Global BSM fits and LHC Data
LHC Physics Center
CERN, 10th-11th of February 2011

Gfitter

Constraints on new physics from electroweak precision data

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Outline

- today: Gfitter results obtained so far
  - global electroweak fit (SM)
    - status, focus on recent developments and new results
    - prospects for LHC data
  - BSM constraints from electroweak data
- tomorrow (Max Baak):
  - SUSY fit results
  - inclusion of LHC data via RooStats workspaces

The Gfitter project

A Generic Fitting Project for HEP Model Testing

- Goal: provide a state-of-the-art model testing tool for the LHC era
- Gfitter software and features:
  - modular, object-oriented C++, relying on ROOT, XML, python
  - core package for data handling, fitting and statistics tools
    - various minimizers: Minuit, Genetic Algorithm and Simulated Annealing
    - consistent treatment of measurements and their uncertainties in fit
      - theo. uncertainties included in χ^2 with flat likelihood in allowed ranges
    - full statistics analysis tool set: parameter scans, *p*-values, MC analyses, goodness-of-fit tests, …
  - independent physics libraries: SM, 2HDM, oblique parameters, SUSY…
- main publication: EPJ C60, 543-583, 2009 [arXiv:0811.0009]
  - updates and new results available at www.cern.ch/Gfitter
- today: electroweak fit, BSM constraints from oblique corrections

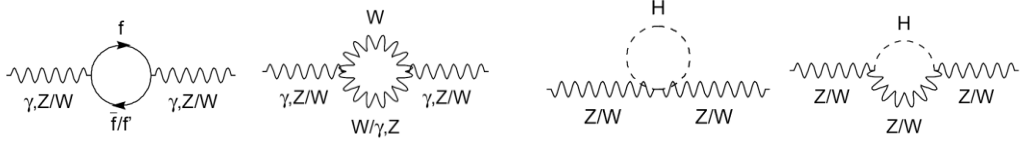
The global electroweak fit

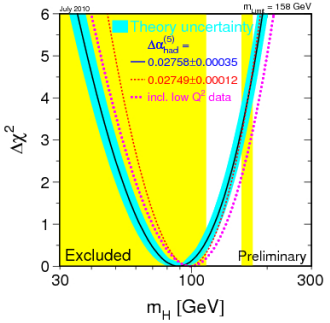
The global electroweak fit with Gfitter

Gfitter package for the global EW fit of the SM

- new implementation of the SM prediction of the EW observables
- based on huge amount of (theo+exp) preparatory work by many

- precise measurements → radiative corrections are important
  - logarithmic dependence on M_H





- state-of-the art calculations; in particular:
  - M_W and $sin^2\theta^l_{eff}$: 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.]

    - theoretical uncertainties: δM_W = 4-6 GeV, $\delta sin^2\theta^l_{eff}=4.7\cdot10^{-5}$
  - radiator functions: N^3LO of the massless QCD Adler function

    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]

- wherever possible cross-checked with Zfitter (FORTRAN)
  → excellent agreement

electroweak fit: experimental input

- free fit parameters:
  - M_Z, M_H, m_t, $\Delta\alpha_{had}^{(5)}(M_Z^2)$, $\alpha_S(M_Z^2)$, $\overline{m}_c$, $\overline{m}_b$
    - scale parameters for theoretical uncertainties on M_W, $sin^2\theta^l_{eff}$ (and the EW form factors ρ_Z^f, κ_Z^f)

- usage of latest experimental input:
  - *Z*-pole observables: LEP/SLD results
    [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
  - M_W and Γ_W: latest LEP+Tevatron averages (03/2010)
    [arXiv:0908.1374][arXiv:1003.2826]
  - m_{top}: latest Tevatron average (07/2010) [arXiv:1007.3178]
  - $\overline{m}_c$ and $\overline{m}_b$: world averages [PDG, J. Phys. G33,1 (2006)]
  - $\Delta\alpha_{had}^{(5)}(M_Z^2)$: latest value (10/2010) [Davier et al., arXiv:1010.4180]
  - direct Higgs searches at LEP and Tevatron (07/2010)
    [ADLO: Phys. Lett. B565, 61 (2003)], [CDF+D0: arXiv:1007.4587]

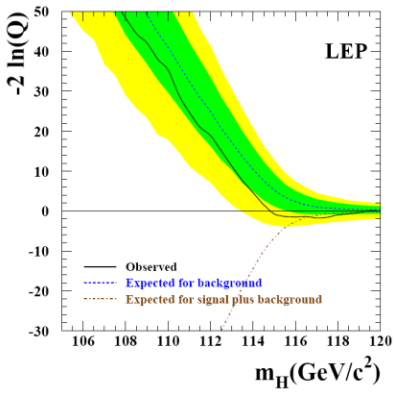
M_Z [GeV]	91.1875 ± 0.0021	LEP
Γ_Z [GeV]	2.4952 ± 0.0023	LEP
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	LEP
R^0_ℓ	20.767 ± 0.025	LEP
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	LEP
A_ℓ (*)	0.1499 ± 0.0018	SLC
A_c	0.670 ± 0.027	SLC
A_b	0.923 ± 0.020	SLC
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	LEP
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	LEP
R^0_c	0.1721 ± 0.0030	SLC
R^0_b	0.21629 ± 0.00066	SLC
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	

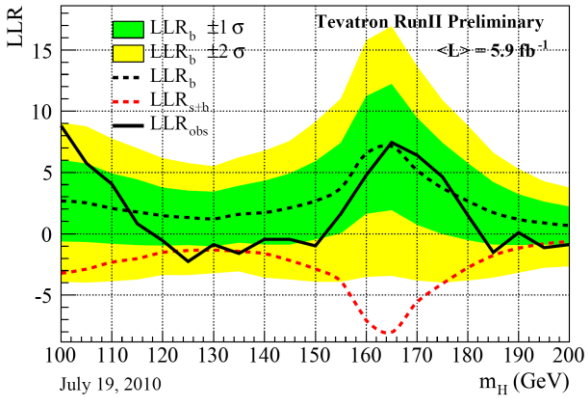
- not considered: $sin^2\theta_{eff}$ results from NuTeV (uncertainties from NLO and nucl. effects of bound nucleon PDF) and APV and polarized Möller scattering (exp. accuracy too low)

electroweak fit: experimental input

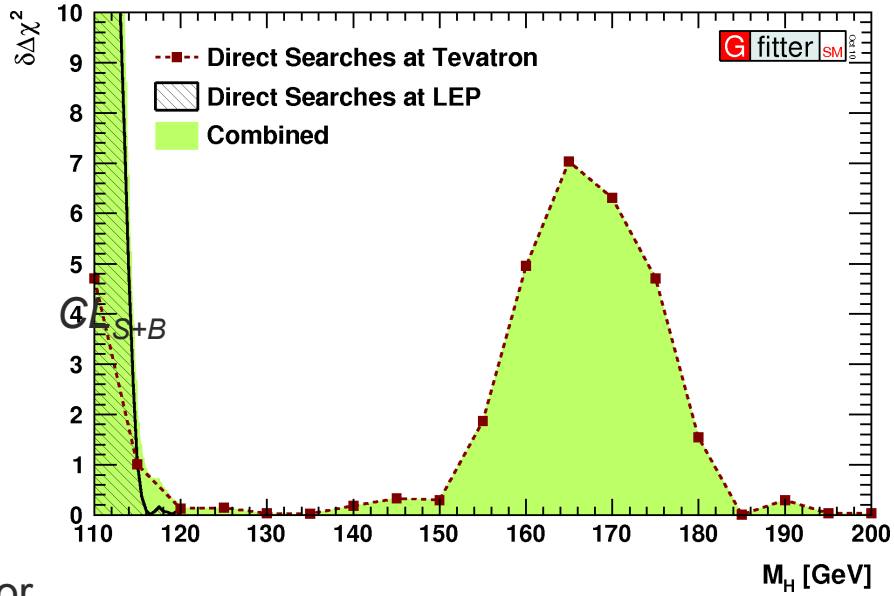
- direct Higgs searches
  - LEP: Higgs-Strahlung
    - $ee \to ZH$ ($H \to bb$, $\tau\tau$)

    [ADLO: Phys. Lett. B565, 61 (2003)]
  - Tevatron: various channels
    - gg fusion with $H \to WW$, associated production, WBF [CDF+D0: arXiv:1007.4587]
    - ICHEP combination 07/2010





