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for the Gfitter group*

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Testing the electroweak Standard Model with Gfitter

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http://cern.ch/Gfitter

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Gfitter

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 (this talk)
  - Library for SM extensions via the oblique parameters (this talk)
  - Library for the 2HDM extension of the SM

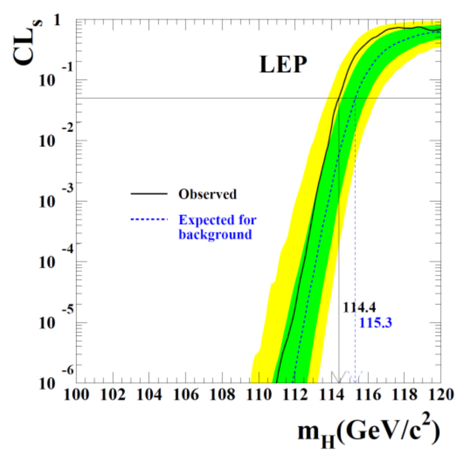
Gfitter SM

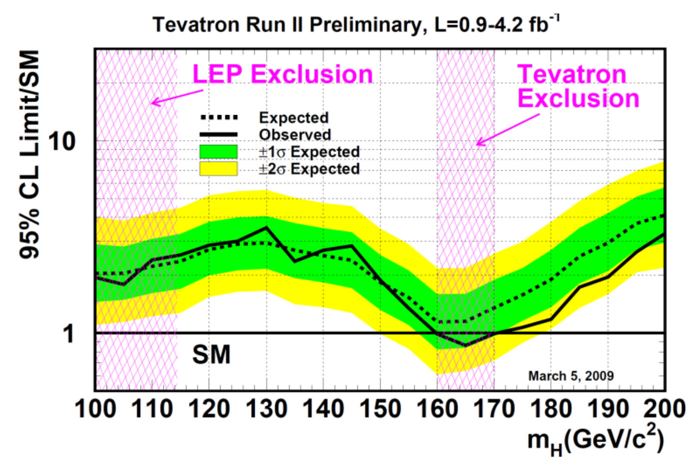
A Gfitter Package for the Global Electroweak Fit

- 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^3LO 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
- theoretical uncertainties: M_W (δM_W=4-6GeV), $\sin^2\theta^l_{eff}$ ($\delta\sin^2\theta^l_{eff}$ =4.7·10^{-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}=173.1 ± 1.3 GeV [D0&CDF, arXiv:0903.2503 [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)]
- 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:0903.4001]





Goodness-of-Fit

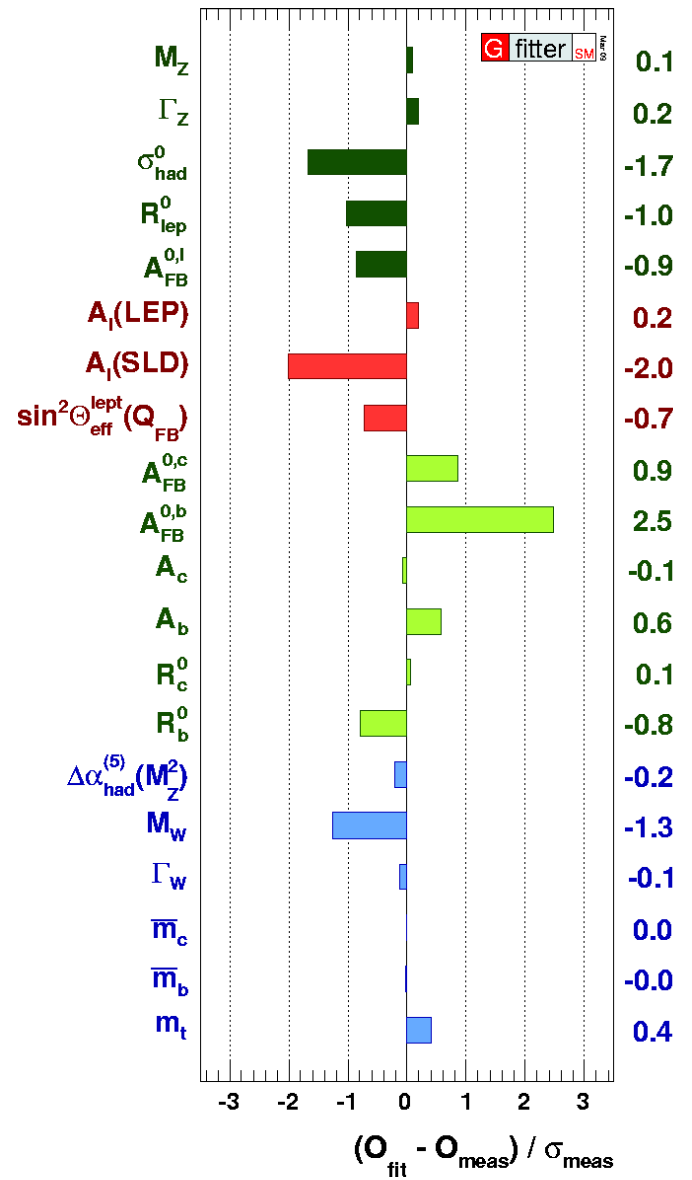
p-value (from MC toy analysis)

- standard fit: $p=0.228 \pm 0.004_{-0.02}$ ($\chi^2_{min}=16.4$)
- complete fit: $p=0.204 \pm 0.004_{-0.02}$ ($\chi^2_{min}=17.9$)

⇒ no significant requirement for new physics

pull-values for complete fit

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



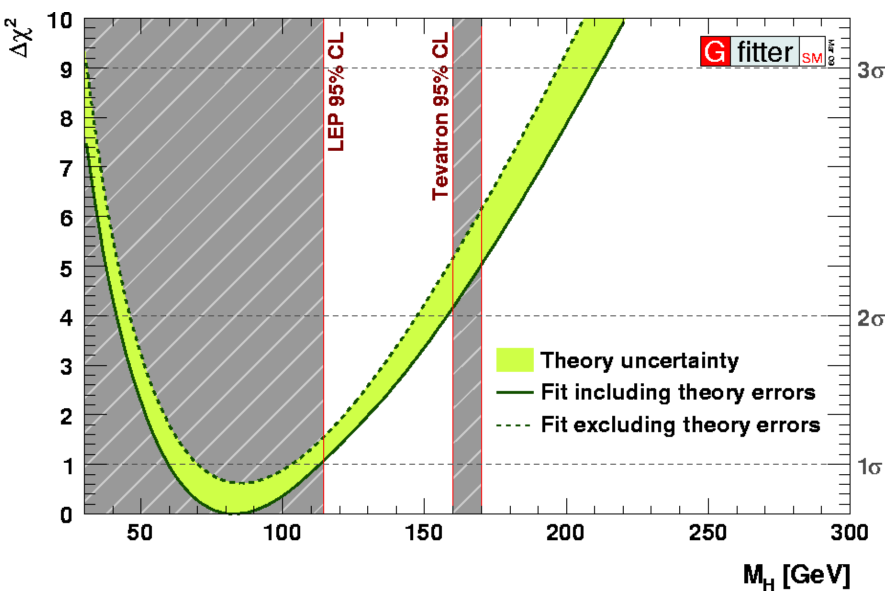
standard fit:

