Robust Determination of the Higgs Couplings: Power to the Data

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arXiv:1207.1344, 1211.4580, 1304.1151

http://hep.if.usp.br/Higgs

Overview

Discovery of a $\simeq$125 GeV "Higgs-like" particle $\rightarrow$EWSB direct exploration:

- Spin
- Parity
- EWSB connected new states
- Couplings

Bottom-up model-independent effective Lagrangian approach:

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

- $\mathcal{L}_{\text{eff}}$: describe the low energy effects of new physics in the couplings of this observed new state in the coefficients of dimension-6 operators.
- Assume observed state is light electroweak doublet scalar and that $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ is linearly realized in the effective theory.
- Choice of operators and basis $\rightarrow$ **Driven by the data**
- Complementarity of experimental searches $\rightarrow$ TGV $\leftrightarrow$ Higgs

Determine coefficients of operators using all available data: Tevatron, LHC, TGV, EWPD.

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Effective Lagrangian

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

Our assumptions are:

- The observed state belongs to a SU(2) doublet.
- The state is CP-even as in SM.
- Narrow resonance and no overlapping resonances.
- $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ SM local symmetry, C and P even, lepton and baryon number conservation

59 dimension-6 operators are enough...[1]

Set reduced by considering only C and P even and EOM to eliminate/choose the basis

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

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

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Effective Lagrangian for Higgs Interactions

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

$$\left(+\frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB}\right)$$

Unitary gauge:

$$\begin{aligned}\mathcal{L}_{\rm eff}^{\rm HVV} &= g_{Hgg}\, HG^a_{\mu\nu}G^{a\mu\nu} + g_{H\gamma\gamma}\, HA_{\mu\nu}A^{\mu\nu} + g^{(1)}_{HZ\gamma}\, A_{\mu\nu}Z^\mu\partial^\nu H + g^{(2)}_{HZ\gamma}\, HA_{\mu\nu}Z^{\mu\nu} \\ &+ g^{(1)}_{HZZ}\, Z_{\mu\nu}Z^\mu\partial^\nu H + g^{(2)}_{HZZ}\, HZ_{\mu\nu}Z^{\mu\nu} + g^{(1)}_{HWW}\left(W^+_{\mu\nu}W^{-\,\mu}\partial^\nu H + \text{h.c.}\right) \\ &+ g^{(2)}_{HWW}\, HW^+_{\mu\nu}W^{-\,\mu\nu}\end{aligned}$$

$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar{f}'_L f'_R H + \text{h.c.}$$

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$$g^{(1)}_{HZZ} = \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W + s^2 f_B}{2c^2} \quad , g^{(2)}_{HZZ} = -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB} + c^4 f_{WW}}{2c^2} \ ,$$

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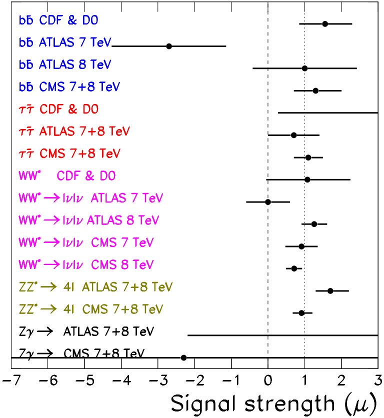
The statistical analysis

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



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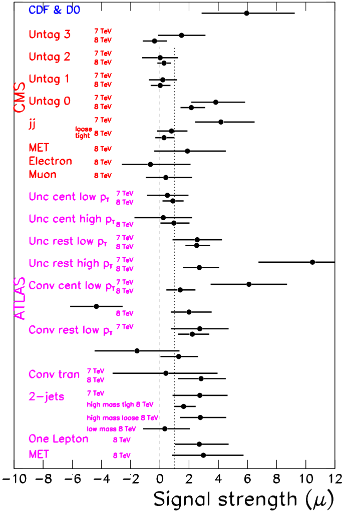


Adding TGV and EWPD

Data on triple electroweak gauge boson vertices:

$$\mathcal{L}_{WWV} = -ig_{WWV}\left\{g_1^V\left(W^+_{\mu\nu}W^{-\,\mu}V^\nu - W^+_\mu V_\nu W^{-\,\mu\nu}\right) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W^+_{\mu\nu} W^{-\,\nu\rho} {V_\rho}^\mu\right\}$$

with

$$\begin{aligned}
\Delta g_1^Z &= g_1^Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2} f_W \ , \\
\Delta\kappa_\gamma &= \kappa_\gamma - 1 = \frac{g^2 v^2}{8\Lambda^2}\left(f_W + f_B\right) \ , \\
\Delta\kappa_Z &= \kappa_Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2}\left(c^2 f_W - s^2 f_B\right) \ .
\end{aligned}$$

LEP data:

$$\begin{aligned}
g_1^Z &= 0.984^{+0.049}_{-0.049} \\
\kappa_\gamma &= 1.004^{+0.024}_{-0.025}
\end{aligned}$$

