Martin Goebel (DESY / Universität Hamburg)
for the Gfitter group

XLIVth Rencontres de Moriond
Electroweak Interactions and Unified Theories
8th March 2009

Revisiting the Global Electroweak Fit of the Standard Model and Beyond with Gfitter

http://cern.ch/Gfitter

paper accepted by Eur. Phys. J. C, (arXiv:0811.0009)
H. Flächer (CERN), M. G. (Univ. Hamburg, DESY), J. Haller (Univ. Hamburg),
A. Höcker (CERN), K. Mönig (DESY), J. Stelzer (DESY)

A Generic Fitter Project for HEP Model Testing

- modular framework for involved fitting problems in the LHC era (and beyond)
- coherent treatment of statistical, systematic errors, and correlations
  - theoretical uncertainties: included in χ^2 estimator with flat likelihood in allowed ranges
- physics plug-in packages
  - Library for the Standard Model fit to the electroweak precision data
  - Library for SM extensions via the oblique parameters
  - Library for the 2HDM extension of the SM

A Gfitter Package for the Global Electroweak Fit

- complete new implementation of SM predictions of electroweak precision observables
- state-of-the art calculations (OMS scheme); in particular:
  - M_W and $\sin^2\theta^f_{eff}$: full two-loop + leading beyond-two-loop correction
    [M. Awramik et al., Phys. Rev D69, 053006 (2004) and ref.][M. Awramik et al., JHEP 11, 048 (2006) and refs.]
  - radiator functions: N^{3}LO of the massless QCD Adler function
    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]
- wherever possible calculations cross-checked against ZFITTER
  → excellent agreement

Fit Input

- usage of latest experimental results:
  - **Z-pole observables**: LEP/SLD results
    [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
  - **M_W and Γ_W**: LEP/Tevatron
    [ADLO, hep-ex/0612034] [CDF, Phys Rev. D77, 112001 (2008)] [CDF, Phys. Lett. 100, 071801 (2008)] [CDF+D0, Phys. Rev. D 70, 092008 (2004)]
  - **m_t**: Tevatron [arXivx:0808.1089 [hep-ex]]
  - **$\Delta\alpha_{had}^{(5)}(M_Z^2)$:** including α_S dependency
    [Hagiwara et al., Phys. Lett. B649, 173 (2007)]
  - **m_c, m_b**: world averages [PDG, J. Phys. G33,1 (2006)]
- theoretical uncertainties: M_W (δM_W=4-6GeV), $\sin^2\theta^l_{eff}$ ($\delta\sin^2\theta^l_{eff}$ =4.7·10^{-5})
- floating fit parameters: M_Z, M_H, m_t, $\Delta\alpha_{had}^{(5)}(M_Z^2)$, $\alpha_S(M_Z^2)$, $\overline{m}_c$, $\overline{m}_b$
- fits are performed in two versions:
  - standard fit: all data except results from direct Higgs searches
  - complete fit: all data including results from direct Higgs searches at LEP [ADLO: Phys. Lett. B565, 61 (2003)] and Tevatron [CDF+D0: arXiv:0804.3423, CDF+D0: arXiv:0808.0534]

Parameter	Input value
M_Z [GeV]	91.1875 ± 0.0021
Γ_Z [GeV]	2.4952 ± 0.0023
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037
R^0_ℓ	$20.767 + 0.025$
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010
A_ℓ $^{(\star)}$	0.1499 ± 0.0018
A_c	0.670 ± 0.027
A_b	0.923 ± 0.020
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016
R^0_c	0.1721 ± 0.0030
R^0_b	0.21629 ± 0.00066
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012
M_H [GeV] $^{(\circ)}$	Likelihood ratios
M_W [GeV]	80.399 ± 0.025
Γ_W [GeV]	2.098 ± 0.048
$\overline{m}_c$ [GeV]	1.25 ± 0.09
$\overline{m}_b$ [GeV]	4.20 ± 0.07
m_t [GeV]	172.4 ± 1.2
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2768 ± 22
$\alpha_s(M_Z^2)$	–

