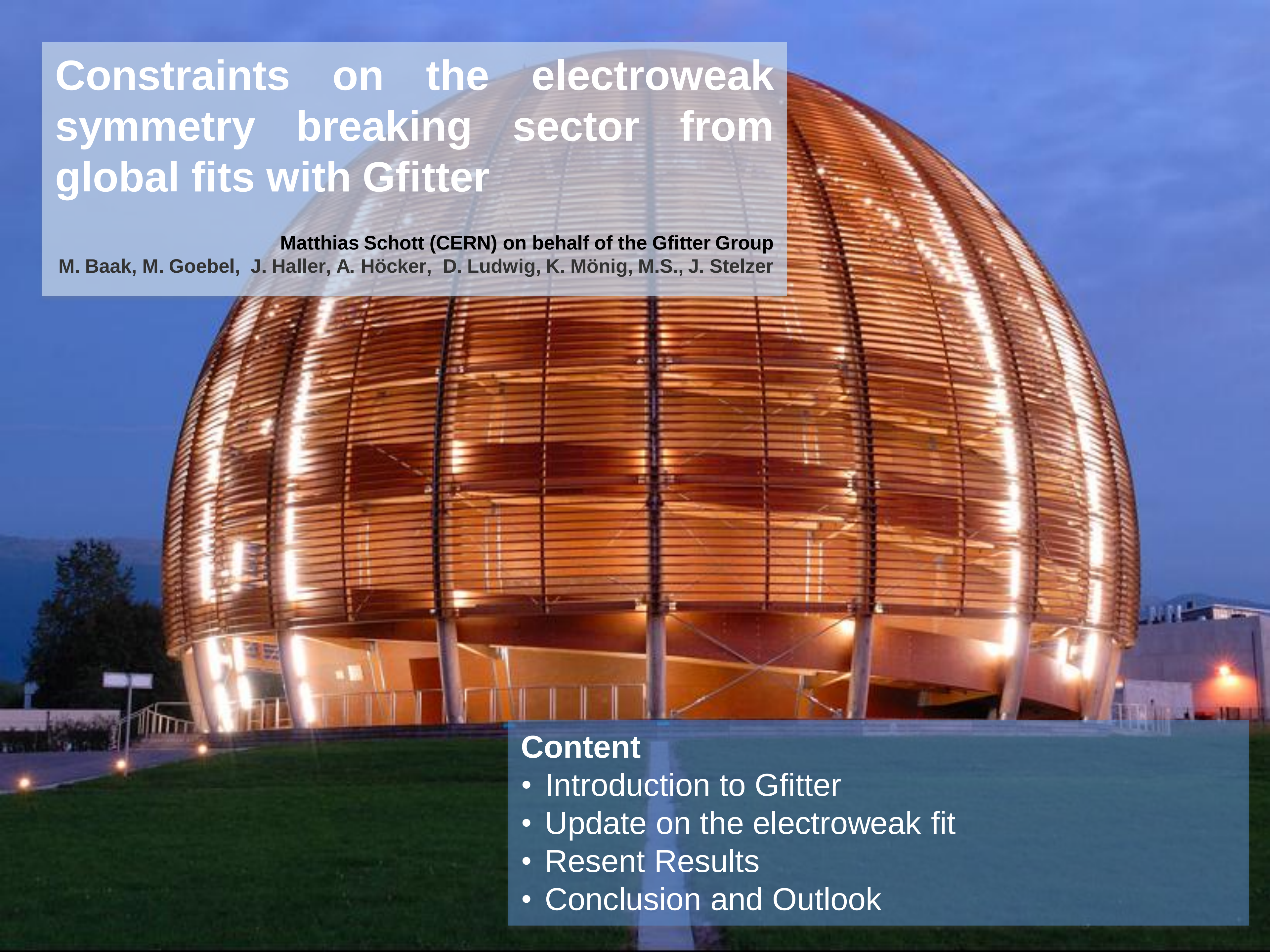


Constraints on the electroweak symmetry breaking sector from global fits with Gfitter

Matthias Schott (CERN) on behalf of the Gfitter Group
M. Baak, M. Goebel, J. Haller, A. Höcker, D. Ludwig, K. Mönig, M.S., J. Stelzer

Content

- Introduction to Gfitter
- Update on the electroweak fit
- Resent Results
- Conclusion and Outlook

