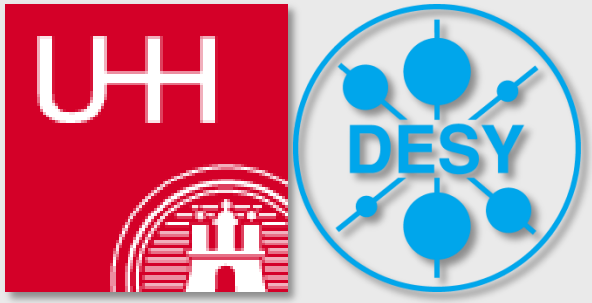
Martin Goebel (DESY / Universität Hamburg)
for the Gfitter group*



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Status of the global fit to electroweak precision data and constraints on the Higgs boson

paper published **Eur. Phys. J. C 60, 543 (2009)**

http://cern.ch/Gfitter

*) M. Baak (CERN), H. Flächer (Rochester), M. G. (Univ. Hamburg, DESY), J. Haller (Univ. Hamburg), A. Höcker (CERN), D. Ludwig (Univ. Hamburg, DESY), K. Mönig (DESY), M. Schott (CERN) J. Stelzer (DESY)

Outline

A Generic Fitter Project for HEP Model Testing

- experimental input
- fit results
  - Goodness-of-Fit
  - determination of strong coupling constant
  - constraints on the Higgs boson mass
  - results on the Top Mass
  - prospects for LHC, ILC, and ILC(+GigaZ)
- conclusions

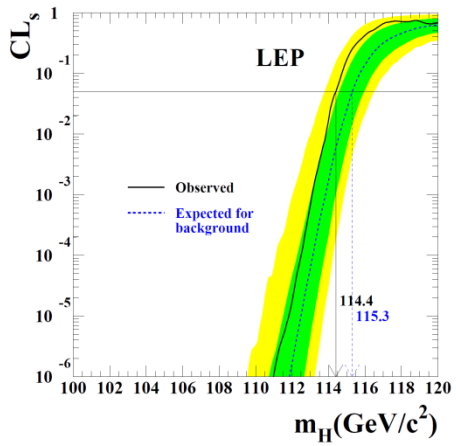
The Global Electroweak Fit

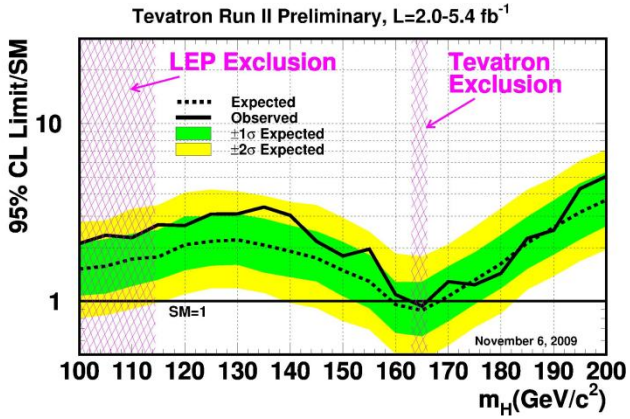
A Gfitter Package for the Global Electroweak Fit

- 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)] [M. Awramik et al., JHEP 11, 048 (2006), (M. Awramik et al., Nucl.Phys.B813:174-187 (2009)]
  - radiator functions: N^{3}LO of the massless QCD Adler function
    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]
- theoretical uncertainties:
  M_W (δM_W=4-6 GeV), $\sin^2\theta^l_{eff}$ ($\delta\sin^2\theta^l_{eff}$ =4.7 $\cdot 10^{-5}$)

Experimental 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 M_W=80.399 ± 0.023 GeV
    [ADLO, hep-ex/0612034] [CDF, Phys. Lett. 100, 071801 (2008)] [CDF&D0, Phys. Rev. D 70, 092008 (2004)][CDF&D0, arXiv:0908.1374v1]
  - **m_{top}**: m_{top}=173.3 ± 1.1 GeV [D0&CDF, arXiv:1007.3178]
  - **$\Delta\alpha_{had}^{(5)}(M_Z^2)$:** including α_S dependency [Hagiwara et al., Phys. Lett. B649, 173 (2007)]
  - **$\overline{m}_c$, $\overline{m}_b$**: world averages [PDG, J. Phys. G33,1 (2006)]
- 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:
  - all data except results from direct Higgs searches
  - all data including results from direct Higgs searches at LEP [ADLO: Phys. Lett. B565, 61 (2003)] and Tevatron [CDF+D0: arXiv:0911.3930]





