Robust determination of the scalar boson couplings

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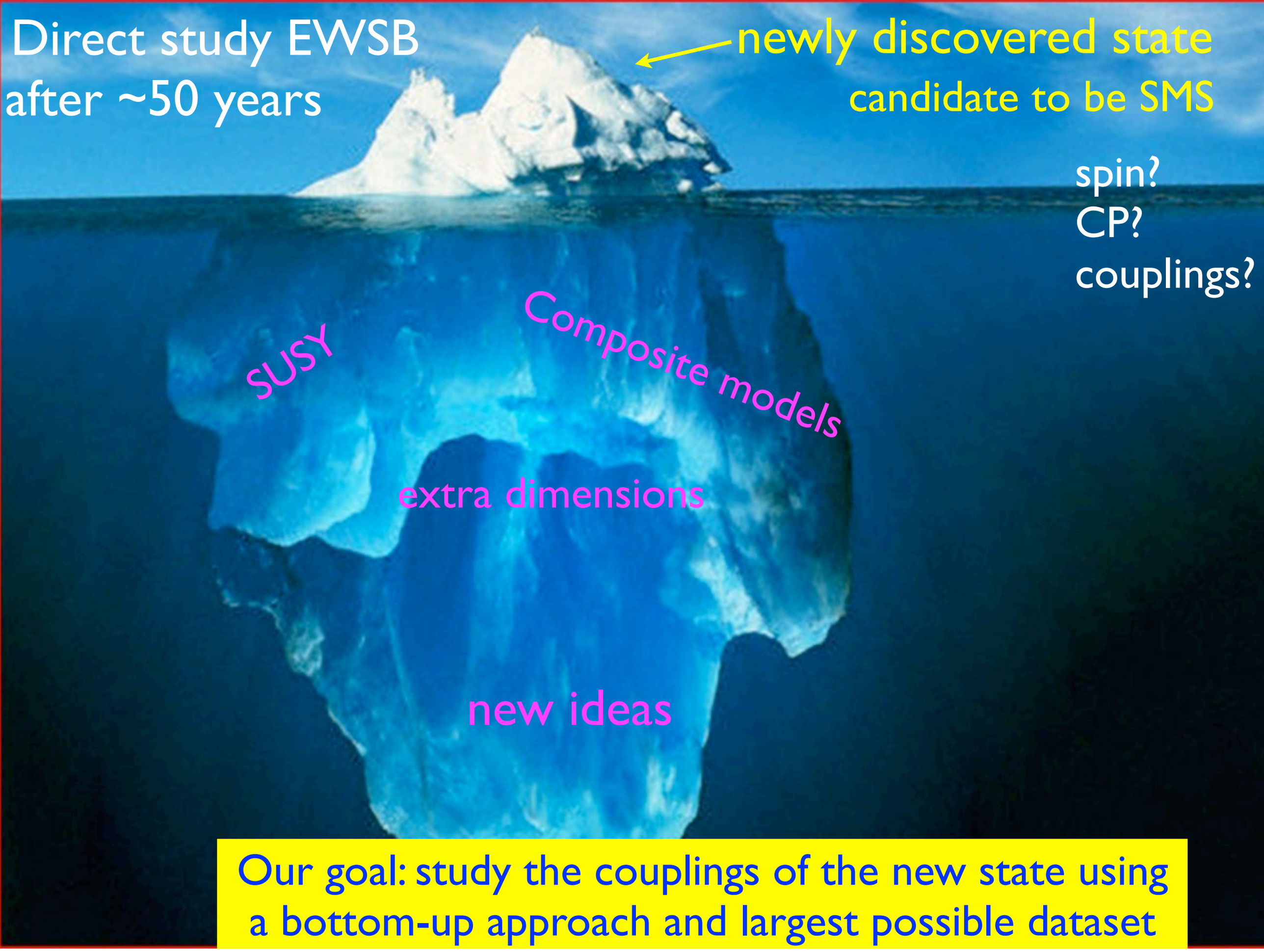
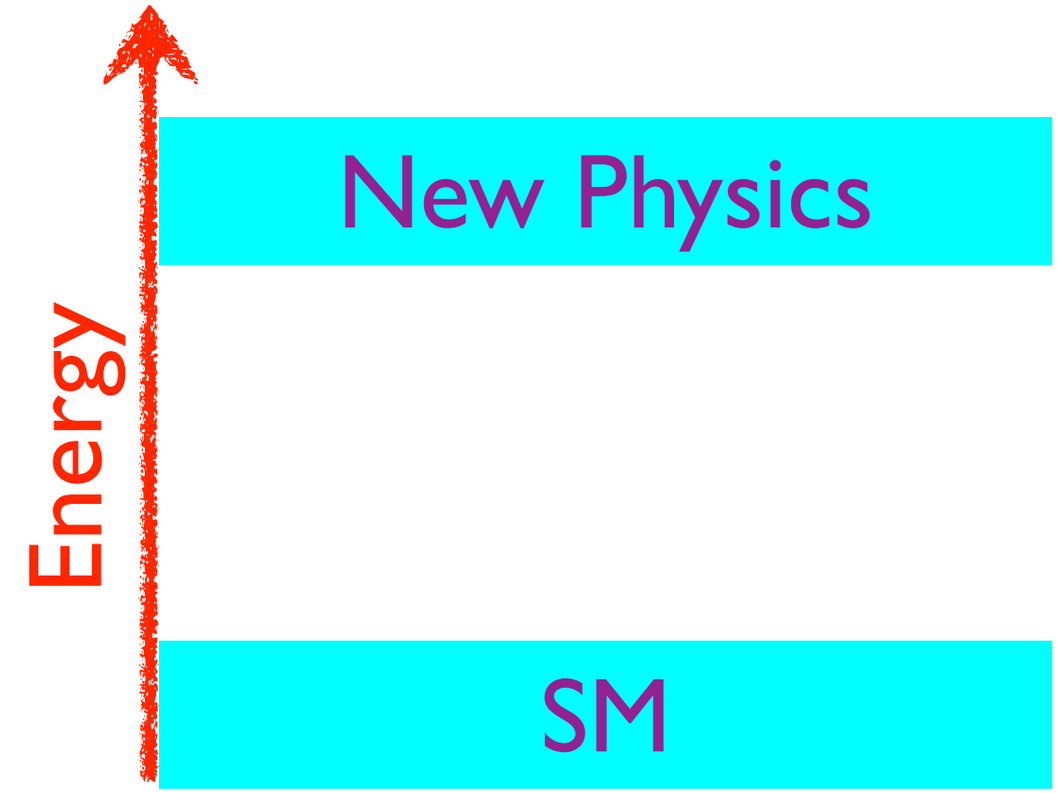
(arXiv:1207.1344 and 1211.4580)


Direct study EWSB
after ~50 years
newly discovered state
candidate to be SMS
spin?
CP?
couplings?
SUSY
Composite models
extra dimensions
new ideas
Our goal: study the couplings of the new state using
a bottom-up approach and largest possible dataset

Reasonable assumptions



- There is a mass gap between SM and NP

- one new state: CP even and spin 0

- new state belongs to SU(2) doublet Φ

- SU(2) x U(1) realized linearly as in the SM

- Building blocks of $\mathcal{L}_{\rm eff}$

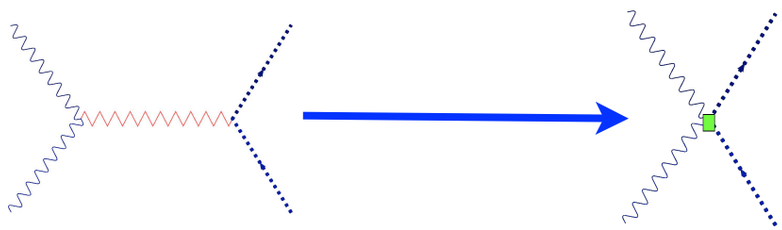
$$\Phi \qquad D_\mu \Phi$$

$$\hat{B}_{\mu\nu} = i\frac{g'}{2} B_{\mu\nu} \qquad \hat{W}_{\mu\nu} = i\frac{g}{2}\sigma^a W^a_{\mu\nu} \qquad G^a_{\mu\nu}$$

$$\ldots \qquad \ldots \qquad \ldots$$

- To measure departures of the SM predictions we write

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{SM} + \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n + \cdots$$



dimension-6 operators summarizing NP effects

- There are 59 "independent" dimension-six operators

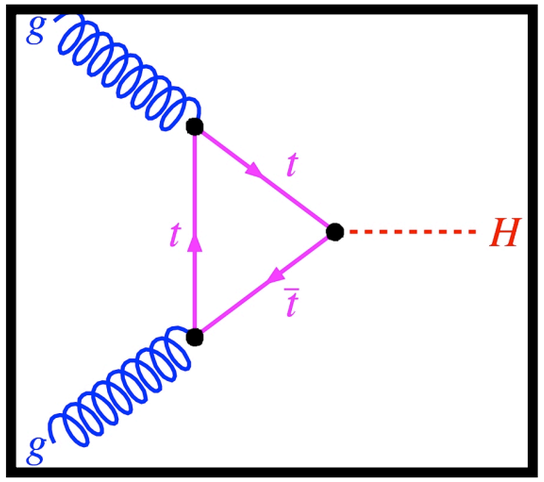
[Buchmuller & Wyler; Grzadkowski et al. arXiv: 1008.4884]

- There is a freedom in choosing the operator basis

- We picked the basis to make better use of all available data

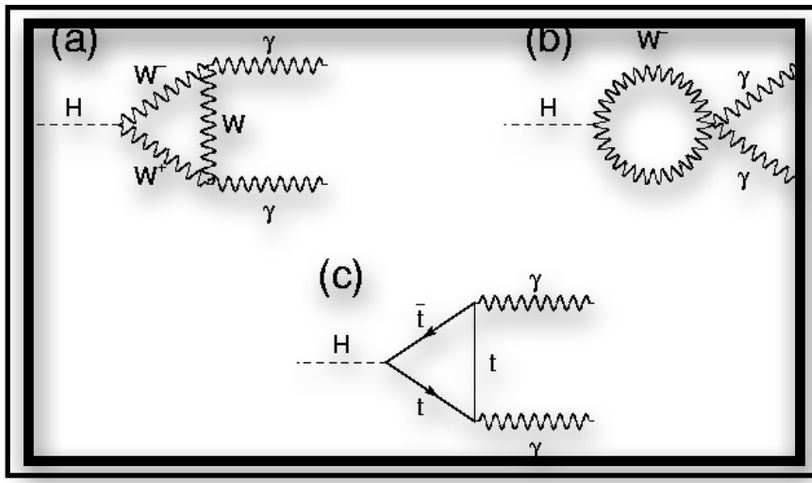
- Operators de modify the SMS interaction to gauge bosons

$$\mathcal{O}_{GG} = \Phi^\dagger \Phi \; G^a_{\mu\nu} G^{a\mu\nu} \quad , \qquad \longleftrightarrow$$



$$\mathcal{O}_{BB} = \Phi^\dagger \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} \Phi \quad , \quad \mathcal{O}_{BW} = \Phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \quad , \quad \mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi$$

$$HVV \quad ; \quad VVV \quad ; \quad VVVV \quad \cdots$$



$$\Delta S \propto f_{BW}$$

- operators containing stress tensors and SMS covariant derivatives

$$\mathcal{O}_B = (D_\mu \Phi)^\dagger \hat{B}^{\mu\nu} (D_\nu \Phi) \quad , \quad \mathcal{O}_W = (D_\mu \Phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \Phi)$$

$$HVV \quad ; \quad VVV \quad ; \quad VVVV \quad \cdots$$

- operators involving doublets and their derivatives

$$\mathcal{O}_{\Phi,1} = (D_\mu \Phi)^\dagger \Phi \Phi^\dagger (D^\mu \Phi) \quad , \quad \mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi\right) \partial_\mu \left(\Phi^\dagger \Phi\right) \quad , \quad \mathcal{O}_{\Phi,4} = (D_\mu \Phi)^\dagger (D^\mu \Phi) \left(\Phi^\dagger \Phi\right)$$

$$\Delta T \propto f_{\Phi,1}$$

field redefinition is needed

$$H = h \left[1 + \frac{v^2}{2\Lambda^2} (f_{\Phi,1} + 2 f_{\Phi,2} + f_{\Phi,4}) \right]^{1/2}$$