The global electroweak fit with Gfitter

- 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

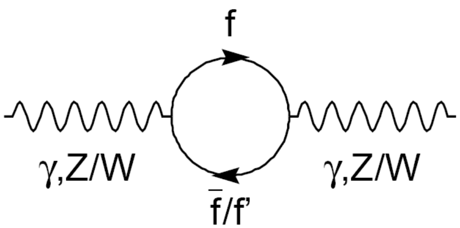
- In particular:
  - M_W : full two-loop + leading beyond-two-loop corrections

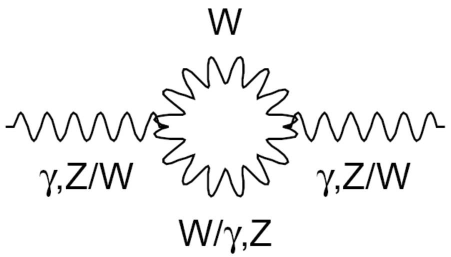
    [M. Awramik et al., Phys. Rev D69, 053006 (2004) and refs.] (Theoretical uncertainties: ΔM_W = 4–6 GeV)
  - $sin^2\theta^l_{eff}$: full two-loop + leading beyond-two-loop corrections

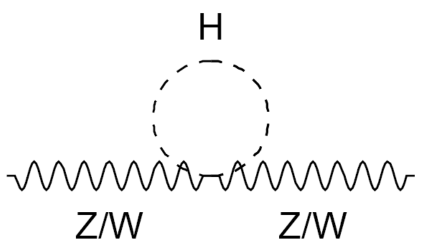
    [M. Awramik et al., JHEP 11, 048 (2006) and refs.] (Theoretical uncertainties: $\Delta sin^2\theta^l_{eff}=4.7\cdot 10^{-5}$)
  - Partial and total widths of *Z* and *W*: based on parameterized formulae
    - [Hagiwara et al. (http://arxiv.org/abs/arXiv:1104.1769)]
    - Small additional correction factors, determined from a comparison with the Fortran ZFITTER package [Arbuzov:2005ma,Bardin:1999yd], are used for M_H> 200 GeV.

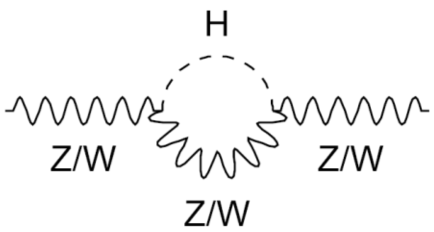
  - Radiator Functions using 3NLO calc. of massless QCD Adler function

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









Electroweak Parameters

- Set of parameters, which are relevant for the electroweak analysis:
  - Coupling constants:
    - electromagnetic (α)
    - weak (G_F)
    - strong (α_S)
  - Boson masses
    - M_γ, M_Z, M_W, M_H
  - Fermion masses:
    - Leptons: m_e, m_μ, m_τ, $m_{\nu e}$, $m_{\nu\mu}$, $m_{\nu\tau}$,
    - Quarks: m_u, m_c, m_t, m_d, m_s, m_b

- Some basic simplifications can be imposed

Massless neutrinos

- $m_{\nu e}=m_{\nu\mu}=m_{\nu\tau}=0$

Electroweak unification

- Massless photon: $M_\gamma=0$
- M_W is a function of M_Z and the couplings α and G_F

Fixing parameters with insignificant uncertainties (e.g. G_F precisely measured)

Leptonic and top contribution to running of α precisely known or small

- replace α by $\Delta\alpha_{had}$

$$\alpha(s) = \frac{\alpha(0)}{1-\Delta\alpha(s)}$$

$$\Delta\alpha(s) = \Delta\alpha_{lep}(s) + \Delta\alpha_{had}^{(5)}(s) + \Delta\alpha_{top}(s)$$

Gfitter

Experimental input

- Free fit parameters
  - M_Z, M_H, m_t, $\Delta a_{had}^{(5)}(M_Z^2)$, $a_S(M_Z^2)$, 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)]
  - new top mass combination from Tevatron mtop=173.2±0.9 GeV from July 2011 (EPS11)
  - latest Tevatron Higgs mass combination using up to 8.6fb^{-1} arXiv:1107.5518
  - new $\Delta\alpha_{had}(M_Z^2)$ including e.g. all available BarBar reults arXiv:1010.4180
  - first results from Higgs mass searches at the LHC: ATLAS (arXiv:1106.2748) CMS (arXiv:1102.5429)

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_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]	173.2 ± 0.9	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