Goodness-of-Fit

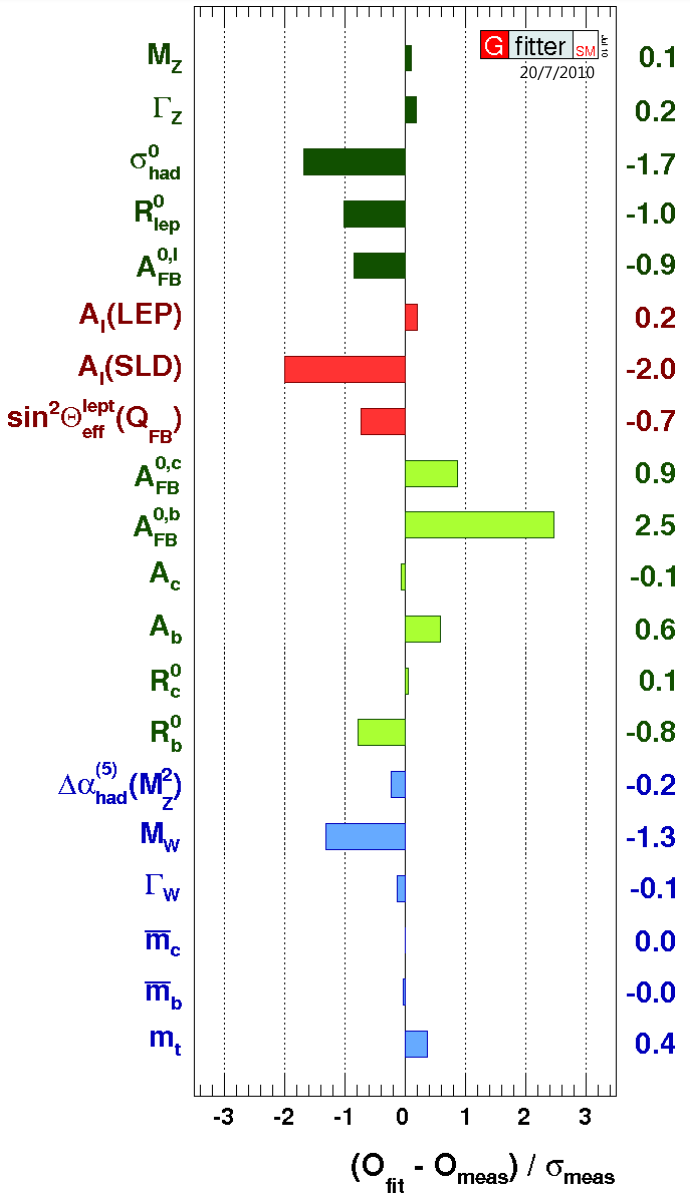
naïve p-value

- w/o direct Higgs searches:
  $\chi^2_{min}=16.4 \rightarrow$ `Prob(`χ^2_{min}`,13)=0.23`
- with direct Higgs searches:
  $\chi^2_{min}=17.8 \rightarrow$ `Prob(`χ^2_{min}`,14)=0.22`

pull-values for the fit with Higgs searches (right figure →)

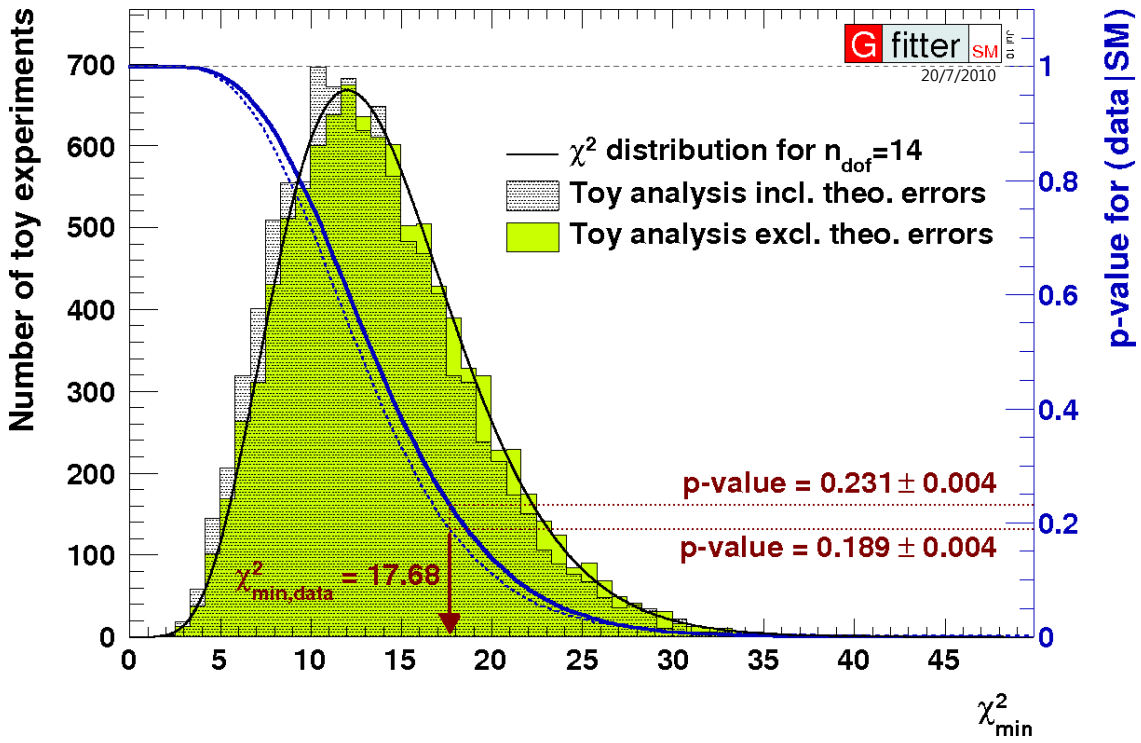
- FB asymmetry of bottom quarks
  → largest contribution to χ^2
- no value exceeds 3σ
- small contributions from M_Z, $\Delta\alpha_{had}^{(5)}$ m_c, and m_b indicate that their input accuracies exceed fit requirements

