Robust Determination of the Higgs Couplings: Power to the Data

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arXiv:1211.4580
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Outline

Motivation

The Higgs boson [1] has been (one of) the only missing piece of the SM for long → **A particle directly related to the EWSB.**

The EWSB is one of the sectors with less experimental information, but a lot of interesting theoretical open questions arise from it → motivations for NP modifying the sector

Studying the couplings of the Higgs could be one of the fastest tracks to NP

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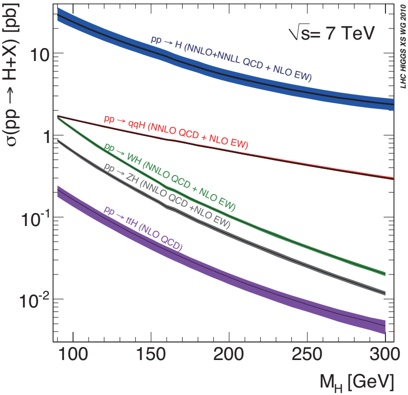
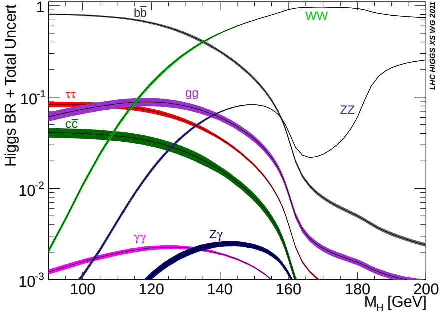
The experimental research

After LEP and Tevatron, now it was the time for the LHC.

At the LHC the SM Higgs boson has to be searched through the following production mechanisms and decay modes:





The experimental research

SM main discovery modes for ≃125 GeV:

$pp \to \gamma\gamma$

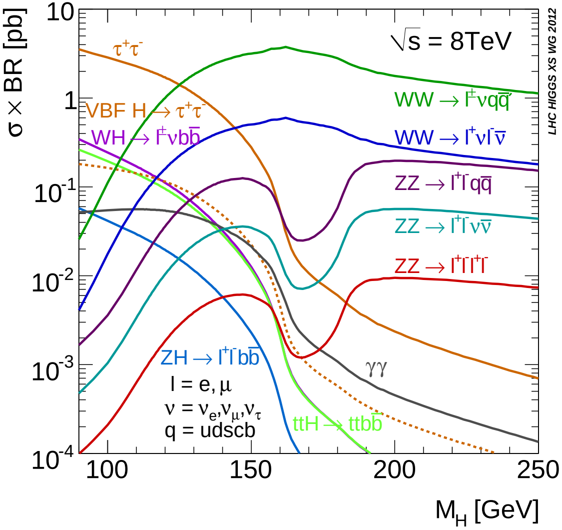
$pp \to ZZ \to \ell\ell\ell\ell$

$pp \to WW \to \ell\nu\ell\nu$

Also may be possible in:

$pp \to b\bar{b}$ (only VH)

$pp \to \tau\bar{\tau}$



¡Eureka!


The INDEPENDENT
HOMOPHOBIA, HIP-HOP AND THE STAR WHO CAME OUT
THE L'OREAL FILES: COULD SARKOZY GO DOWN?
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The New York Times
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Rapid H.I.V. Home Test Wins Federal Approval
EL PAÍS
EL PERIÓDICO GLOBAL EN ESPAÑOL
Hallada la partícula clave para la comprensión del universo
La Audiencia Nacional imputa a toda la cúpula de Bankia
LA VANGUARDIA
La 'partícula de Dios' abre nuevas puertas a la física
El juez imputa a Rato y 32 consejeros de Bank
Descubierta la partícula que abre una era

CMS Status

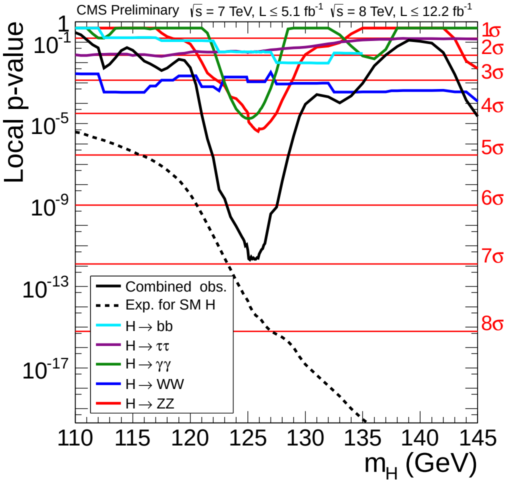
(Last update mid-November 2012)*[2]

6.9σ for 125.8 GeV (Nov 12)

$\gamma\gamma$: "Driving" the excess, but not updated since July... (still 5.3 fb^{-1} for 8 TeV).

