The SFitter Project

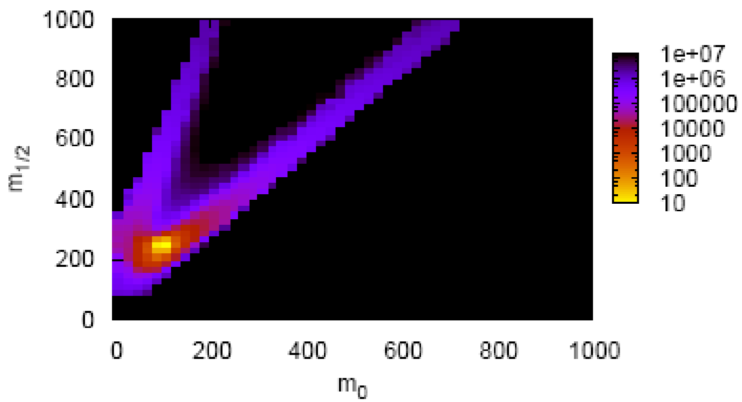
2nd JCL meeting
Saclay
November 27, 2013
Dirk Zerwas
LAL Orsay

- Introduction
- Determination of Higgs Couplings
- Conclusions

Introduction

SFitter origin: determine supersymmetric parameters
No one-to-one correlation of parameters to observables
correlations exp and theoretical errors
treatment of theory errors!
→ global ansatz necessary

Lafaye, Plehn, Rauch, Zerwas



SFitter, arXiv:hep-ph/0404282.
SFitter, Eur. Phys. J. C54, 617 (2008)
E. Turlay and SFitter, J.Phys. G38 (2011) 035003
C. Adam, J.-L Kneur and SFitter, Eur.Phys.J. C71 (2011) 1520

Search for parameter point, determine errors including treatment of error correlations:
Apply techniques developed for SUSY to the Higgs sector

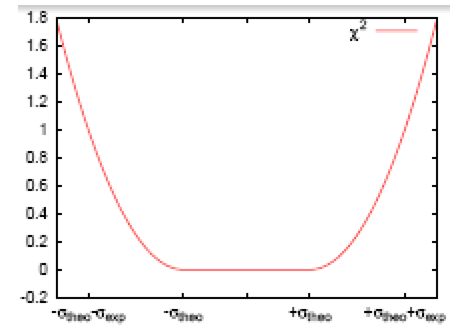
Duhrssen and SFitter JHEP0908 (2009) 009, arXiv:0904.3866 [hep-ph]
SFitter and Klute, Phys.Rev.Lett. 109 (2012) 101801
SFitter and Klute, Europhys.Lett. 101 (2013) 51001
Englert, P. Zerwas and SFitter Phys.Lett. B707 (2012) 512-516
Bock, P. Zerwas and SFitter Phys.Lett. B694 (2010) 44-53

many other groups: Contino, Falkowski, Espinosa, Ellis
Frank Simon in LCD WG meeting

The Higgs sector: errors and parameter definition

RFit Scheme: Höcker, Lacker, Laplace, Lediberder

$$\chi^2 = \sum_{\text{measurements}} \begin{cases} 0 & \text{for } |x_{\text{data}} - x_{\text{pred}}| < \sigma_{\text{theo}} \\ \left(\frac{|x_{\text{data}} - x_{\text{pred}}| - \sigma_{\text{theo}}}{\sigma_{\text{exp}}} \right)^2 & \text{for } |x_{\text{data}} - x_{\text{pred}}| \geq \sigma_{\text{theo}} \end{cases}$$



- **No information within theory errors: flat distribution**
- **intuitively reasonable**
- **central value not biased!**
- **not necessarily "conservative" (and probability….)**

Definition: ΔX deviation of XXH coupling from SM value:

$g_{XXH} = g_X \rightarrow g_X^{SM}(1+\Delta X)$

Loop induced coupling:

$g_{XXH} = g_X \rightarrow g_X^{SM}(1+\Delta X^{SM}+\Delta X)$

As observables are in g_j^2 : expected ambiguity for -2 and 0!

