Higgs and Precision Electroweak Data

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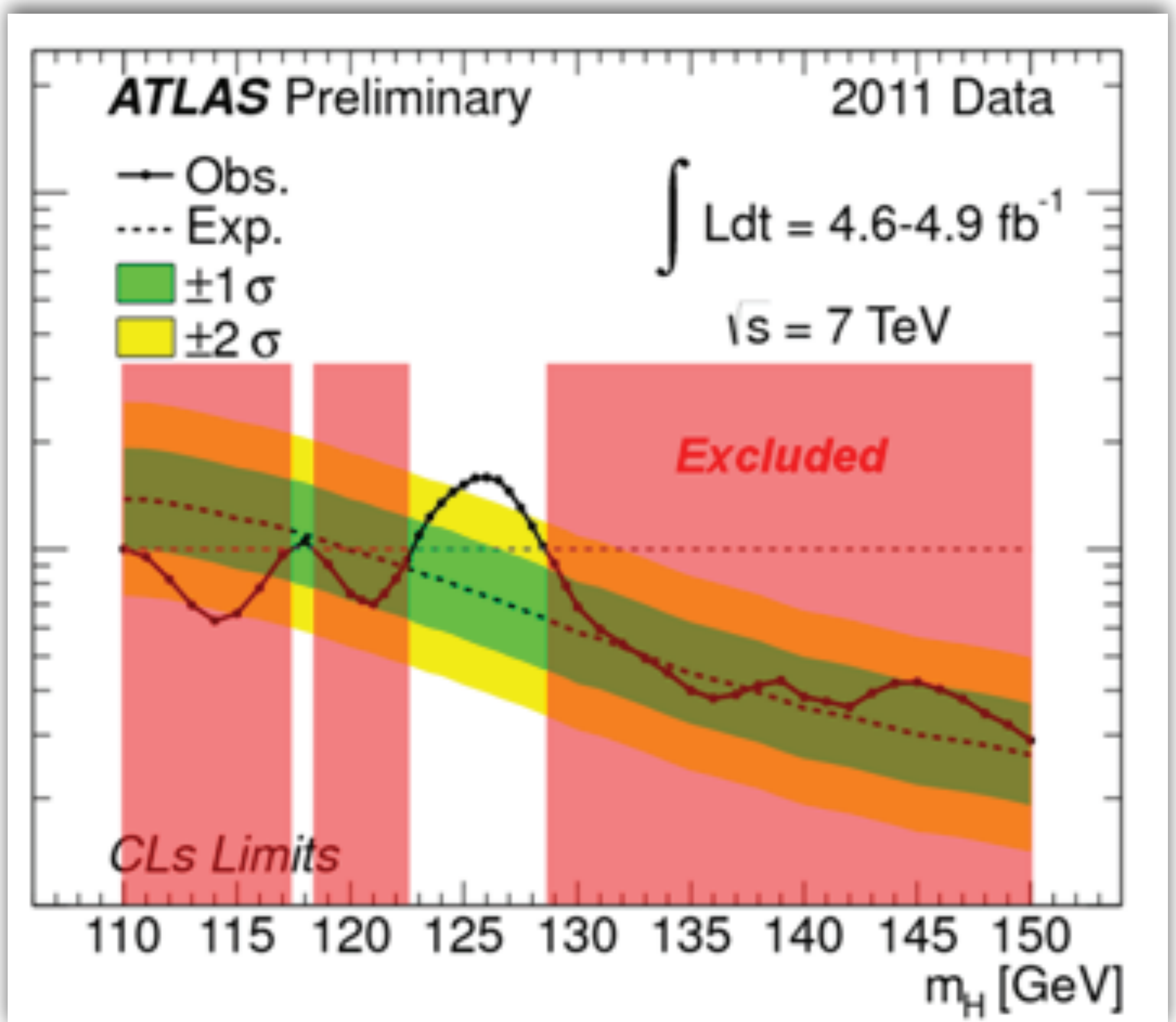
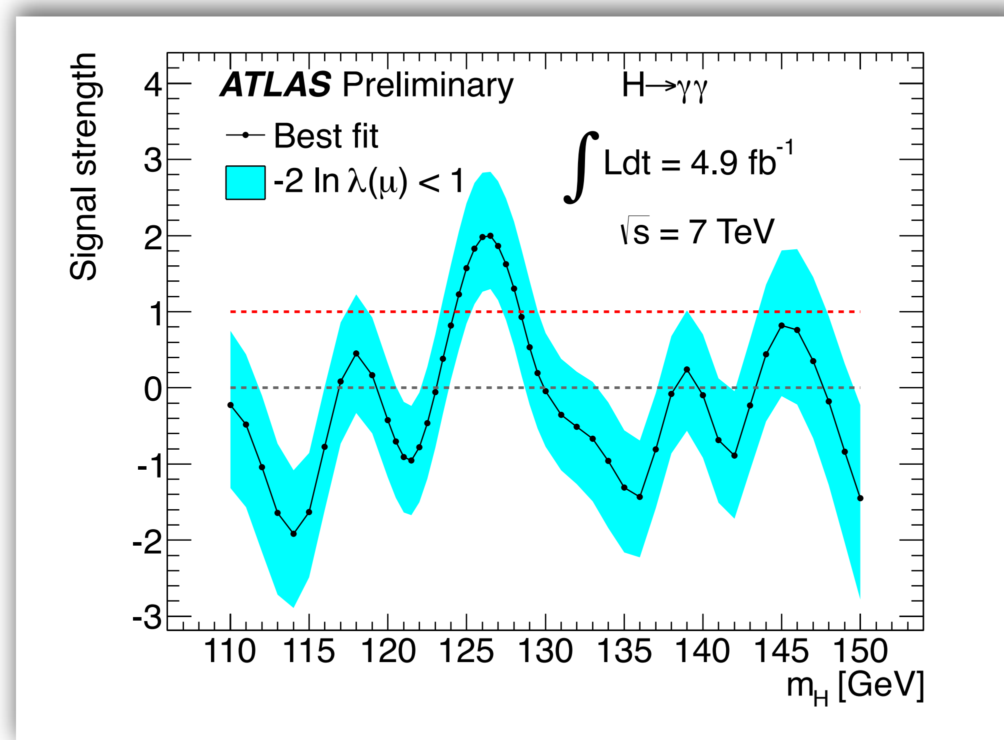
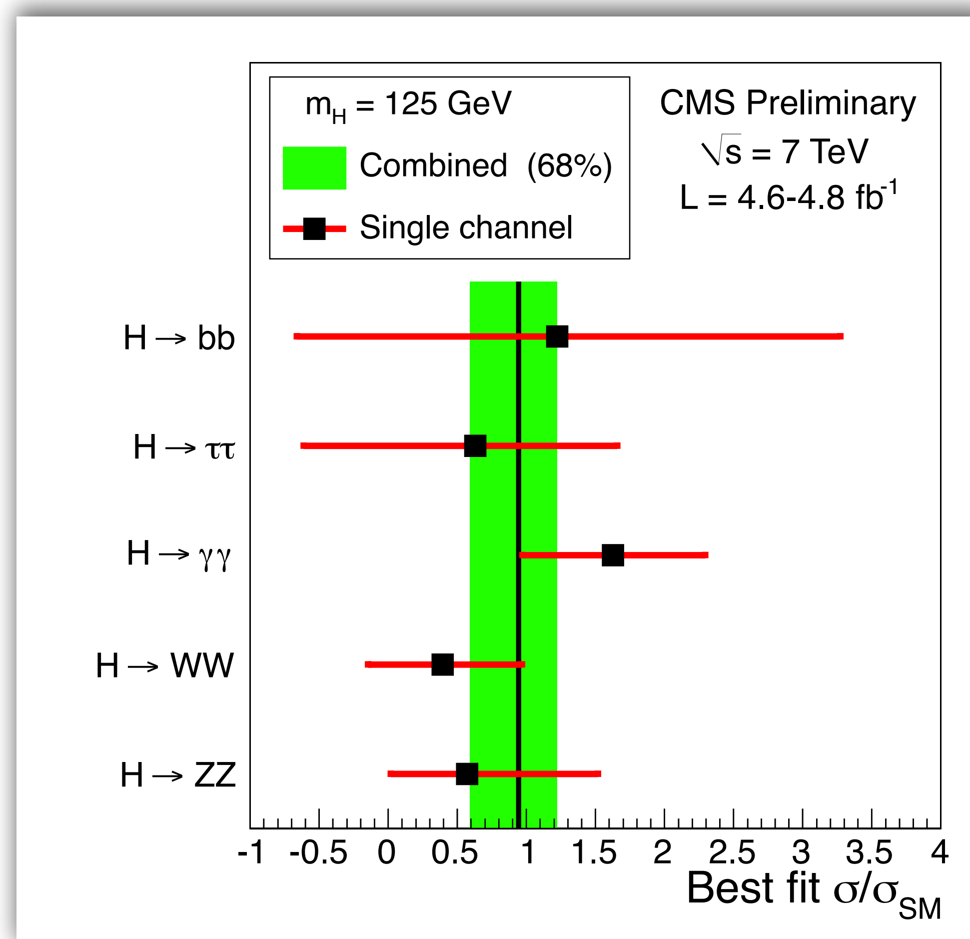
work in progress with Stefania Gori and Lian-Tao Wang