Input from Direct Higgs-Searches

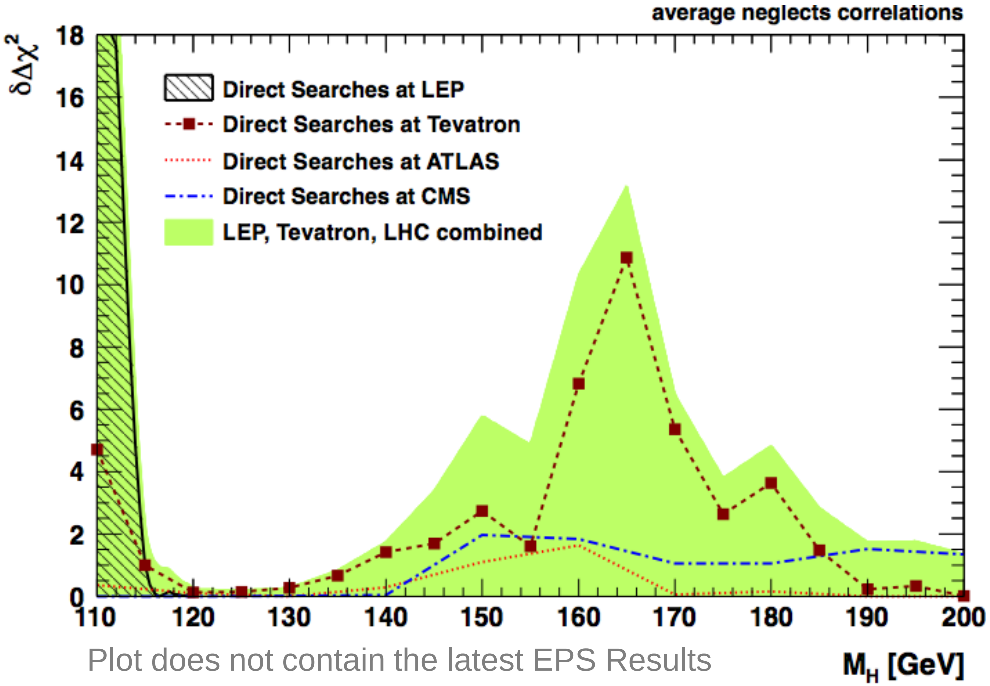
- Include Results from the 2010 LHC run
  - ATLAS (combining six different final states)
  - CMS ($H \rightarrow WW \rightarrow l\nu l\nu$)