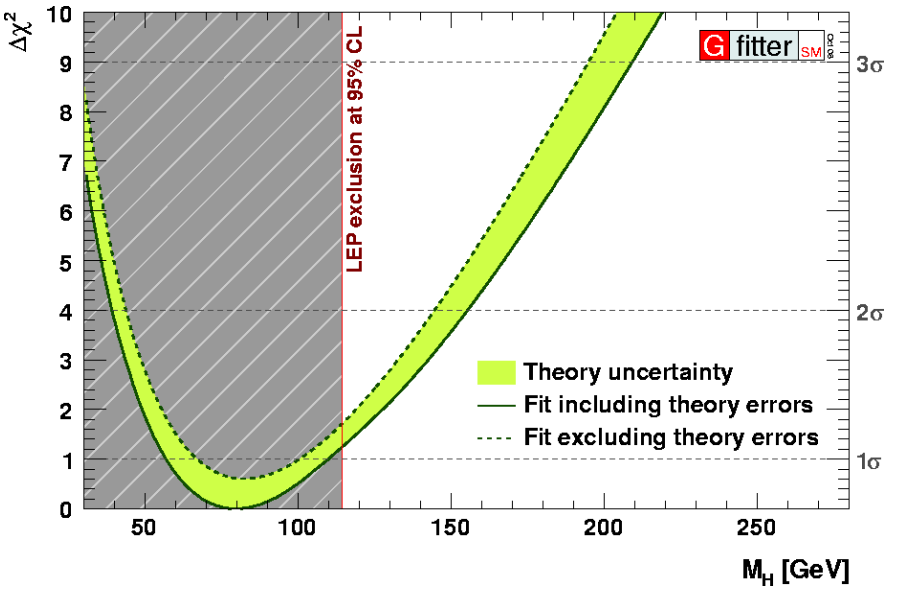
† in units of 10^{-5}

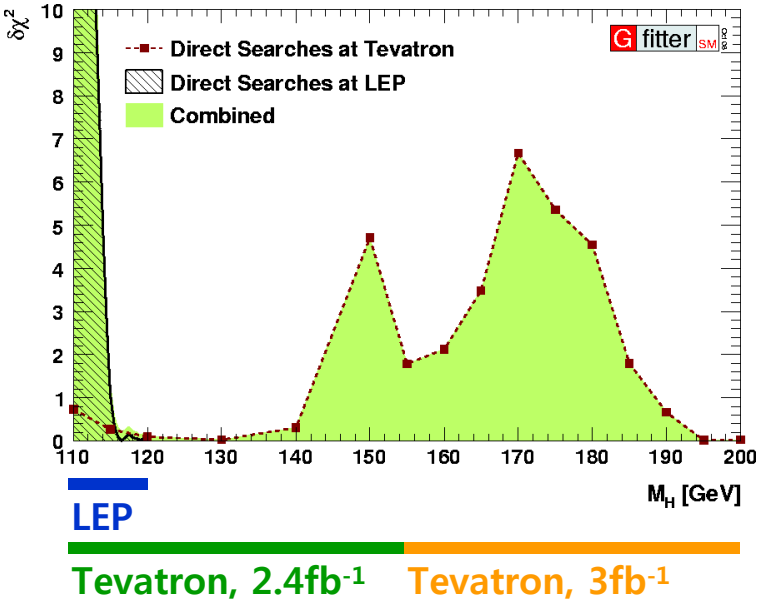
Higgs Mass Constraints

- standard fit:
  - from MC toy: p-value=0.225±0.004$_{-0.02}$
  - Higgs mass
    - central value ±1σ: $M_H = 80^{+30}_{-23}$ GeV
    - 2σ interval: [39, 155] GeV
    - 3σ interval: [26, 209] GeV

- green error band
  - theory uncertainties directly included in χ^2 ("flat likelihood")

- direct Higgs searches from LEP and Tevatron
  - resulting contribution added to the χ^2 during the fit



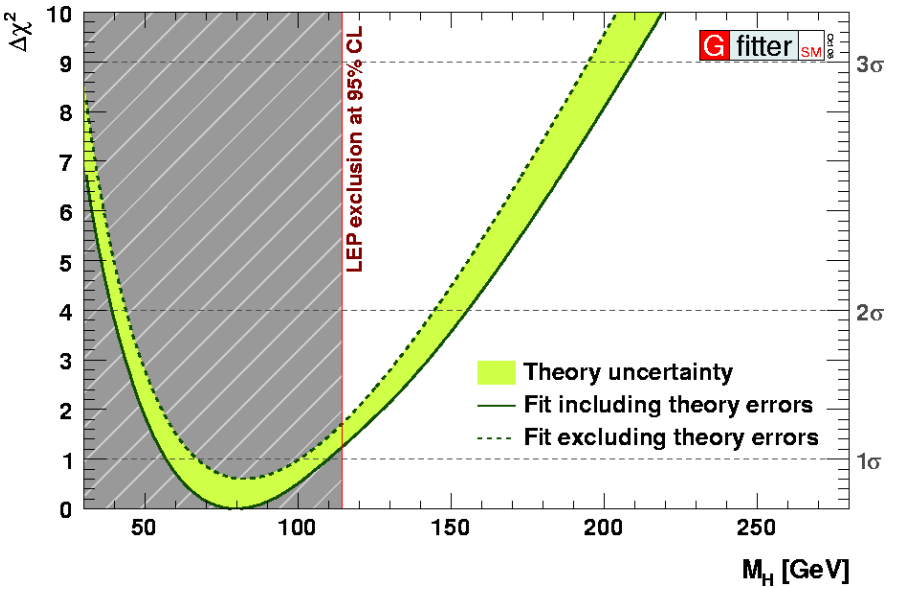


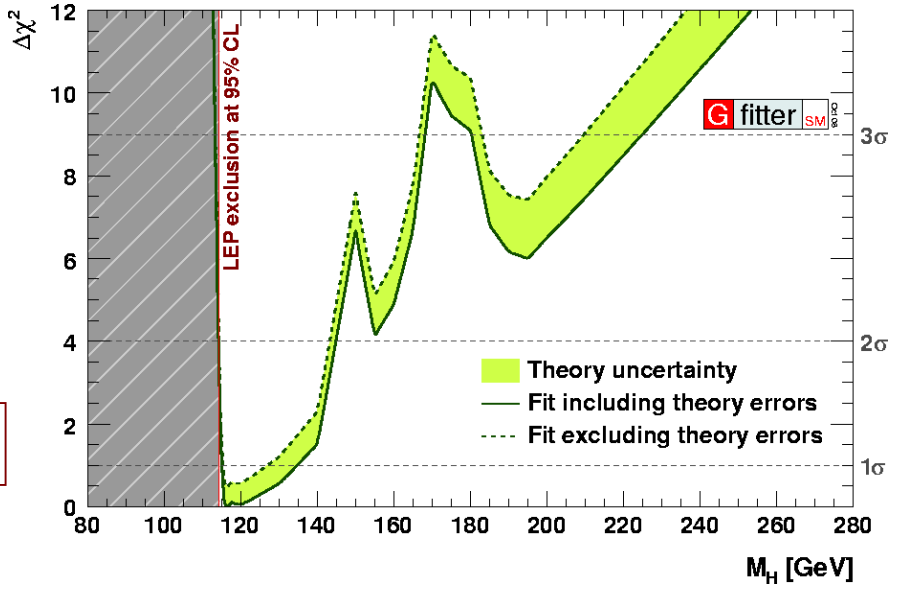
Higgs Mass Constraints

- standard fit:
  - from MC toy: p-value=0.225±0.004$_{-0.02}$
  - Higgs mass
    - central value ±1σ: $M_H = 80^{+30}_{-23}$ GeV
    - 2σ interval: [39, 155] GeV
    - 3σ interval: [26, 209] GeV

