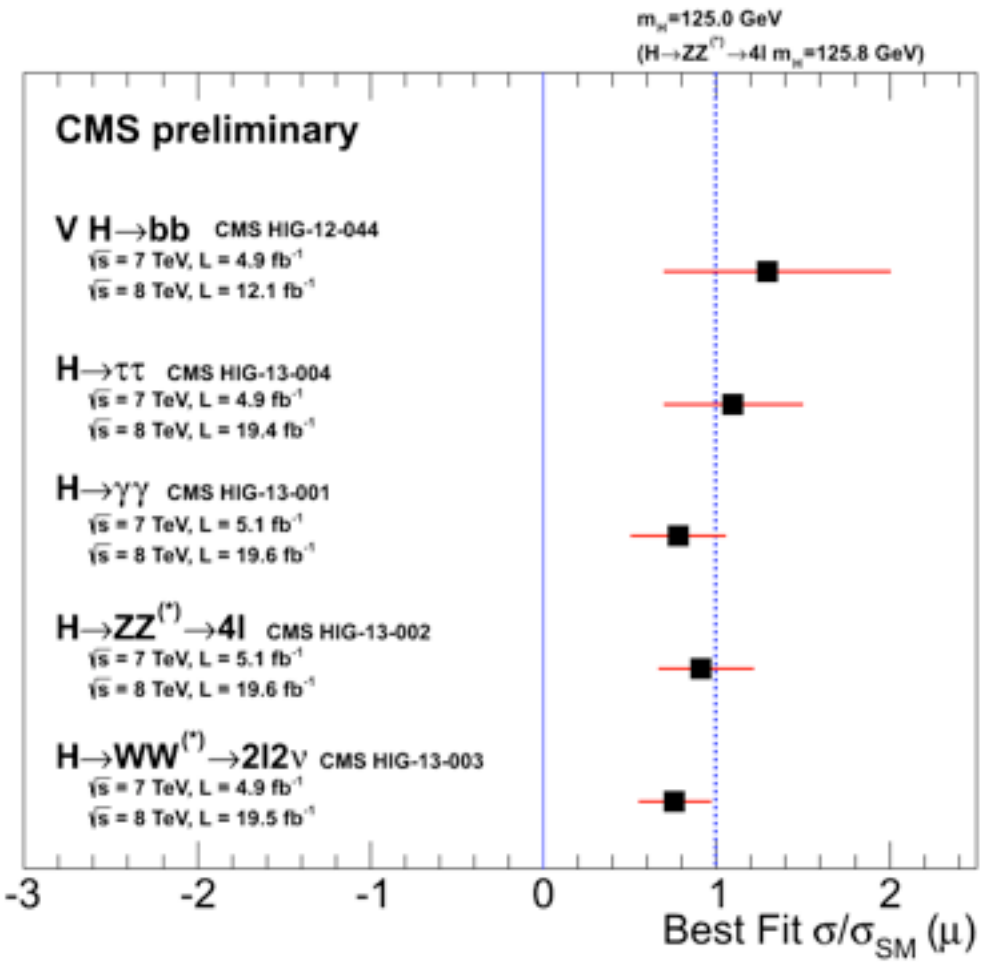
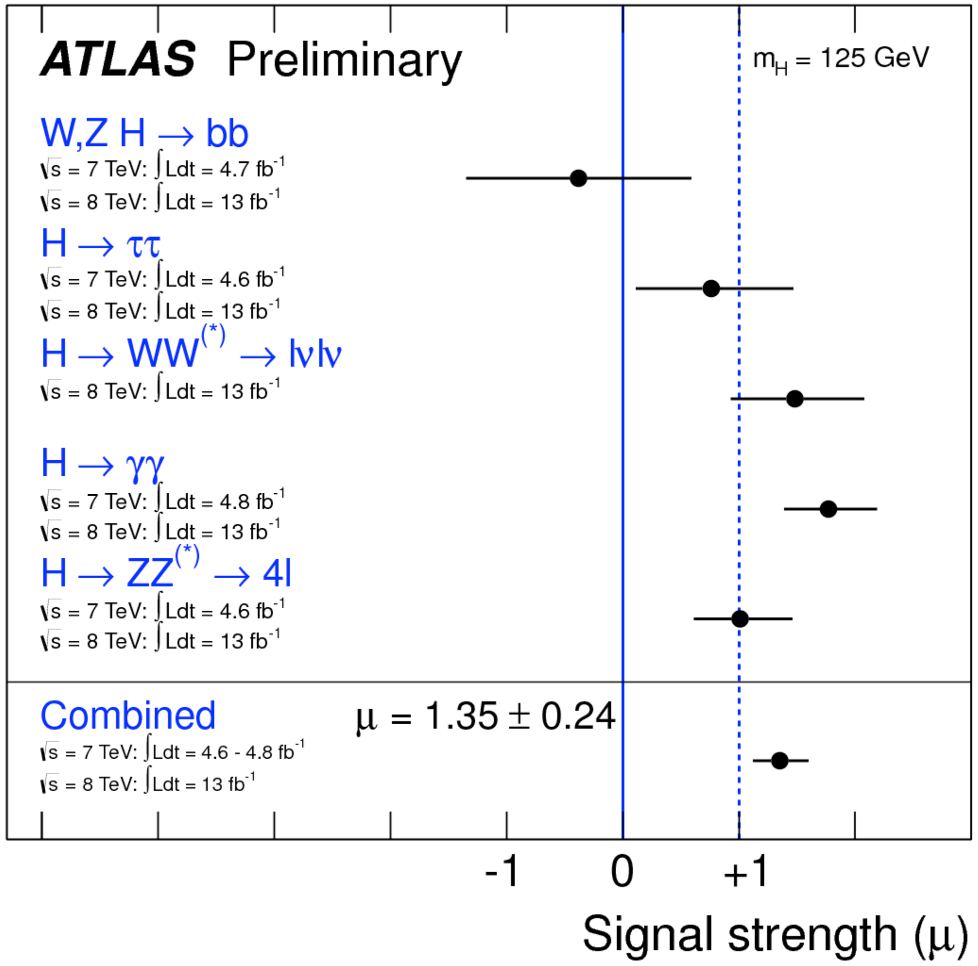




Coupling SM-like?

- Yes.
- Any deviations?





Coupling SM-like?

- Yes.

- Any deviations?

Nothing significant, of course.
There are plenty of rooms though.

Precision fit after 2011

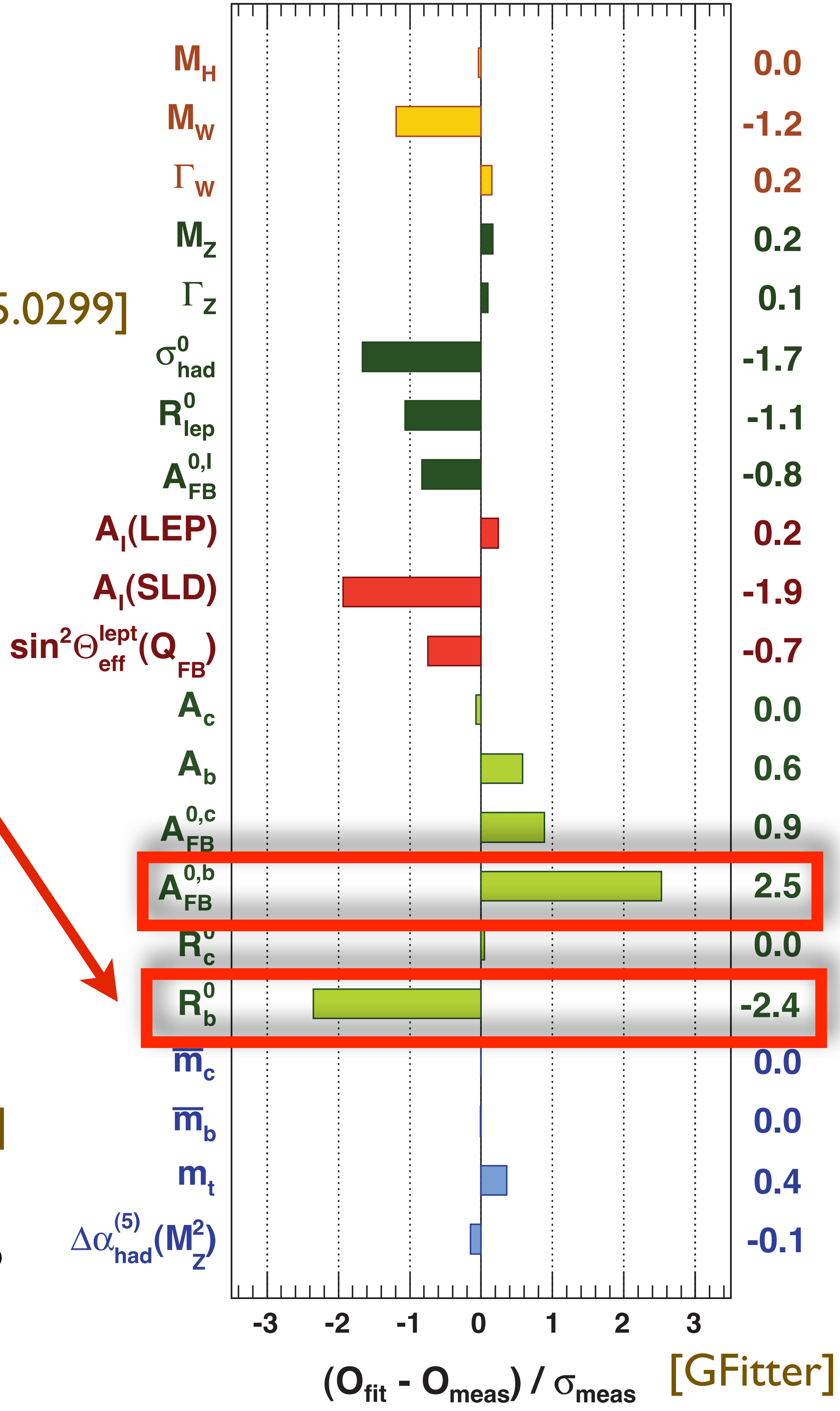
1. Electroweak two loop corrections for R_b [Freitas, Huang, 1205.0299]

Now $> 2\sigma$ discrepancy.

