News from the Electroweak SM Fit and Constraints on SM Extensions

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for the Gfitter Group*

LoopFest XI, Pittsburgh

May 11th 2012

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Introduction to Gfitter

***Reference paper*:**
EPJ C60, 543-583,2009 [arXiv:0811.0009]
***Update & BSM*:**
accepted by EPJ C, [arXiv:1107.0975]
http://www.cern.ch/gfitter

1. Goal

- provide state-of-the-art model testing tool for LHC era

2. Input to Gfitter

- electroweak precision measurements from **LEP, SLD, Tevatron und LHC**
- **theoretical predictions**

3. The Gfitter Package

- C++, ROOT, xml
- Core Package: data handling, fitting and statistics tools
- full statistics analysis
  - parameter scans
  - p-values
  - toy MC analyses
  - goodness-of-the-fit tests
- physics libraries

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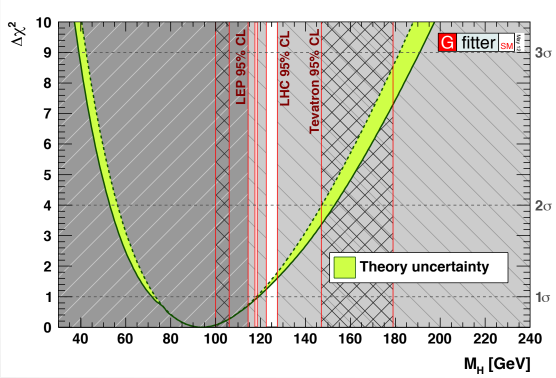
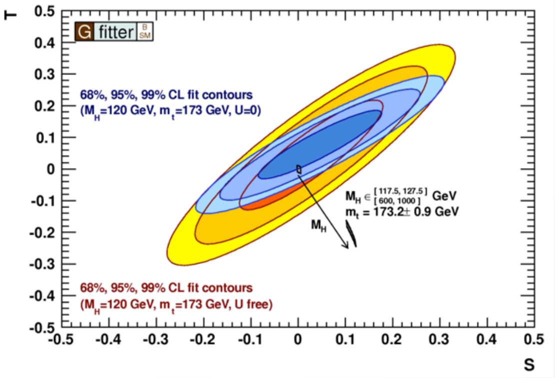
4. SM: global electroweak Fit

- constraints on M_H
- constraints on M_W, m_t
- determination of α_{S}, $\sin^2\theta_{eff}$, pull-values of electroweak observables

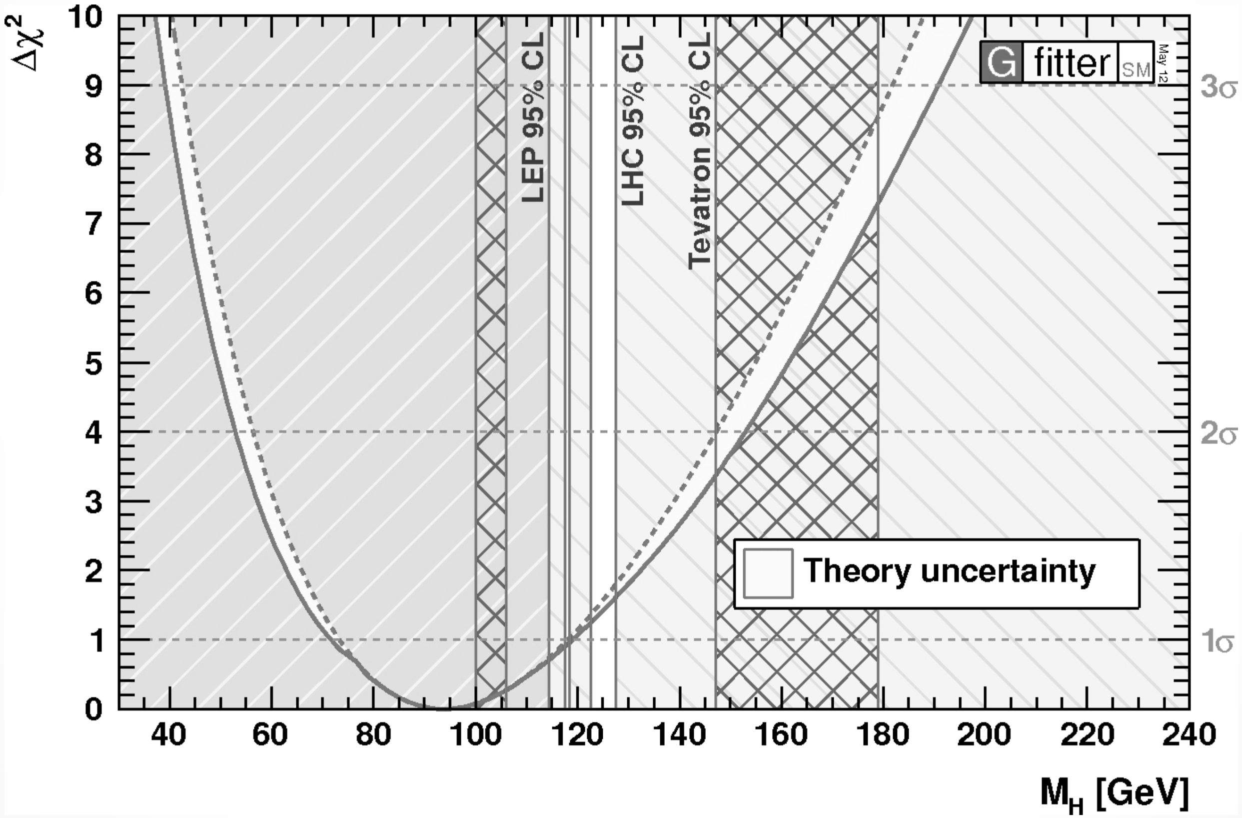


5. BSM physics models – STU Parameter

- introduce oblique parameters
- ew fit - sensitive to BSM physics through oblique corrections
- SM vs. BSM physics



THE ELECTROWEAK FIT WITH GFITTER



The Electroweak Fit: Experimental Input I

- Z-pole observables including their correlations: LEP/SLD experiments

  [ADLO+SLD, Phys. Rept. 427, 257 (2006)]

- new W mass measurements from D0 and CDF combined with LEP result:

  M_W = 80.385±0.015GeV

  [ADLO, hep-ex/0612034][D0,arXiv:1203.0293]
  [CDF,arXiv:1203.0275][LEPEWWG]

- Γ_W: LEP/Tevatron

  [ADLO, hep-ex/0612034][CDF& D0, arXiv:0908.1374]

- m_c , m_b: world averages

  [PDG, J.Phys.G G37 (2010)]

- m_t : Tevatron using 5.8 fb^{-1}

  [D0& CDF, arXiv:1107.5255]

- $\Delta\alpha^{(5)}_{had}$ (M_Z^2): including a_s dependency

  [Davier et al. EPJ C71 (2011)]

Parameter	Input value	Free in fit
M_Z [GeV]	91.1875 ± 0.0021	yes
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] $^{(\circ)}$	95% CL limits	yes
M_W [GeV]	80.385 ± 0.015	–
Γ_W [GeV]	2.085 ± 0.042	–
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes
m_t [GeV]	173.2 ± 0.9	yes
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2757 ± 10	yes
$\alpha_s(M_Z^2)$	–	yes
$\delta_{\rm th} M_W$ [MeV]	$[-4, 4]_{\rm theo}$	yes
$\delta_{\rm th} \sin^2\theta^\ell_{\rm eff}$ $^{(\dagger)}$	$[-4.7, 4.7]_{\rm theo}$	yes

The Electroweak Fit: Experimental Input II

- direct Higgs mass exclusions (at 95% CL):
  - **LEP:** M_H > 114 GeV
    [ADLO: Phys. Lett. B565, 61 (2003)]
  - **Tevatron:** 100-119 GeV and 141-184 GeV
    [TEVNPH: arXiv:1203.3782]
  - **ATLAS:** 110-117.5 GeV, 118.5-122.5 GeV, and 129-539 GeV
    [ATLAS-CONF-2012-019]
  - **CMS:** 127.5-600 GeV
    [CMS-PAS-HIG-12-008]
  - **LHC+Tevatron:** excess at 125 GeV

