The global electroweak fit and constraints on new physics

Matthias Schott (CERN) on behalf of the Gfitter Group
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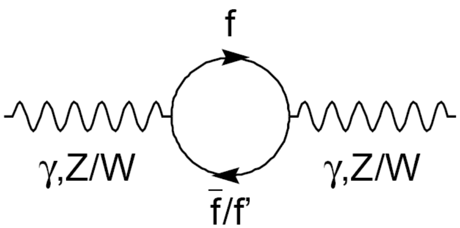
Content

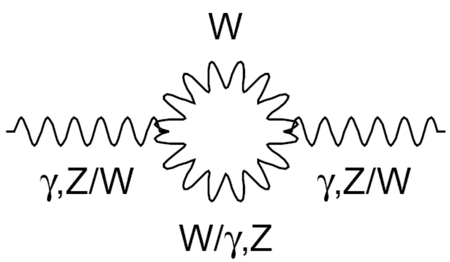
- Introduction to Gfitter
- Update on the electroweak fit
- Oblique Parmeters
- Constrains on new physics
- Conclusion and Outlook

The global electroweak fit with Gfitter

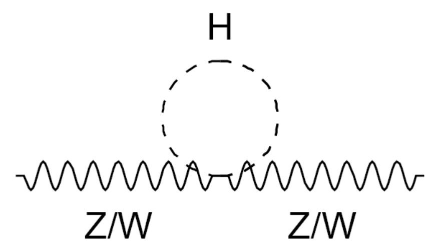
- A Gfitter package for the global EW fit of the SM
  - State of the art implementation of SM predictions of EW precision observables
  - Based on huge amount of pioneering work by many people
  - Radiative corrections are important (Logarithmic dependence on M_H through virtual corrections)



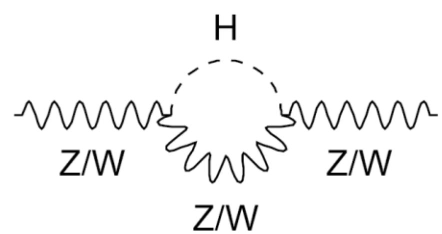
- Gfitter/GSM sub-package used in the global EW fit of the SM
  [Co-authored by Gfitter and ZFITTER groups] [H. Flaecher et al., Eur. Phys. J. C60 (2009) 543; Erratum in preparation] [A.B. Arbuzov et al., Comput. Phys. Commun. 174, 728 (2006)] [D.Y. Bardin et al., Comput. Phys. Commun. 133, 229 (2001)]



- In particular:
  - M_W : full two-loop + leading beyond-two-loop corrections
    [M. Awramik et al., Phys. Rev D69, 053006 (2004) and refs.] (Theoretical uncertainties: ΔM_W = 4–6 GeV)
  - $sin^2\theta^l_{eff}$: full two-loop + leading beyond-two-loop corrections
    [M. Awramik et al., JHEP 11, 048 (2006) and refs.] (Theoretical uncertainties: $\Delta\sin^2\theta^{\,l}_{eff}$=4.7·10^{-5})
  - Partial and total widths of *Z* and *W*: integrated from ZFITTER
    See also: http://zfitter.desy.de
    Including up to two-loop electroweak and all known QCD corrections
    [A.B. Arbuzov et al., Comput. Phys. Commun. 174, 728 (2006)] [D.Y. Bardin et al., Comput. Phys. Commun. 133, 229 (2001)] [A.A. Akhundov et al., Nucl. Phys. B276, 1 (1986)] [D.Y. Bardin et al., Z. Phys. C32, 121 (1986)] [R..Barbieri et al., Nucl. Phys.B409, 105 (1993)] [J. Fleischer et al., Phys. Lett. B319, 249 (1993)] [G. Degrassi et al., Phys. Lett. B350, 75 (1995)] [G. Degrassi et al., hep-ph/9507286] [G. Degrassi et al., Phys. Lett. B383, 219 (1996)] [G. Degrassi, P. Gambino, Nucl. Phys. B567, 3 (2000)] [D. Y. Bardin et al., hep-ph/9709229] [D.Y. Bardin, G. Passarino, Oxford, UK: Clarendon (1999) 685p] [B.A. Kniehl, Nucl. Phys. B347, 86 (1990)]



    Added in GSM: Radiator Functions using 3NLO calc. of massless QCD Adler function [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]



Experimental input

- Free fit parameters
  - M_Z, M_H, m_t, $\Delta\alpha_{had}^{(5)}(M_Z^2)$, $\alpha_S(M_Z^2)$, m_c, m_b
  - Scale parameters for theoretical uncertainties on M_W, $\sin^2\theta^l_{eff}$ (and the EW form factors r_Z^f, k_Z^f)

- Latest experimental input
  - Z-pole observables: LEP / SLC results [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
  - M_W and Γ_W latest from LEP/Tevatron (03/2010) [ADLO,CFD+D0: arXiv:0908.1374v1]
  - m_{top} : latest Tevatron average (07/2010) [CDF&D0: new combination ICHEP'10]
  - m_c, m_b world averages [PDG, J. Phys. G33,1 (2006)]
  - **$\Delta\alpha_{had}^{(5)}(M_Z^2)$** including α_S dependency (10/2010) [Davier et al., arXiv:1010.4180]
  - **Direct Higgs searches from LEP/Tevatron/LHC** (03/2011) [ADLO: Phys. Lett. B565, 61 (2003)], [CDF+D0: Moriond 2011][ATLAS+CMS: Moriond 2011]
  - Not considered: $\sin^2\theta_{eff}$ results from NuTeV. APV and polarized Möller scattering

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] $^{(\circ)}$	Likelihood ratios	yes
M_W [GeV]	80.399 ± 0.023	–
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]	173.3 ± 1.1	yes
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2749 ± 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
$\delta_{\rm th}\rho^f_Z$ $^{(\dagger)}$	$[-2,2]_{\rm theo}$	yes
$\delta_{\rm th}\kappa^f_Z$ $^{(\dagger)}$	$[-2,2]_{\rm theo}$	yes