PHENO 2012

Higgs


ATLAS Preliminary
2011 Data
Obs.
Exp.
±1 σ
±2 σ
∫ Ldt = 4.6-4.9 fb-1
√s = 7 TeV
Excluded
CLs Limits
110 115 120 125 130 135 140 145 150
mH [GeV]


ATLAS Preliminary
H→γγ
Best fit
-2 ln λ(μ) < 1
∫ Ldt = 4.9 fb-1
√s = 7 TeV
Signal strength
4 3 2 1 0 -1 -2 -3
110 115 120 125 130 135 140 145 150
mH [GeV]


mH = 125 GeV
Combined (68%)
Single channel
CMS Preliminary
√s = 7 TeV
L = 4.6-4.8 fb-1
H → bb
H → ττ
H → γγ
H → WW
H → ZZ
-1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4
Best fit σ/σSM

Rates

e.g. most recent phenomenological fit:

Giardino, Kannike, Raidal, Strumia, 1203:4254

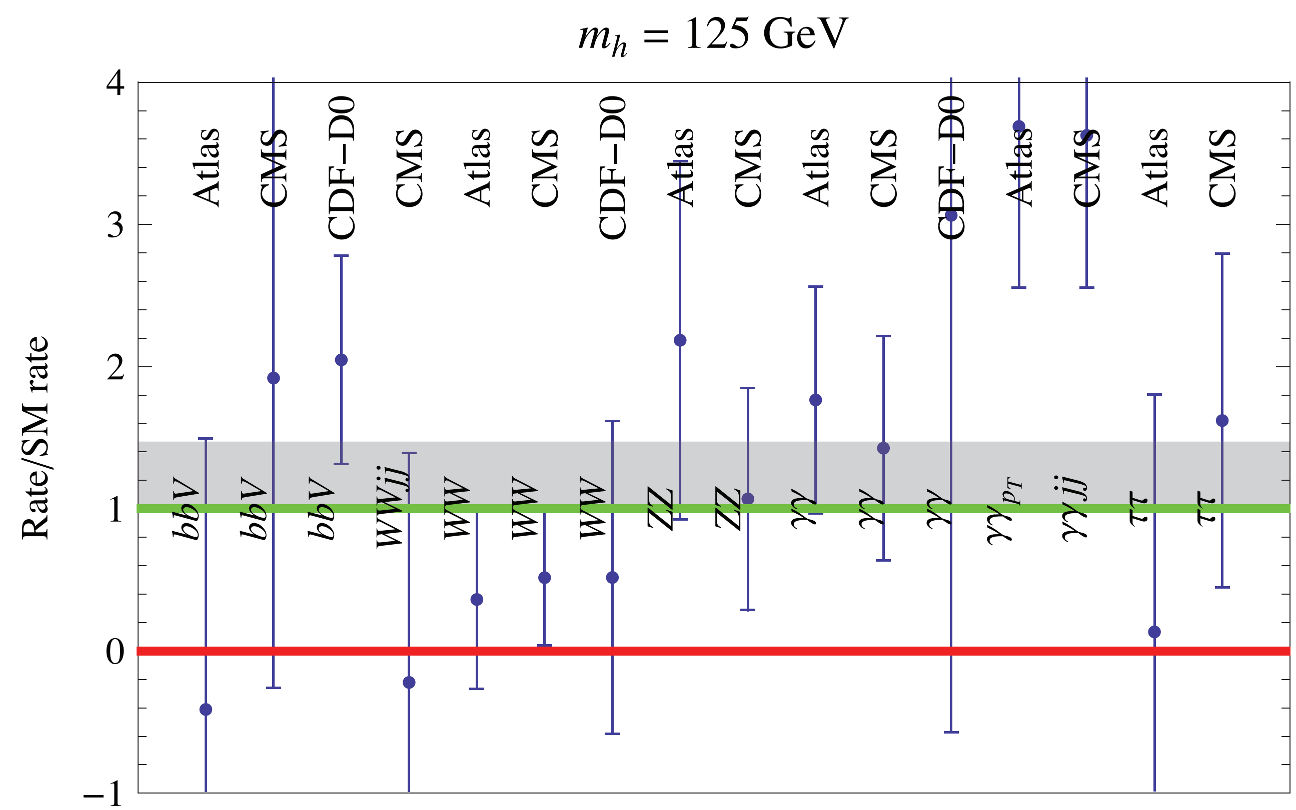
1. SM gives a good fit to data

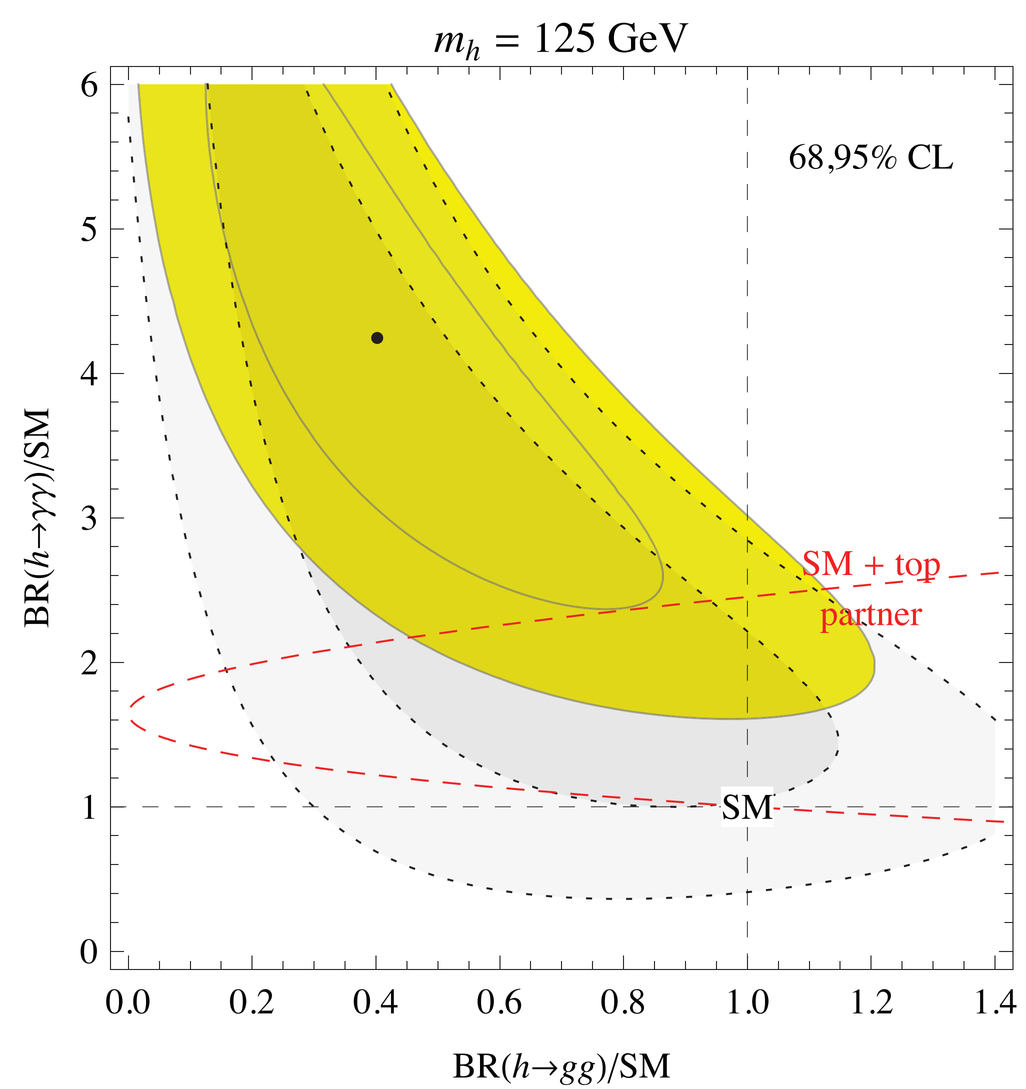
Global χ^2 =16 for 15 d.o.f.

2. Best fit obtained for free hgg and $h\gamma\gamma$ couplings

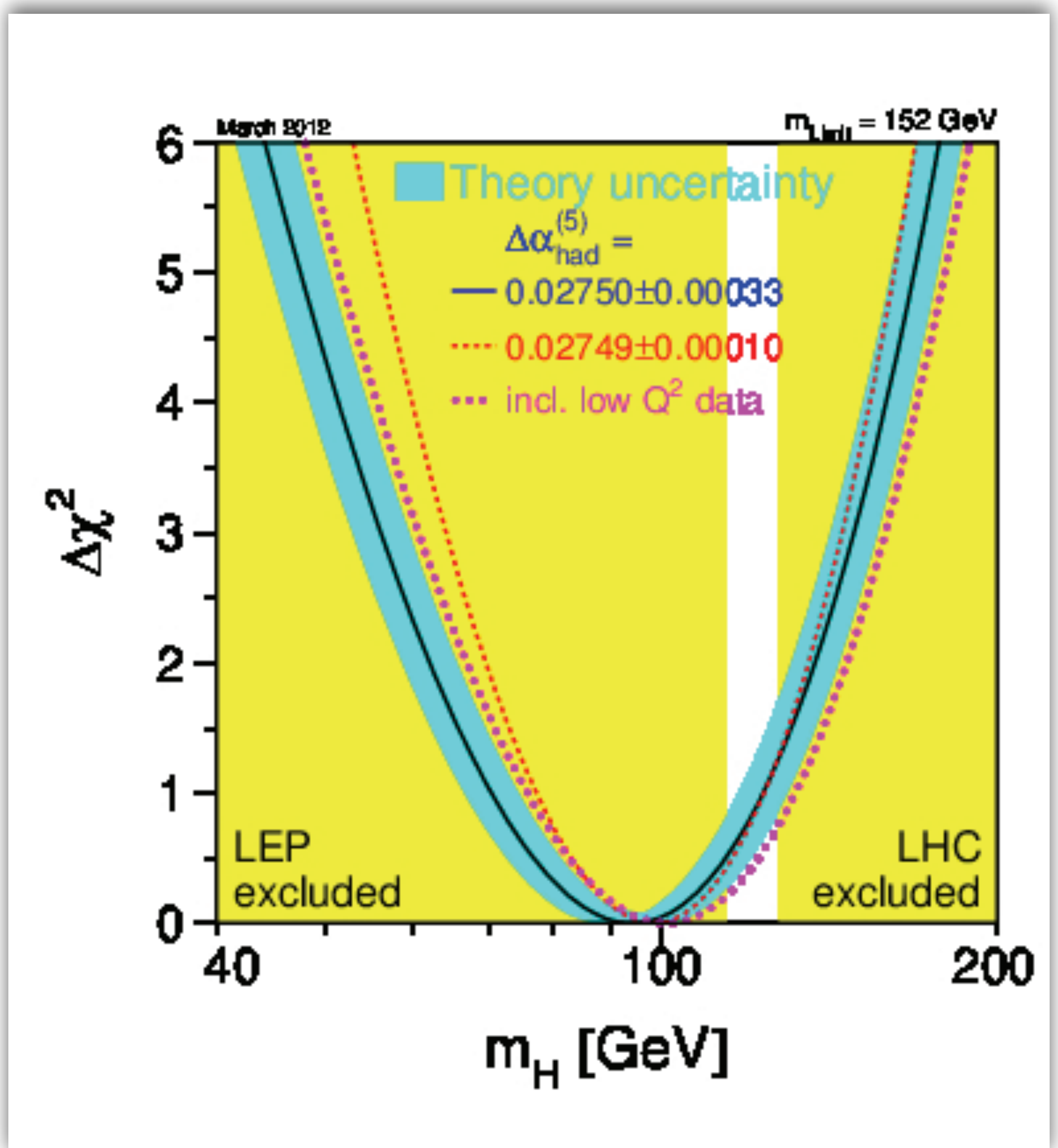
Global χ^2 5.5 for 17 d.o.f.