Allowed Regions

- 117.5 – 118.5 GeV
- 122.5 – 127.5 GeV

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The Electroweak Fit: Theoretical Input I

- electroweak precision observables expressed as functions of the free SM parameters:

$$\mathbf{M_Z, M_H, m_t, \Delta\alpha^{(5)}_{had}(M_Z^2), \alpha_S(M_Z^2), m_c, m_b}$$

- most important predictions for constraining the Higgs mass
  - 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)]
  - theoretical uncertainties (due to e.g. truncation of higher QCD orders):
    M_W (δM_W=4 MeV) and $\sin^2\theta^f_{eff}$ ($\delta\sin^2\theta^f_{eff} = 4.7\cdot10^{-5}$)
  - $\sin^2\theta^f_{eff}$ defines asymmetry parameter and forward-backward asymmetry

- width of W boson not crucial for fit due to large experimental uncertainty

  [Hagiwara et al., arXiv:1104.1769)]

The Electroweak Fit: Theoretical Input II

- partial Z widths (or ratio of them)
  - important for determination of α_S
  - Z couplings implemented by parametrization
    - one-loop, partly at two-loop level for $O(\alpha\alpha_S)$

    [Hagiwara et al., arXiv:1104.1769)][more information in DESY-THESIS-2011-029]
  - Correction applied for large Higgs masses (M_H>500 GeV)
    - accounting for difference between ZFitter and parametrization

    [Bardin et al, CPC 133,299(2001)][Arbuzov et al., CPC 174,728(2006)]
  - radiator functions describe final QCD and QED radiation

    [Hagiwara et al, Z.Phys. C64, 559 (1994), Bardin et al. ,The standard model in the making (1999), Bardin et al., CPC. 133, 229 (2001)]
  - including N3LO to hadronic Z decay

    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022, P.A. Baikov et al., arXiv: 1201.5804 [hep-ph]]

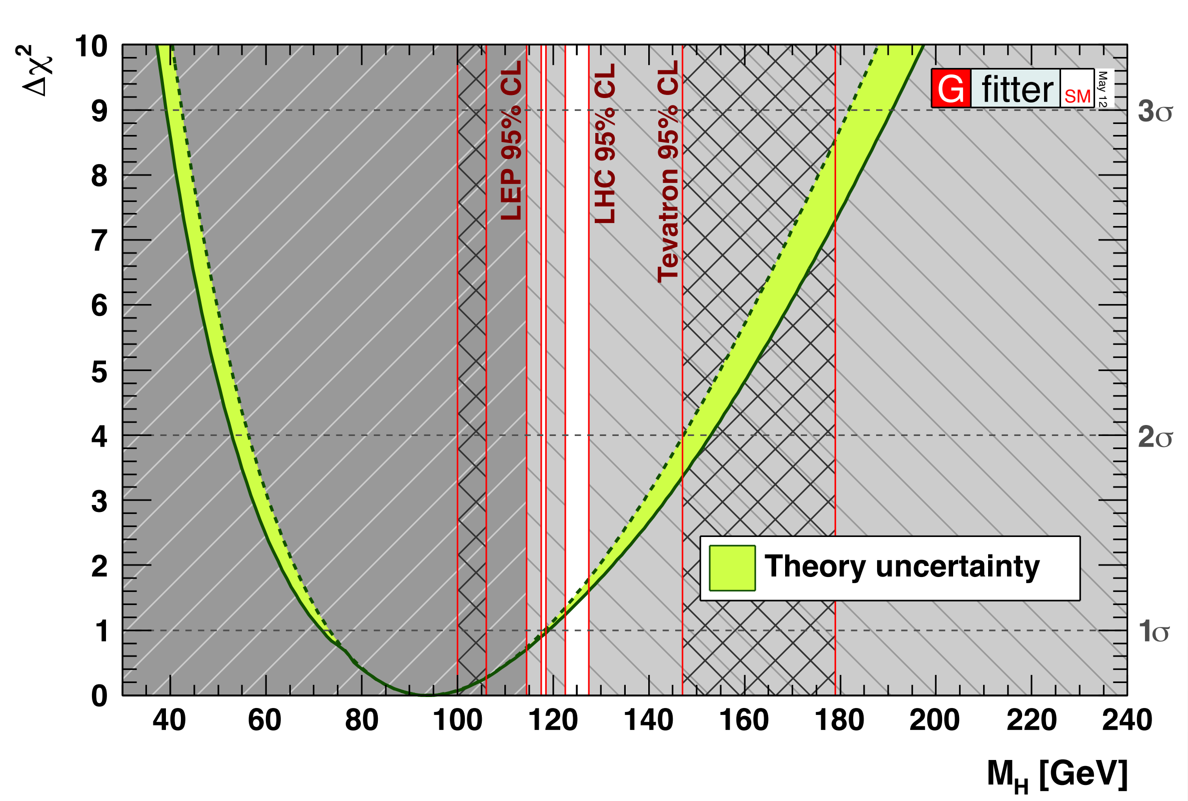
- Include new R_b calculation

  [Freitas and Huang, arxiv:1205.0299]

The Electroweak Fit: Constraints on Higgs mass

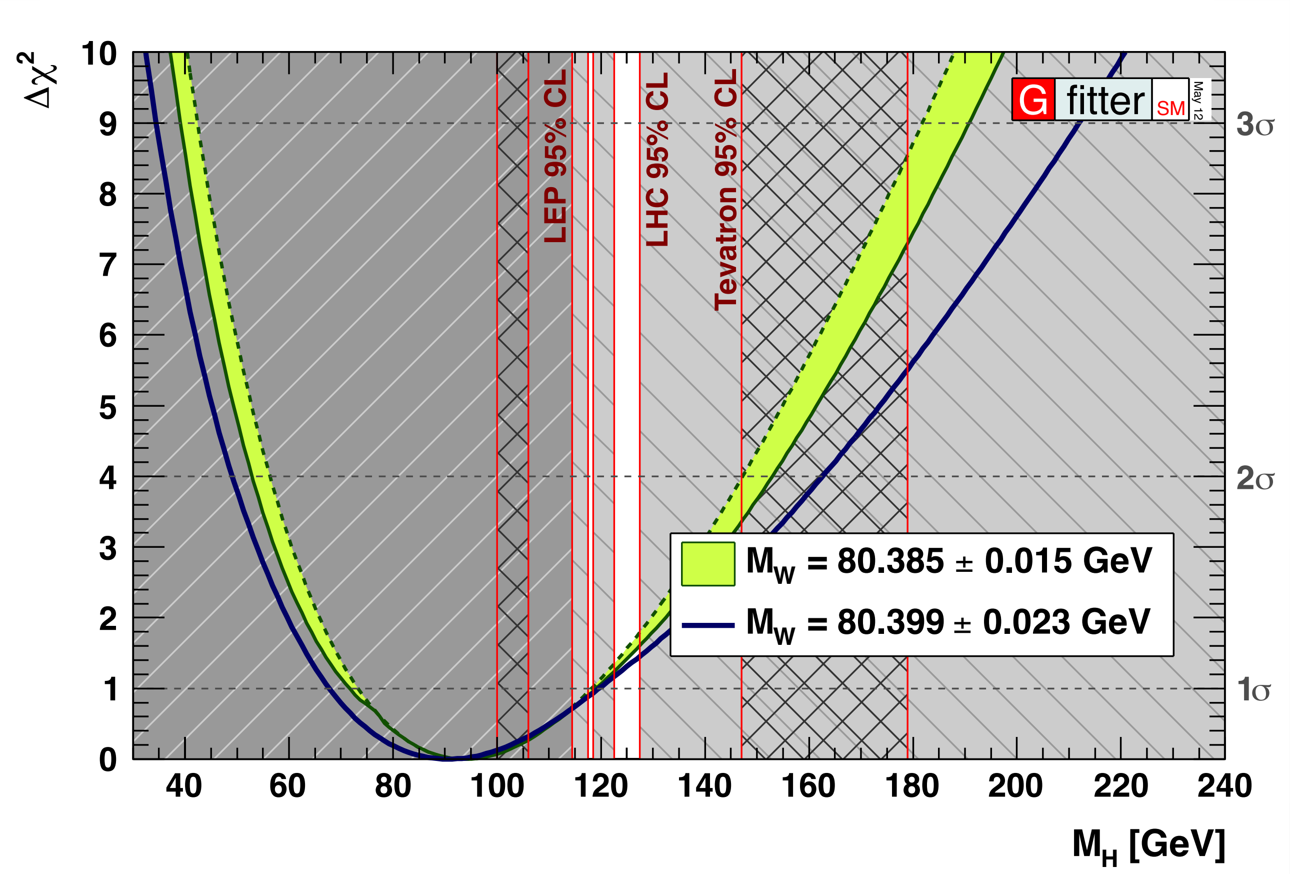
- M_H from fit including all data except results from direct Higgs searches at LEP, Tevatron, LHC