Input from Direct Higgs-Searches

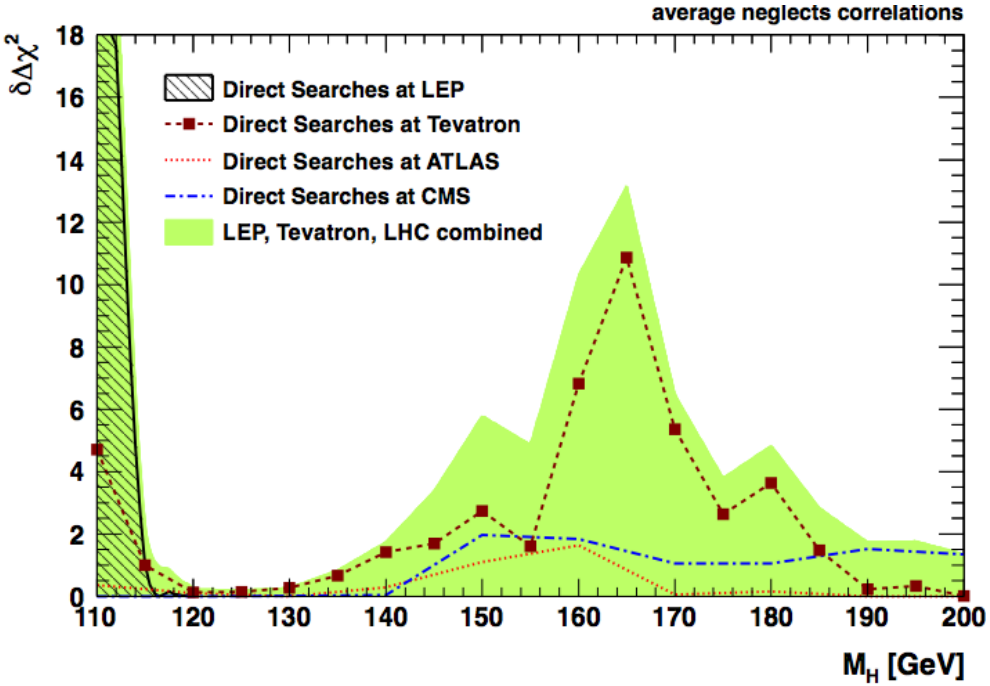
- Include Results from the 2010 LHC run
  - ATLAS (combining six different final states)
  - CMS (H →WW → lνlν)

- Assume SM to be true to test compatibility with the data
  - Transform the one-sided confidence level, CL_{s+b} into a two-sided confidence level, $CL^{2-sided}_{s+b}$.
  - reduces the statistical constraint from the direct searches compared to one-sided CL_{s+b}

- The contribution to the χ2 estimator minimized in the fit is obtained from

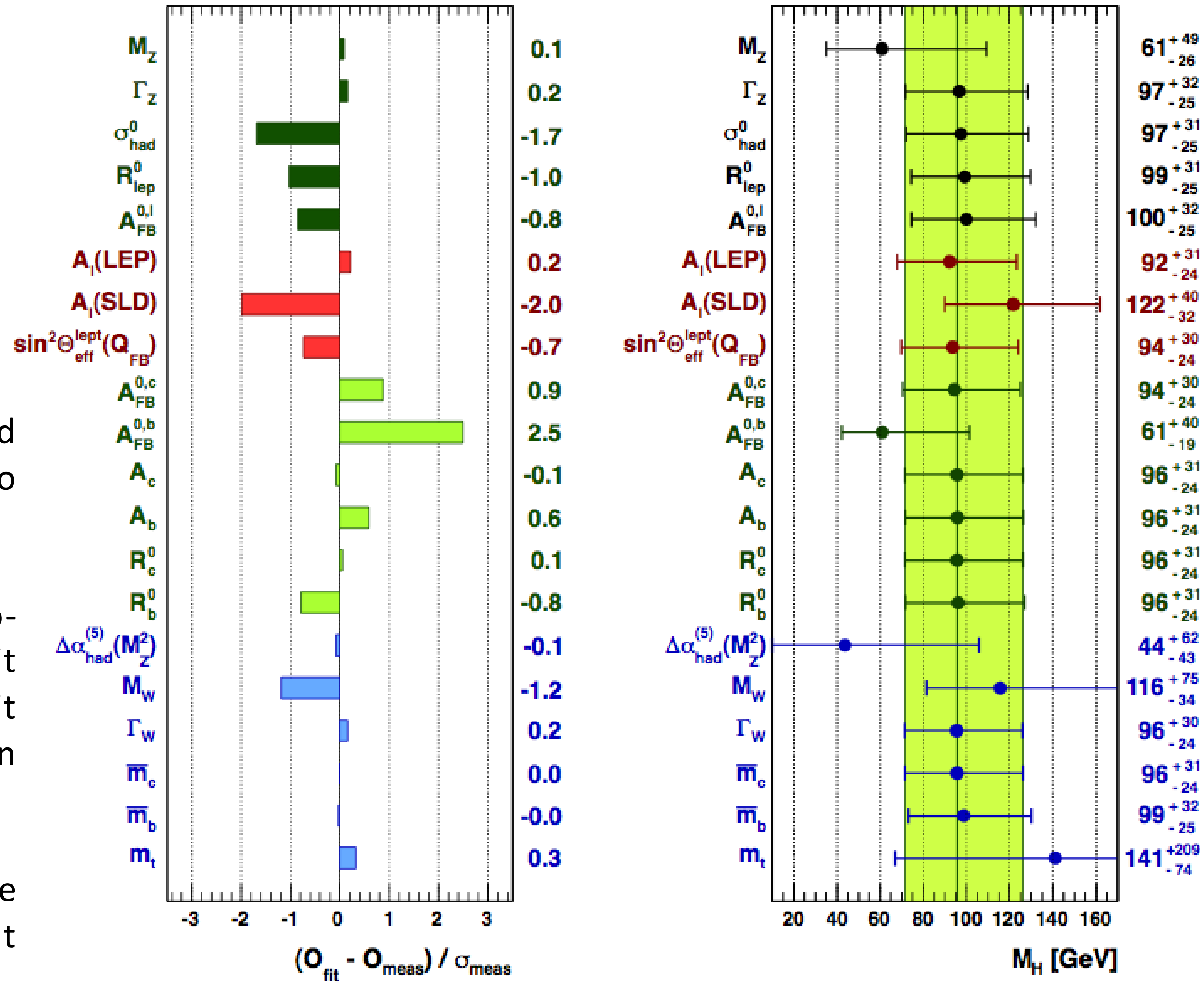
$$\delta\chi^2 = 2\cdot[\mathrm{Erf}^{-1}(1-\mathrm{CL}^{2-\mathrm{sided}}_{s+b})]^2$$