rescale of SM couplings + new ones

- A partial list of operators is

$$\mathcal{O}_{GG} = \Phi^\dagger\Phi\, G^a_{\mu\nu}G^{a\mu\nu} \ , \qquad \mathcal{O}_{WW} = \Phi^\dagger\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\Phi \ , \qquad \mathcal{O}_{BB} = \Phi^\dagger\hat{B}_{\mu\nu}\hat{B}^{\mu\nu}\Phi \ ,$$

$$\mathcal{O}_{BW} = \Phi^\dagger\hat{B}_{\mu\nu}\hat{W}^{\mu\nu}\Phi \ , \qquad \mathcal{O}_{W} = (D_\mu\Phi)^\dagger\hat{W}^{\mu\nu}(D_\nu\Phi) \ , \qquad \mathcal{O}_{B} = (D_\mu\Phi)^\dagger\hat{B}^{\mu\nu}(D_\nu\Phi) \ ,$$

$$\mathcal{O}_{\Phi,1} = (D_\mu\Phi)^\dagger\,\Phi\Phi^\dagger\,(D^\mu\Phi) \ , \quad \mathcal{O}_{\Phi,2} = \tfrac{1}{2}\partial^\mu\left(\Phi^\dagger\Phi\right)\partial_\mu\left(\Phi^\dagger\Phi\right) \ , \quad \mathcal{O}_{\Phi,4} = (D_\mu\Phi)^\dagger\,(D^\mu\Phi)\left(\Phi^\dagger\Phi\right) \ ,$$

but they are not independent when
we consider fermionic operators

- The SMS couplings to fermions are modified by

$$\mathcal{O}_{e\Phi,ij} = (\Phi^\dagger\Phi)(\bar{L}_i\Phi e_{R_j})$$
$$\mathcal{O}_{u\Phi,ij} = (\Phi^\dagger\Phi)(\bar{Q}_i\tilde{\Phi}u_{R_j})$$
$$\mathcal{O}_{d\Phi,ij} = (\Phi^\dagger\Phi)(\bar{Q}_i\Phi d_{Rj})$$

these modify the Yukawa couplings

$$\mathcal{O}^{(1)}_{\Phi L,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{L}_i\gamma^\mu L_j)$$
$$\mathcal{O}^{(1)}_{\Phi Q,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{Q}_i\gamma^\mu Q_j)$$
$$\mathcal{O}^{(1)}_{\Phi e,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{e}_{R_i}\gamma^\mu e_{R_j})$$
$$\mathcal{O}^{(1)}_{\Phi u,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{u}_{R_i}\gamma^\mu u_{R_j})$$
$$\mathcal{O}^{(1)}_{\Phi d,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{d}_{R_i}\gamma^\mu d_{R_j})$$
$$\mathcal{O}^{(1)}_{\Phi ud,ij} = \tilde{\Phi}^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{u}_{R_i}\gamma^\mu d_{R_j})$$

$$\mathcal{O}^{(3)}_{\Phi L,ij} = \Phi^\dagger(i\overleftrightarrow{D}^a_\mu\Phi)(\bar{L}_i\gamma^\mu\sigma_a L_j)$$
$$\mathcal{O}^{(3)}_{\Phi Q,ij} = \Phi^\dagger(i\overleftrightarrow{D}^a_\mu\Phi)(\bar{Q}_i\gamma^\mu\sigma_a Q_j)$$

these modify the couplings of gauge bosons to fermions

- all these operators containing the SMS are NOT independent when we consider the equations of motion

• The right of choice

• Idea: operators related by EOM lead to the same S matrix elements [Politzer; Georgi; Artz; Simma]

• The EOM lead to the relations

$$2\mathcal{O}_{\Phi,2} - 2\mathcal{O}_{\Phi,4} = \sum_{ij} \left(y^e_{ij} \mathcal{O}_{e\Phi,ij} + y^u_{ij} \mathcal{O}_{u\Phi,ij} + y^d_{ij} (\mathcal{O}_{d\Phi,ij})^\dagger + \text{h.c.} \right)$$

$$2\mathcal{O}_{\mathcal{B}} + \mathcal{O}_{WB} + \mathcal{O}_{BB} + g'^2 \left(\mathcal{O}_{\Phi,1} - \tfrac{1}{2}\mathcal{O}_{\Phi,2} \right) = \frac{g'^2}{2} \sum_i \left(\tfrac{1}{2}\mathcal{O}^{(1)}_{\Phi L,ii} - \tfrac{1}{6}\mathcal{O}^{(1)}_{\Phi Q,ii} + \mathcal{O}^{(1)}_{\Phi e,ii} - \tfrac{2}{3}\mathcal{O}^{(1)}_{\Phi u,ii} + \tfrac{1}{3}\mathcal{O}^{(1)}_{\Phi d,ii} \right)$$

$$2\mathcal{O}_{W} + \mathcal{O}_{WB} + \mathcal{O}_{WW} + g^2 \left(\mathcal{O}_{\Phi,4} - \tfrac{1}{2}\mathcal{O}_{\Phi,2} \right) = -\frac{g^2}{4} \sum_i \left(\mathcal{O}^{(3)}_{\Phi L,ii} + \mathcal{O}^{(3)}_{\Phi Q,ii} \right)$$

with this we can further eliminate 3 operators

• Very large operator basis ➡ we must choose it to take full advantage of the available data

• Avoid theoretical prejudice (tree vs loop, etc)

• Care is needed in the interpretation

- strongly constrained operators should be kept

Z pole physics, LEP2, atomic parity violation, etc constrain

Z

$$\mathcal{O}^{(1)}_{\Phi L,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{L}_i \gamma^\mu L_j)$$
$$\mathcal{O}^{(1)}_{\Phi Q,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{Q}_i \gamma^\mu Q_j)$$
$$\mathcal{O}^{(1)}_{\Phi e,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{e}_{R_i} \gamma^\mu e_{R_j})$$
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$$\mathcal{O}^{(3)}_{\Phi L,ij} = \Phi^\dagger (i\overleftrightarrow{D}^a_\mu \Phi)(\bar{L}_i \gamma^\mu \sigma_a L_j)$$
$$\mathcal{O}^{(3)}_{\Phi Q,ij} = \Phi^\dagger (i\overleftrightarrow{D}^a_\mu \Phi)(\bar{Q}_i \gamma^\mu \sigma_a Q_j)$$

Z,W

EWPT bounds: $\alpha \Delta S = -\hat{e}^2 \frac{v^2}{\Lambda^2} f_{BW}$ and $\alpha \Delta T = -\frac{1}{2}\frac{v^2}{\Lambda^2} f_{\Phi,1}$

FCNC constrains the off-diagonal elements of

$$\mathcal{O}_{e\Phi,ij} = (\Phi^\dagger \Phi)(\bar{L}_i \Phi e_{R_j}) \quad \mathcal{O}_{u\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \tilde{\Phi} u_{R_j}) \quad \mathcal{O}_{d\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \Phi d_{R_j})$$

$$\mathcal{L}^{Hee}_{eff} = \sum_{i,j} \frac{f_{e\Phi,ij}}{\Lambda^2} \mathcal{O}_{e\Phi,ij} + \text{h.c.} \quad \Longrightarrow$$

$$\mathcal{L}^{Hee} = \sum_{i,j} g^e_{Hij}\ h\ \bar{e}_{Li} e_{Rj} + \text{h.c. with } g^e_{Hij} = -\frac{m^e_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2}(f_{e\Phi})_{ij}$$

■ The operators $(\mathcal{O}_B \ , \ \mathcal{O}_W)$ modify the TGV

$$\mathcal{O}_W = (D_\mu \Phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \Phi) \ , \qquad \mathcal{O}_B = (D_\mu \Phi)^\dagger \hat{B}^{\mu\nu} (D_\nu \Phi)$$

$$\mathcal{L}_{WWV} = -i g_{WWV} \left\{ g_1^V \left(W^+_{\mu\nu} W^{-\,\mu} V^\nu - W^+_\mu V_\nu W^{-\,\mu\nu} \right) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} \right\} + \quad \ldots$$

[Hagiwara, Hikasa, Peccei,Zeppenfeld]

with

$$\Delta g_1^Z = g_1^Z - 1 = \frac{g^2 v^2}{8 c^2 \Lambda^2} f_W$$

$$\Delta \kappa_\gamma = \kappa_\gamma - 1 = \frac{g^2 v^2}{8 \Lambda^2} \left(f_W + f_B \right)$$

$$\Delta \kappa_Z = \kappa_Z - 1 = \frac{g^2 v^2}{8 c^2 \Lambda^2} \left(c^2 f_W - s^2 f_B \right)$$

there are data on that.

- we choose the basis:

$$\left\{\mathcal{O}_{GG} \quad , \quad \mathcal{O}_{BW} \quad , \quad \mathcal{O}_{WW} \quad , \quad \mathcal{O}_{W} \quad , \quad \mathcal{O}_{B} \quad , \quad \mathcal{O}_{\Phi,1} \quad , \quad \mathcal{O}_{f\Phi} \quad , \quad \mathcal{O}^{(1)}_{\Phi f} \quad , \quad \mathcal{O}^{(3)}_{\Phi f}\right\}$$

- we choose the basis:

$$\left\{ \mathcal{O}_{GG} \;,\; \cancel{\mathcal{O}_{BW}} \;,\; \mathcal{O}_{WW} \;,\; \mathcal{O}_{W} \;,\; \mathcal{O}_{B} \;,\; \cancel{\mathcal{O}_{\Phi,1}} \;,\; \cancel{\mathcal{O}_{f\Phi}} \;,\; \cancel{\mathcal{O}^{(1)}_{\Phi f}} \;,\; \cancel{\mathcal{O}^{(3)}_{\Phi f}} \right\}$$

- we choose the basis:

$$\left\{ \mathcal{O}_{GG} \ , \ \cancel{\mathcal{O}_{BW}} \ , \ \mathcal{O}_{WW} \ , \ \mathcal{O}_{W} \ , \ \mathcal{O}_{B} \ , \ \cancel{\mathcal{O}_{\Phi,1}} \ , \ \cancel{\mathcal{O}_{f\Phi}} \ , \ \cancel{\mathcal{O}^{(1)}_{\Phi f}} \ , \ \cancel{\mathcal{O}^{(3)}_{\Phi f}} \right\}$$

- after discarding the constrained operators ➡ 13:
  - too many!
- 9 fermions: $\mathcal{O}_{e\Phi,jj}$, $\mathcal{O}_{u\Phi,jj}$, $\mathcal{O}_{d\Phi,jj}$
  - neglecting the effects of couplings to first two generations
  - due to small statistics we trade $f_{top} \to f_g$ and f_{WW}
- gauge bosons: $\mathcal{O}_W$, $\mathcal{O}_B$, $\mathcal{O}_{WW}$, $\mathcal{O}_{GG}$

- Summarizing:

coefficients related by gauge invariance

	hgg	$h\gamma\gamma$	$h\gamma Z$	hZZ	hW^+W^-	γW^+W^-	ZW^+W^-
$\mathcal{O}_{GG}$	✓						
$\mathcal{O}_{WW}$		✓	✓	✓	✓		
$\mathcal{O}_B$			✓	✓		✓	✓
$\mathcal{O}_W$			✓	✓	✓	✓	✓

supplemented by shifts in the Yukawa couplings (3rd family)

nice feature: dimension-six operators lead to relations between anomalous couplings