  - value at minimum ±1σ: $M_H = 94^{+25}_{-22}$GeV
- 95% (99%) upper bound: 152 GeV (176 GeV)

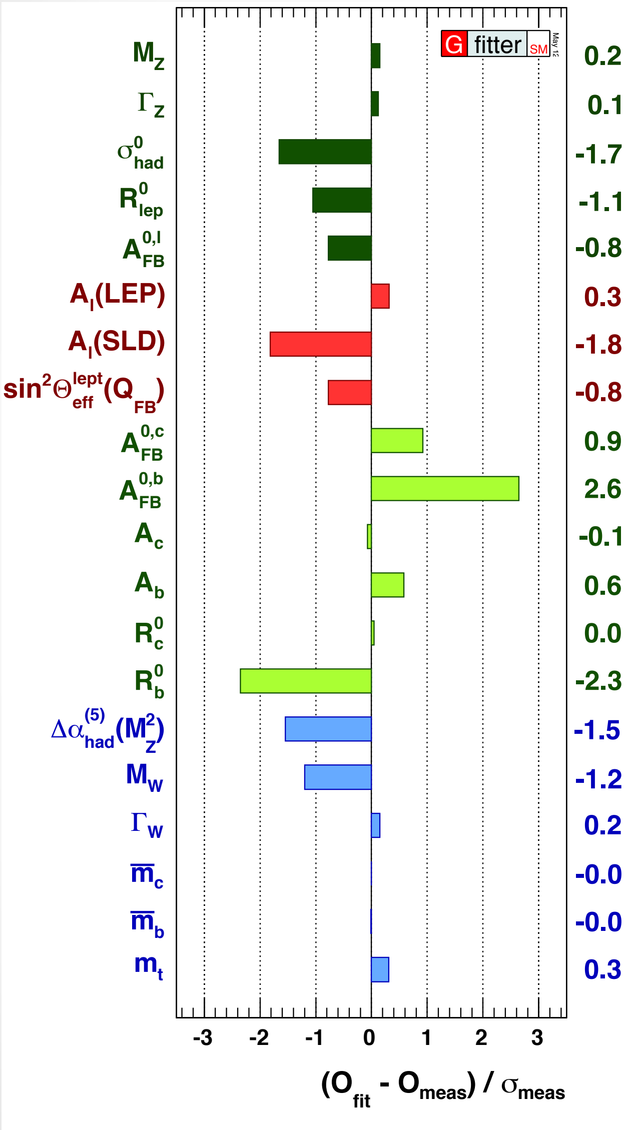


The Electroweak Fit: New M_W

- new M_W measurement improves the 95% and 99% CL limits



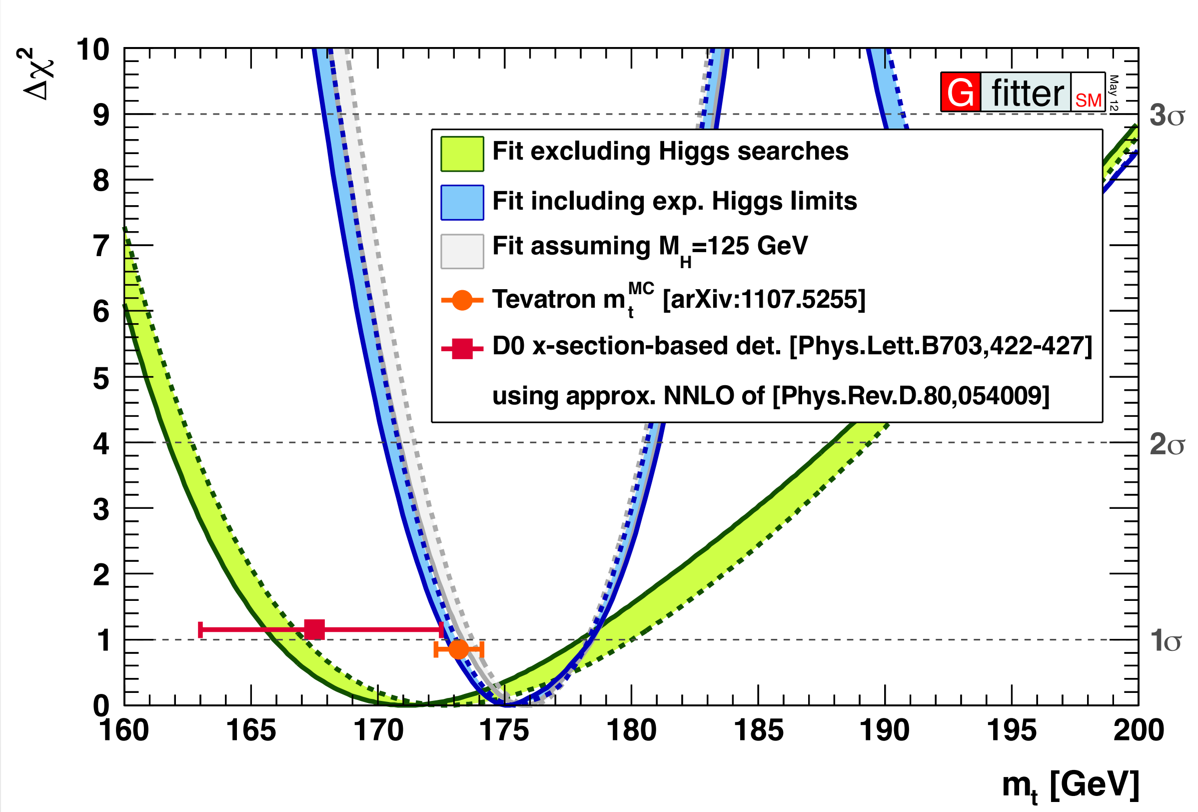
The Electroweak Fit: SM Fit Results



- goodness-of-the fit:
  - excl. (incl.) direct Higgs searches:
    - χ^2_{min} = 20.3 (21.8)
    - Prob(χ^2_{min}, 13(14)) = 0.09 (0.08)
    - reduced by new R_b calculation
  - values before 2011:
    - χ^2_{min} = 16.6 (17.8)
    - Prob(χ^2_{min},13(14)) = 0.21 (0.23)
- pull values (incl. direct Higgs searches)
  - increased pull-value of R_b: -0.8 → -2.3
  - $A^{0;b}_{FB}$ largest contributor to χ^2_{min}
  - no individual pull exceeds 3σ
  - small contributions from M_Z, $\Delta\alpha^{(5)}_{had}(M_Z^2)$, m_c, m_b
    - input accuracies exceed fit requirements
- good agreement between data and SM