  - No correlations are taken into account among LEP, Tevatron and LHC results



Standard Model Fit Results

- Standard Fit Results
  - χ^2_{min} = 16.7
  - 13 degrees of freedom
  - Prob(χ^2_{min},13) = 0.21
- Complete Fit Results
  - χ^2_{min} = 17.6
  - 14 degrees of freedom
  - Prob(χ^2_{min},14) = 0.23
- Probabilities confirmed by pseudo Monte Carlo experiments
- Improvement in the p-value of the complete fit due to increased best-fit value of the Higgs mass in the standard fit
- new result reduces the tension with the direct Higgs boson searches



G fitter

SM Higgs Results

- $\Delta\chi^2$ estimator for the standard and complete fits versus M_H

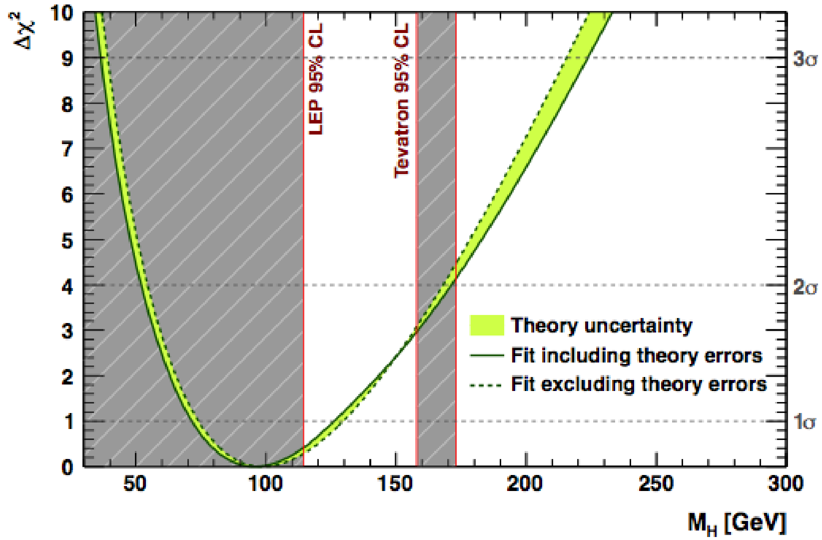
$$M_H = \begin{cases} 96\,^{+31}_{-24}\ \text{GeV} & \text{(standard fit)} \\ 120\,^{+12}_{-5}\ \text{GeV} & \text{(complete fit)} \end{cases}$$

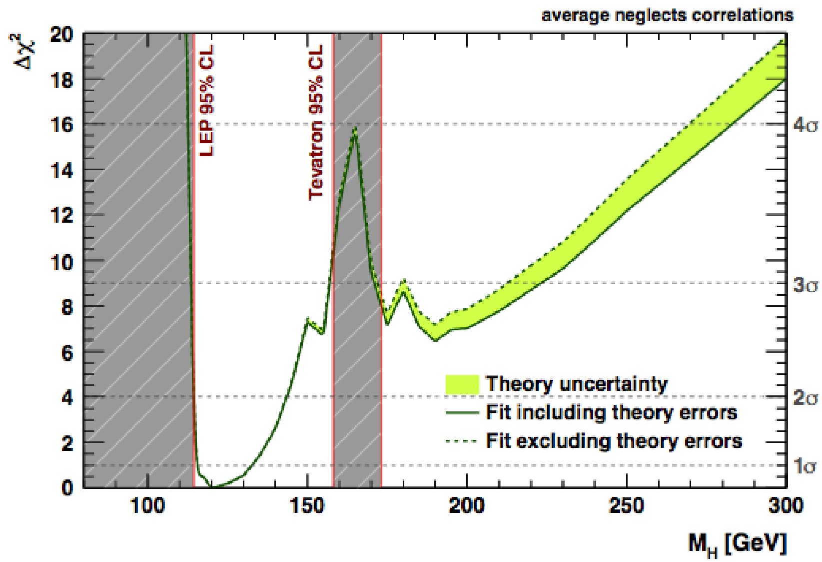
- with the 95% (99%) upper bounds of
  - 169GeV (200 GeV) for the standard fit
  - 143GeV (149 GeV) for the complete fit

- The errors and limits include the various theory uncertainties that taken together amount to approximately 8 GeV on M_H .

- The standard fit value for MH has moved by +12 GeV as a consequence of the new $\Delta\alpha^{(5)}_{had}(M_Z^2)$
- Using the preliminary result $\Delta\alpha^{(5)}_{had}(M_Z^2)$ of K. Hagiwara, R. Liao, A. D. Martin, D. Nomura and T. Teubner, 1105.3149, we find

$$M_H = 88\,^{+29}_{-23}\ \text{GeV}$$





Indirect Determination of m_t and m_W

- Indirect Determinations
  - Perform (complete) fit for each parameter or observable, obtained by scanning the profile likelihood without using the corresponding experimental or phenomenological constraint in the fit