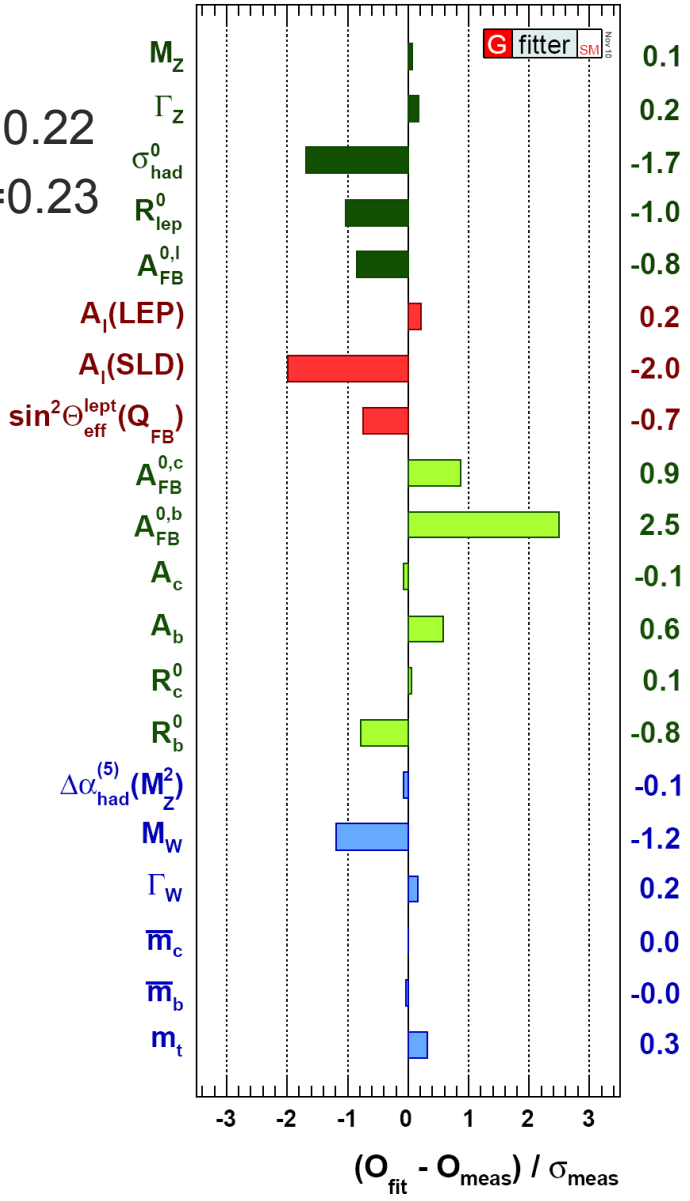
- stat. interpretation in global fit: 2-sided CL_{S+B}
  - experiments measure test statistics: $LLR = -2 \ln Q$, where $Q = L_{S+B}/L_B$
  - LLR is transformed by experiments into using toy-MC experiments
  - we transform 1-sided CL_{S+B} into 2-sided CL^{2s}_{S+B}
    - we measure deviations from the SM !
  - χ^2 contribution calculated via inverse error function: $\delta\chi^2 = Erf^{-1}(1-CL^{2s}_{S+B})$



alternative treatment: χ^2 contribution calculated as $-2 \ln Q$ (cf. Erler)

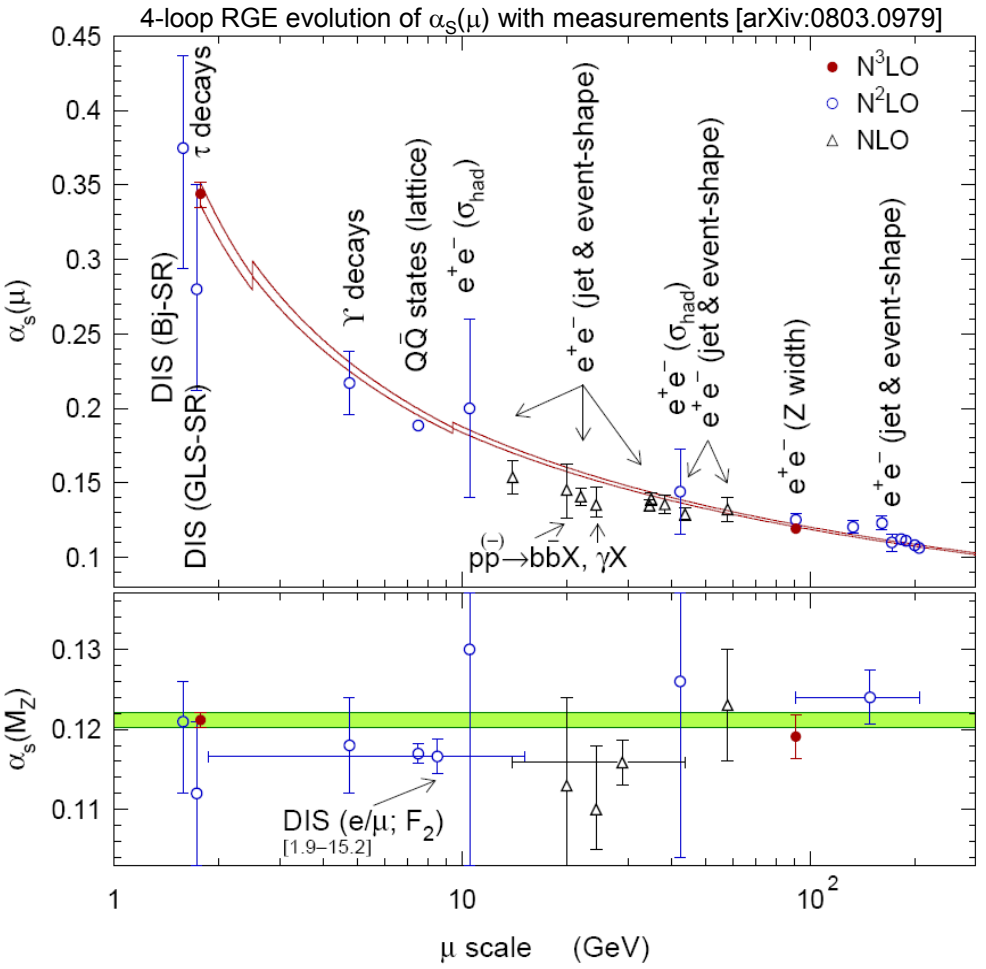
electroweak fit: fit results

- goodness-of-fit:
  - w/o *H* searches: χ^2_{min}=16.6 → Prob(χ^2_{min},13)=0.22
  - with *H* searches: χ^2_{min}=17.5 → Prob(χ^2_{min},14)=0.23
- pull values:
  - at fit minimum all observables described
  - no individual value exceeds 3σ
  - A_{FB}(b) asymmetry largest contributor
- contribution of some floating parameters (M_Z, $\Delta\alpha_{had}$, m_c, m_b, (m_t)) rather small
  - variation of these within respective error estimates has small effects
  - parameters could have been fixed without significant impact on goodness-of-fit
  - can describe the data with only two free parameters (α_S, M_H)



electroweak fit: α_S constraints

- no measurement of α_S used in fit
- α_s mainly constrained by $R_l = \Gamma_{had}/\Gamma_l$ (*radiator functions*)
- *N³LO* α_S from fit:
  - $\alpha_s(M_Z^2) = 0.1193 \quad \pm 0.0028 \quad \pm 0.0001$
  - 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 $\alpha_S^4(M_Z)$
  - excellent agreement with *N³LO* result from τ decays

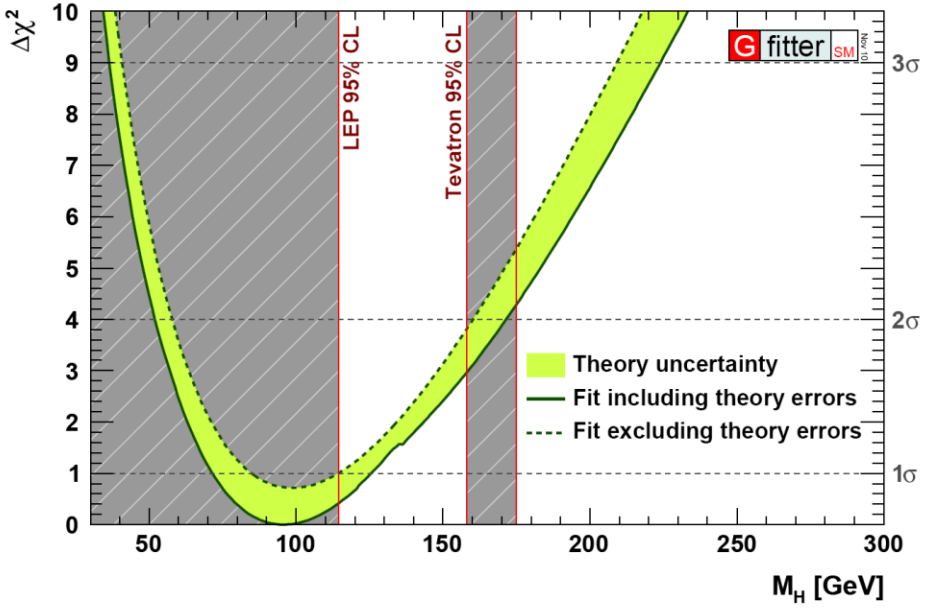


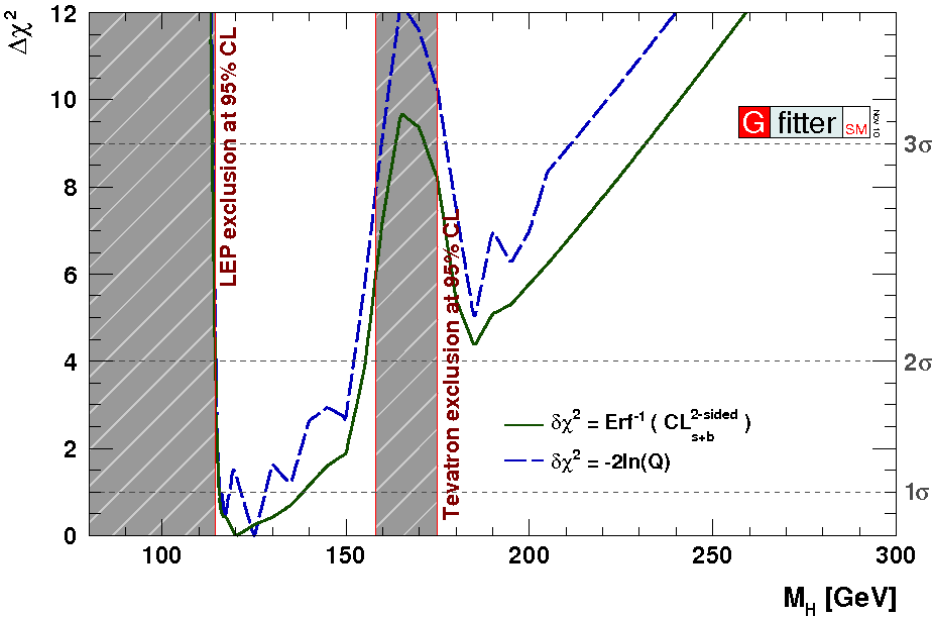
[Davier et al., EPJ C56, 305 (2008), arXiv:0803.0979]

electroweak fit: Higgs mass constraints

- M_H from fit w/o Higgs searches:
  - central value ±1σ:
    $$M_H = 95.7^{+30.6}_{-24.2}\ \text{GeV}$$
  - 2σ interval:
    $$[52, 171]\ \text{GeV}$$