Total 8 TeV run collected:

$$\mathcal{L} = 21.79\ fb^{-1}$$



[2] In December first $Z\gamma$ results presented: with 5.0 fb^{-1} for 7 TeV and 5.2 fb^{-1} for 8 TeV sensitivity is about O(10) x SM

ATLAS Status

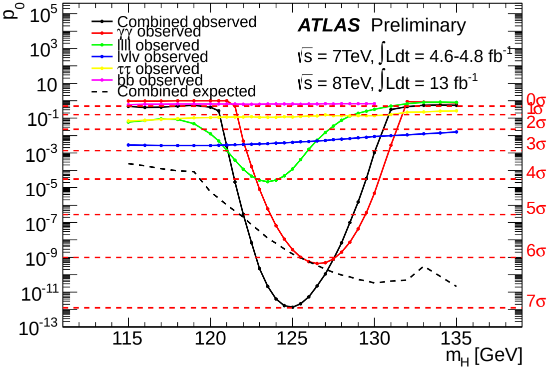
(Last update mid-December 2012)[3]

$\sim\boldsymbol{7}\sigma$ for 125 GeV (Dec 12)[3]

All analyses with
$\sim$5 fb^{-1} for 7 TeV and
$\sim$13 fb^{-1} for 8 TeV

Total 8 TeV run collected

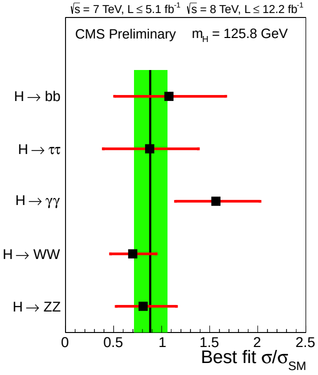
$\mathcal{L}$ =21.7 fb^{-1}

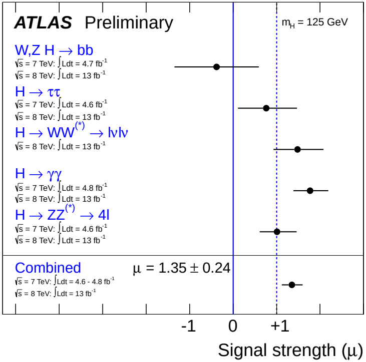


[3] ZZ and $\gamma\gamma$ mass measurement discrepance unexplained

Signal strenghts

Are the starting points of many analysis: $\mu = \frac{\sigma_{obs}}{\sigma_{SM}}$





2012 summary / 2013 perspectives

Finally, 2012 has been the year of the well stablished discovery of the Higgs(-like) particle

We will have a more clear picture of the properties during 2013:

- $\sim 10\ \text{fb}^{-1}$ 8 TeV data to analyze in almost all of the channels, in some of them even more...
- Will CMS $\gamma\gamma$ new analysis dilute the excess?
- ATLAS ZZ and $\gamma\gamma$ mass discrepance still needs explanation.
- New parity, spin, $Z\gamma$ etc analyses expected.

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Overview

Discovery of a ≃125 GeV "Higgs-like" particle →EWSB direct exploration:

- Spin
- Parity
- EWSB connected new states
- Couplings

Bottom-up model-independent effective Lagrangian approach:

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

- 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.
- $\mathcal{L}_{\rm eff}$: describe the low energy effects of new physics in the couplings of this observed new state in the coefficients of dimension-6 operators.
- Choice of operators and basis → **Driven by the data**

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

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Effective Lagrangian

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

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...[4]

But we can use EOM to eliminate 3 of them:

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

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

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

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The right of choice

Higgs interactions with gauge bosons[5]:

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Effective Lagrangian for Higgs Interactions

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

Unitary gauge:

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

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

$$g_{Hgg} = -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} \quad , g_{H\gamma\gamma} = -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}}{2} \; ,$$

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

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

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$$g^f_{Hij} = -\frac{m_i^f}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} f'_{f\Phi,ij}$$

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&+ 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}$$

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Collider data: building the χ^2