- W mass is 1.6σ below and exceeds in precision the experimental world average

$$M_W = 80.359\,^{+0.017}_{-0.010}\ \text{GeV}$$

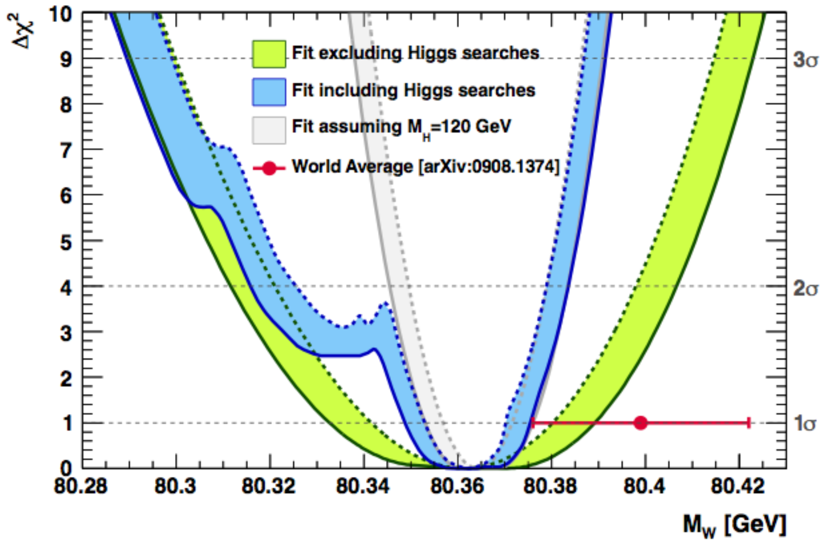
- Allowed 1σ regions are found from the indirect constraint of the top quark pole mass in the complete fit

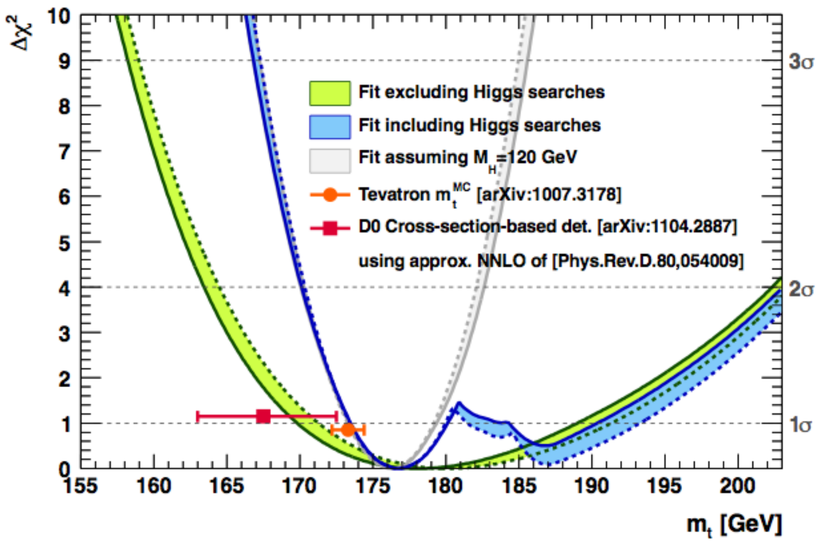
$$m_t = [173.5, 181.1]\ \text{GeV} \quad \text{and} \quad [184.3, 190.3]\ \text{GeV}$$

- *N^3LO* a_S from fit

$$\alpha_S(M_Z^2) = 0.1193 \pm 0.0028$$

  - Negligible theoretical uncertainty
  - Excellent agreement with result *N^3LO* from τ-decays





G fitter

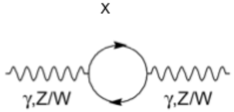
Oblique Corrections

- Gfitter Beyond Standard Model Package
  - At low energies, BSM physics appears dominantly through vacuum polarization corrections
  - Called: oblique corrections

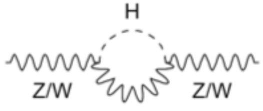
- Oblique corrections reabsorbed into electroweak parameters

  - $\Delta\rho$, $\Delta\kappa$, Δr parameters, appearing in
  - M_W^2, $\sin^2\theta_{eff}$, G_F, α, etc

- Electroweak fit sensitive to BSM physics through oblique corrections



  - In direct competition with sensitivity to Higgs loop corrections



- Oblique corrections from New Physics described through STU parametrization [Peskin and Takeuchi, Phys. Rev. D46, 1 (1991)]

$$O_{meas} = O_{SM,REF}(m_H,m_t) + c_S S + c_T T + c_U U$$

- **S-Parameter:** New Physics contributions to neutral currents
- (S+U) Parameter describes new physics processes to charged current processes
- **T-Parameter:** Difference between neutral and charged current processes – sensitive to weak isospin violation
- **U-Parameter:** (+S) New Physics contributions to charged currents. U only sensitive to W mass and width, usually very small in BSM models (often: U=0)

- Also implemented: correction to Z→bb coupling, extended parameters (VWX) [Burgess et al., Phys. Lett. B326, 276 (1994)] [Burgess et al., Phys. Rev. D49, 6115 (1994)]

Fit to Oblique Parameters

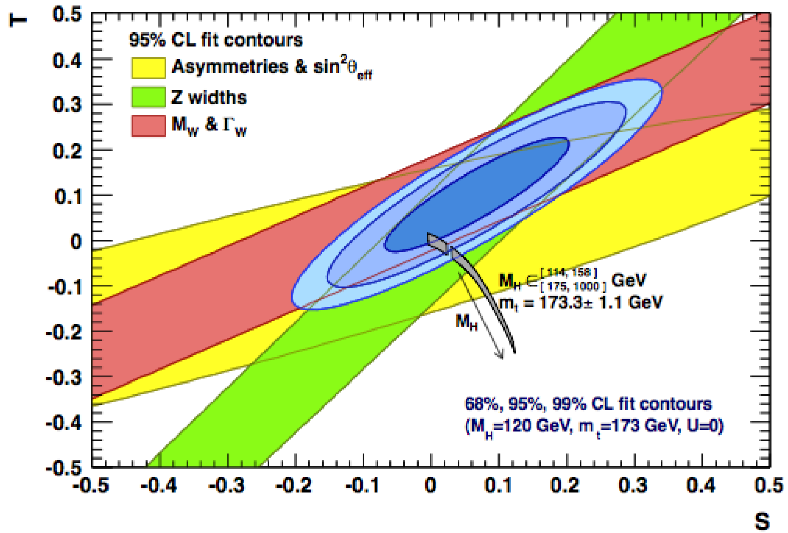
- S,T,U obtained from fit to EW observables