⇒ no significant requirement for new physics

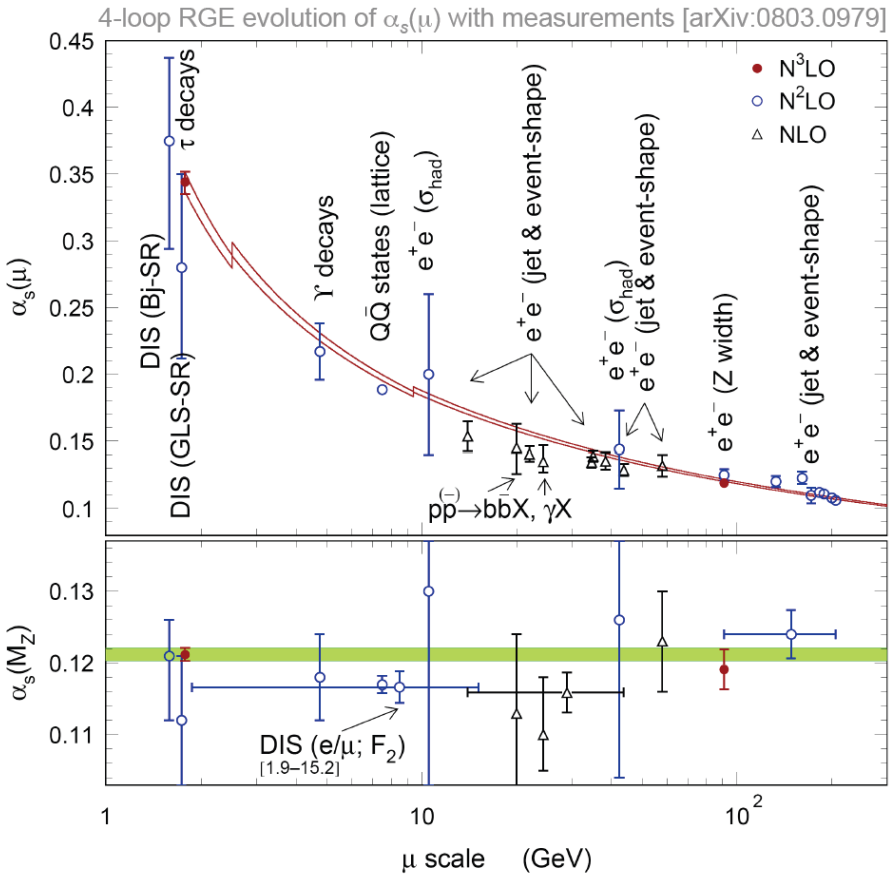


Goodness-of-Fit

- 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
- p-value for fit with Higgs searches $0.23 \pm 0.01\ {}^{-0.02}_{theo}$



Determination of Strong Coupling



- R_l observable most sensitive to α_s
- N^{3}LO (massless Adler function) determination of α_S from complete fit:

$$\alpha_s(M_Z) = 0.1193 \pm 0.0028 \pm 0.0001$$

  - first error experimental
  - second error theoretical
    [incl. variation of renorm. scale from $M_Z/2$ to $2M_Z$ and massless terms of order/beyond $a_s^5(M_Z)$ and massive terms of order/beyond $a_s^4(M_Z)$]
  - excellent agreement with N^{3}LO result from hadronic τ decays [M. Davier et al., arXiv:0803.0979]

$$\alpha_s(M_Z) = 0.1212 \pm 0.0005_{exp} \pm 0.0008_{theo} \pm 0.0005_{evol}$$

Higgs Mass Constraints

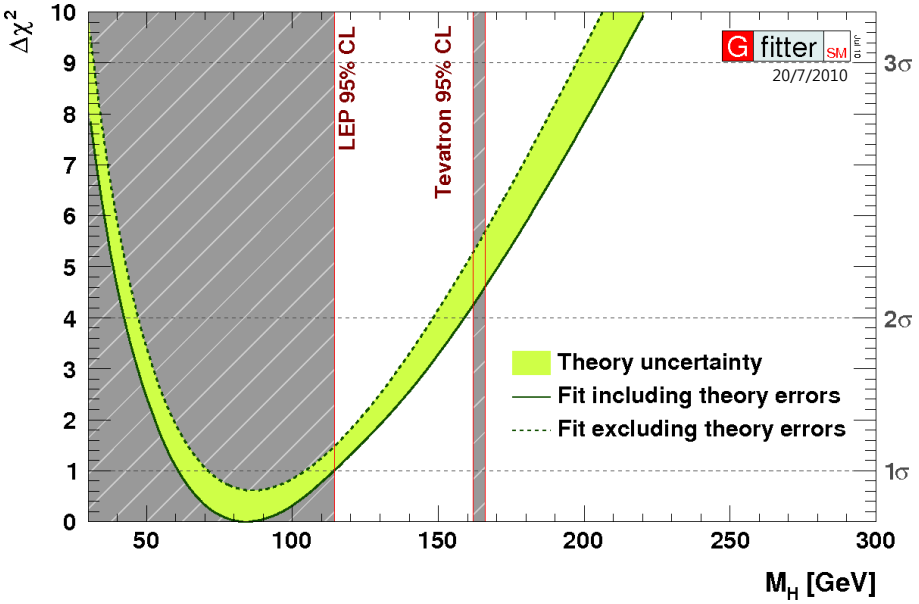
w/o direct Higgs searches:

