Higgs Couplings

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Universität Heidelberg

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Higgs physics 2013-20XX

Fundamental questions

1– What is the ‘Higgs’ Lagrangian?

Higgs physics 2013-20XX

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CP-even spin-0 scalar expected
spin-1 vector unlikely
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couplings assume operator basis
eventually renormalization [mass dimension]
'anomalous couplings' to dimension-6

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Elephant channel in the room

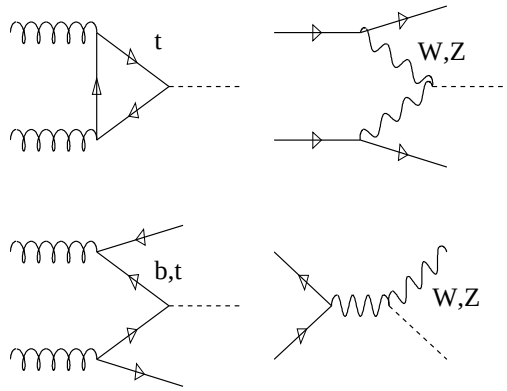
– inclusive searches = gluon fusion
– couplings discovered $g_{Hgg}, g_{H\gamma\gamma}, g_{HZZ}, g_{HWW}$
– eventually $H \to Z\gamma$ [ATLAS-CONF-2013-009, CMS-HIG-13-006]

Additional production channels

WBF production

- \+ second-largest rate [small QCD corrections]
- \+ tagging jets to trigger and get $S/B \sim 1$ [m_{jj} very useful]
- – sensitive to pile-up
- – tricky jet veto

$\Rightarrow$ accessible $H \to WW, \tau\tau, \mu\mu$, invisible



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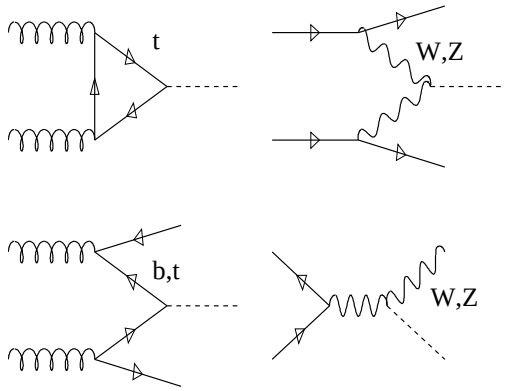

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WH/ZH production

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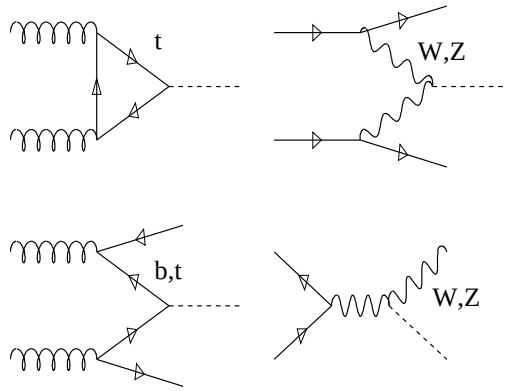

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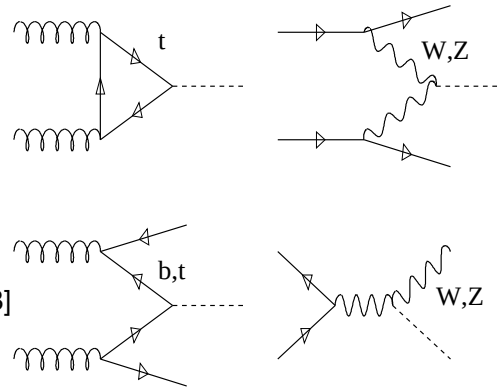
$t\bar{t}H$ production [$b\bar{b}H$ only in 2HDM]

- – low rate, complex final state
- – relevant decays $\gamma\gamma$, WW, $b\bar{b}$ at high luminosities [trying to change ordering]

$\Rightarrow$ accessible $gg \to t\bar{t}H$

SFitter



Coupling for SM operators [Dührssen et al; SFitter 2009-2013]

- higher orders only in QCD
- couplings from production & decay rates [observables: S,B]
- setup by Michael Dührssen