- M_H from fit with Higgs searches:
  - central value ±1σ:
    $$M_H = 120.6^{+17.9}_{-\ 5.2}\ \text{GeV}$$
  - 2σ interval:
    $$[114, 155]\ \text{GeV}$$

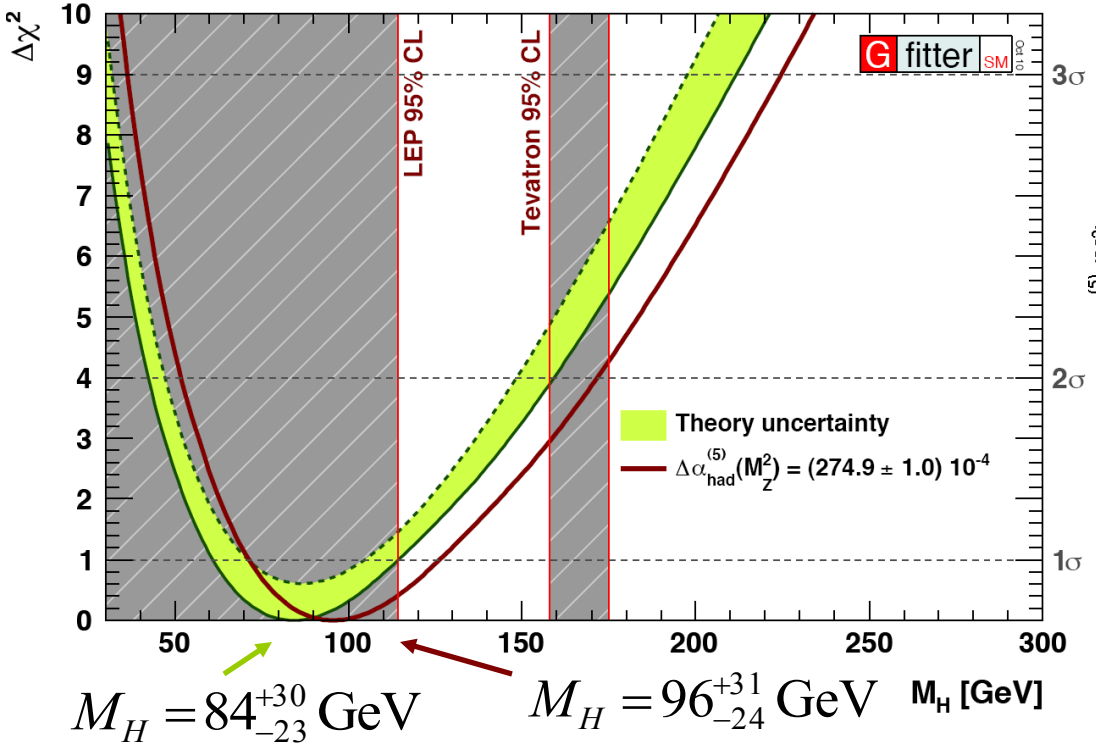




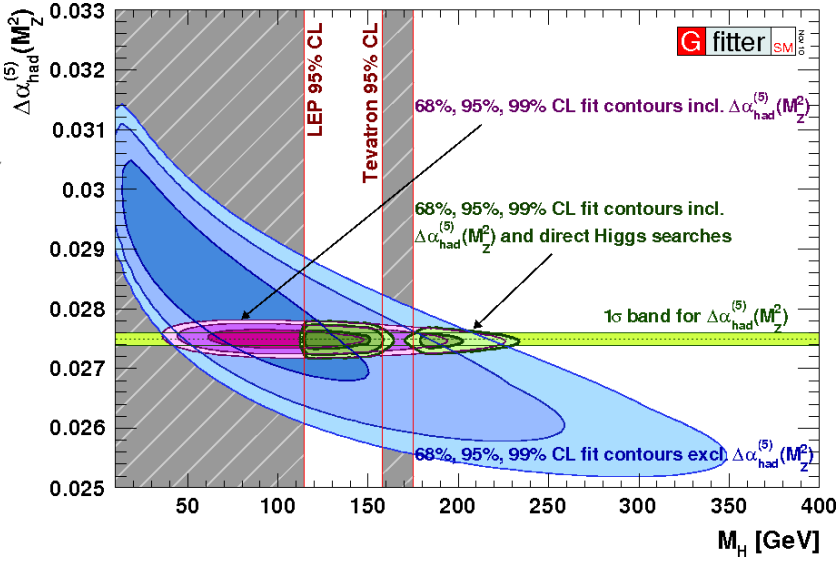
- green bands shows difference of fit results when including/excluding theory uncertainties.
- flat likelihood term: excluded errors → larger n_{dof} → larger χ^2_{min}

electroweak fit: impact of $\Delta\alpha_{had}^{(5)}(M_Z^2)$

- we use latest value $\Delta\alpha_{had}^{(5)}(M_Z) = (274.9 \pm 1.0)\cdot 10^{-4}$ [Davier et al., arXiv:1010.4180]
  - includes new $\pi^+\pi^-$ data from Kloe, multi-hadron data from Babar
  - value decreased compared to value used before $\Delta\alpha_{had}^{(5)}(M_Z) = (276.8 \pm 2.2)\cdot 10^{-4}$ [Hagiwara et al., PLB B649, 173 (2007)]



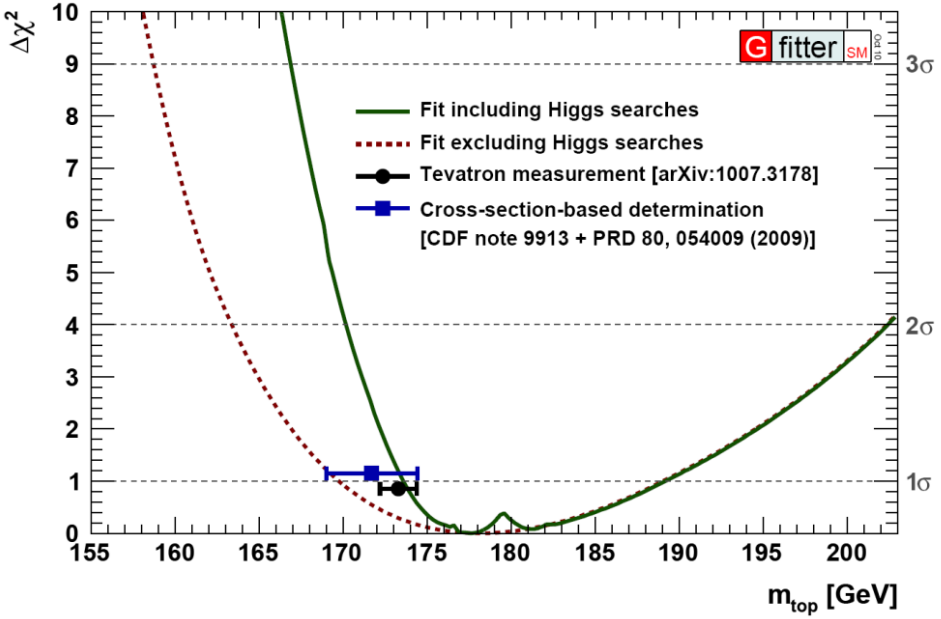
- increase of M_H (by 12 GeV) due to negative correlation

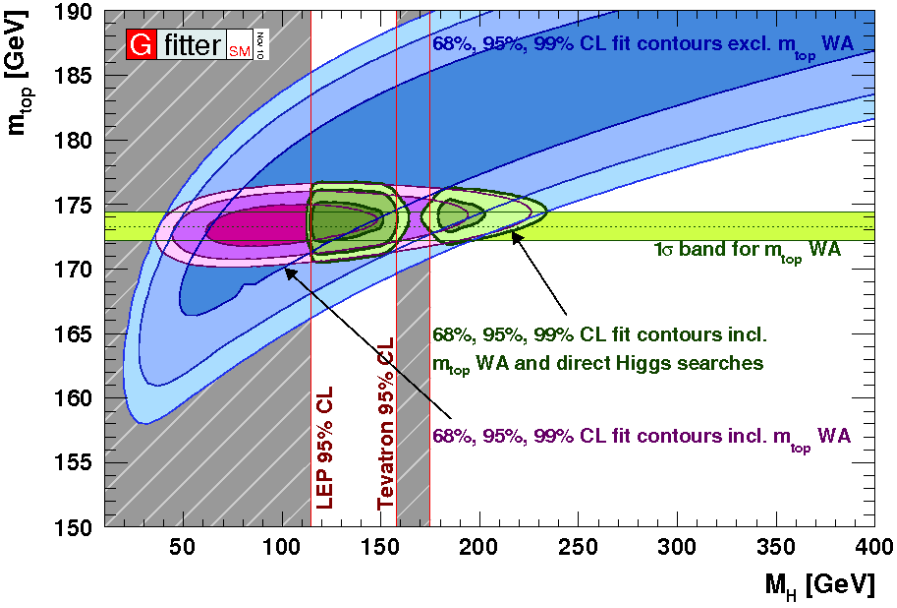


- for comparison: prelim value $(275.9 \pm 15)\cdot 10^{-4}$ (Teubner at Tau2010) $M_H = 90^{+30}_{-24}$ GeV
- LEP EW WG: $(2758 \pm 35)\cdot 10^{-4}$ (Burghardt&Pietrzyk, 2005): $M_H = 89^{+36}_{-26}$ GeV