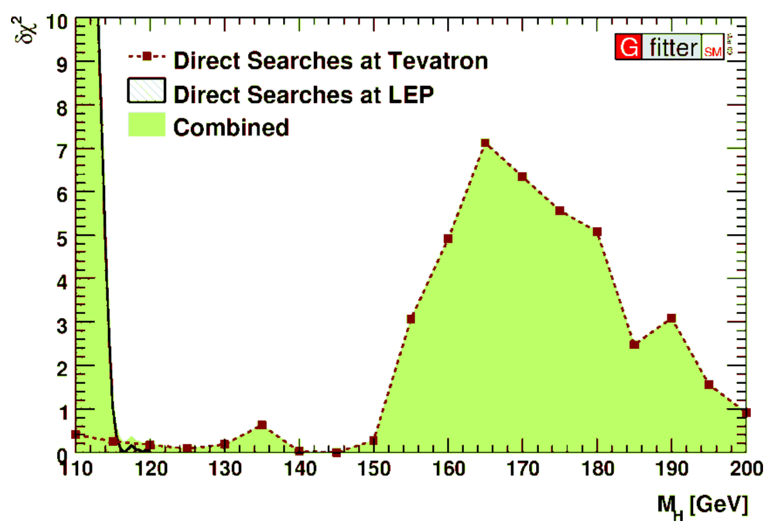
- central value ±1σ: $\boxed{M_H = 83^{+30}_{-23}\ \mathrm{GeV}}$
- 2σ interval: [42, 158] GeV

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

complete fit:

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





LEP

Tevatron, 4.2fb^{-1}

Higgs Mass Constraints

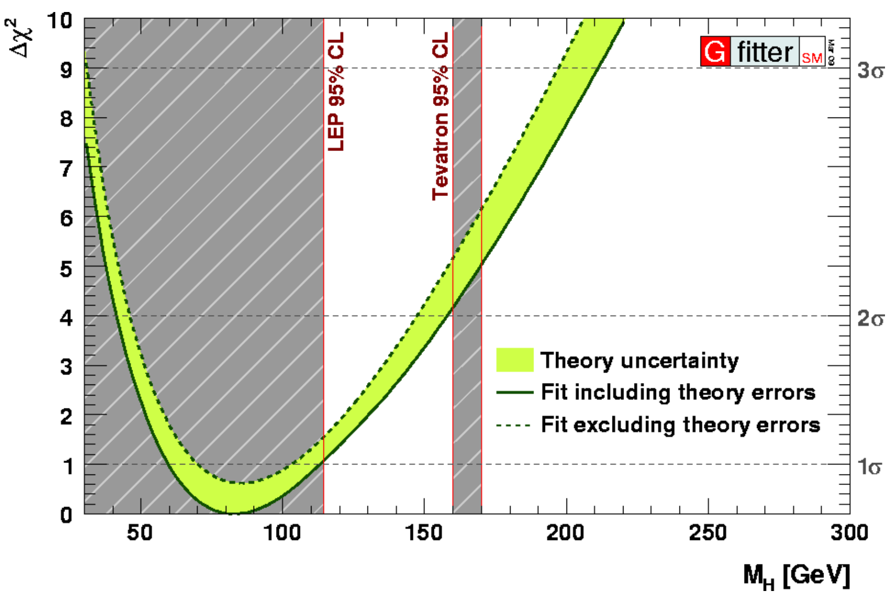
standard fit:

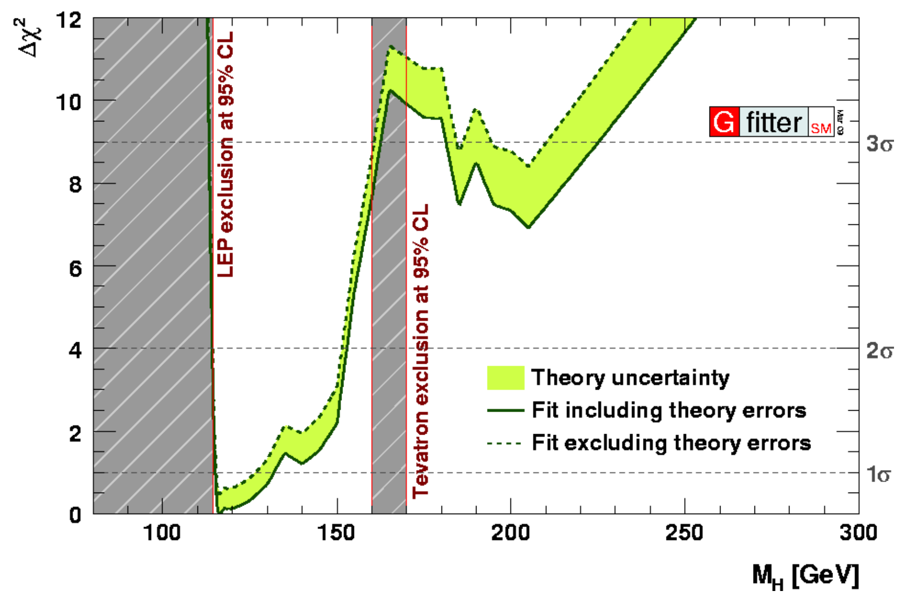
- central value ±1σ: $\boxed{M_H = 83^{+30}_{-23}\ \text{GeV}}$
- 2σ interval: [42, 158] GeV

complete fit:

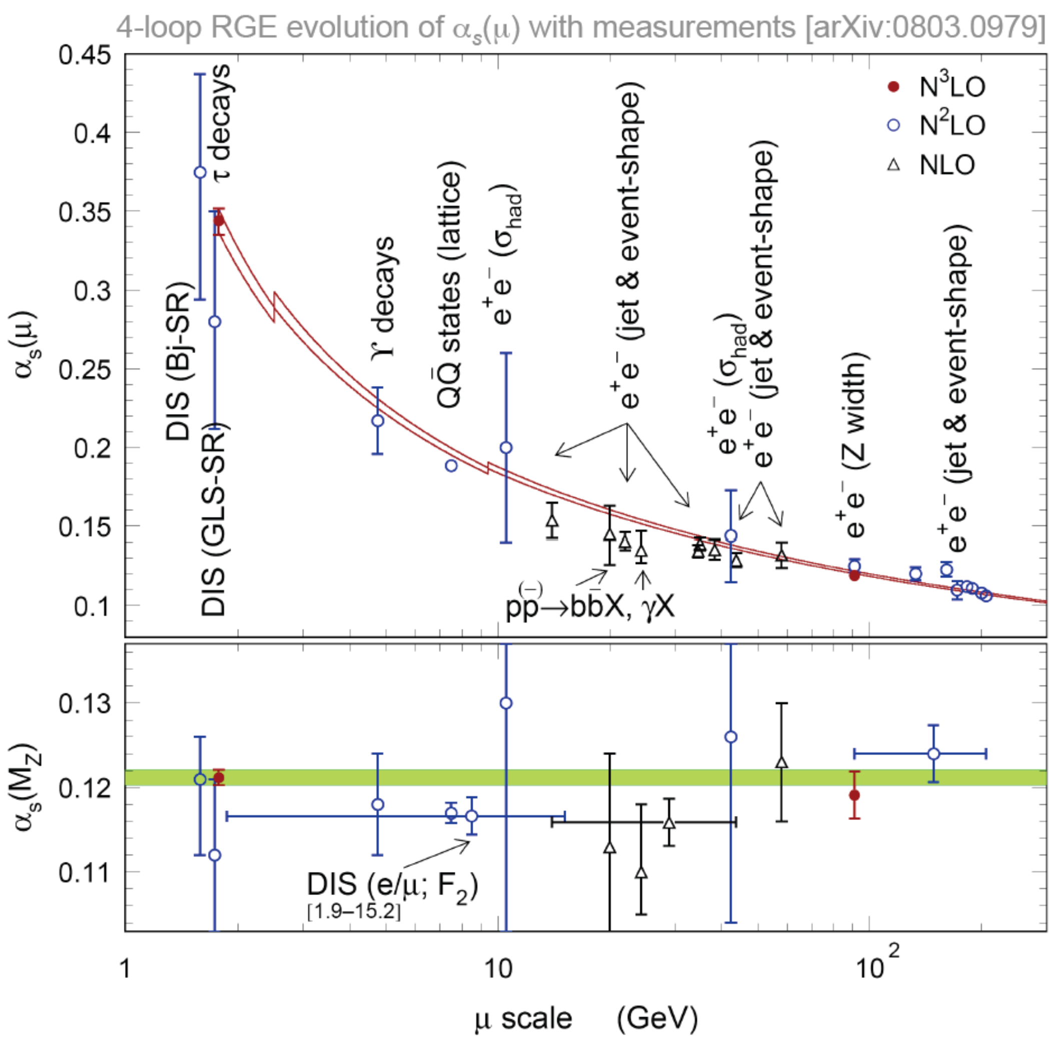
- central value ±1σ: $\boxed{M_H = 116.3^{+15.6}_{-1.3}\ \text{GeV}}$
- 2σ interval: [114, 145] GeV

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





Determination of Strong Coupling



N³LO (massless Adler function) **determination of α_S from complete fit:**

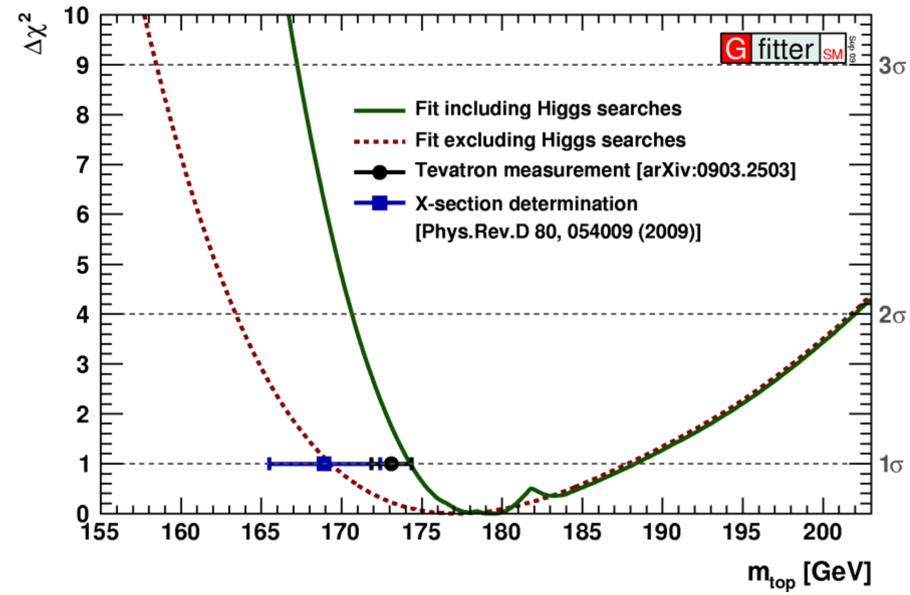
$$\alpha_s(M_Z) = 0.1193 \pm 0.0028 \pm 0.0001$$

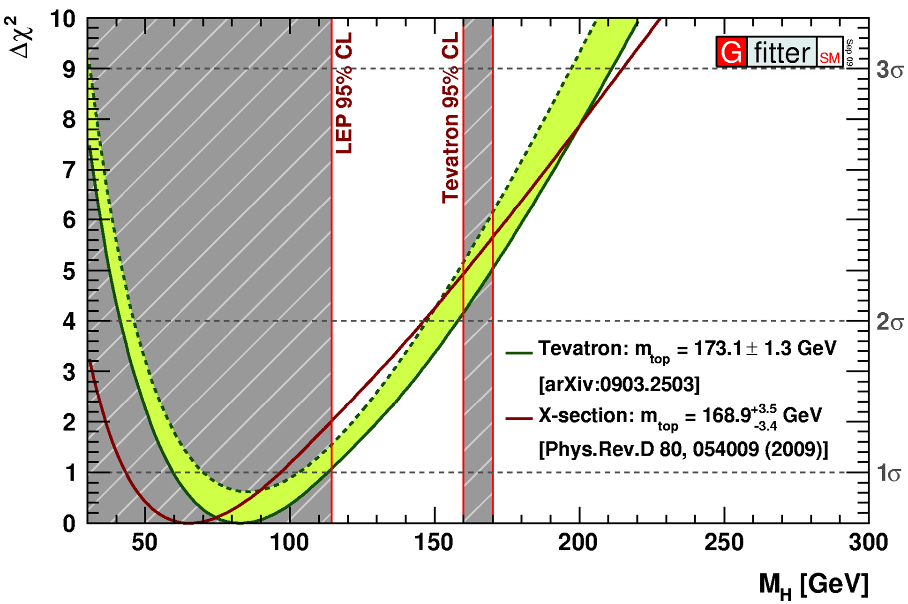
- First error experimental
- Second error theoretical
  [incl. variation of renorm. scale from $M_Z/2$ to $2M_Z$ and massless terms of order/beyond $a_S^5(M_Z)$ and massive terms of order/beyond $a_S^4(M_Z)$]
- Excellent agreement with N³LO result from hadronic τ decays[M. Davier et al., arXiv:0803.0979]