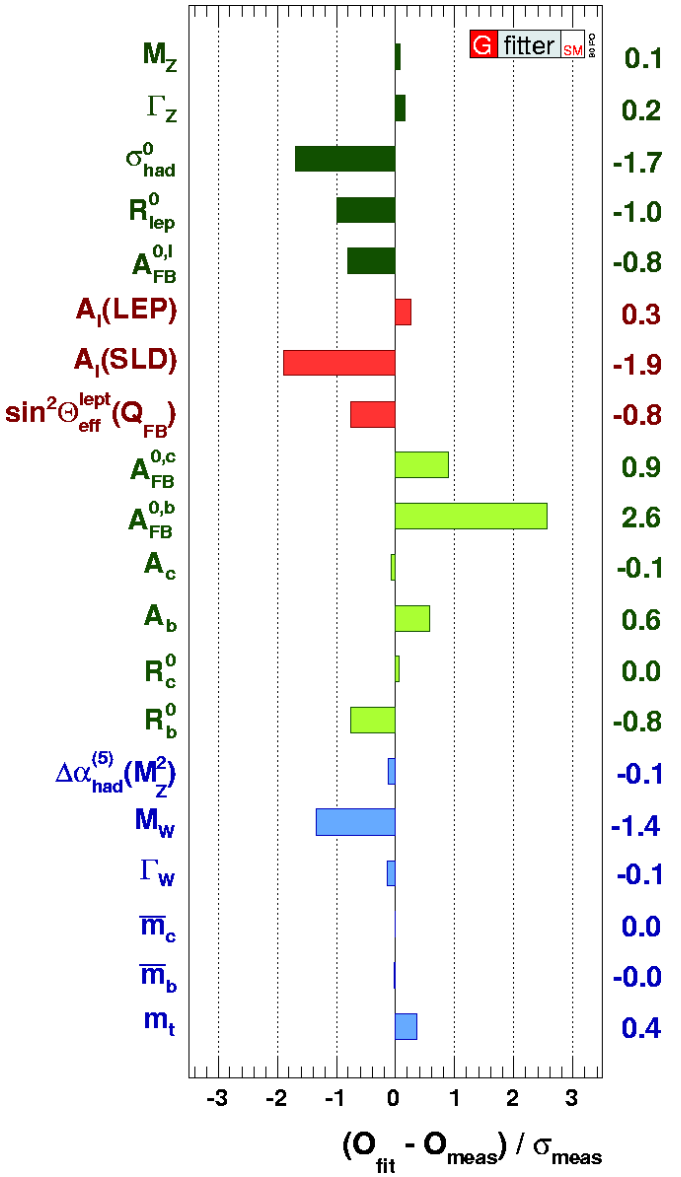
- green error band
  - theory uncertainties directly included in χ^2 ("flat likelihood")

- complete fit:
  - from MC toy: p-value=0.217±0.004$_{-0.02}$
  - including direct Higgs searches
  - Higgs mass:
    - central value ±1σ: $M_H = 116.4^{+18.3}_{-1.3}$ GeV
    - 2σ interval: [114, 145] GeV





Pulls and Results for Complete Fit



- pull values of complete fit
  - no value exceeds 3σ
  - FB asymmetry of bottom quarks → largest contribution to χ^2

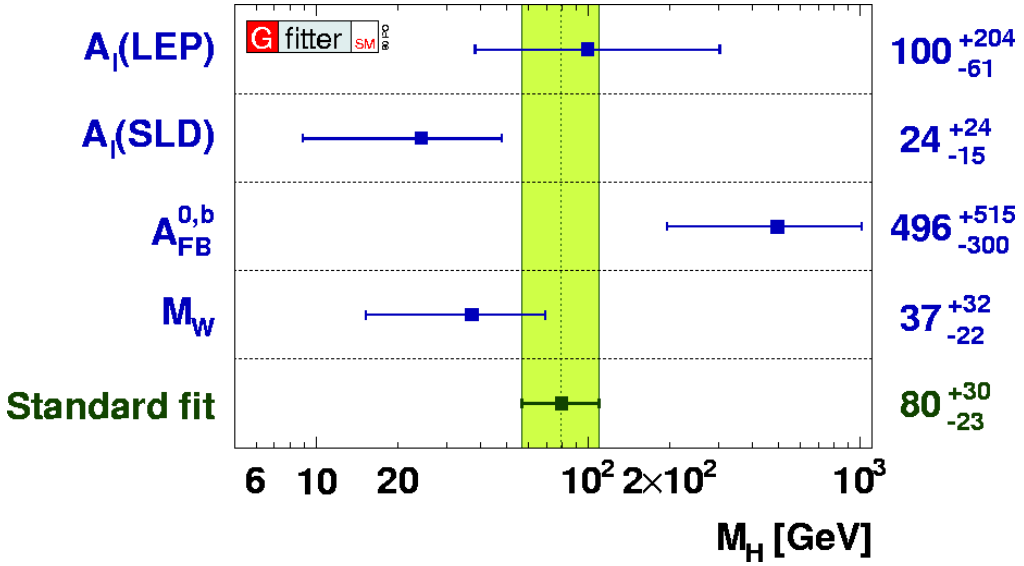
- α_S from complete fit:

$$\alpha_S(M_Z^2) = 0.1193^{+0.0028}_{-0.0027} \pm 0.0001$$

  - including N^{3}LO of the massless QCD Adler function
  - first error is experimental fit error
  - second error due to missing QCD orders:
    - incl. variation of renorm. scale from $M_Z/2$ to $2M_Z$ and massless terms of order/beyond $\alpha_S^5(M_Z)$ and massive terms of order/beyond $\alpha_S^4(M_Z)$