2. Higgs mass directly measured!

Global fit (Gfitter): [arXiv:1209.2716]

$$\chi^2/\text{d.o.f.} = 21.8/14, \qquad p = 0.08$$



[GFitter]

Interesting to ask:

- What new physics can "fix" Zbb?
- Implication for Higgs couplings.
  - Constraints!
  - Connection to possible deviations.

Possible resolutions of A^b_{FB}, R_b discrepancies

1. New physics directly alters A^b_{FB}, R_b

- Focus on tree level shifts to $Zb\bar{b}$ couplings

2. A^b_{FB}, R_b due to measurement errors

- Remove measurements from EW fit. Is there tension with 125 GeV Higgs?

How compelling are each of these resolutions?

To answer this question, we have performed a global fit to the precision electroweak data

A^b_{FB}, R_b due to systematic effect

EW data alone (w/o LHC Higgs mass measurement)

SM w/o A^b_{FB}, R_b :

$$\chi^2/d.o.f = 5.6/12$$
$$m_h = 70 \pm 30 \text{ GeV}$$

SM w/o A^b_{FB}, R_b
+ S, T, $m_h^{\rm ref} = 125$:

$$\chi^2/d.o.f = 5.6/9$$
$$S = -0.08 \pm 0.10$$
$$T = 0.0 \pm 0.08$$

- Only Slight tension between m_h = 70 and 125 GeV
- New contribution to S and T ⇒ marginal improvements.
- No obvious motivation for NP in this case.

Modify $Zb_R\bar{b}_R$ coupling

[Haber, Logan '99]
[Choudhury, Tait, Wagner '01]

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu \bar{b}(g_{Lb}P_L + g_{Rb}P_R)b$$

$$g_{Lb} = -\frac{1}{2} + \frac{1}{3}s_w^2 \approx -0.43$$
$$g_{Rb} = \frac{1}{3}s_w^2 \approx 0.0771$$

Goal: shift A_{FB}^b and R_b

$$A_{FB} = \frac{3}{4}\frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2}\frac{g_{Lb}^2 - g_{Rb}^2}{g_{Lb}^2 + g_{Rb}^2} \qquad R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{g_{Lb}^2 + g_{Rb}^2}{\sum_q [g_{Lq}^2 + g_{Rq}^2]}$$

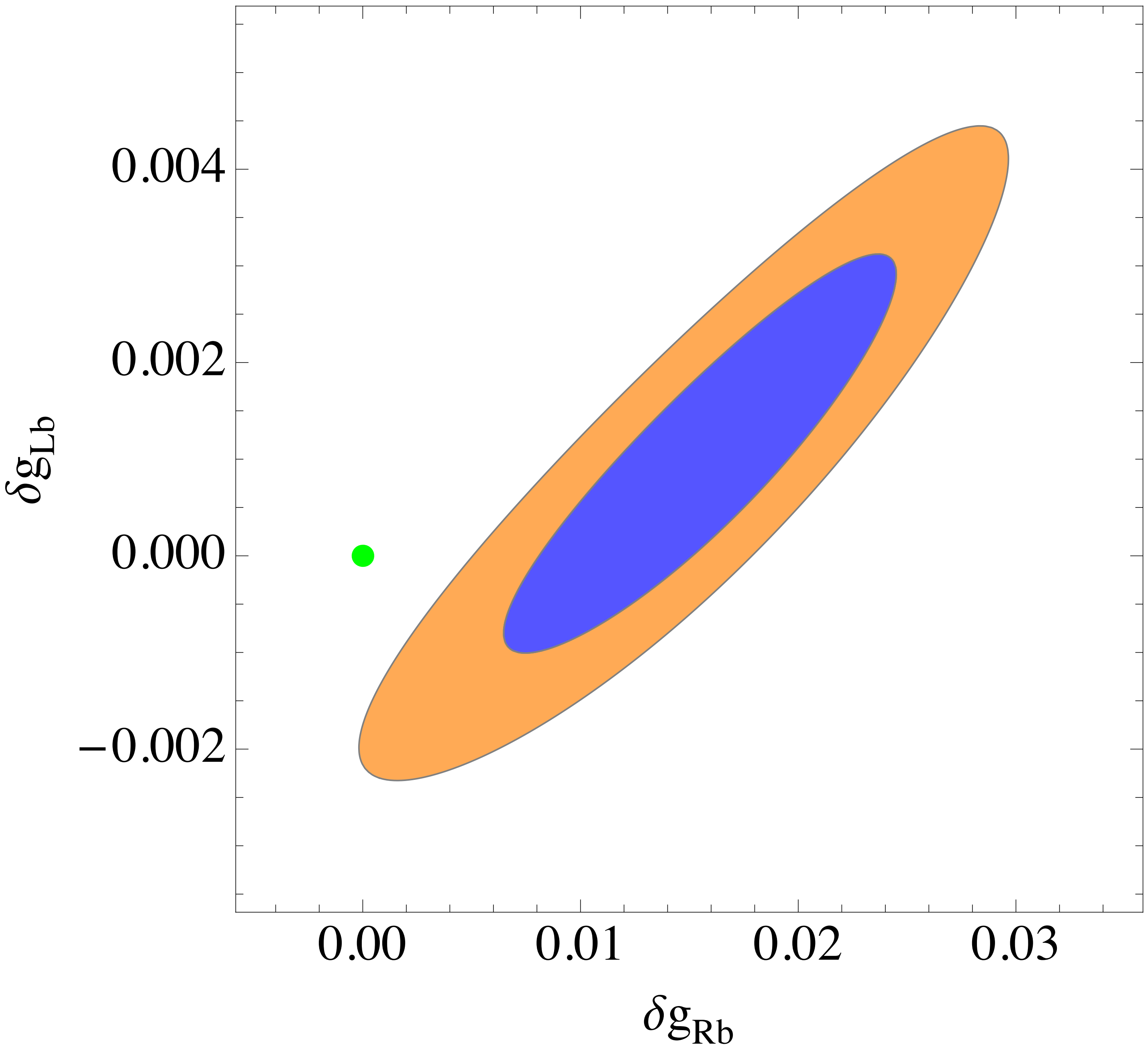
Z-pole data allows 4 solutions in $(\delta g_{Lb}, \delta g_{Rb})$, off-peak data for A_{FB}^b eliminate 2 possible solutions