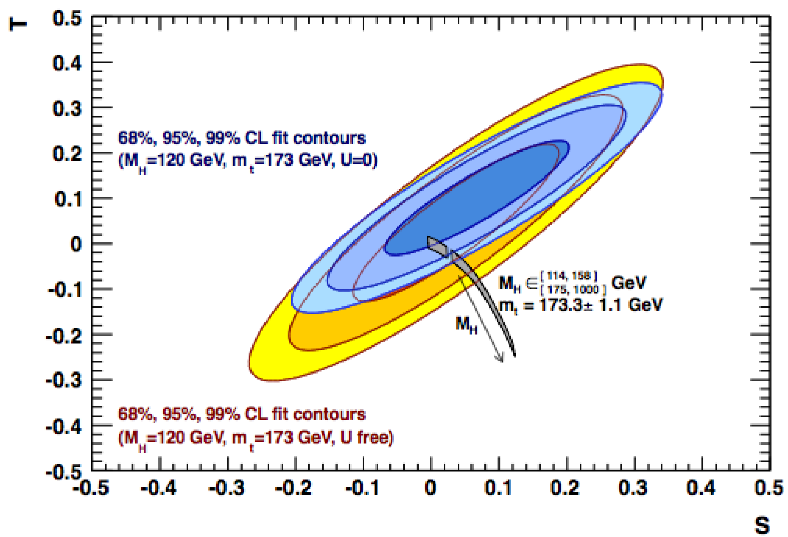
- Results for STU:
  - $S = 0.04 \pm 0.10$
  - $T = 0.05 \pm 0.11$
  - $U = 0.08 \pm 0.11$

- SM prediction
  - SM_{ref} chosen at: $M_H = 120$ GeV and $m_t = 173.1$ GeV
  - This defines (S,T,U) = (0,0,0)
  - S, T: logarithmically dependent on M_H

- Comparison of EW data w/ SM prediction:
  - Preference for small M_H
  - No indication for new physics

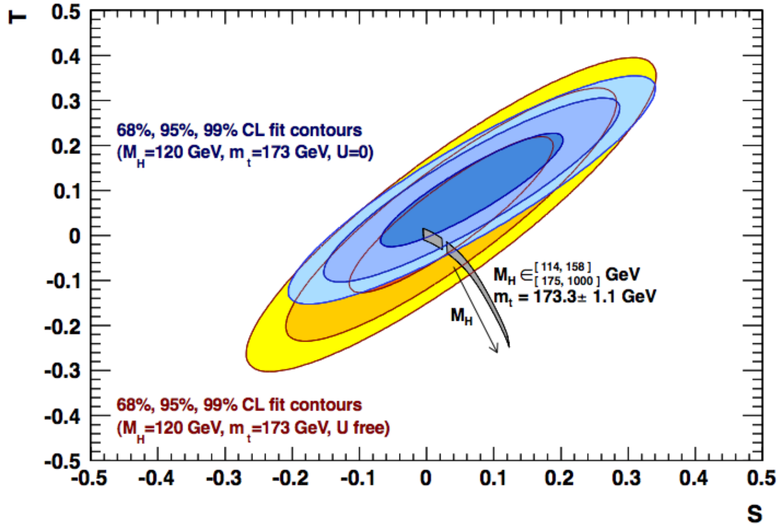
- Many BSM models also compatible with the EW data:
  - Variation of model parameters often allows for large area in ST-plane
  - Tested: UED, 4th fermion generation, Littlest Higgs, SUSY, Two-Higgs-Doublet Model, Inert HDM, etc.



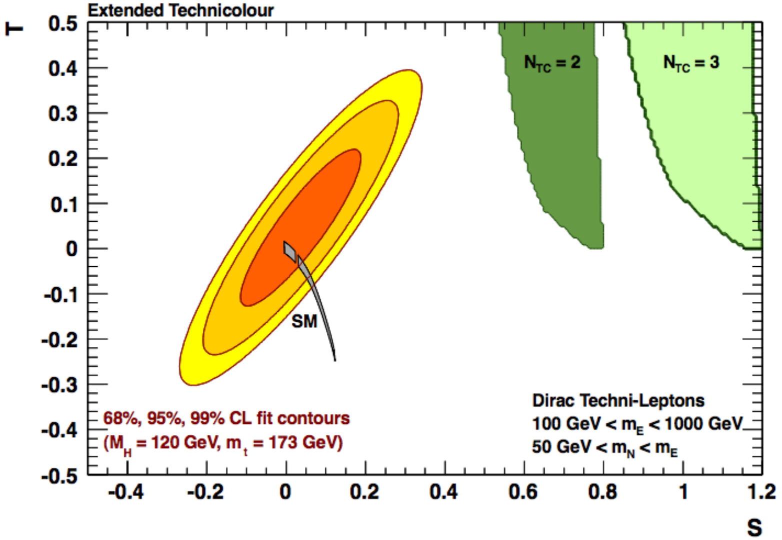


Well Known Example: Extended Technicolor

- Basic Idea of Technicolor
  - Dynamical explanation for electroweak symmetry breaking
  - Introduce a new QCD-like gauge interaction that is asymptotically free at high energies but confining at the electroweak scale
  - Gauge interaction is to be based on a SU(NTC) gauge group GTC, where NTC
  - "Scaled up" version of QCD



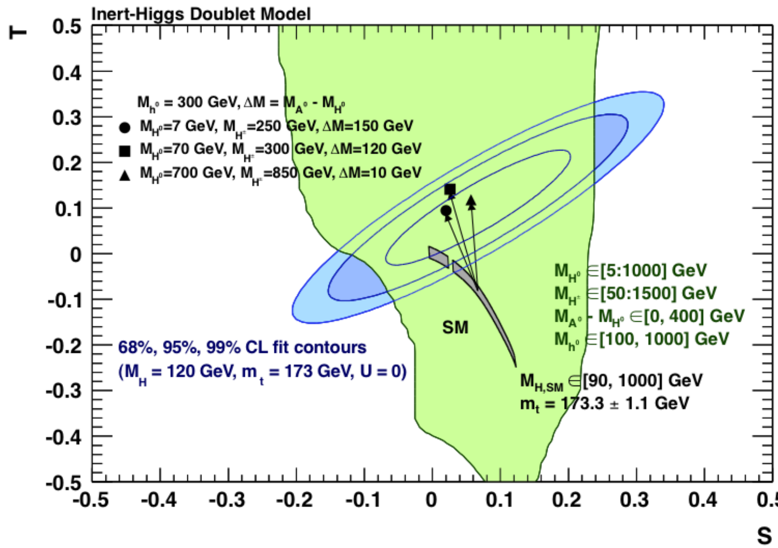
- Well known result for all QCD-like technicolor models
  - Full incompatibility with electroweak precision data
  - One reason for the "death" of extended technicolor theories
  - Possible solution: "Walking" technicolor