- value at minimum ±1σ:

$$M_H = 83^{+30}_{-23}\ \text{GeV}$$

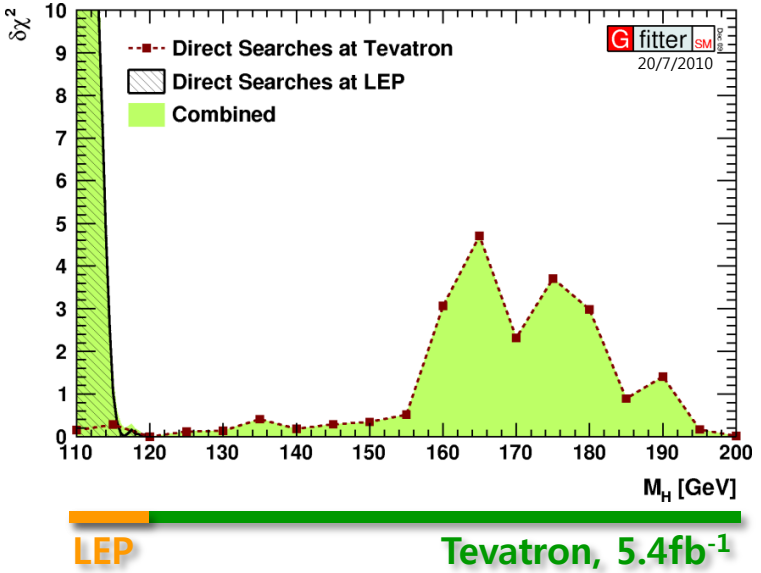
- 2σ interval: [42, 159] GeV

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



with direct Higgs searches:

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



Higgs Mass Constraints

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- value at minimum ±1σ:

$$M_H = 83^{+30}_{-23}\ \text{GeV}$$

- 2σ interval: [42, 159] GeV

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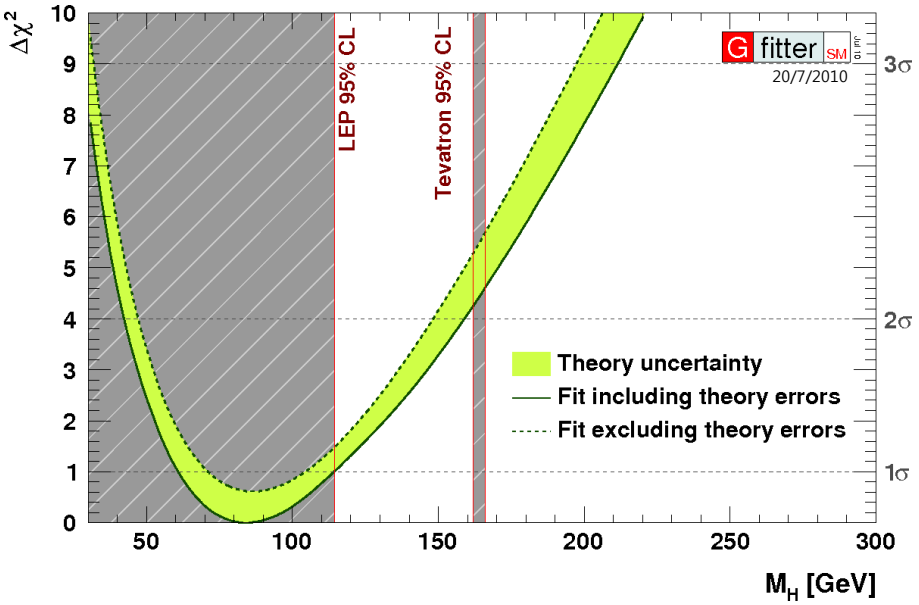
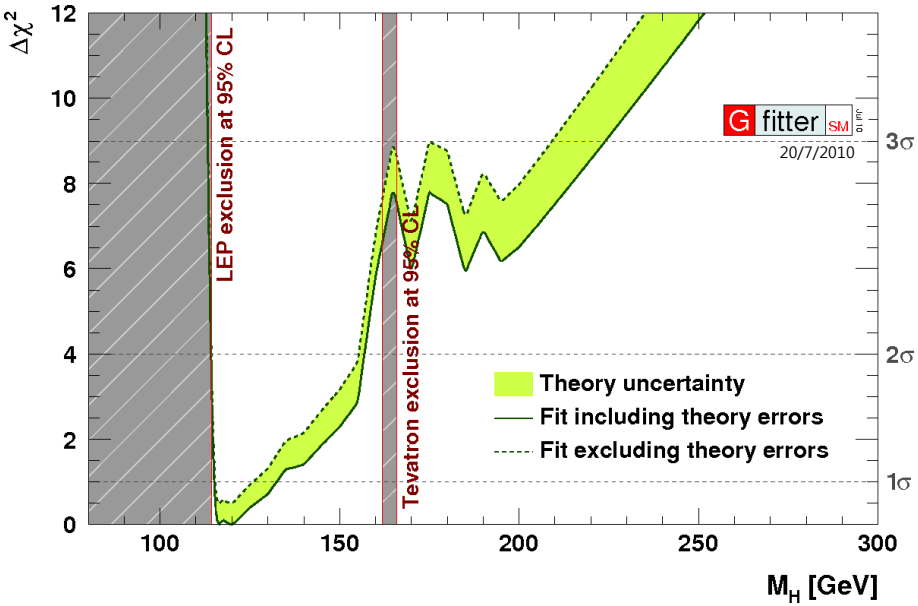
with direct Higgs searches:

- value at minimum ±1σ:

$$M_H = 119.1^{+13.5}_{-4.0}\ \text{GeV}$$

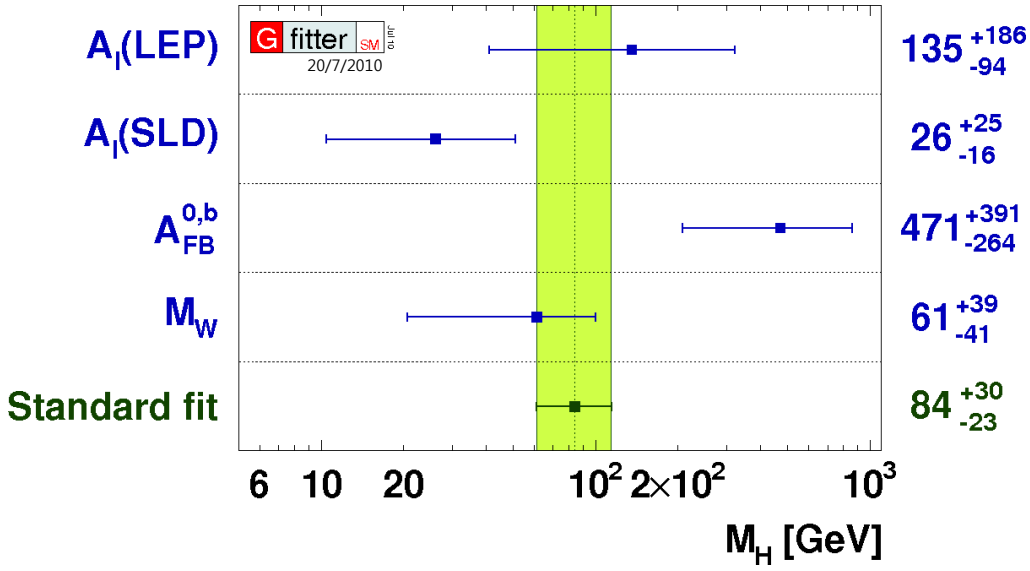
- 2σ interval: [114, 157] GeV





Testing most sensitive observables

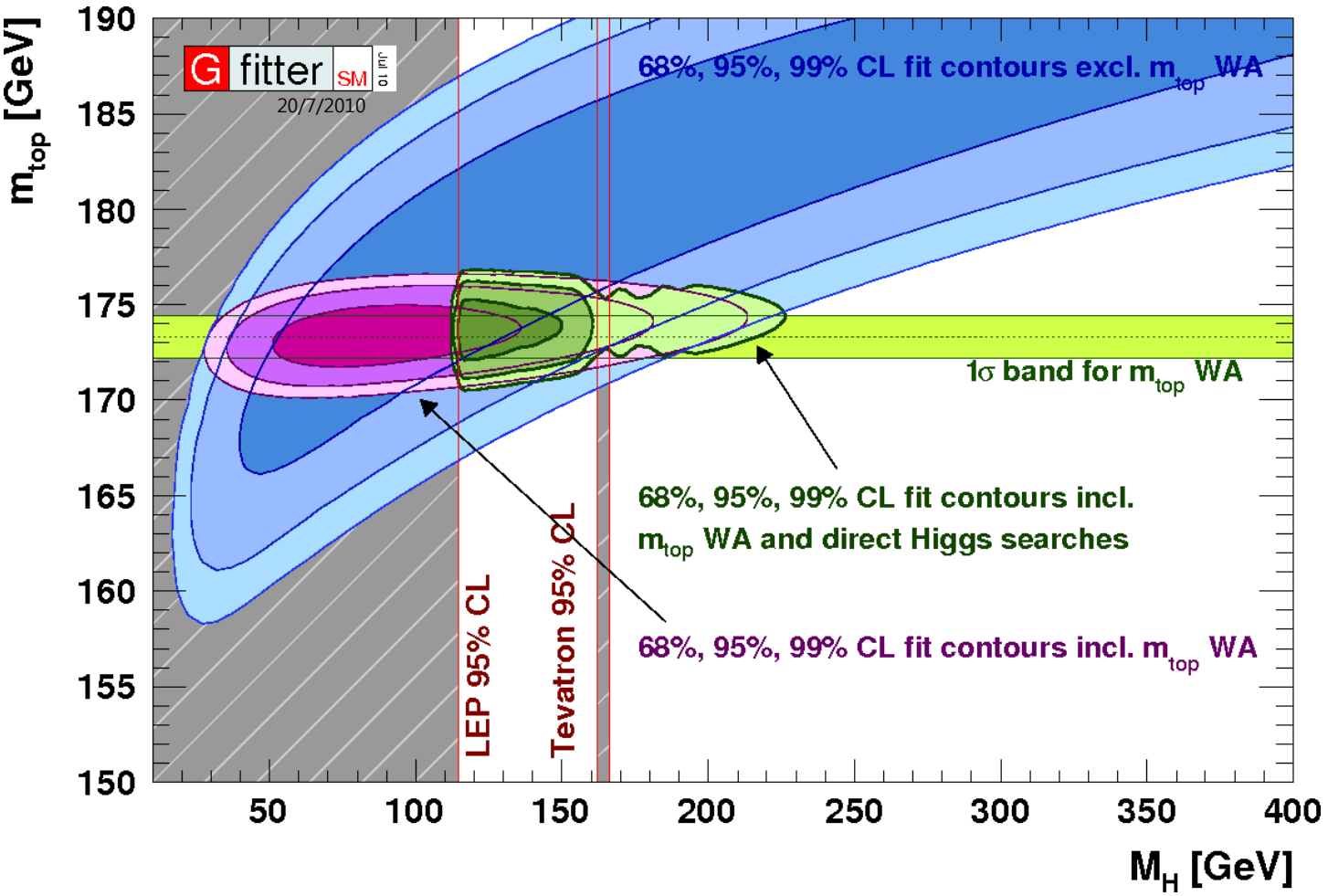
- Higgs mass constraints from most sensitive observables
  - known tension between M_W, A_l(SLD), and $A_{FB}^{0,b}$
  - including measurements of floating fit parameters