$\Rightarrow$ straightforward except for width and theory errors

$$\boxed{\begin{array}{l} gg \to H \\ qq \to qqH \\ gg \to t\bar{t}H \\ qq' \to VH \end{array}} \quad \longleftrightarrow \quad \boxed{g_x = g_x^{\text{SM}} \; (1 + \Delta_x)} \quad \longleftrightarrow \quad \boxed{\begin{array}{l} H \to ZZ \\ H \to WW \\ H \to b\bar{b} \\ H \to \tau^+\tau^- \\ H \to \gamma\gamma \end{array}}$$

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Systematic uncertainties

luminosity measurement	5 %
detector efficiency	2 %
lepton reconstruction efficiency	2 %
photon reconstruction efficiency	2 %
WBF tag-jets / jet-veto efficiency	5 %
b-tagging efficiency	3 %
τ-tagging efficiency (hadronic decay)	3 %
lepton isolation efficiency ($H \to 4\ell$)	3 %

	$\Delta B^{(\text{syst})}$
$H \to ZZ$	1%
$H \to WW$	5%
$H \to \gamma\gamma$	0.1%
$H \to \tau\tau$	5%
$H \to b\bar{b}$	10%

Error bars

Sources in profile likelihood

- statistical error: Poisson
  systematic error: Gaussian, if measured
  theory error: not Gaussian
- simple argument
  LHC rate 10% off: no problem
  LHC rate 30% off: no problem
  LHC rate 300% off: Standard Model wrong
- theory likelihood flat centrally and zero far away [correlations still an issue]
- profile likelihood construction: RFit [CKMFitter]

$$-2 \log \mathcal{L} = \chi^2 = \vec{\chi}_d^T \; C^{-1} \; \vec{\chi}_d$$

$$\chi_{d,i} = \begin{cases} 0 & |d_i - \bar{d}_i| < \sigma_i^{(\text{theo})} \\ \dfrac{|d_i - \bar{d}_i| - \sigma_i^{(\text{theo})}}{\sigma_i^{(\text{exp})}} & |d_i - \bar{d}_i| > \sigma_i^{(\text{theo})} \end{cases}$$

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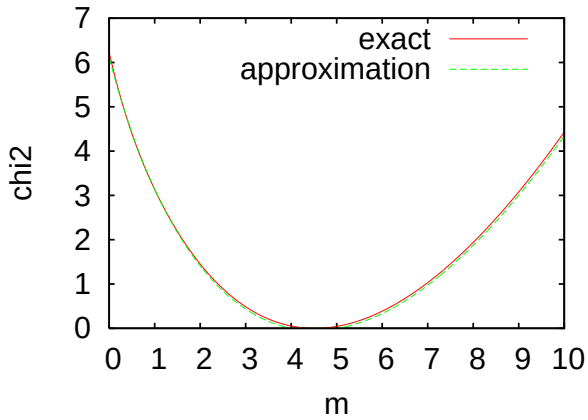
Efficient combination in SFitter

- Gaussian $\otimes$ Gaussian: half width added in quadrature
  Gaussian/Poisson $\otimes$ flat: RFit
  Gaussian $\otimes$ Poisson: ??
- approximate formula

$$\frac{1}{\log \mathcal{L}_{\text{comb}}} = \frac{1}{\log \mathcal{L}_{\text{Gauss}}} + \frac{1}{\log \mathcal{L}_{\text{Poisson}}}$$