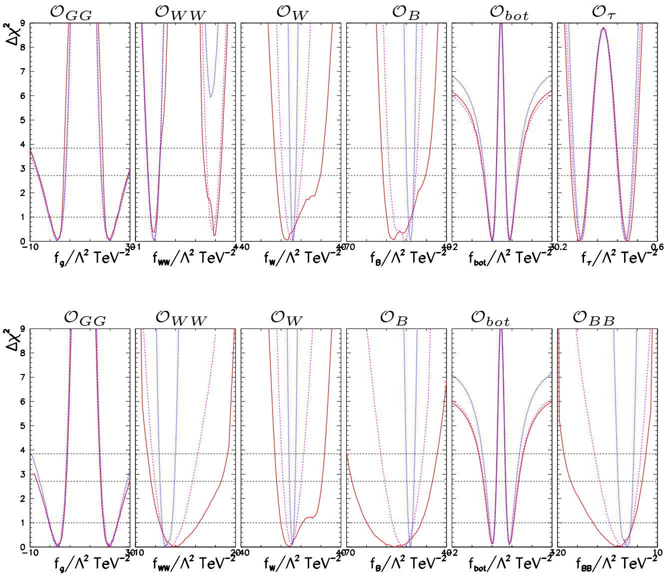
with a correlation factor $\rho = 0.11$.

Data on EWPD in terms of the S,T,U parameters:

$$\Delta S = 0.00 \pm 0.10 \qquad \Delta T = 0.02 \pm 0.11 \qquad \Delta U = 0.03 \pm 0.09$$

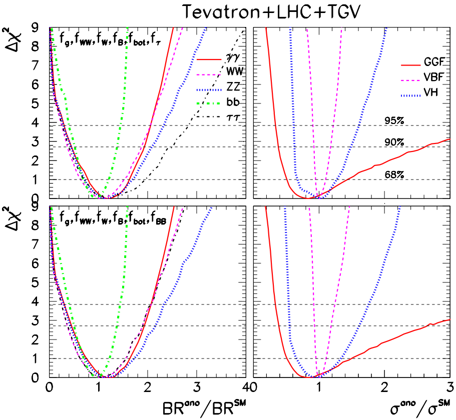
$$\rho = \begin{pmatrix} 1 & 0.89 & -0.55 \\ 0.89 & 1 & -0.8 \\ -0.55 & -0.8 & 1 \end{pmatrix}$$

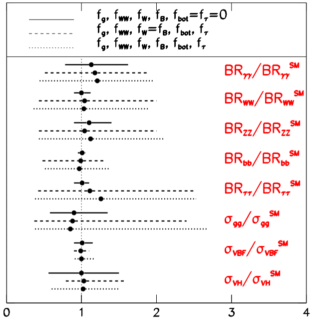
$\Delta\chi^2$ vrs f_X



BRs and production CS

arXiv:1207.1344, 1211.4580
http://hep.if.usp.br/Higgs

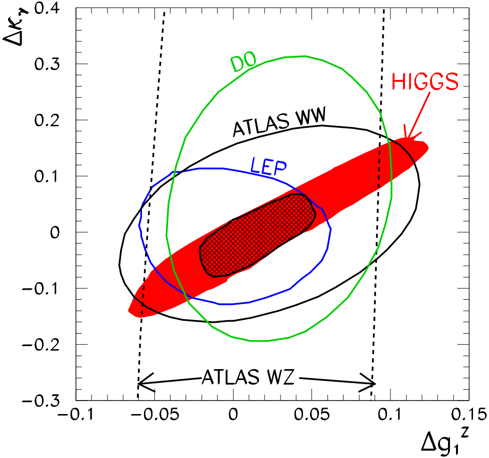




Determining TGV from Higgs data

arxiv:1304.1151

- Gauge Invariance → TGV and Higgs couplings related: $\mathcal{O}_W$ and $\mathcal{O}_B$
- **Complementarity in experimental searches:** Higgs data bounds on $f_W \otimes f_B \equiv \Delta\kappa_\gamma \otimes \Delta g_1^Z$



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Discussion and Conclusions

THANK YOU!

- **Model independent** analysis where the effects of new physics in the Higgs couplings are parametrized in $\mathcal{L}_{eff}$. $SU(2)_L$ doublet $\rightarrow SU(2)_L \times U(1)_Y$ gauge symmetry linearly realized:

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

  So far observations consistent with Higgs boson.

- Choice of basis:
  Power to the data $\rightarrow$ operators whose coefficients are more easily related to existing data.