electroweak fit: top mass

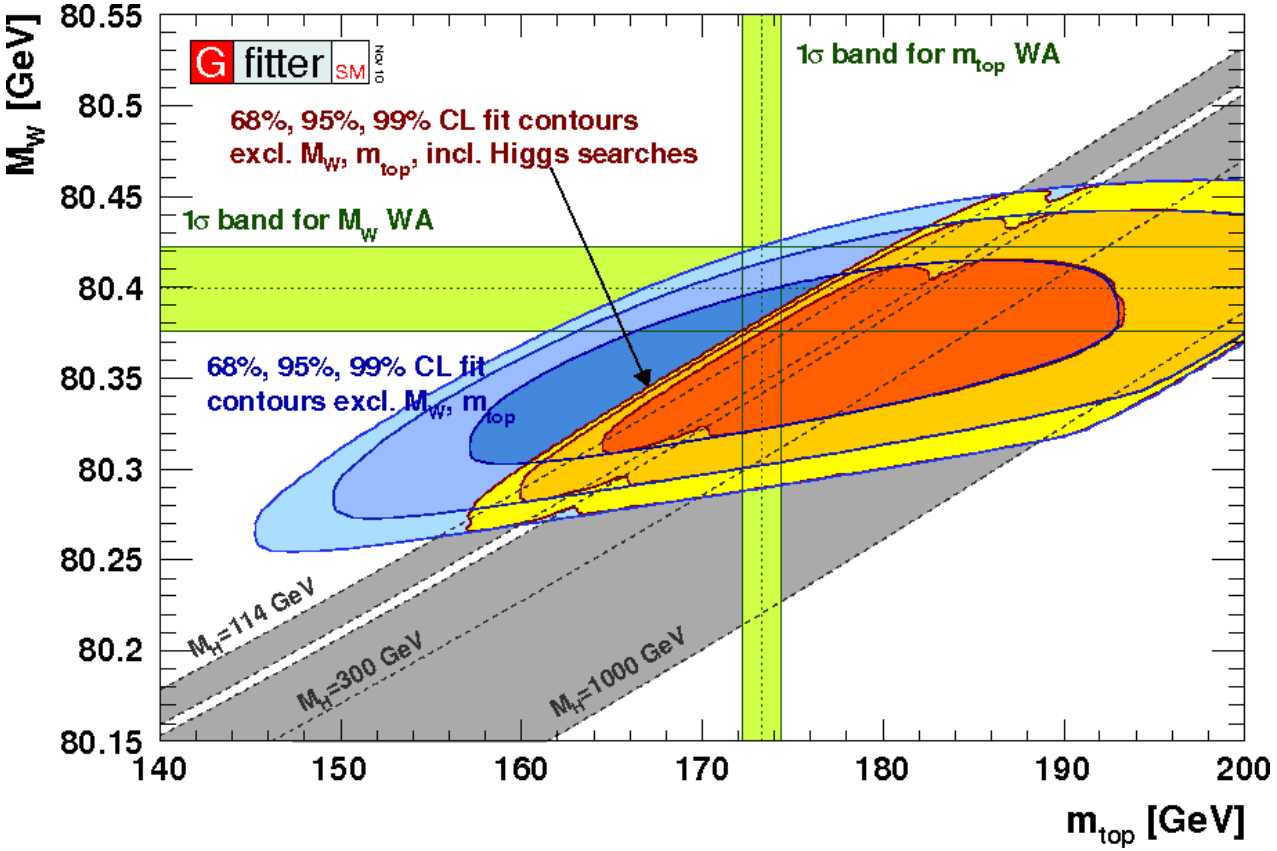
- theoretical prediction use top pole mass
- unclear def. of m_{top} at TeVatron: "MC" or pole mass? $m_{top} = 173.1 \pm 1.1\,\text{GeV}$
  → additional uncertainty? [Hoang&Steward, Nucl. Phys. Proc. Suppl. 185:220 (2008)]
- alternative: extract m_{top} from total top pair Xsection $m_{top} = 171.7 \pm 2.7\,\text{GeV}$
  [Langenfeld, Moch, Uwer, PRD80:054009,2009, CDF, CDF note 9913]
- indirect results from SM fit:
  - w/o Higgs searches: $m_{top} = 177.2^{+10.7}_{-7.8}\,\text{GeV}$
  - with Higgs searches: $m_{top} = 177.4^{+11.8}_{-3.5}\,\text{GeV}$



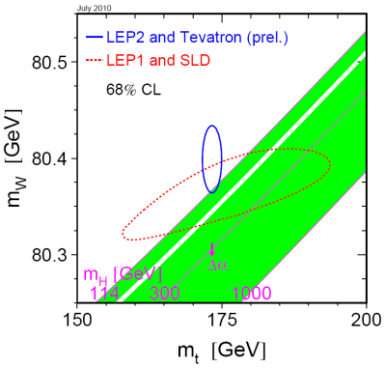


→ m_{top} important input for fit (correlation with M_H: 0.31)

electroweak fit: m_{top} vs. M_W



for comparison:



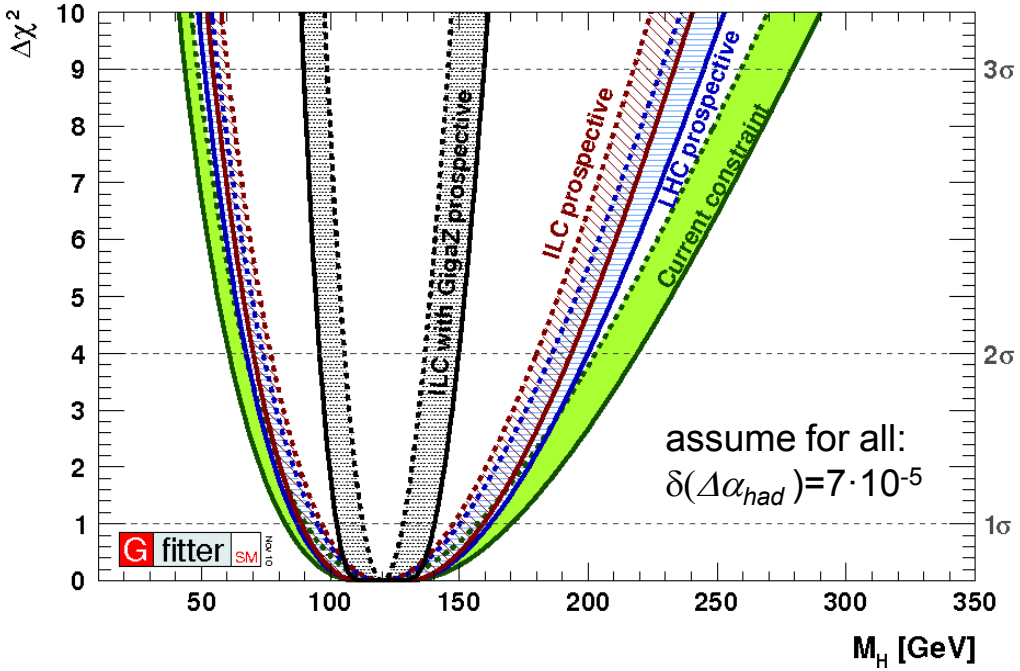
- indirect fit results agree with direct measurements
- results from Higgs searches significantly reduce the allowed parameter space
- illustrative probe of SM (if M_H is measured at LHC and/or ILC)

Prospect for LHC and ILC

- LHC, ILC (+GigaZ)*
  - exp. improvement of M_W, m_{top}, $\sin^2\theta^l_{eff}$, R_l^0
- in addition: improved $\Delta\alpha_{had}$

  [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^0_ℓ $[10^{-2}]$	2.5	2.5	2.5	0.4
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $[10^{-5}]$	10 (7)	10 (7)	10 (7)	10 (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: treatment of theo. uncertainties
- GigaZ: significant improvement for α_S due to R_l^0

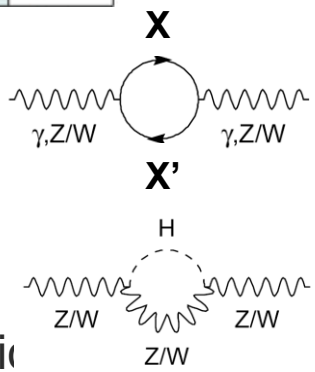
*[ATLAS, Physics TDR (1999)][CMS, Physics TDR (2006)][A. Djouadi et al., arXiv:0709.1893][I. Borjanovic, EPJ C39S2, 63 (2005)][S. Haywood et al., hep-ph/0003275][R. Hawkings, K. Mönig, EPJ direct C1, 8 (1999)][A. H. Hoang et al., EPJ direct C2, 1 (2000)][M. Winter, LC-PHSM-2001-016]

Constraints on new physics models using the EW fit

BSM constraints using the *oblique parameters*

A package to constraint SM extensions

- assumption:
  - high-scale BSM physics appears only through vacuum polarisation corrections



- electroweak fit sensitive to BSM physics through these *oblique corrections*
  - in direct competition with sensitivity to Higgs loop correcti

- oblique corrections from New Physics described through *STU* parametrization

$$O_{\mathrm{BSM}} = O_{\mathrm{SM,ref}}(M_H, m_t) + c_S S + c_T T + c_U U$$

[Peskin + Takeuchi, Phys. Rev. D46,1(1991)]

  - *STU* measure deviations from EW rad. cor. expected. in $\mathrm{SM}_{\mathrm{ref}}$
  - $S=T=U=0$ if data are equal to $\mathrm{SM}_{\mathrm{ref}}$ prediction
    - *S*: NP contributions to neutral currents
    - *T*: difference btw neutral and ch. current processes (sensitive to isospin violation effects)
    - *U*: (+*S*) NP contribution to charged currents. *U* only sensitive to M_W and Γ_W [usually very small in NP models (often *U*=0)]
      - also implemented: corrections to *Zbb* coupling, extended parameters (*VWX*)

[Burgess et al., Phys. Lett. B326, 276 (1994)] [Burgess et al., Phys. Rev. D49, 6115 (1994)]