$$\Gamma_{\text{tot}} = \sum_{\text{obs}} \Gamma_x(g_x) + \text{2nd generation} < 2\,\text{GeV}$$

+ couple the 2nd and 3rd generation quarks

Overall phase choice: HWW positive
two sets of models:

- **without anomalous effective couplings**
- **with anomalous effective couplings**

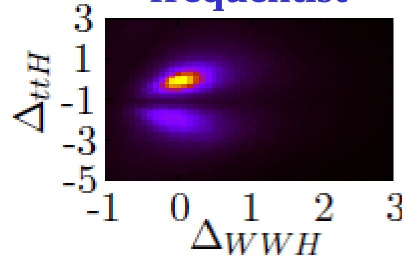
Essential: decay and cross section calculation

First step: likelihood map and projections to study correlations.

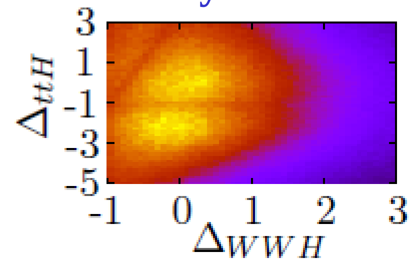
The Higgs sector: likelihood maps

- **model: mH, ΔW, ΔZ, Δt, Δb, Δτ**
- **ΔW>-1 (unobservable global sign)**
- **general positive correlation among couplings due to total width ≈ bbH**
- **frequentist approach better adapted (no real secondary minima)**
- **thanks to γγ correct sign chosen for ttH**

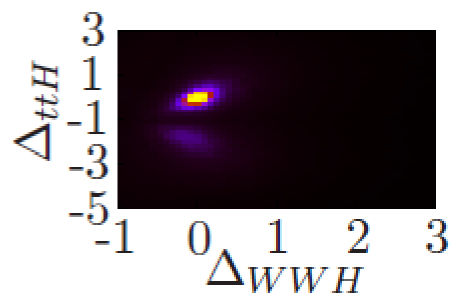
frequentist

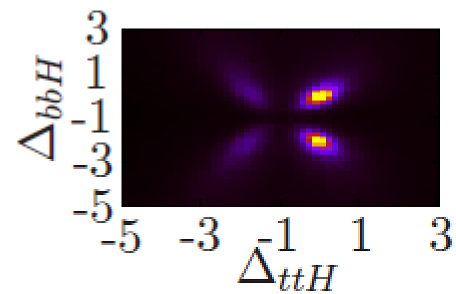


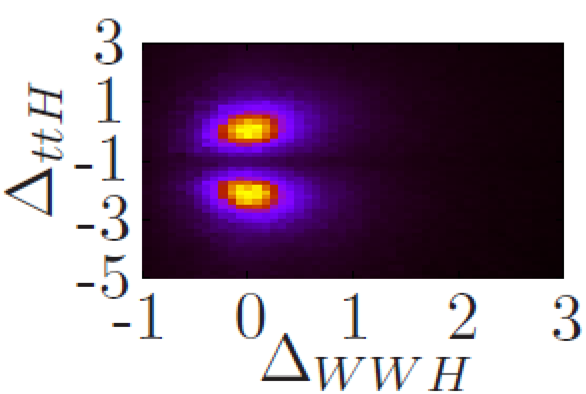
bayesian



- **model: mH, ΔW, ΔZ, Δt, Δb, Δτ, Δg, Δγ**
- **additional freedom prevents γγ correct sign choice**
- **some loss in sensitivity to Δt (contribution measured via Δg)**







Measurements at LHC:
$\sigma \cdot BR \cdot L \cdot \sim g^2 \cdot g^2/\Gamma$
blind to simultaneous coupling/√width changes:

Assume:

$$\Gamma_{\text{tot}} = \sum_{\text{obs}} \Gamma_x(g_x) + \text{2nd generation} < 2\,\text{GeV}$$

The Higgs sector precision

Higgs portal:

- add a hidden sector

2-parameter model: $\Delta H = \cos\chi$, Γ_{hid}

$$\sigma = \cos^2\chi\,\sigma^{SM}$$
$$\Gamma_{vis} = \cos^2\chi\,\Gamma_{vis}^{SM}$$
$$\Gamma_{inv} = \cos^2\chi\,\Gamma_{inv}^{SM} + \Gamma_{hid}\ .$$

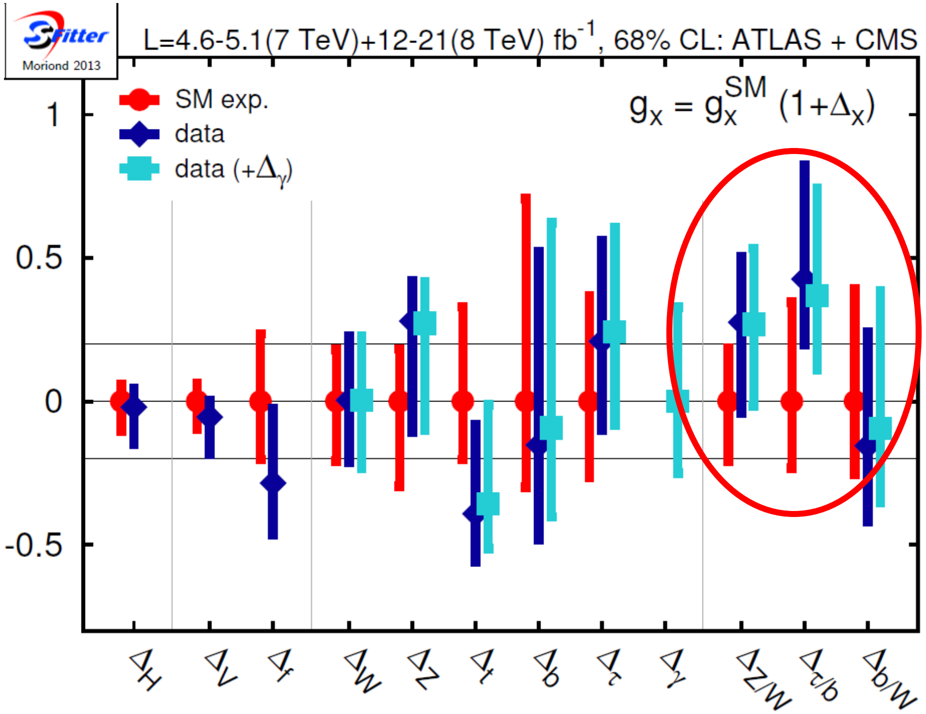
- postulating no effective couplings lead to a slight increase of precision

ΔZ Δt Δb $\Delta\tau$:
- direct coupling
- +correl with Δb

ΔZ Δt Δb $\Delta\tau$ $\Delta\gamma$:
- effective coupling
- additional contribution BSM

$\Delta Z/W$ $\Delta\tau/b$ $\Delta b/W$:
- coupling ratio
- error reduced: +correlation with Δb