- compatibility of 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

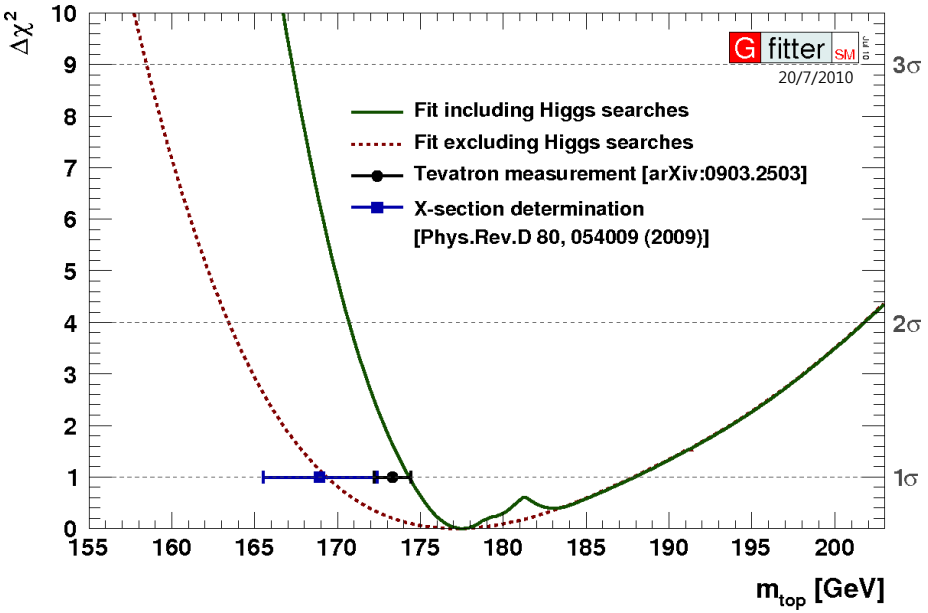
Top vs. Higgs Mass

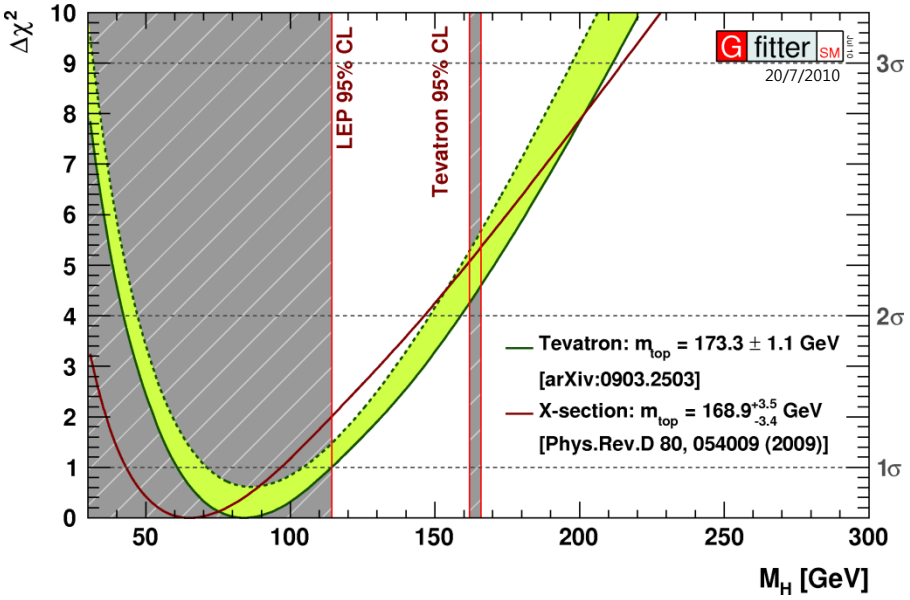
top mass important input for fit (correlation factor with M_H 0.31)