The Electroweak Fit: Determination of m_t

- direct top mass measurement is not included
  - fit excluding (including) direct Higgs searches
  - fit with fixed Higgs mass
- fit results in agreement with direct measurements



w/o direct Higgs searches

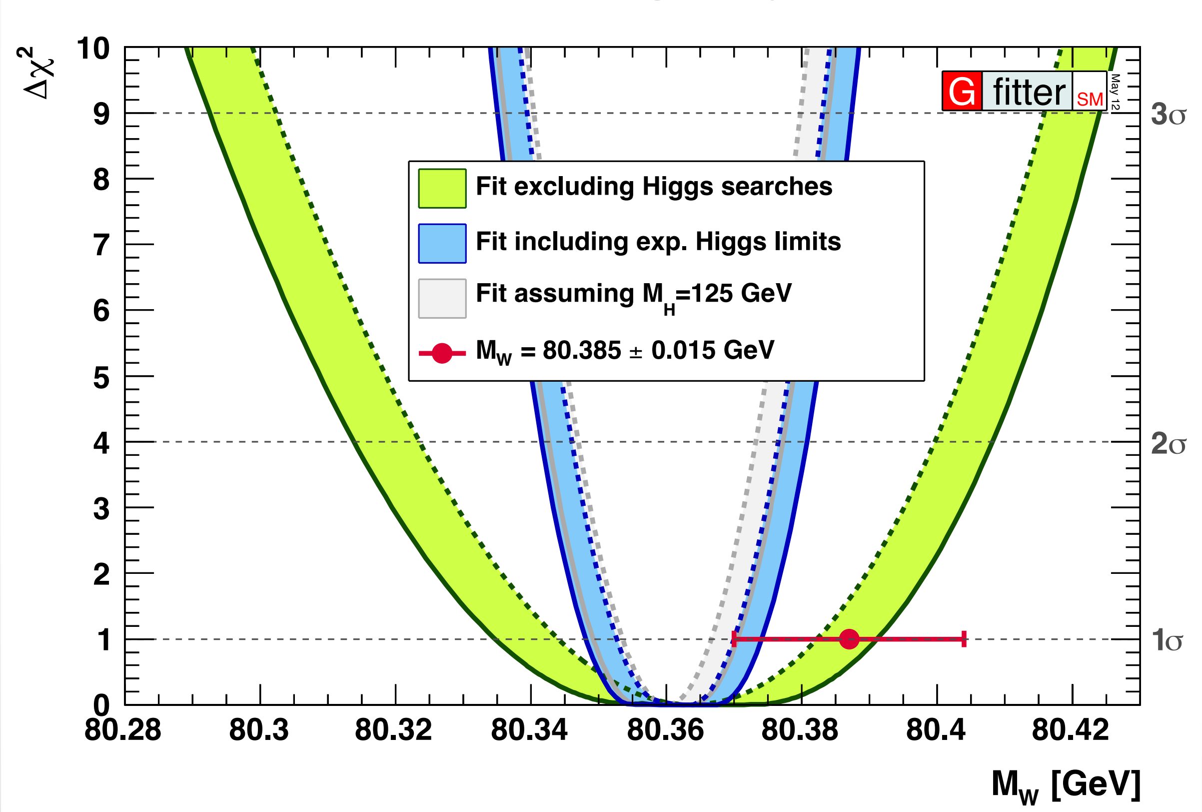
- $171.1^{+6.8}_{-5.2}$ GeV

with direct Higgs searches

- $175.1^{+3.3}_{-2.4}$ GeV

The Electroweak Fit: Determination of M_W

- direct W mass measurement is not included
  - fit excluding (including) direct Higgs searches
  - fit with fixed Higgs mass
- fit results in agreement with direct measurements
- indirect determination higher precision than world average



w/o direct Higgs searches

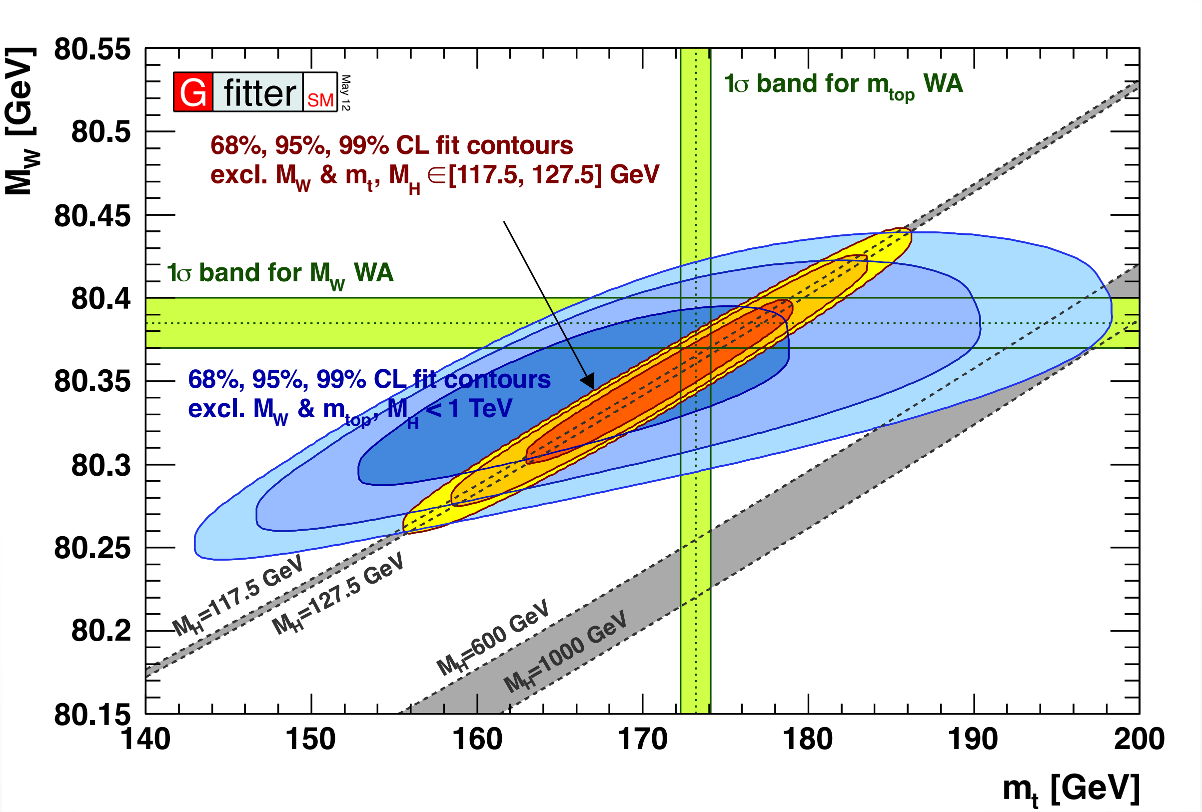
- 80.363 ± 0.028 GeV

with direct Higgs searches

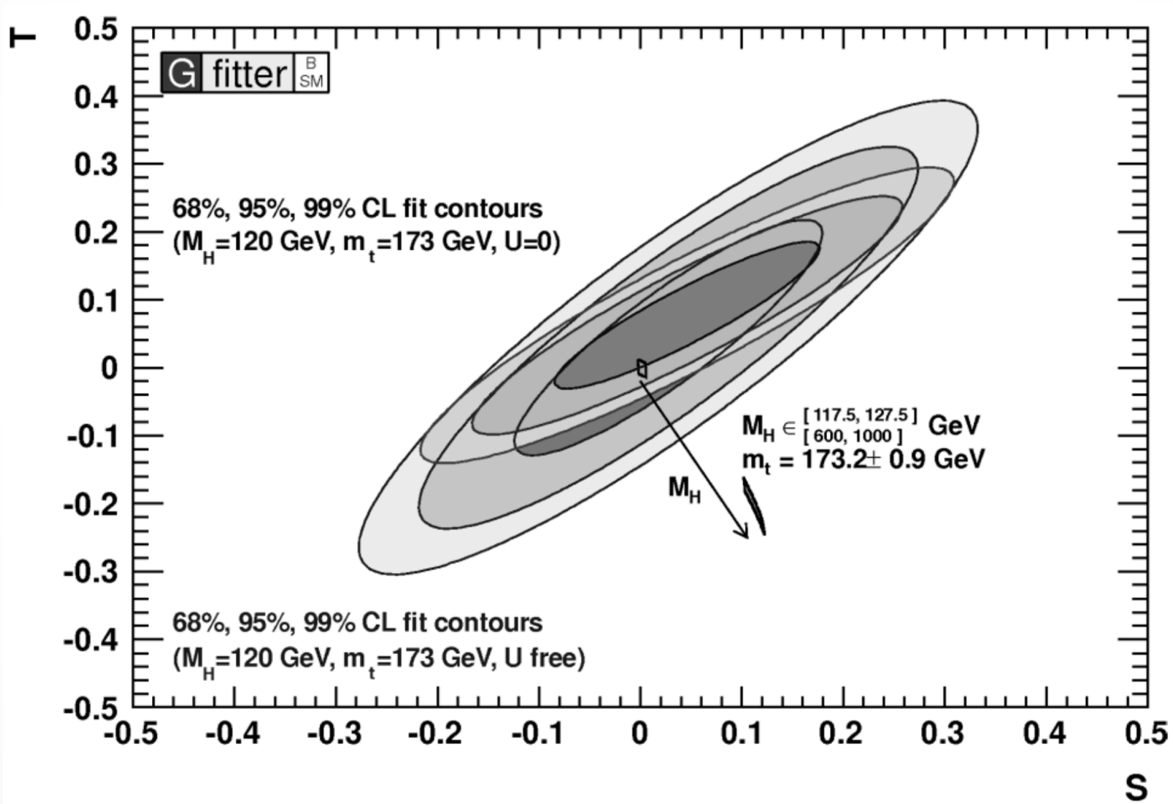
- 80.361 ± 0.013 GeV

The Electroweak Fit: Scan of m_t and M_W

- green bands: world average, agree with indirect constraints
- direct Higgs searches constrain both observables significantly
- possible to probe SM or BSM physics models



