Probing the "Higgs" Couplings

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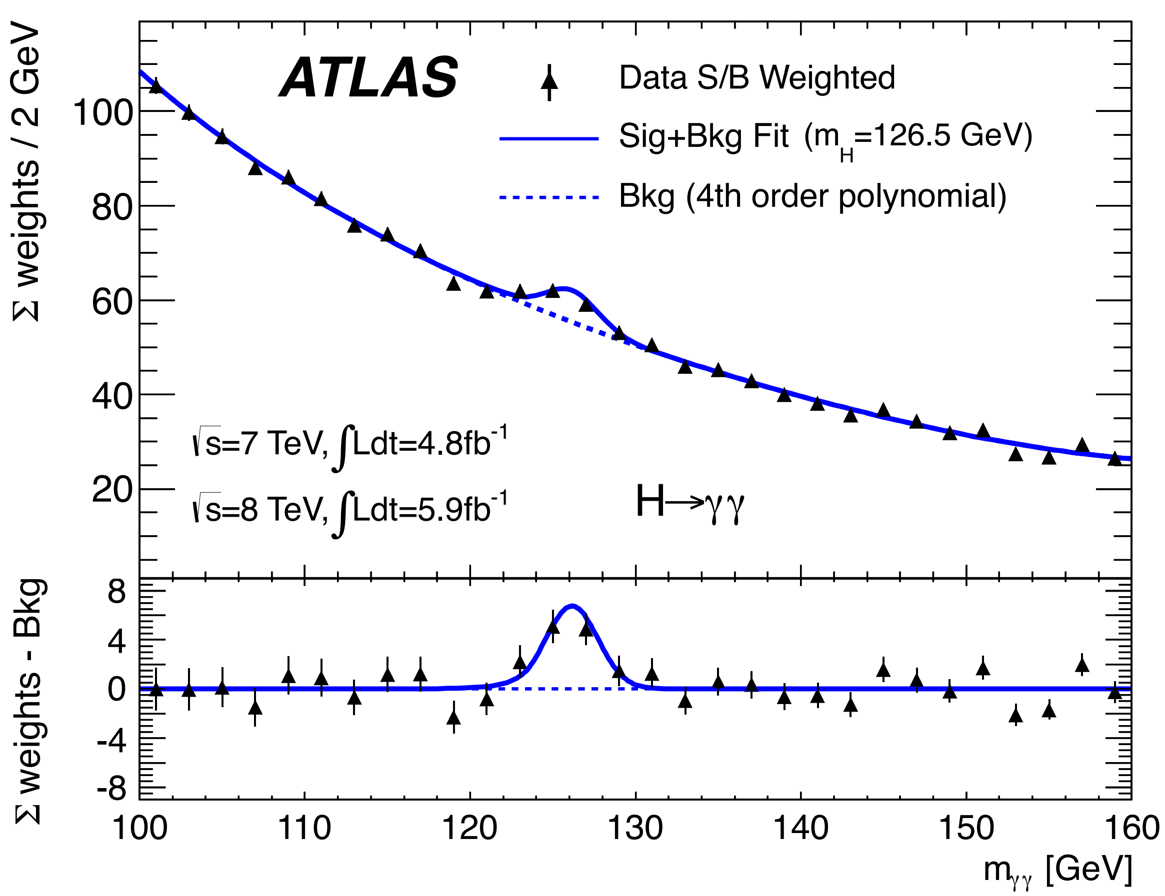
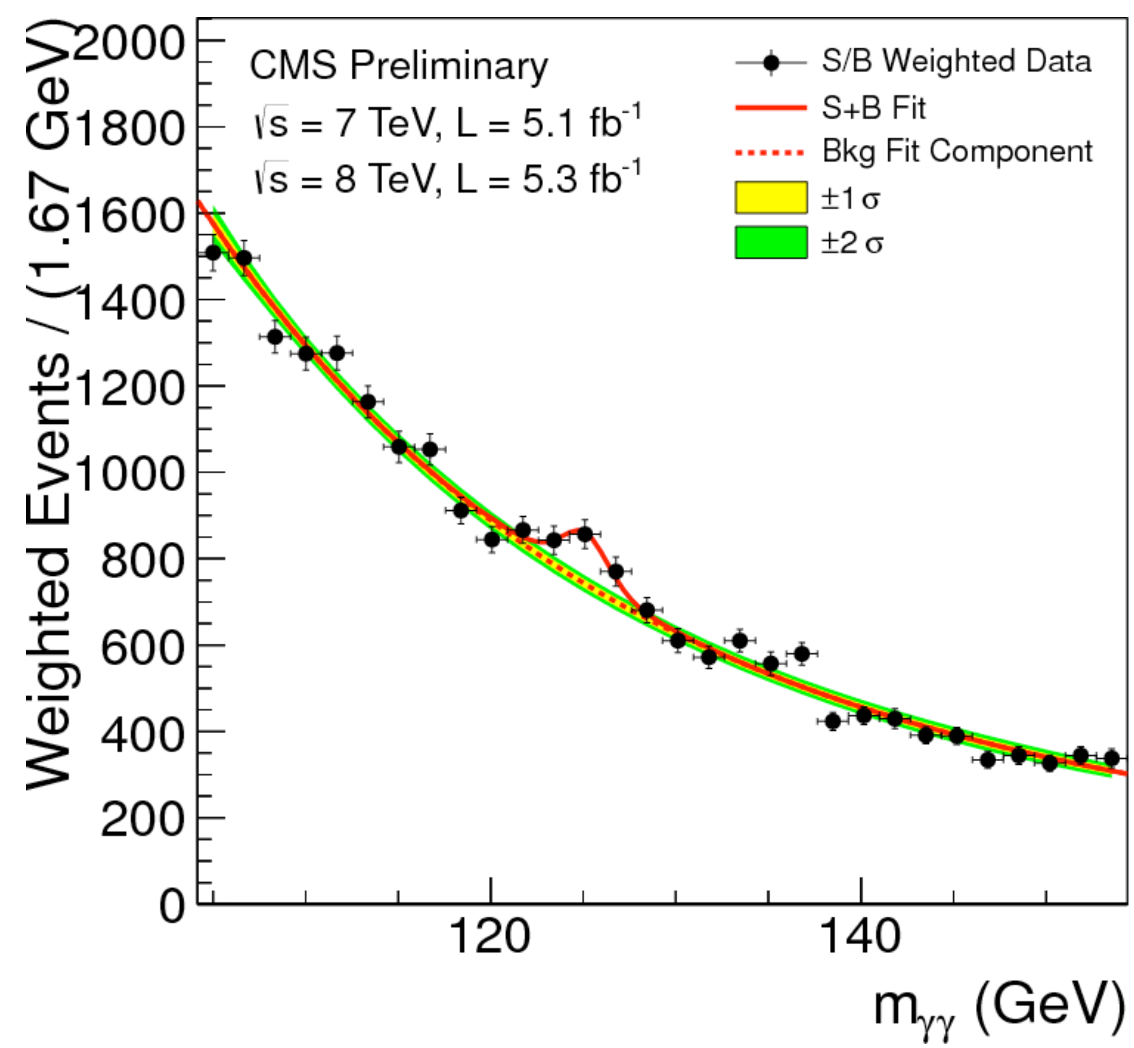
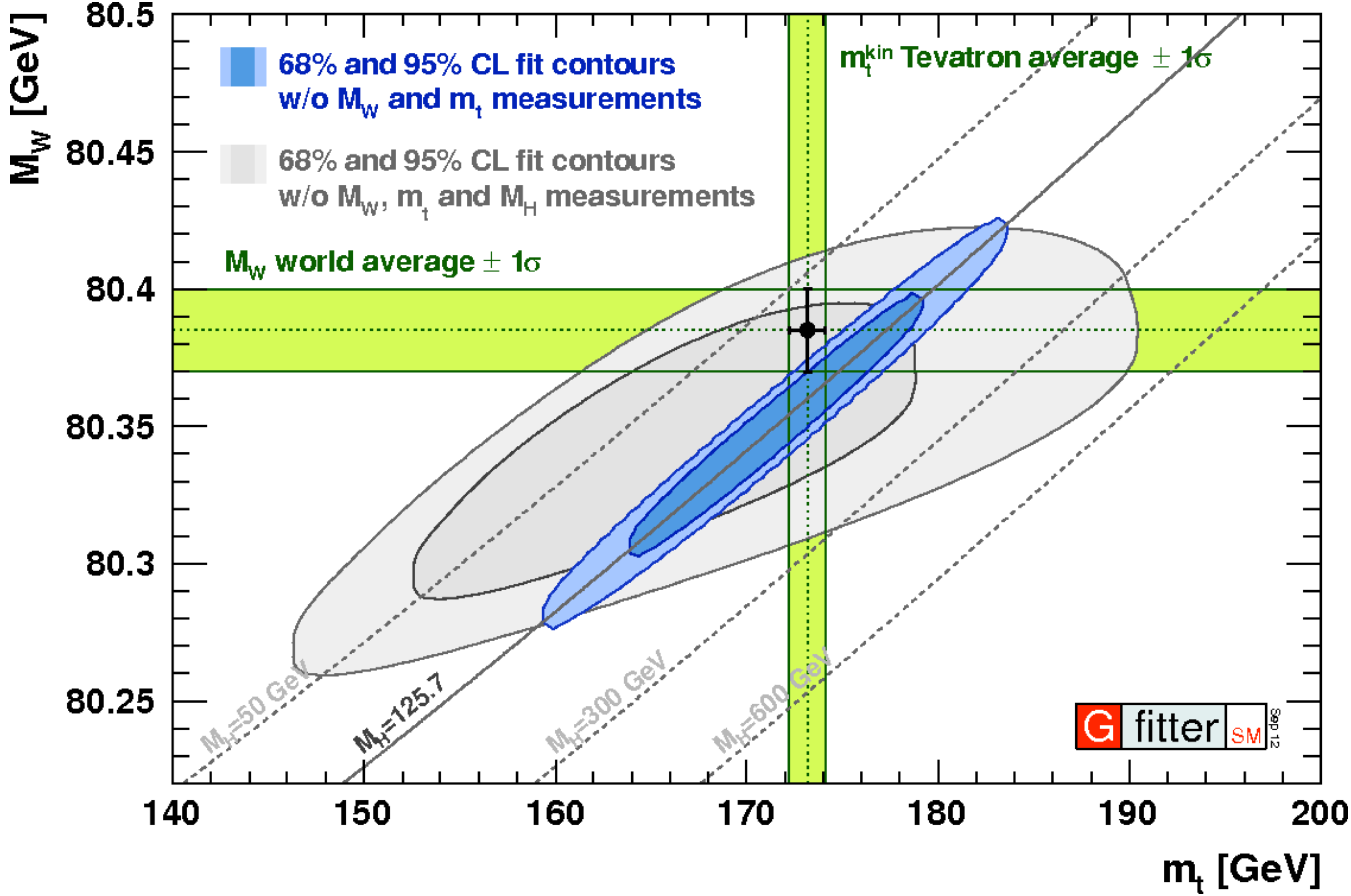
(arXiv:1207.1344 and 1211.4580)

- 48 years between theory and discovery
- 1964: theory [Englert&Brout; Higgs; Guralnik&Hagen&Kibble]
- 07/04/2012: discovery of the "scalar" boson of the SM
- The discovery required many channels: AA, ZZ, WW...





The new state fits the global picture!



1. Analyses framework

Our assumptions are:

- The observed state belongs to a SU(2) doublet.
- The state is CP-even as in the Standard Model.
- The observed resonance is narrow.
- There are no overlapping resonances.

To measure departures of the SM predictions we write

$$\mathcal{L}_{\rm eff} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n$$

and add dimension-six operators to the SM

- There are 59 independent dimension-six "operators"

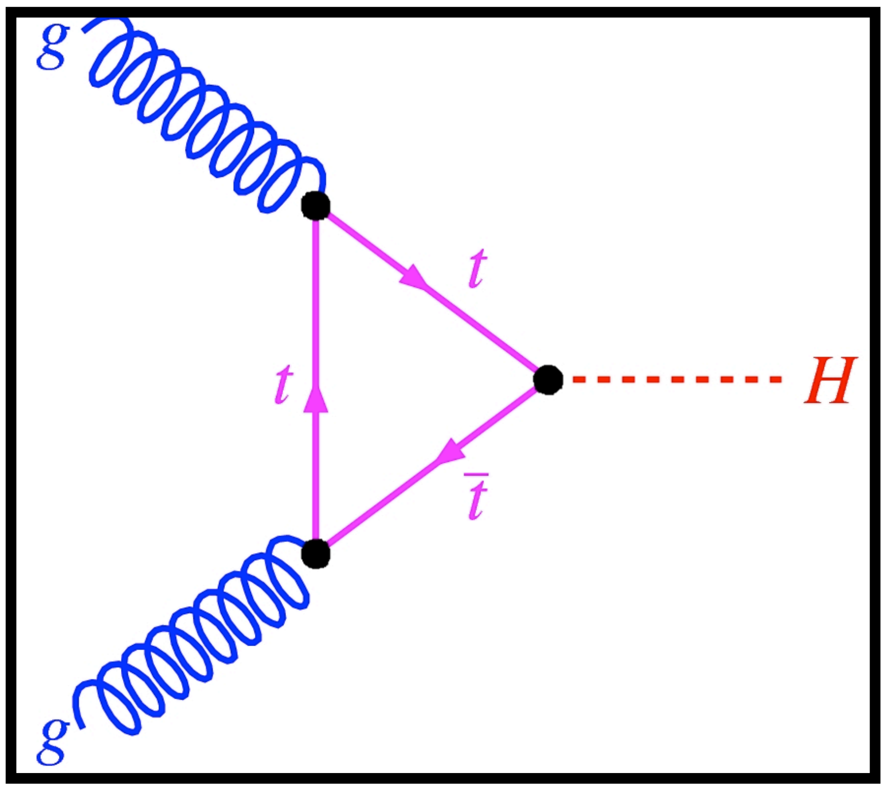
[Buchmuller & Wyler; Grzadkowski et al. arXiv: 1008.4884]

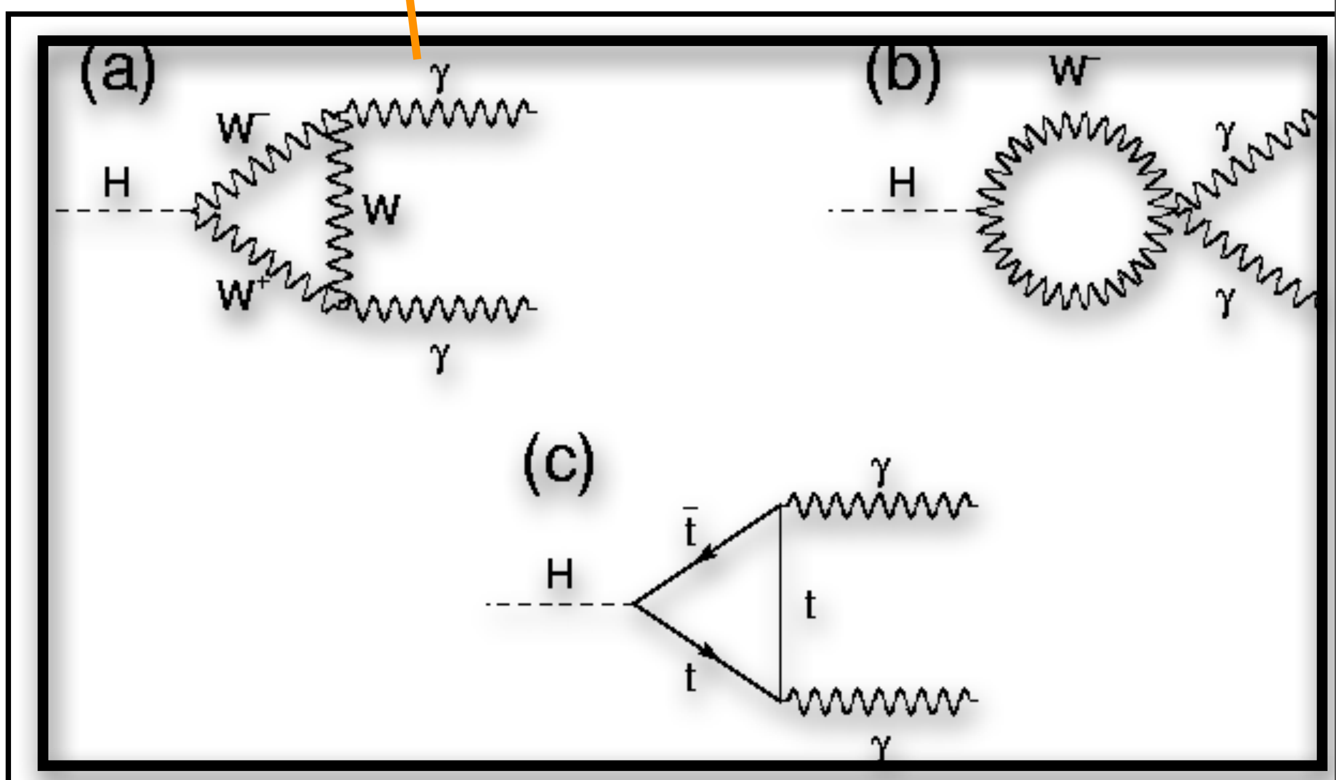
- The Higgs interactions with gauge bosons are modified by