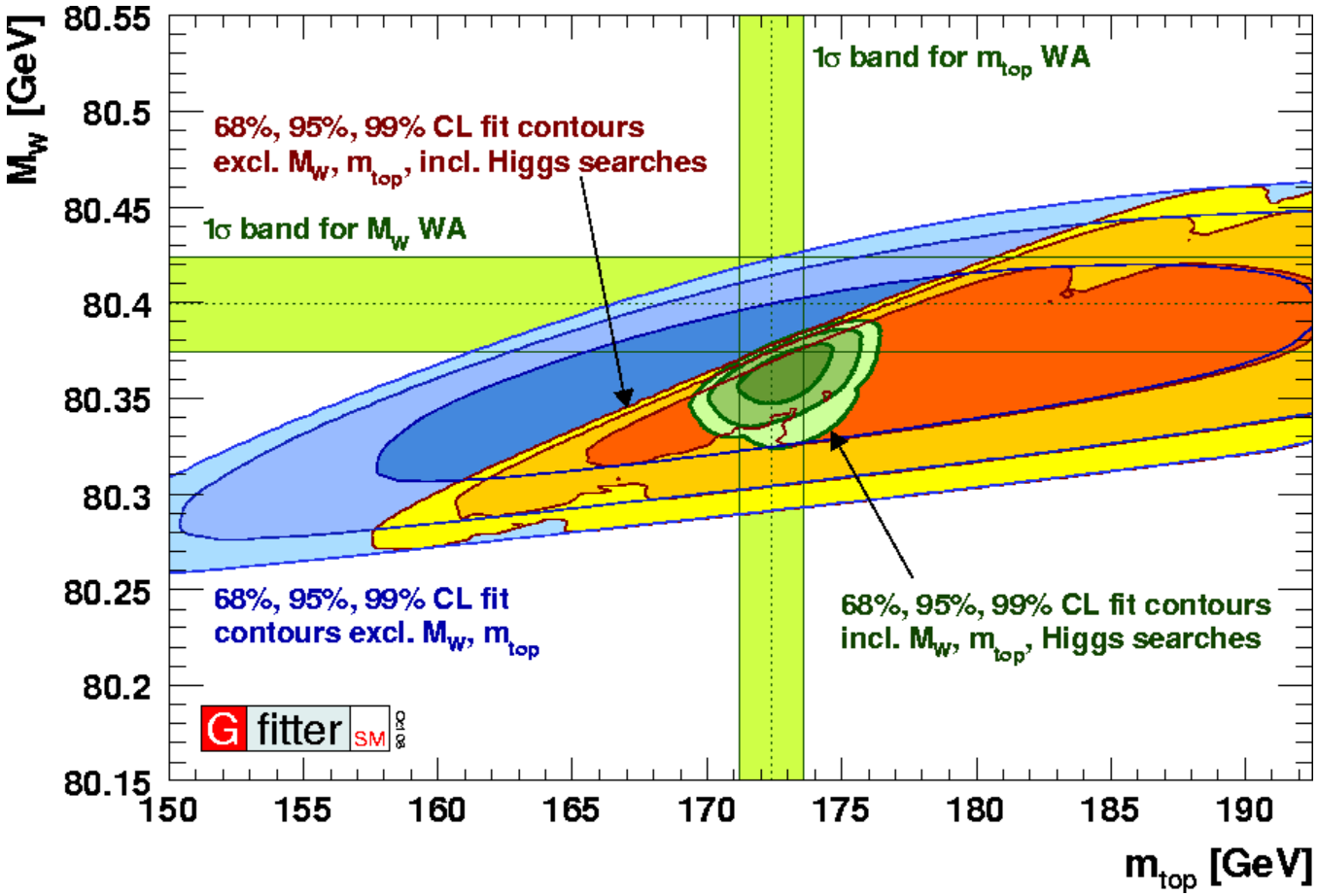
Standard Fit: Deeper Look

- Higgs mass constraints from most sensitive observables
  - tension between M_W, A_l(SLD), and $A_{FB}^{0,b}$
  - including measurements of floating fit parameters

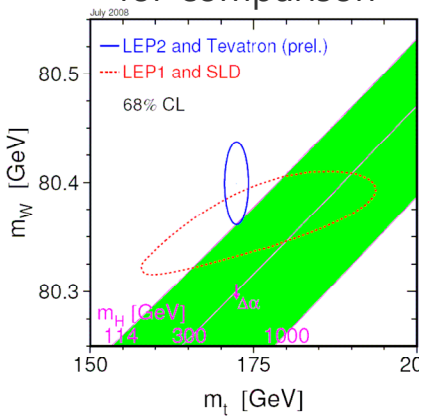


- How compatible are these measurements?
  - MC toy analysis ("look-elsewhere-effect")
    - compare the χ^2_{min} of the full fit with χ^2_{min} of a fit without the least compatible measurement (here $A_{FB}^{0,b}$) → $\Delta\chi^2_{min}$=8.0
    - Generate toy sample around fitted values and repeat procedure by calculating the $\Delta\chi^2_{min}$ → $\Delta\chi^2_{min}{}^{toy}$-distribution
  - 1.4% (2.5σ) of toys show a result worse than the $\Delta\chi^2_{min}$ of the data