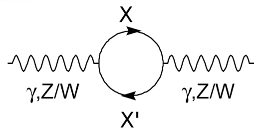
Constraints on New Physics Models



"OBLIQUE" PARAMETERS

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

1. **assumption:** high-scale BSM physics appears only through **vacuum polarisation corrections** (cf. rad. corr.from mt , MH in SM)



2. ew fit sensitive to BSM physics through these **oblique corrections**

3. **oblique corrections** from New Physics described through **STU parametrization**

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

4. **STU measure deviations** from electroweak radiative correction expected in SM_{ref}

S: new physics contribution to **neutral current processes**

U: (+S) new physics contribution to **charged current processes**

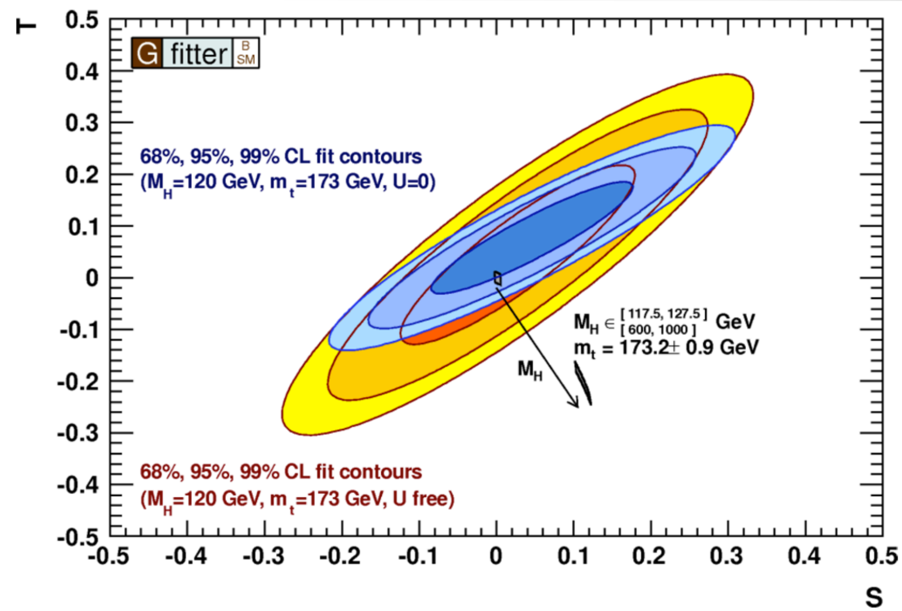
- U only sensitive to M_W and Γ_W
- usually very small in new physics models (often: U=0)

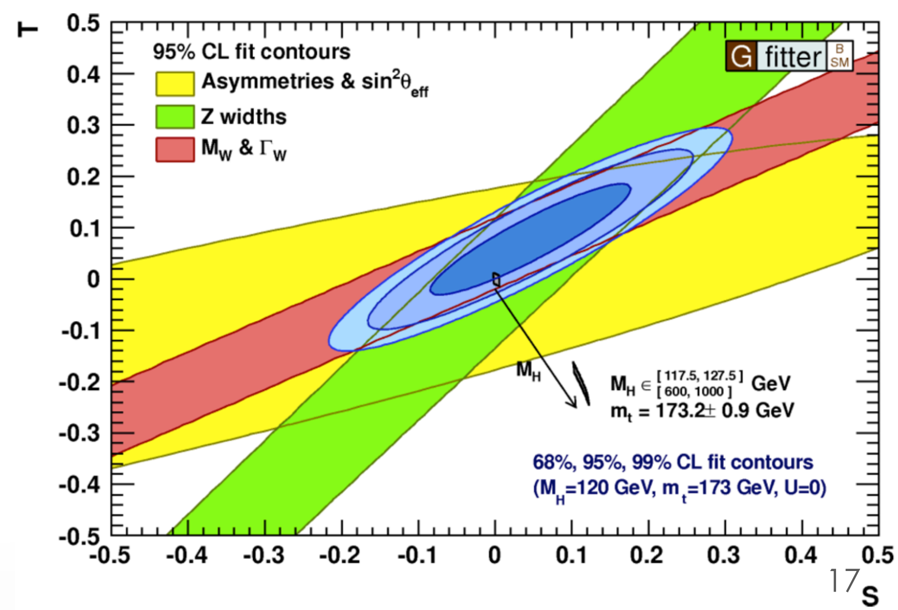
T: difference between neutral and charged current processes

- sensitive to weak isospin violation

Fit of S-T-U

- S, T, U derived from fit to electroweak observables
  - SM_{ref}: m_t = 173 GeV, M_H = 120 GeV
- results for STU:
  - S = 0.04 ± 0.10, T = 0.05 ± 0.11, U = 0.08 ± 0.11
- gray area: SM prediction
  - for SM_{ref} : S = T = U = 0
  - S, T: logarithmically dependent on M_H
  - small M_H compatible with data
- BSM physics models
  - large S-T area allowed due to unconstrained model parameters
  - heavy Higgs masses due to compensation
- status of recent publication
  - update is in progress
  - new m_t, M_H partially included
  - no new M_W, R_b, N3LO to hadronic Z decay





Sequential Fourth Generation

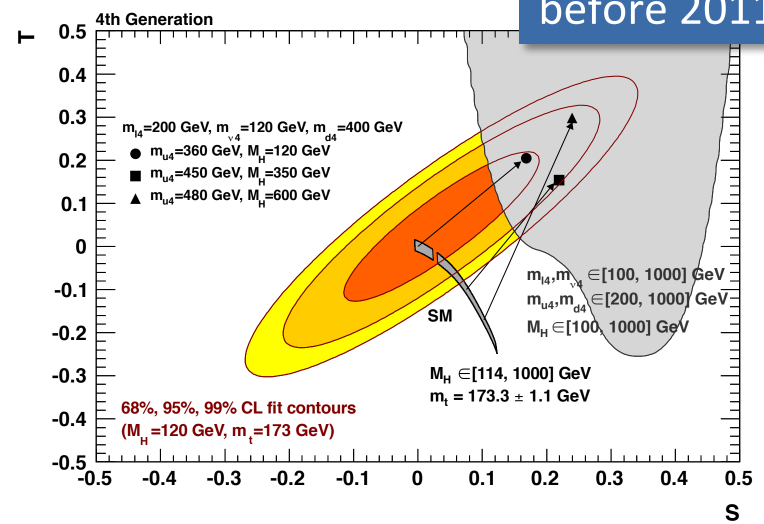
[Hubisz et al., JHEP 0601:135 (2006)]

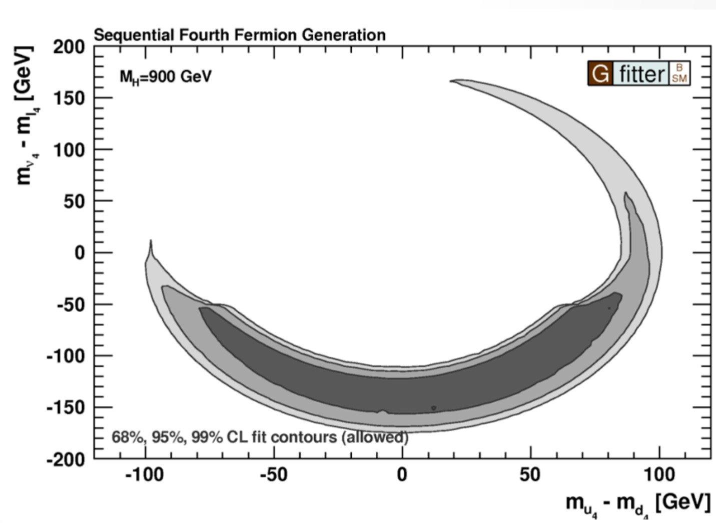
- models with a fourth generation
  - SM: no explanation for n=3 generations
  - introduction of new states for leptons and quarks