BSM constraints using the *oblique parameters*

- *S, T, U* derived from fit to electroweak observables
  - SM_{ref} chosen with: $m_t = 173.1$ GeV, $M_H = 120$ GeV

- Results

$S = 0.02 \pm 0.11$

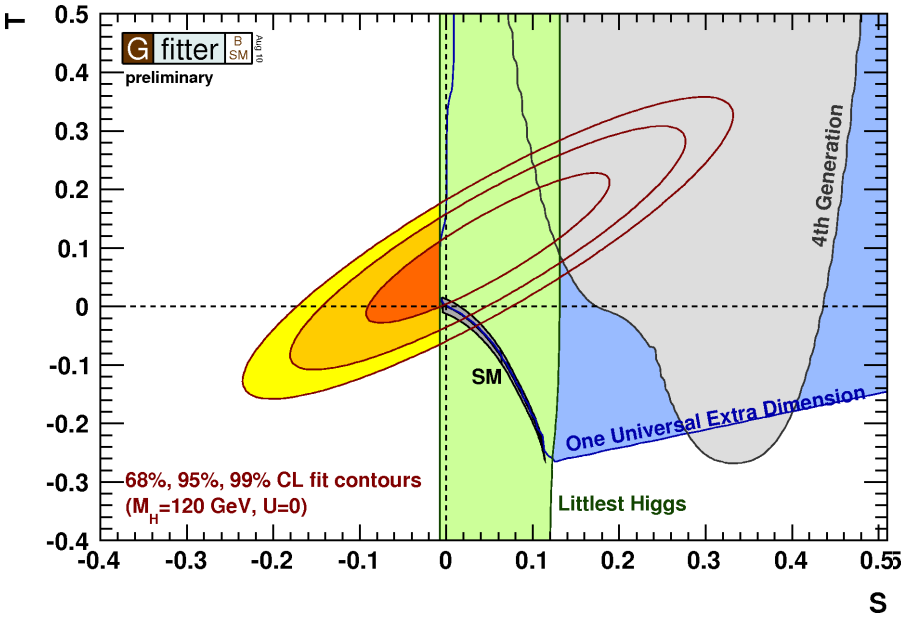
$T = 0.05 \pm 0.12$

$U = 0.07 \pm 0.12$

- Correlation matrix

	S	*T*	*U*
S	1	0.879	-0.469
T		1	-0.716
U			1

ST-plane for *U*=0



- SM predictions (grey areas) are compatible with data
  - e.g. SM_{ref}: $S = T = U = 0$
  - variation of the free parameters → large area in *ST*-plane
  - for some parameter values: large M_H allowed (compensation of effects)

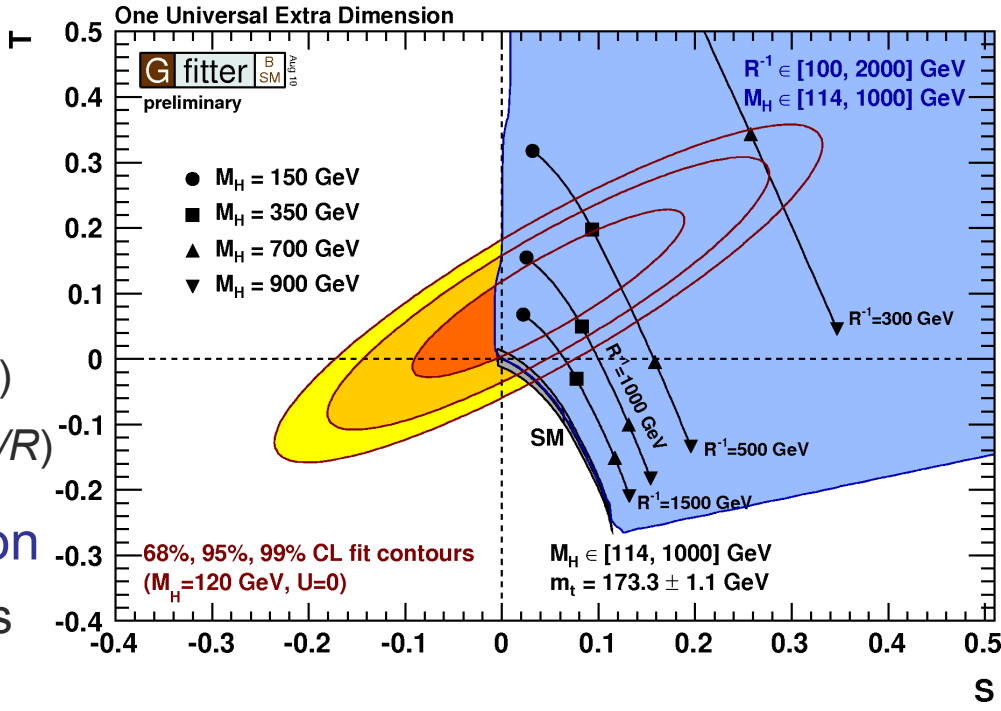
- Littlest Higgs, Universal Extra Dimension, 4th generation:
  - small M_H compatible with data
  - M_H dependent on M_{new}

- Combined data/SM prediction:
  - compatible with data
  - new physics

Example: Constraints on Universal Extra Dimensions

[Appelquist et al., Phys. Rev. D67 055002 (2003)] [Gogoladze et al., Phys. Rev. D74 093012 (2006)]

- UED:
  - all SM particles can propagate into Extra Dimensions (*universal*)
  - compactification → KK modes
  - conservation of KK parity
    - phenomenology similar to SUSY
    - lightest KK state stable: CDM candidate
- free parameters:
  - d_{ED}: number of ED (fixed to d_{ED}=1)
  - R^{-1}: compactification scale ($m_{KK} \sim n/R$)
- Contribution to vacuum polarisation
  - from KK-top/bottom and KK-Higgs
- STU prediction for UED:
  - for large R^{-1}: UED prediction approaches SM
  - for small R^{-1}: large T values possible

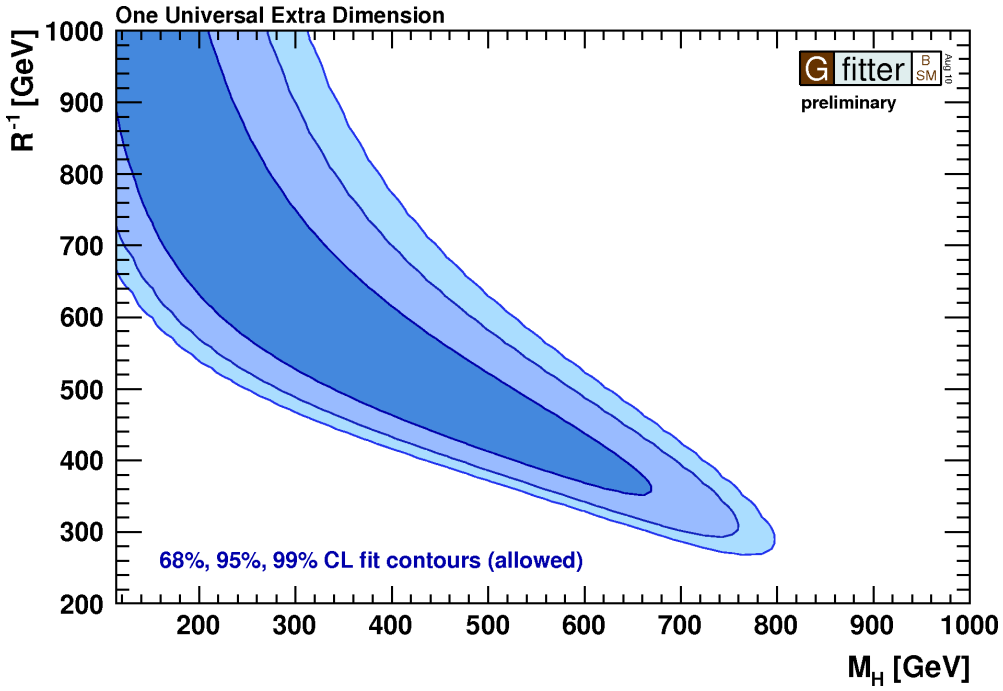


- to avoid large T:
  - large R^{-1}
  - large M_H

Example: Constraints on Universal Extra Dimensions

[Appelquist et al., Phys. Rev. D67 055002 (2003)] [Gogoladze et al., Phys. Rev. D74 093012 (2006)]

- allowed regions in the UED parameter space



- large R^{-1}: UED approaches SM → only small M_H allowed
- small R^{-1}: UED contribution compensated by large M_H
- excluded: $R^{-1} < 300$ GeV and $M_H > 800$ GeV
  - heavy Higgs still allowed

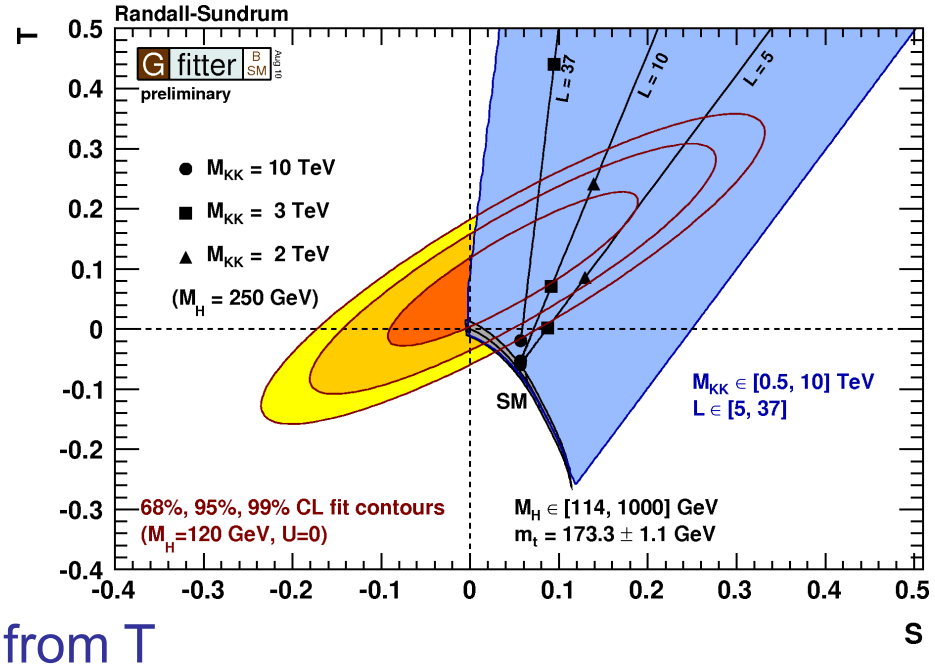
Example: Constraints on Warped Extra Dimensions