- modified Minuit gradient fit last step
- error bars from toy measurements



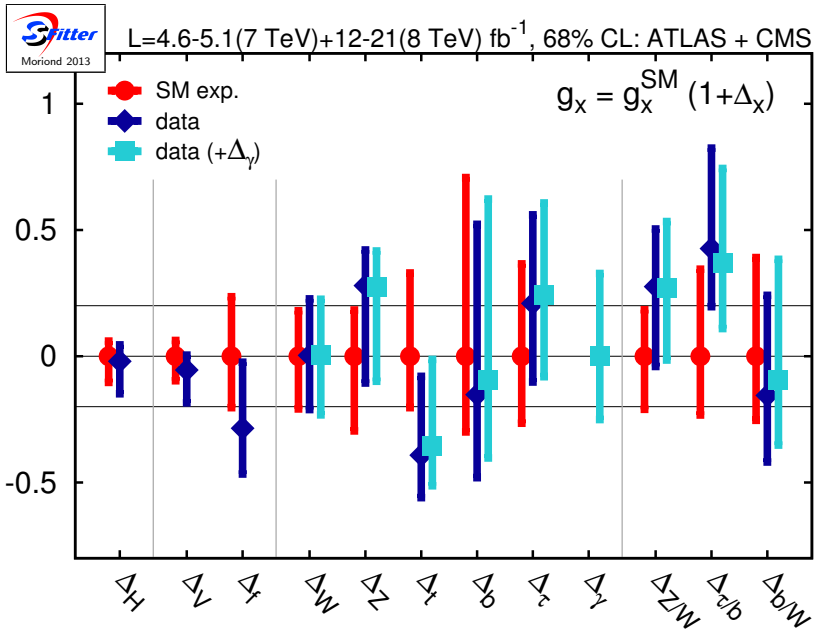
Higgs couplings

LHC including Moriond/Aspen data [SFitter: Klute, Lafaye, TP, Rauch, Zerwas]

- focus SM-like [secondary solutions possible]
- six couplings and ratios from data

  g_b from width
  g_g vs g_t not yet possible

  [similar: Ellis etal, Djouadi etal, Strumia etal, Grojean etal]
- poor man's analyses: $\Delta_H, \Delta_V, \Delta_f$
- Tevatron $H \to b\bar{b}$ with little impact



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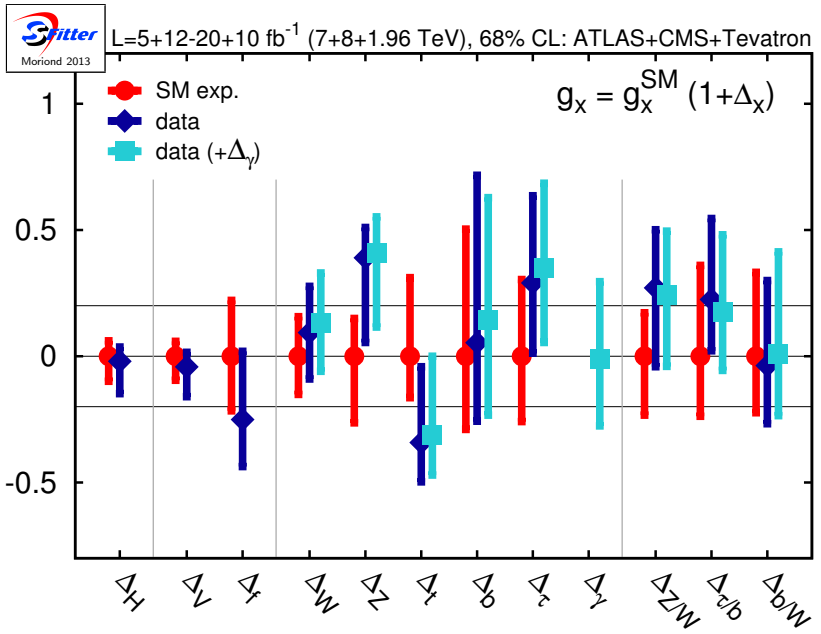