    $\Psi_L = (\Psi_1,\Psi_2)_L,\ \Psi_{1,R},\ \Psi_{2,R}$
- free parameters:
  - masses of new quarks and leptons

    mu4 , md4 , me4 m4
  - assuming: no mixing of extra fermions
  - model-independent
- contribution to STU from new fermions
- sensitivity to mass difference between up-type and down-type elds, rather than absolute mass scale
- results:
  - with appropriate mass differences: 4th fermion model consistent with data
  - large MH is allowed
  - data prefer a heavier charged lepton

before 2011





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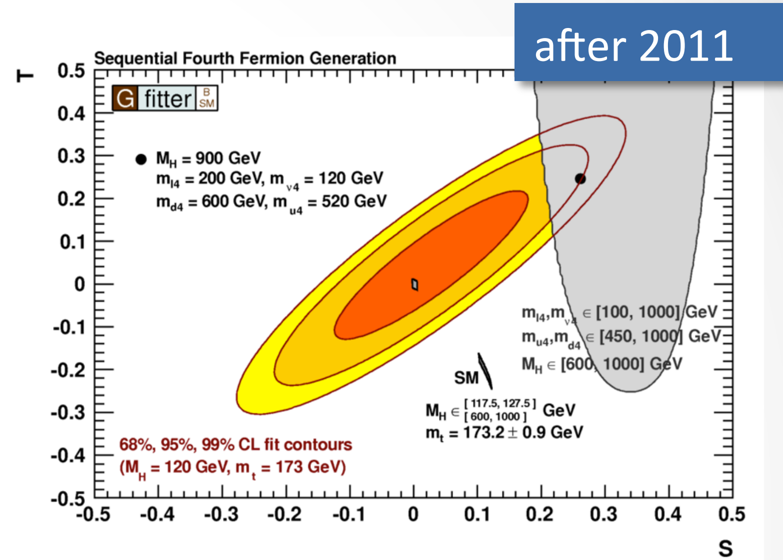
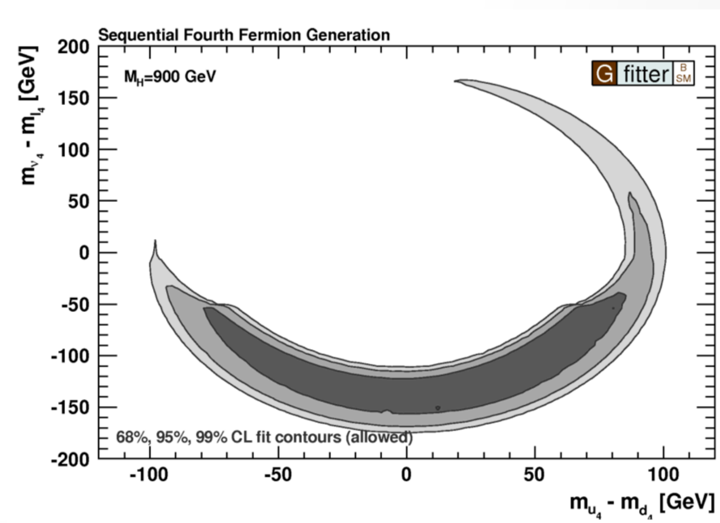
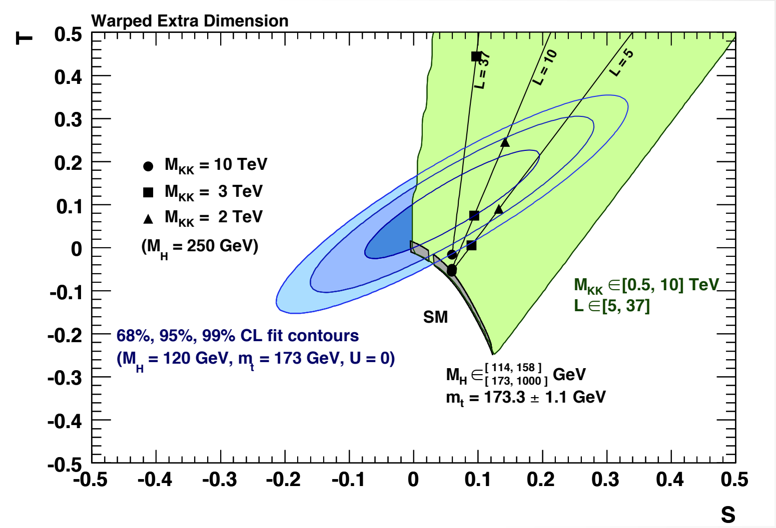


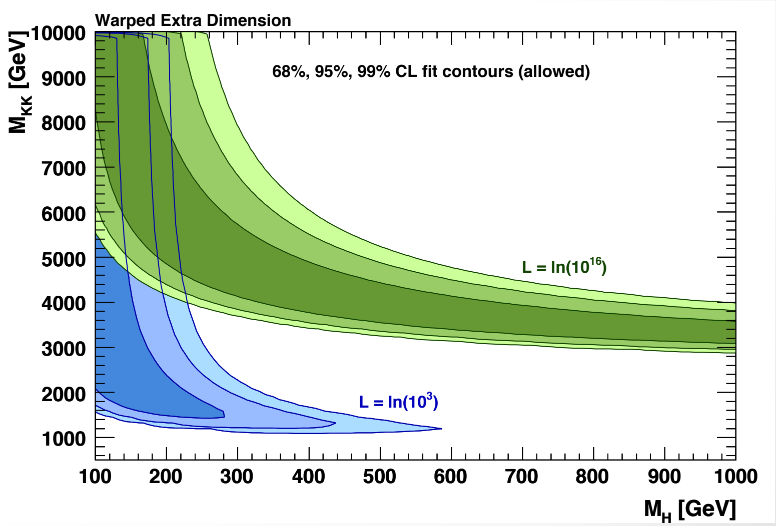


WARPED EXTRA DIMENSION

[L.Randall, R.Sundrum, Phys. Rev. Lett. 83, 3370 (1999)] [S. Casagrande et al., JHEP10(2008)094]

- extra dimension (ED) confined by two branes for solving hierarchy problem
- generation of weak scale on IR brane from UV brane: introduction of warp factor (exp. func. of compactication radius of ED)
- originally: ED only accessible to gravity
- here: SM fermions, gauge bosons propagate into bulk, Higgs does not
- free parameters
  - MKK : KK scale (heavy KK modes)
  - L: log of warp factor
- results:
  - large L requires large MKK
  - compensation if MH is large