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

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

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





In the unitary gauge

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$

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

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

- The Higgs the couplings to fermions are modified by

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

$$\mathcal{O}^{(1)}_{\Phi L,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{L}_i\gamma^\mu L_j)$$
$$\mathcal{O}^{(1)}_{\Phi Q,ij} = \Phi^\dagger(i\overleftrightarrow{D}_\mu\Phi)(\bar{Q}_i\gamma^\mu Q_j)$$
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$$\mathcal{O}^{(3)}_{\Phi L,ij} = \Phi^\dagger(i\overleftrightarrow{D}^a_\mu\Phi)(\bar{L}_i\gamma^\mu\sigma_a L_j)$$
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these modify the Yukawa couplings

these modify the couplings of gauge bosons to fermions

- there are also four-fermion operators and

$$\mathcal{O}_{WWW} = \mathrm{Tr}[\hat{W}_{\mu\nu}\hat{W}^{\nu\rho}\hat{W}^{\mu}_{\rho}]$$

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

- Idea: operators related by EOM lead to the same S matrix elements [e.g. Arzt hep-ph/9304230]
- The EOM lead to the relations

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

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

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

with this we can eliminate 3 operators

- Idea: operators related by EOM lead to the same S matrix elements [e.g. Arzt hep-ph/9304230]
- The EOM lead to the relations

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

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

with this we can eliminate 3 operators

- Very large operator basis => we must choose it to take full advantage of the available data

- strongly constrained operators should be kept

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

Z

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

Z,W

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

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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

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

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

with

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

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

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

there are data on that.

- we choose the basis:

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

- we choose the basis:

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

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- after discarding the constrained operators => 13:

- 9 fermions: $\mathcal{O}_{e\Phi,jj}$, $\mathcal{O}_{u\Phi,jj}$, $\mathcal{O}_{d\Phi,jj}$

- gauge bosons: $\mathcal{O}_{W}$, $\mathcal{O}_{B}$, $\mathcal{O}_{WW}$, $\mathcal{O}_{GG}$

- Summarizing:

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

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

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

- Summarizing:

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

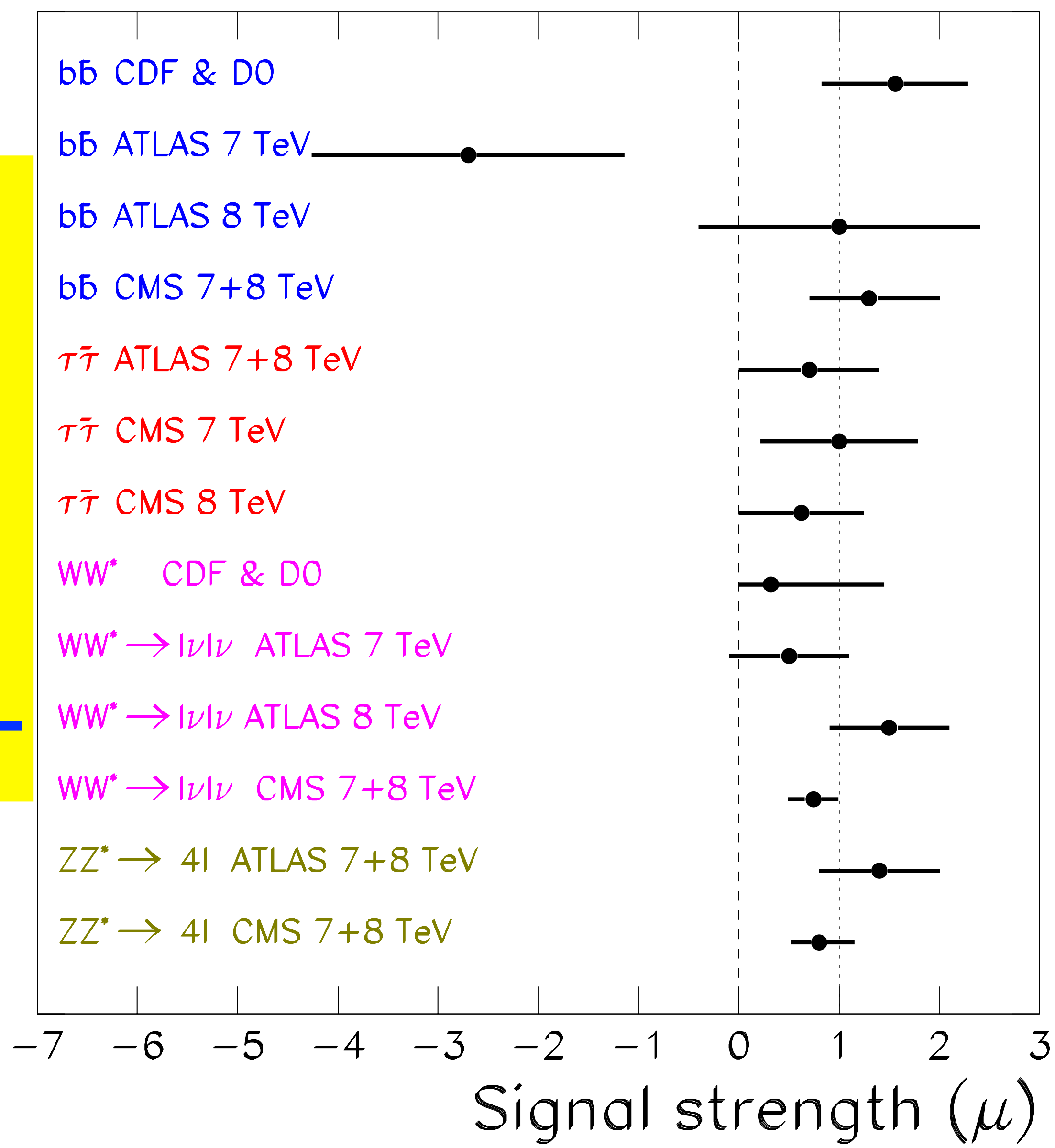
supplemented by shifts in the Yukawa couplings (3rd family)

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

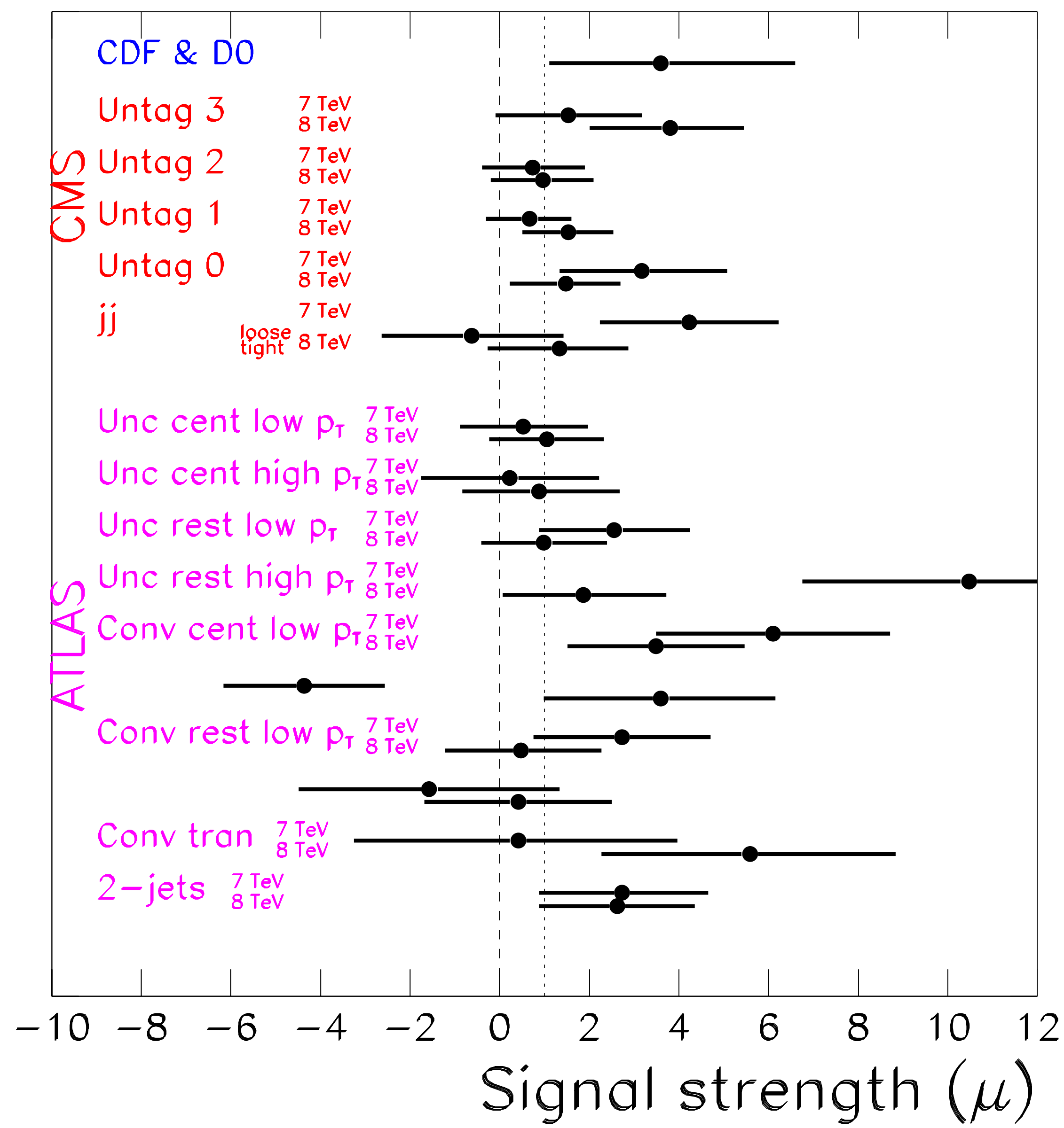
Fitting procedure

- Inputs: signal strength for the different channels $\mu = \dfrac{\sigma_{obs}}{\sigma_{SM}}$
- using all available data

updated 11/12



$\gamma\gamma$



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

FeynRules/MadGraph5

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

- use all available information

[correlated theoretical error]

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

- 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]

$$\alpha\Delta S = -\hat{e}^2\frac{v^2}{\Lambda^2}f_{BW} - \frac{1}{6}\frac{\hat{e}^2}{16\pi^2}\Bigg\{3(f_W+f_B)\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) + 2\left(f_{\Phi,2}-f_{\Phi,4}\right)\frac{v^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$

$$+ 2\left[(5\hat{c}^2-2)f_W - (5\hat{c}^2-3)f_B\right]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$

$$- \left[(22\hat{c}^2-1)f_W - (30\hat{c}^2+1)f_B\right]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)$$

$$- 24(\hat{c}^2 f_{WW} + \hat{s}^2 f_{BB})\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\Bigg\},$$

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

$$+ (\hat{c}^2 f_W + f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)$$

$$+ \left[2\hat{c}^2 f_W + (3\hat{c}^2-1)f_B\right]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\Bigg\},$$