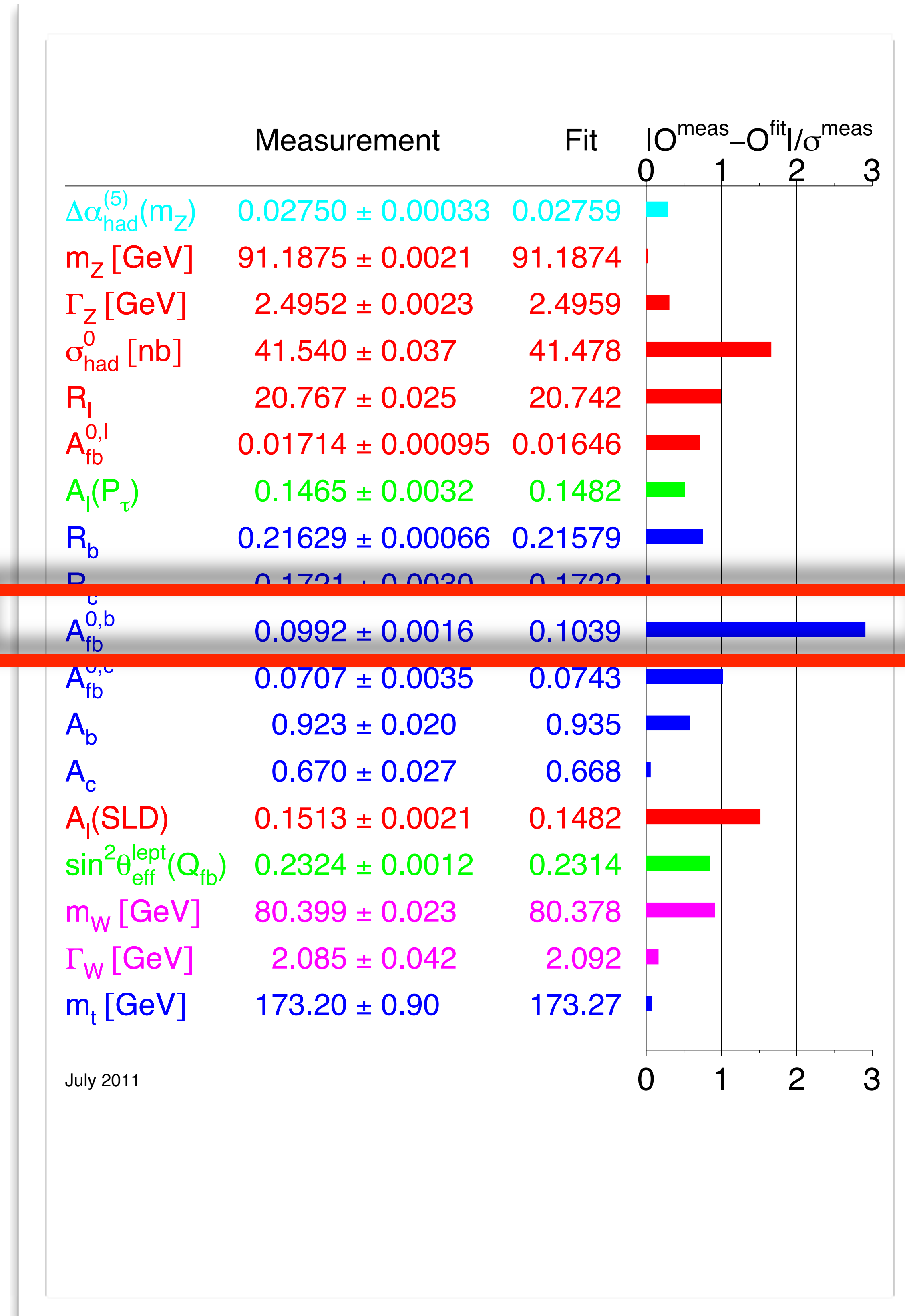
O(1) enhancement in $\gamma\gamma$ channel!





Precision Electroweak Data





A^b_{FB}

from PDG

$$A^b_{FB,\mathrm{exp}} = 0.0992 \pm 0.0016,$$
$$A^b_{FB,\mathrm{SM}} = 0.1034 \pm 0.0007$$

2.6σ deviation for m_h free in fit

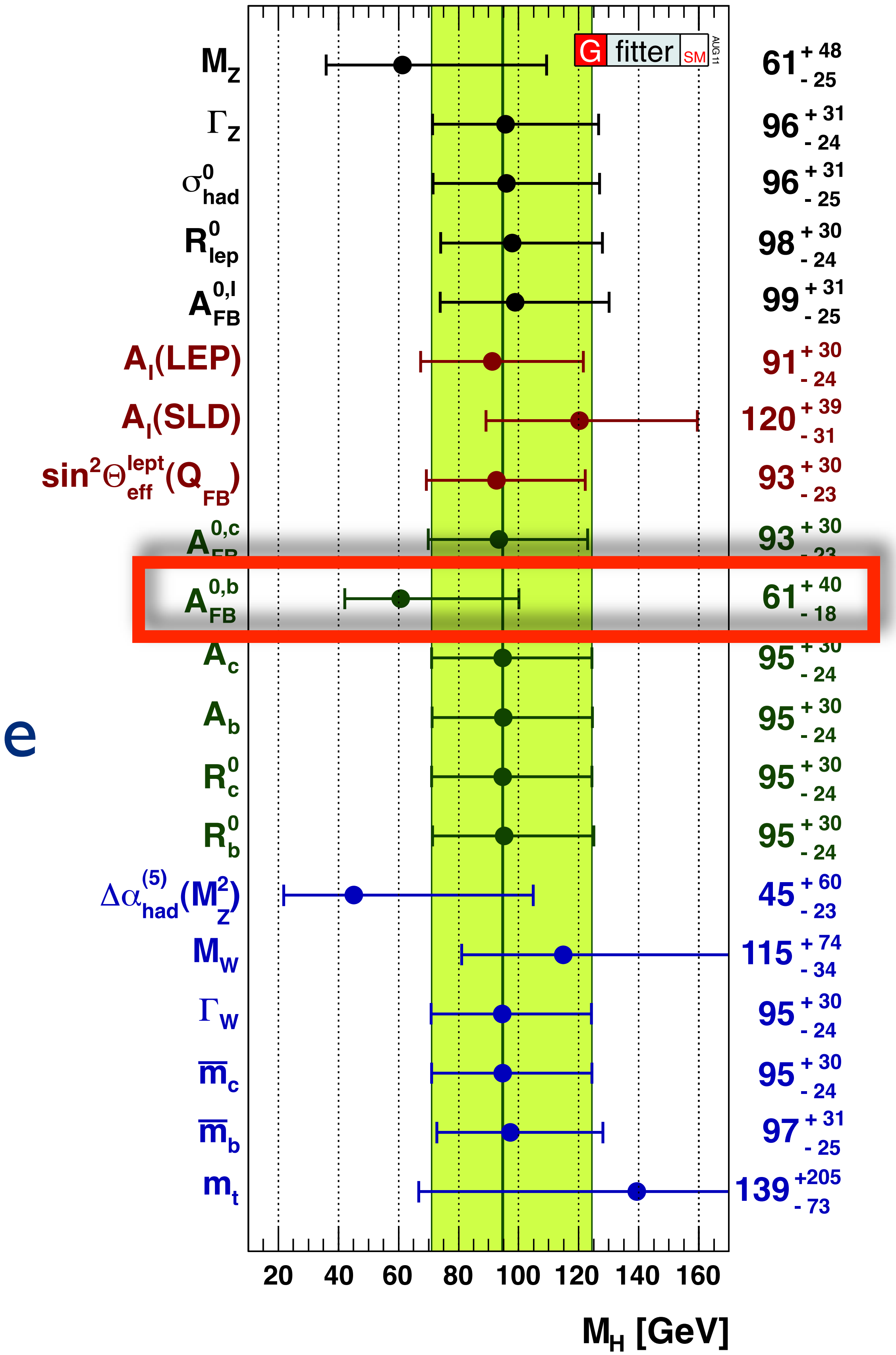
2.3σ deviation for $m_h = 124.5\,\mathrm{GeV}$