- 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



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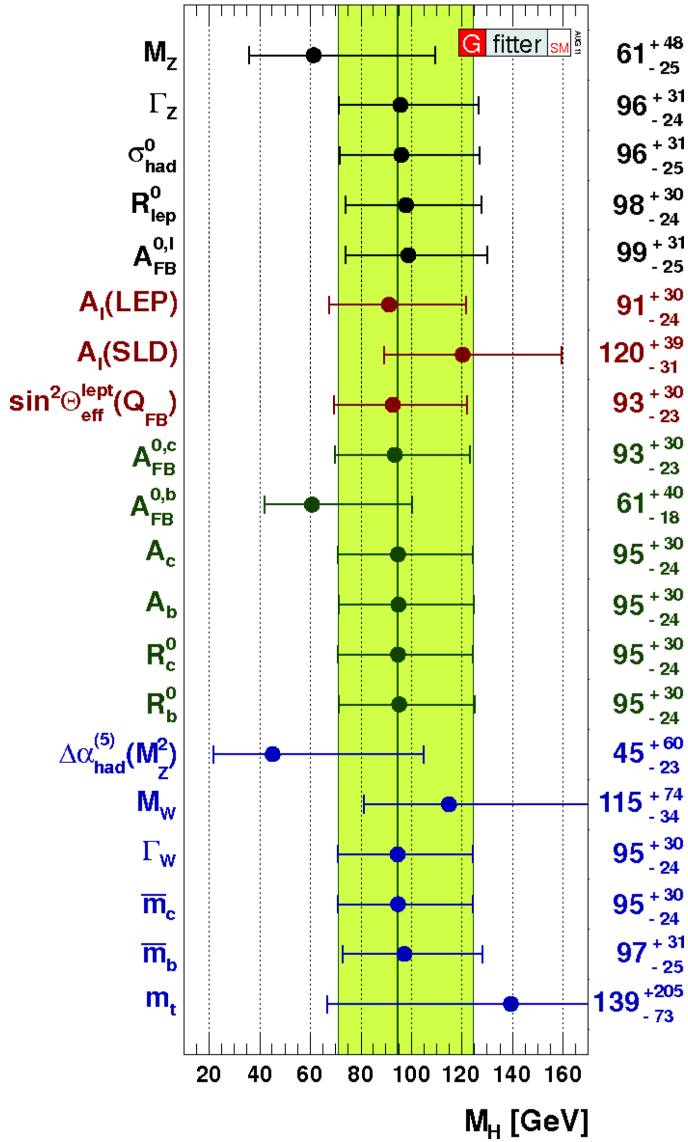
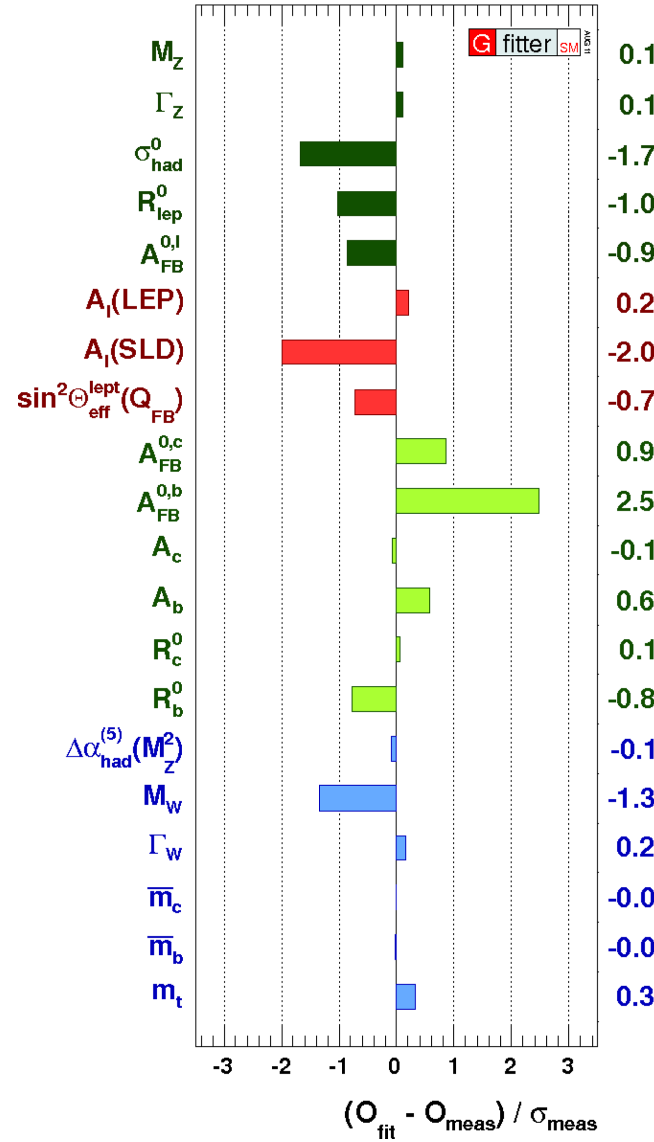
SM Fit Results (1/2)