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

$$+ (2f_W - 5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\Bigg\},$$

- In the fitting we used that

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

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

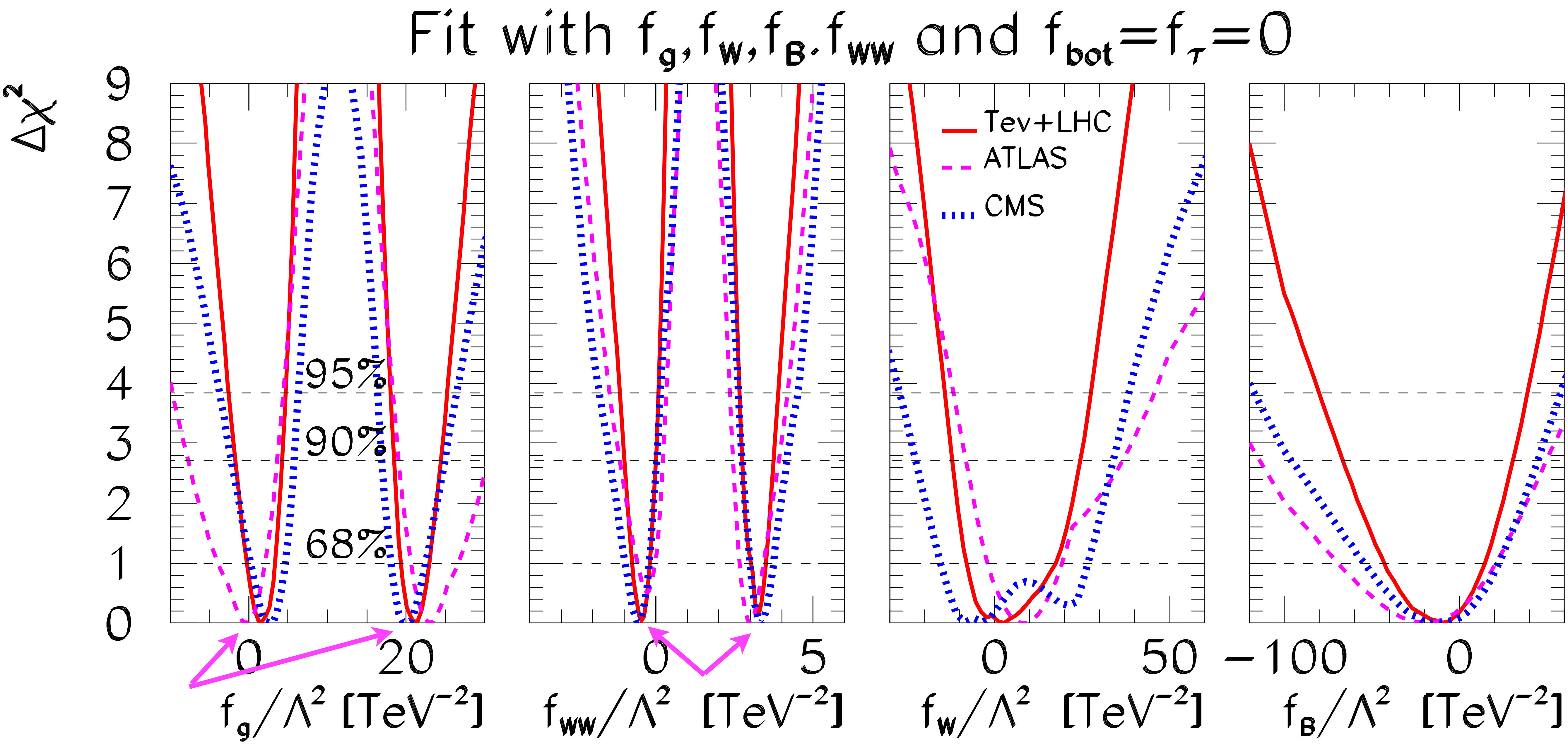
TGV bounds

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, $\rho = 0.11$

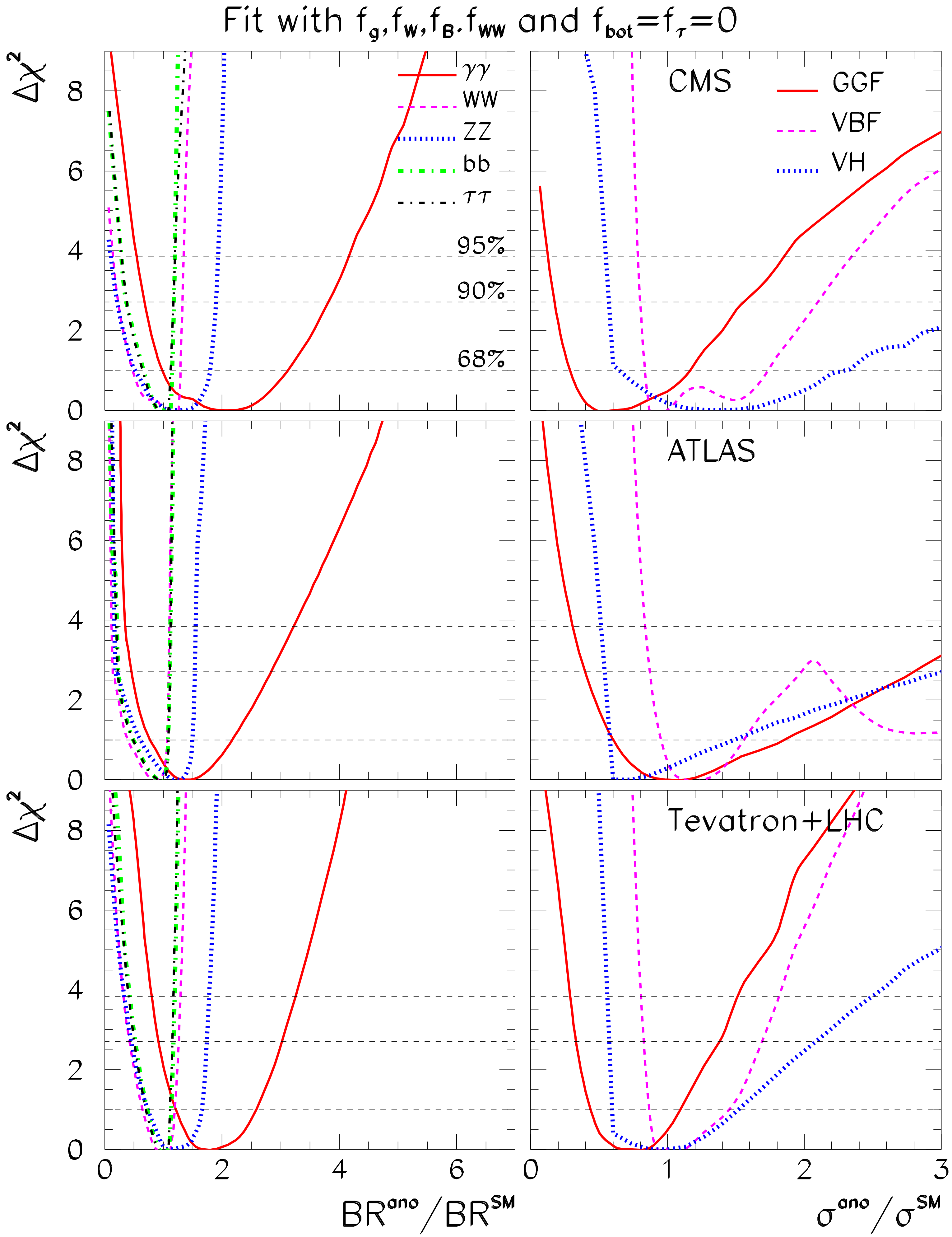
2. Results

• **First scenario:** $(f_{GG} \quad , \quad f_{WW} \quad , \quad f_W \quad , \quad f_B \quad , \quad f_{bot} = 0 \quad , \quad f_\tau = 0)$

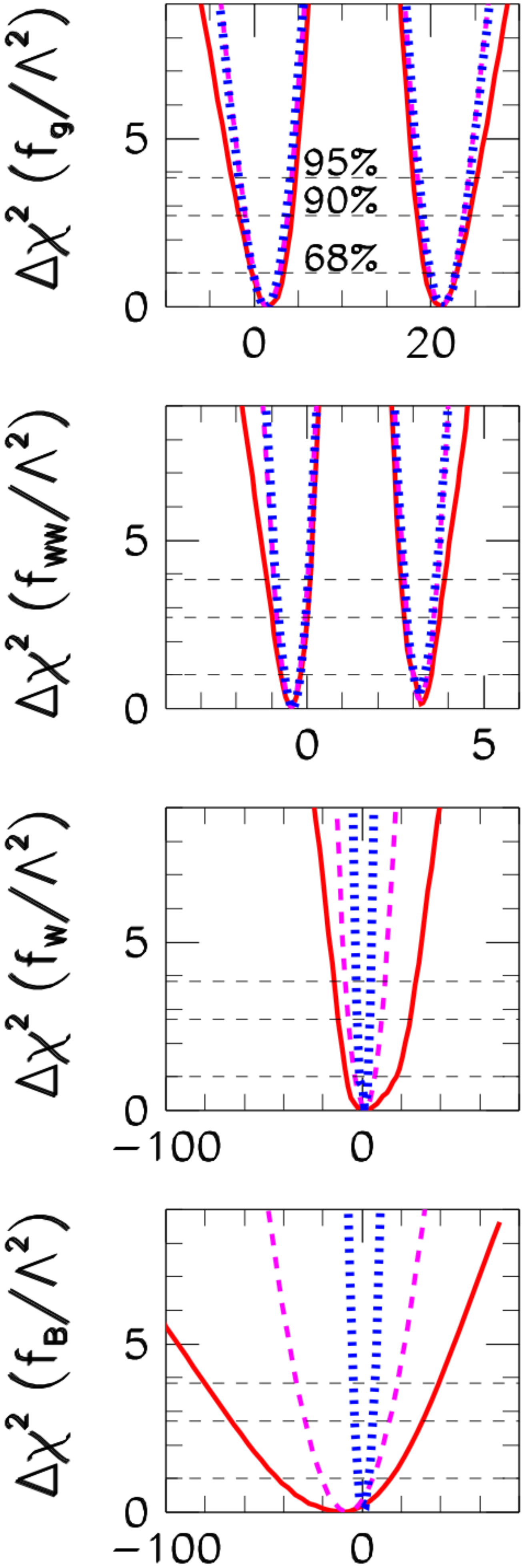
using collider available data [$\chi^2_{min} = 44.0 \quad \chi^2_{SM} = 48$ **60% CL]**