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

Top Mass Determination

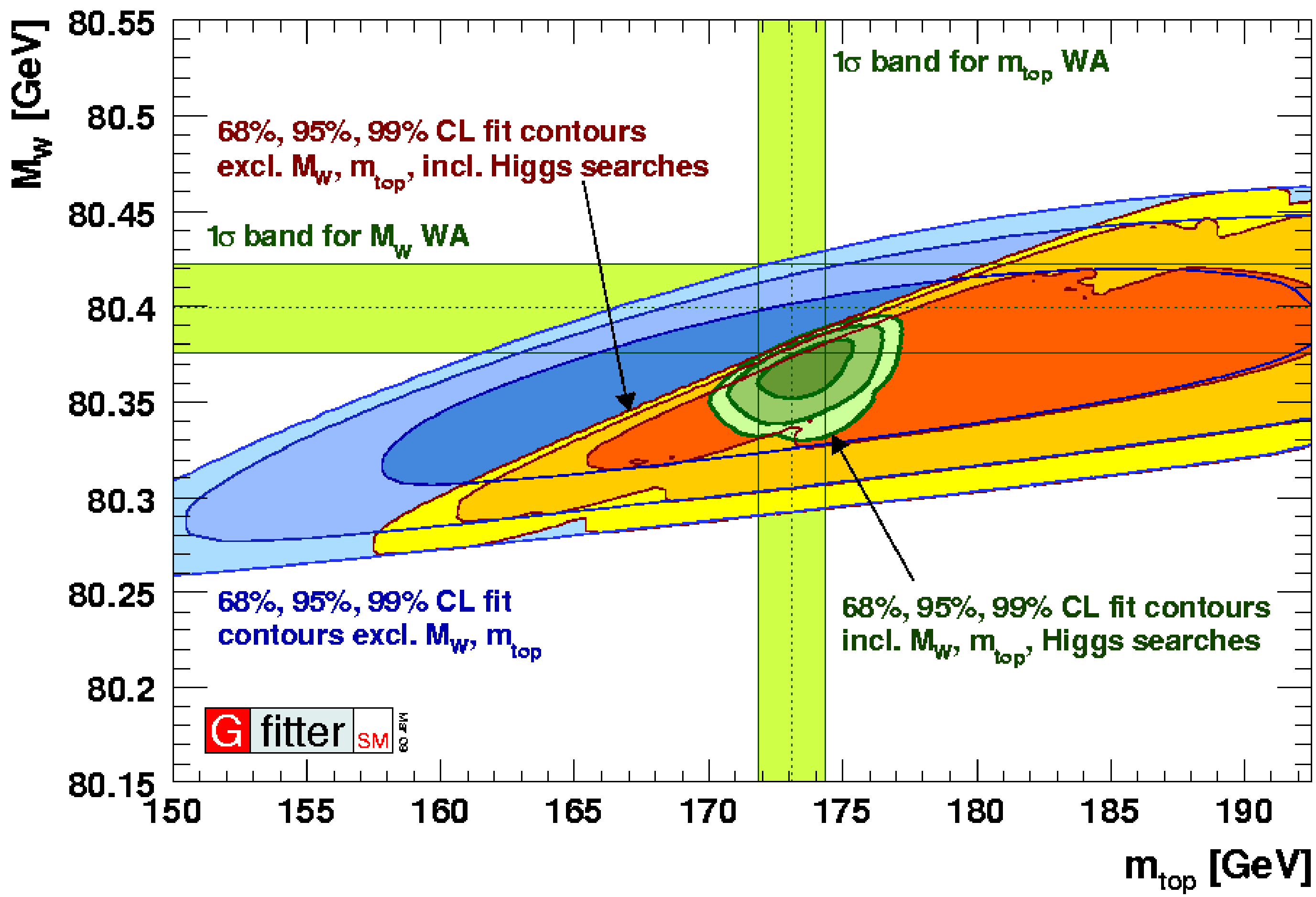
- top mass crucial input for Fit (correlation factor with M_H 0.31)
- SM calculations assume top pole mass
- which top mass at Tevatron: "MC" or pole mass
  [Hoang &Steward., Nucl.Phys.Proc.Suppl.185:220-226,2008]
- additional uncertainty?



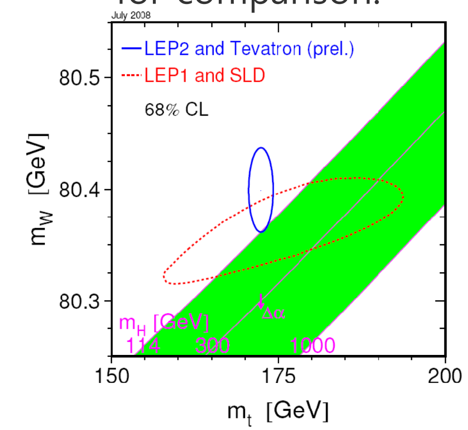


- extraction of MS top mass from total X-section
  [Langenfeld ,Moch,Uwer, Phys.Rev.D80:054009,2009]
- smaller mean value, but larger error than direct measurement

W and Top Mass



for comparison:



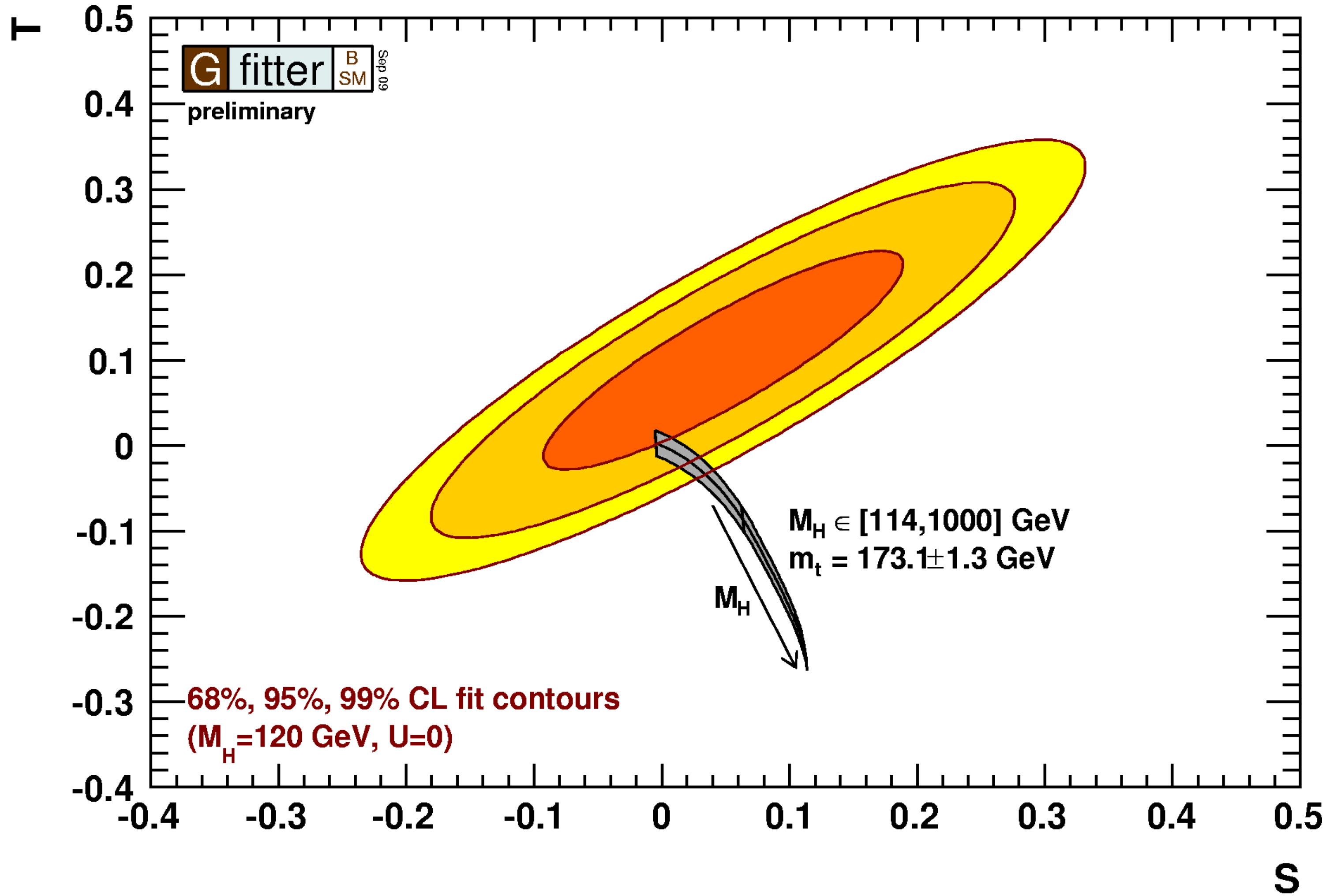
- indirect fit results agree with experimental values
- results from Higgs searches significantly reduce the allowed parameter space
- probe of SM, if M_H is measured at LHC and/or ILC

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)]

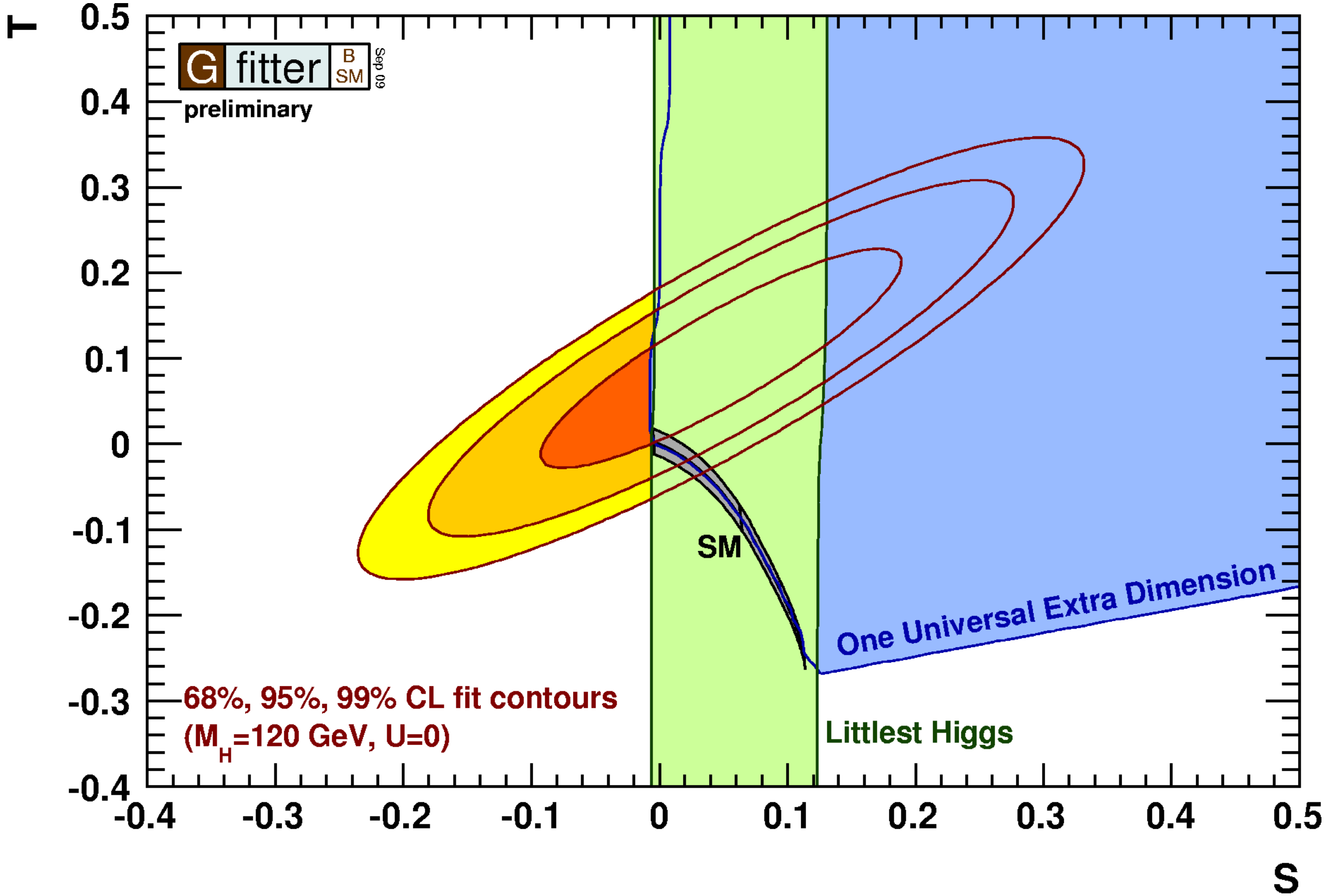
Fit to Oblique Parameters

- derived from fit to electroweak observables (see global SM fit)
- comparison with SM prediction of ST parameters



