Higgs couplings

ILC & High Lumi LHC perspectives

Remi Lafaye

On behalf of the SFitter team

What's SFitter?

- Goal: measure ~~supersymmetric parameters~~ Higgs couplings
  - Map LHC/ILC observables to Higgs couplings
  - Taking into account th. and exp. error correlations
  - "Flat" (R-fit scheme) th. errors
  - Find minimum with Cooling Markov Chains + MINUIT
  - Generate 5000 toys/minimum to find 68% CL
  - Now: Apply technics developed for SUSY to the Higgs sector

Supersymmetric publications:

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

Higgs couplings publications:

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

- Why?
  - Higgs couples to all particles proportional to their masses
  - Indirect searches for New Physics

ILC proposals:

J. Brau et al, ILC Collaboration, arXiv:0712.1950
P. Azzi et al, arXiv:1208.1662

- (Pseudo-)Data:
  - Today: 2012 ICHEP data ATLAS+CMS
  - ILC 250 fb^{-1} @ 250 GeV (LC250) + 500 fb^{-1} @500 GeV (LC500)
  - High-luminosity LHC: 3000 fb^{-1} @14 TeV

SFitter

Klute, Lafaye, Plehn, Rauch, Zerwas

Higgs couplings analysis setup

Higgs couplings definition

- Factors of the tree-level terms in the Lagrangian

  Defined relatively to SM predictions: $g_{xxH} \equiv g_{\gamma} = (1+\Delta_x)\, g_x^{SM}$

- Additional terms for loop induced processes: $g_{\gamma}=(1+\Delta_{\gamma}^{SM\ (tree)}+\Delta_{\gamma})g_{\gamma}^{SM}$

Uncertainties

- Statistical errors Gaussian or Poisson
- Uncertainties can be correlated (luminosity, tagging efficiencies)
- Theoretical errors are taken as flat (Rfit scheme)

Combination with experimental errors: (not a convolution!)

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

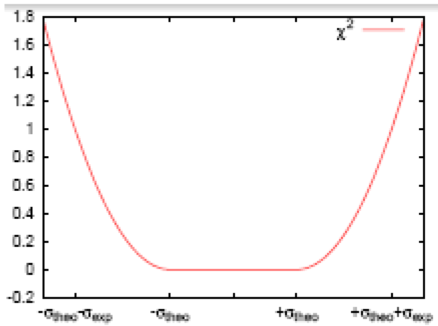
Rfit scheme:

Höcker et al, Eur. Phys. J. C 21, 225 (2001).
In Sfitter: Eur. Phys. J. C54, 617 (2008)

No information inside theory errors $\rightarrow$ flat distribution

Not necessarily conservative !

Linearly propagated to observables (not quadratically)



Higgs coupling extraction 2012 LHC data

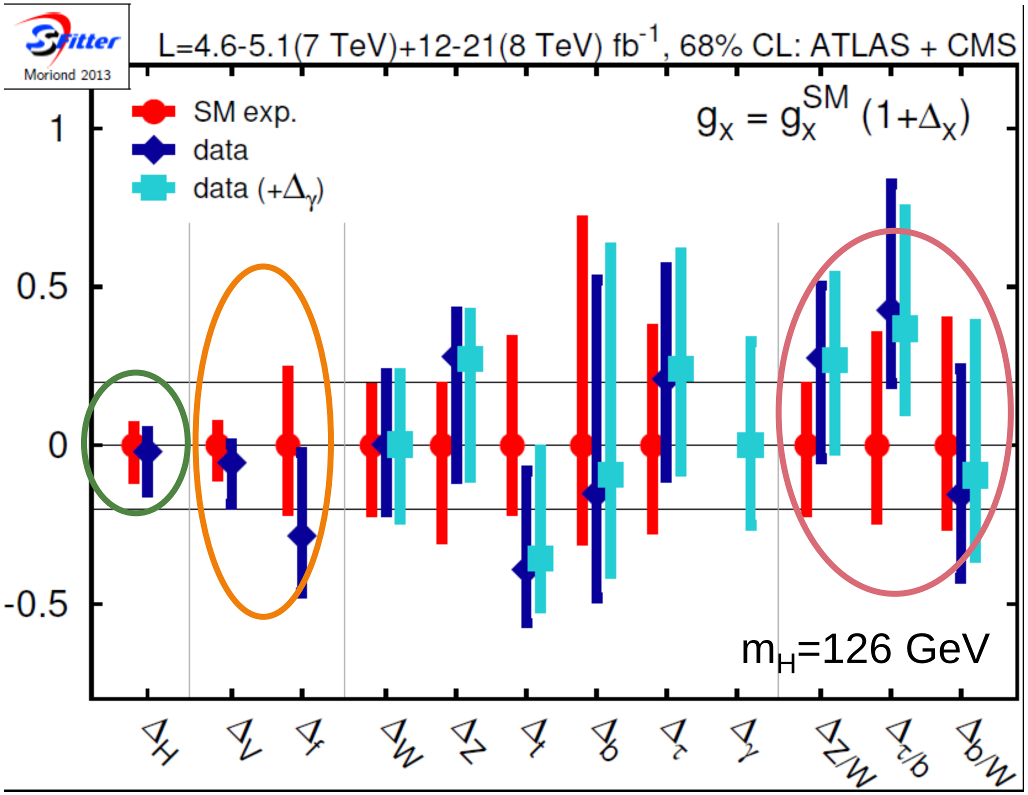
Fitting all Higgs measurements from LHC (as of ICHEP2012) + top and bottom masses