A puzzle?

After all, $2-3\sigma$ discrepancies come and go all the time!

But ... if A^b_{FB} attributed to experimental error, or statistical fluctuation, electroweak fit prefers a very light Higgs, in tension with LEP bound

Chanowitz '01



from GFitter group

Can the A_{FB}^b anomaly and Higgs rates be due to same underlying new physics?

I will tell you two stories:

1. New physics alters A_{FB}^b (measurement correct)

2. Throw out A_{FB}^b (experimental error or statistical fluctuation)

⇨ Electroweak data suggest NP for 125 GeV Higgs

1. New physics alters A_{FB}^{b}

A_{FB}^b ingredients

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.

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

Modify $Zb_R\bar{b}_R$ coupling

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

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

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

Goal: shift A_{FB}^b without affecting R_b

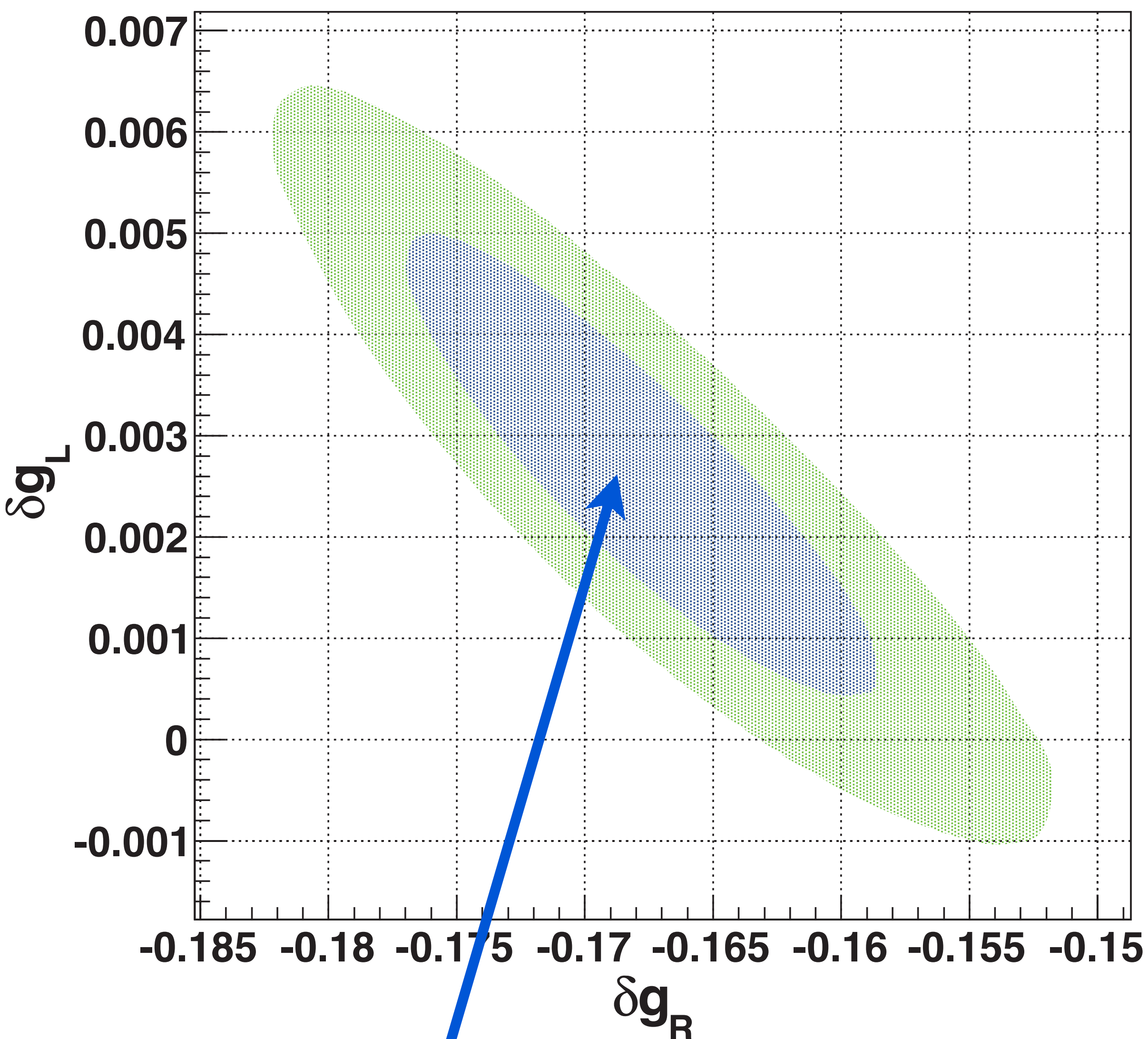
$$A_{FB} = \frac{3}{4} \frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2} \frac{g_{Lb}^2 - g_{Rb}^2}{g_{Lb}^2 + g_{Rb}^2} \qquad R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{g_{Lb}^2 + g_{Rb}^2}{\sum_q [g_{Lq}^2 + g_{Rq}^2]}$$

