# BSM with explicitly broken custodial symmetry

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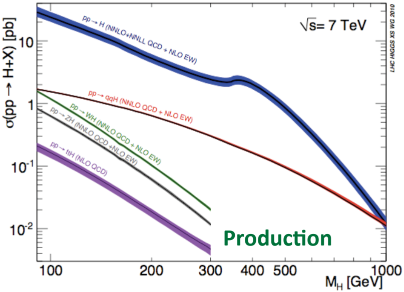
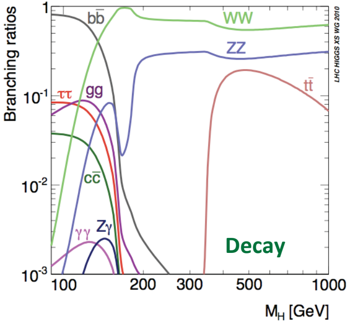
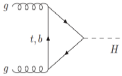
Based on arXiv:1205.0011 [hep-ph] with C. Grojean, E. Salvioni

# Higgs@LHC

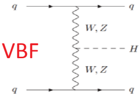


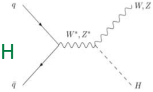

ggH



VBF



VH



Cross sections and BR
from the LHC cross section working group:

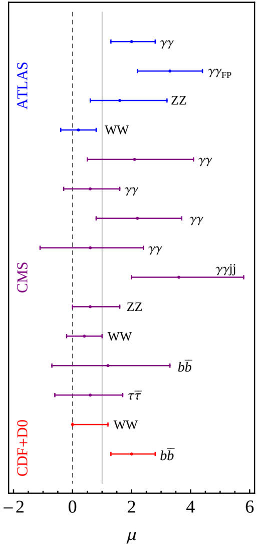
# Experimental Results

Experimental Results in terms of:

$$\mu = \frac{(\sigma_{prod} \times BR)^{obs}}{(\sigma_{prod} \times BR)^{SM}}$$

Higgs hints @ $125\ GeV$
Trends:

- $WW$ vs $ZZ$
- enhanced $\gamma\gamma$ channels
- enhanced VBF



# Lagrangian

Useful recipe for model independent parametrization:

- Take the chiral lagrangian

$$\mathcal{L} = \frac{v^2}{4}\text{Tr}\left[(D_\mu\Sigma)^\dagger\,(D^\mu\Sigma)\right] - \frac{v}{\sqrt{2}}\sum_{i,j}\left(\bar{u}_L^{(i)}d_L^{(i)}\right)\Sigma\begin{pmatrix}\lambda_{ij}^u\,u_R^{(j)}\\ \lambda_{ij}^d\,d_R^{(j)}\end{pmatrix} + \text{h.c.}$$

- Add a scalar resonance $h$

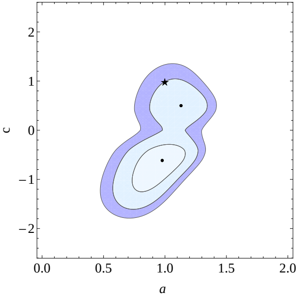
$$\mathcal{L}_h = \frac{1}{2}\left(\partial_\mu h\right)^2 - V(h) + \frac{v^2}{4}\text{Tr}\left[(D_\mu\Sigma)^\dagger\,(D^\mu\Sigma)\right]\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \ldots\right)$$

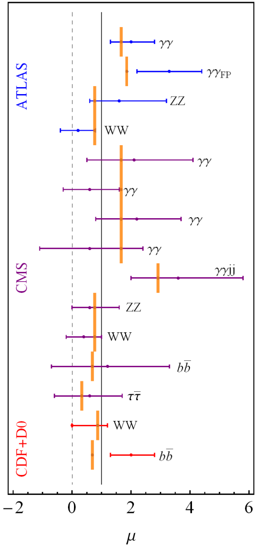
$$-\frac{v}{\sqrt{2}}\sum_{i,j}\left(\bar{u}_L^i d_L^i\right)\Sigma\left(1 + c\,\frac{h}{v} + c_2\,\frac{h^2}{v^2} + \cdots\right)\begin{pmatrix}\lambda_{ij}^u\,u_R^j\\ \lambda_{ij}^d\,d_R^j\end{pmatrix} + \text{h.c.}$$

(SM retrieved by $a = b = c = 1$ , $c_2 = 0$ and vanishing terms of higher order in $h$)

# Fit results

- $\chi^2 = 9.7$ for 13 d.o.f
- Best fit for $c < 0$
  $(\Gamma_{\gamma\gamma} \propto |aA_W - cA_t|^2)$




Further reading:
1202.3144,1202.3415,1202.3697,1203.4254...