This approach leads to a better fit then SM-alone

Best-fit region: positive δg_{Rb}

$$\delta g_{Lb} \sim 0.001 \pm 0.001$$

$$\delta g_{Rb} \sim 0.015 \pm 0.005$$



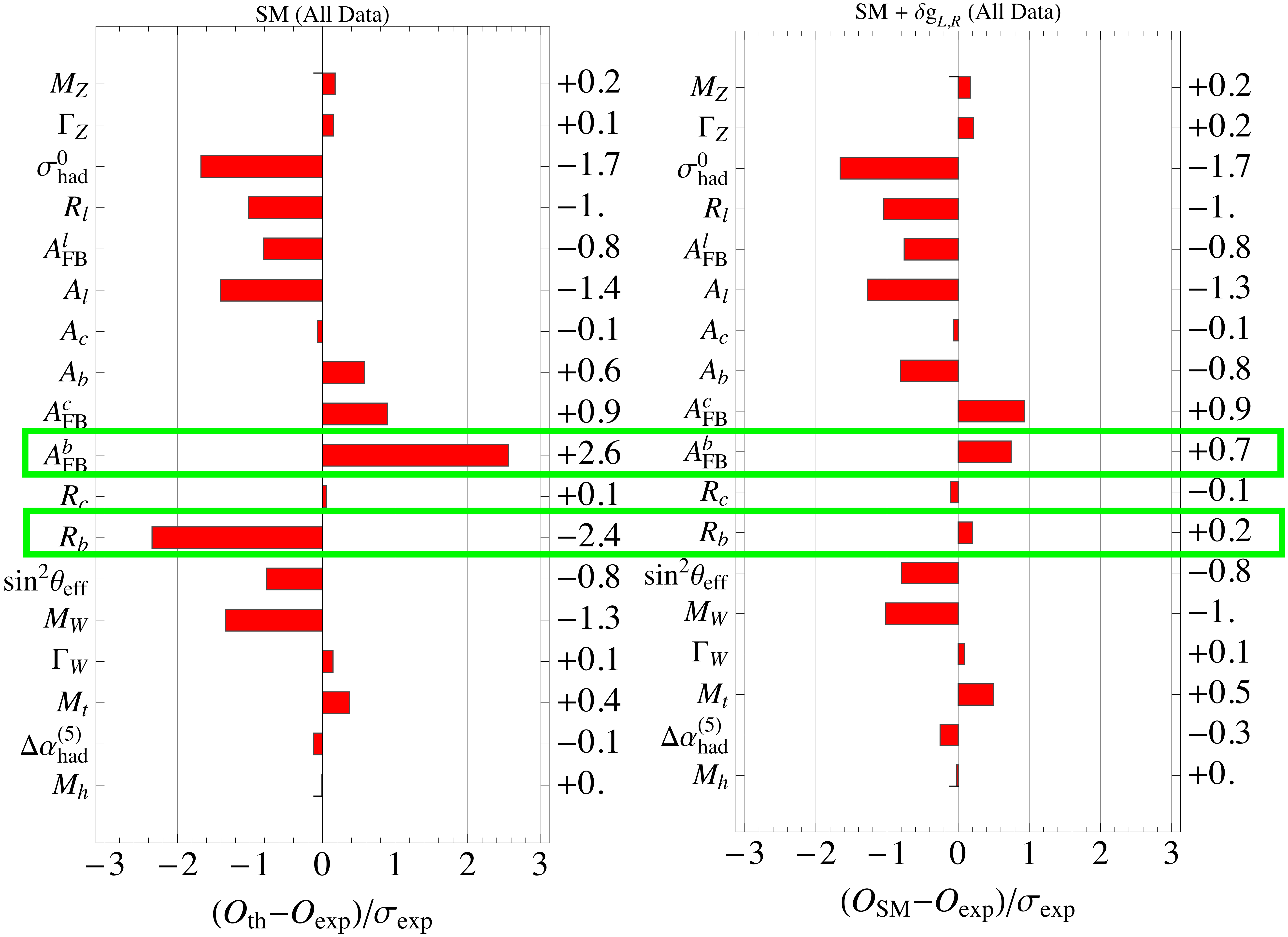
Another possible region (not shown in Fig)
large negative δg_{Rb}

$$\delta g_{Rb} \sim -0.17 \pm 0.005$$

Always $|\delta g_{Rb}| >> |\delta g_{Lb}|$

See also:

[Choudhury, Tait, Wagner '01]
[Kumar, Shepard, Tait, Vega-Morales '10]


SM (All Data)
M_Z +0.2
Γ_Z +0.1
$\sigma^0_{\rm had}$ −1.7
R_l −1.
$A^l_{\rm FB}$ −0.8
A_l −1.4
A_c −0.1
A_b +0.6
$A^c_{\rm FB}$ +0.9
$A^b_{\rm FB}$ +2.6
R_c +0.1
R_b −2.4
$\sin^2\theta_{\rm eff}$ −0.8
M_W −1.3
Γ_W +0.1
M_t +0.4
$\Delta\alpha^{(5)}_{\rm had}$ −0.1
M_h +0.
−3 −2 −1 0 1 2 3
$(O_{\rm th}-O_{\rm exp})/\sigma_{\rm exp}$
SM + $\delta g_{L,R}$ (All Data)
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M_h +0.
−3 −2 −1 0 1 2 3
$(O_{\rm SM}-O_{\rm exp})/\sigma_{\rm exp}$

Putting in New Physics

Adding new ingredients

Basic idea: Mix new vector-like quark B'$_{L,R}$
with bottom quark

$$\mathcal{L} \supset -\left(\bar{b}'_L \;\; \bar{B}'_L\right)\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}\begin{pmatrix} b'_R \\ B'_R \end{pmatrix} + \text{h.c.}$$

Diagonalize mass matrix via rotations of $b_{i(L,R)}$, with angles $\theta_{L,R}$

Shifts in couplings sensitive to mixing angles and SU(2)$_L$ representation of new B' (in particular its T$_{3L,R}$)

$$\boxed{\delta g_{Lb} = \left(t_{3L} + \frac{1}{2}\right) s_L^2, \qquad \delta g_{Rb} = t_{3R} s_R^2,}$$

Higgs physics

see also Wagner, Morrissey '03

Main effects in Higgs production and decay:

1. Rotations shift in the $hb\bar{b}$ vertex: $\mathcal{L}_{hbb} \simeq -c_R^2 \dfrac{m_b}{v} h\bar{b}b$

⇨ Partial width $h \to b\bar{b}$ suppressed by c_R^4

2. Heavy quark B contributes to $h \to gg$ and $h \to \gamma\gamma$

can be characterized
in terms of ratios

$$r_b, r_g, r_\gamma, \qquad r_i \equiv \frac{\Gamma(h \to i)}{\Gamma(h \to i)_{\rm SM}}$$

also define:

$$\mu_i = \frac{\sigma(pp \to h \to i)}{\sigma_{\rm SM}(pp \to h \to i)}$$

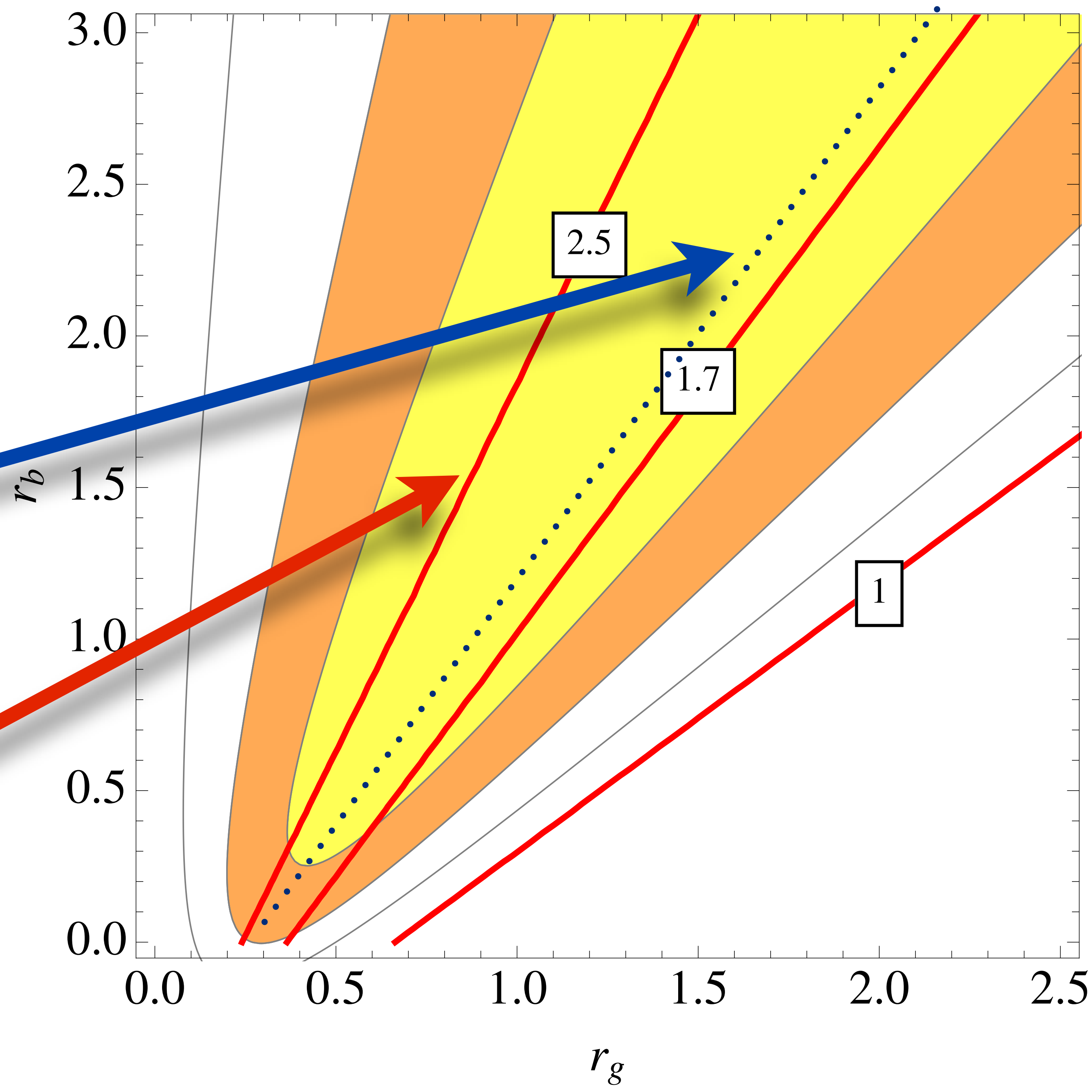
What does the signal strength data say?

$$\mu_i = \frac{\sigma(pp \to h \to i)}{\sigma_{\rm SM}(pp \to h \to i)}$$

$$\mu_{\gamma\gamma} \simeq \frac{r_g r_\gamma}{1 + {\rm Br}_b(r_b - 1) + {\rm Br}_g(r_g - 1)},$$

$$\mu_{VV} \simeq \frac{r_g}{1 + {\rm Br}_b(r_b - 1) + {\rm Br}_g(r_g - 1)},$$

$$\mu_{b\bar{b}} \simeq \frac{r_b}{1 + {\rm Br}_b(r_b - 1) + {\rm Br}_g(r_g - 1)}$$



Shallow direction in $r_g - r_b$ plane

r_γ

Minimal models.