Tilman Plehn, Michael Rauch. arXiv:1207.6108 EPL and update Moriond/Aspen 2013



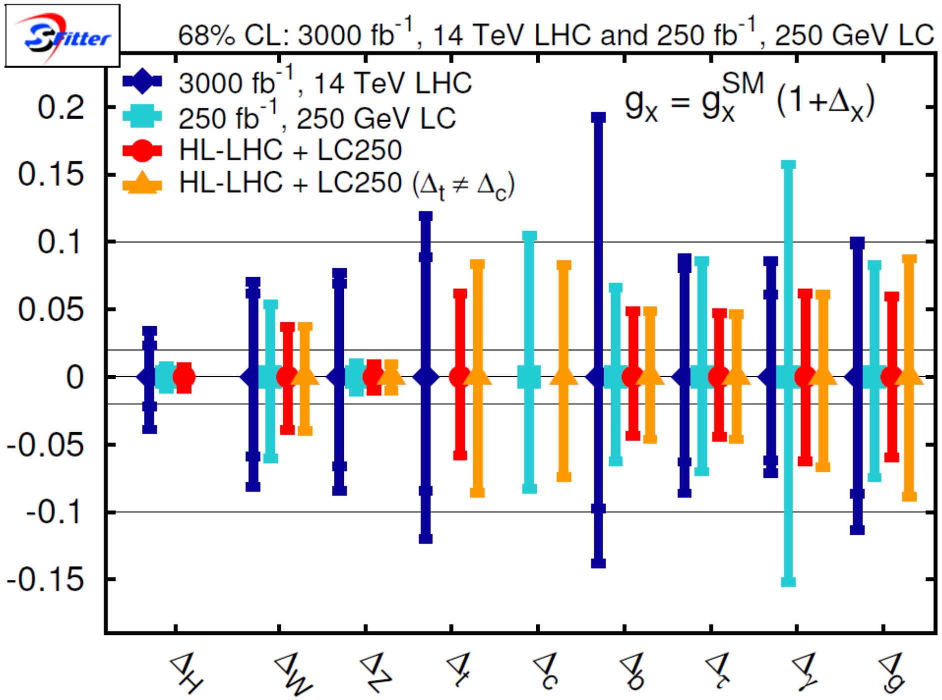
Enter the Linear Collider Collaboration

	ILC 250/500/1000 GeV		ILC LumiUp‡ 250/500/1000 GeV		CLIC 1.4/3.0 TeV		TLEP (4 IPs)	
	ZH	$\nu\nu H$	ZH	$\nu\nu H$	$ZH^\dagger$	$\nu\nu H$	ZH	$\nu\nu H$
Inclusive	2.5/–/–%	–	1.2/–/–%	–	4.2%†	–	0.4%	–
$H \to \gamma\gamma$	29-38%	–/20-26/7-10%	16/19/–%	–/13/5.4%	–	11%/tbd	3.0%	tbd
$H \to gg$	7/11/–%	–/4.1/2.3%	3.3/6.0/–%	–/2.3/1.4%	6%	1.4/1.4%	1.4%	tbd
$H \to ZZ^*$	19/25/–%	–/8.2/4.1%	8.8/14/–%	–/4.6/2.6%	tbd	2.3/1.5%	3.1%	tbd
$H \to WW^*$	6.4/9.2/–%	–/2.6/1.6%	3.0/5.1/–%	–/1.4/1.0%	2%	0.75/0.5%	0.9%	tbd
$H \to \tau\tau$	4.2/5.4/–%	–/14/3.5%	2.0/3.0/–%	–/7.8/2.2%	5.7%	2.8%/tbd	0.7%	tbd
$H \to b\bar{b}$	1.2/1.8/–%	11/0.66/0.32%	0.56/1.0/–%	4.9/0.37/0.20%	1%	0.23/0.15%	0.2%	0.6%
$H \to c\bar{c}$	8.3/13/–%	–/6.2/3.1%	3.9/7.2/–%	–/3.2/2.0%	5%	2.2/2.0%	1.2%	tbd
$H \to \mu\mu$	–	–/–/31%	–	–/–/20%	–	21/12%	13%	tbd
	$t\bar{t}H$		$t\bar{t}H$		$t\bar{t}H$		$t\bar{t}H$	
$H \to b\bar{b}$	–/28/6.0%		–/16/3.8%		8%/tbd		–	

Taken from Snowmass draft

- **qualitative game changer: inclusive measurement**
- **qualitative change: distinguish c and top**
- **typical experimental error: % level**
- **quantitative game changer: gain on the theory error (0.5% Xsec ZH, WWH, 1% ttH)**