- Summarizing:

coefficients related by gauge invariance

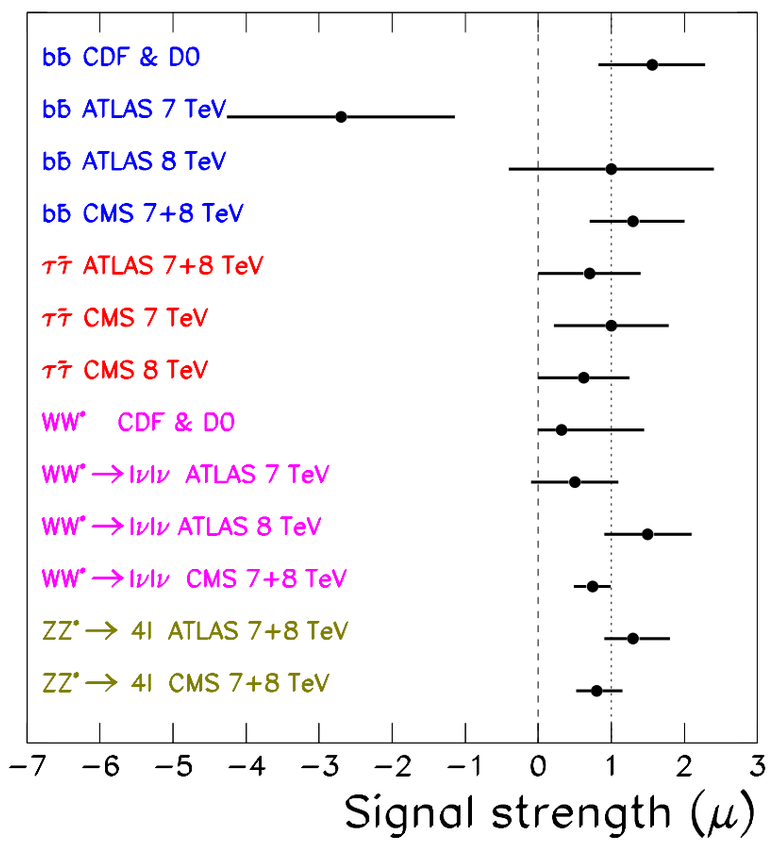
	hgg	$h\gamma\gamma$	$h\gamma Z$	hZZ	hW^+W^-	γW^+W^-	ZW^+W^-
$\mathcal{O}_{GG}$	✓						
$\mathcal{O}_{WW}$		✓	✓	✓	✓		
$\mathcal{O}_B$			✓	✓		✓	✓
$\mathcal{O}_W$			✓	✓	✓	✓	✓

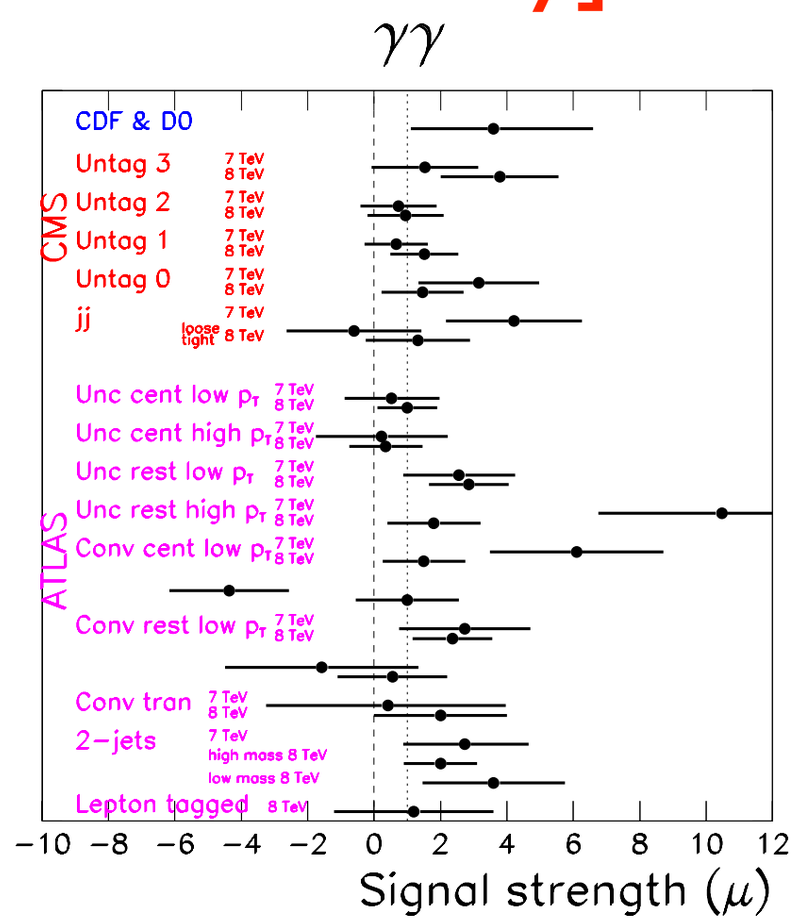
supplemented by shifts in the Yukawa couplings (3rd family)

$$\mathcal{L}_{eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG} + \frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW} + \frac{f_W}{\Lambda^2}\mathcal{O}_W + \frac{f_B}{\Lambda^2}\mathcal{O}_B + \frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33} + \frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33}$$

Fitting procedure

- Inputs: signal strength for the different channels $\mu = \frac{\sigma_{obs}}{\sigma_{SM}}$
- using all available data [outdate since today]





- The statistical analyses were done using

$$\chi^2 = \min_{\xi_{pull}} \sum_j \frac{(\mu_j - \mu_j^{\exp})^2}{\sigma_j^2} + \sum_{pull} \left(\frac{\xi_{pull}}{\sigma_{pull}} \right)^2$$

- we also used that

EWPT:

$$\Delta S_{PDG} = 0.00 \pm 0.10 \qquad \Delta T_{PDG} = 0.02 \pm 0.11 \qquad \Delta U_{PDG} = 0.03 \pm 0.09$$

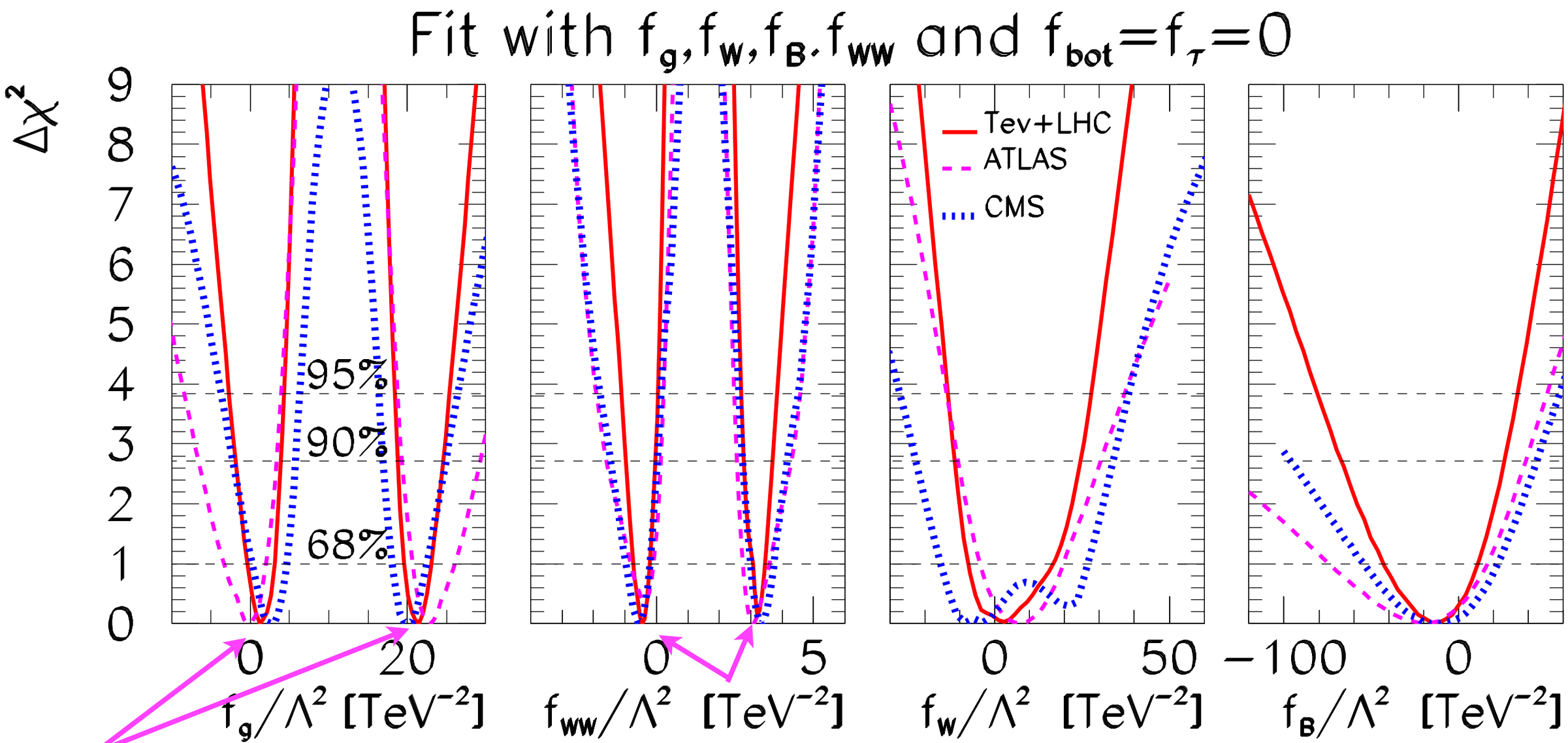
$$\rho = \begin{pmatrix} 1 & 0.89 & -0.55 \\ 0.89 & 1 & -0.8 \\ -0.55 & -0.8 & 1 \end{pmatrix}$$

TGV bounds:

g_1^Z	κ_γ	κ_Z	Ref	Asummption
$0.984^{+0.022}_{-0.019}$	$0.973^{+0.044}_{-0.045}$	$0.924^{+0.059}_{-0.056}$	PDG	1-par fit (others SM)
$1.004^{+0.024}_{-0.025}$	$0.984^{+0.049}_{-0.049}$	GI: $\kappa_Z = g_1^Z - (\kappa_\gamma - 1)s^2/c^2$	LEPEWWG	2-par fit with GI, $\rho = 0.11$

Results

- First scenario: $(f_{GG} \;,\; f_{WW} \;,\; f_W \;,\; f_B \;,\; f_{bot} = 0 \;,\; f_\tau = 0)$
- Second scenario: $(f_{GG} \;,\; f_{WW} \;,\; f_W \;,\; f_B \;,\; f_{bot} \;,\; f_\tau = 0)$



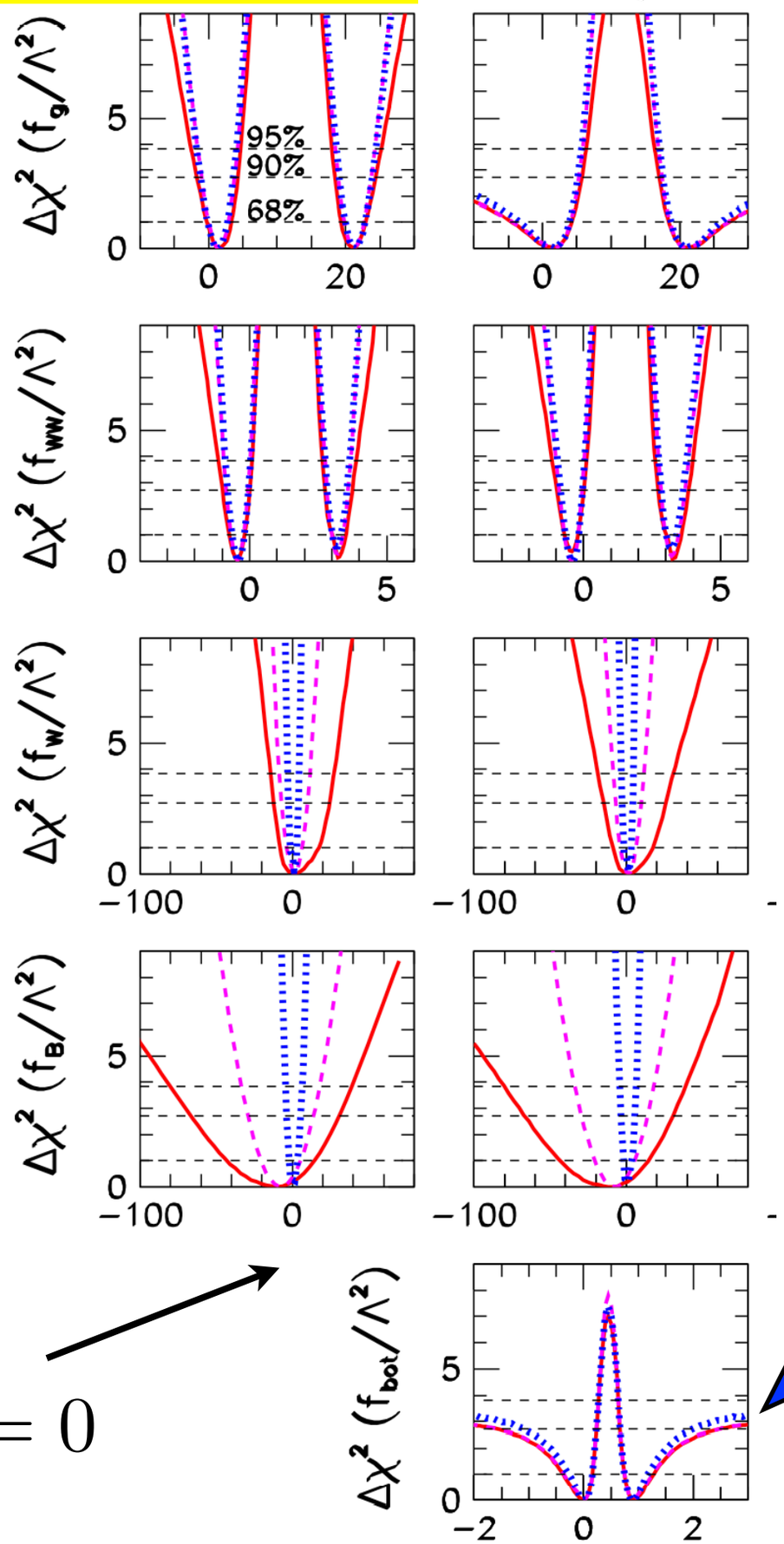
interference with SM contribution leads to (near) degeneracy