- 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

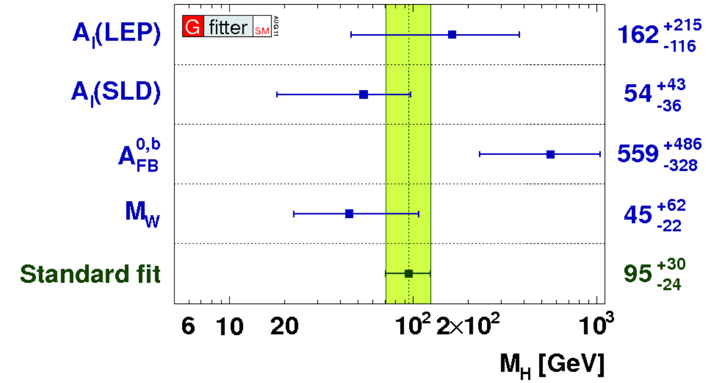


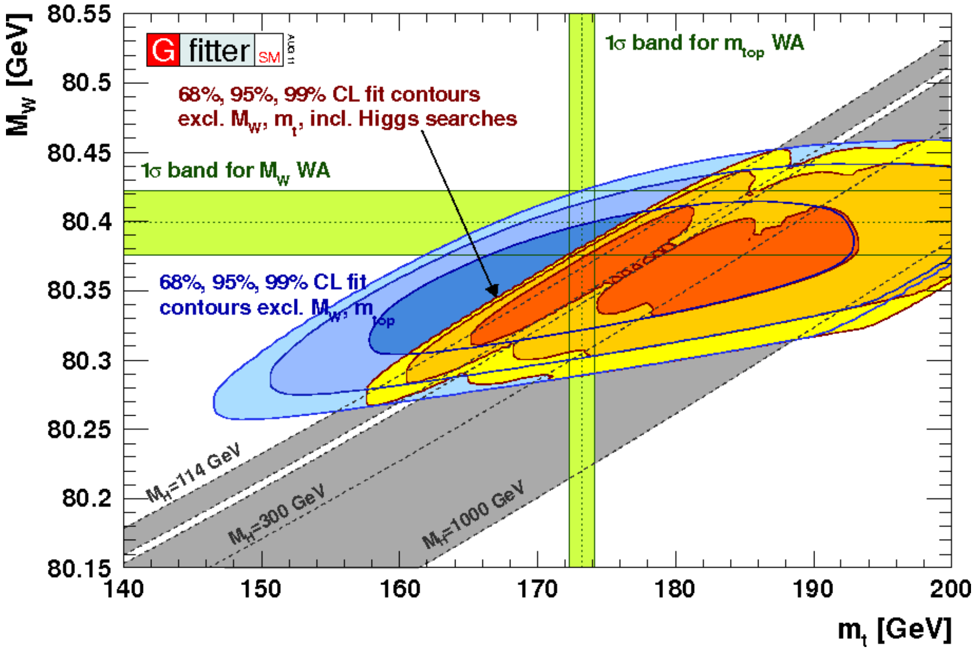


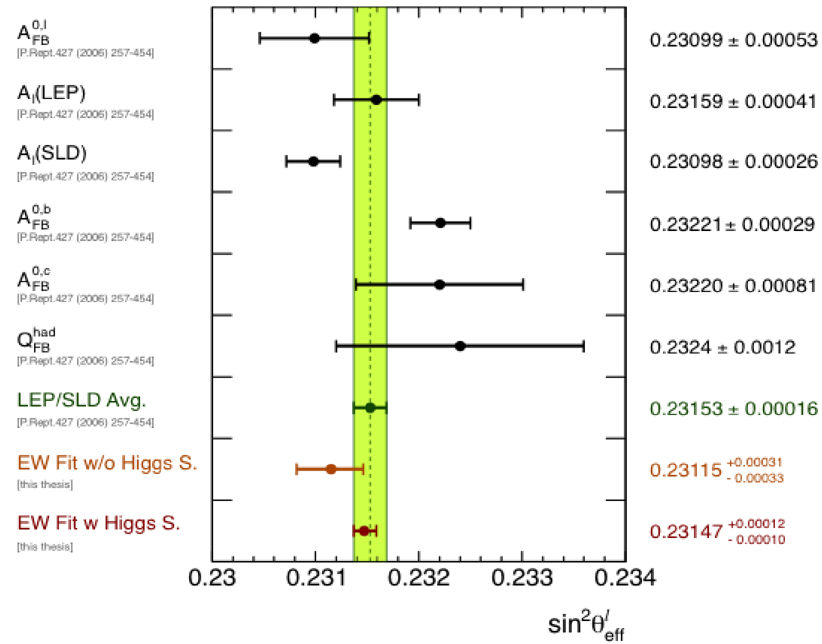
SM Fit Results (2/2)

- Determination of M_H and $\sin^2\theta$ excluding all the sensitive observables from the standard fit except the one given

- Largest tension in both observables from $A_{FB}^{0,b}$







SM Higgs Results (1/2)

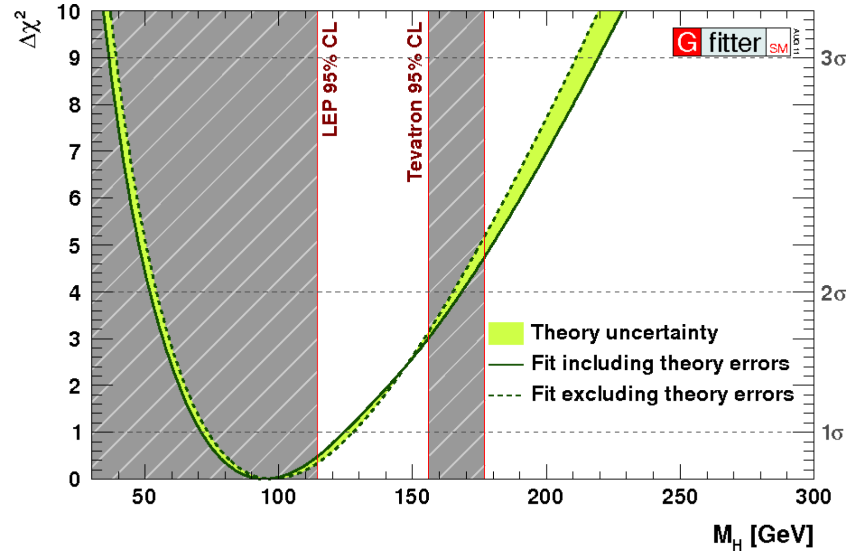
- $\Delta\chi^2$ estimator for the standard and complete fits versus M_H