The Higgs sector precision

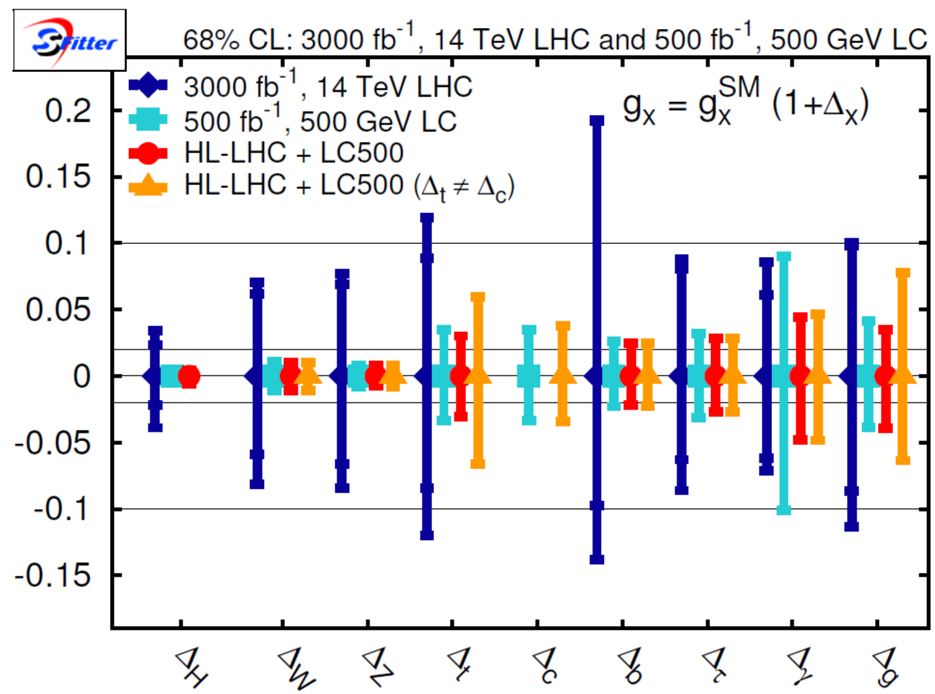


LCC (250GeV):

- **great precision on ΔZ**
- **but not an order of magnitude gain in others?**
- **total width an issue:**
  - **σ*BR(ZZ) difficult (low BR)**
  - **width determined at 10% level via:**

$$\Gamma_{tot} \leftarrow \frac{\sigma_{\nu\nu bb}/\sigma_{Zbb}}{\sigma_{ZWW}/\sigma_{ZH}} \times \sigma_{ZH}$$

Cries for higher energy ☺



LHC+LCC combined analysis (…500GeV):

- **ILC only Gauss errors**
- **clear improvement on Δt**
- **some improvement on D5 couplings $\Delta\gamma$, Δg**
- **LHC⊕LCC better than each machine alone**

And at higher energies?

Snowmass study:

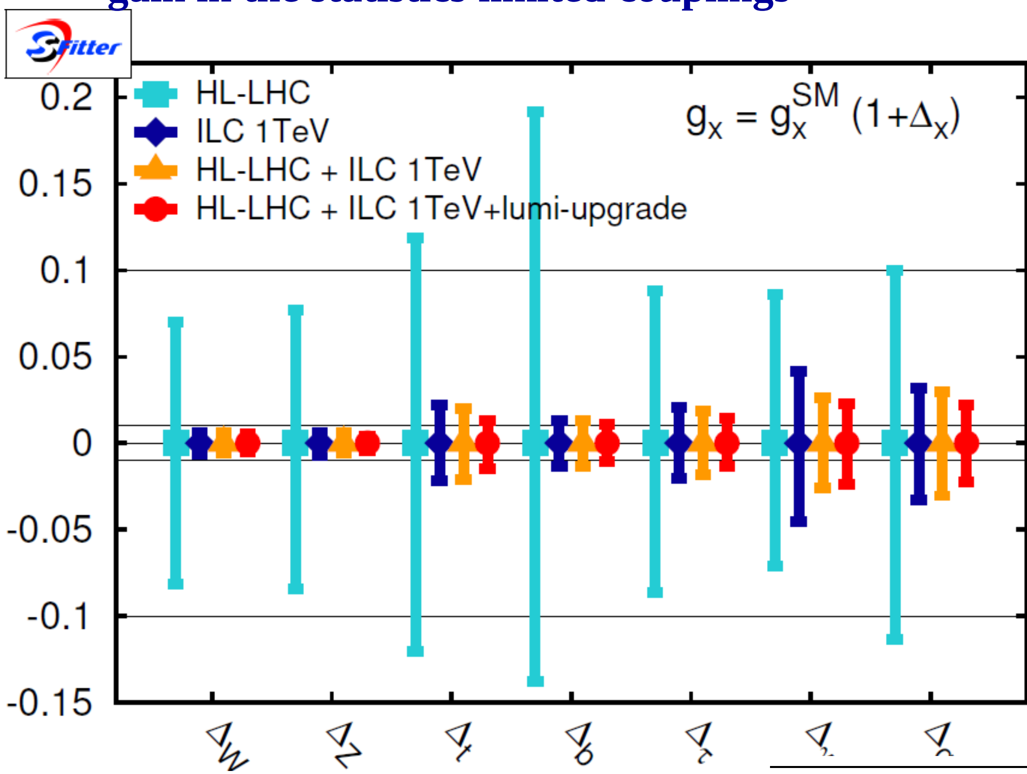
- **CMS projections (fusion error)**
- **kappa setup requested**
- **0.1% LCC error applied, Gauss (correl) everywhere**