SM compatible at 71% CL level

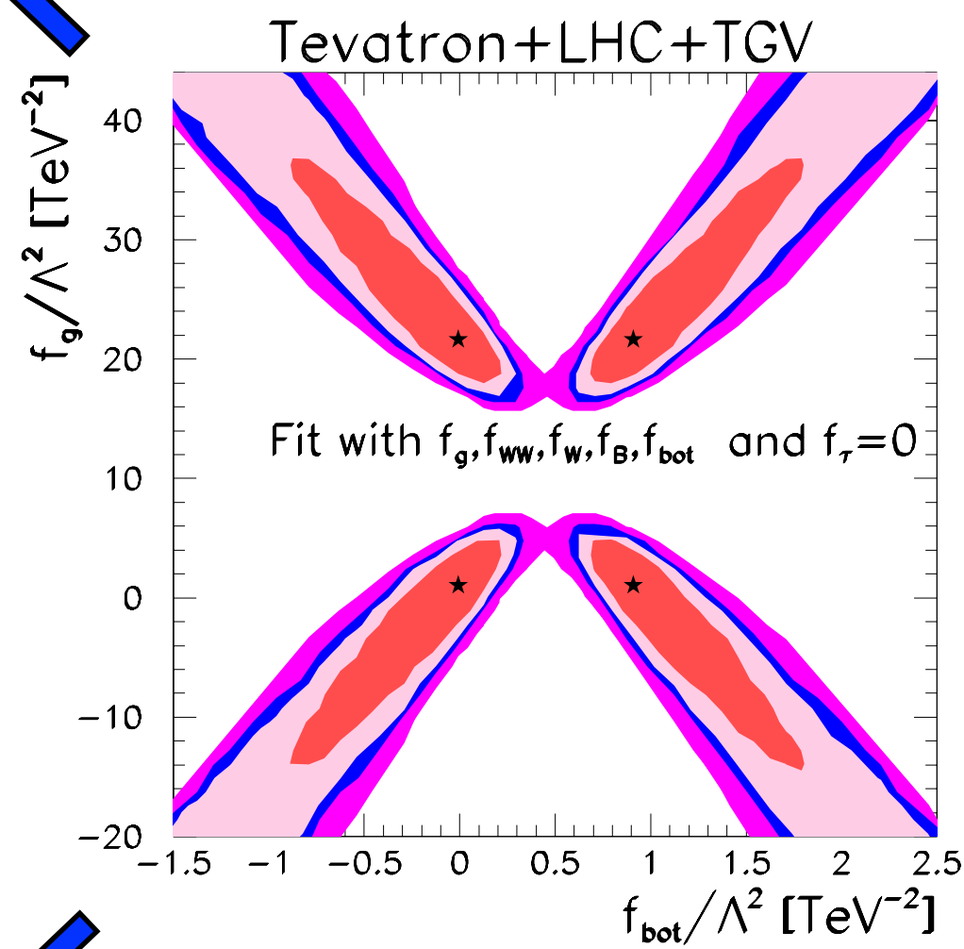
SMS + TGV + EWPT

$f_{bot} \neq 0 \ , \ f_\tau = 0$

$f_\tau \neq 0$ does not change the picture



largest impact of TGV+EWPT



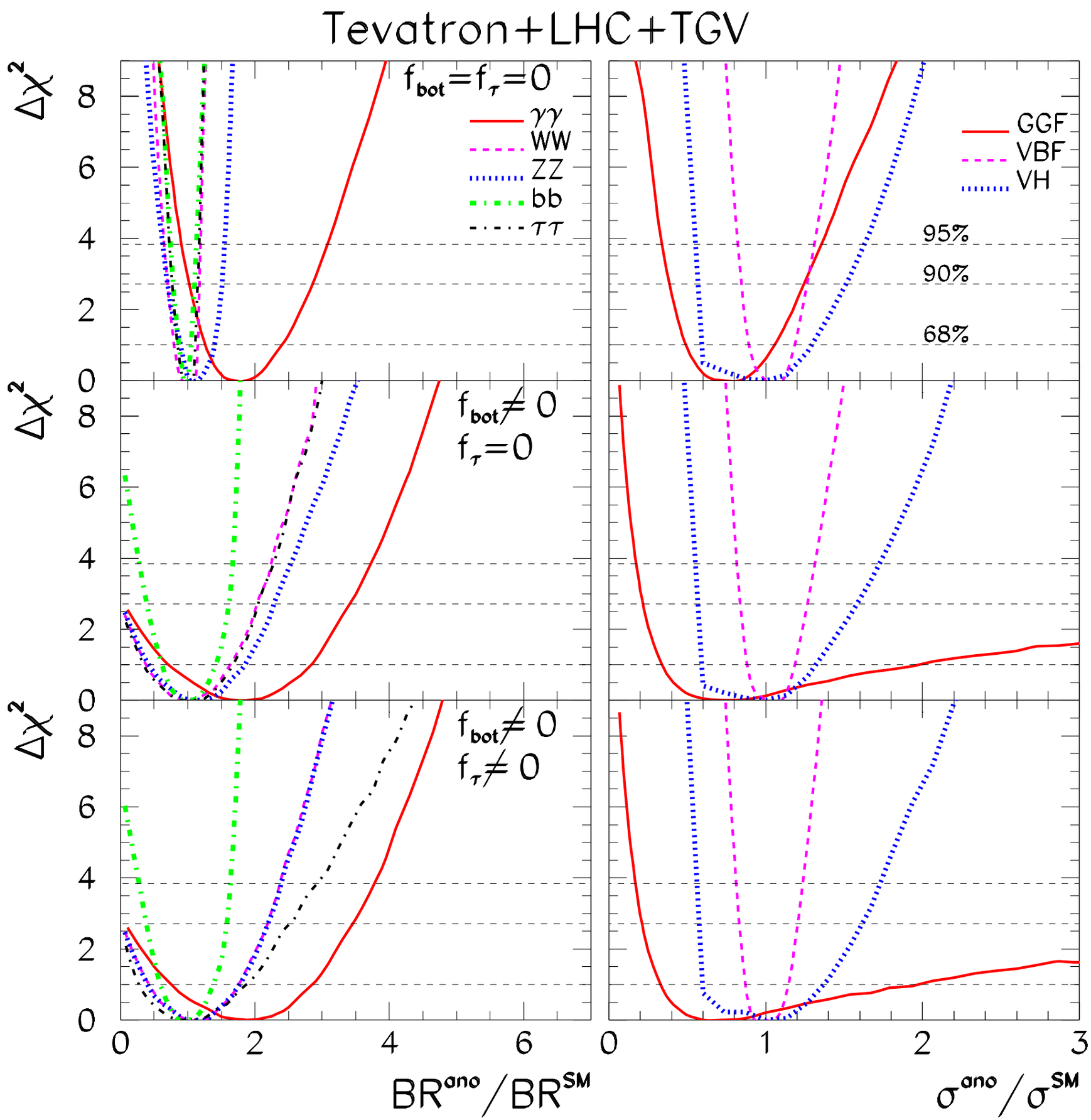
strong correlation

$f_g \otimes f_{bot}$

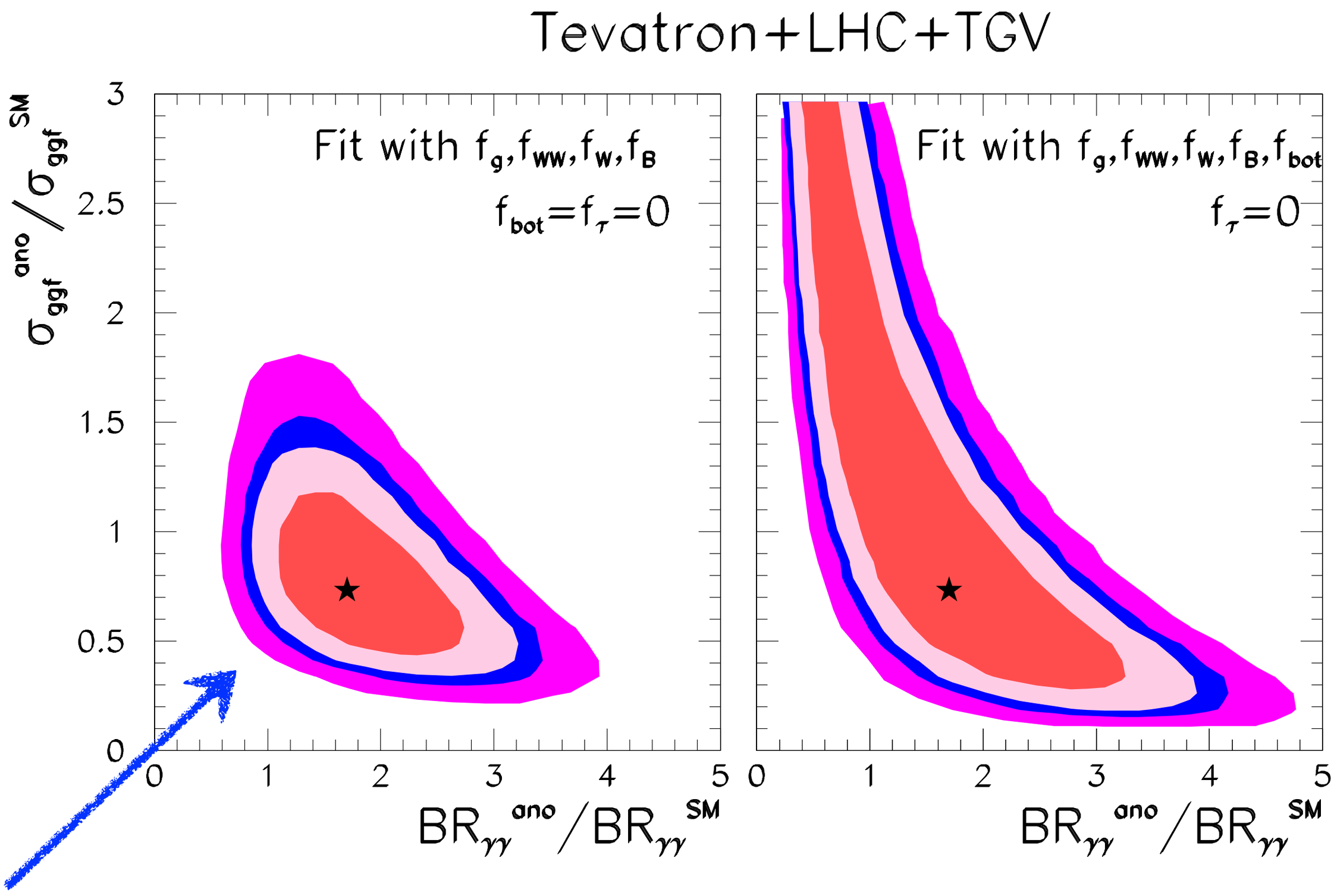
$$\sigma(pp \to h \to \gamma\gamma) \propto \frac{f_g^2}{f_{bot}^2}$$