W and Top Mass



for comparison

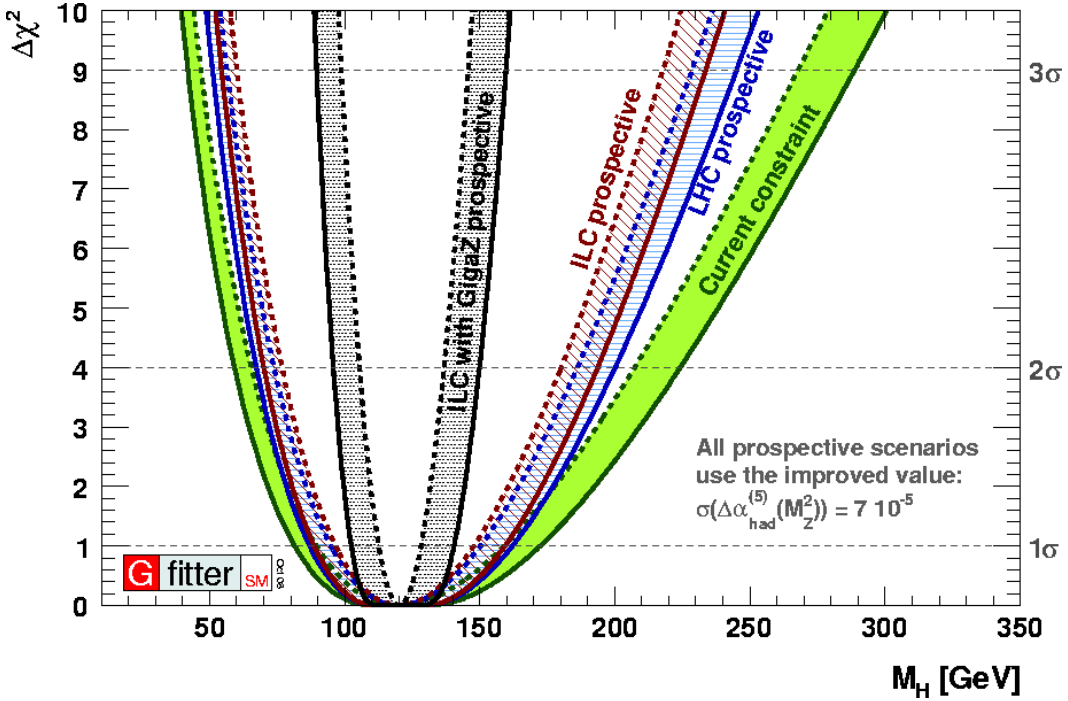


- indirect fit results agree with experimental values
- results from Higgs searches significantly reduce the allowed parameter space
- probe of SM, if M_H is measured at LHC and/or ILC

Prospects for LHC and ILC

- LHC, ILC (+GigaZ)*
  - exp. improvement on M_W, m_t, $\sin^2\theta^l_{eff}$, R_l^0
  - in addition improved $\Delta\alpha_{had}^{(5)}(M_Z^2)$
    [F. Jegerlehner, hep-ph/0105283]

Quantity	Present	Expected uncertainty LHC	ILC	GigaZ (ILC)
M_W [MeV]	25	15	15	6
m_t [GeV]	1.2	1.0	0.2	0.1
$\sin^2\theta^\ell_{\rm eff}$ $[10^{-5}]$	17	17	17	1.3
R^0_ℓ $[10^{-2}]$	2.5	2.5	2.5	0.4
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $[10^{-5}]$	22 (7)	22 (7)	22 (7)	22 (7)
$M_H(=120$ GeV) [GeV]	$^{+56}_{-40}$ $(^{+52}_{-39})$ $[^{+39}_{-31}]$	$^{+45}_{-35}$ $(^{+42}_{-33})$ $[^{+30}_{-25}]$	$^{+42}_{-33}$ $(^{+39}_{-31})$ $[^{+28}_{-23}]$	$^{+27}_{-23}$ $(^{+20}_{-18})$ $[^{+8}_{-7}]$
$\alpha_s(M_Z^2)$ $[10^{-4}]$	28	28	27	6



- assume M_H=120 GeV by adjusting central values of observables
- improvement of M_H prediction
  - to be confronted with direct measurement → goodness-of-fit
  - broad minima: Rfit treatment of theo. uncertainties
- GigaZ: significant improvement for M_H and $\alpha_S(M_Z^2)$

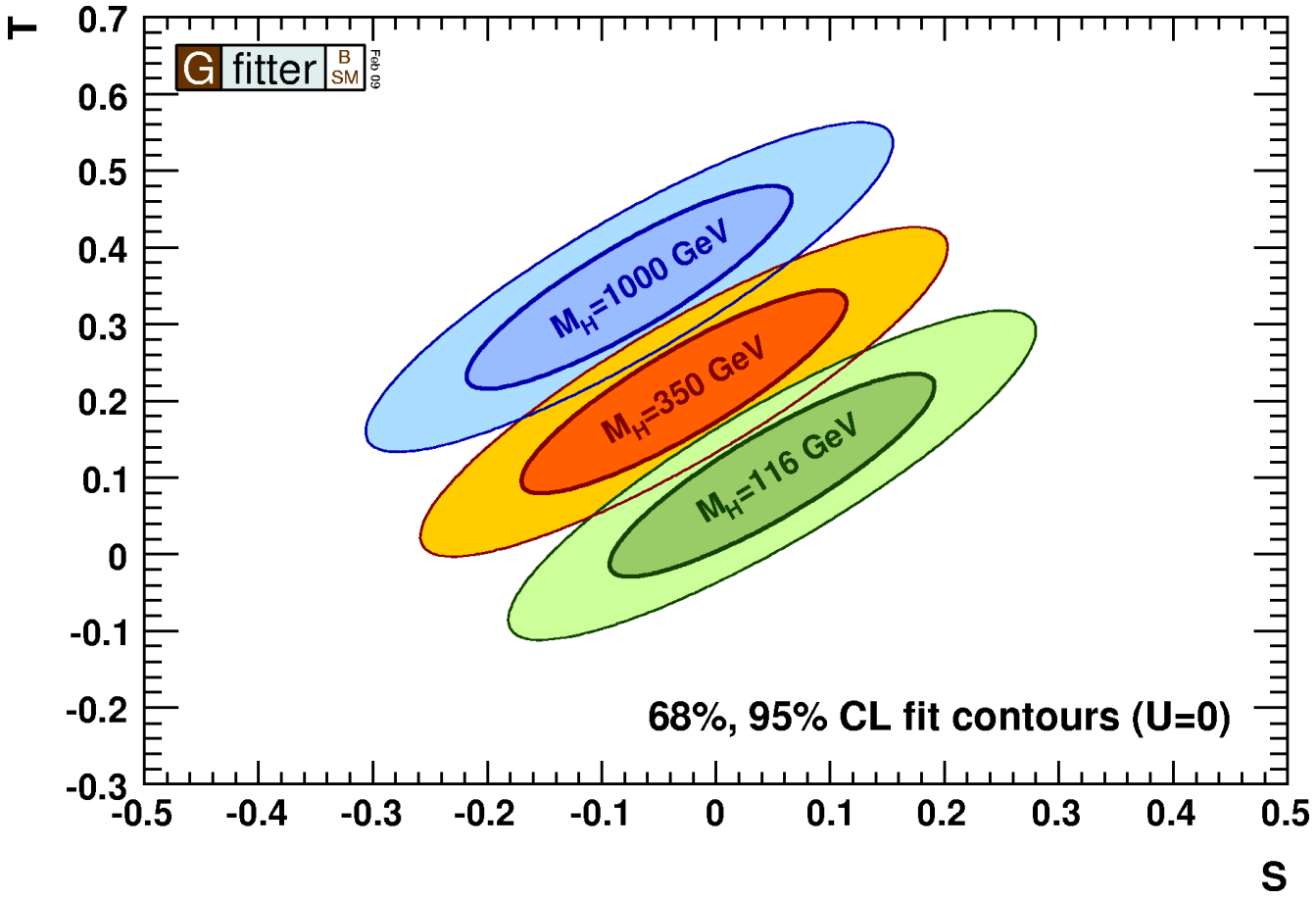
*[ATLAS, Physics TDR (1999)][CMS, Physics TDR (2006)][A. Djouadi et al., arXiv:0709.1893][I. Borjanovic, EPJ C39S2, 63 (2005)][S. Haywood et al., hep-ph/0003275][R. Hawkings, K. Mönig, EPJ direct C1, 8 (1999)][A. H. Hoang et al., EPJ direct C2, 1 (2000)][M. Winter, LC-PHSM-2001-016]