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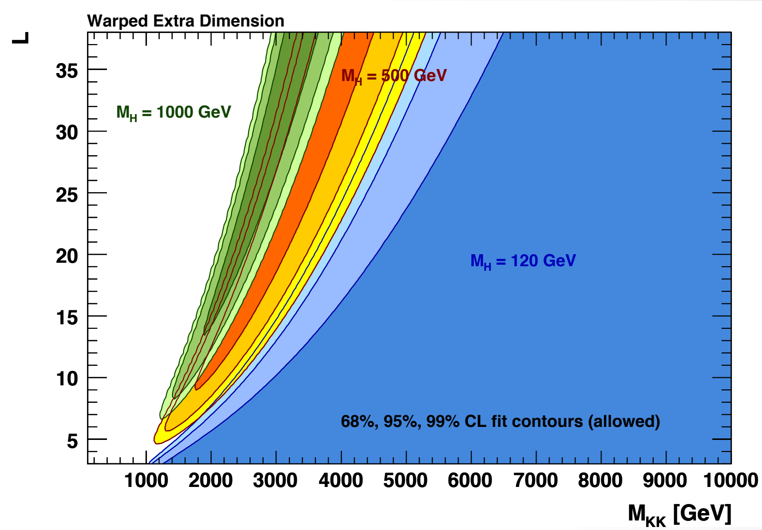
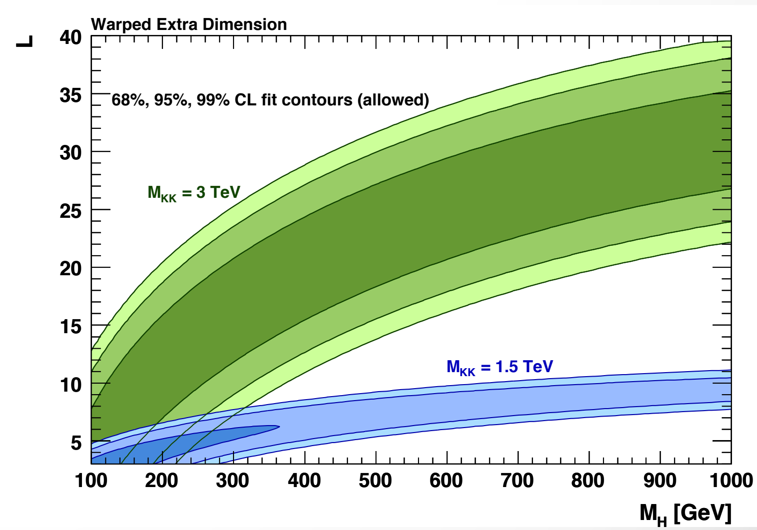
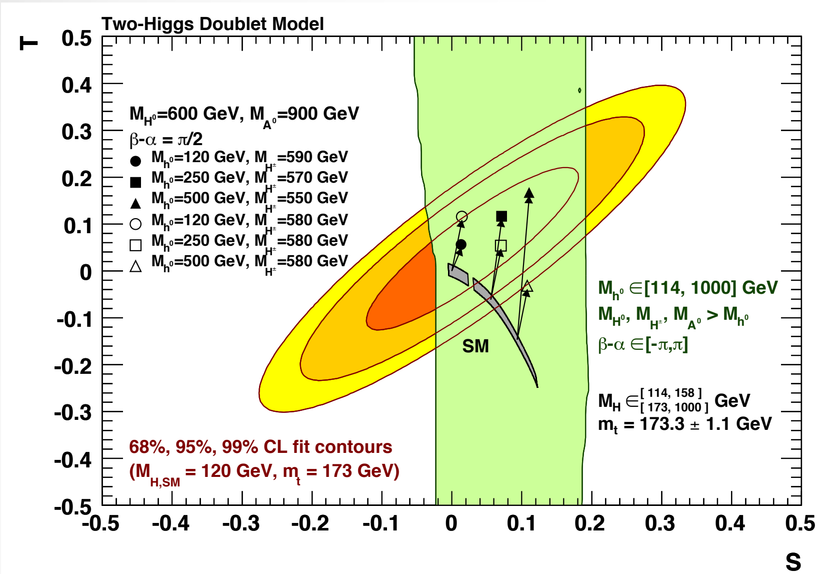




Two-Higgs Doublet Model I

[H. E. Haber et al., Nucl. Phys. B161, 493 (1979).],[C. D. Froggatt et al., Phys. Rev. D45, 2471 (1992).]

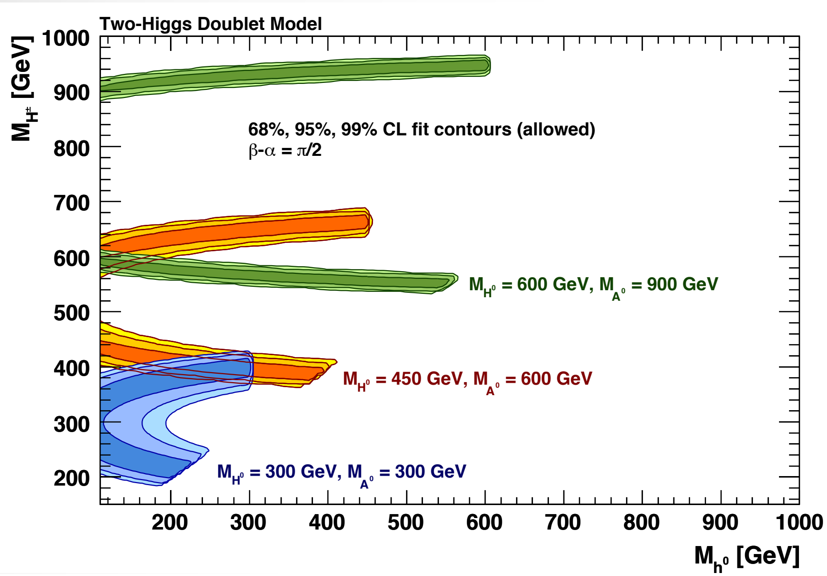


- introduce one additional $SU(2)_L \times U(1)_Y$ Higgs doublet with hypercharge Y = 1
- 2 Higgs doublets
  → 5 physical Higgs boson states
- FCNC can be suppressed with appropriate choice of the Higgs-to-fermion couplings

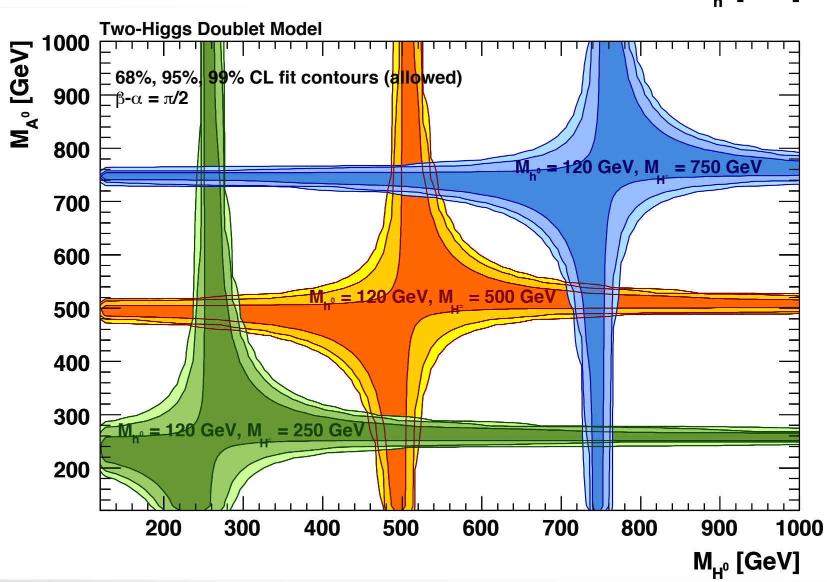
- different 2HDM types:
  - Type-I: only one doublet couples to fermion sector
  - Type-II: one doublet couples to up-type fermions, one to down-type fermions, resembles Higgs sector of MSSM
  - type distinction irrelevant for study of oblique corrections
  - defined according to Yukawa couplings, do not enter oblique corrections at one-loop order
- free parameters:
  - Higgs masses M_{h0} , M_{H0} , M_{A0} , M_H
    LEP limit: $M_H > 78.6$ GeV
  - ratio of the vev of the two doublets, $\tan\beta = v2/v1$ (mixing of charged and neutral fields)
  - angle α (mixing of the neutral CP-even Higgs fields)

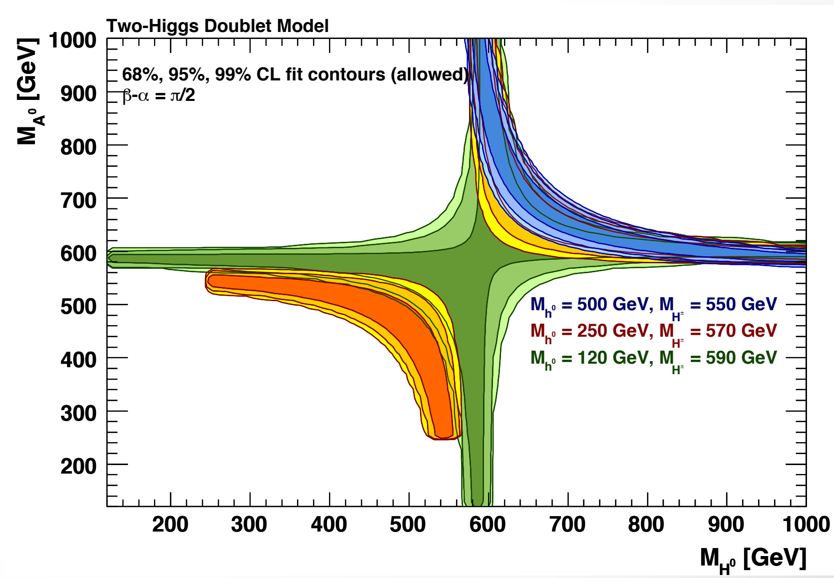
Two-Higgs Doublet Model II

[H. E. Haber et al., Nucl. Phys. B161, 493 (1979).],[C. D. Froggatt et al., Phys. Rev. D45, 2471 (1992).]