$$f_{\rm bot} = f_\tau = 0$$

cross sections and branching ratios



interesting correlations



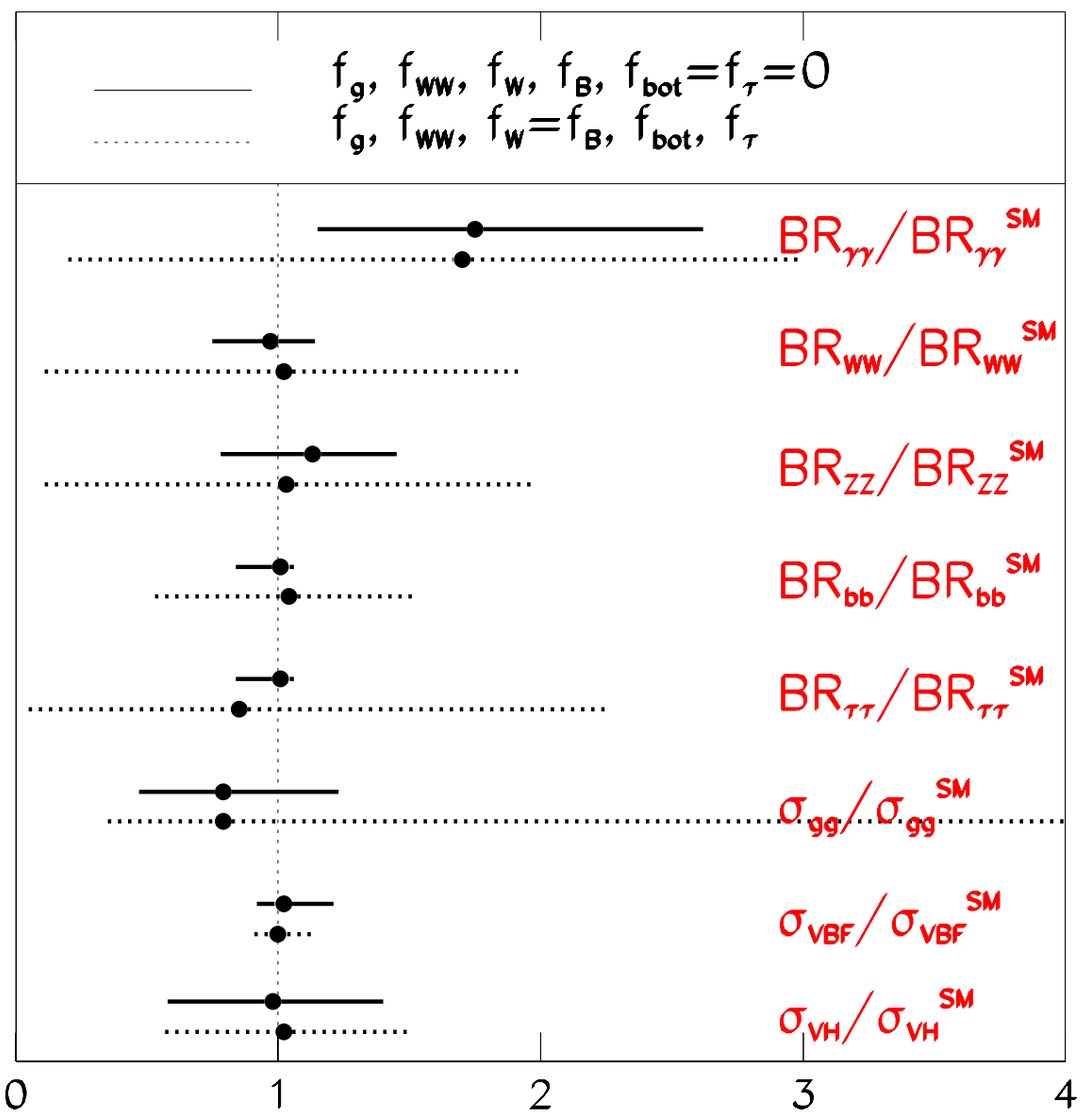
due to the diphoton channel

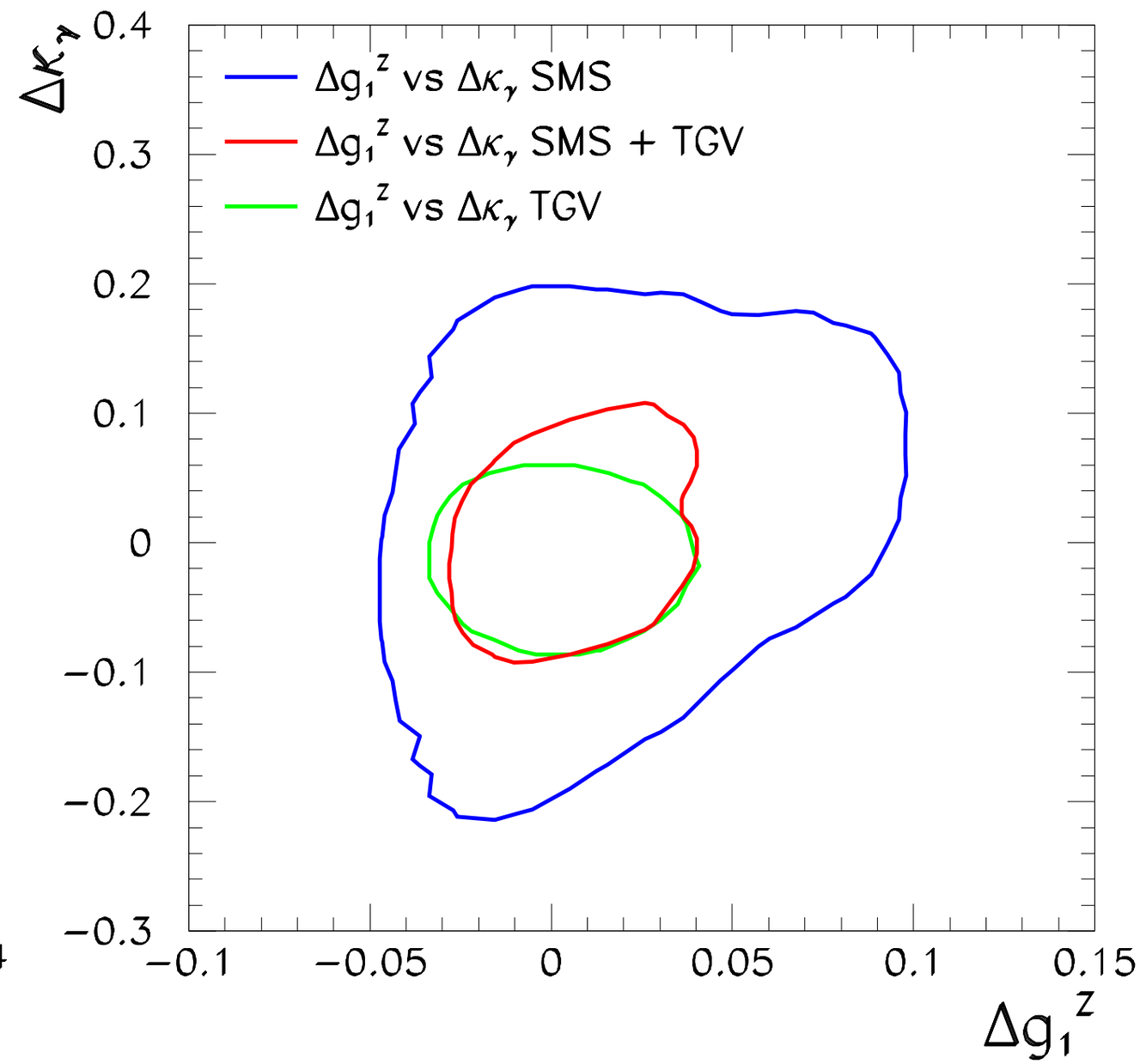
Discussion

- we can constrain SMS couplings and TGV as well.

  both measurements can profit from the basis choice

[Campos, Gonzalez-Garcia,Novaes]





90% CL allowed regions

THANK YOU

updated results at http://hep.if.usp.br/Higgs

BACKUP SLIDES

- The HVV new interactions are

$$\mathcal{L}_{\rm eff}^{\rm HVV} = g_{Hgg}\, H G^a_{\mu\nu} G^{a\mu\nu} + g_{H\gamma\gamma}\, H A_{\mu\nu} A^{\mu\nu} + g^{(1)}_{HZ\gamma}\, A_{\mu\nu} Z^\mu \partial^\nu H + g^{(2)}_{HZ\gamma}\, H A_{\mu\nu} Z^{\mu\nu}$$

$$+ g^{(1)}_{HZZ}\, Z_{\mu\nu} Z^\mu \partial^\nu H + g^{(2)}_{HZZ}\, H Z_{\mu\nu} Z^{\mu\nu} + \cancel{g^{(3)}_{HZZ}}\, H Z_\mu Z^\mu$$

$$+ g^{(1)}_{HWW}\, \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu H + \text{h.c.}\right) + g^{(2)}_{HWW}\, H W^+_{\mu\nu} W^{-\,\mu\nu} + \cancel{g^{(3)}_{HWW}}\, H W^+_\mu W^{-\,\mu}$$

with

$$g_{Hgg} = \frac{f_{GG} v}{\Lambda^2} \equiv -\frac{\alpha_s}{8\pi} \frac{f_g v}{\Lambda^2}$$

$$g_{H\gamma\gamma} = -\left(\frac{g^2 v s^2}{2\Lambda^2}\right) \frac{\cancel{f_{BB}} + f_{WW}}{2}$$

$$g^{(1)}_{HZ\gamma} = \left(\frac{g^2 v}{2\Lambda^2}\right) \frac{s(f_W - f_B)}{2c}$$

$$\cancel{g^{(2)}_{HZ\gamma}} = \left(\frac{g^2 v}{2\Lambda^2}\right) \frac{s[2s^2 \cancel{f_{BB}} - 2c^2 f_{WW}]}{2c}$$

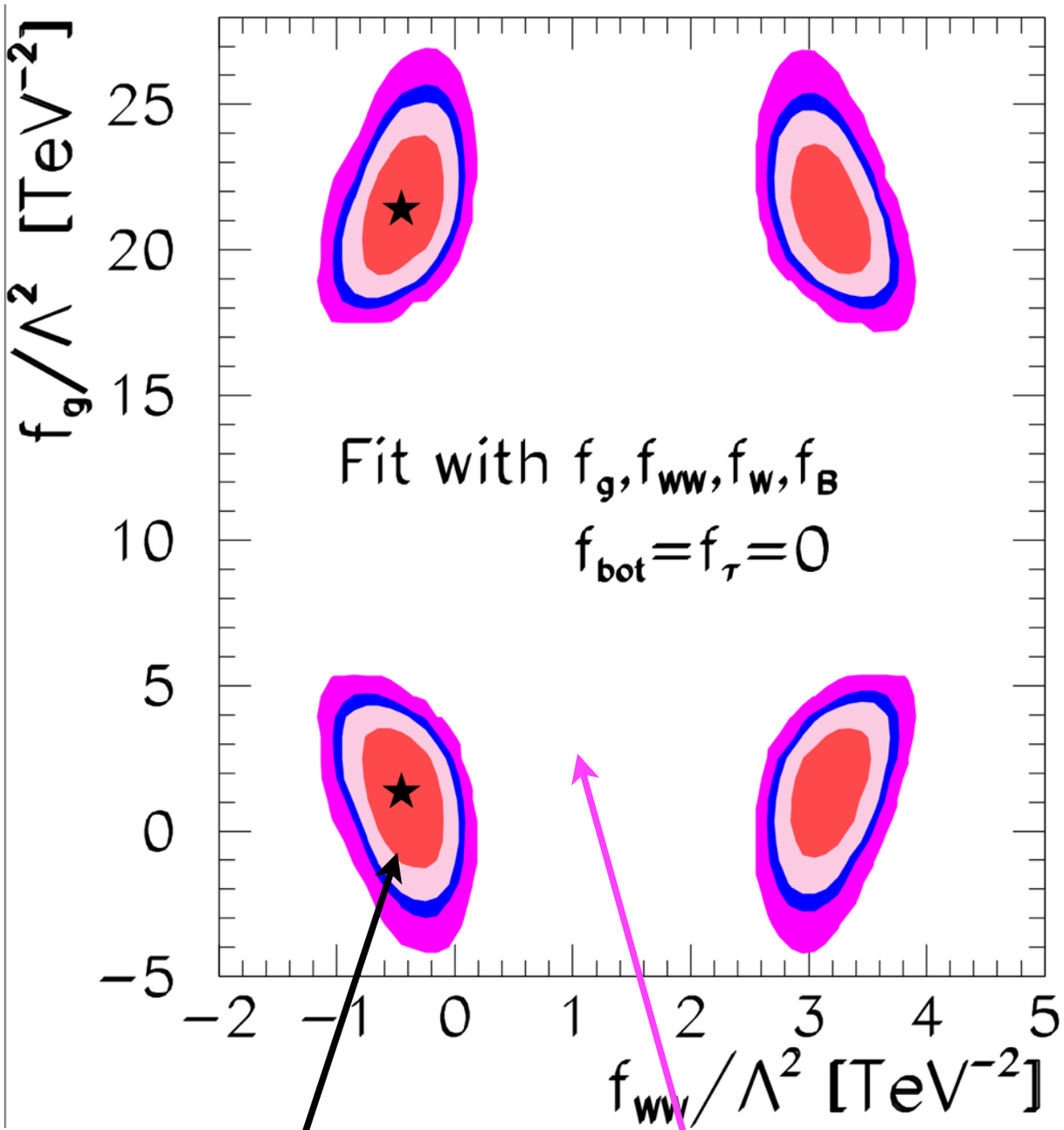
$$g^{(1)}_{HZZ} = \left(\frac{g^2 v}{2\Lambda^2}\right) \frac{c^2 f_W + s^2 f_B}{2c^2}$$