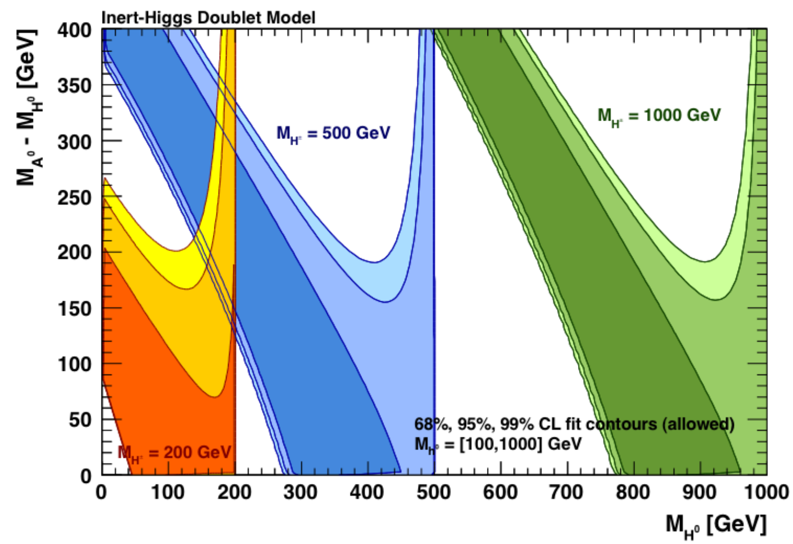


Inert Doublet Model (IDM)

- Basic Concept of IDM:
  - Introduction of extra Higgs doublet to help solve hierarchy problem
    - Does not couple to fermions (“inert”). Does not acquire a VEV.
- Three new Higgses
  - Two neutral (M_H, M_A), one charged (M_{H+})
  - Lightest inert particle (“LIP”) is stable (M_L), assumed neutral.
  - Natural dark matter candidate
- Contributions to:
  - T: isospin violation between neutral and charged Higgses.
  - S: H^+H^- and HA loop corrections to self energy of Z-photon propagator
- Results: large SM Higgs mass allowed

[Barbieri et al., hep-ph/0603188v2 (2006)]





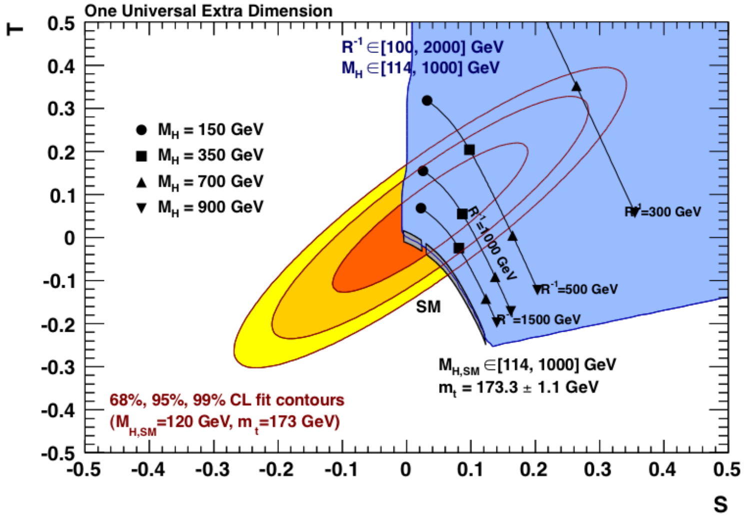
Universal Extra Dimensions

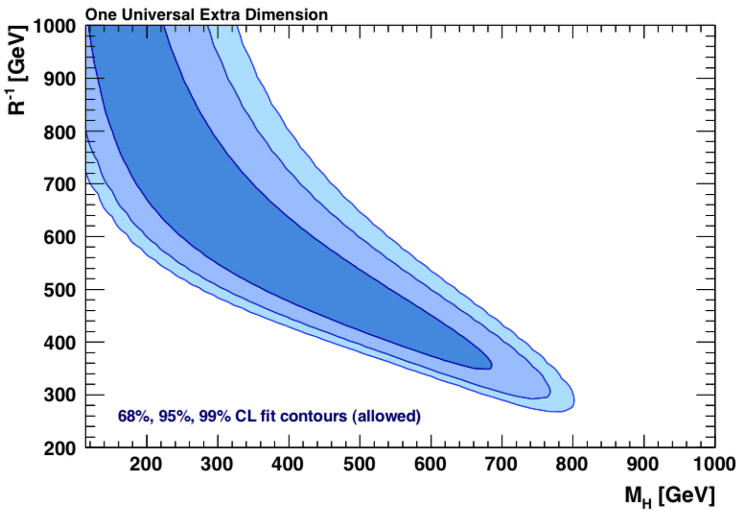
- Basic Concept of UED
  - All SM particles can propagate into ED
  - Compactification → KK excitations
  - Conservation of KK parity
    - Phenomenology similar to SUSY
    - Lightest stable KK state: DM candidate
  - Model parameters
    - d_{ED}: number of ED (fixed to d_{ED}=1)
    - R^{-1}: compactification scale (m_{KK}~n/R)

- Contribution to vac. polarisation (*STU*):
  - From KK-top/bottom and KK-Higgs loops
  - Dependent on R^{-1}, M_H (and m_t)

- Results:
  - Large R^{-1}: UED approaches SM (exp.)
    - Only small M_H allowed
  - Small R^{-1}: large UED contribution can be compensated by large M_H
  - Excluded: R^{-1}< 300 GeV and M_H> 800 GeV