# Custodial breaking term

- In principle the chiral Lagrangian could contain an additional term

$$v^2 \left( \text{Tr} \left[ \Sigma^\dagger D_\mu \Sigma \, \sigma^3 \right] \right)^2$$

- Gauge invariant but explicitly breaking custodial symmetry $\Rightarrow$ large deviations from $\rho = 1$.
  Its coefficient has to be very small $O(10^{-3})$

# Custodial breaking term

- Introduce custodial breaking coupling by

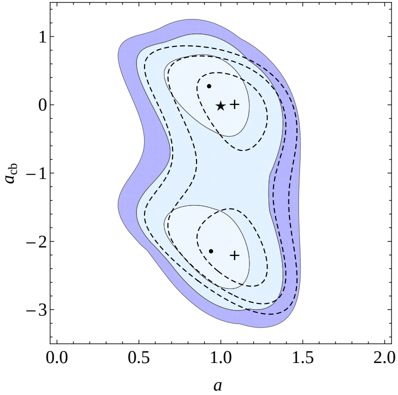
$$\mathcal{L}_{cb} = -\frac{v^2}{8} \left(\text{Tr}\left[\Sigma^\dagger D_\mu \Sigma\, \sigma^3\right]\right)^2 \left(0 + 2a_{cb}\frac{h}{v} + \cdots\right),$$

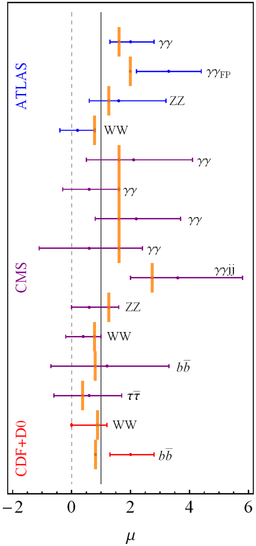
- Quadratic divergences require new light degrees of freedom
- In the unitary gauge

$$\mathcal{L}_{hVV} = \left[a\, m_W^2 W_\mu^+ W_\mu^- + \frac{1}{2}(a + a_{cb})\, m_Z^2 Z_\mu Z_\mu\right]\left(2\frac{h}{v}\right)$$

# Custodial breaking fit results

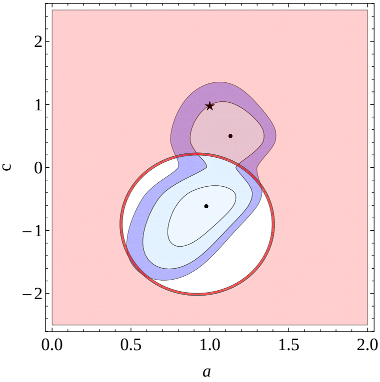
- $\chi^2 = 9.2$ for 13 d.o.f
- Two degenerate best fit points $a_{cb} \gtrless 0$



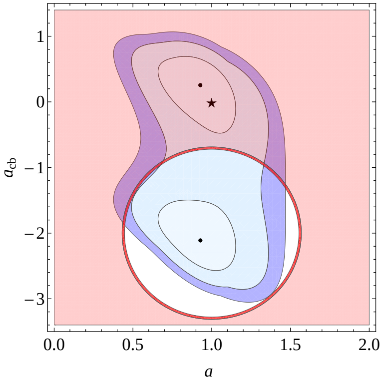



# Higgs Diseases

DysFermiophilia




DysZphilia

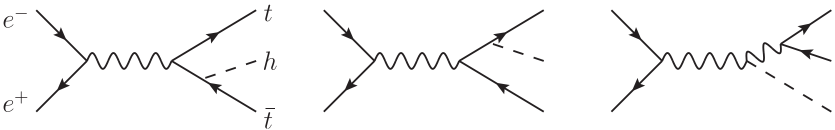


# Testing the sign

We are interested in a sign flip $a + a_{cb} \gtrless 0$ (or $c \gtrless 0$).
We need:

- Interference between diagrams with and without the $hZZ$ vertex
- Separation of the $\gtrless 0$ cases bigger than both experimental and theoretical uncertainties
- Linear colliders are perfect for precision measurements ($g_{hZZ}$ and $g_{hWW}$ measured at $1\%$)
- We assume $|\delta a|,\ |\delta(a + a_{cb})| \sim 1\%$