[Randall, Sundrum, PRL 83, 3370 (1999); Casagrande et al., JHEP 0810 (2008) 094]

- one warped ED confined by two three-branes (curvature *k*, size *r*) for tackling the hierarchy problem
- extension: SM gauge and matter field allowed to propagate in bulk region
  - each SM fermion accompanied by two towers of heavy KK modes
- free parameters of the model
  - logarithm of warp factor:

$$L = -\ln \varepsilon = -\ln(e^{-kr\pi})$$

    - warp factor ε determines metric; to explain the gauge hierarchy: $L = -\ln 10^{-16} \approx 37$
  - KK scale $M_{KK} = k\varepsilon = ke^{-kr\pi}$
    - mass scale for KK excitations, mass of lightest states ~2.45·M_{KK}

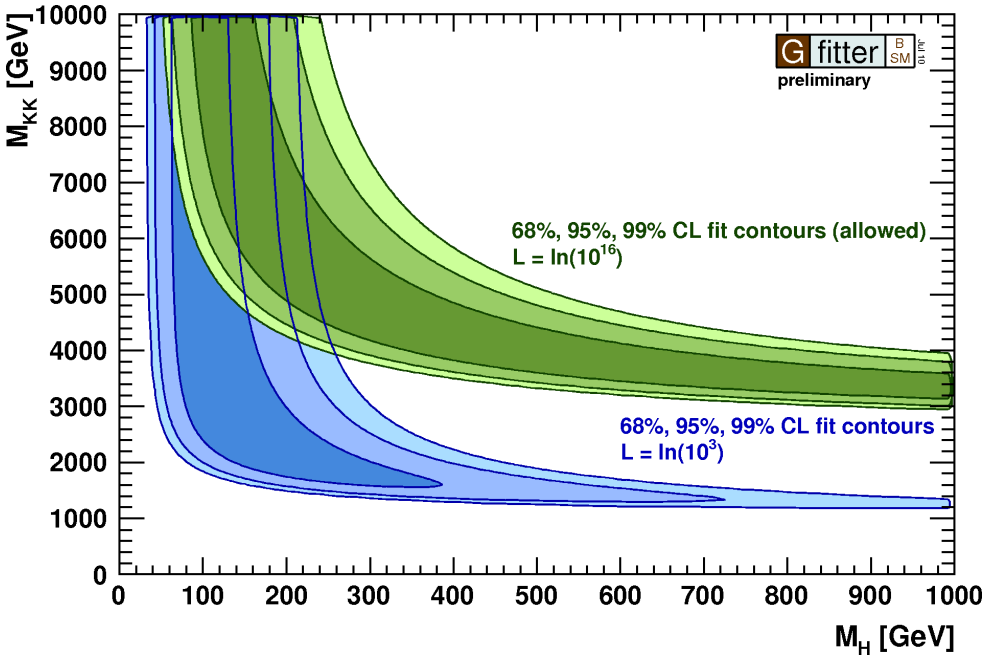


- as usual: main constraint comes from T
  - large values of *L* and small values of M_{KK} give large T values
  - to avoid large T: a) high M_{KK}, b) low *L*, c) high M_H

Example: Constraints on Warped Extra Dimension

[Randall, Sundrum, PRL 83, 3370 (1999); Casagrande et al., JHEP 0810 (2008) 094]

- allowed regions in the WED parameter space
- in general (*cf.* UED):
  - higher Higgs mass compatible with the data
  - a higher Higgs mass can compensate a lower KK scale



- for solution of full gauge hierarchy problem (i.e. $L = -\ln(10^{-16})$):
  - M_{KK}>3TeV

  → Masses of lightest KK modes >7.4 TeV

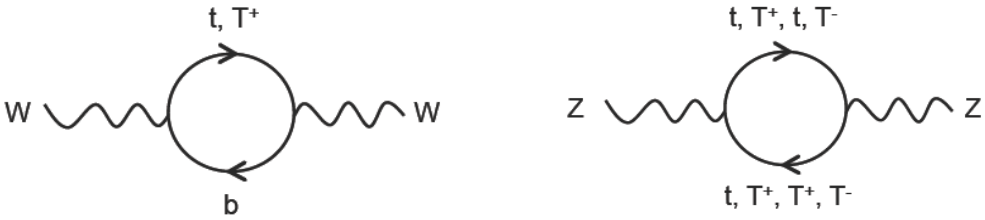
- "little RS" model (e.g. $L = -\ln(10^{-3})$)
  - stabilizes hierarchy between electroweak scale and 10^3 TeV
  - M_{KK}>1.1TeV

  → Masses of lightest KK modes >3 TeV

Example: Constraints on the Littlest Higgs Model with T- parity

[Hubisz et al., JHEP 0601:135 (2006)]

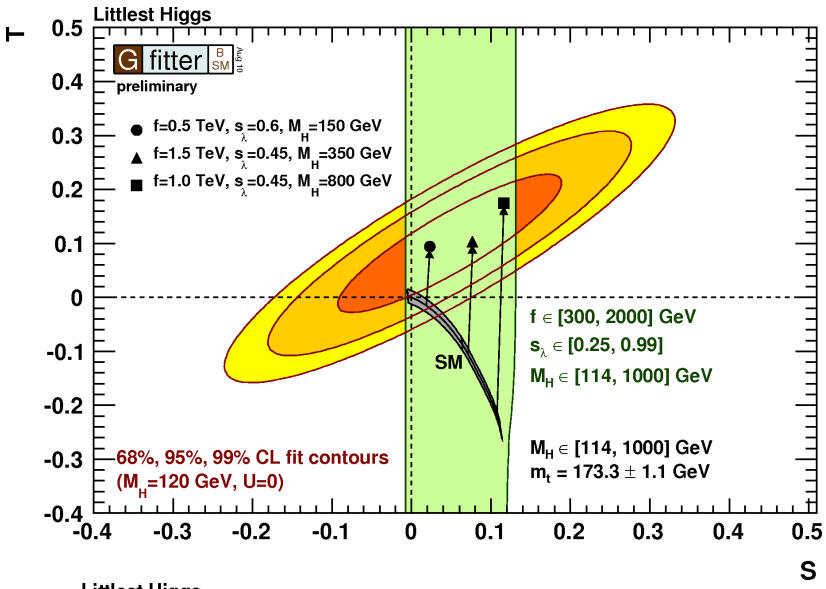
- LHM solves hierarchy problem as an alternative to SUSY
  - new global SU(5)/SO(5) symmetry broken at scale f ~1 TeV
    - Higgs= pseudo-Goldstone-Boson
  - new SM-like fermion and new gauge bosons at the scale f ~1 TeV
  - SM contributions to Higgs mass cancelled by new particles
- Conservation of *T*-Parity similar to conservation of *R*-parity in SUSY
  - dark matter candidate → $E_{T,miss}$ at LHC
  - no direct coupling of new gauge bosons (*T*-odd) to final state SM particles (*T*-even)
    - forbids tree-level contributions from heavy gauge bosons to SM observables
- Two new heavy top-states: *T*-even m_{T+} and *T*-odd m_{T-}
- Dominant oblique corrections:

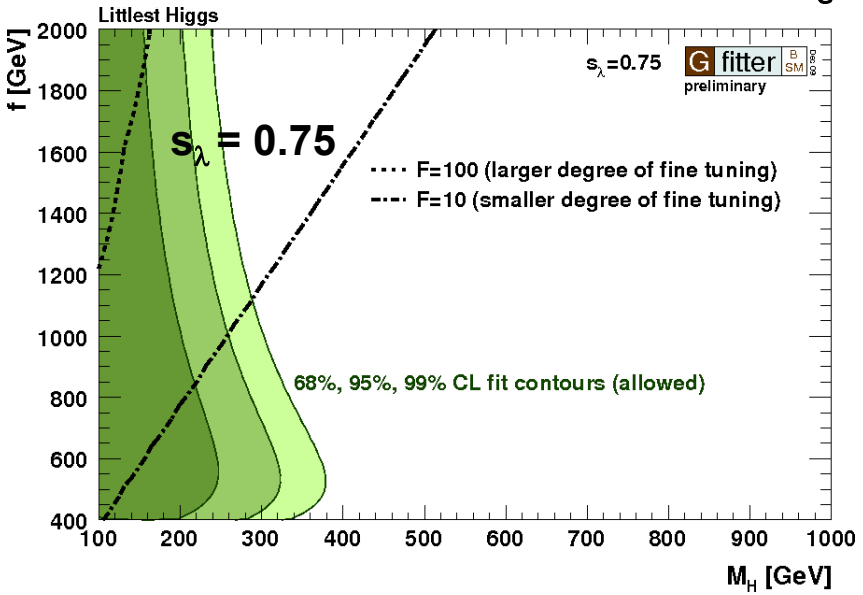


Example: Constraints on the Littlest Higgs Model with T- parity

[Hubisz et al., JHEP 0601:135 (2006)]