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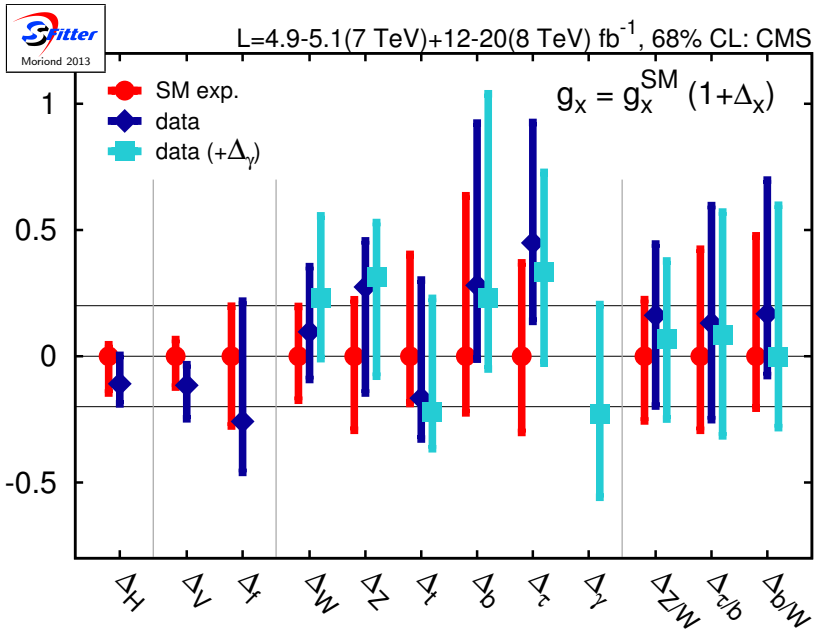

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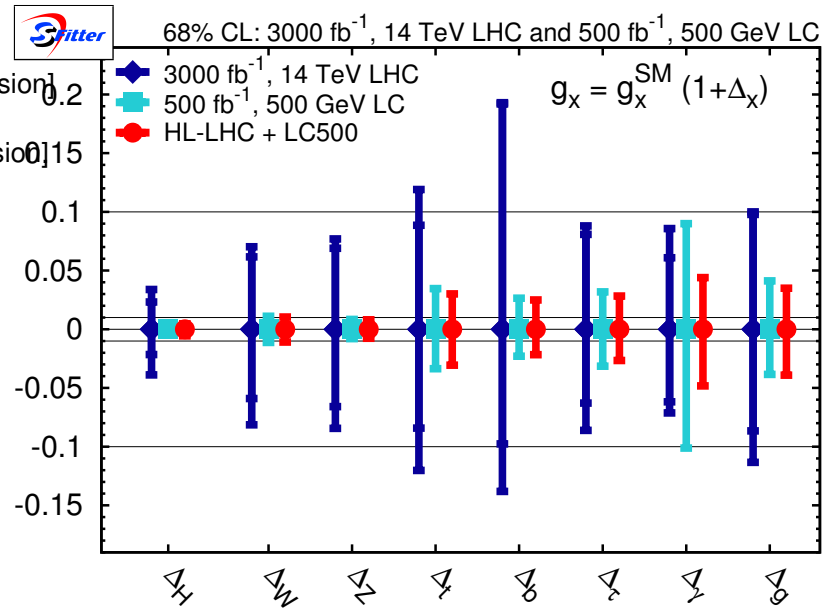
Future dinosaurs

- LHC extrapolations unclear [SFitter version]
- theory extrapolations tricky [SFitter version]
- ILC case obvious [500 GeV for now]
- interplay in loop-induced couplings
- $t\bar{t}H$ important at LHC and ILC



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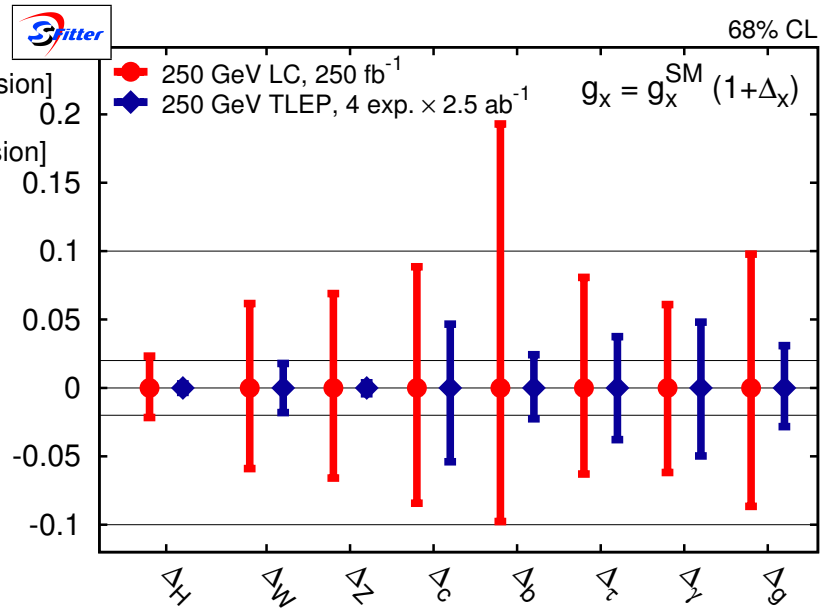