A Gfitter Package for SM Extensions

- oblique electroweak corrections to SM observables (physics beyond SM appear only through vacuum polarizations)
  - STU parameters [Peskin and Takeuchi, Phys. Rev. D46, 1 (1991)]
    - $O_{measurement} = O_{SM}(M_H, m_t) + c_S S + c_T T + c_U U$
    - S : new physics contribution to neutral current processes
    - (S+U) : new physics contribution to charged current processes
      U only sensitive to W mass and width
      usually very small in new physics models (often: U=0)
    - T : difference between neutral and charged current processes (sensitive to isospin violation)
  - also implemented extended parameters (VWX) and corrections to Zbb couplings [Burgess et al., Phys. Lett. B326, 276 (1994)] [Burgess et al., Phys. Rev. D49, 6115 (1994)]

Fit to Oblique Parameters

- derived from fit to electroweak observables (see global SM fit)
- floating fit parameters: M_Z, $\alpha_s(M_Z^2)$, $\Delta\alpha_{had}^{(5)}(M_Z^2)$
- 68%, 95% CL ellipses for various M_H values and m_t = 172 GeV (fixed)



M_H=116 (350) GeV

S=0.02(-0.06) ± 0.11

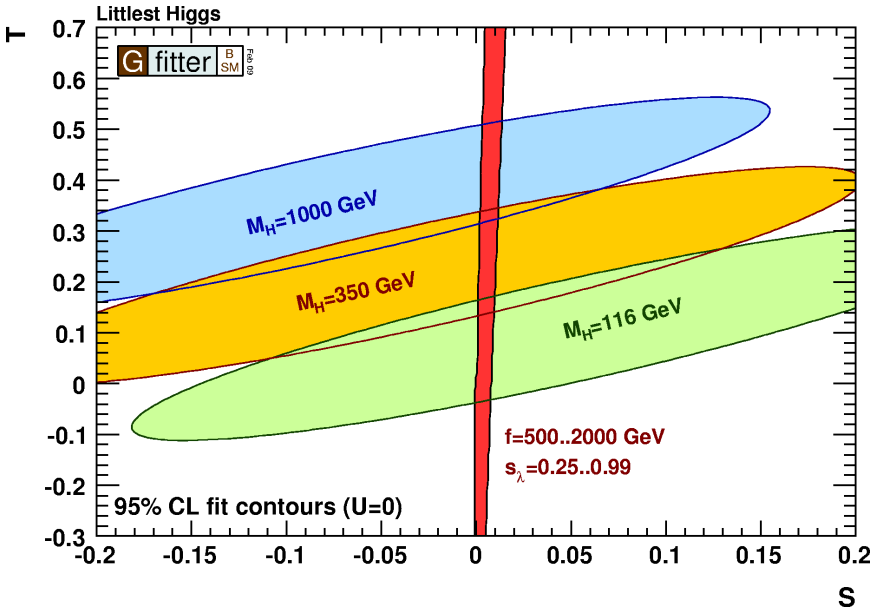
T=0.05(0.15) ± 0.12

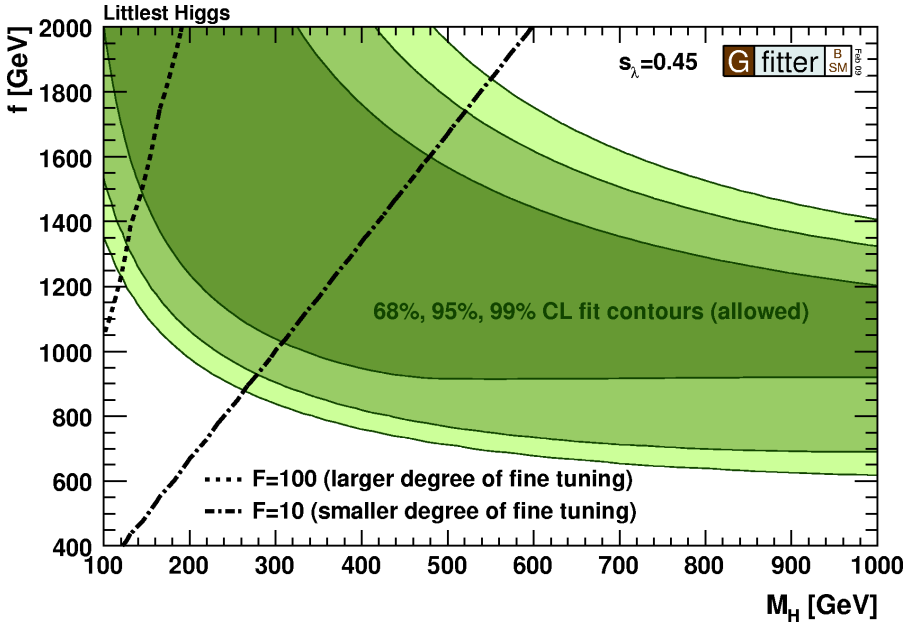
U=0.07(0.08) ± 0.12

Littlest Higgs with T-Parity

- Higgs pseudo-Nambu-Goldstone boson
- new fermions and new gauge bosons
  - two new top states (T-odd m_{T-} and T-even m_{T+})
  - LH solves hierarchy problem (new particles cancel SM loops)
- T-parity
  - provide dark matter candidate