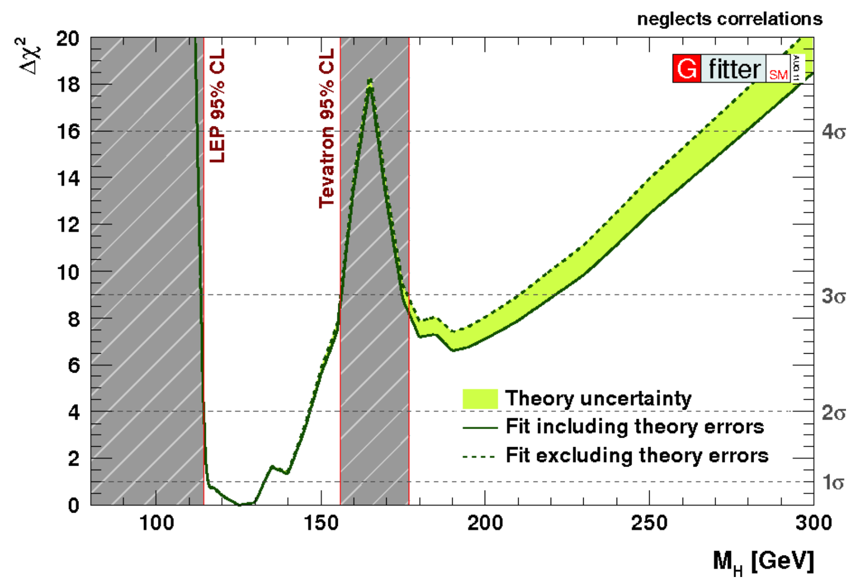
$$M_H = 95^{+30\ [+74]}_{-24\ [-43]}\ \text{GeV (Standard Fit)}$$