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- $t\bar{t}H$ important at LHC and ILC
- fundamental advantages in $e^+e^- \to ZH$:

  width measured independently
  $H \to c\bar{c}$ accessible
  invisible decays hugely improved
  unobserved decays avoided

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Moving towards the Standard Model?

- should we worried by SM $\pm 20\%$?
- what is expected in BSM models [Heidi's talk]

	ΔhVV	$\Delta h\bar{t}t$	$\Delta h\bar{b}b$
mixed-in singlet	6%	6%	6%
composite Higgs	8%	tens of %	tens of %
MSSM	$< 1\%$	3%	depends...

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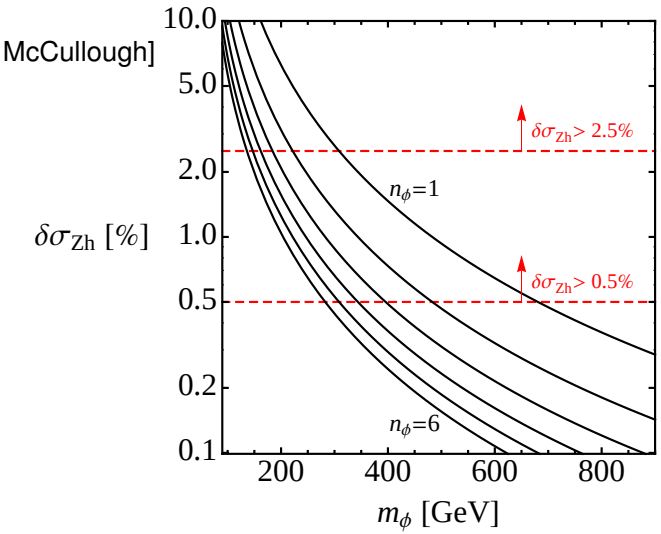
- m_ϕ and λ_j given by hierarchy problem
- contributing to σ_{ZH} through self energy



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$\Rightarrow$ trivial: want best possible precision

Anomalous couplings

Anomalous Higgs couplings [Hagiwara etal; Corbett, Eboli, Gonzales-Fraile, Gonzales-Garcia]

- assume Higgs is largely Standard Model
- additional higher-dimensional couplings

$$\begin{aligned}\mathcal{L}_{\text{eff}} = &- \frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}(\Phi^\dagger\Phi)G_{\mu\nu}G^{\mu\nu} + \frac{f_{WW}}{\Lambda^2}\Phi^\dagger W_{\mu\nu}W^{\mu\nu}\Phi \\ &+ \frac{f_W}{\Lambda^2}(D_\mu\Phi)^\dagger W^{\mu\nu}(D_\nu\Phi) + \frac{f_B}{\Lambda^2}(D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi) + \frac{f_{WWW}}{\Lambda^2}\text{Tr}(W_{\mu\nu}W^{\nu\rho}W^{\mu}_{\rho}) \\ &+ \frac{f_b}{\Lambda^2}(\Phi^\dagger\Phi)(\overline{Q}_3\Phi d_{R,3}) + \frac{f_\tau}{\Lambda^2}(\Phi^\dagger\Phi)(\overline{L}_3\Phi e_{R,3})\end{aligned}$$