Higgs portal to hidden sector
e.g.: 2-parameter model
$\Delta H = f(\cos\chi\ ,\ \Gamma_{hid})$
ΔH precision is already10%

2 parameter fits
$\Delta V=\Delta Z=\Delta W$
is well within SM prediction
$\Delta f=\Delta t=\Delta b=\Delta\tau$
is a bit low but within 1σ

Using ratio does not help much because we are statistically limited

Tilman Plehn, Michael Rauch. arXiv:1207.6108 EPL



Individual couplings compatible with SM
Precision: 20 to 50% as expected

From ICHEP2012 data:

$$\Delta_\gamma = 0.16 + 0.47 - 0.61 \quad (68\%\ \mathrm{CL})$$

Secondary minimum (~same χ^2/ndof=28/49)

$$\Delta_\gamma = -0.22$$ No enhanced coupling to γ!

HL-LHC observables

HL-LHC: 3000 fb^{-1}@14 TeV with detector and machine upgrade

Uncertainties

- 5% error on luminosity (2% if improvement assumed)
- Statistical errors scaled to luminosity from 14 TeV predictions
- Systematics unchanged (statistics improves but conditions worsen)
- No improvement assumed on theory errors
- Dominant th. error is on cross section production

Higgs to charm quarks not negligible O(1%) and too challenging to measure

- Link to 3rd generation: $g_c = m_c/m_t \times g_t^{\mathrm{SM}}(1+\Delta_t)$
- Total Higgs width assumed <2 GeV (larger would be visible)

production	decay
$gg \to H$	ZZ
qqH	ZZ
$gg \to H$	WW
qqH	WW
$t\bar{t}H$	$WW(3\ell)$
$t\bar{t}H$	$WW(2\ell)$
inclusive	$\gamma\gamma$
qqH	$\gamma\gamma$
$t\bar{t}H$	$\gamma\gamma$
WH	$\gamma\gamma$
ZH	$\gamma\gamma$
qqH	$\tau\tau(2\ell)$
qqH	$\tau\tau(1\ell)$
$t\bar{t}H$	$b\bar{b}$
WH/ZH	$b\bar{b}$

HL-LHC scenarios:

cf SFitter Higgs couplings papers
Duhrssen et al, Phys. Rev. D 70, 113009 (2004);
Zeppenfeld, et al, Phys. Rev. D 62, 013009 (2000)

ILC observables

ILC with 2 phases: 250 GeV + 500 GeV

Uncertainties

- 0.3% error on luminosity
- 0.5% error on ZH, $\nu\nu$H and 1% on ttH productions
- Dominant th. error is on Higgs width: 4% for quarks, 2% gluons, 1% others
- Error on BR is linear sum of errors on width

Total Higgs width indirectly measured from combination of observables (included in fit)

(with 10% precision @LC250)

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

ZH inclusive measured from system recoiling against Z$\to\mu\mu$

Observable	Error
ILC at 250 GeV with 250 fb^{-1}	
$\sigma(Zh)$	0.025
$\sigma(Zh)\cdot BR(b\bar{b})$	0.011
$\sigma(Zh)\cdot BR(c\bar{c})$	0.074
$\sigma(Zh)\cdot BR(gg)$	0.091
$\sigma(Zh)\cdot BR(WW)$	0.064
$\sigma(Zh)\cdot BR(ZZ)$	0.19
$\sigma(Zh)\cdot BR(\tau^+\tau^-)$	0.042
$\sigma(Zh)\cdot BR(\gamma\gamma)$	0.38
$\sigma(WW)\cdot BR(b\bar{b})$	0.105
$\sigma(Zh)\cdot BR(\text{invisible})$	0.005
ILC at 500 GeV with 500 fb^{-1}	
$\sigma(Zh)\cdot BR(b\bar{b})$	0.018
$\sigma(Zh)\cdot BR(c\bar{c})$	0.12
$\sigma(Zh)\cdot BR(gg)$	0.14
$\sigma(Zh)\cdot BR(WW)$	0.092
$\sigma(Zh)\cdot BR(ZZ)$	0.25
$\sigma(Zh)\cdot BR(\tau^+\tau^-)$	0.054
$\sigma(Zh)\cdot BR(\gamma\gamma)$	0.38
$\sigma(WW)\cdot BR(b\bar{b})$	0.0066
$\sigma(WW)\cdot BR(c\bar{c})$	0.062
$\sigma(WW)\cdot BR(gg)$	0.041
$\sigma(WW)\cdot BR(WW)$	0.026
$\sigma(WW)\cdot BR(ZZ)$	0.082
$\sigma(WW)\cdot BR(\tau^+\tau^-)$	0.14
$\sigma(WW)\cdot BR(\gamma\gamma)$	0.26
$\sigma(t\bar{t}h)\cdot BR(b\bar{b})$	0.25