$$M_H = 125^{+8\ [+21]}_{-10\ [-11]}\ \text{GeV (Complete Fit)}$$

- 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

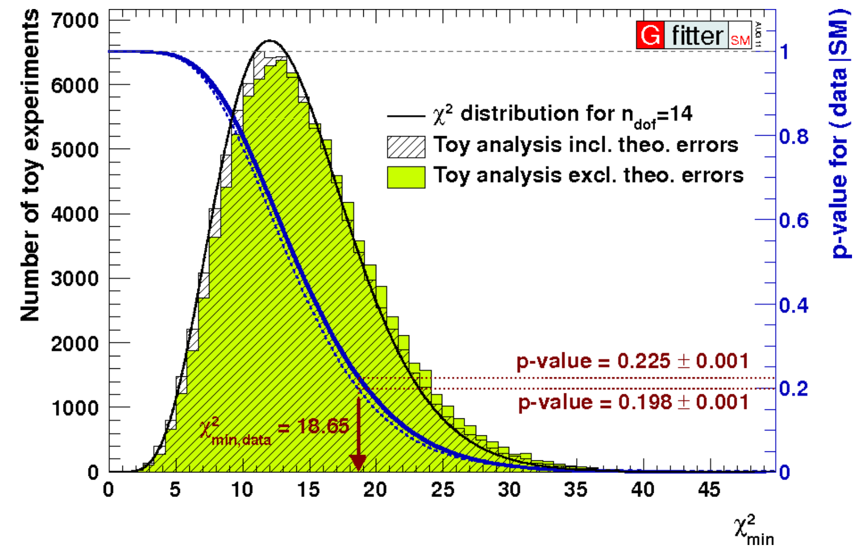
$$M_H = 88^{+29}_{-23}\ \text{GeV}$$

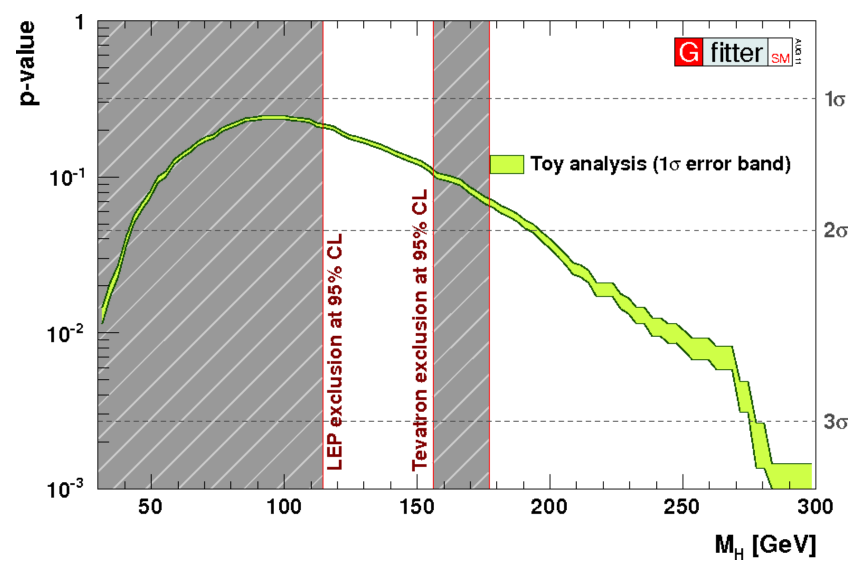




SM Higgs Results (2/2)

- We did not include the latest ATLAS and CMS results
  - Combination not trivial anymore
- In the meanwhile
  - P-value versus M_H of the standard electroweak fit as obtained from pseudo-MC simulation.
  - The error band represents the statistical error from the MC sampling size
- Some speculations
  - m_H =140±0 GeV : p = Prob(18.95, 14) = 0.17
  - m_H = 140±30 GeV: p = Prob(18.1, 14) = 0.20





G fitter

Indirect Determination of m_t, m_W and α_S

- 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

$$M_W = 80.360^{+0.012}_{-0.011}\ \text{GeV (Complete Fit)}$$

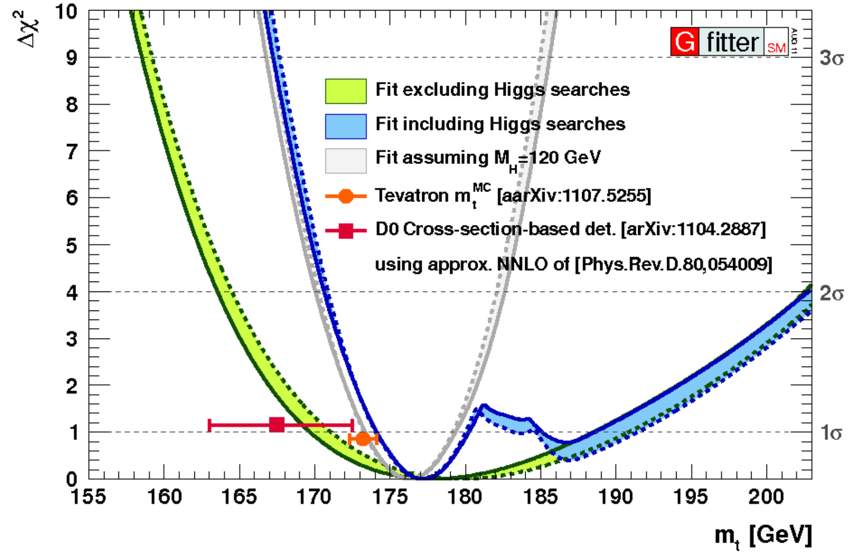
- Allowed 1σ regions are found from the indirect constraint of the top quark pole mass in the complete fit