  - forbids tree-level contribution from heavy gauge bosons to SM observables

- parameters of LH model
  - f symmetry breaking scale (scale of new particles)
  - $s_\lambda \cong m_{T-} / m_{T+}$ ratio of masses in top sector
  - order one-coefficient δ_c (exact value depends on detail of UV physics)
    - treated as theory uncertainty in fit (Rfit) δ_c=-5…5
- oblique parameters replaced by corrections from LH model
  [Hubisz et al., JHEP 0601:135 (2006)]



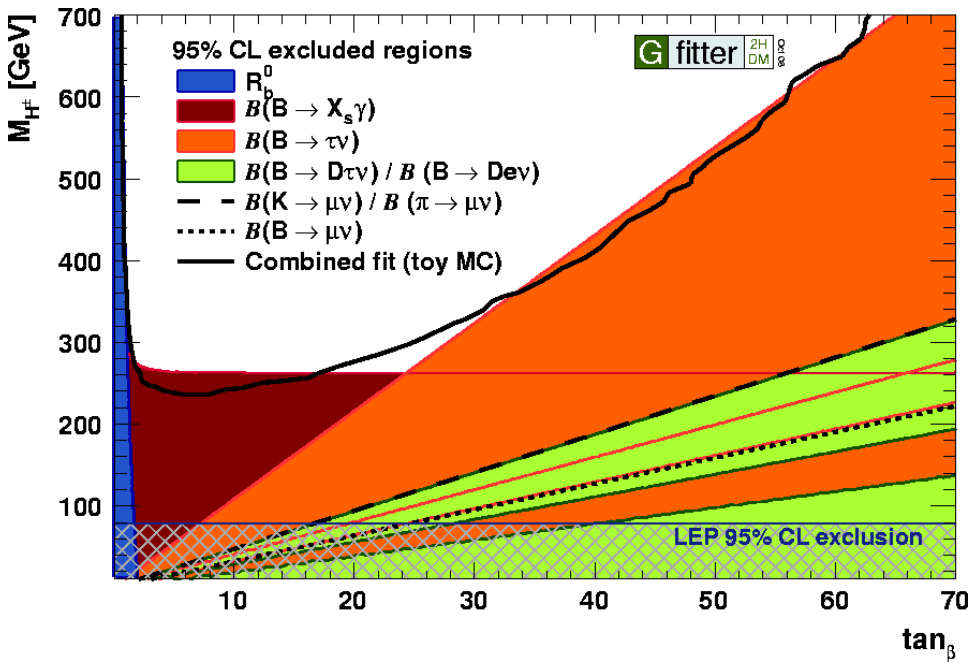


A Gfitter Package for 2HDM SM Extensions

- Two Higgs Doublet Model (Type-II)
  - additional Higgs doublet
  - one doublet couples to up-type, one doublet couples to down-type fermions
  - 6 free parameters → $M_{H\pm}$, M_{A0}, M_{H0}, M_h, $\tan\beta$, $|\alpha|$

Two Higgs Doublet Model

observable	input value	exp. ref	calculation
R_b^0	0.21629 ± 0.00066	[ADLO, Phys. Rept.427, 257 (2006)	[H. E. Haber and H. E. Logan, Phys. Rev. D62, 015011 (2000)]
BR (B->$X_s\gamma$)	(3.52±0.23±0.09) ·10^{-4}	[HFAG, latest update]	[M. Misiak et al., Phys. Rev. Lett. 98, 022002 (2007)]
BR (B->τν)	(1.51±0.33) ·10^{-4}	[P.Chang, Talk at ICHEP 2008]	[W. S. Hou, Phys. Rev. D48, 2342 (1993)]
BR (B->μν)	(-5.7±6.8±7.1) ·10^{-4}	[E. Baracchini, Talk at ICHEP 2008]	[W. S. Hou, Phys Rev. D48, 2342 (1993)]
BR (K->μν)/ BR(π->μν)	1.004±0.007	[FlaviaNet,, arXiv:0801.1817]	[FlaviaNet, arXiv:0801.1817]
BR(B->Dτν)/ BR(B->Dev)	0.416±0.117±0.052	[Babar, Phys. Rev. Lett 100, 021801 (2008)]	[J. F. Kamenik and F. Mescia, arXiv:0802.3790]