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

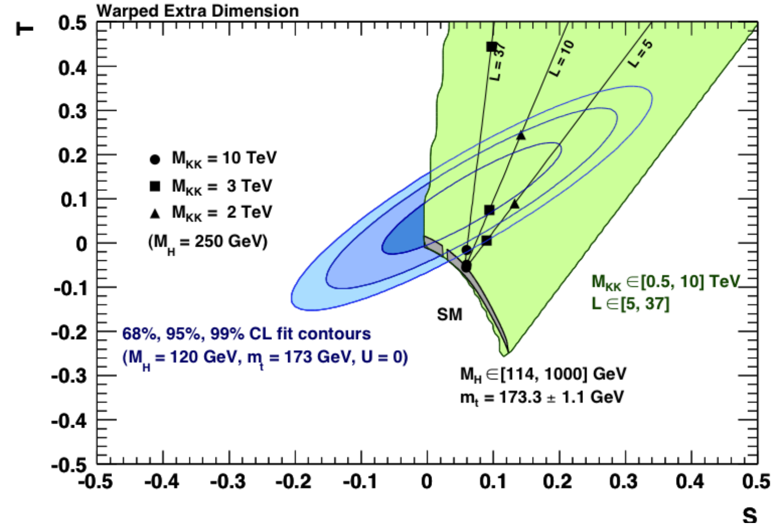




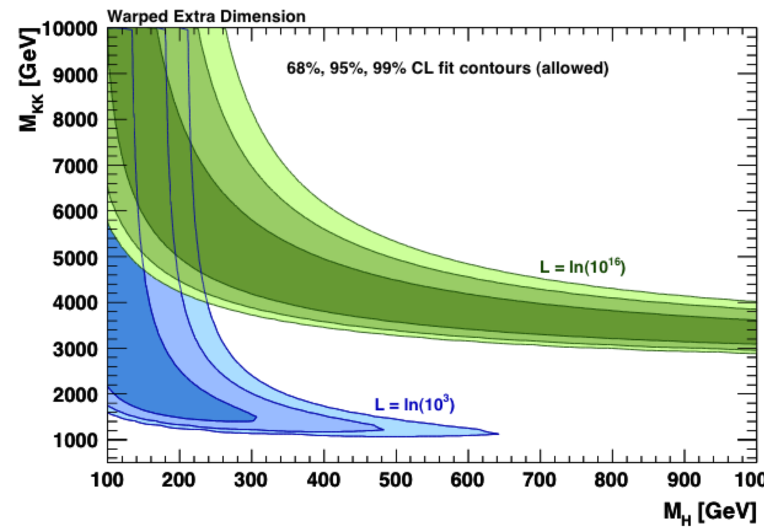
Warped Extra Dimensions (Randall-Sundrum)

[L. Randall, R. Sundrum, Phys. Rev. Lett. 83, 3370 (1999)]
[M. Carena et al., Phys. Rev. D68, 035010 (2003)]

- Basic Concept of WED
  - Introduction of one extra dimension (ED) to help solve the hierarchy problem
  - RS model characterized by one warped ED, confined by two three-branes
  - Higgs localized on “IR” brane
  - Gauge and matter fields allowed to propagate in bulk region
  - SM particles accompanied by towers of heavy KK modes.



- Model parameters:
  - *L*: inverse warp factor, function of compactification radius, explains hierarchy between EW an Pl scale
  - M_{KK}: KK mass scale



- Results
  - Large values of T possible
  - Large *L* forces large M_{KK} (several TeVs)
  - Some compensation if M_H is large

4^{th} fermion generation

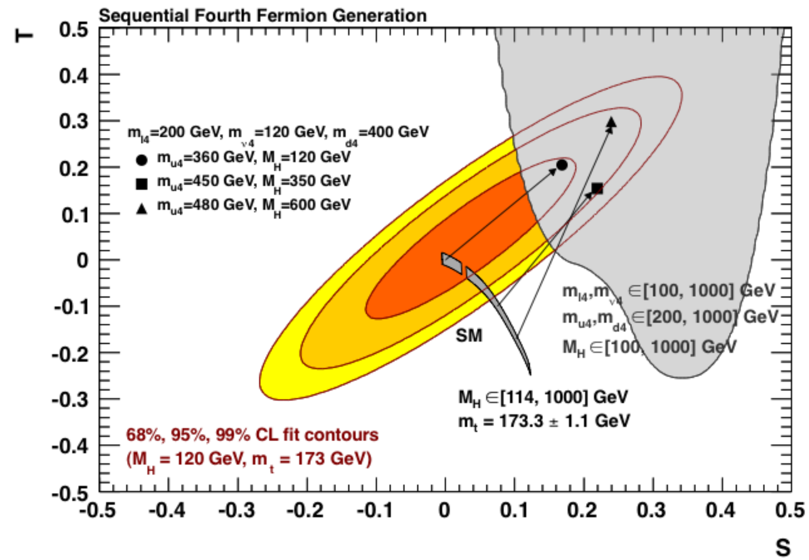
- Models with a fourth generation
  - No explanation for *n=3* generations
  - Intr. new states for leptons and quarks
    - [illegible]
  - Free parameters: [illegible]
    - masses of new quarks and leptons
    - assume: no mixing of extra fermions

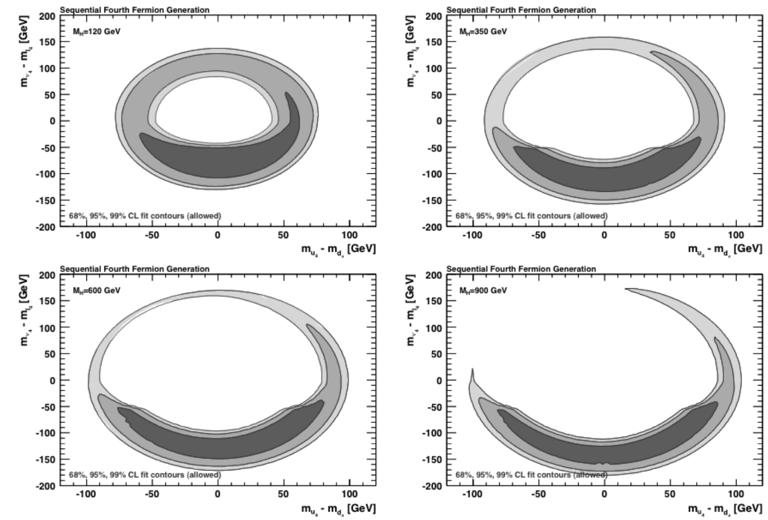
- Contrib. to *STU* from new fermions
  - Discrete shift in S from extra generation
  - Sensitive to mass difference between up- and down-type fields. (not to absolute mass scale)