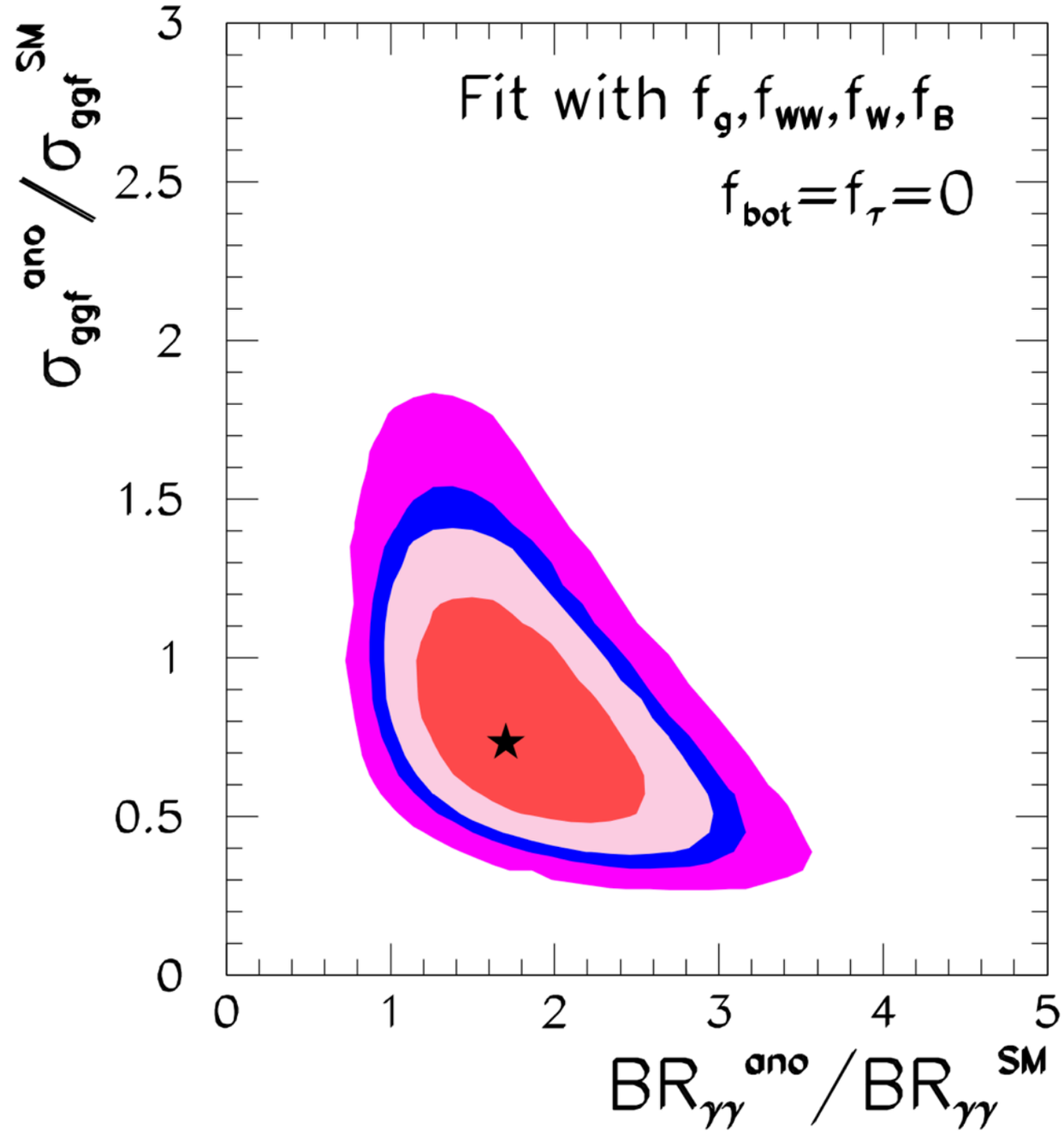
$$g^{(2)}_{HZZ} = -\left(\frac{g^2 v}{2\Lambda^2}\right) \frac{\cancel{s^4 f_{BB}} + c^4 f_{WW}}{2c^2}$$

$$g^{(1)}_{HWW} = \left(\frac{g^2 v}{2\Lambda^2}\right) \frac{f_W}{2}$$

$$g^{(2)}_{HWW} = -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW}$$

interesting correlations





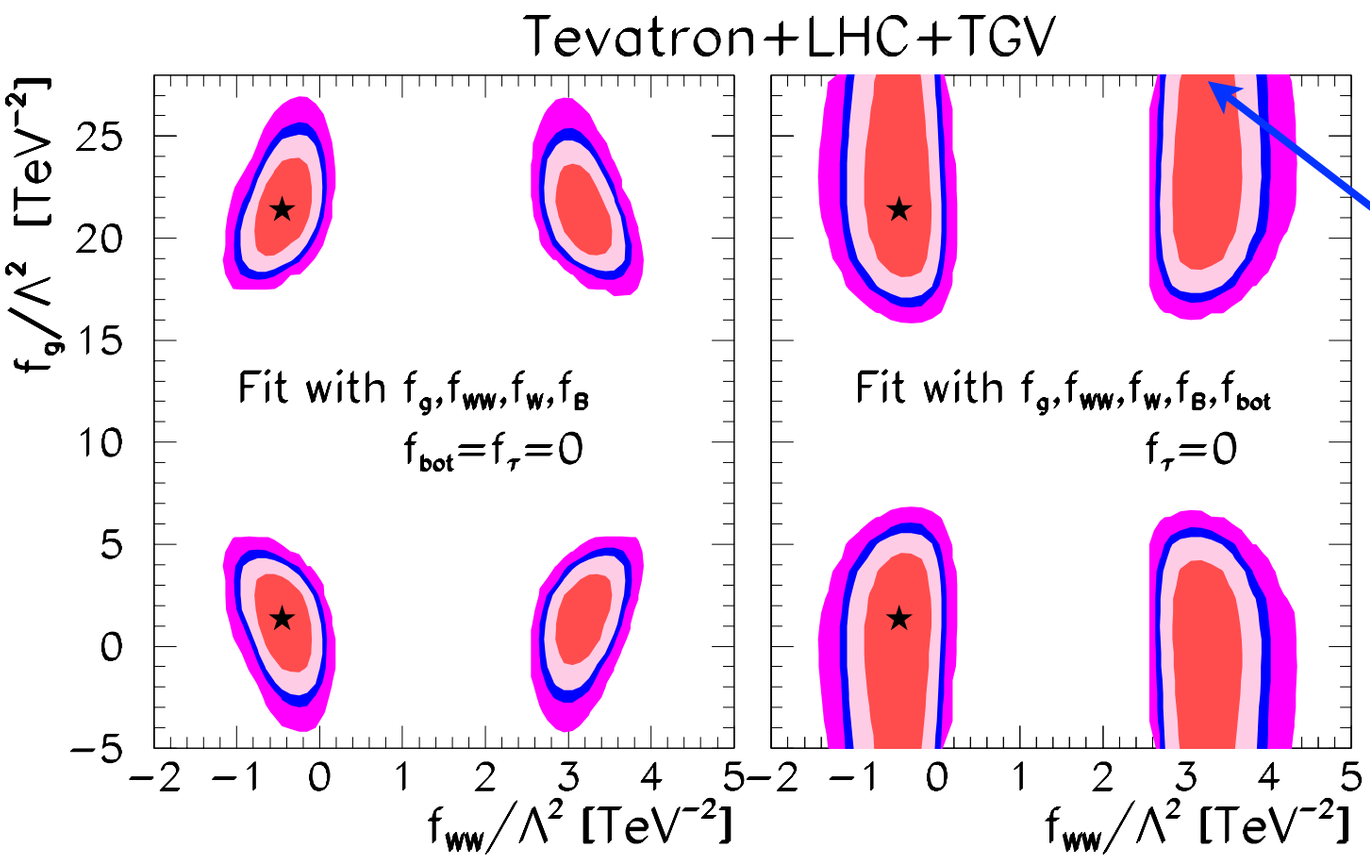
strong correlation

($\gamma\gamma$ data)

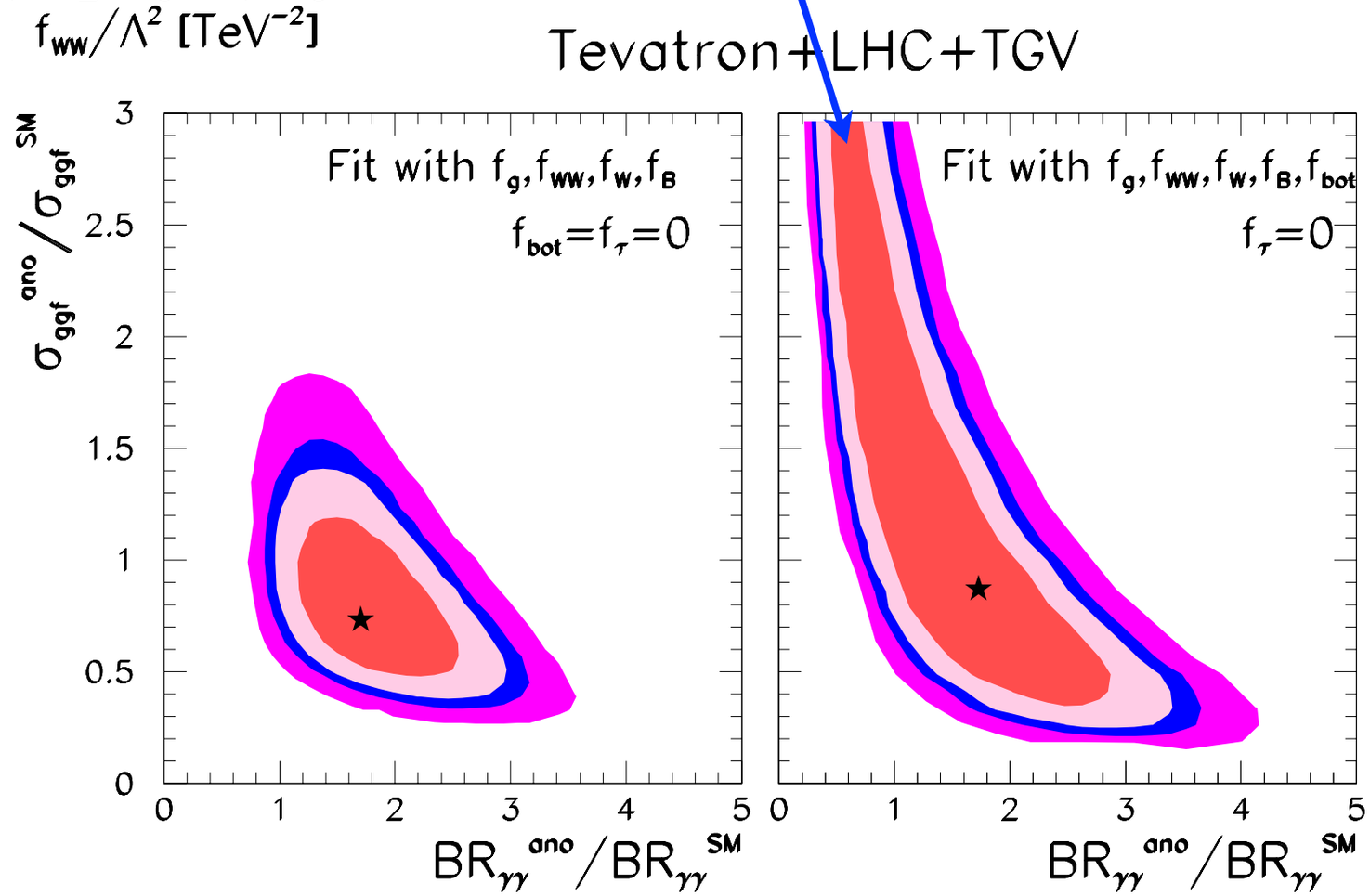
gap is filled without $b\bar{b}$

(σ_{gg} decreases)

effect of the bottom Yukawa on correlations



lack of gg->bb data



- To evaluate cross sections we write $\sigma_Y^{ano} = \left.\frac{\sigma_Y^{ano}}{\sigma_Y^{SM}}\right|_{tree} \sigma_Y^{SM}\big|_{soa}$