- so far: only looked at processes sensitive to charged Higgs → $M_{H\pm}$, tanβ
- overlay of individual 95% CL excluded regions
  - assuming n_{dof}=1 and 2-sided limits
- combined fit:
  - ndof ambiguity resolved by MC toy study assuming 2-sided limits
- excluded at 95% CL:
  - small tanβ
  - for all tanβ
    - M_H < 240 GeV
    - M_H < 780 GeV for tanβ=70

Conclusion

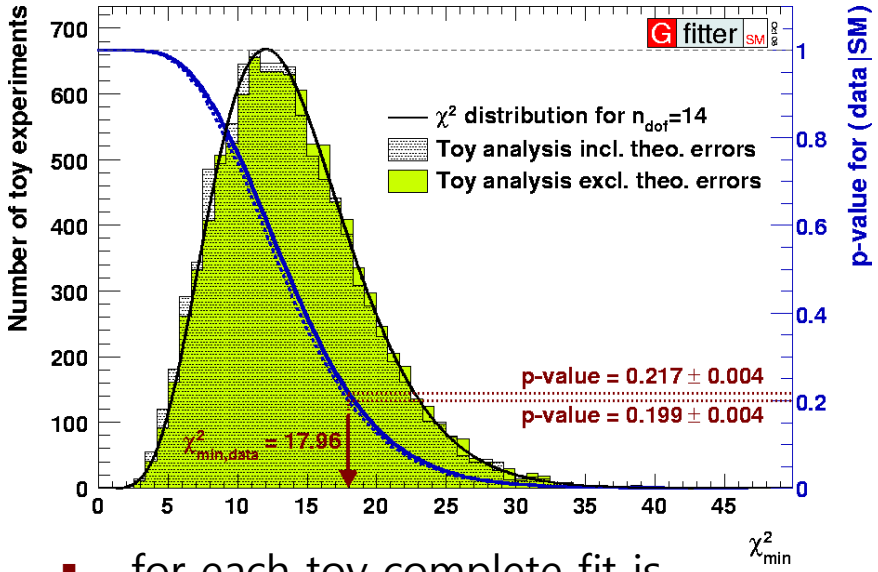
- Gfitter is a framework for involved fitting problems
  - advanced studies of statistical fit properties
- results for electroweak fit of the SM
  - inclusion of direct Higgs searches → $M_H = 116.4^{+18.3}_{-1.3}\ \mathrm{GeV}$
  - no evidences for physics beyond SM (p-value, pull values, small oblique corrections)
- assuming new physics models
  - constraints on Littlest Higgs model
  - constraints on Two-Higgs-Doublet Model (Type II)
- continuous support
  - Stay tuned for updated results with new Higgs combination from Tevatron at end of conference
- more information/results:
  - http://cern.ch/Gfitter
  - paper accepted by Eur. Phys. J. C, (arXiv:0811.0009)

A Generic Fitter Project for HEP Model Testing

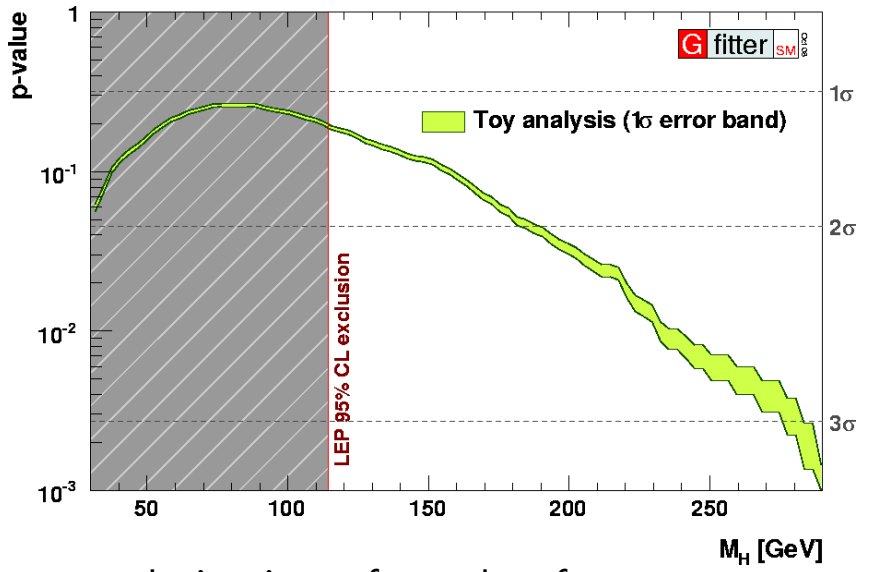
Backup

Goodness of Global Fit

- determine p-value by using MC toy experiments
  - p-value: probability for wrongly rejecting the SM
  - p-value: probability for getting a $\chi^2_{min,toy}$ larger than the $\chi^2_{min,data}$ from data



- for each toy complete fit is performed
- p-value = $(21.7 \pm 0.4_{-0.2})\%$
  - no significant requirement for new physics



- derivation of p-value for standard fit as function of M_H
- small p-values for large Higgs masses (M_H~250 GeV)

- usually unable to indicate signals for physics beyond SM
  - sensitive observables mixed with insensitive ones

Complete Fit: Direct Higgs Searches

- complete fit: $\chi^2_{min}/n_{dof}=18.0/14$
  - Higgs mass:
    - central value ±1σ: $M_H = 116.4^{+18.3}_{-1.3}$ GeV
    - 2σ interval: [114, 145] GeV
- direct Higgs searches from LEP and Tevatron
  - using one-sided CL_{s+b}
    - sensitive to too few Higgs-like events
  - we are interested in any kind of deviation from "s+b" hypothesis
    - also too many Higgs-like events
    - transform one-sided CL_{s+b} into 2-sided $CL_{s+b}^{2\text{-sided}}$
  - compute contribution χ^2 to assuming symmetric PDF:

$$\delta\chi^2 = \mathrm{Erf}^{-1}(1-\mathrm{CL}_{s+b}^{2-\mathrm{sided}})$$