“beautiful mirrors”[Choudhury, Tait, Wagner ’01]

Shifts in $Z\bar{b}b$ couplings:

$$\boxed{\delta g_{Lb} = \left(t_{3L} + \frac{1}{2}\right) s_L^2, \qquad \delta g_{Rb} = t_{3R} s_R^2,}$$

Single out 3 possible vector-like representations:

$$\Psi_{L,R} \sim (3,2,1/6), (3,2,-5/6), (3,3,2/3)$$

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$\delta g_{Lb} > \delta g_{Rb}$, not useful

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Single out 3 possible vector-like representations:

$$\Psi_{L,R} \sim \underbrace{(3,2,1/6),(3,2,-5/6)}_{\text{Only consider these}}, \underbrace{(3,3,2/3)}_{\delta g_{Lb} > \delta g_{Rb}, \text{ not useful}}$$

$$\Psi_{L,R} \sim (T,B) \sim (3,2,1/6)$$

Choudhury, Tait, Wagner '01
Morrissey, Wagner '03

$$\delta g_{Lb} = \left(t_{3L} + \frac{1}{2}\right) s_L^2, \qquad \delta g_{Rb} = t_{3R} s_R^2,$$

$T_{3R}(B) = -1/2$
Want to have $\delta g_{Rb} \approx -0.17$

Mixing between T and top quark ⇒ $W t_R b_R$ coupling

Ruled out by $b \to s\gamma$.

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No T-t mixing ⇒ Large custodial breaking.

Precision data: $M_{T,B}$ 100-200 GeV, very heavy Higgs.
Inconsistent with m_h = 126 GeV !

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Precision data: $M_{T.B}$ 100-200 GeV, very heavy Higgs.
Inconsistent with $m_h = 126$ GeV !

Even if this can be fixed.
Sizable negative δg_{bR} ⇒ large $HB_R b_R$ coupling.

$M_{T.B}$ 100-200 GeV ⇒ $\mu_{VV} \sim 2.4$, in conflict with Higgs data!

$$\Psi_{L,R} \sim (B, X) \sim (3, 2, -5/6)$$

$$\delta g_{Lb} = \left(t_{3L} + \frac{1}{2}\right) s_L^2, \qquad \delta g_{Rb} = t_{3R} s_R^2,$$ Want to have $\delta g_{Rb} \approx 0.016$

X charge -4/3. No mixing with top quark.
Only need smaller mixing angle: $s_R \approx 0.2$

Good fit to precision data.

Consistent with Higgs data.
Deviation from SM very small.

Explore more variations

- Adding singlet exotic fermions:

$$\Psi^T_{L,R} = (B, X) \sim (3, 2, -5/6),$$
$$\hat{B}_{L,R} \sim (3, 1, -1/3),$$
$$\hat{X}_{L,R} \sim (3, 1, -4/3).$$

- Quantum numbers under $SU(2)_L \times SU(2)_R \times U(1)_X$

$$\Psi^T_{L,R} = (B, X) \sim (2, 1)_{-5/6}$$
$$\hat{\Psi}^T_{L,R} = (\hat{B}, \hat{X}) \sim (1, 2)_{-5/6}$$

- Such representations can find motivation in composite Higgs models

[Agashe, Contino, Da Rold, Pomarol '06]

Lagrangian

$$
\begin{aligned}
-\mathcal{L} \supset\ & M_1 \bar{\Psi}'_L \Psi'_R + M_2 \bar{\hat{B}}'_L \hat{B}'_R + M_3 \bar{\hat{X}}'_L \hat{X}'_R \\
& + y_1 \bar{Q}'_L H b'_R + y_2 \bar{Q}'_L H \hat{B}'_R \\
& + y_3 \bar{\Psi}'_L \tilde{H} b'_R + y_4 \bar{\Psi}'_L \tilde{H} \hat{B}'_R \\
& + y_5 \bar{\hat{B}}'_L \tilde{H}^\dagger \Psi'_R \\
& + y_6 \bar{\Psi}'_L H \hat{X}'_R \\
& + y_7 \bar{\hat{X}}'_L H^\dagger \Psi'_R
\end{aligned}
$$

- Custodial limit: $M_2 = M_3,\ y_4 = y_6,\ y_5 = y_7$

- Note that $y_1,\ y_2,\ y_3$ explicitly break custodial symmetry, but only small values required to obtain required shifts $\delta g_{Lb},\ \delta g_{Rb},$

Yukawa contributions small, suggested by collider limits

$$Y_i = y_i v/\sqrt{2} \ll M_{1,2,3}$$

Integrate out heavy fermions to obtain effective theory

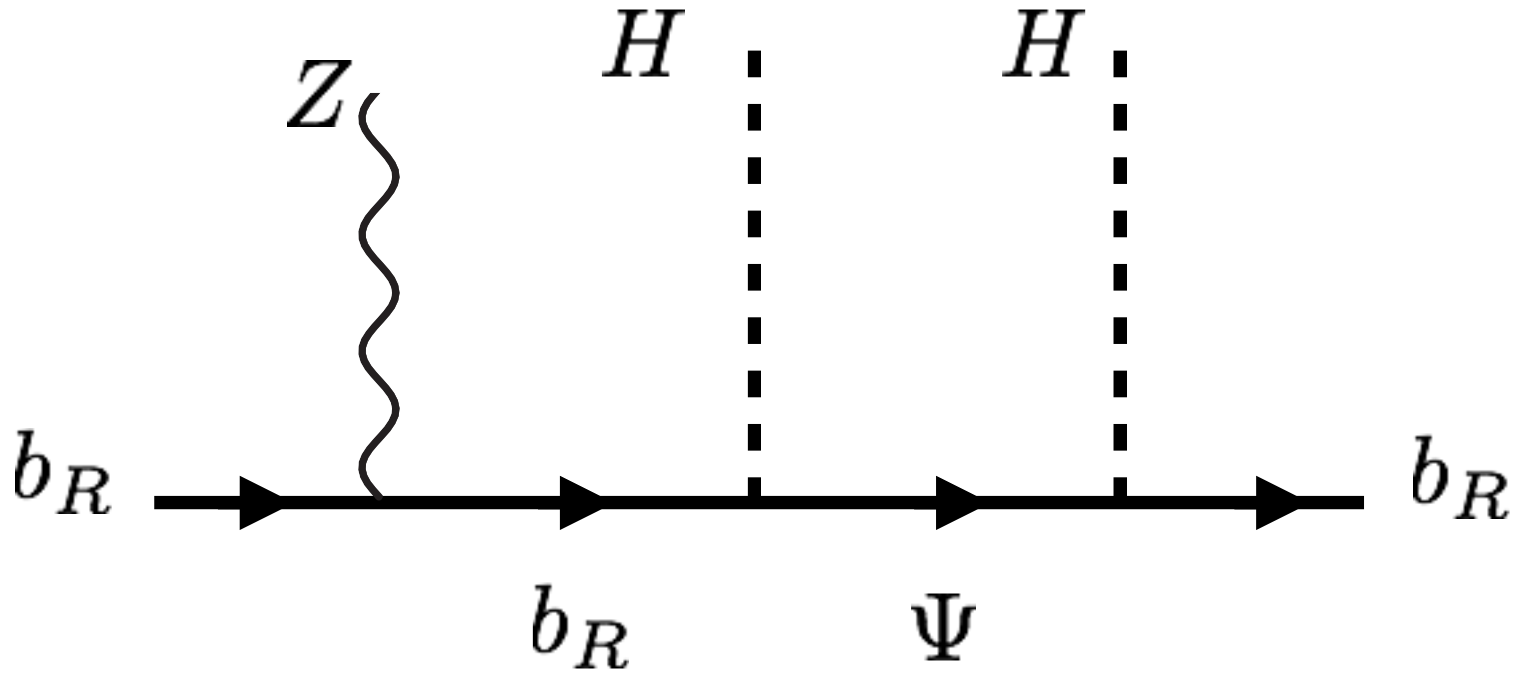
$$\mathcal{L} = \sum_i a_i \mathcal{O}_i$$