- plus e-w precision data and triple gauge couplings

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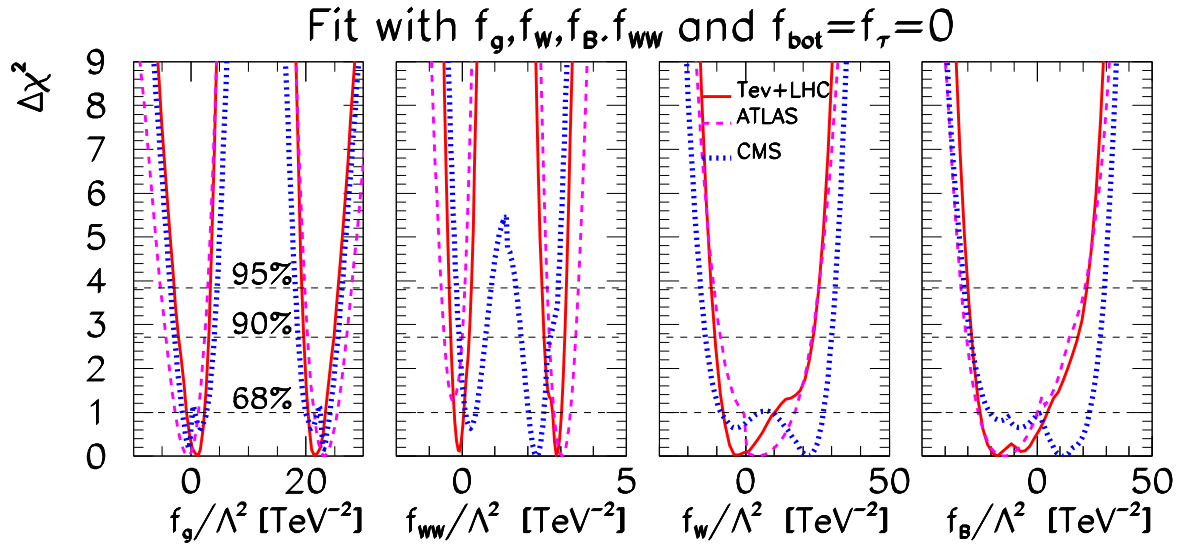

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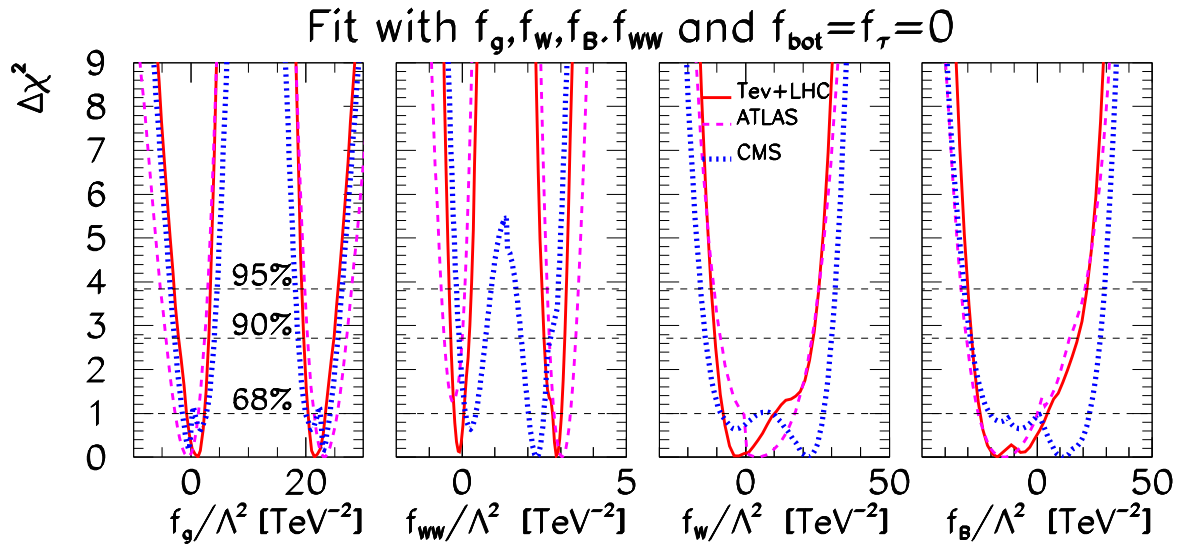

$\Rightarrow$ remember what your operators are!

Outlook

Higgs and the future

- discovery an amazing experimental success
- coupling measurements established

- new channels making the difference at LHC [where are the great papers by youngsters??]
- do not listen too much to theorists, couplings for now straightforward

- Higgs studies a case for linear collider
- precision, width, model independence the keys

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