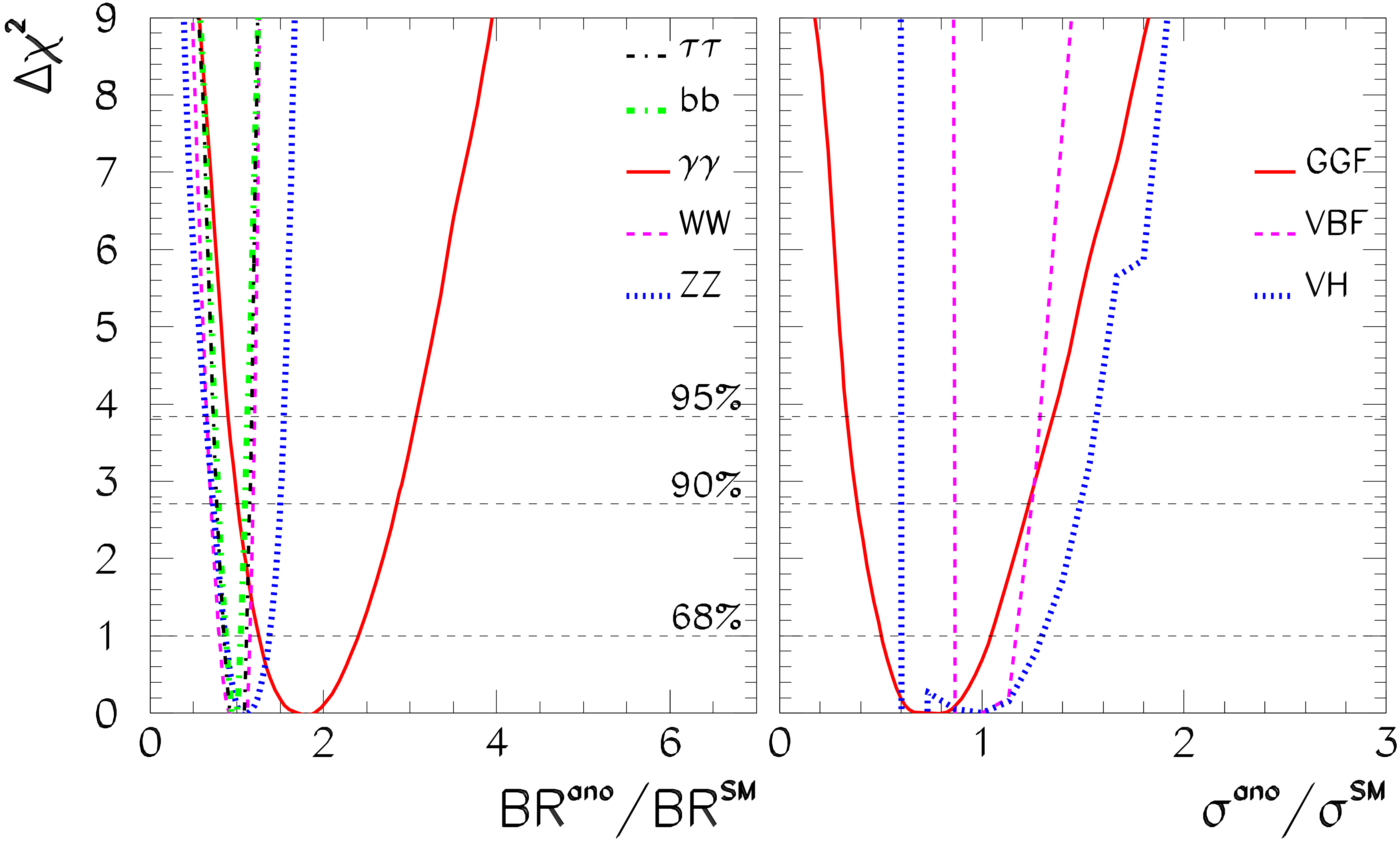


branching ratios and cross section comparison



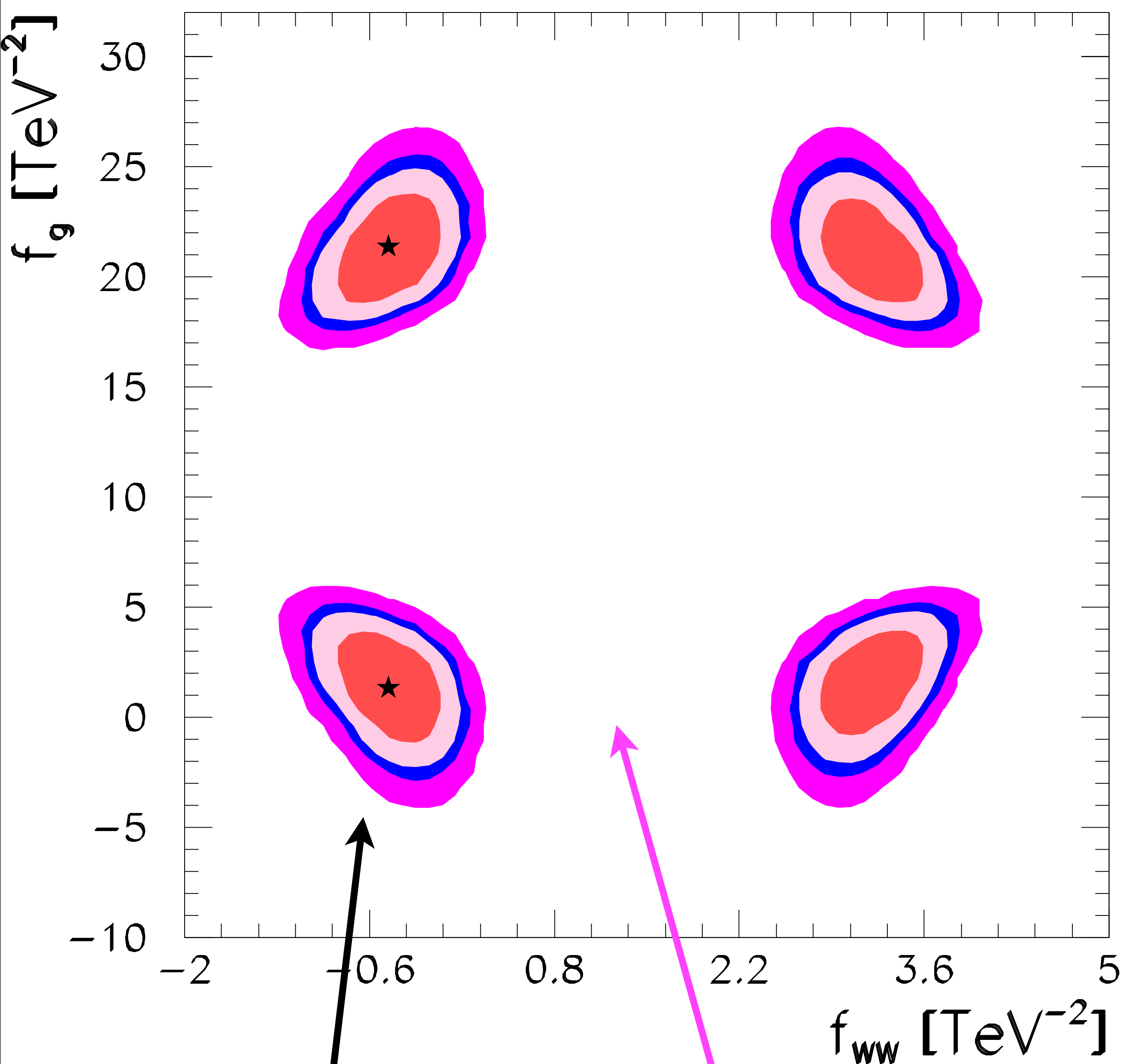
Collider +
TGV +
EWPD

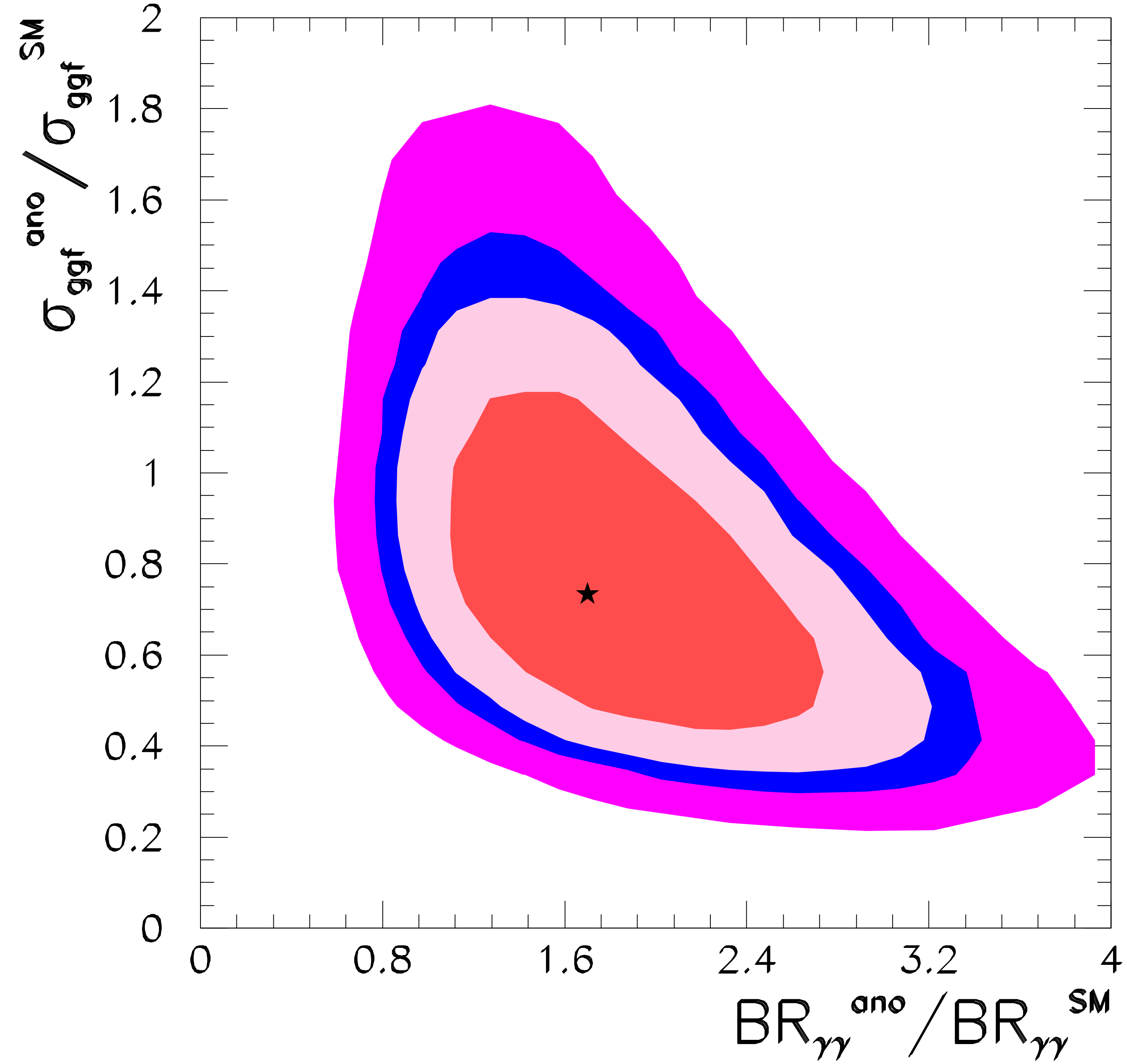




collider + TGV

interesting correlations





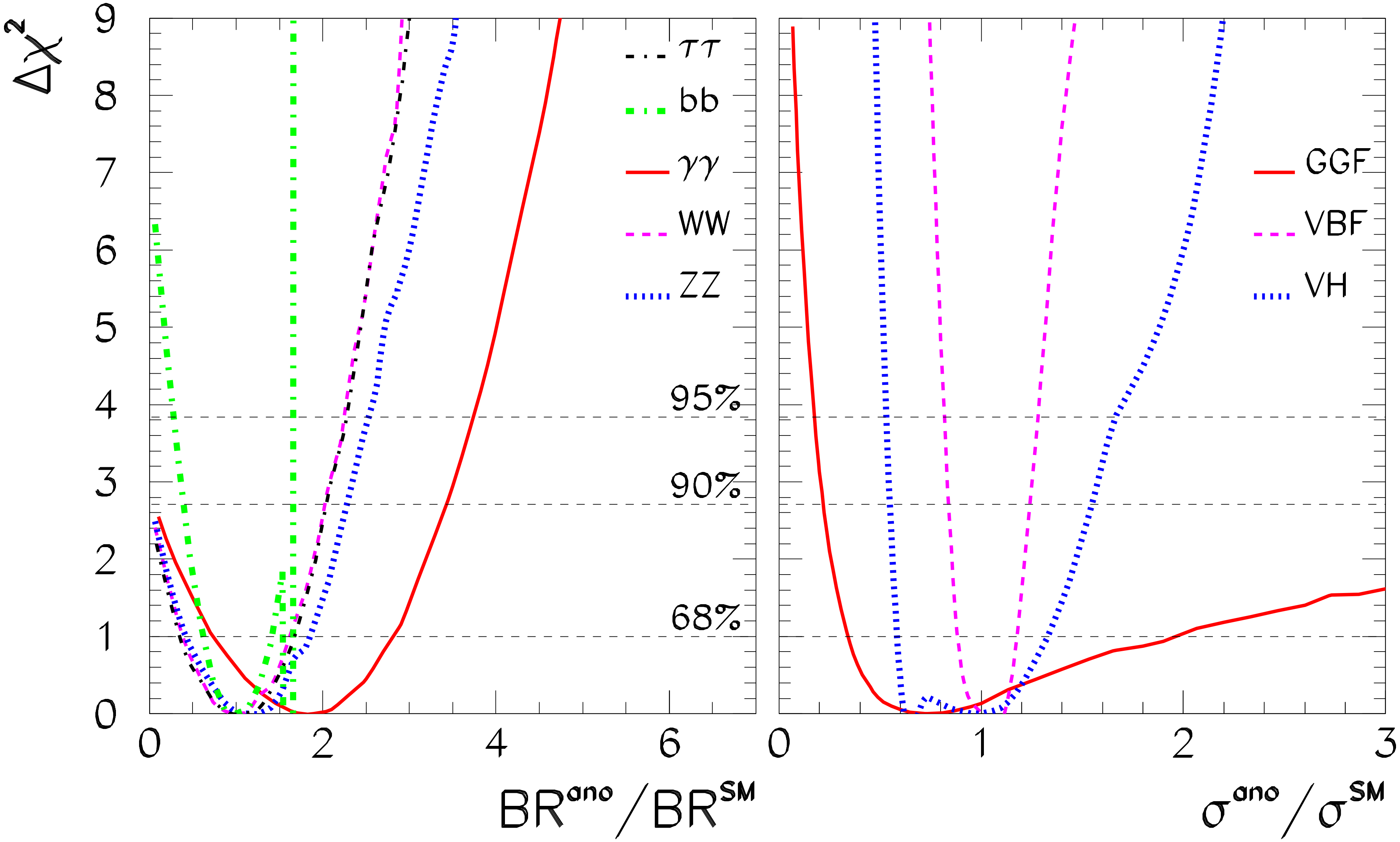
strong correlation

($\gamma\gamma$ data)

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

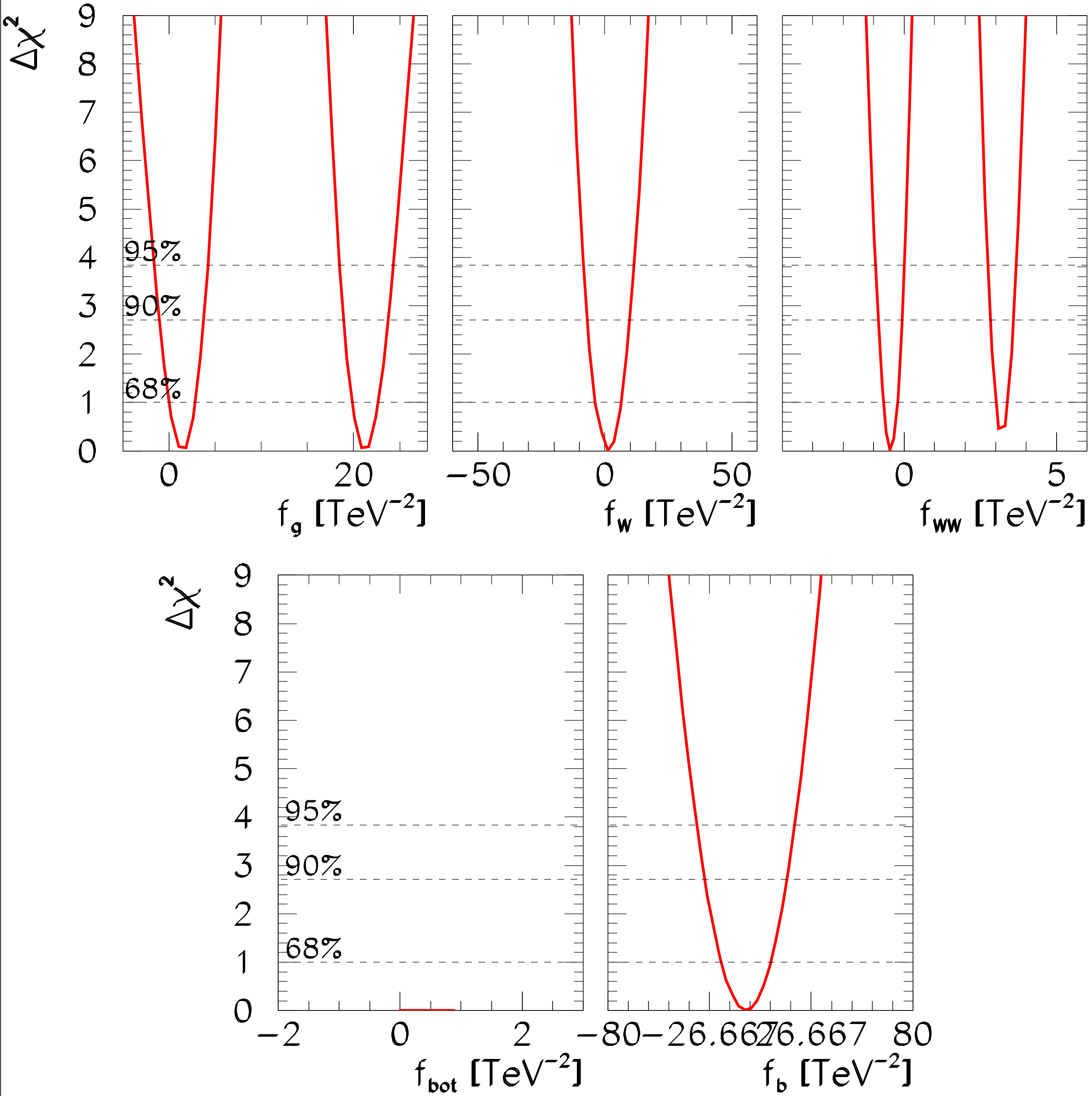
(σ_{gg} decreases)