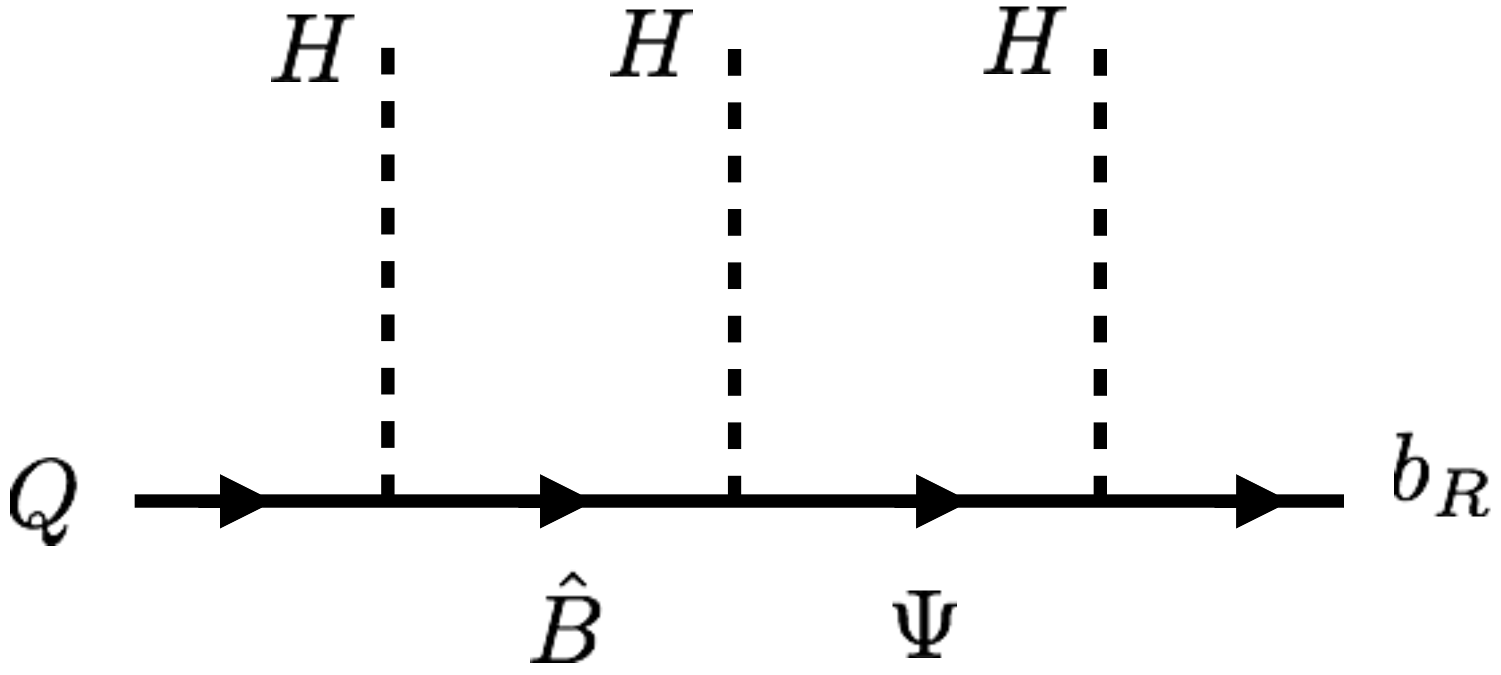
$$\left.\begin{aligned} \mathcal{O}_{Hb} &= i(H^\dagger D_\mu H)(\bar{b}_R \gamma^\mu b_R) + \text{h.c.}, \\ \mathcal{O}^s_{HQ} &= i(H^\dagger D_\mu H)(\bar{Q} \gamma^\mu Q) + \text{h.c.}, \\ \mathcal{O}^t_{HQ} &= i(H^\dagger \sigma^a D_\mu H)(\bar{Q} \gamma^\mu \sigma^a Q) + \text{h.c.}, \end{aligned}\right\}$$

lead to shift in $\delta g_{Lb},\ \delta g_{Rb}$,

$$\left.\mathcal{O}_{HY} = (H^\dagger H)(\bar{Q} H b_R) + \text{h.c.}.\ \right\}$$

lead to shift in $m_b, y_{hb\bar{b}}$


Z
H
H
b_R
b_R
b_R
Ψ


H
H
H
Q
b_R
$\hat{B}$
Ψ

$$\delta g_{Lb} = \frac{Y_2^2}{2M_2^2}, \quad \delta g_{Rb} = \frac{Y_3^2}{2M_1^2} \qquad Y_i = y_i v/\sqrt{2}$$

To fix Zbb, $\delta g_{Rb} \sim 0.015, \quad \delta g_{Lb} \sim 0.001,$

⇨ $Y_2 \simeq \pm 0.04\, M_2 \quad Y_3 \simeq \pm 0.17\, M_1$

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⇨ $Y_2 \simeq \pm 0.04\, M_2 \quad Y_3 \simeq \pm 0.17\, M_1$

b-quark mass &
hbb coupling

$$m_b = Y_1 \left(1 - \frac{Y_2^2}{2M_2^2} - \frac{Y_3^2}{2M_1^2}\right) + \frac{Y_2 Y_3 Y_5}{M_1 M_2}$$

$$y_{hbb} = \frac{1}{v}\left[Y_1 \left(1 - \frac{3Y_2^2}{2M_2^2} - \frac{3Y_3^2}{2M_1^2}\right) + \frac{3Y_2 Y_3 Y_5}{M_1 M_2}\right]$$

$$r_b = \left(\frac{y_{hbb}}{m_b/v}\right)^2 \approx 1 + 8\sqrt{\delta g_{Rb}\delta g_{Rb}}\,\frac{Y_5}{m_b}$$

Large corrections to $h \to b\bar{b}$ possible if Y_5 large

$h \to gg$ and $h \to \gamma\gamma$: Use low energy theorem

[Ellis, Gaillard, Nanopoulos `76]
[Shifman, Vainshtein, Voloshin, Zakharov `79]

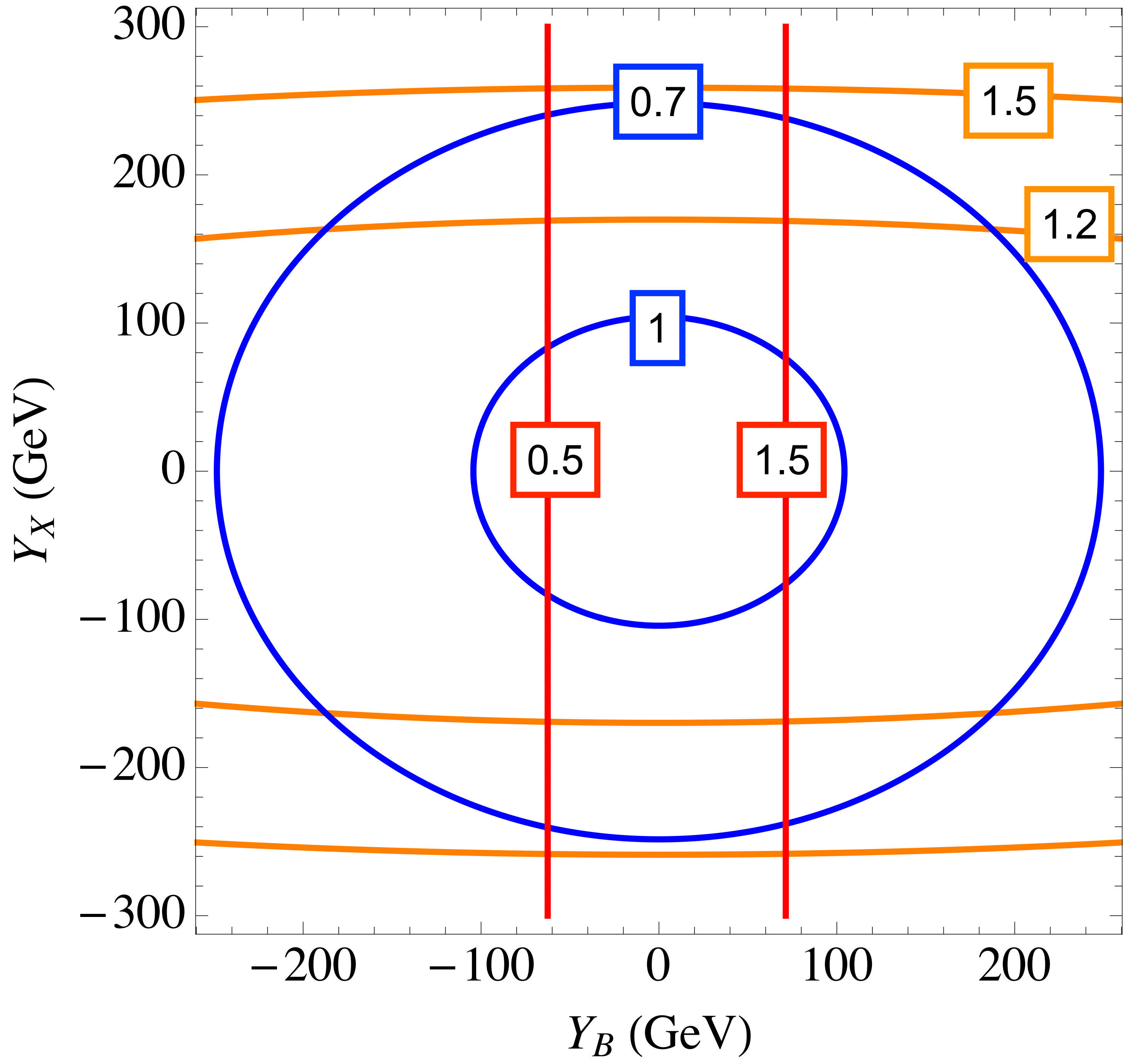
$$\mathcal{L} \supset \frac{\alpha}{16\pi v}\left[\sum_{f=B,X} b_f^{EM} z_f\right] hF_{\mu\nu}F^{\mu\nu} + \frac{\alpha_s}{16\pi v}\left[\sum_{f=B,X} b_f^{c} z_f\right] hG^a_{\mu\nu}G^{\mu\nu a},$$