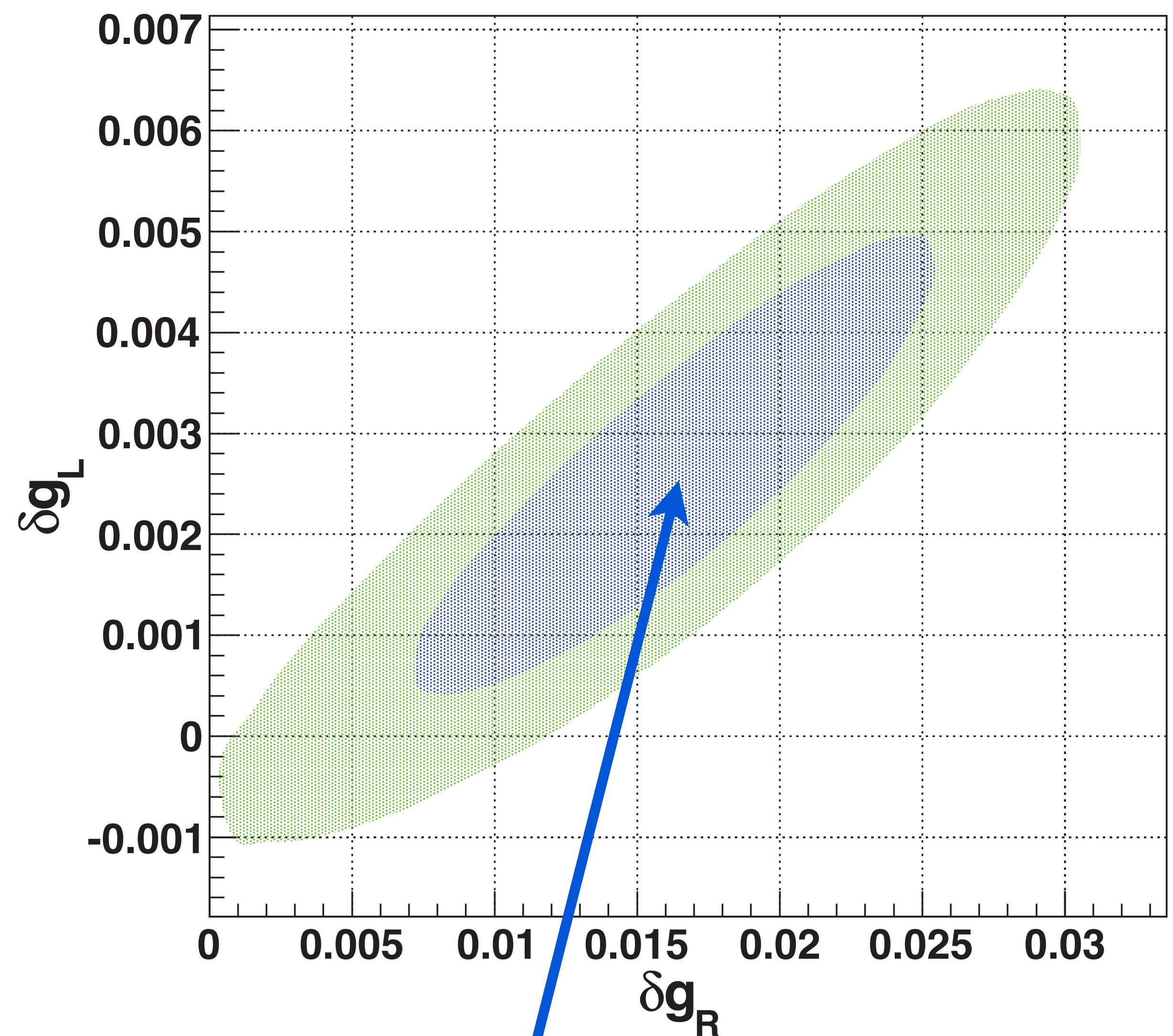
Z-pole data allows 4 solutions in $(\delta g_{Lb}, \delta g_{Rb})$, off-peak data for A_{FB}^b eliminate 2 possible solutions

Data prefers a bigger shift in δg_{Rb}, smaller shift in δg_{Lb}

Fit: 2 solutions

Kumar, Shepherd, Tait, Vega-Morales '10





Large negative δg_R^b solution

Small positive δg_R^b solution

$\delta g_{Lb} \sim 0.003 \qquad \delta g_{Rb} \sim -0.17$

$\delta g_{Lb} \sim 0.003 \qquad \delta g_{Rb} \sim 0.02$

Beautiful Mirrors

Choudhury, Tait, Wagner '01

Basic idea: Mix new vector-like quark 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 $\theta_{L,R}$

Z boson interactions: $$\mathcal{L} \supset \frac{g}{c_w} Z_\mu \sum_{ij} \bar{b}_i \gamma^\mu (L_{ij} P_L + R_{ij} P_R) b_j$$

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

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

Singles out 3 vector-like representations:

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

Focus on $\Psi \sim (3, 2, -5/6) \sim \begin{pmatrix} B \\ X \end{pmatrix}$

$t^B_{3R} = \frac{1}{2}$ ➡ $\delta g_{Rb} = \frac{1}{2} s_R^2 = 0.02$ ➡ $\sin\theta_R \approx 0.2$

Consider EFT with general Higgs couplings:

$$\mathcal{L} \supset -y_1 \bar{Q} H b_R - y_2 \bar{\Psi}_L H^\dagger b_R - M \bar{\Psi}_L \Psi_R \ + \text{h.c.}$$

$$-a\frac{|H|^2}{\Lambda}\bar{\Psi}_L\Psi_R - b\frac{|H|^2}{\Lambda^2}\bar{Q}Hb_R - c\frac{|H|^2}{\Lambda^2}\bar{\Psi}_L H^\dagger b_R + \ldots \quad + \text{h.c.}$$

$$\to -\left(\bar{b}_L \ \bar{B}_L\right)\left\{\begin{pmatrix} Y_1 + \frac{bv^3}{2\sqrt{2}\Lambda^2} & 0 \\ Y_2 + \frac{cv^3}{2\sqrt{2}\Lambda^2} & M + \frac{av^2}{2\Lambda}\end{pmatrix} + h\begin{pmatrix} \frac{Y_1}{v} + \frac{3bv^2}{2\sqrt{2}\Lambda^2} & 0 \\ \frac{Y_2}{v} + \frac{3cv^2}{2\sqrt{2}\Lambda^2} & \frac{av}{\Lambda}\end{pmatrix}\right\}\begin{pmatrix} b_R \\ B_R \end{pmatrix} + \text{h.c.}$$

Diagonalize mass matrix via rotations...