FeynRules/MadGraph5

- For widths $\Gamma^{ano}(h \to X) = \left.\frac{\Gamma^{ano}(h \to X)}{\Gamma^{SM}(h \to X)}\right|_{tree} \Gamma^{SM}(h \to X)\big|_{soa}$

- use all available information

[correlated theoretical error]

$$\mu_F = \frac{\epsilon_{gg}^F \sigma_{gg}^{ano}(1+\xi_g) + \epsilon_{VBF}^F \sigma_{VBF}^{ano} + \epsilon_{WH}^F \sigma_{WH}^{ano} + \epsilon_{ZH}^F \sigma_{ZH}^{ano} + \epsilon_{t\bar{t}H}^F \sigma_{t\bar{t}H}^{ano}}{\epsilon_{gg}^F \sigma_{gg}^{SM} + \epsilon_{VBF}^F \sigma_{VBF}^{SM} + \epsilon_{WH}^F \sigma_{WH}^{SM} + \epsilon_{ZH}^F \sigma_{ZH}^{SM} + \epsilon_{t\bar{t}H}^F \sigma_{t\bar{t}H}^{SM}} \otimes \frac{\mathrm{Br}^{ano}[h \to F]}{\mathrm{Br}^{SM}[h \to F]}$$

- The statistical analyses were done using

$$\chi^2 = \min_{\xi_{pull}} \sum_j \frac{(\mu_j - \mu_j^{\exp})^2}{\sigma_j^2} + \sum_{pull} \left(\frac{\xi_{pull}}{\sigma_{pull}}\right)^2$$

we neglected correlation between the different channels

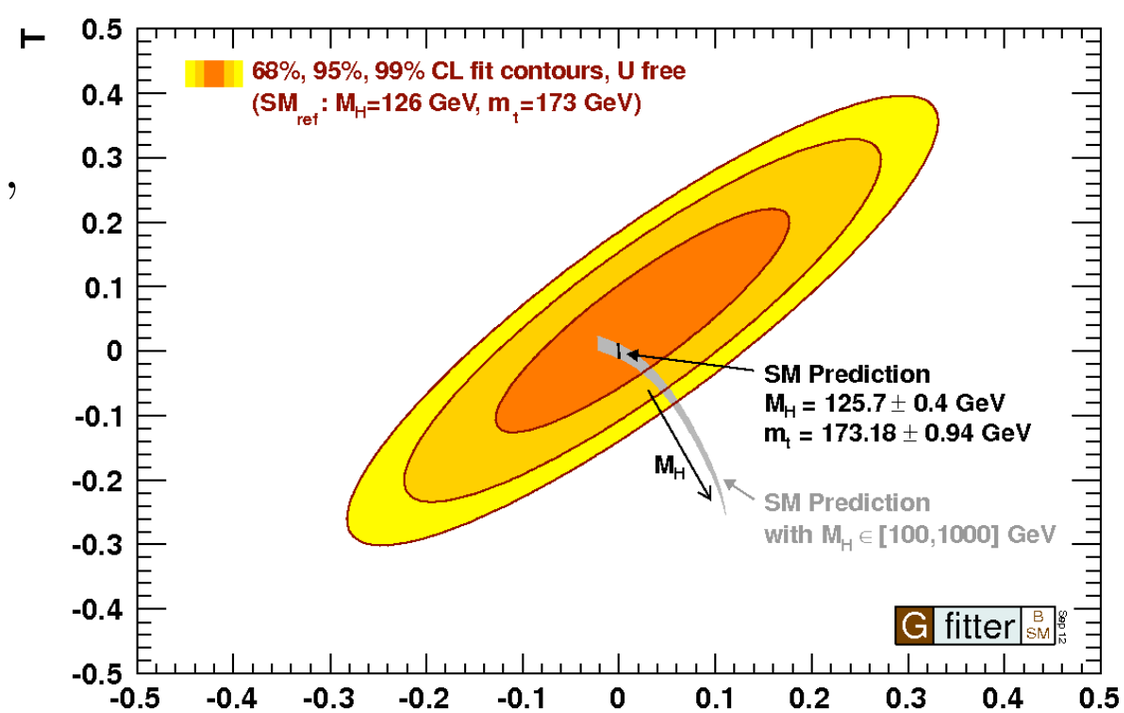
EWPT: there anomalous contributions to the oblique parameters

[Hagiwara, et al.; Alam, Dawson, Szalapski]

$$\alpha\Delta S = -\hat{e}^2\frac{v^2}{\Lambda^2}f_{BW} - \frac{1}{6}\frac{\hat{e}^2}{16\pi^2}\Bigg\{3(f_W+f_B)\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) + 2\left(f_{\Phi,2}-f_{\Phi,4}\right)\frac{v^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$
$$+2\Big[(5\hat{c}^2-2)f_W-(5\hat{c}^2-3)f_B\Big]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$
$$-\Big[(22\hat{c}^2-1)f_W-(30\hat{c}^2+1)f_B\Big]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)$$
$$-24(\hat{c}^2f_{WW}+\hat{s}^2f_{BB})\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\Bigg\},$$

$$\alpha\Delta T = -\frac{1}{2}\frac{v^2}{\Lambda^2}f_{\Phi,1} - \frac{3}{4\hat{c}^2}\frac{\hat{e}^2}{16\pi^2}\Bigg\{f_B\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) - \left(f_{\Phi,2}-f_{\Phi,4}\right)\frac{v^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$
$$+(\hat{c}^2f_W+f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$
$$+\Big[2\hat{c}^2f_W+(3\hat{c}^2-1)f_B\Big]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\Bigg\},$$

$$\alpha\Delta U = \frac{1}{3}\frac{\hat{e}^2\hat{s}^2}{16\pi^2}\Bigg\{(-4f_W+5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$
$$+(2f_W-5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\Bigg\},$$

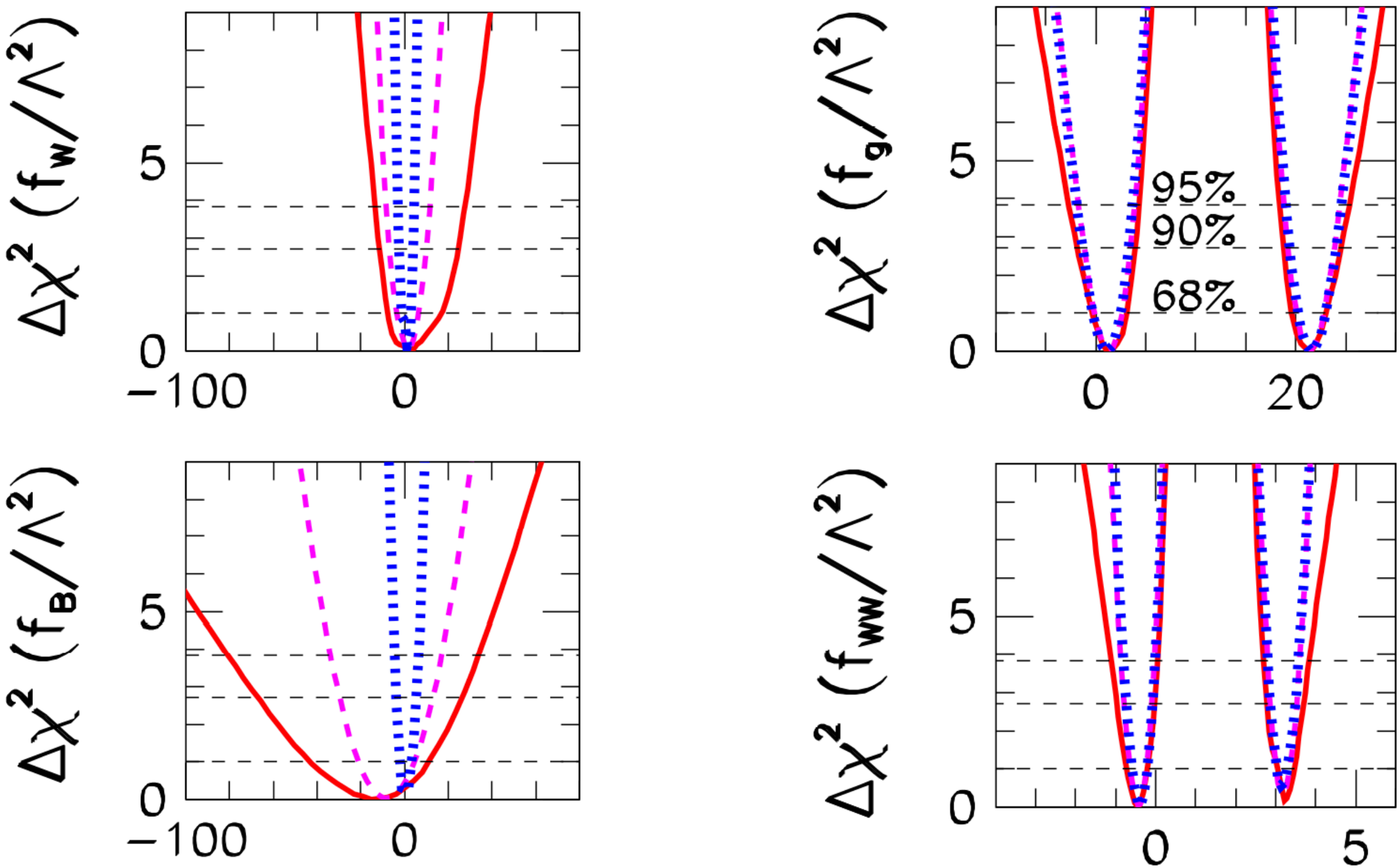


- Summarizing the results:

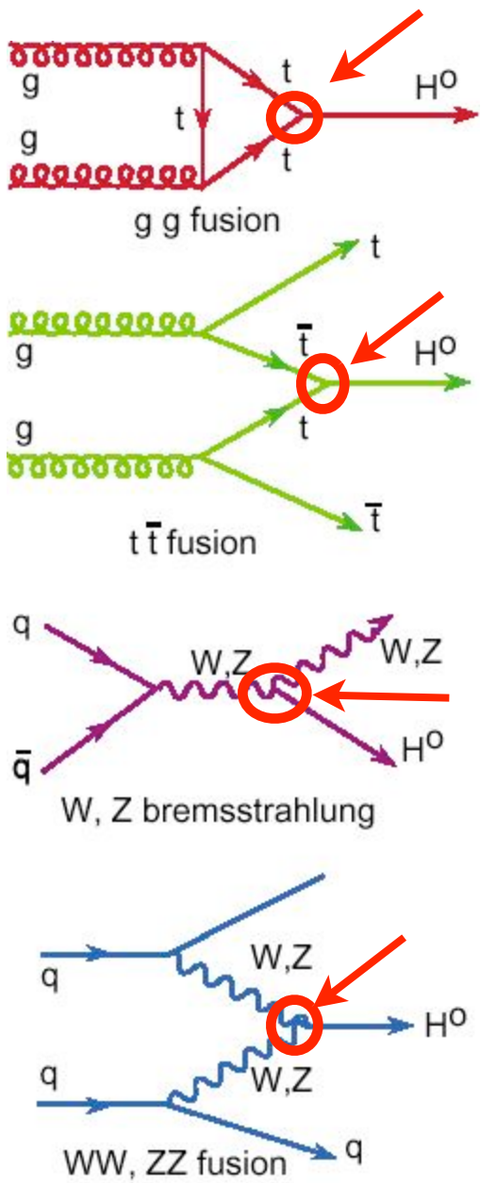
SMS (LHC+Tevatron) + TGV

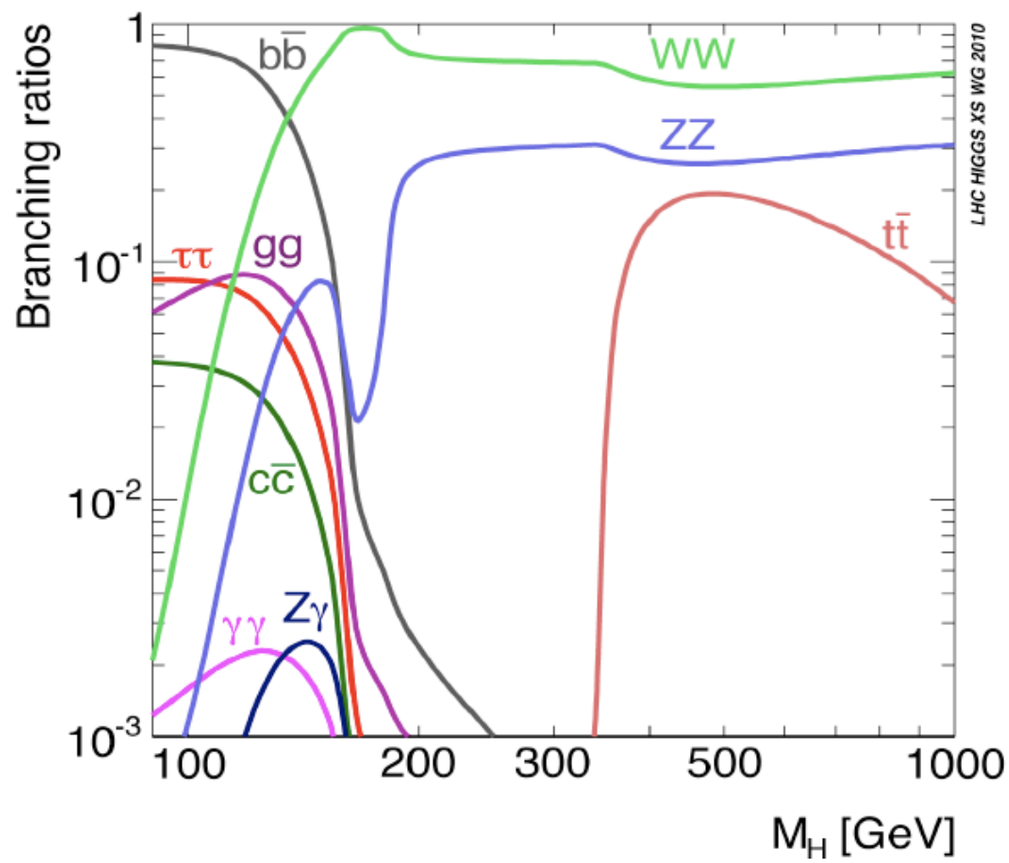
	Fit with $f_{bot} = f_\tau = 0$		Fit with f_{bot} and f_τ	
	Best fit	90% CL allowed range	Best fit	90% CL allowed range
f_g/Λ^2 (TeV^{-2})	1.3, 21.4	$[-1.2, 3.5] \cup [19, 24]$	1.3, 21.4	$[-21, 4.8] \cup [18, 44]$
f_{WW}/Λ^2 (TeV^{-2})	-0.43	$[-0.80, -0.10] \cup [2.85, 3.55]$	-0.39	$[-0.80, 0] \cup [2.85, 3.65]$
f_W/Λ^2 (TeV^{-2})	1.43	$[-7.0, 10]$	0.42	$[-7.4, 7.6]$
f_B/Λ^2 (TeV^{-2})	-8.4	$[-30, 13]$	0.42	$[-7.4, 7.6]$
f_{bot}/Λ^2 (TeV^{-2})	—	—	0.00, 0.90	$[-1.2, 0.20] \cup [0.70, 2.1]$
f_τ/Λ^2 (TeV^{-2})	—	—	0.02, 0.32	$[-0.07, 0.13] \cup [0.2, 0.40]$
$BR^{ano}_{\gamma\gamma}/BR^{SM}_{\gamma\gamma}$	1.75	[1.15, 2.62]	1.70	[0.20, 3.00]
$BR^{ano}_{WW}/BR^{SM}_{WW}$	0.97	[0.75, 1.14]	1.02	[0.11, 1.94]
$BR^{ano}_{ZZ}/BR^{SM}_{ZZ}$	1.13	[0.78, 1.45]	1.03	[0.11, 1.96]
$BR^{ano}_{bb}/BR^{SM}_{bb}$	1.01	[0.84, 1.06]	1.04	[0.53, 1.53]
$BR^{ano}_{\tau\tau}/BR^{SM}_{\tau\tau}$	1.01	[0.84, 1.06]	0.85	[0.05, 2.25]
$\sigma^{ano}_{gg}/\sigma^{SM}_{gg}$	0.79	[0.47, 1.23]	0.79	[0.35, 8]
$\sigma^{ano}_{VBF}/\sigma^{SM}_{VBF}$	1.02	[0.92, 1.21]	1.00	[0.91, 1.13]
$\sigma^{ano}_{VH}/\sigma^{SM}_{VH}$	0.98	[0.58, 1.40]	1.02	[0.57, 1.49]

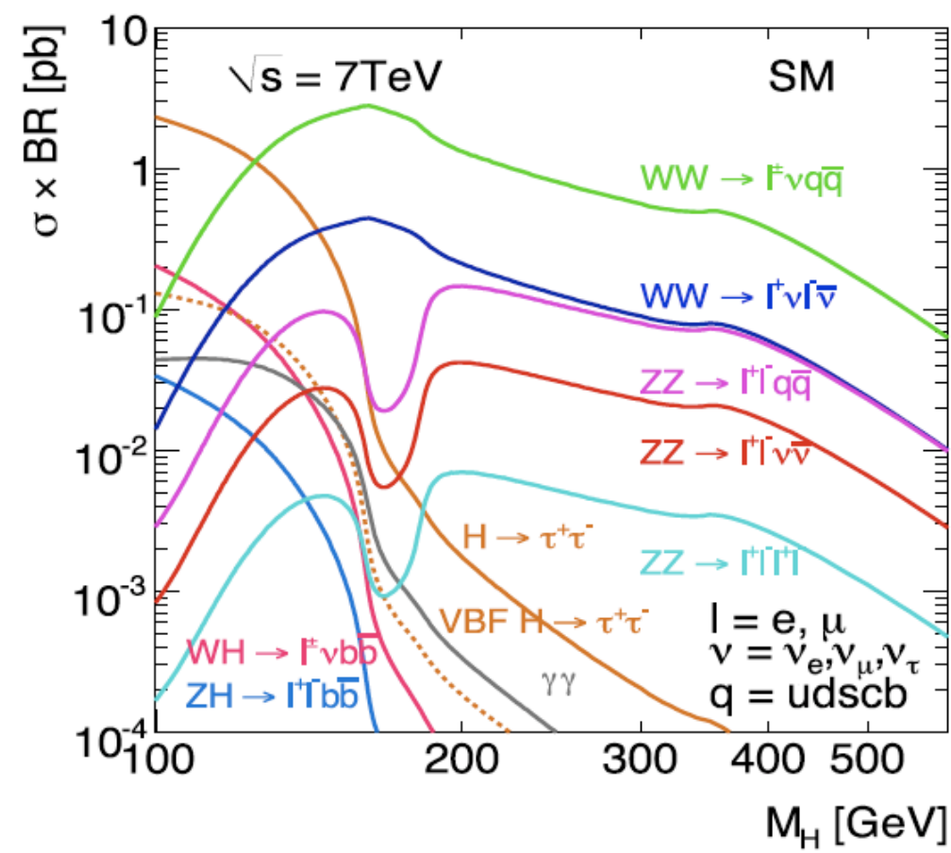
Collider + TGV + EWPD



- SMS production mechanisms and cross sections

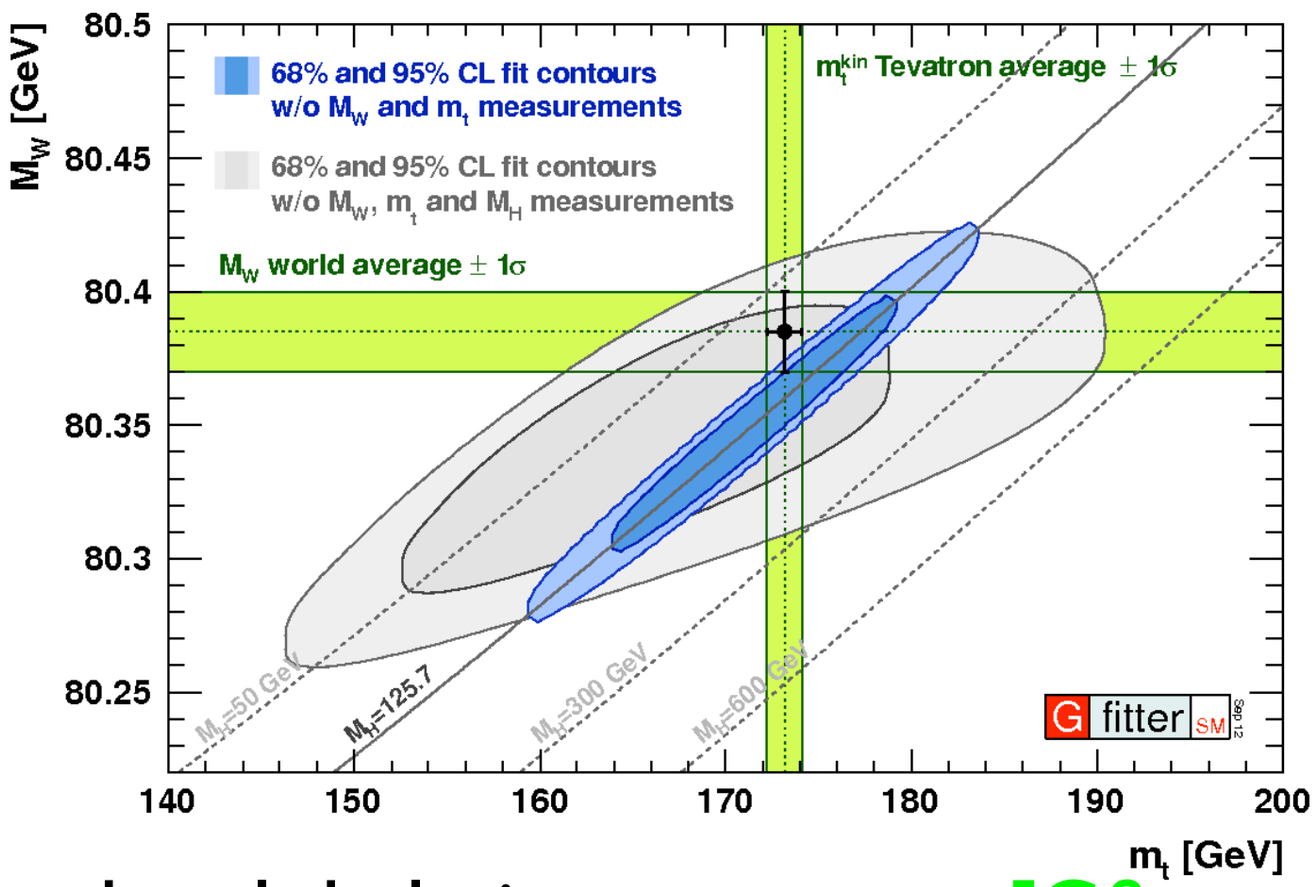






- 4th July, 2012 marks the dawning of new era

- 48 years between EWSB theory and discovery
- 1964: theory [Englert&Brout; Higgs; Guralnik&Hagen&Kibble]
- signal in many channels AA, ZZ, WW... as for the SMS



the new state fits the global picture [Gfitter arXiv:1209.2716]