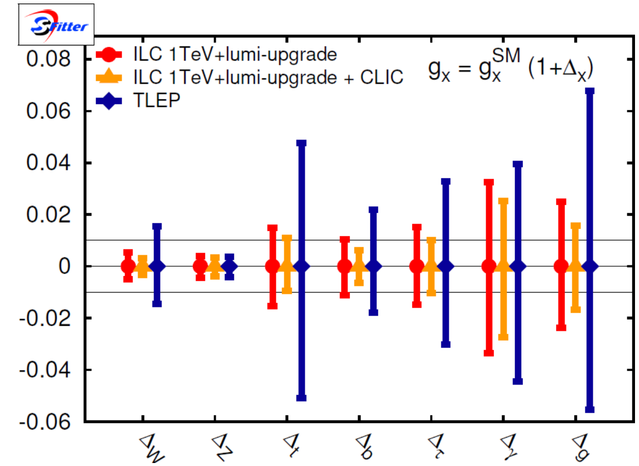
coupling	LHC +ILC	LHC +ILC Lumi-up	HL-LHC +ILC Lumi-up	HL-LHC +CLIC	HL-LHC +ILC Lumi-up +CLIC	HL-LHC +TLEP +CLIC
Γ_H	2.0 – 2.0%	1.1 – 1.1%	1.1 – 1.1%	4.4 – 7.3%	0.9 – 1.0%	1.1 – 1.2%
BR_{inv}	0.8 – 0.8%	0.4 – 0.4%	0.4 – 0.4%	2.2 – 3.9%	0.4 – 0.4%	0.5 – 0.5%
κ_γ	2.4 – 2.7%	2.0 – 2.2%	1.3 – 2.0%	1.8 – 3.4%	1.2 – 2.0%	1.2 – 1.6%
κ_g	1.3 – 1.3%	0.8 – 0.8%	0.8 – 0.8%	1.3 – 2.0%	0.6 – 0.6%	0.6 – 0.6%
κ_W	0.5 – 0.5%	0.3 – 0.3%	0.3 – 0.3%	1.1 – 1.9%	0.3 – 0.3%	0.3 – 0.3%
κ_Z	0.6 – 0.6%	0.3 – 0.3%	0.3 – 0.3%	1.1 – 1.9%	0.3 – 0.3%	0.3 – 0.3%
κ_μ	13.8 – 14.2%	9.9 – 9.9%	7.0 – 7.8%	5.2 – 6.0%	4.6 – 4.7%	4.0 – 4.1%
κ_τ	1.5 – 1.6%	0.9 – 0.9%	0.7 – 0.9%	1.3 – 2.3%	0.7 – 0.8%	0.5 – 0.6%
κ_c	1.6 – 1.6%	0.9 – 0.9%	0.9 – 0.9%	1.4 – 2.1%	0.7 – 0.7%	0.7 – 0.7%
κ_b	0.8 – 0.8%	0.5 – 0.5%	0.5 – 0.5%	1.1 – 1.9%	0.3 – 0.3%	0.4 – 0.4%
κ_t	2.8 – 2.9%	1.9 – 1.9%	1.7 – 1.8%	3.5 – 4.5%	1.7 – 1.8%	3.2 – 3.8%
Δ_γ	2.5 – 2.8%	2.0 – 2.2%	1.5 – 2.1%	2.8 – 4.6%	1.4 – 2.0%	1.7 – 2.0%
Δ_g	3.8 – 3.8%	2.5 – 2.5%	2.3 – 2.4%	4.1 – 4.8%	2.1 – 2.3%	4.0 – 4.7%