# $e^+e^- \to t\bar{t}h$ (I)

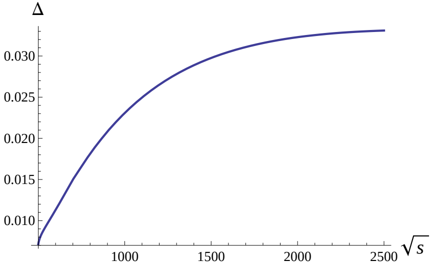



Total cross section for the two cases $a + a_{cb} = \pm 1$

$$\sigma_\pm = \left(\sigma_t + \sigma_Z \pm \sigma_{int}\right),$$

with $\sigma_{int}$ few percent.
Defining

$$\Delta = \left|\frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}\right|$$



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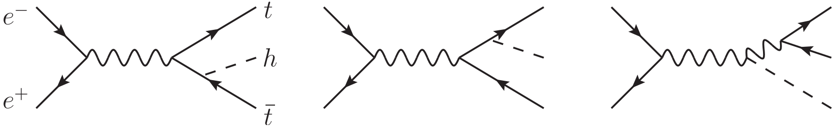


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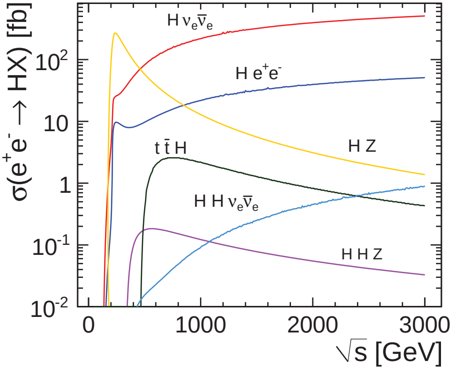

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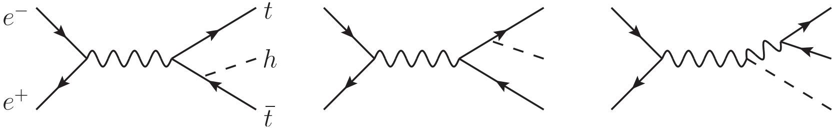


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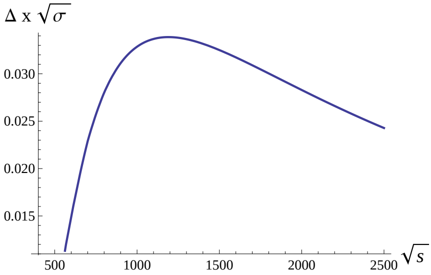
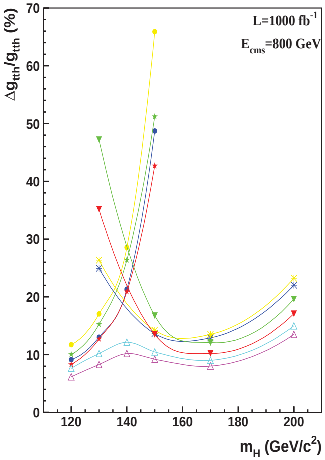


# $e^+e^- \to t\bar{t}h$ (II)

On the experimental side




- At ILC with $\sqrt{s} = 800$ GeV and with $1000\ \mathrm{fb}^{-1}$

$$g_{tth} \sim 6\%$$

- Translating in cross section

$$\Delta\sigma \sim 10 - 12\%$$

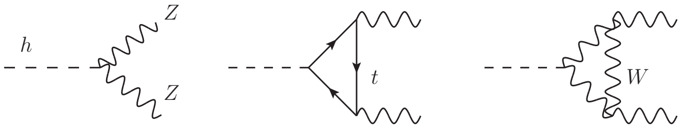
- Versus $\Delta \sim 3 - 4\%$

A.Gay [hep-ph/0604034]

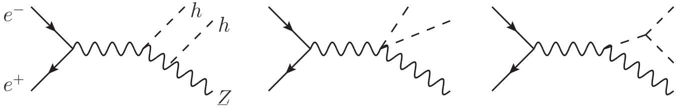
# Other tests

Other tests are possible and should help sheding light

- Higgs width in $ZZ \Rightarrow \Delta = \left|\frac{\Gamma_Z^+ - \Gamma_Z^-}{\Gamma_Z^+ + \Gamma_Z^-}\right| = \delta \approx 1\%$




- $e^+e^- \to Zhh \Rightarrow \Delta = \left|\frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}\right| \approx 50\%$



# Conclusions

- First hints of Higgs at LHC and Tevatron may point to non-standard couplings
- The Higgs could have contracted a disease like dysZphilia (or dysfermiophylia)
- Lepton colliders are crucial to test the symptoms