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

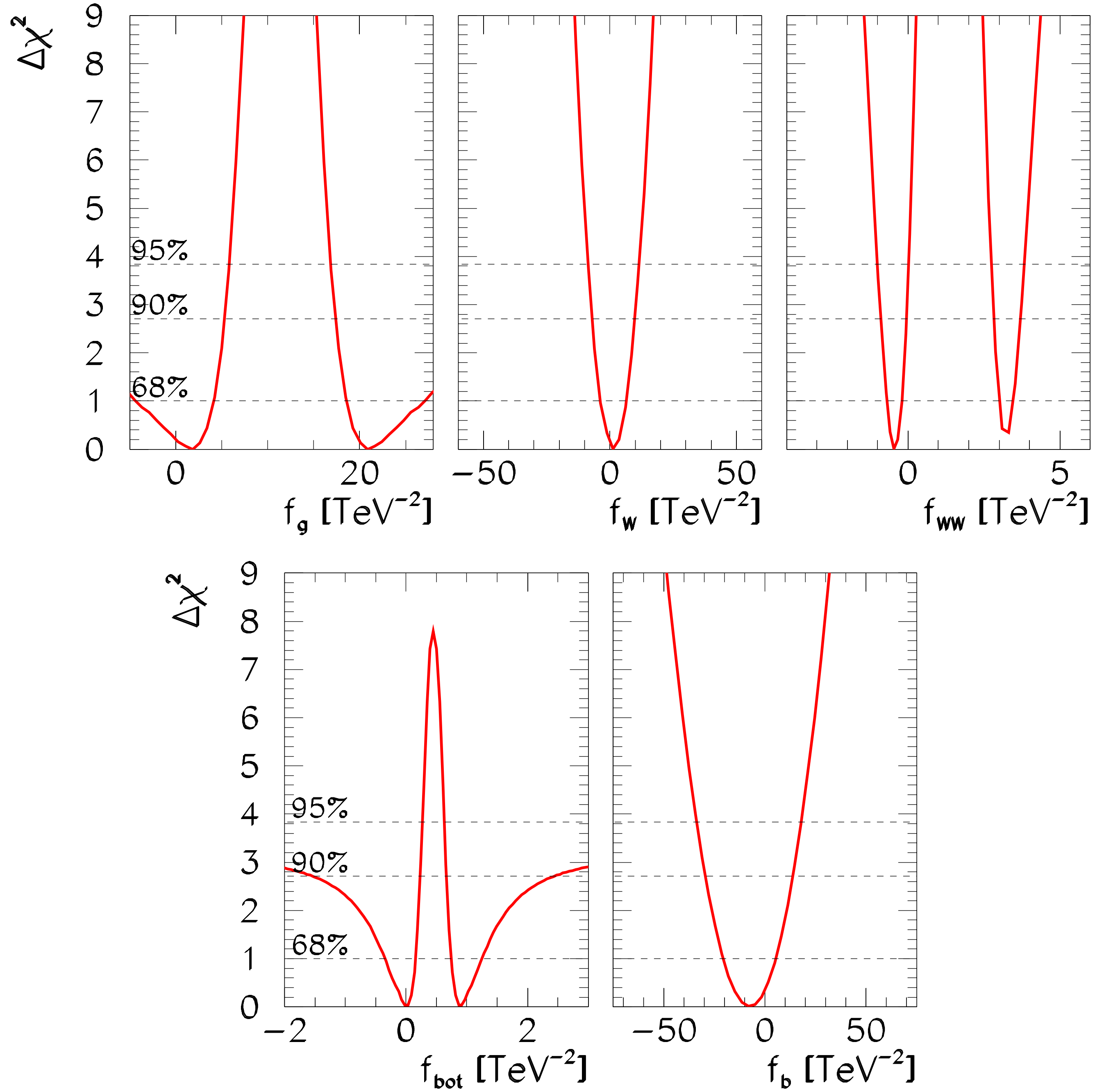


using all LHC available data and TGV

First scenario

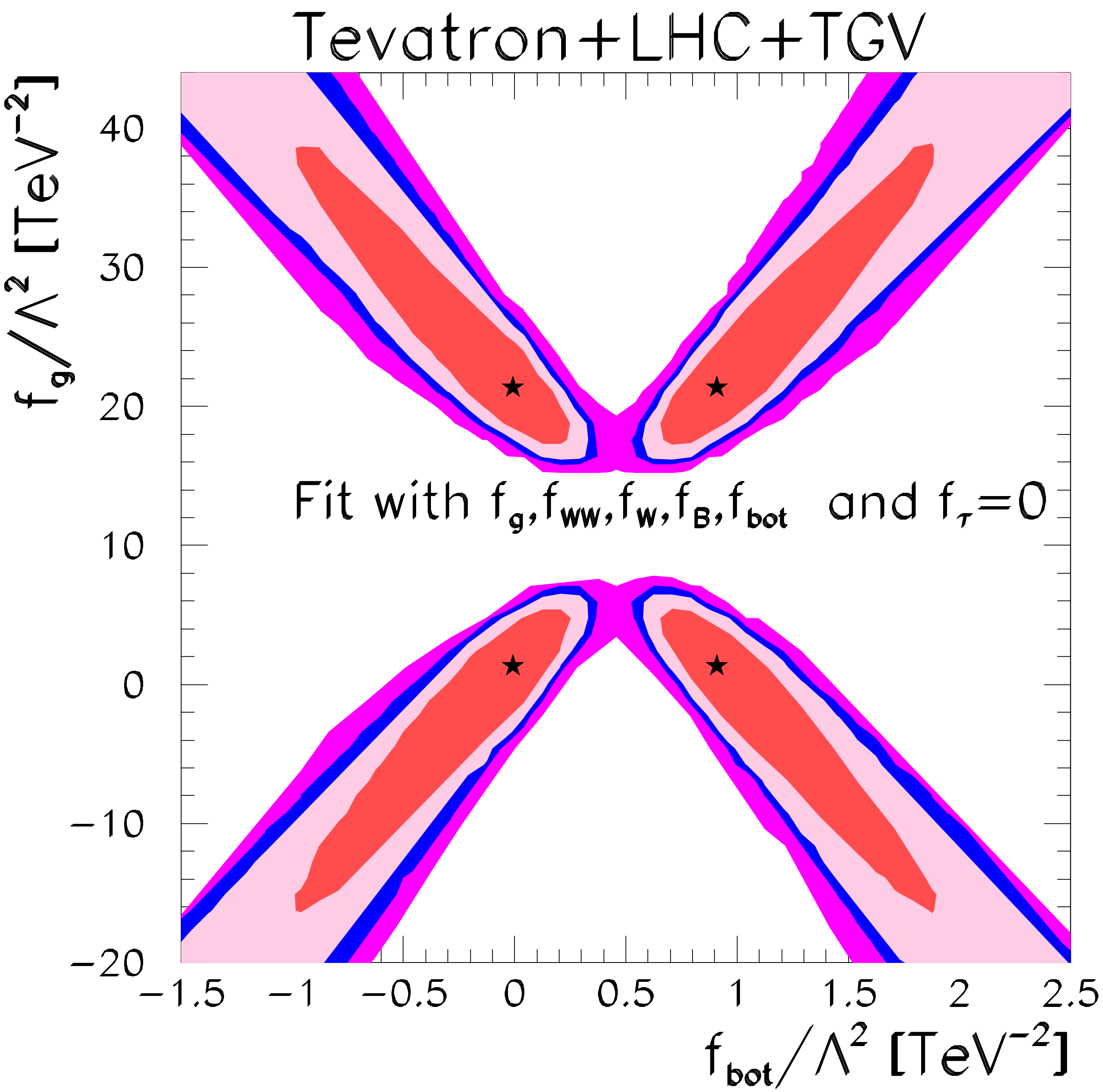


Second scenario



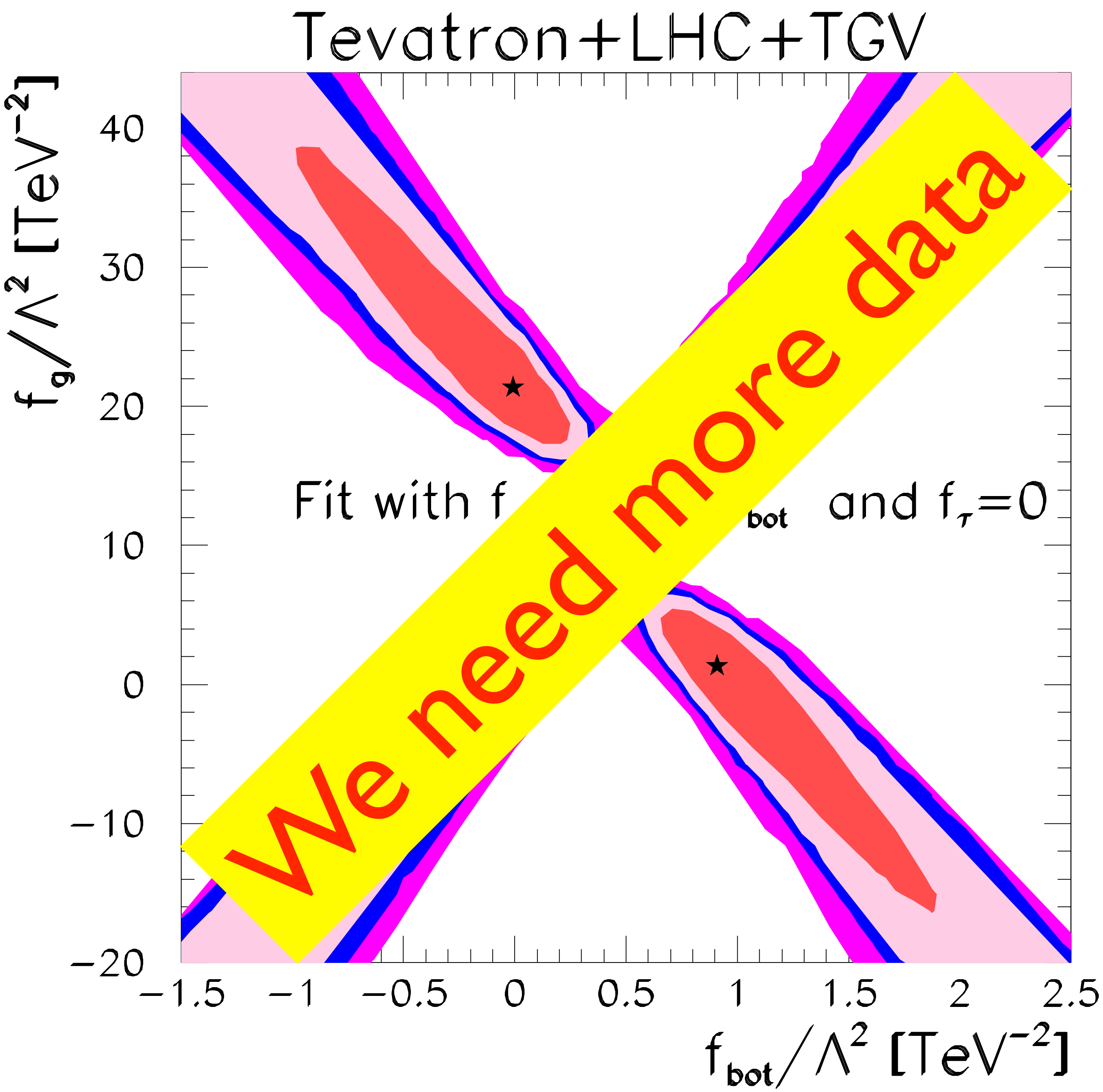
there is a strong correlation between f_{GG} and f_{bot}

68%, 90%, 95%, and 99% CL regions



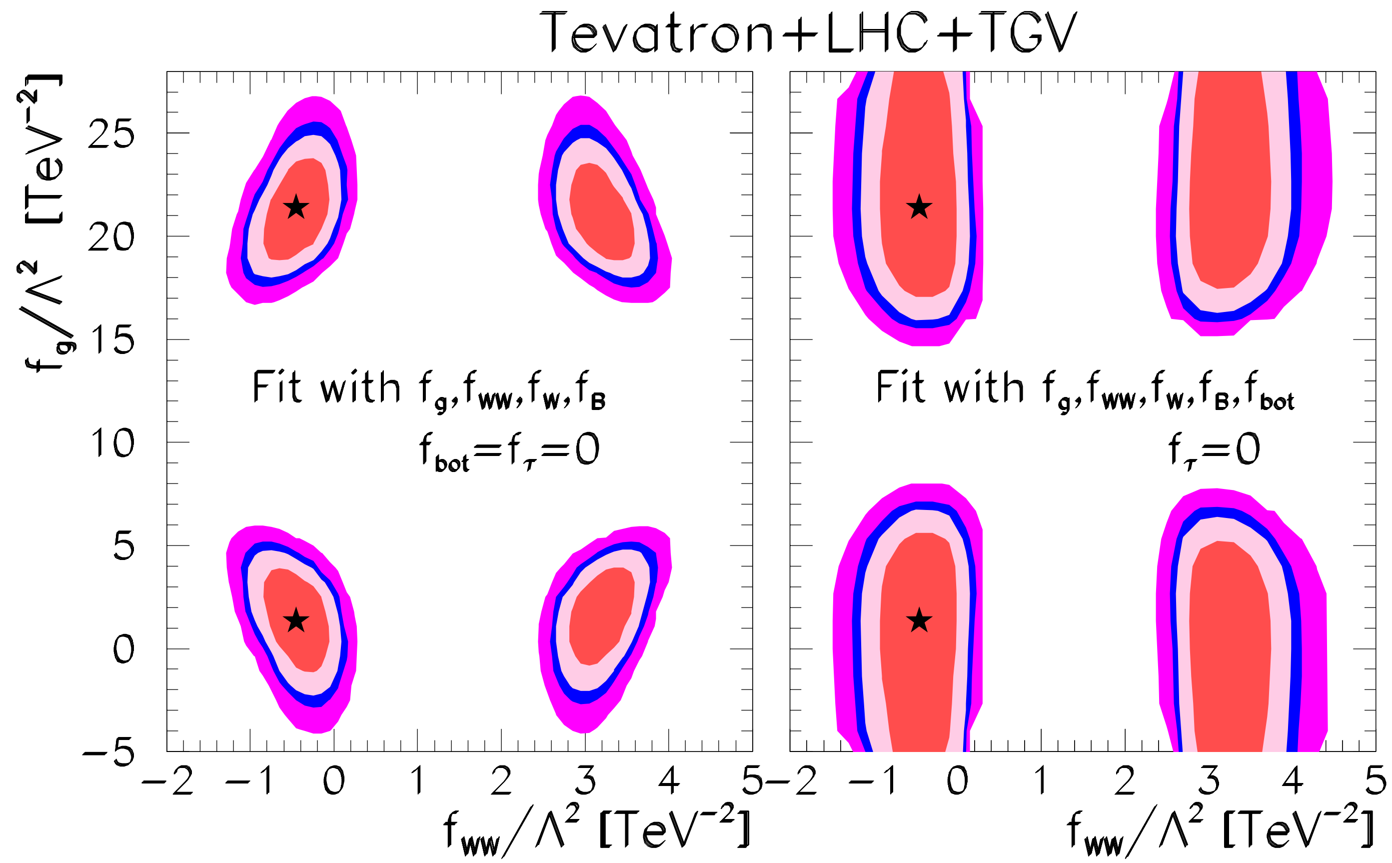
$$\sigma(pp \to h \to \gamma\gamma) \propto \frac{f_{GG}^2}{f_{bot}^2}$$

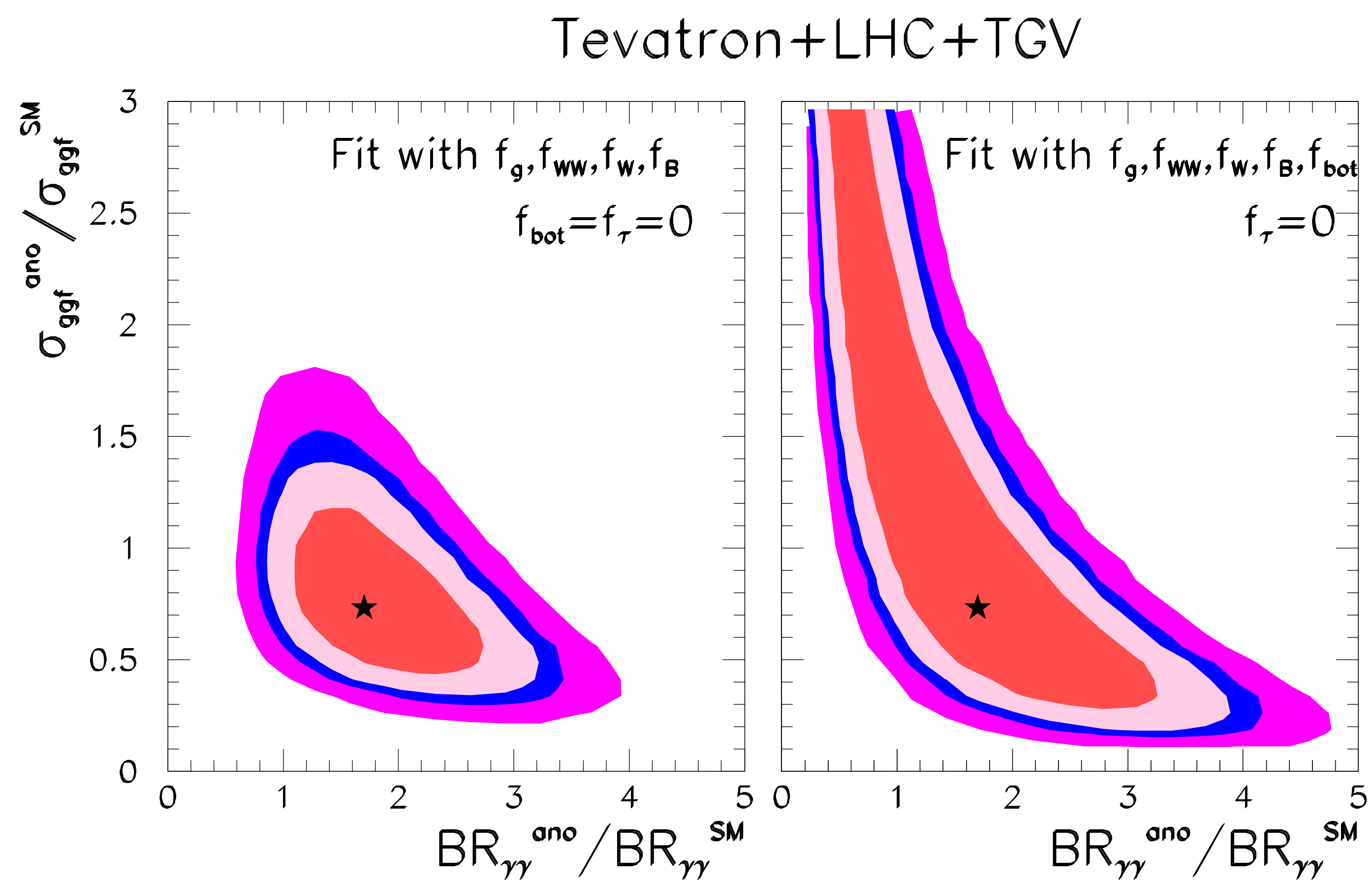
68%, 90%, 95%, and 99% CL regions



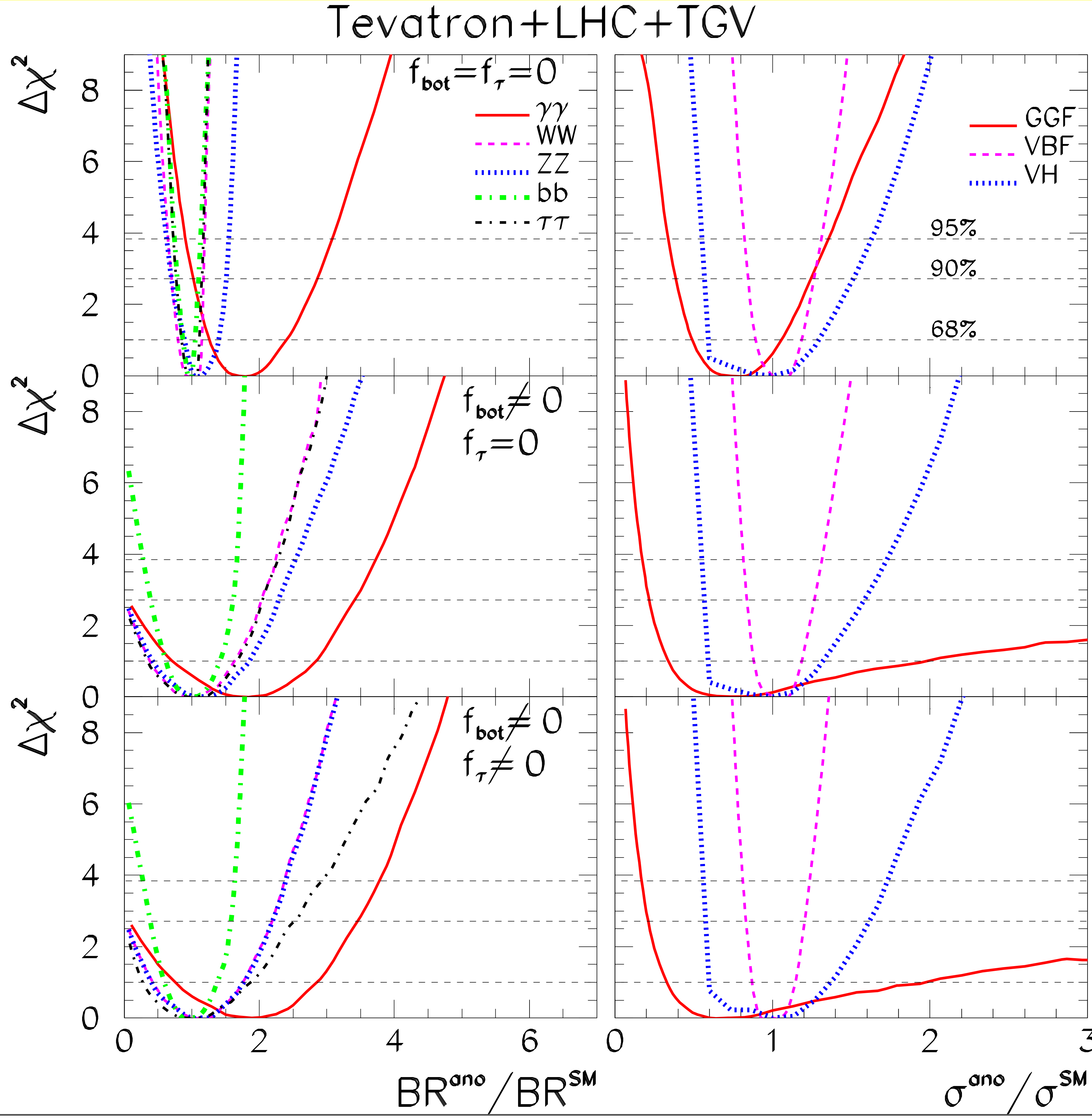
$$\sigma(pp \to h \to \gamma\gamma) \propto \frac{f_{GG}^2}{f_{bot}^2}$$

effect of the bottom Yukawa on correlations





• Third scenario: $(f_{GG}\ ,\ f_{bot}\ ,\ f_W = f_B\ ,\ f_{bot}\ ,\ f_\tau)$



3. Discussion and conclusions (?)

- Summarizing the results:

	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})	1.4, 21.3	$[-1.1, 3.8] \cup [19, 24]$	1.6, 21.1	$[-27, 5] \cup [17, 50]$
f_{WW}/Λ^2 (TeV^{-2})	-0.43	$[-0.85, -0.05] \cup [2.8, 3.6]$	-0.42	$[-0.85, 0] \cup [2.75, 3.7]$
f_W/Λ^2 (TeV^{-2})	1.70	$[-7.2, 10]$	0.42	$[-7.5, 7]$
f_B/Λ^2 (TeV^{-2})	-7.6	$[-29, 14]$	0.42	$[-7.5, 7]$
f_{bot}/Λ^2 (TeV^{-2})	—	—	0.01, 0.89	$[-1.6, 0.25] \cup [0.65, 2.5]$
f_τ/Λ^2 (TeV^{-2})	—	—	0.02, 0.32	$[-0.08, 0.13] \cup [0.2, 0.42]$
$BR^{ano}_{\gamma\gamma}/BR^{SM}_{\gamma\gamma}$	1.76	$[1.1, 2.8]$	1.84	$[0.1, 3.4]$
$BR^{ano}_{WW}/BR^{SM}_{WW}$	0.98	$[0.75, 1.15]$	1.03	$[0.05, 2.15]$
$BR^{ano}_{ZZ}/BR^{SM}_{ZZ}$	1.13	$[0.75, 1.5]$	1.03	$[0.05, 2.15]$
$BR^{ano}_{bb}/BR^{SM}_{bb}$	1.03	$[0.85, 1.1]$	1.03	$[0.4, 1.6]$
$BR^{ano}_{\tau\tau}/BR^{SM}_{\tau\tau}$	1.03	$[0.8, 1.1]$	0.84	$[0.05, 2.5]$
$\sigma^{ano}_{gg}/\sigma^{SM}_{gg}$	0.78	$[0.4, 1.2]$	0.73	$[0.25, 12]$
$\sigma^{ano}_{VBF}/\sigma^{SM}_{VBF}$	1.03	$[0.9, 1.25]$	1.03	$[0.9, 1.15]$
$\sigma^{ano}_{VH}/\sigma^{SM}_{VH}$	0.98	$[0.55, 1.4]$	1.03	$[0.55, 1.55]$

- Br[h to WW/ZZ] is agreement with SM
- data prefer a slightly enhanced Br[h to AA]
- VH and VBF cross sections in agreement with SM
- There is a preference for a depleted gg cross section
- LHC Higgs data leads to constraints on TGV similar to LEP
- direct limits on f_{WW} better than EWPT

- HOWEVER,

1. ATLAS and CMS data show different tendencies (h to AA)

2. there are still large statistical errors

3. we need more data to study Higgs couplings to fermions

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1. ATLAS and CMS data show different tendencies (h to AA)

2. there are still large statistical errors

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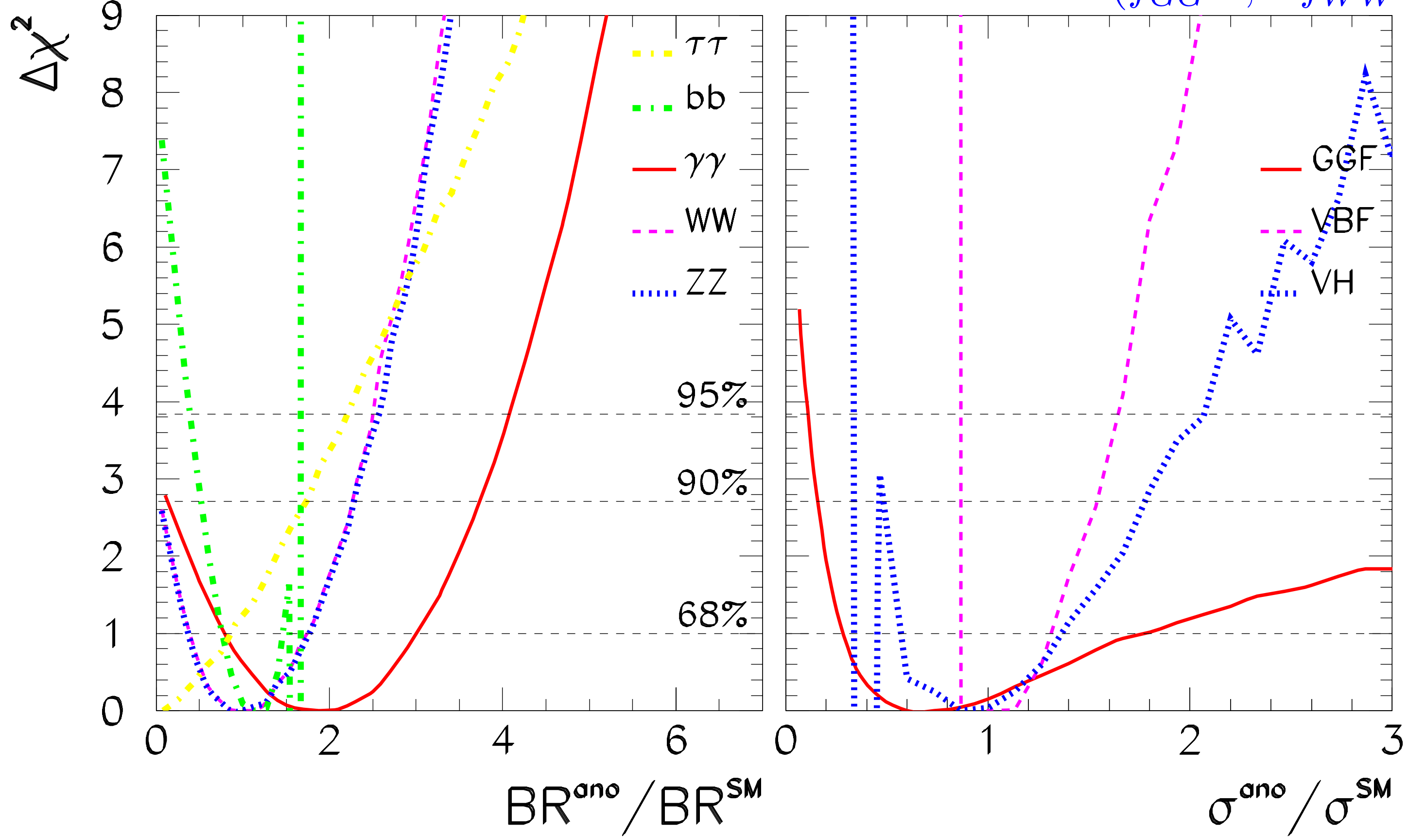
THANK YOU

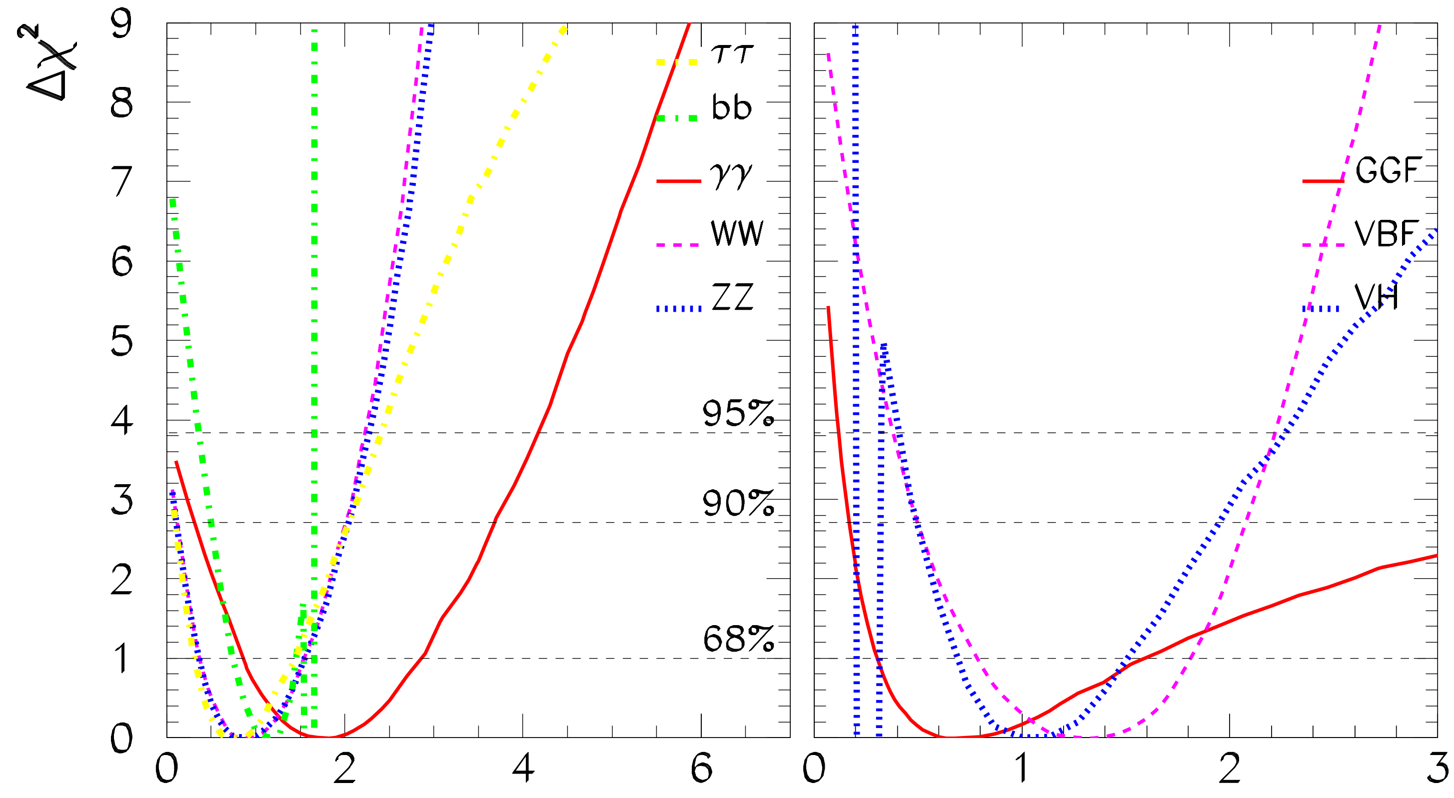
OVERFLOW

• Comparison between different bases

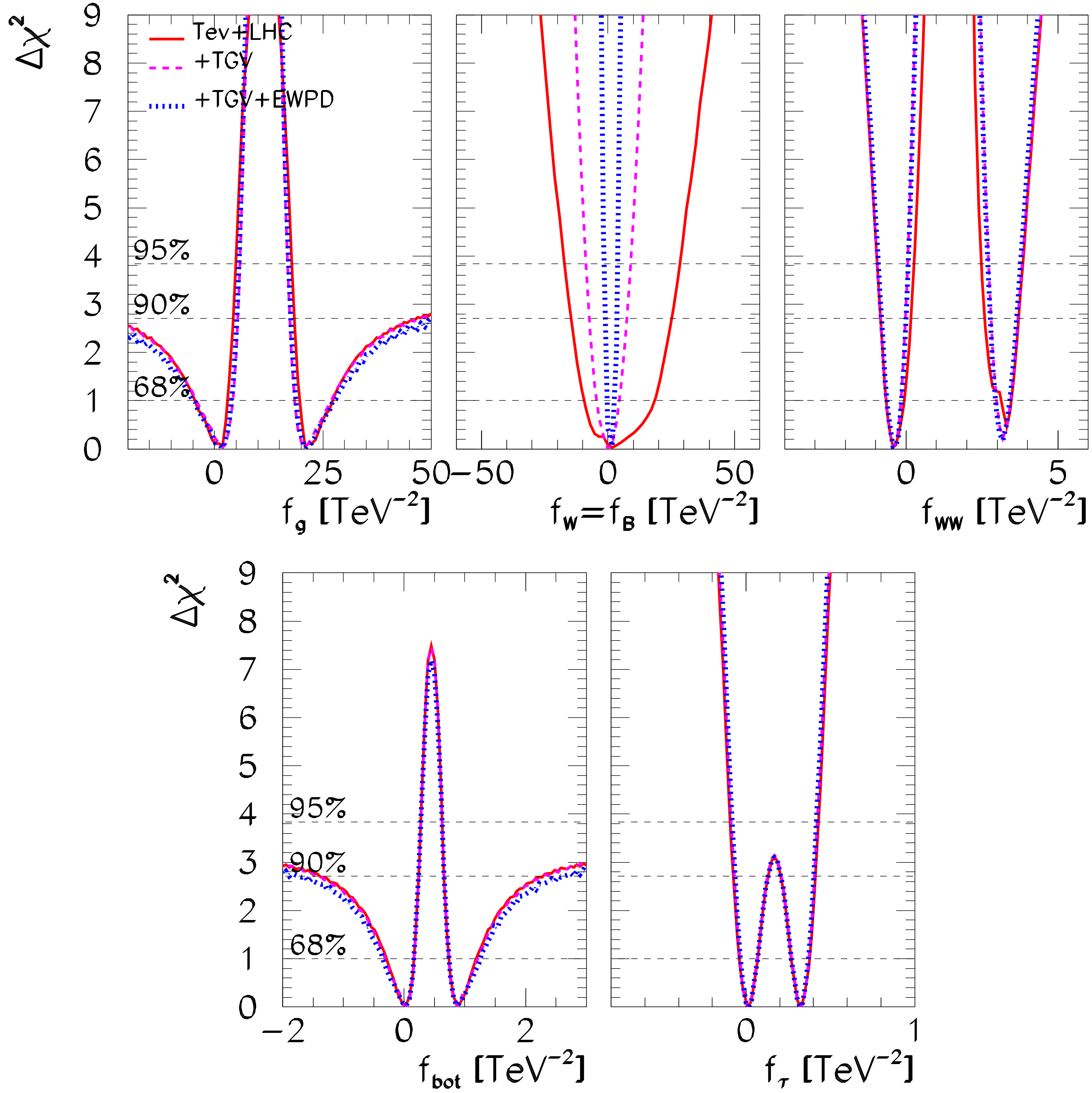
$(f_{GG} \quad , \quad f_{WW} \quad , \quad f_W = f_B \quad , \quad f_{bot} \quad , \quad f_{top} = 0)$