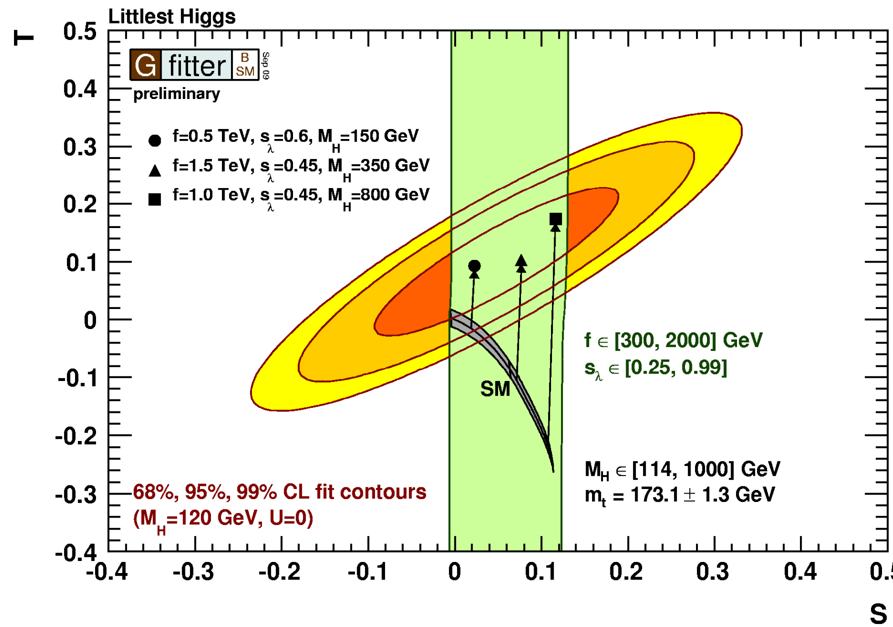
Fit to Oblique Parameters

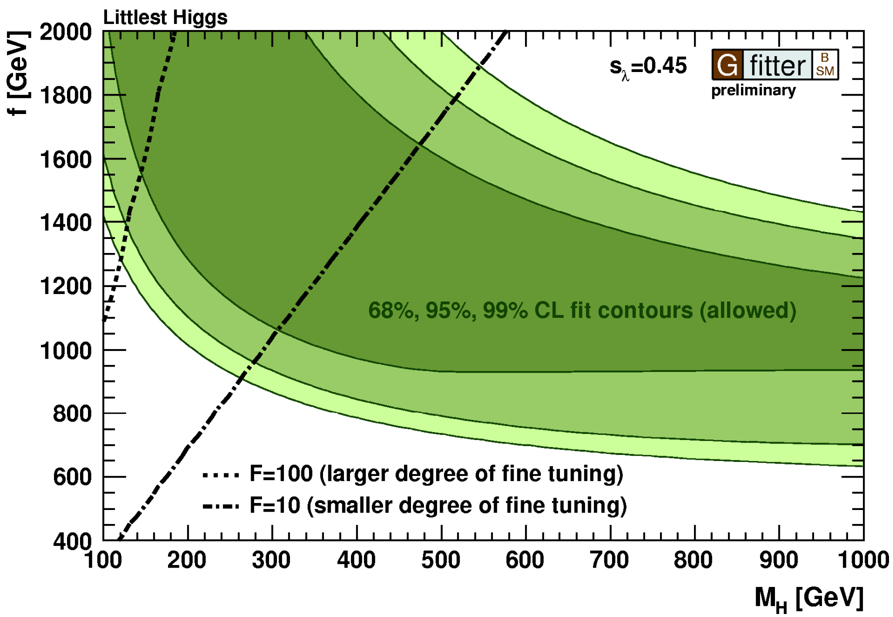
- derived from fit to electroweak observables (see global SM fit)
- comparison with prediction from new physics models