- **combinations dominated by the lepton colliders (i.e. you)**
- **kappa setup does not allow to determine new-physics effects in loop-induced couplings separately**
- **HL-LHC + LCC is a great package for sub% level Higgs couplings**

Flat theory errors SFitter-style

- ILC errors dominated by branching ratio errors (2% for b-quarks, mass induced)
- gain in the statistics limited couplings





- Theory errors on BR are important!
- non-measurement of Δt means determination via Δc, theory error 3x reflected in deterioration of precision
- cascades into Δg
- impacts the total width

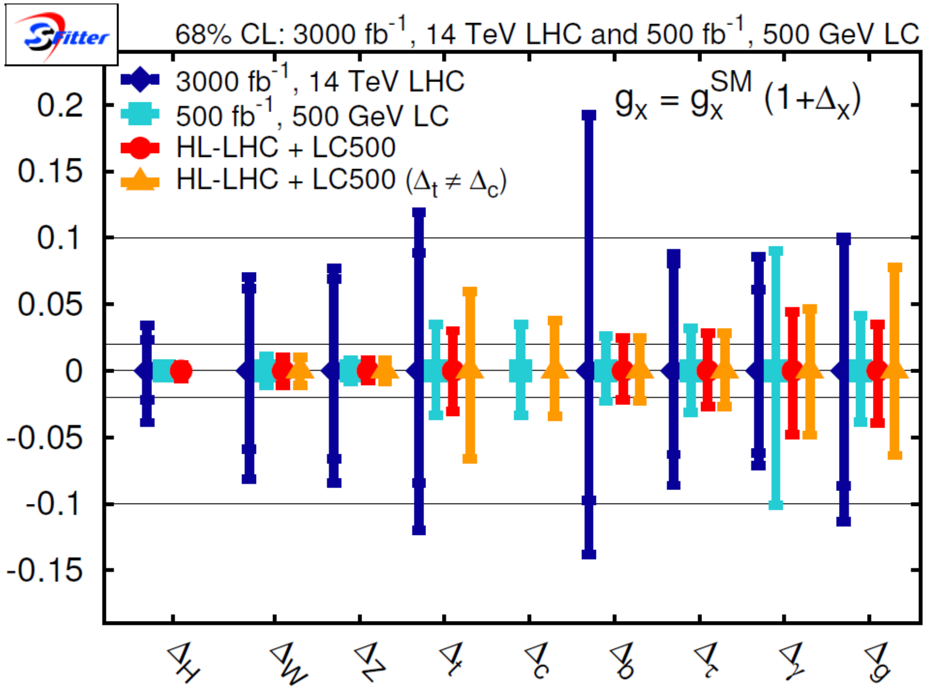
- ILC+ expected errors will be sensitive to new models:

	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	$< 1\%$	3%	$10\%^a$, $100\%^b$
LHC 14 TeV, $3\,\text{ab}^{-1}$	8%	10%	15%

Gupta, Rzehak, Wells: Phys.Rev. D86 (2012) 095001

Conclusions

• **ILC in great shape to take the Higgs precision to the next level**



Thanks to: Tilman Plehn, Michael Duehrssen, Remi Lafaye and Michael Rauch