Higgs physics

see also Wagner, Morrissey '03 for $(3,2,1/6)$

$$\mathcal{L}_{hqq} \supset -\xi_{hbb}\frac{m_b}{v}h\bar{b}b - \xi_{hBB}\frac{m_B}{v}h\bar{B}B$$
$$-\xi_{hXX}\frac{m_X}{v}h\bar{X}X$$

$$\xi_{hbb} \approx c_R^2 + \frac{bv^3}{\sqrt{2}m_b\Lambda^2} - \frac{c\,s_R v^3}{\sqrt{2}m_B\Lambda^2}$$

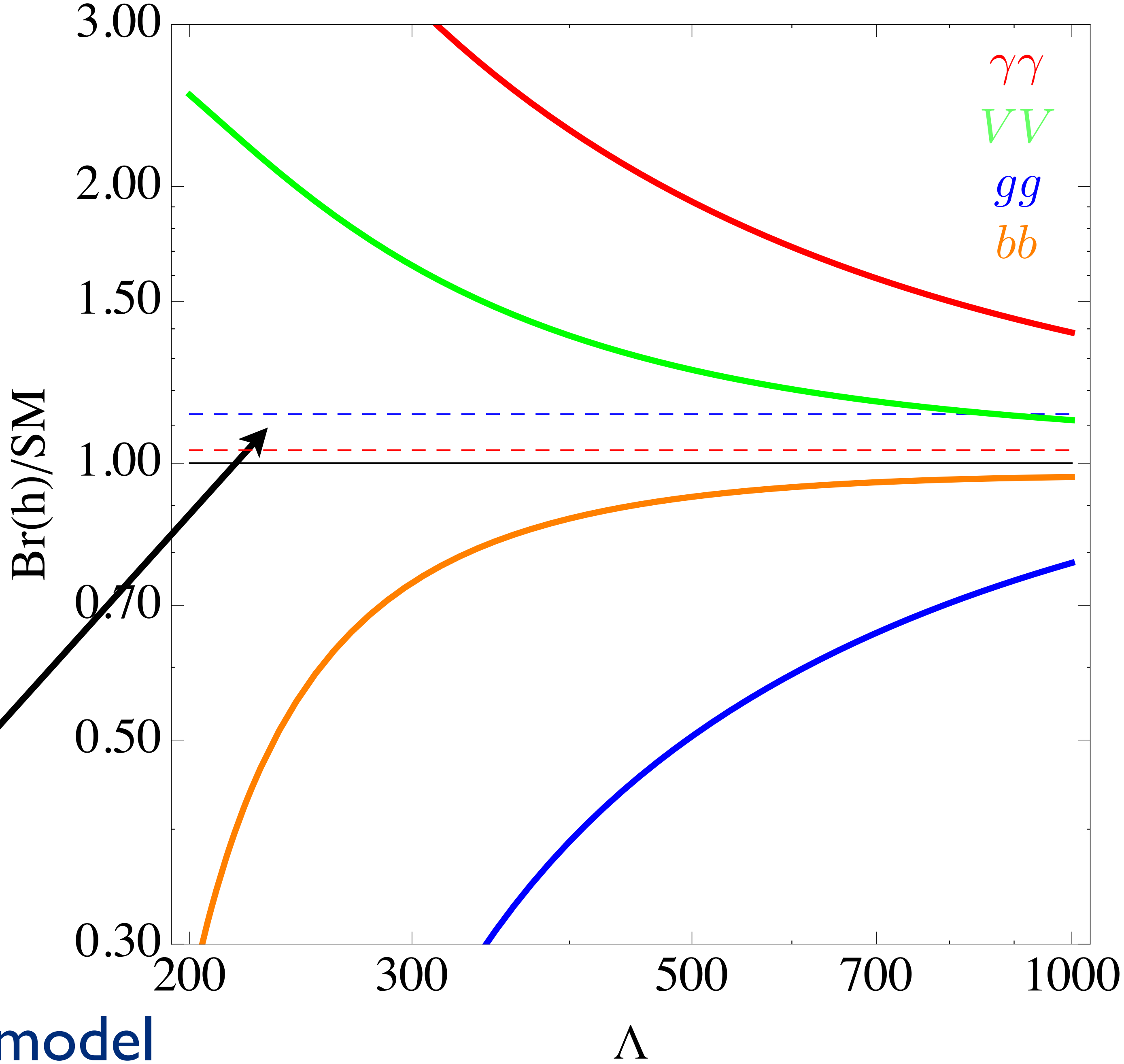
$$\xi_{hBB} \approx s_R^2 + \frac{av^2}{m_B\Lambda} + \frac{c\,s_R v^3}{\sqrt{2}m_B\Lambda^2}$$

$$\xi_{hXX} = \frac{av^2}{m_X\Lambda}$$

To enhance $\gamma\gamma$ rate:

- Suppress $h \to b\bar{b}$ partial width: $\xi_{hbb} < 1$
- Heavy quarks interfere constructively with SM $h \to \gamma\gamma$ amplitude: $\xi_{hBB}, \xi_{hXX} < 0$

$a = -1,\ b = -0.01,\ c = 0,\ m_B = 600\,\mathrm{GeV}$



Renormalizable model
$(a = b = c = 0)$

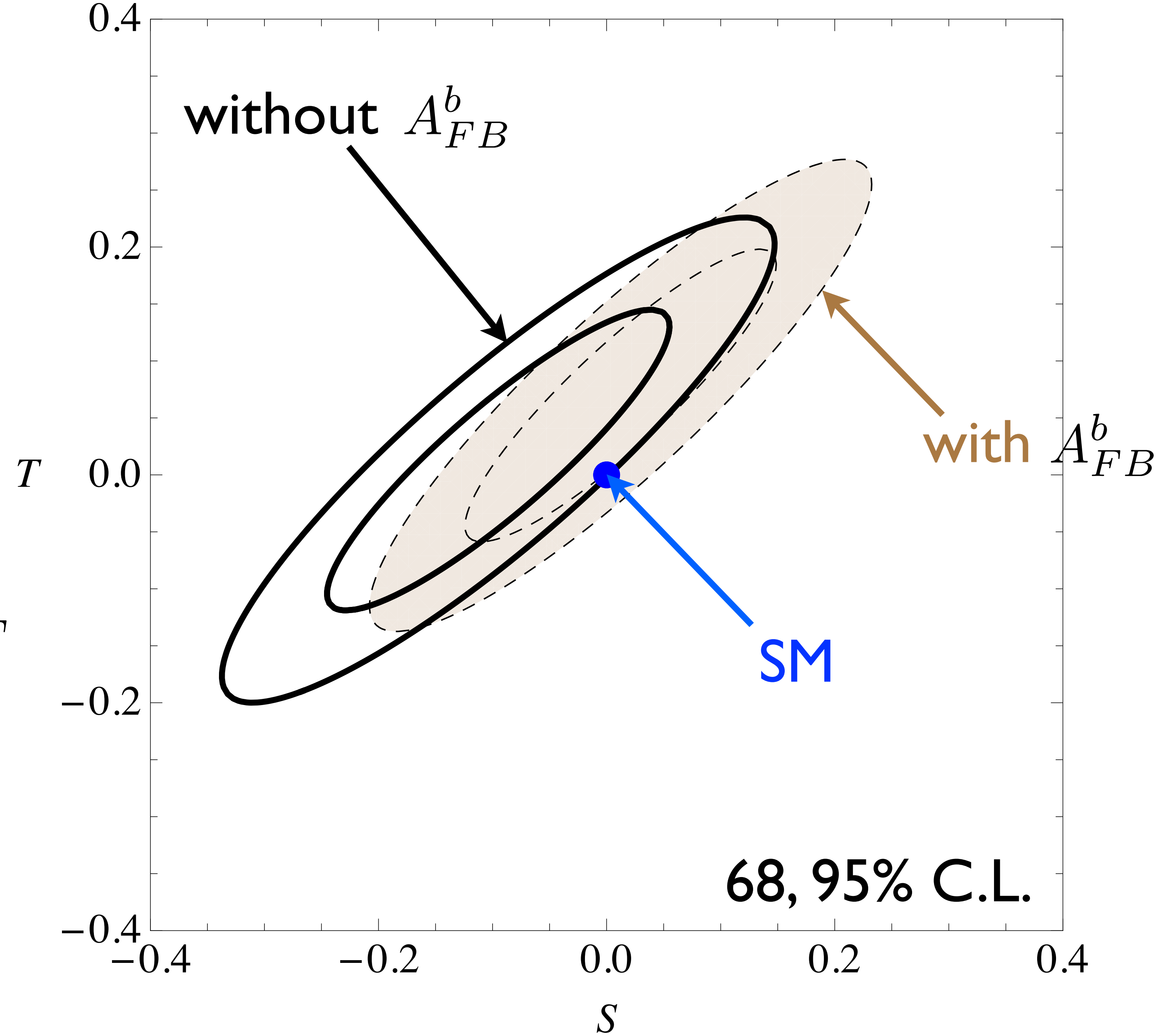
- Enhancement in $\gamma\gamma$
- Suppression in gluon fusion
- "Acceptable" suppression in $b\bar{b}$