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

Where

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

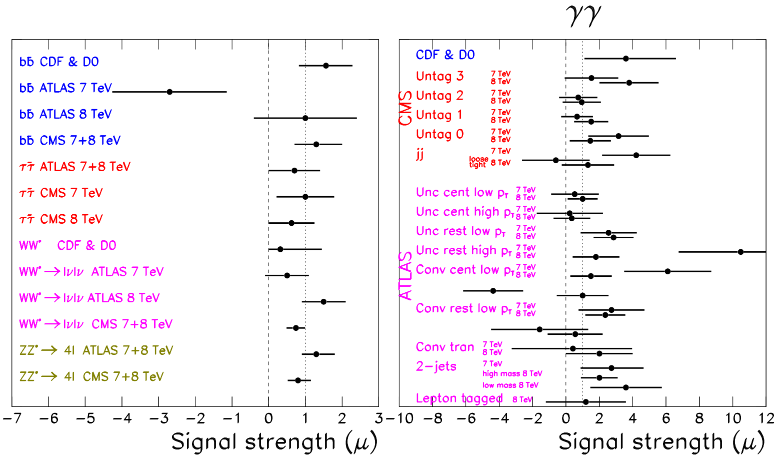
For the anomalous calculations:

$$\sigma_Y^{ano} = \left. \frac{\sigma_Y^{ano}}{\sigma_Y^{SM}} \right|_{tree} \left. \sigma_Y^{SM} \right|_{soa}$$

and

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

Collider data: the data points



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

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

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:

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

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

S,T,U Parameters

$$
\begin{aligned}
\alpha\Delta S &= \frac{1}{6}\frac{e^2}{16\pi^2}\left\{3(f_W+f_B)\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)+\right.\\
&+2\left[(5c^2-2)f_W-(5c^2-3)f_B\right]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\\
&-\left[(22c^2-1)f_W-(30c^2+1)f_B\right]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\\
&\left.-24c^2 f_{WW}\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\right\},\\
\alpha\Delta T &= \frac{3}{4c^2}\frac{e^2}{16\pi^2}\left\{f_B\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\right.\\
&+(c^2 f_W+f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\\
&\left.+\left[2c^2 f_W+(3c^2-1)f_B\right]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\right\},\\
\alpha\Delta U &= -\frac{1}{3}\frac{e^2 s^2}{16\pi^2}\left\{(-4f_W+5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\right.\\
&\left.+(2f_W-5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\right\}
\end{aligned}
$$

$\Delta\chi^2$ vrs f_X

Columns (analysis):

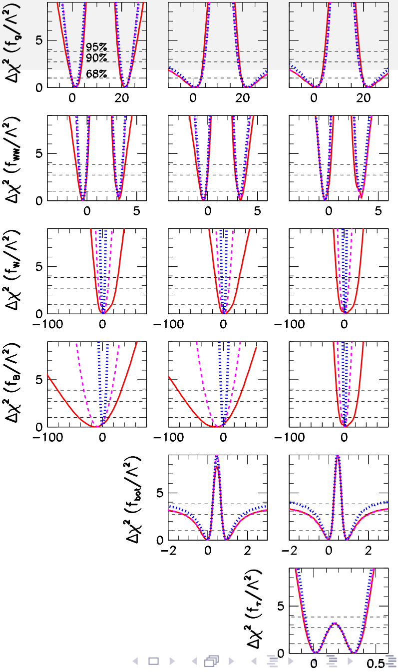
1st: f_g, f_{WW}, f_W, f_B
2nd: f_g, f_{WW}, f_W, f_B, $f_{\rm bot}$
3rd: f_g, f_{WW}, f_W, f_B, $f_{\rm bot}$, f_τ

Rows (parameters):

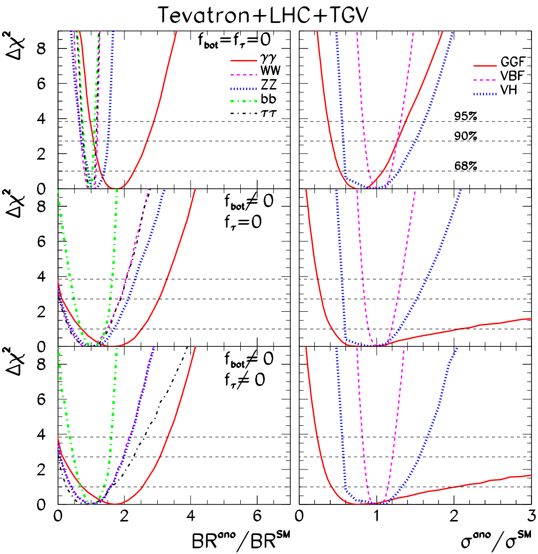
1st: f_g
2nd: f_{WW}
3rd: f_W
4th: f_B
5th: $f_{\rm bot}$