$$b_B^{EM} = 4/9, \qquad b_X^{EM} = 64/9, \qquad b_B^c = b_X^c = 2/3.$$

$$z_f \equiv \frac{\partial}{\partial \log v}\left(\sum_i \log m_{f,i}^2(v)\right),$$

$$z_B \simeq -4\frac{Y_4Y_5}{M_1M_2} \qquad z_X \simeq -4\frac{Y_6Y_7}{M_1M_3}$$

$$r_\gamma \simeq \left|1 + 0.13\left(\frac{Y_4 Y_5}{M_1 M_2} + 16\frac{Y_6 Y_7}{M_1 M_3}\right)\right|^2 \quad , \quad r_g \simeq \left|1 - 2.1\left(\frac{Y_4 Y_5}{M_1 M_2} + \frac{Y_6 Y_7}{M_1 M_3}\right)\right|^2$$



$Y_4 = Y_5 = Y_B$
$Y_6 = Y_7 = Y_X$
$M_{1,2,3} = 800$ GeV

Direct searches for Heavy Quarks

- Signatures similar to minimal $(3, 2, -5/6)$ model

[Kumar, Shepard, Tait, Vega-Morales '10]

- Most robust limit comes from top prime searches

CMS search in dilepton channel [CMS-EXO-11-050]

$$pp \to t'\bar{t}' \to (W^+b)(W^-\bar{b}) \to \ell^+\ell^-\nu\nu\bar{b}\bar{b}$$

Bounds masses heavier than $m_{t'} > 557$ GeV

- These bounds apply since X decays via $X \to bW^-$

Other possible decay mode $X \to BW^-$ requires $m_X > m_B + m_W$, not favored by Higgs data (see shortly)

- Also bounds exist from bottom prime searches:

$$pp \to b'\bar{b}' \to W^-tW^+\bar{t} \to 4W2b \to 3\ell + b \text{ or SS } \ell + b$$

[CMS-EXO-11-036]

Bounds masses heavier than $m_{b'} > 611$ GeV

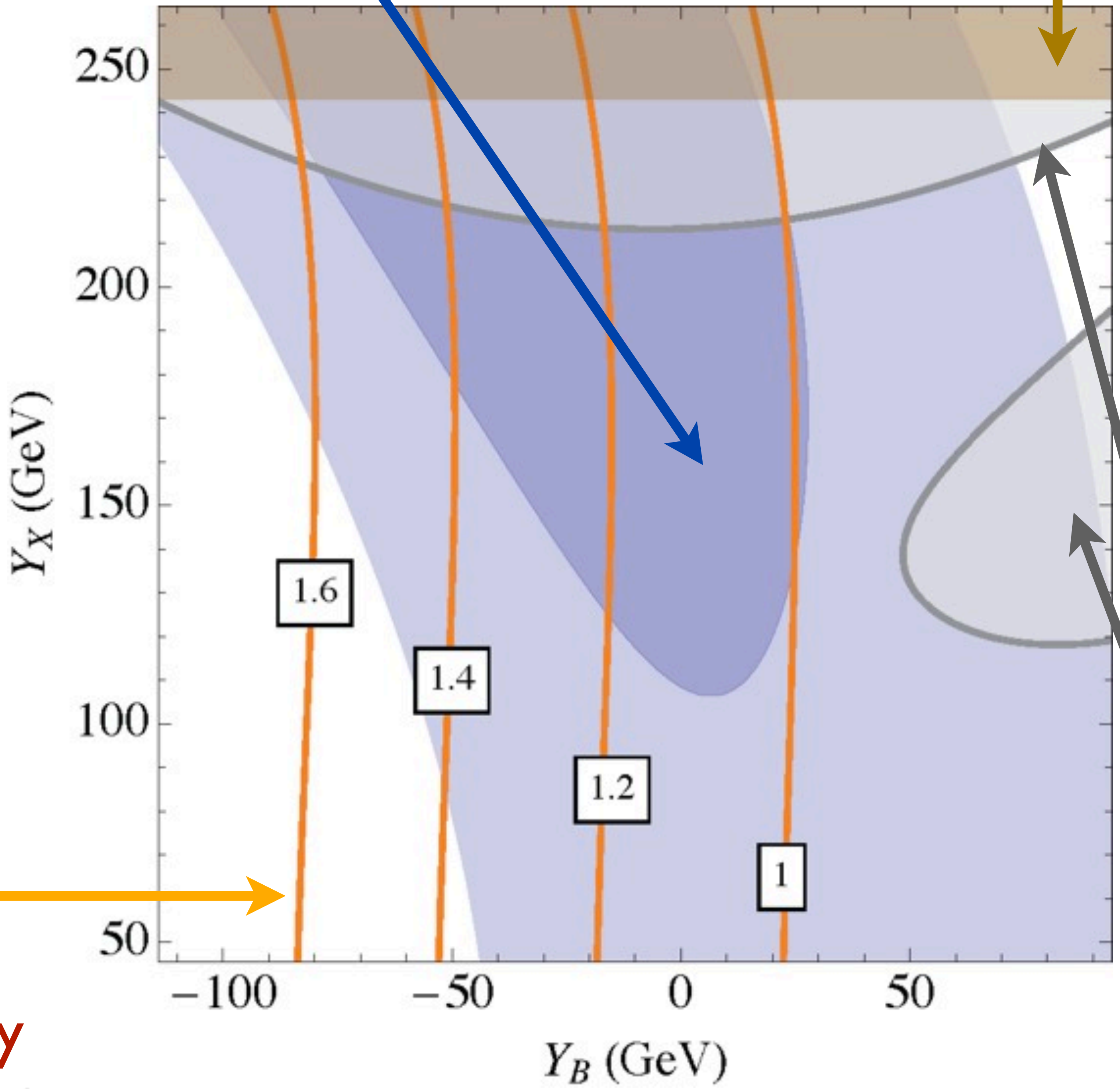
Results:

Higgs signal strength
$1\sigma, 2\sigma$ regions

top prime searches
$M - Y_X < 557$ GeV

We have fixed

$$M_{1,2,3} = 800 \text{ GeV}$$
$$Y_{2,3} \leftrightarrow \delta g_{L,R}$$
$$Y_1 \leftrightarrow m_b$$
$$Y_4 = Y_5 = Y_B,$$
$$Y_6 = Y_7 = Y_X$$



$\mu_{\gamma\gamma}$

Best-fit regions display
enhancement $1 \lesssim \mu_{\gamma\gamma} \lesssim 1.6$

$> 1\sigma$ tension with S, T

Results:

We have fixed

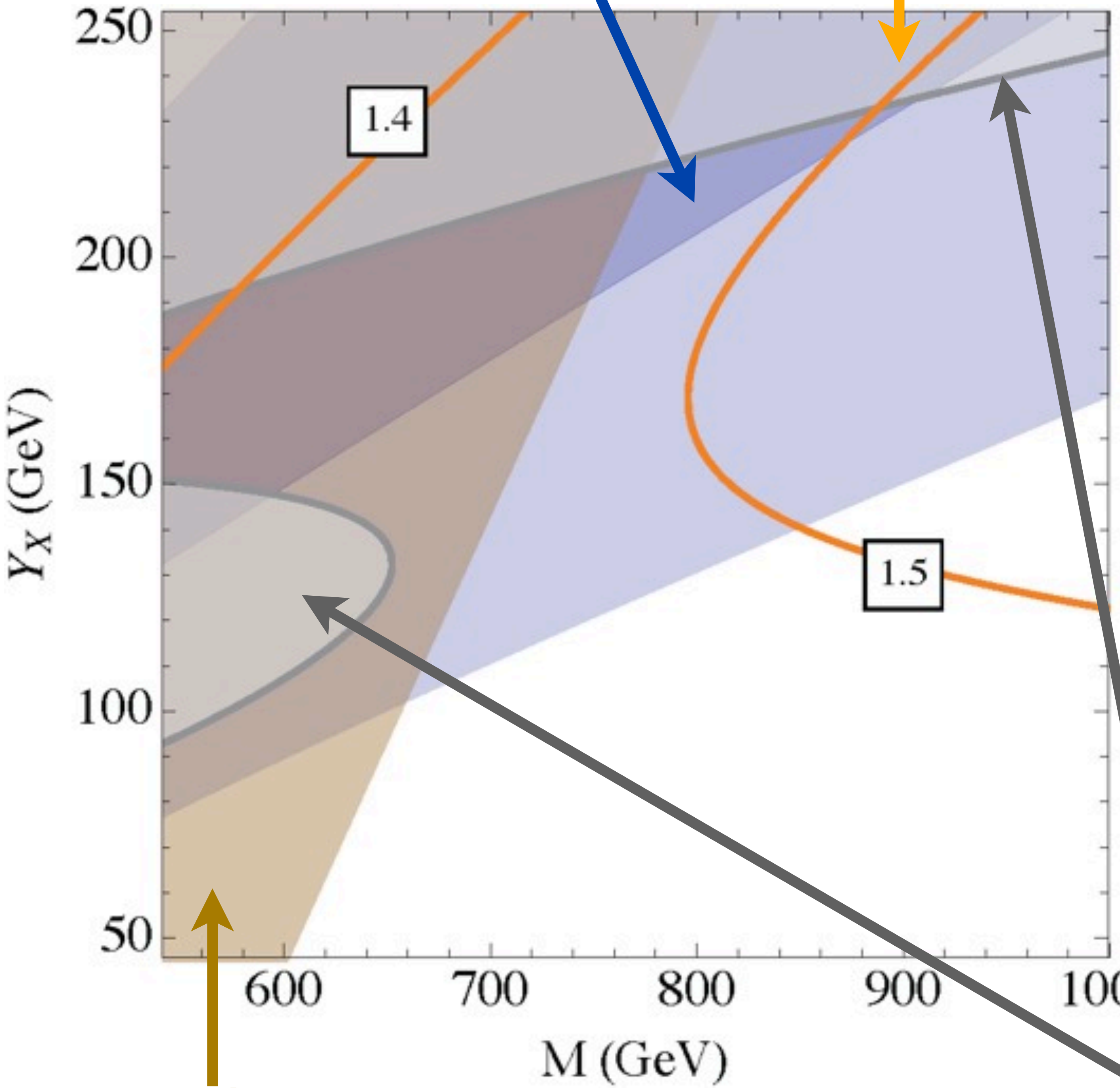
$$Y_{2,3} \leftrightarrow \delta g_{L,R}$$

$$Y_1 \leftrightarrow m_b$$

$$Y_4 = Y_5 = -65 \text{ GeV}$$

$$Y_6 = Y_7 = Y_X$$

$$M_1 = M_2 = M_3 = M$$



Higgs signal strength $1\sigma, 2\sigma$ regions

$\mu_{\gamma\gamma}$

top prime searches $M - Y_X < 557$ GeV

$> 1\sigma$ tension with S, T

Outlook:

- 125 GeV Higgs discovered - as suggested by EW data
- Higgs SM-like. Still plenty of room for deviation, such as in $\mu_{\gamma\gamma}$.
- Two discrepancies in EW data: $A_{FB}^{b}\,(2.6\sigma)$, $R_b\,(2.4\sigma)$
- Can shift $Z\bar{b}_R b_R$ by $b-B$ mixing
- Exotic B-quark can cause deviations in Higgs properties, interesting limits from Higgs data already.
- Model is directly testable at LHC via search for exotic ("beautiful mirror") quarks

Backup

Caveat: Vacuum stability

As emphasized recently in several works, new fermions with O(1) Yukawa's drive Higgs quartic negative at low scale

Jogelkar, Schwaller, Wagner `12
Arkani-Hamed, Blum, D'Agnolo, Fan `12
Reece `12

In our model,

$$16\pi^2\beta_\lambda \simeq \quad 24\lambda^2 + 12\lambda(y_t^2 + y_4^2 + y_5^2 + y_6^2 + y_7^2) - 6(y_t^4 + y_4^4 + y_5^4 + y_6^4 + y_7^4)$$

e.g. $y_4 = y_5 = 0, y_6 = y_7 = 1;$ VL threshold $M = 800 \text{ GeV}$

⇨ $\lambda = 0$ at $Q = 2 \text{ TeV}$

- Model requires a UV completion to stabilize vacuum...
- Obvious candidate is a SUSY version (beyond scope here)

Ingredients going into the electroweak fit:

- Observables

$$m_Z,\ \Gamma_Z,\ \sigma^0_{\rm had},\ R_\ell,\ R_c,\ R_b,$$
$$A^\ell_{FB},\ A_\ell,\ A_c,\ A_b,\ A^c_{FB},\ A^b_{FB},\ \sin^2\theta_{\rm eff},$$
$$m_W,\ \Gamma_W,\ m_t,\ \Delta\alpha^{(5)}_{\rm had},\ m_h$$

- Vary SM + NP parameters in fit

$$m_H, m_Z, m_t, \Delta\alpha^{(5)}_{\rm had}, \alpha_s,$$
$$S, T, \delta g_{Lb}, \delta g_{Rb}$$

- Theory predictions taken from various numerical parameterizations in literature...

A^b_{FB}

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu \bar{b}(g_{Lb}P_L + g_{Rb}P_R)b$$

Consider the process

$$e^+e^- \to \gamma, Z, \to b\bar{b}$$

Forward, backward
cross sections:

$$\sigma_{F,B} = \mp \int_0^{\pm 1} \frac{d\sigma}{d\cos\theta} d\cos\theta$$

Polarized
cross sections:

$$\sigma_{LL} \equiv \sigma(e^+_L e^-_L \to b_L \bar{b}_L),$$ etc.

Forward-backward
asymmetry:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4}\frac{\sigma_{LL} + \sigma_{RR} - \sigma_{LR} - \sigma_{RL}}{\sigma_{LL} + \sigma_{RR} + \sigma_{LR} + \sigma_{RL}}$$

On Z-pole:

$$\sigma_{LL} \propto \frac{g_{Le}g_{Lb}}{m_Z\Gamma_Z}$$, etc.

⇒

$$A_{FB} = \frac{3}{4}\frac{g^2_{Le} - g^2_{Re}}{g^2_{Le} + g^2_{Re}}\frac{g^2_{Lb} - g^2_{Rb}}{g^2_{Lb} + g^2_{Rb}}$$

R_b

$$\mathcal{L} \supset \frac{g}{c_W} Z_\mu \bar{b}(g_{Lb}P_L + g_{Rb}P_R)b$$

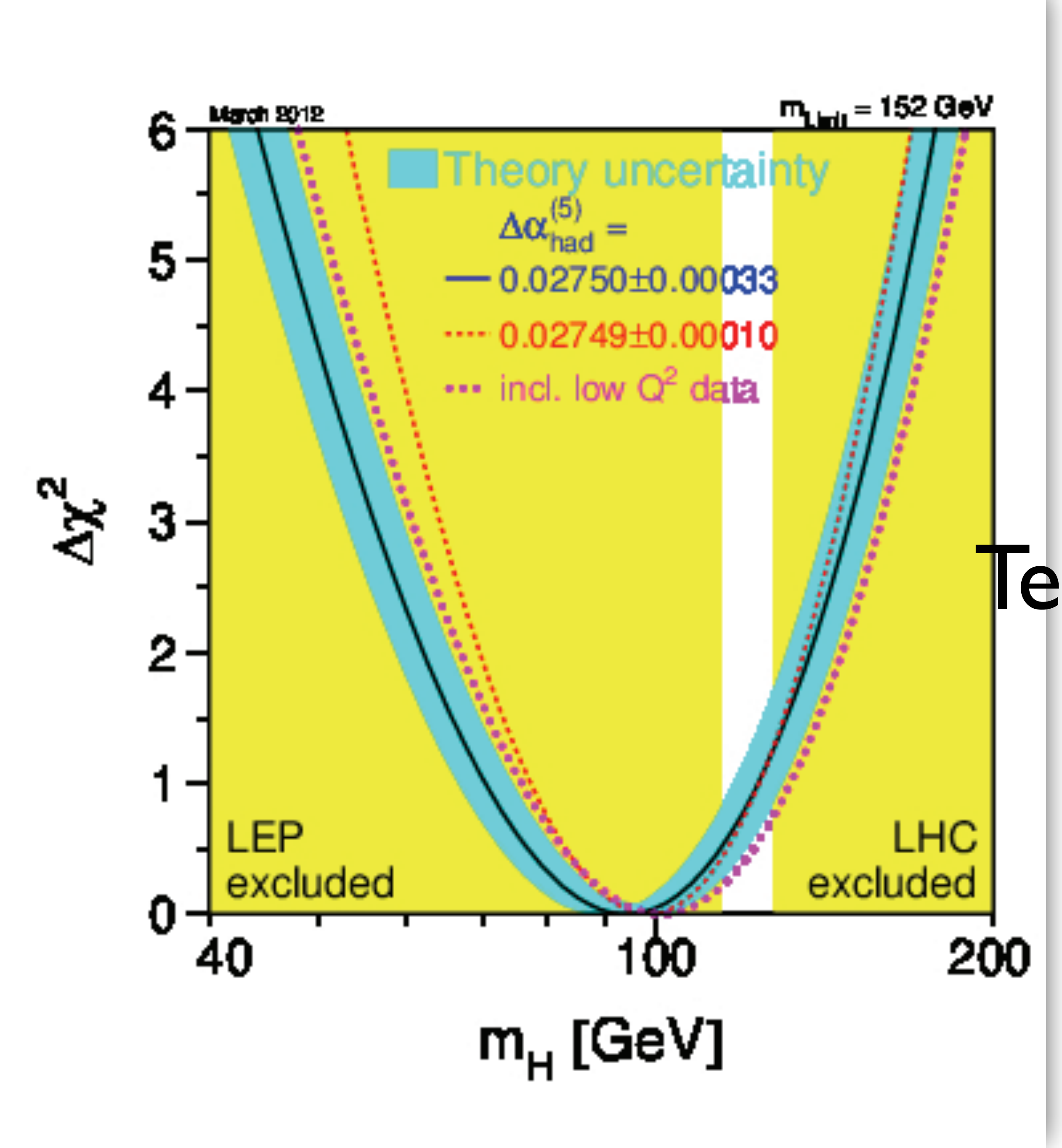
Z boson partial width: $\Gamma(Z \to \psi_i\bar{\psi}_i) \simeq \frac{g^2}{24\pi c_W^2}(g_{Li}^2 + g_{Ri}^2)M_Z$