- CDF+D0 & CMS: SM4G Higgs partially excluded:
  - CDF+D0: 131 > M_H > 204 GeV @ 95% CL
  - CMD: 144 > M_H > 207 GeV @ 95% CL

- Fit-Results:
  - With appropriate mass differences: 4^{th} fermion model consistent with EW data (large M_H is allowed)
  - 5+ generations disfavored
  - Data prefer a heavier charged lepton / up-type quark (which both reduce size of S)

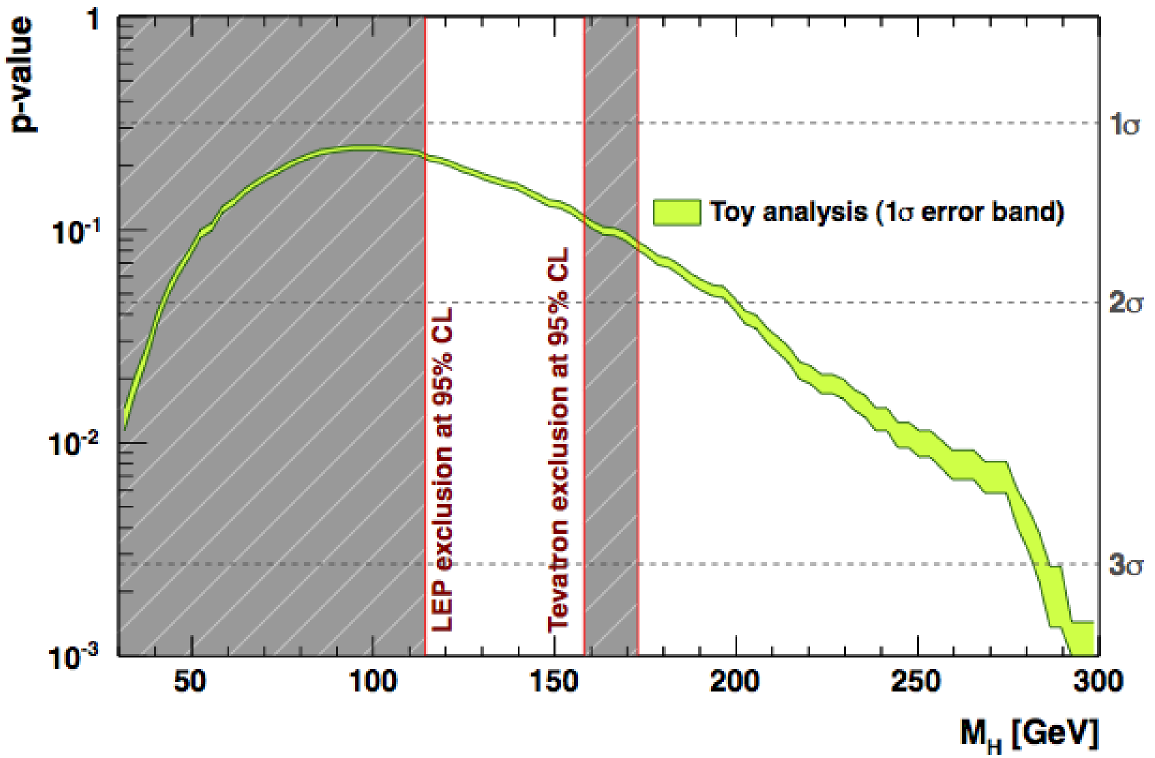
[H. He et al., Phys. Rev. D 64, 053004





Last Minute Updates (?)

- Unfortunately we didn't receive the latest CL_{S+B} values from the experiments
- Hopefully an Update will be available during the next week, maybe even during the conference
  - In the latter case: We will update this slide with the latest exclusion limits
  - Otherwise: Look at Gfitter's contribution during the Higgs-Hunter Workshop
- In the meanwhile:
  - P-value versus MH of the standard electroweak fit as obtained from pseudo-MC simulation.
  - The error band represents the statistical error from the MC sampling size



Conclusion & Prospects

- Gfitter is a powerful framework for HEP model fits.
  - Latest results/updates and new results always available at: **http://cern.ch/Gfitter**

- Results shown
  - New & updated global fit of the electroweak SM
  - Very happy to see first LHC Higgs results included in EW fit !
  - SM Higgs mass strongly constrained. Light Higgs very much preferred by SM.
  - Oblique parameters (still!) a powerful method to constrain BSM theories
  - Presented constraints on various BSM theories
  - Heavy Higgs boson allowed in many BSM models !

- The future
  - Maintain and extend existing fits.
  - Update with latest Tevatron and LHC results
  - 2011: SUSY results

Preview

Updated Status of the Global Electroweak Fit and Constraints on New Physics

M. Baak, M. Goebel, J. Haller, A. Hoecker, D. Ludwig, K. Moenig, M. Schott, J. Stelzer

We present an update of the Standard Model fit to electroweak precision data. We include newest experimental results on the top quark mass, the W mass and width, and the Higgs boson mass bounds from LEP, Tevatron and the LHC. We also include a new determination of the electromagnetic coupling strength at the Z pole. We find for the Higgs boson mass (96 +31 -24) GeV and (120 +12 -5) GeV when not including and including the direct Higgs searches, respectively. From the latter fit we indirectly determine the W mass to be (80.362 +- 0.013) GeV. We exploit the data to determine experimental constraints on the oblique vacuum polarisation parameters, and confront these with predictions from the Standard Model (SM) and selected SM extensions. By fitting the oblique parameters to the electroweak data we derive allowed regions in the BSM parameter spaces. We revisit and consistently update these constraints for a fourth fourth fermion generation, two Higgs doublet, inert Higgs and littlest Higgs models, models with large, universal or warped extra dimensions and technicolour. In most of the models studied a heavy Higgs boson can be made compatible with the electroweak precision data.

Comments: 58 pages, 27 figures, submitted to EPJ-C
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