Colours/lines (data):

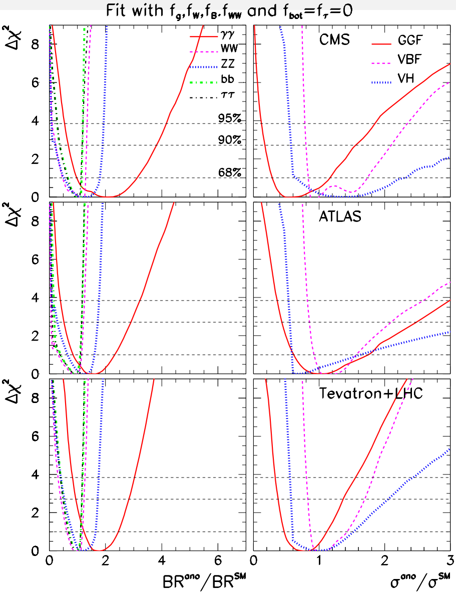
Solid red: Collider
Dash pink: Collider + TGV
Dot blue: Collider + TGV + EWPD



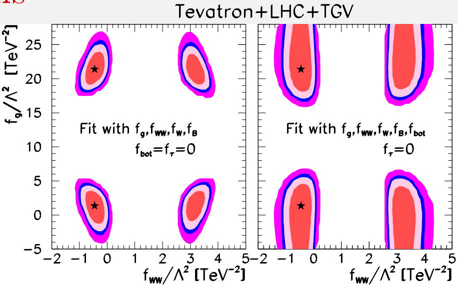
BRs and production CS

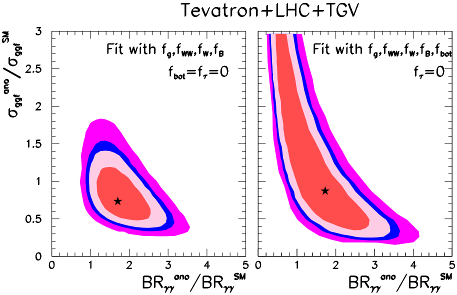


CMS vrs ATLAS

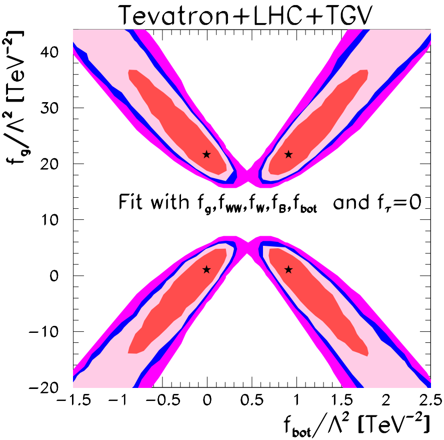


2d correlations





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})	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	$[-0.8, -0.1] \cup [2.85, 3.55]$	-0.39	$[-0.8, 0] \cup [2.85, 3.65]$
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	$[0.57, 1.49]$

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

Discussion and Conclusions

- **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:

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

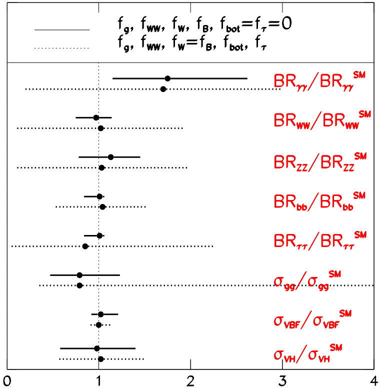
- Choice of basis:
  Power to the data $\rightarrow$ operators whose coefficients are more easily related to existing data

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

Discussion and Conclusions

THANK YOU!

- Present status of the analysis using Tevatron, LHC, TGV and EWPD data:



SM compatible with data (60%-90% CL).
Preference for larger–than–SM BR to photons and a smaller–than–SM gluon fusion production CS and decay BR into $\tau's$

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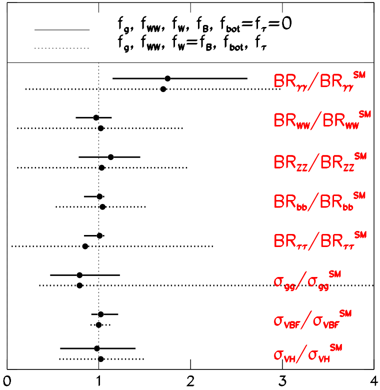

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