ILC observables:

Peskin, arXiv:1207.2516; Ono and Miyamoto,, arXiv:1207.0300
Aguilar-Saavedra et al, hep-ph/0106315.
Aarons et al, ILC Collaboration, arXiv:0709.1893
Duerig, Master thesis, University Bonn (2012)

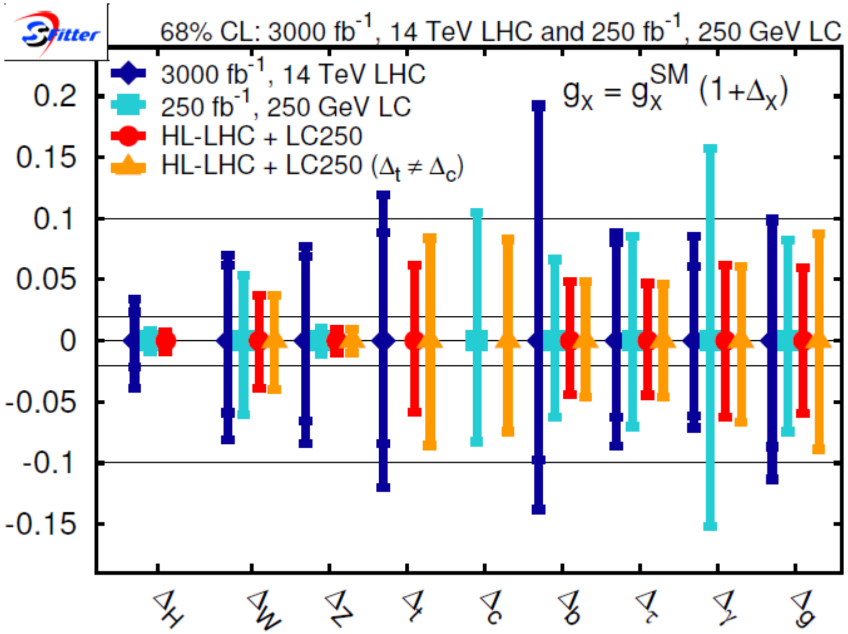
Higgs coupling extraction HL-LHC+ILC

Simple SM extension scenarios:

- Higgs portal scenario
- Strongly interacting extensions

Can be describe from total variation: Δ_H

- HL-LHC can measure Δ_H @ 4% (th. error limited, from σ errors)
- LC250 @ 1% (lower th. error from BR)



HL-LHC precision is 8% (bosons) to 15% (quarks)

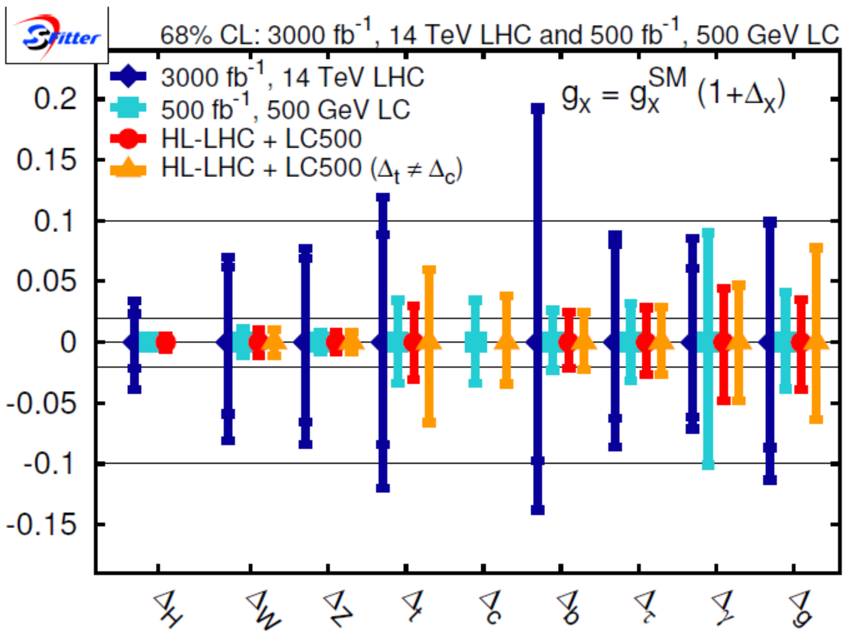
LC250 measurements are statistically limited

LC500 essential for Δ_t (access to ttH prod)

HL-LHC+LC dominated by LC precision

Combination essential for loop induced couplings (Δ_γ and Δ_g).

Δ_γ benefits from Δ_W impact on $\Delta_\gamma^{SM(tree)}$



Conclusions

LHC 2013-data: Extracted couplings show no significant deviation

HL-LHC: can measure couplings with a precision 8-15%

ILC: improves precision by an order of magnitude

+ measurement of Δ_c and direct access to Higgs total width

LC@500 GeV needed to accurately measure Δ_t

HL-LHC+ILC combination: essential for loop induced couplings