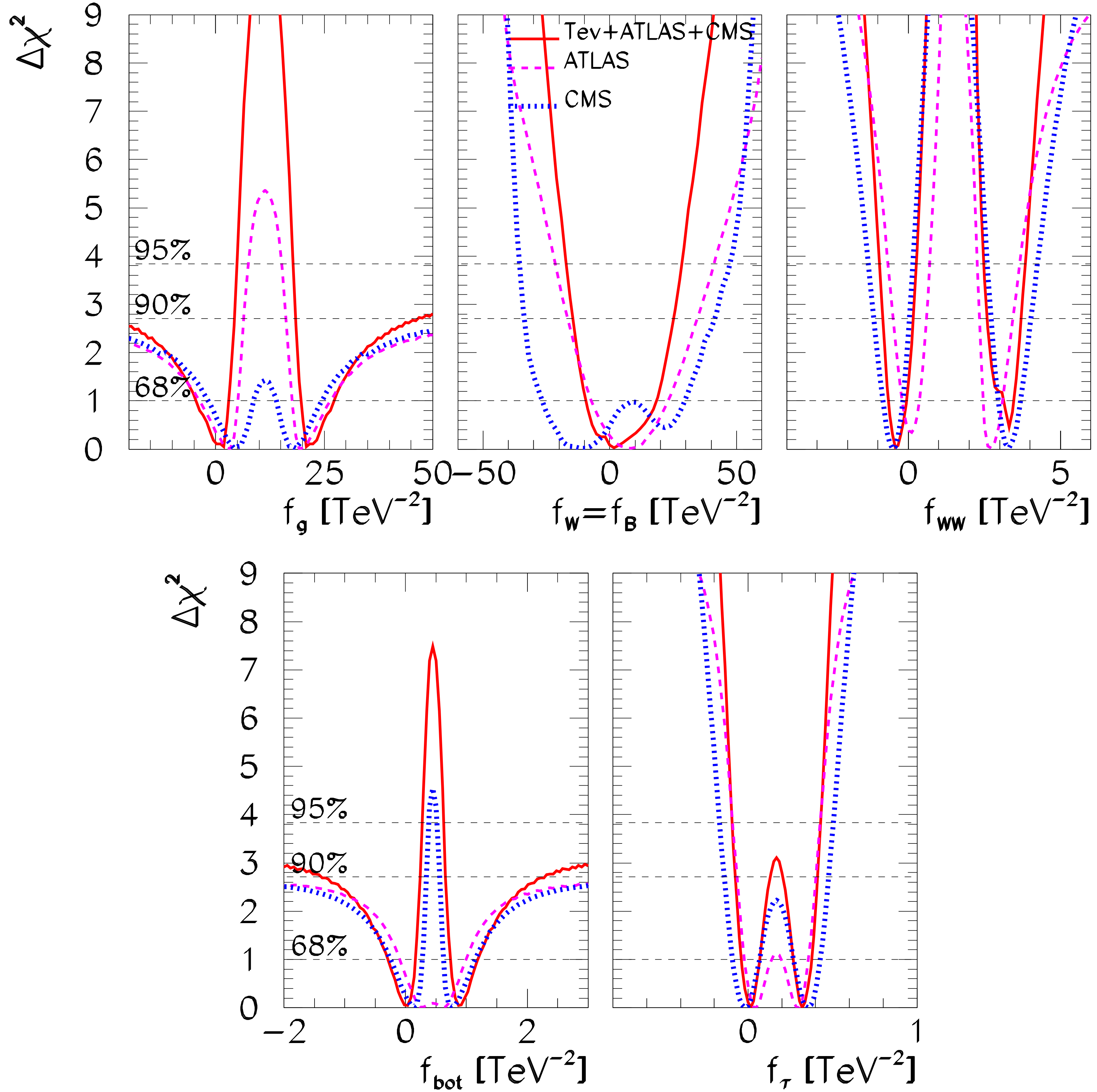
$(f_{GG} \quad , \quad f_{\Phi,2} \quad , \quad f_W = f_B \quad , \quad f_{bot} \quad , \quad f_{top} = 0)$



effects of including TGV and EWPT



ATLAS X CMS



Tev+ATLAS+CMS
ATLAS
CMS
95%
90%
68%
Δχ²
f_g [TeV⁻²]
f_W=f_B [TeV⁻²]
f_WW [TeV⁻²]
f_bot [TeV⁻²]
f_τ [TeV⁻²]

- The HVV new interactions are

$$
\begin{aligned}
\mathcal{L}_{\text{eff}}^{\text{HVV}} = \; & g_{Hgg}\, HG^a_{\mu\nu}G^{a\mu\nu} + g_{H\gamma\gamma}\, HA_{\mu\nu}A^{\mu\nu} + g^{(1)}_{HZ\gamma}\, A_{\mu\nu}Z^{\mu}\partial^{\nu}H + g^{(2)}_{HZ\gamma}\, HA_{\mu\nu}Z^{\mu\nu} \\
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\end{aligned}
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with

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

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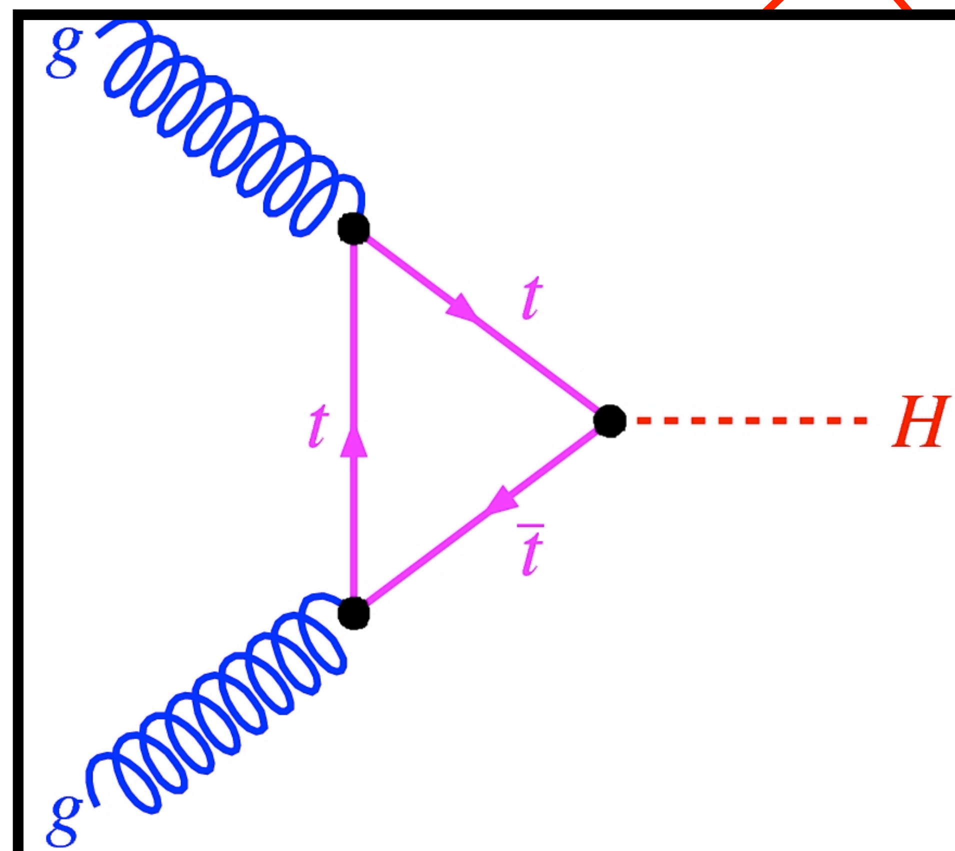

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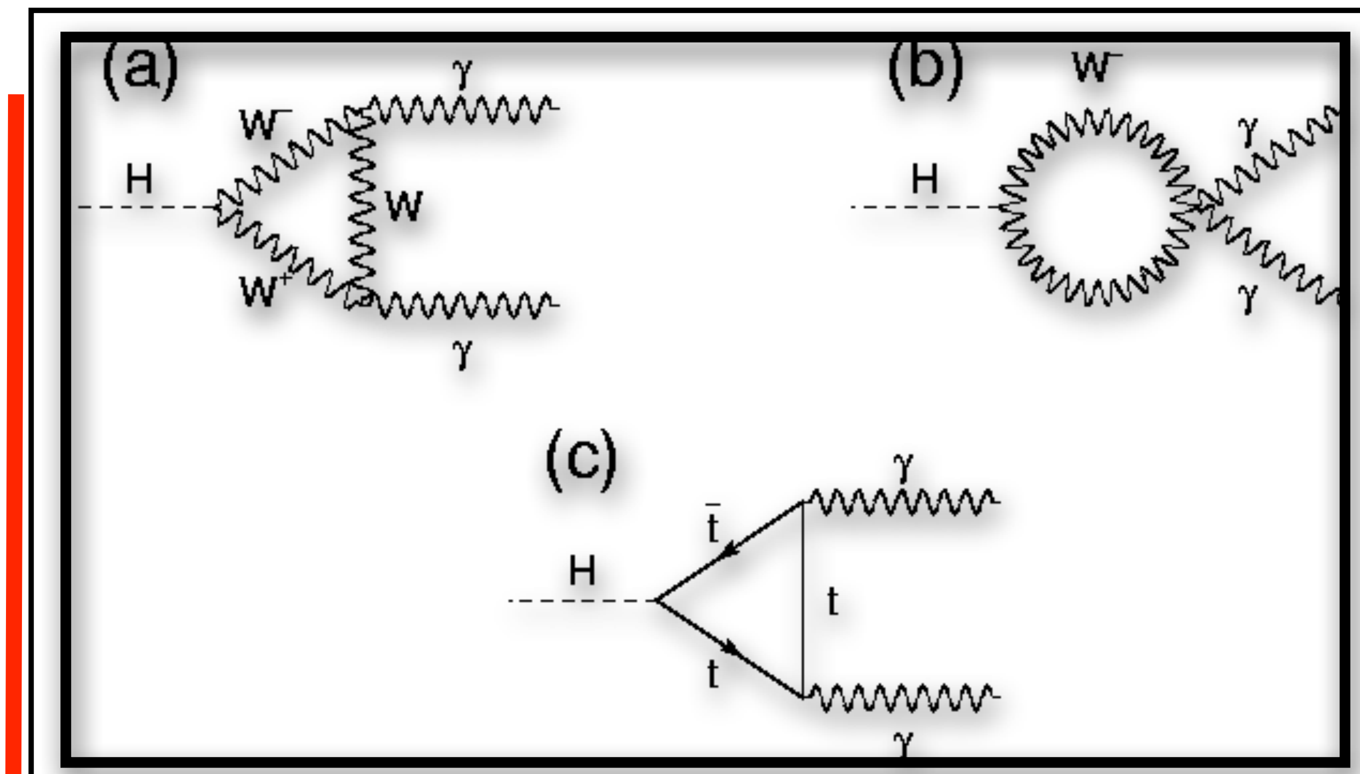

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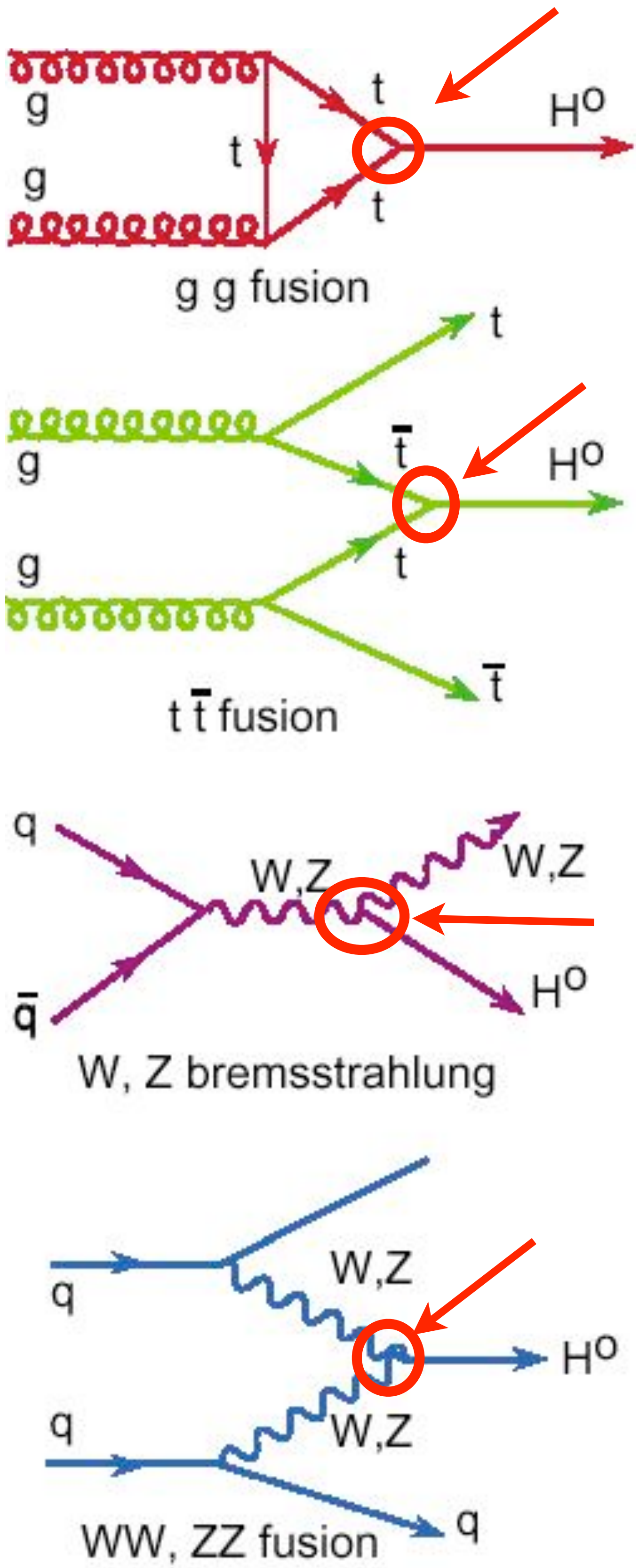
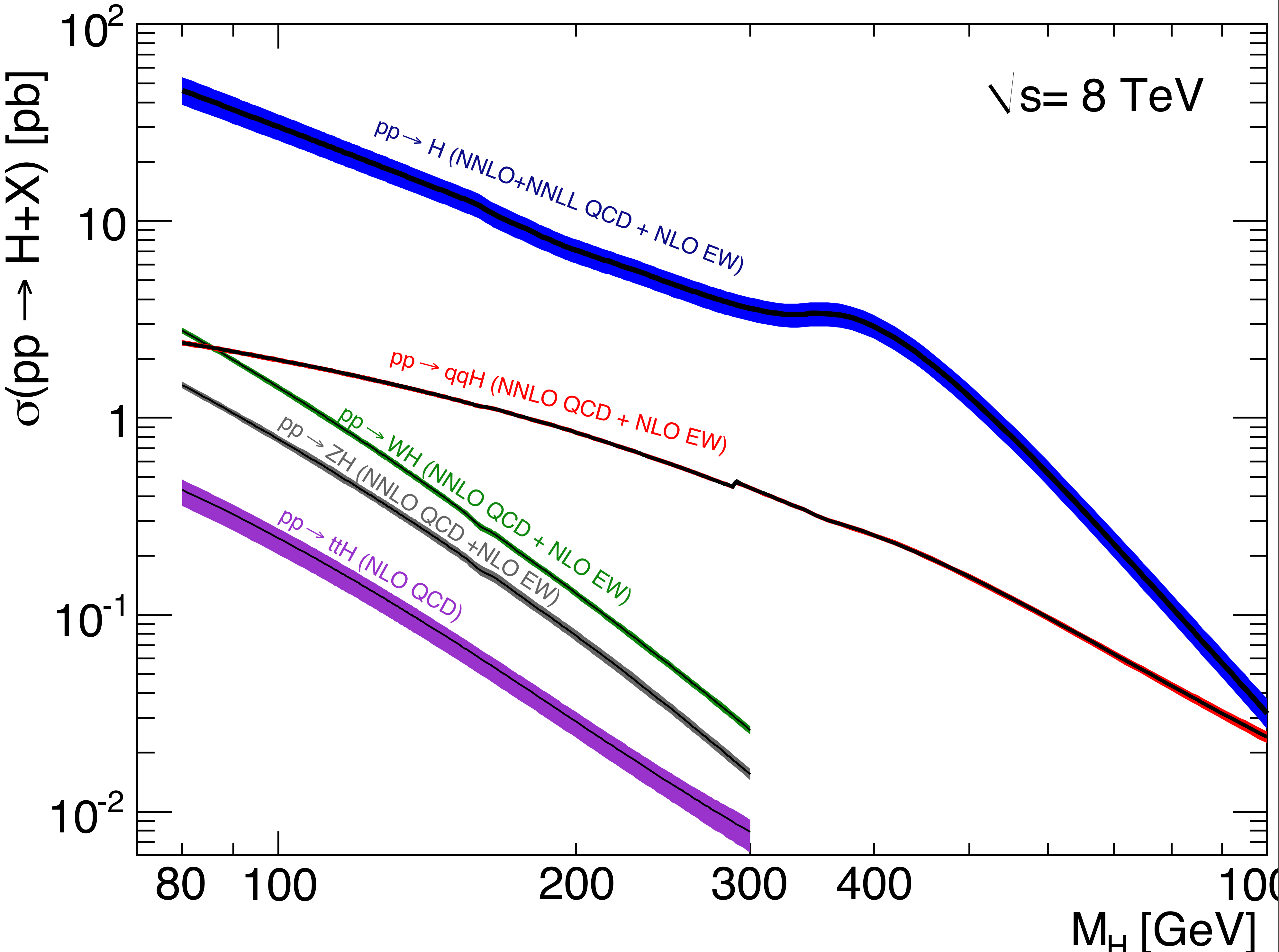
OLD SLIDES