Top Mass Determination

- theoretical predictions use top pole mass
- unclear definition of top mass at Tevatron: "MC" or pole mass?
  [Hoang &Steward., Nucl.Phys.Proc.Suppl.185:220-226,2008]
  ⇒ additional uncertainty?
- alternative: extract top mass from total top pair cross-section
  [Langenfeld, Moch, Uwer, Phys.Rev.D80:054009,2009]
  [see talk 187 by P. Uwer]



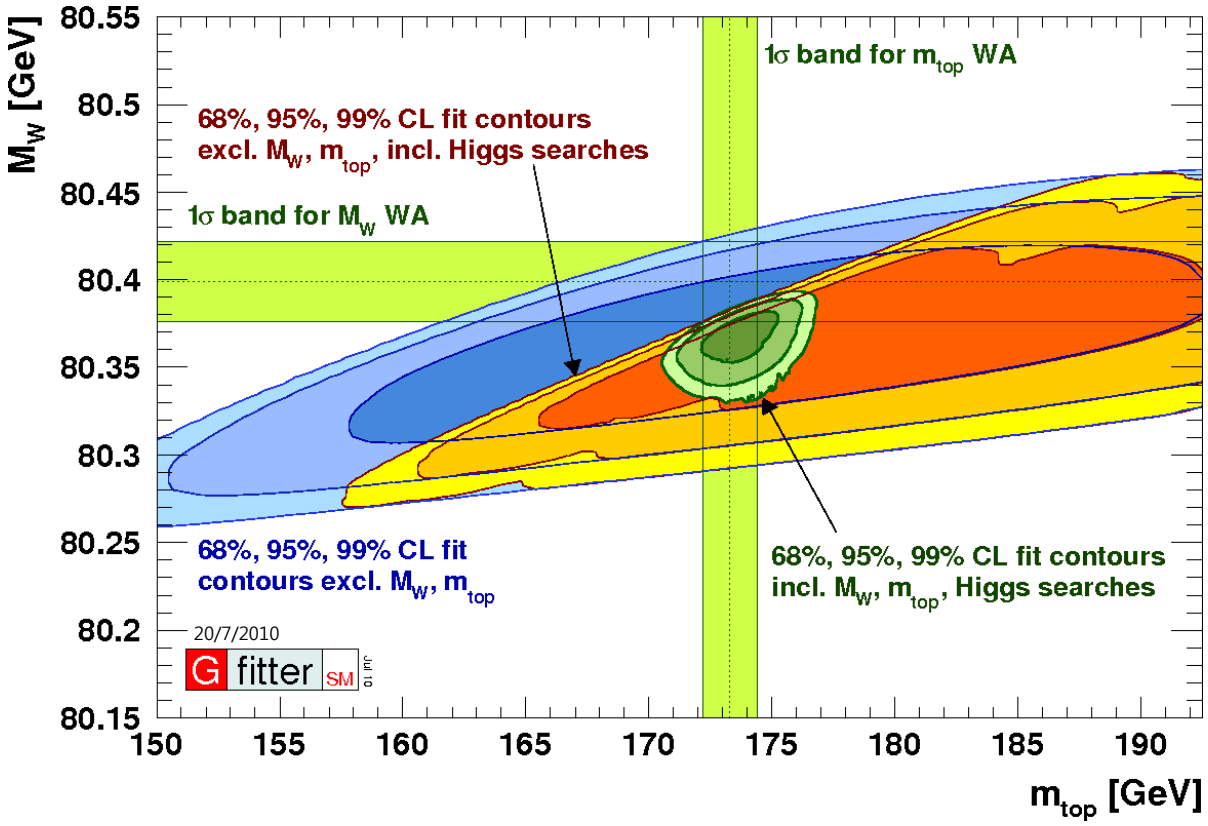


- direct: m_{top}=173.3 ± 1.1 GeV
- X-section: m_{top}=168.9 $^{+3.5}_{-3.4}$ GeV

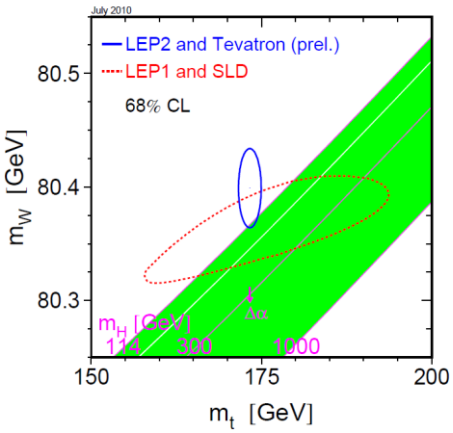
SM Fit:

- w Higgs searches:
  m_{top}=177.2 $^{+10.7}_{-7.8}$ GeV
- w/o Higgs searches:
  m_{top}=177.5 $^{+10.4}_{-3.2}$ GeV

W and Top Mass



for comparison:

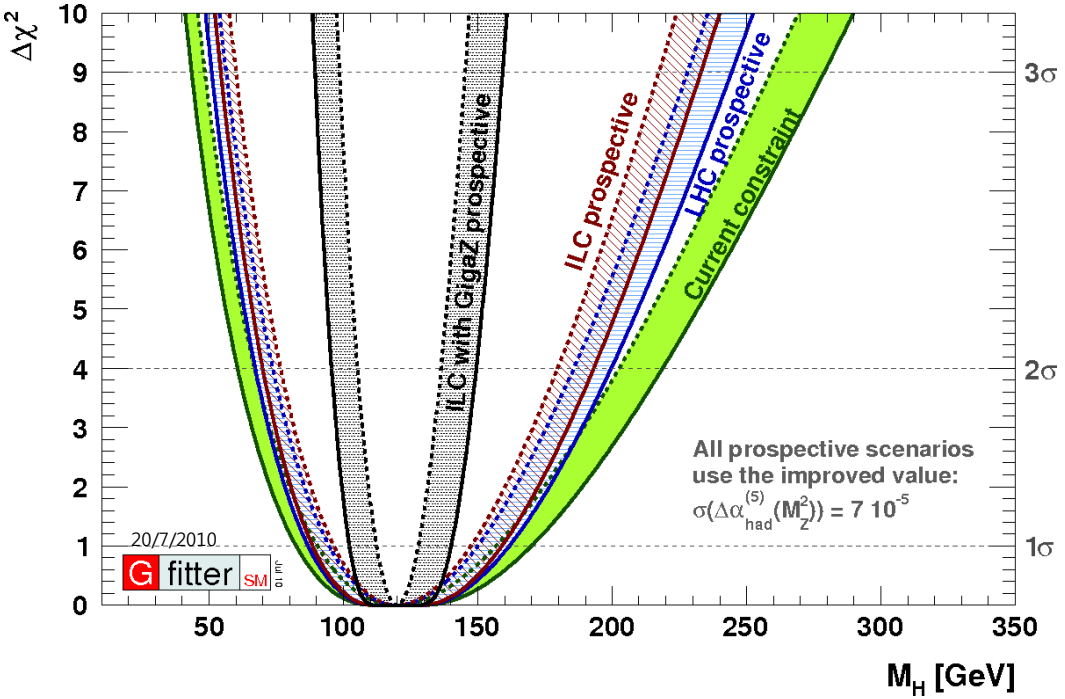


- indirect fit results agree with experimental values
- results from Higgs searches significantly reduce the allowed parameter space
- illustrative probe of SM (if M_H is measured at LHC and/or ILC)

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]	23	15	15	6
m_t [GeV]	1.1	1.0	0.2	0.1
$\sin^2\theta^\ell_{\rm eff}$ $[10^{-5}]$	17	17	17	1.3
R_ℓ^0 $[10^{-2}]$	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]	$^{+53}_{-40}$ $(^{+50}_{-37})$ $[^{+37}_{-30}]$	$^{+44}_{-35}$ $(^{+42}_{-33})$ $[^{+30}_{-25}]$	$^{+42}_{-33}$ $(^{+39}_{-31})$ $[^{+27}_{-24}]$	$^{+26}_{-23}$ $(^{+20}_{-18})$ $[^{+8}_{-8}]$
$\alpha_s(M_Z^2)$ $[10^{-4}]$	28	28	28	7



- 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 $\alpha_S(M_Z^2)$ due to R_l

*[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]

Conclusion

- using state-of-the art predictions for the electroweak observables
- Toy Analysis of p-value: p = 0.23 ±0.01 -0.02
- small Higgs masses are preferred from SM Fit
- N^{3}LO determination of $\alpha_s(M_Z)$ = 0.1193 ±0.0028 ±0.0001

- detailed information in Eur. Phys. J. C 60, 543 (2009)
- stay tuned on http://cern.ch/Gfitter
- SM Fit used to constrain beyond SM models (UED, RS, SUSY, 4th generation, Littlest Higgs)
  - talk 314 by D. Ludwig in "Beyond the Standard Model" session

Fit Correlation

correlation coefficients between free fit parameters

Parameter	$\ln M_H$	$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$	M_Z	$\alpha_S(M_Z^2)$	m_t	$\overline{m}_c$	$\overline{m}_b$
$\ln M_H$	1	−0.395	0.113	0.041	0.309	−0.001	−0.006
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$		1	−0.006	0.101	−0.007	0.001	0.003
M_Z			1	−0.019	−0.015	−0.000	0.000
$\alpha_S(M_Z^2)$				1	0.021	0.011	0.043
m_t					1	0.000	−0.003
$\overline{m}_c$						1	0.000

Interpretation of Direct Higgs Searches

- 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: $\delta\chi^2 = \mathrm{Erf}^{-1}(1-\mathrm{CL}_{s+b}^{2-\mathrm{sided}})$
- alternative (Bayesian) use of test statistics - 2lnQ
  - similar behavior, but deeper minimum

  ⇒ slightly stronger constraint