⇨ $$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{g_{Lb}^2 + g_{Rb}^2}{\sum_q [g_{Lq}^2 + g_{Rq}^2]}$$

Note: both A_{FB}^b, R_b depend on couplings $g_{Lb}, \quad g_{Rb}$

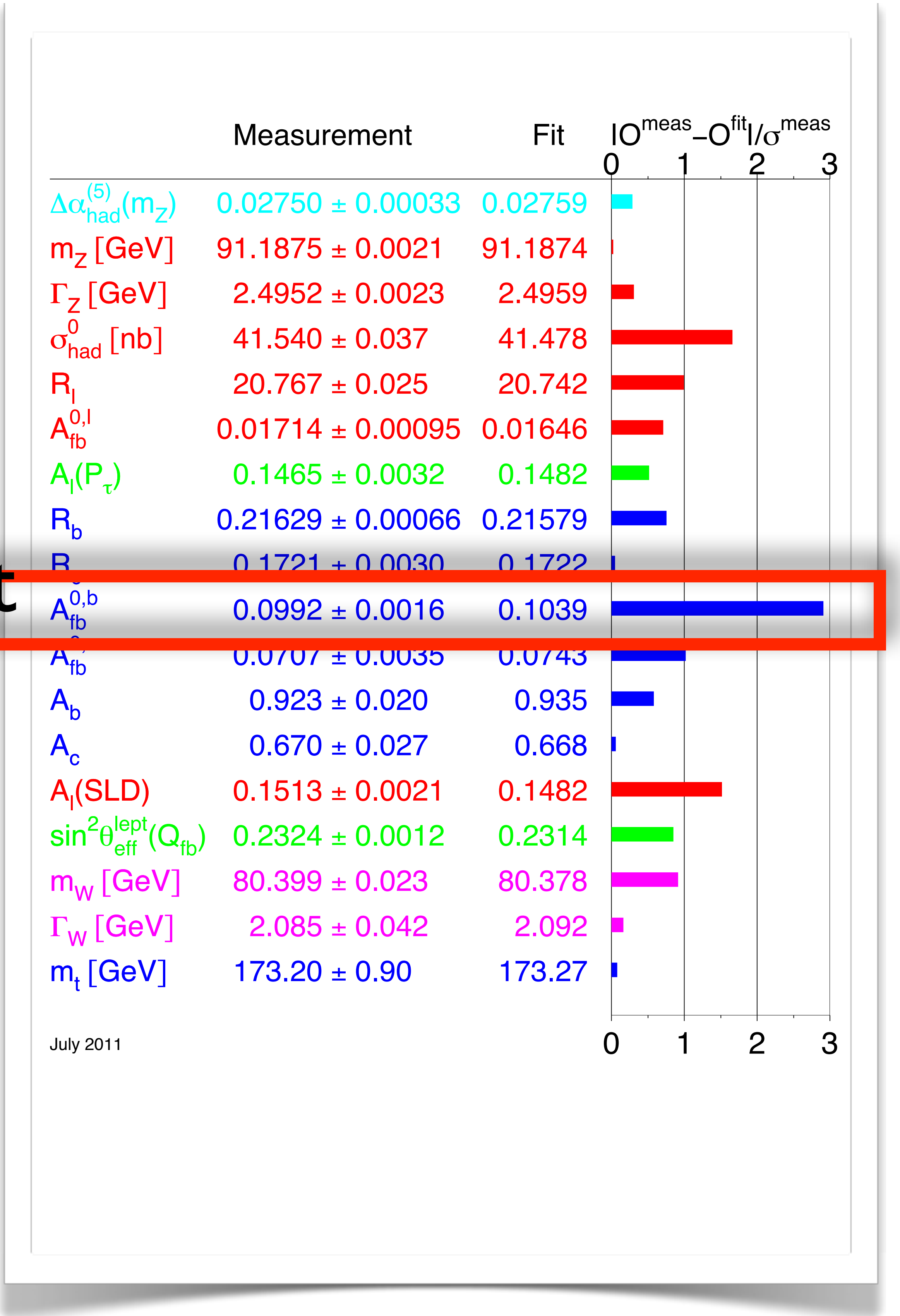
Suggests common resolution: tree-level shifts in $Zb\bar{b}$

Precision Electroweak Data (circa December 2011)



[LEP EWWG]

Text



	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02750 ± 0.00033	0.02759	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.742	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01646	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1482	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1039	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0743	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1482	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.399 ± 0.023	80.378	
Γ_W [GeV]	2.085 ± 0.042	2.092	
m_t [GeV]	173.20 ± 0.90	173.27	

A_{FB}^b, R_b due to systematic effect

Including LHC Higgs mass measurement:

SM w/o A_{FB}^b, R_b :

$$p = 0.67$$
$$m_h = 125.7 \text{ GeV}$$

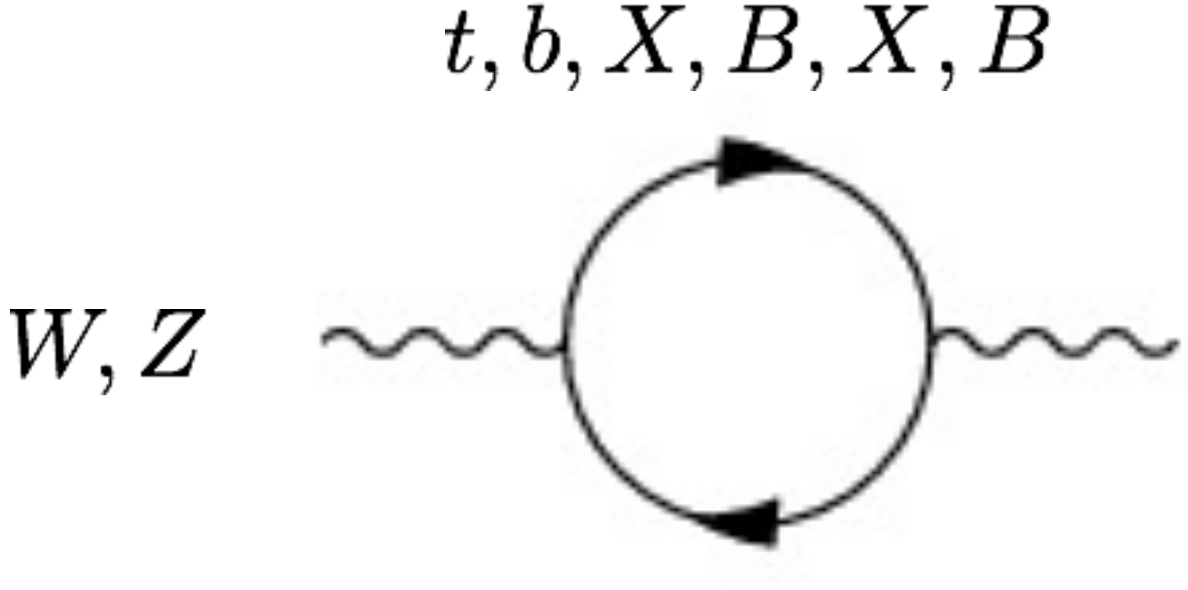
SM w/o A_{FB}^b, R_b
\+ S, T :

$$p = 0.78$$
$$S = -0.08 \pm 0.10$$
$$T = 0.0 \pm 0.08$$

- Marginal improvement with oblique parameters.
- No strong argument for new physics to pull up Higgs mass

Oblique corrections

[Peskin, Takeuchi `90, `92]



- Contribution from new mirror quarks
- $W\bar{t}b, Z\bar{b}b$ vertices modified - include t, b and subtract off SM
- Restrict to 1σ regions determined by fit (including $\delta g_{L,R}$)

$$S = -0.02 \pm 0.09, \quad T = 0.03 \pm 0.08, \quad \rho \sim 0.90$$