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

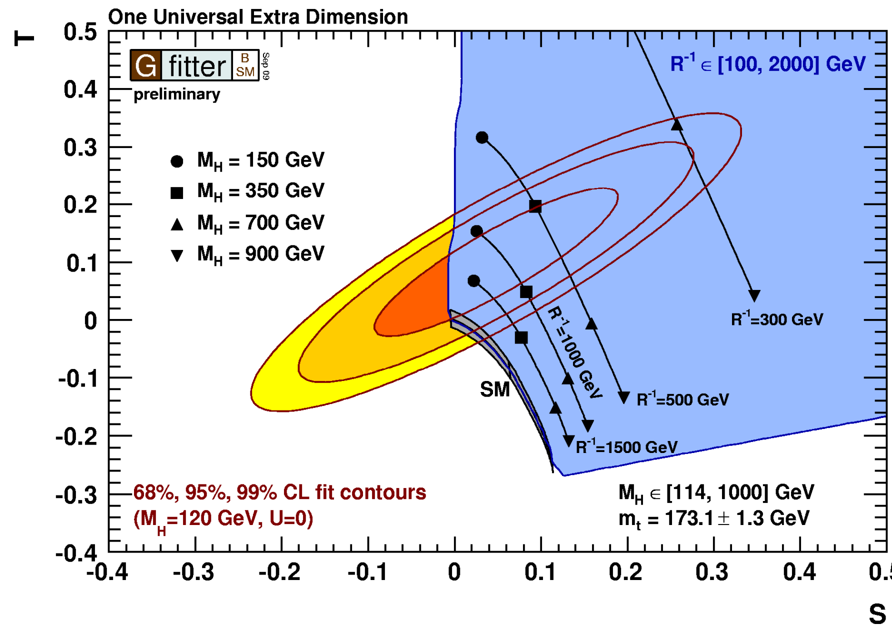


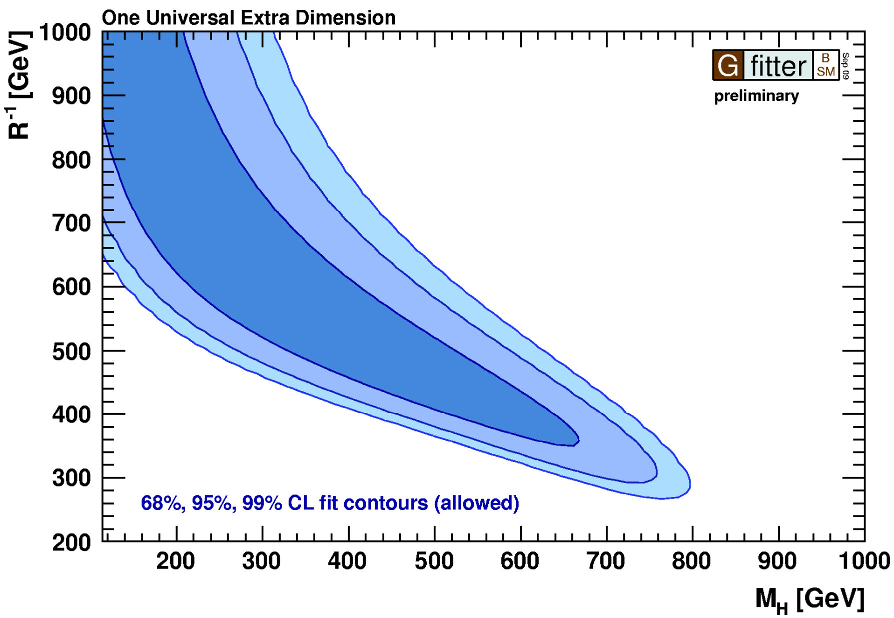


- parameters of LH model
  - f symmetry breaking scale (scale of new particles)
  - $s_\lambda \cong m_{T-} / m_{T+}$ ratio of masses in top sector
  - order one-coefficient δ_c (exact value depends on detail of UV physics)
    - treated as theory uncertainty in fit (Rfit) δ_c=-5…5
- oblique parameters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

One Universal Extra Dimension

- all SM particles propagate in extra Dimension
- conservation of Kaluza-Klein (KK) parity → similar phenomenology as SUSY
- lightest KK state stable → Dark Matter candidate





- parameters of UED model
  - R^{-1} compactification scale (size of extra dimension) $m_{KK} \cong n/R$
  - oblique parameters depend on M_H
- oblique parameters replaced by corrections from UED model
  [Gogoladze et al., Phys.Rev. D 74, 093012 (2006)]
  [Appelquist et al., Phys.Rev. D67 (2003) 055002]

Conclusion

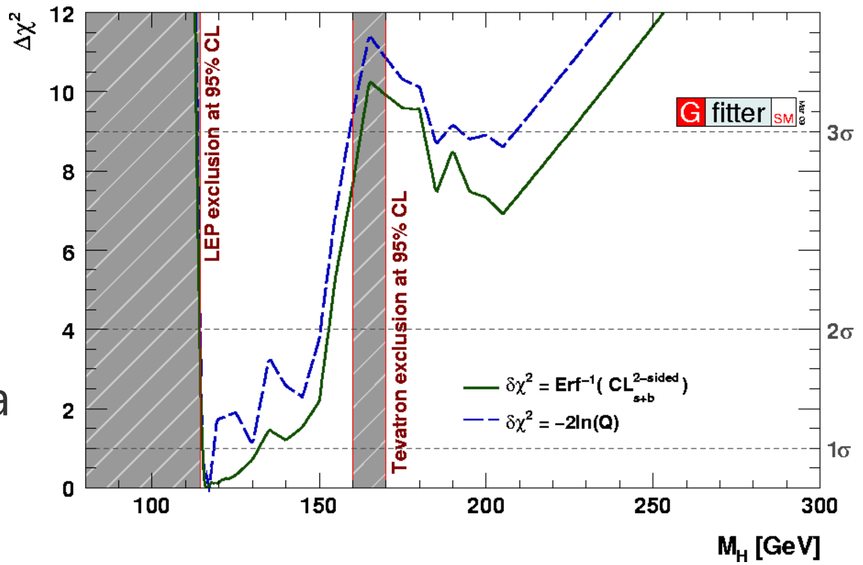
- Gfitter is a framework for involved fitting problems
  - advanced studies of statistical fit properties
- results for electroweak fit of the SM
  - inclusion of direct Higgs searches → $M_H = 116.3^{+15.6}_{-1.3}$ GeV
  - no evidences for physics beyond SM (p-value, pull values, etc.)
- analysis of oblique parameters
  - constraints on oblique parameters
  - constraints on Littlest Higgs and UED model
- continuous support
- more information/results:
  - http://cern.ch/Gfitter
  - paper published in Eur. Phys. J. C 60, 543 (2009), (arXiv:0811.0009)

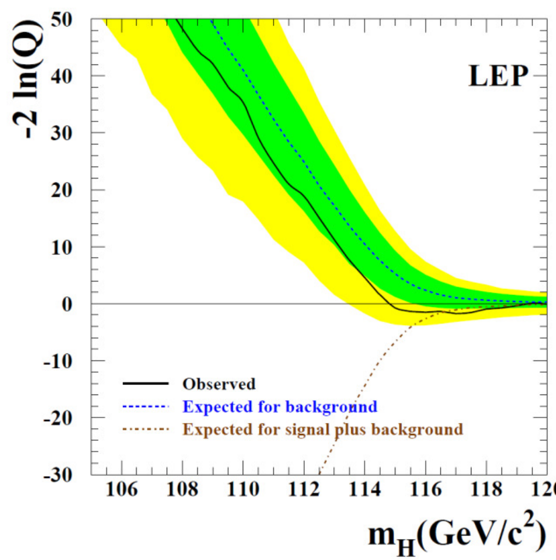
A Generic Fitter Project for HEP Model Testing