- Exploit interesting **complementarity between experimental searches**: TGV and Higgs data

arXiv:1207.1344, 1211.4580, 1304.1151
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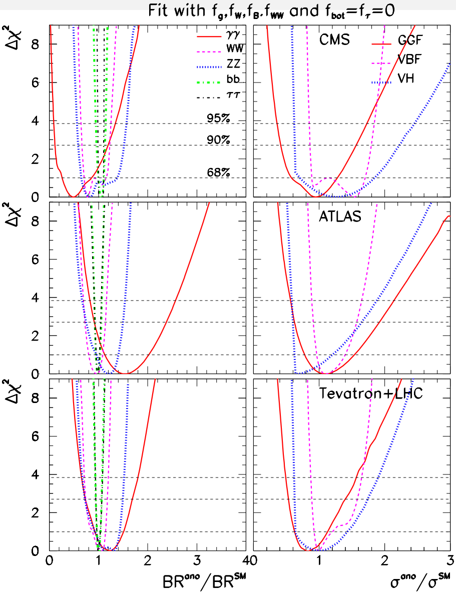
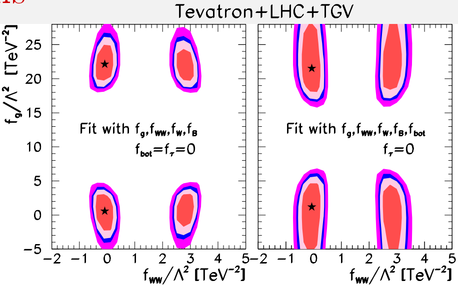
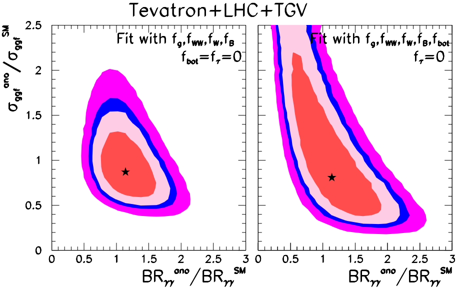
CMS vrs ATLAS

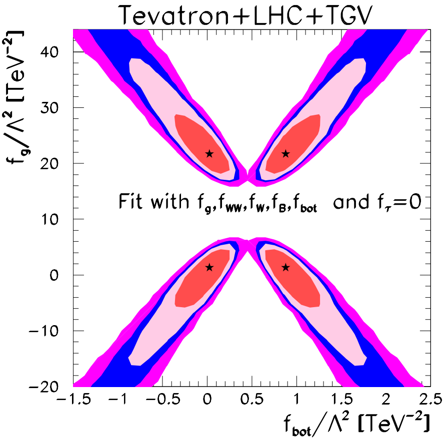


2d correlations





2d correlations



Best fit and ranges

	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})	0.64, 22.1	$[-1.8, 2.7] \cup [20, 25]$	0.71, 22.0	$[-6.2, 4.4] \cup [18, 29]$
f_{WW}/Λ^2 (TeV^{-2})	-0.083	$[-0.35, 0.15] \cup [2.6, 3.05]$	-0.095	$[-0.39, 0.19]$
f_W/Λ^2 (TeV^{-2})	0.35	$[-6.2, 8.4]$	-0.46	$[-7.1, 6.5]$
f_B/Λ^2 (TeV^{-2})	-5.9	$[-22, 6.7]$	-0.46	$[-7.1, 6.5]$
f_{bot}/Λ^2 (TeV^{-2})	—-	—-	0.01, 0.89	$[-0.34, 0.23] \cup [0.67, 1.2]$
f_τ/Λ^2 (TeV^{-2})	—-	—-	-0.01, 0.34	$[-0.07, 0.05] \cup [0.28, 0.40]$
$BR^{ano}_{\gamma\gamma}/BR^{SM}_{\gamma\gamma}$	1.13	$[0.78, 1.62]$	1.18	$[0.51, 1.9]$
$BR^{ano}_{WW}/BR^{SM}_{WW}$	1.00	$[0.9, 1.12]$	1.04	$[0.43, 2.0]$
$BR^{ano}_{ZZ}/BR^{SM}_{ZZ}$	1.10	$[0.9, 1.4]$	1.04	$[0.43, 2.0]$
$BR^{ano}_{bb}/BR^{SM}_{bb}$	1.01	$[0.95, 1.05]$	0.99	$[0.48, 1.3]$
$BR^{ano}_{\tau\tau}/BR^{SM}_{\tau\tau}$	1.01	$[0.9, 1.1]$	1.11	$[0.42, 2.6]$
$\sigma^{ano}_{gg}/\sigma^{SM}_{gg}$	0.90	$[0.58, 1.35]$	0.88	$[0.37, 2.4]$
$\sigma^{ano}_{VBF}/\sigma^{SM}_{VBF}$	1.01	$[0.9, 1.15]$	0.99	$[0.9, 1.1]$
$\sigma^{ano}_{VH}/\sigma^{SM}_{VH}$	1.0	$[0.56, 1.5]$	1.03	$[0.79, 1.6]$

Best fit values and 90% CL allowed ranges for the combination of all available Tevatron and LHC Higgs data as well as TGV.