- Parameters of the LH model
  - f: symmetry breaking scale
  - $s_\lambda \sim m_{T-}/m_{T+} < 0$: ratio of T-odd/T-even masses in top sector
    - δ_c: order one-coefficient (value depends on details of UV physics) treated as theory uncertainty in fit: δ_c: [-5,5]
- Results:
  - for appropriate parameters large M_H could be allowed
  - dependent on s_λ:
    - For large f: LHM approaches the SM prediction and SM M_H constraints (as expected)
    - For smaller f: M_H can be large
  - no absolute exclusion limits due to s_λ dependence

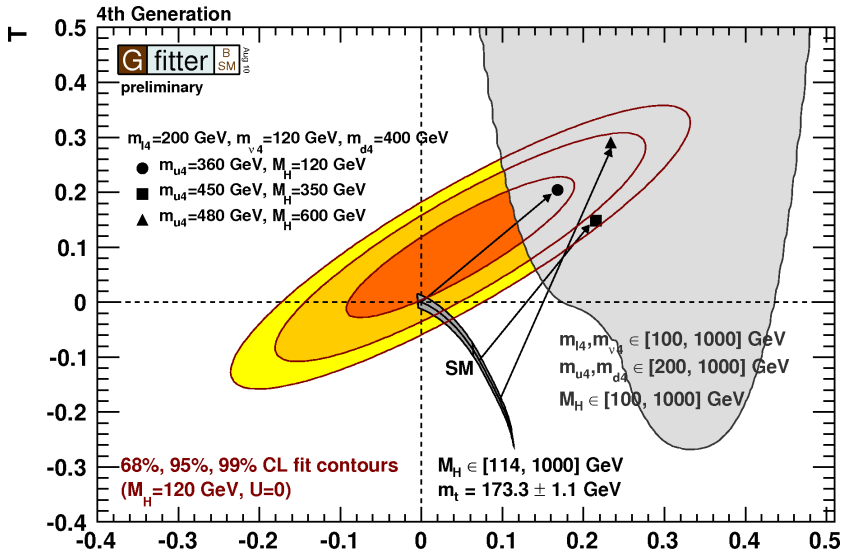


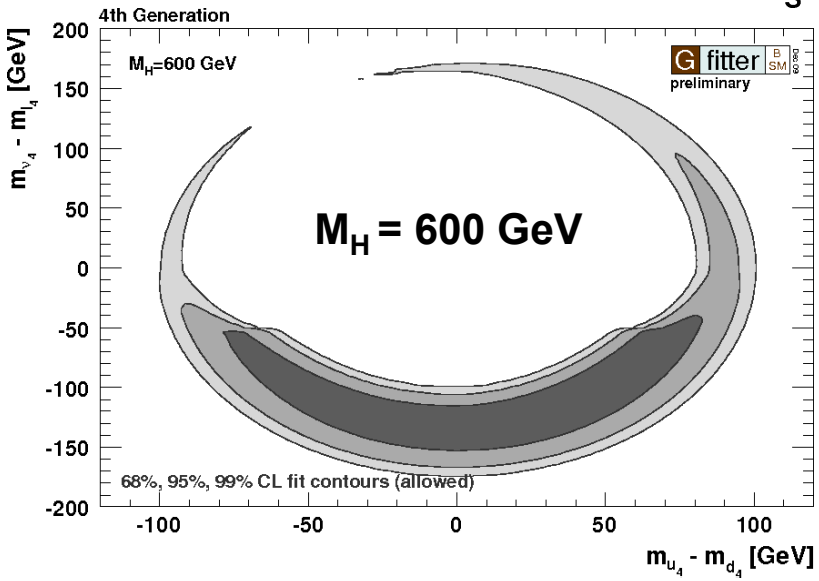


Example: Constraints on a 4th fermion generation

[He et al., Phys. Rev. D64, 053004 (2001)]

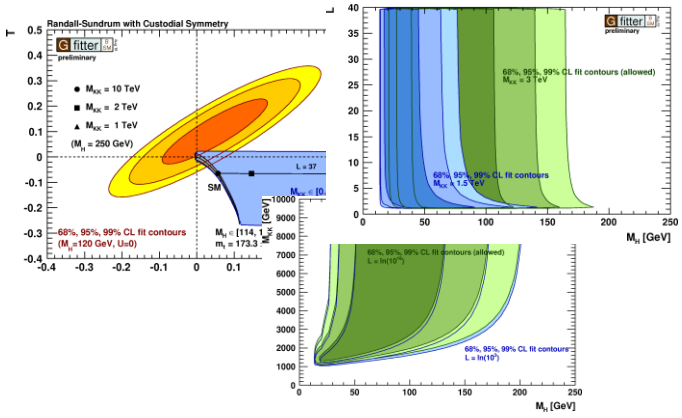
- Models with a fourth generation
  - no explanation for *n=3* generations
  - intr. new states for leptons and quarks
    - $\Psi_L = (\Psi_1, \Psi_2)_L,\ \Psi_{1,R},\ \Psi_{2,R}$
  - free parameters: $m_{u_4}, m_{d_4}, m_{e_4}, m_{\nu_4}$
    - masses of new quarks and leptons
    - assuming: no mixing of extra fermions
- contrib. to *STU* from new fermions
  - sensitivity to mass difference between up-type and down-type fields (T↑)
    (not to absolute mass scale)
- Results:
  - with appropriate mass differences: 4th fermion model consistent with data
    - In particular a large M_H is allowed
  - data prefer a heavier charged lepton



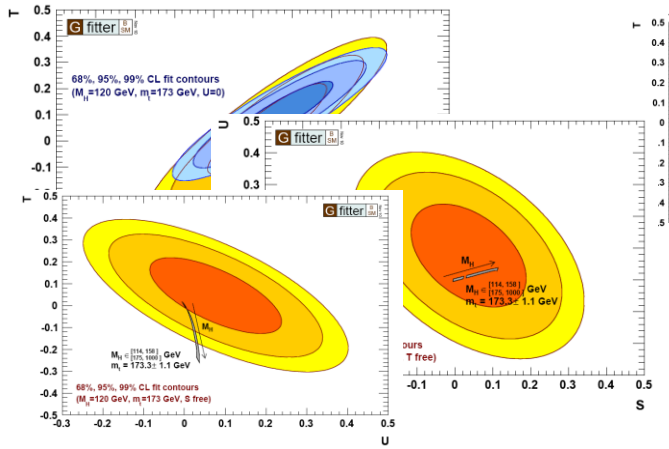


… and more …

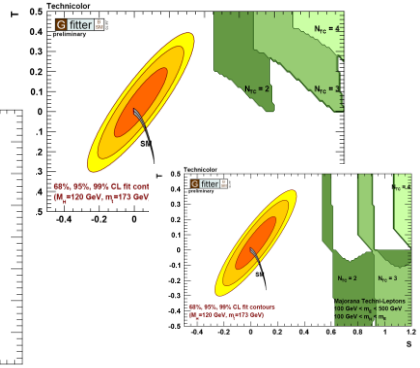
WED with custodial symmetry



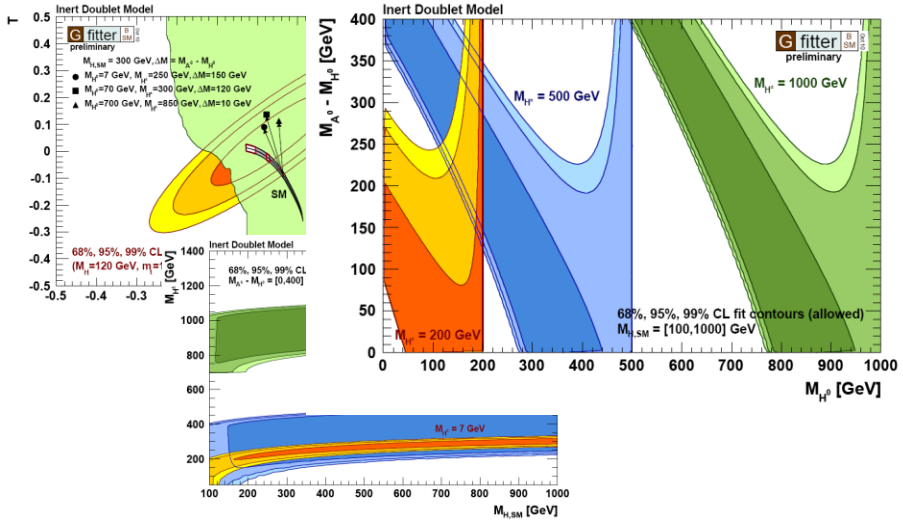
STU results



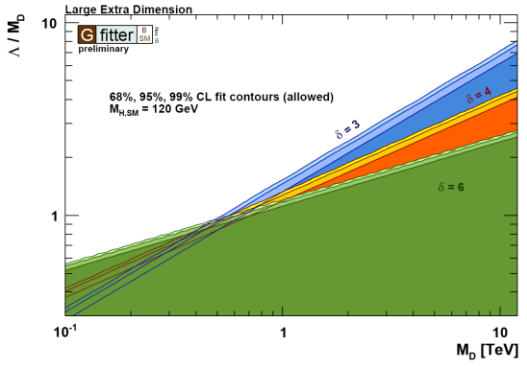
Technicolor



Inert Higgs Doublet Model



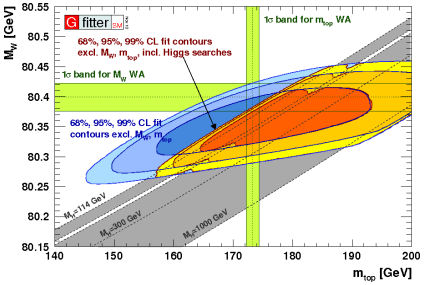
Large Extra Dimensions

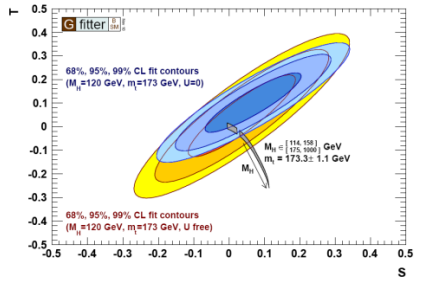


… available soon

Conclusions and outlook

- **G fitter** is a powerful framework for HEP model fits
- status:
  - global fit of the electroweak SM
    - light Higgs
  - constraints on BSM using the oblique parameters
    - heavier Higgs boson could be realized in various models
  - constraints in the 2HDM (not shown today)