Backup

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

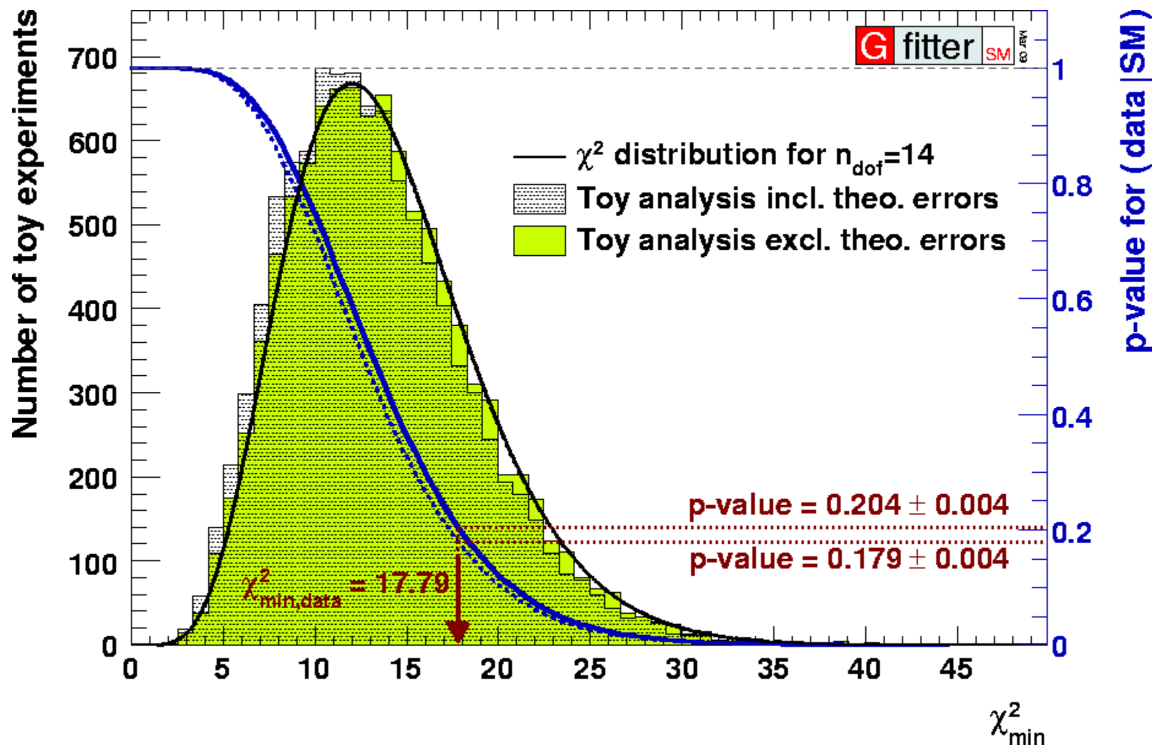




Goodness-of-Fit

p-value (probability for wrongly rejecting the SM)

p-value for complete fit by using MC toy experiments



p-value = $(20.4 \pm 0.4_{-0.2})$%

→ no significant requirement for new physics

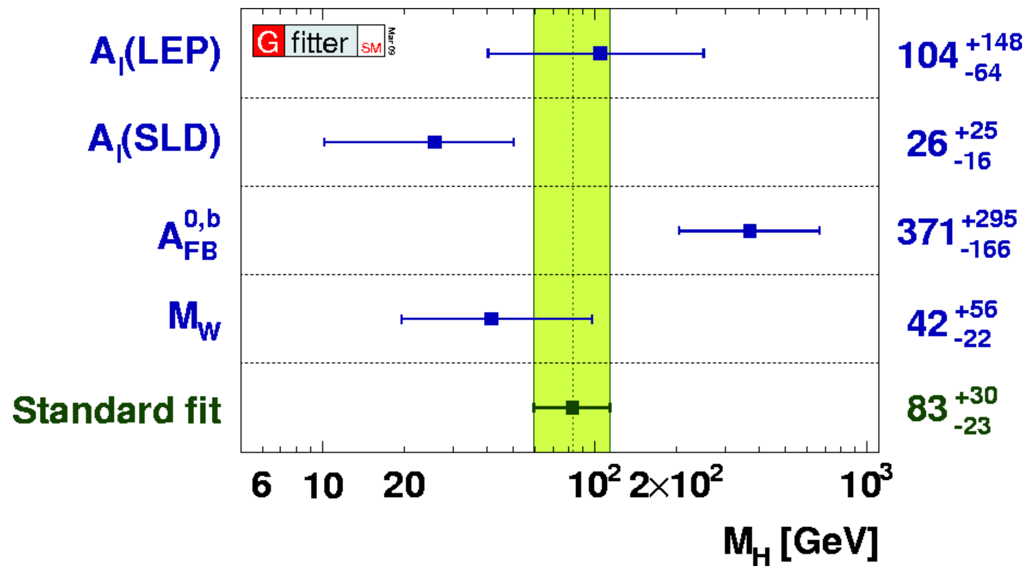
for comparison: naïve p-value

Prob(χ^2_{min}=17.9, n_{dof}=14) = 21%

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

Testing most sensitive observables

- 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

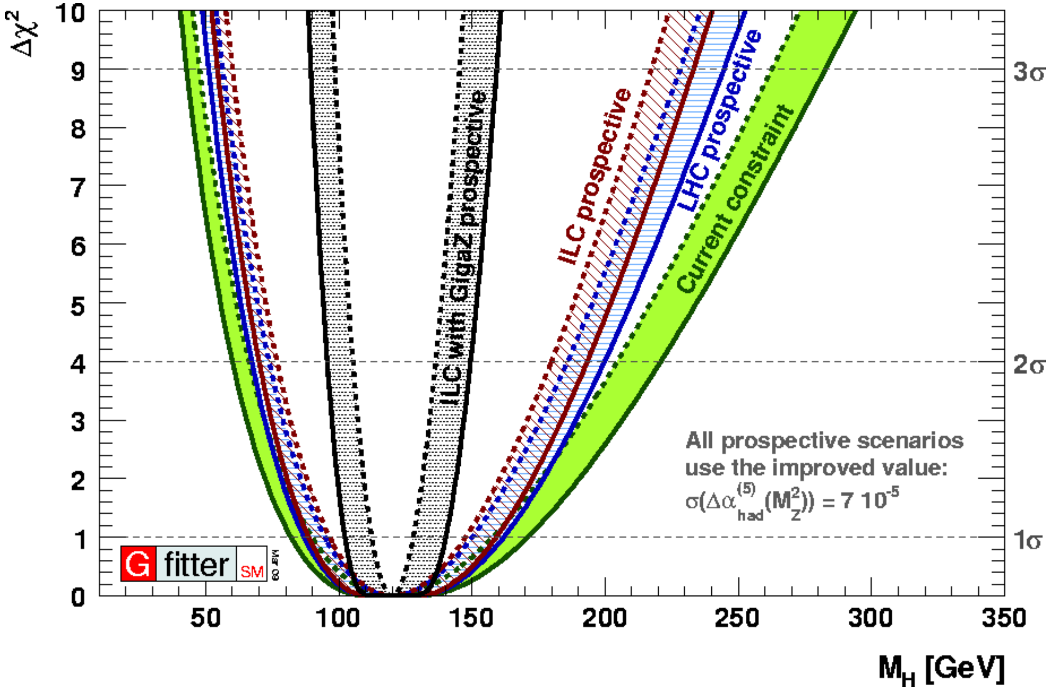


- How compatible are these measurements?
  - MC toy analysis ("look-elsewhere-effect")
    - compare the χ^2_{min} of the full fit with χ^2_{min} of a fit without the least compatible measurement (here $A_{FB}^{0,b}$) → $\Delta\chi^2_{min}=8.0$
    - Generate toy sample around fitted values and repeat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

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	Expected uncertainty			
	Present	LHC	ILC	GigaZ (ILC)
M_W [MeV]	23	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]	$^{+54}_{-40}$ $(^{+51}_{-38})$ $[^{+38}_{-30}]$	$^{+45}_{-35}$ $(^{+42}_{-33})$ $[^{+30}_{-25}]$	$^{+42}_{-33}$ $(^{+39}_{-31})$ $[^{+28}_{-23}]$	$^{+26}_{-23}$ $(^{+20}_{-18})$ $[^{+8}_{-8}]$
$\alpha_s(M_Z^2)$ [10^{-4}]	28	28	28	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]