Hunting the SM Higgs

- Higgs production mechanisms and cross sections





Hunting the SM Higgs

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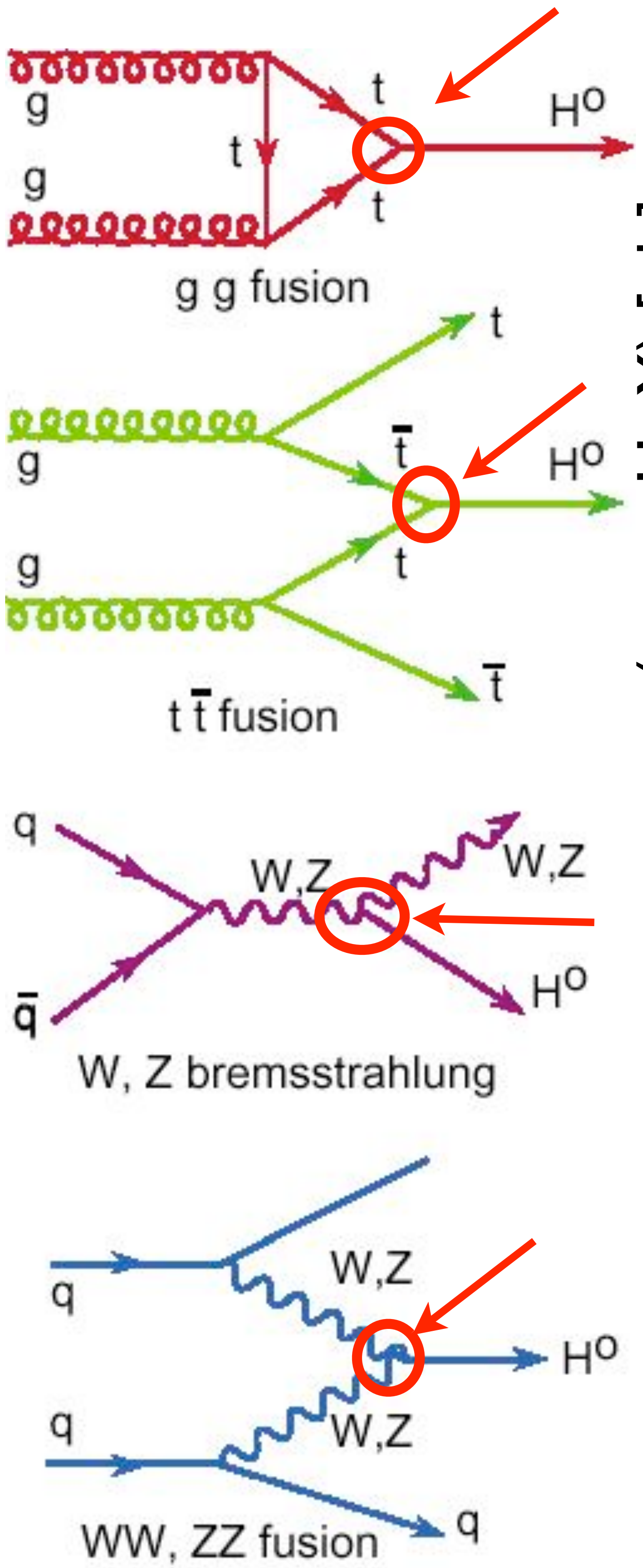
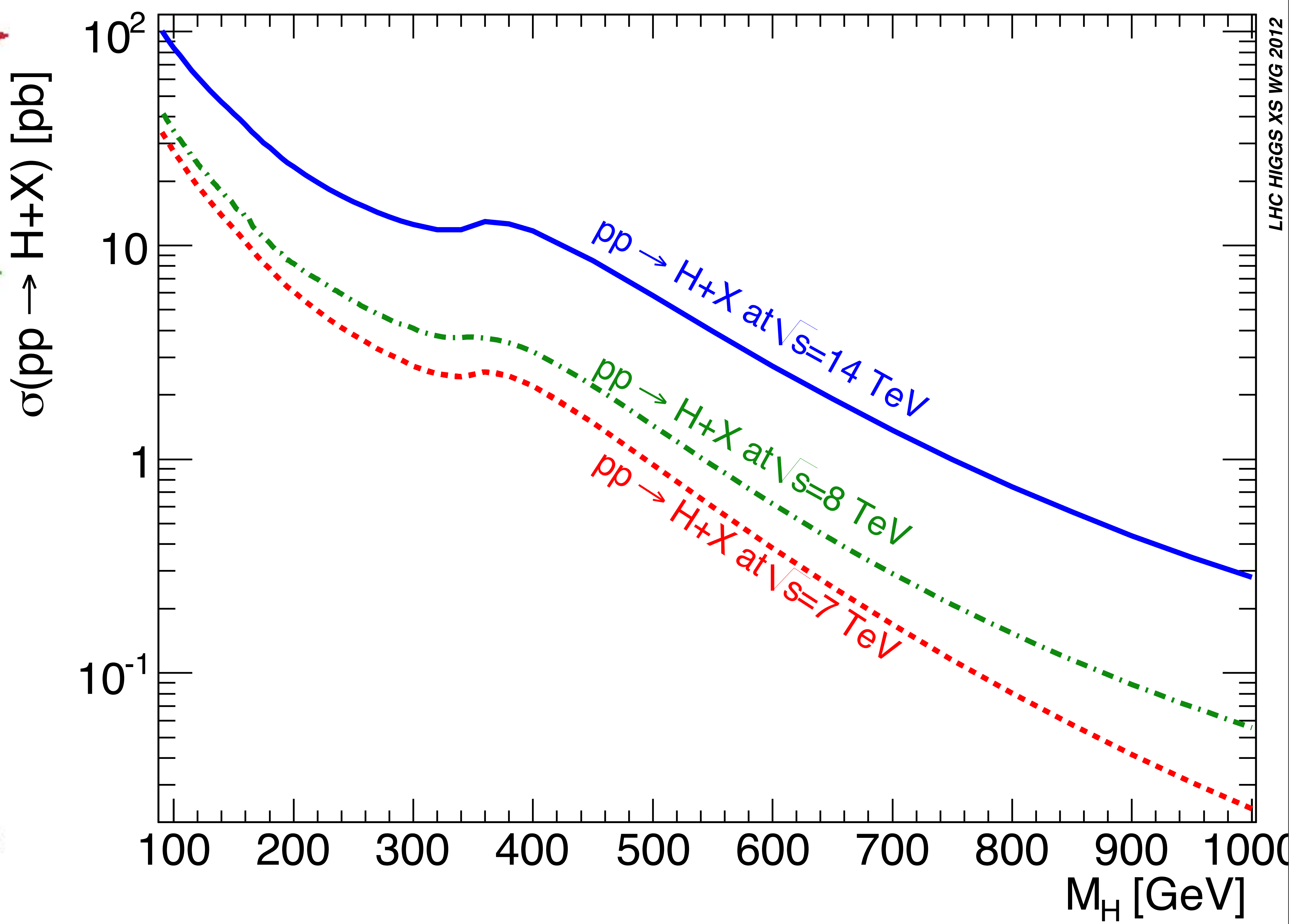
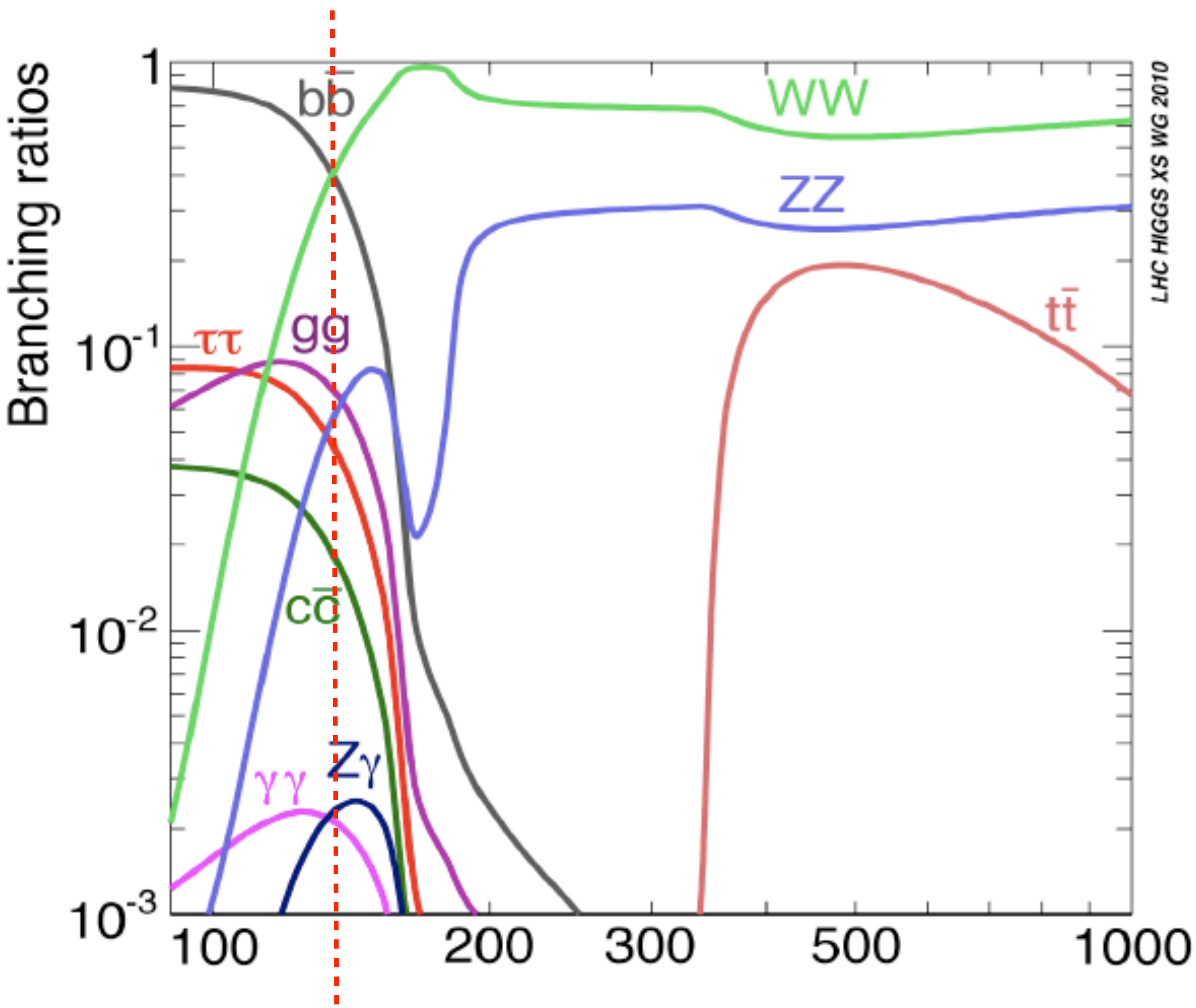
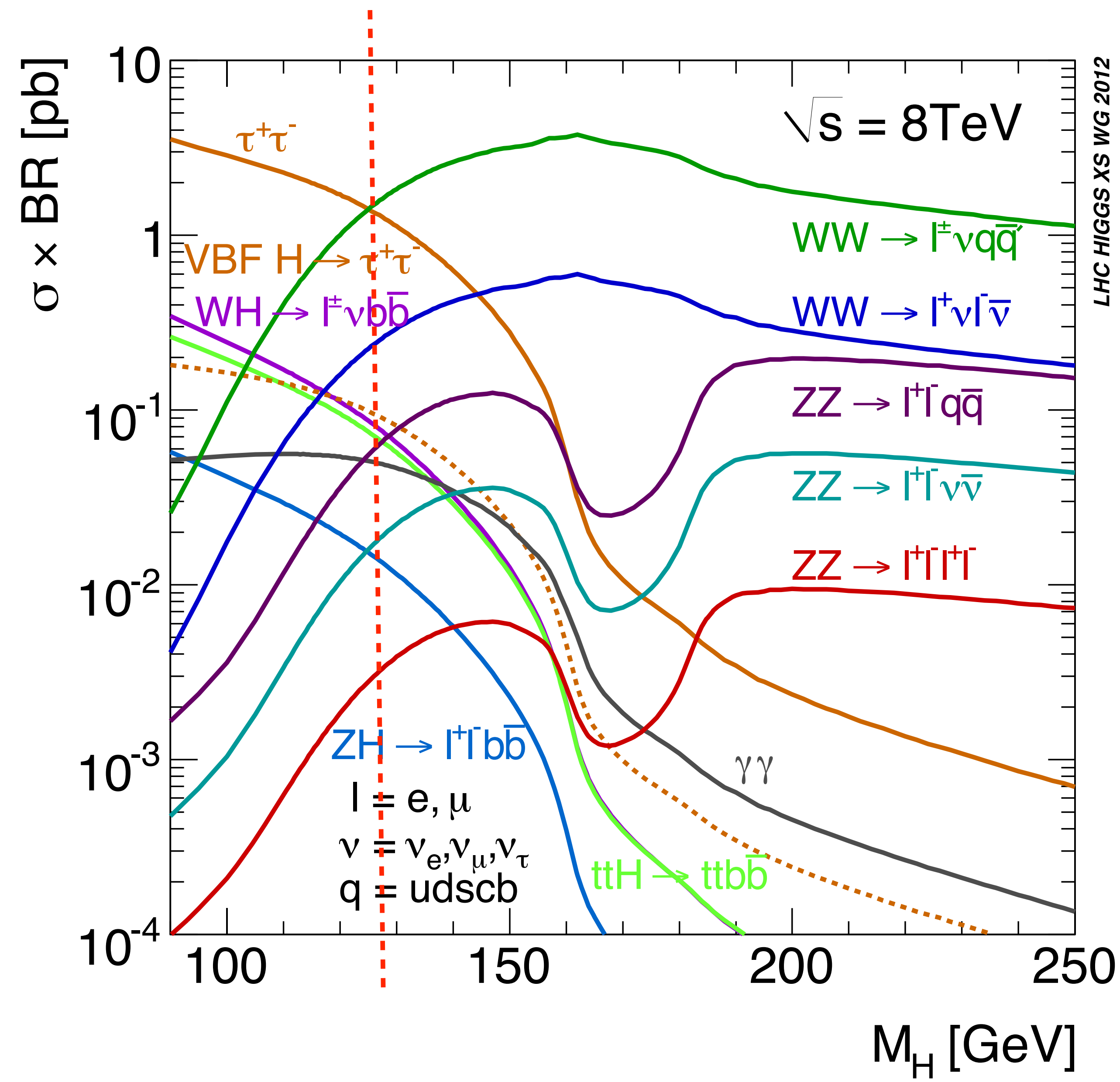




• We must take into account the H decays





Thursday, November 22, 12

- The Higgs interactions with gauge bosons are modified by

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

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

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

with

$$D_\mu\Phi = \left(\partial_\mu + i\tfrac{1}{2}g'B_\mu + ig\tfrac{\sigma_a}{2}W^a_\mu\right)\Phi$$

$$\hat{B}_{\mu\nu} = i\tfrac{g'}{2}B_{\mu\nu}$$

$$\hat{W}_{\mu\nu} = i\tfrac{g}{2}\sigma^a W^a_{\mu\nu}$$

$$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$$

$$W^a_{\mu\nu} = \partial_\mu W^a_\nu - \partial_\nu W^a_\mu - g\epsilon_{abc}W^b_\mu W^c_\nu$$

$$G^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu - g_s f_{abc}G^b_\mu G^c_\nu$$

In the unitary gauge

$$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$

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

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

Is this the SM scalar boson?

- Yang's theorem rules out spin one states $V \cancel{\to} \gamma\gamma$
- The state can have spin 0 or 2
- What is the CP assignment of this state?
- We need to measure its couplings to the SM