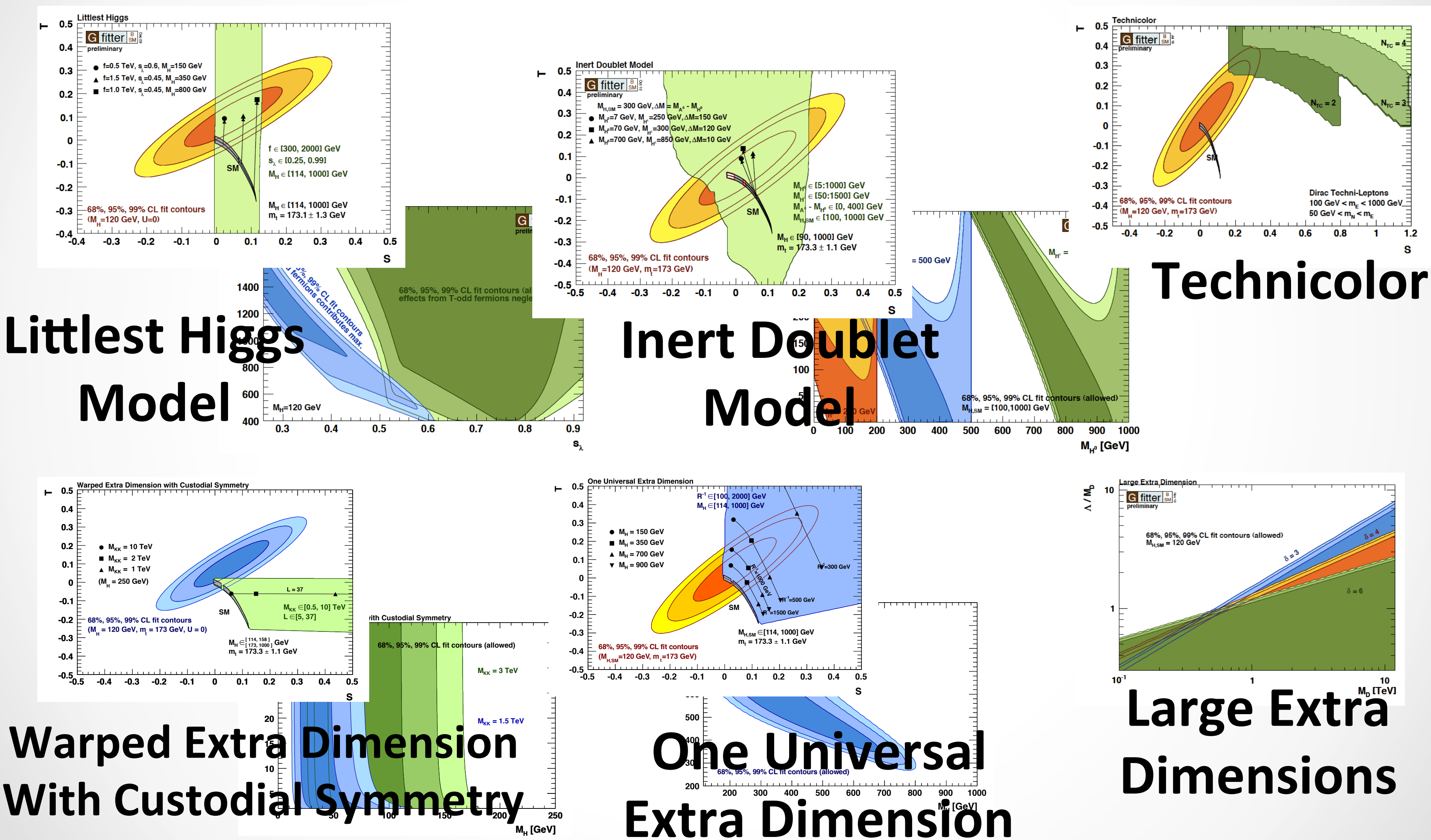


- parameter constraints only dependent of other parameters
- for light M_{h0}:
  - similar values of the heavy Higgs masses preferred





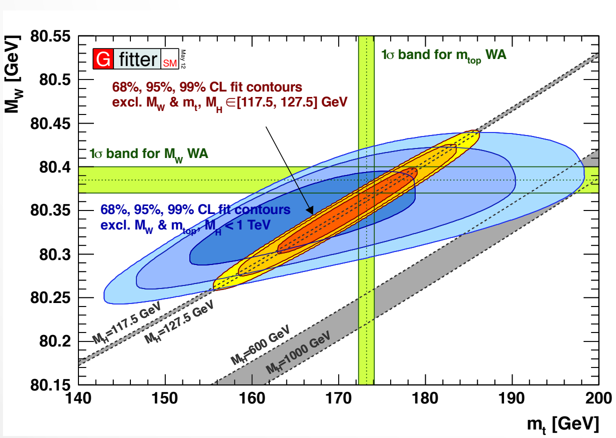
Many More Models



Conclusion

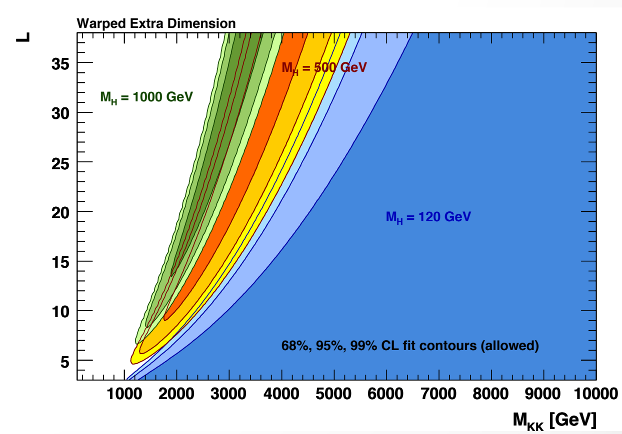
Standard Model

- global fit of the electroweak SM
- good compatibility of the SM and the electroweak precision data
- inclusion of latest direct Higgs searches
  - Higgs mass strongly constrained
  - light Higgs preferred by SM
- inclusion of the latest R_b calculations



BSM physics models

- test compatibility of various BSM models with electroweak precision data via the oblique parameters
- set constraints on BSM model parameters
- heavier Higgs boson allowed in various BSM models



THANK YOU FOR YOUR ATTENTION!

REFERENCE PAPER: EPJ C60, 543-583,2009 [ARXIV:0811.0009]
UPDATE & BSM: ACCEPTED BY EPJ C, [ARXIV:1107.0975]
HTTP://WWW.CERN.CH/GFITTER

BACKUP

Statistical Interpretation of Direct Higgs Searches

- Statistical interpretation
  - Experiments measure test statistic
  - Transformed by experiments into 1-sided upper limit (CLS=CLS+B/CLB) using pseudo experiments
  - We transform 1-sided CLS+B into 2-sided CL2sS+B
    - SM is null hypothesis. We measure both down- and upward deviations from SM !
  - χ2 contribution calculated via inverse error function:

  dχ2 = Erf-1(1-CL2sS+B)
- Alternative treatment, followed here:
  - χ2 contribution is: -2lnQ
  - Lacks statistical information from experiments.
  - No 2-sided interpretation
  - ATLAS CLS+B not public

- Note about combination of ATLAS and CMS H→WW results
  - Ignores correlations between x-section theory and luminosity uncertainties !
  - Tevatron/LHC combination procedure needed