- prospects:
  - maintain and improve core statistics package (e.g. fitter efficiency)
  - maintain electroweak fit in line with experimental and theoretical progress
    - Tevatron updates and of course LHC results (measurements + Higgs results) !
  - publish, maintain and extend the oblique parameter fit (*STU*)
    - combination with direct searches ?
  - SUSY fits: inclusion of LHC data, see talk by Max Baak on Friday
- Latest results/updates and new results always available at:

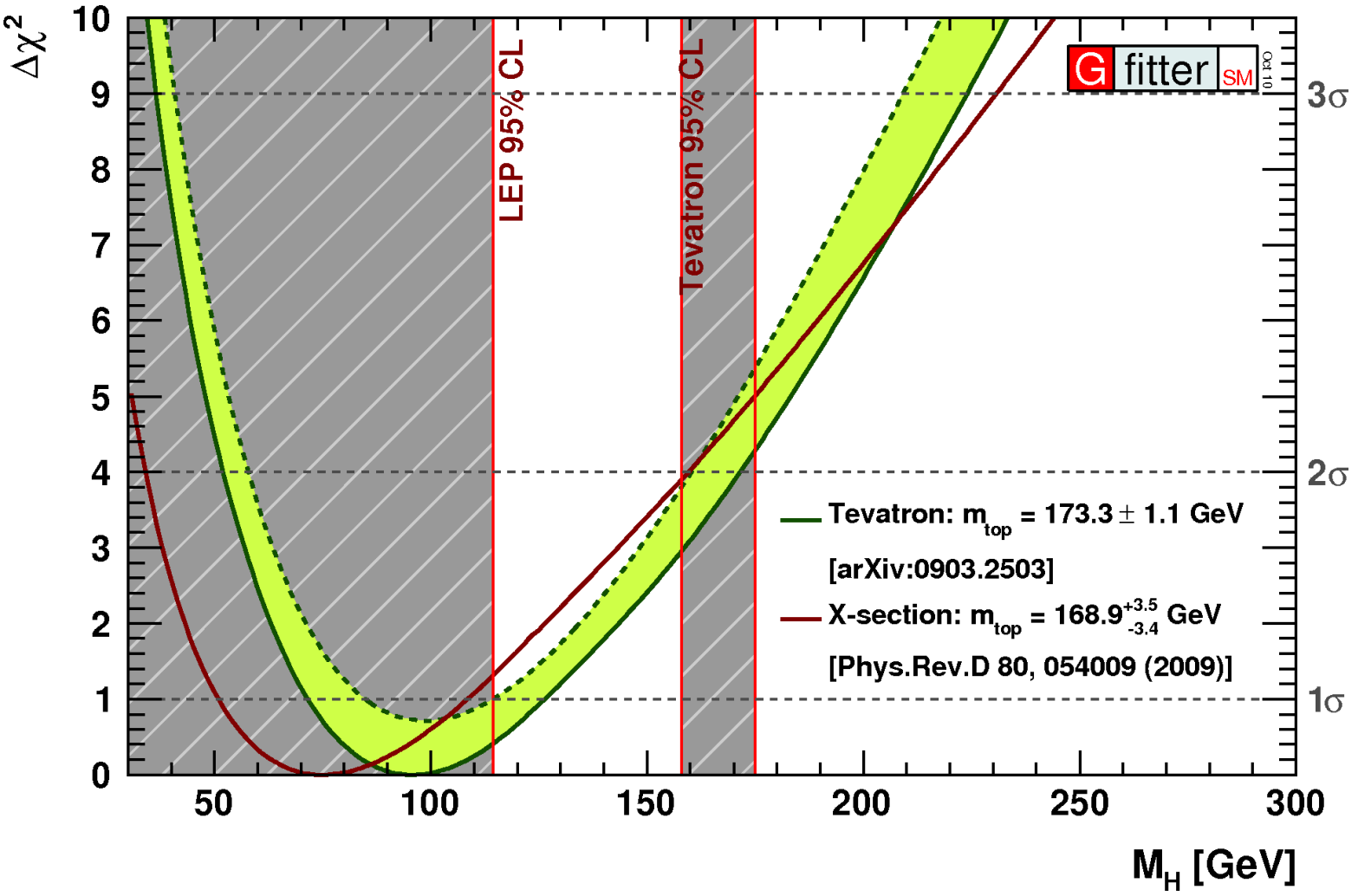
  http://cern.ch/Gfitter

Back-up slides

Experimental input and fit results

Parameter	Input value	Free in fit	Results from global EW fits: *Standard fit*	*Complete fit*	*Complete fit w/o exp. input in line*
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1874 ± 0.0021	91.1877 ± 0.0021	$91.1942^{+0.0168}_{-0.0114}$
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4960 ± 0.0015	$2.4956^{+0.0015}_{-0.0014}$	$2.4952^{+0.0014}_{-0.0016}$
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	–	41.478 ± 0.014	41.478 ± 0.014	41.469 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.742 ± 0.018	$20.741^{+0.018}_{-0.017}$	20.718 ± 0.026
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	–	0.01641 ± 0.0002	$0.01625^{+0.0002}_{-0.0001}$	$0.01624^{+0.0002}_{-0.0001}$
A_ℓ (*)	0.1499 ± 0.0018	–	0.1479 ± 0.0010	$0.1472^{+0.0010}_{-0.0006}$	–
A_c	0.670 ± 0.027	–	$0.6683^{+0.00044}_{-0.00043}$	$0.6680^{+0.00042}_{-0.00027}$	$0.6679^{+0.00039}_{-0.00022}$
A_b	0.923 ± 0.020	–	0.93469 ± 0.00009	$0.93464^{+0.00007}_{-0.00005}$	$0.93462^{+0.00008}_{-0.00004}$
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	–	0.0741 ± 0.0005	$0.0738^{+0.0005}_{-0.0003}$	0.0739 ± 0.0004
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	–	0.1037 ± 0.0007	$0.1032^{+0.0007}_{-0.0004}$	$0.1036^{+0.0005}_{-0.0004}$
R^0_c	0.1721 ± 0.0030	–	0.17225 ± 0.00006	0.17225 ± 0.00006	0.17225 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	$0.21578^{+0.00005}_{-0.00008}$	$0.21576^{+0.00007}_{-0.00008}$	$0.21577^{+0.00005}_{-0.00008}$
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	–	0.23141 ± 0.00012	$0.23150^{+0.00007}_{-0.00013}$	$0.23149^{+0.00008}_{-0.00011}$
M_H [GeV] (○)	Likelihood ratios	yes	$95.7^{+30.6[+75.8]}_{-24.2[-43.7]}$	$120.6^{+17.9[+34.7]}_{-5.2[-6.2]}$	$95.7^{+30.6[+75.8]}_{-24.2[-43.7]}$
M_W [GeV]	80.399 ± 0.023	–	$80.382^{+0.014}_{-0.015}$	$80.370^{+0.005}_{-0.009}$	$80.360^{+0.016}_{-0.024}$
Γ_W [GeV]	2.085 ± 0.042	–	2.092 ± 0.001	2.092 ± 0.001	2.092 ± 0.001
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes	$1.27^{+0.07}_{-0.11}$	$1.27^{+0.07}_{-0.11}$	–
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes	$4.20^{+0.16}_{-0.07}$	$4.20^{+0.16}_{-0.07}$	–
m_t [GeV]	173.3 ± 1.1	yes	173.4 ± 1.1	173.7 ± 1.0	$177.4^{+11.8}_{-3.5}$
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ (†△)	2749 ± 10	yes	2750 ± 10	2748 ± 10	2729^{+39}_{-55}
$\alpha_s(M_Z^2)$	–	yes	$0.1192^{+0.0028}_{-0.0027}$	$0.1193^{+0.0028}_{-0.0027}$	$0.1193^{+0.0028}_{-0.0027}$
$\delta_{\rm th} M_W$ [MeV]	$[-4, 4]_{\rm theo}$	yes	4	4	–
$\delta_{\rm th}\sin^2\theta^\ell_{\rm eff}$ (†)	$[-4.7, 4.7]_{\rm theo}$	yes	4.7	4.7	–
$\delta_{\rm th}\rho^f_Z$ (†)	$[-2, 2]_{\rm theo}$	yes	2	2	–
$\delta_{\rm th}\kappa^f_Z$ (†)	$[-2, 2]_{\rm theo}$	yes	2	2	–

(*)Average of LEP ($A_\ell = 0.1465 \pm 0.0033$) and SLD ($A_\ell = 0.1513 \pm 0.0021$) measurements. The *complete fit* w/o the LEP (SLD) measurement gives $A_\ell = 0.1475 \pm 0.0008$ ($A_\ell = 0.1468^{+0.0008}_{-0.0007}$). (○)In brackets the 2σ. (†)In units of 10^{-5}. (△)Rescaled due to α_s dependency.


$\Delta\chi^2$
10
9
8
7
6
5
4
3
2
1
0
50
100
150
200
250
300
M_H [GeV]
LEP 95% CL
Tevatron 95% CL
G fitter SM
Oct 10
3σ
2σ
1σ
Tevatron: m_{top} = 173.3 ± 1.1 GeV
[arXiv:0903.2503]
X-section: $m_{top} = 168.9^{+3.5}_{-3.4}$ GeV
[Phys.Rev.D 80, 054009 (2009)]