2. Throw out A_{FB}^{b}

(experimental error or statistical fluctuation)

$S-T$ fit
without A^b_{FB}

$$A^b_{FB} - (A^b_{FB})_{\rm SM} \simeq -0.020\, S + 0.014\, T$$



Electroweak data (w/o A^b_{FB}) indicate
a positive T, negative S

Simplest example: a second scalar doublet

$$S \sim (1,2,1/2) = \begin{pmatrix} S^+ \\ \frac{1}{\sqrt{2}}(S_0^R + iS_0^I) \end{pmatrix}$$

$$V \supset m^2|S|^2 + \lambda_1|S|^2|H|^2 + \lambda_2(H^\dagger S)(S^\dagger H) + [\lambda_3(H^\dagger S)(H^\dagger S) + \text{h.c.}] + \ldots$$

hS^+S^- coupling

contribution to $h \to \gamma\gamma$

Custodial breaking

$$S \simeq \frac{\lambda_2 v^2}{24\pi m^2}$$

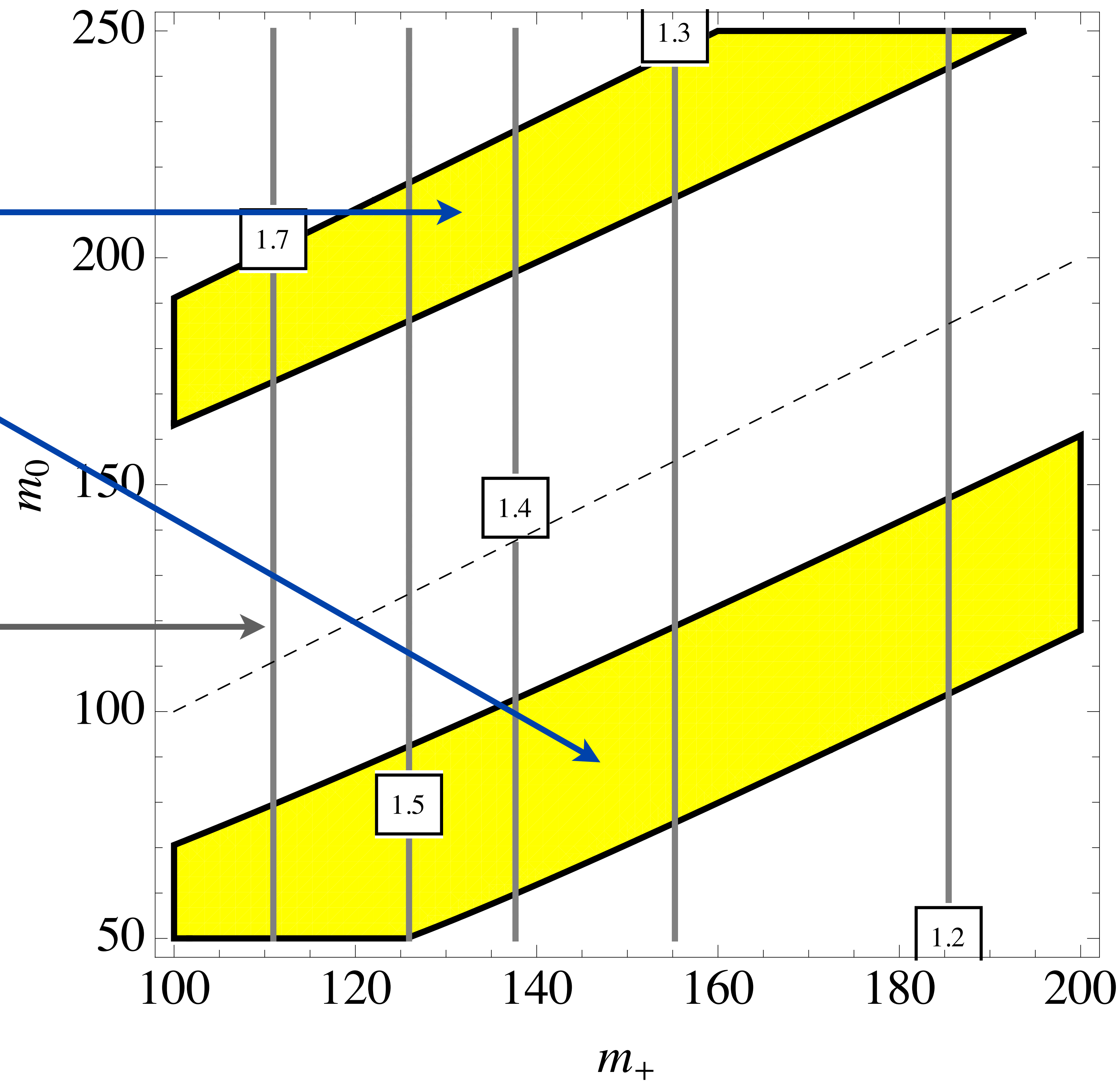
$$T \simeq \frac{v^4}{192\pi s_w^2 M_W^2 m^2}[(\lambda_2)^2 - 4(\lambda_3)^2]$$

e.g. $\lambda_1 = -2,\ \lambda_3 = 0$

$S - T$

preferred regions

$\mathrm{Br}(h \to \gamma\gamma)/\mathrm{SM}$



Requires mass splittings ~ 60-70 GeV

Summary

Hints for Higgs at 125 GeV, as suggested by Precision Electroweak Data

$A_{FB}^{b}: 2-3\,\sigma$ discrepancy - Is it a puzzle?

Two approaches

- New physics directly influences for A_{FB}^{b}
- A_{FB}^{b} a statistical fluctuation or measurement error

... invoke NP to improve EW data for 125 GeV Higgs

The same new physics can simultaneously modify Higgs rates