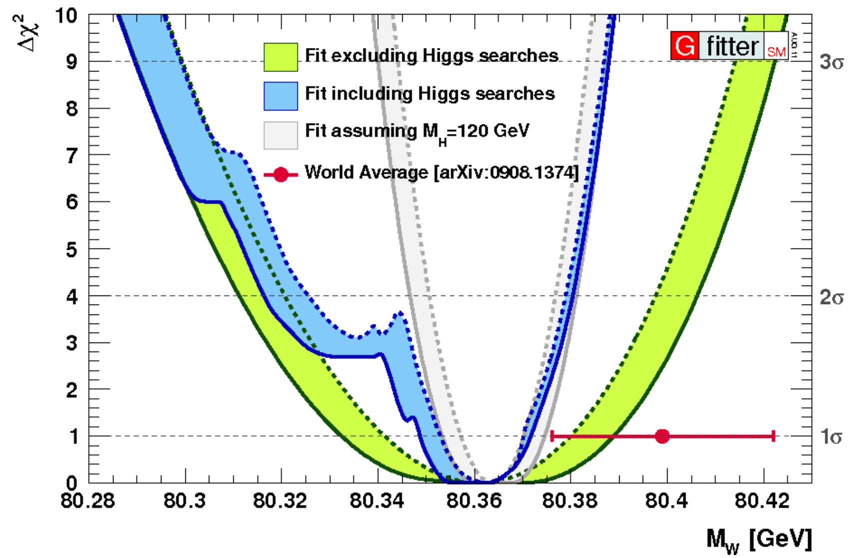
$$m_t = 177.2^{+2.9}_{-3.1}\ \text{GeV (Complete Fit)}$$

- N^3LO α_S from fit

$$\alpha_S = 0.1193 \pm 0.0028\ \text{(Complete Fit)}$$

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





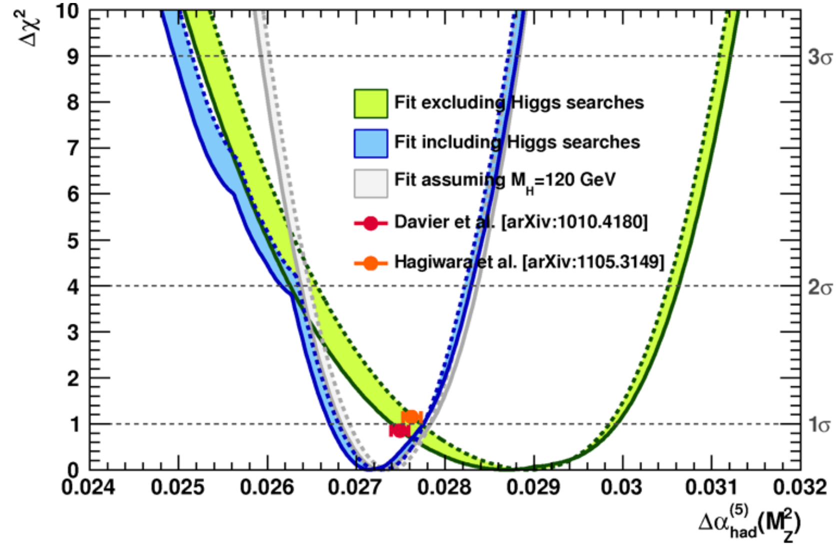
Conclusion & Prospects

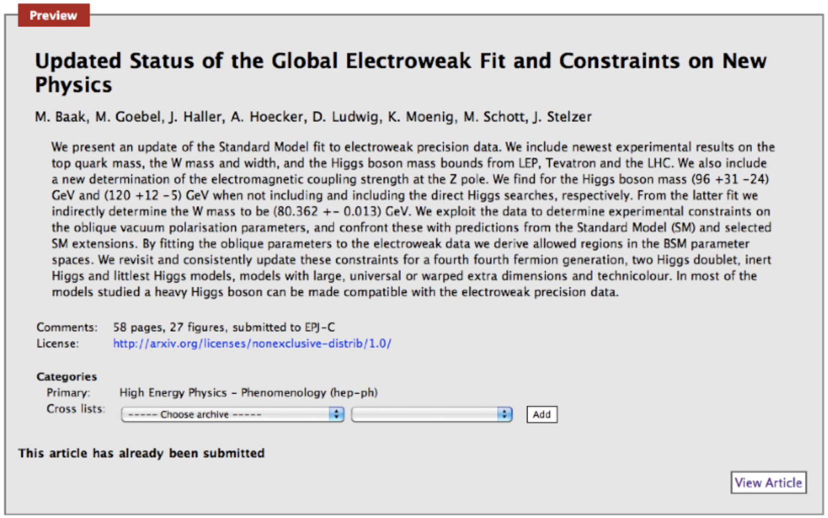
- Gfitter is a powerful framework for HEP model fits.
- Latest results/updates and new results always available at: **http://cern.ch/Gfitter**

- 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.

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

- Much more and detailed information to be found in our recent publication
  - http://arxiv.org/abs/1107.0975





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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Categories
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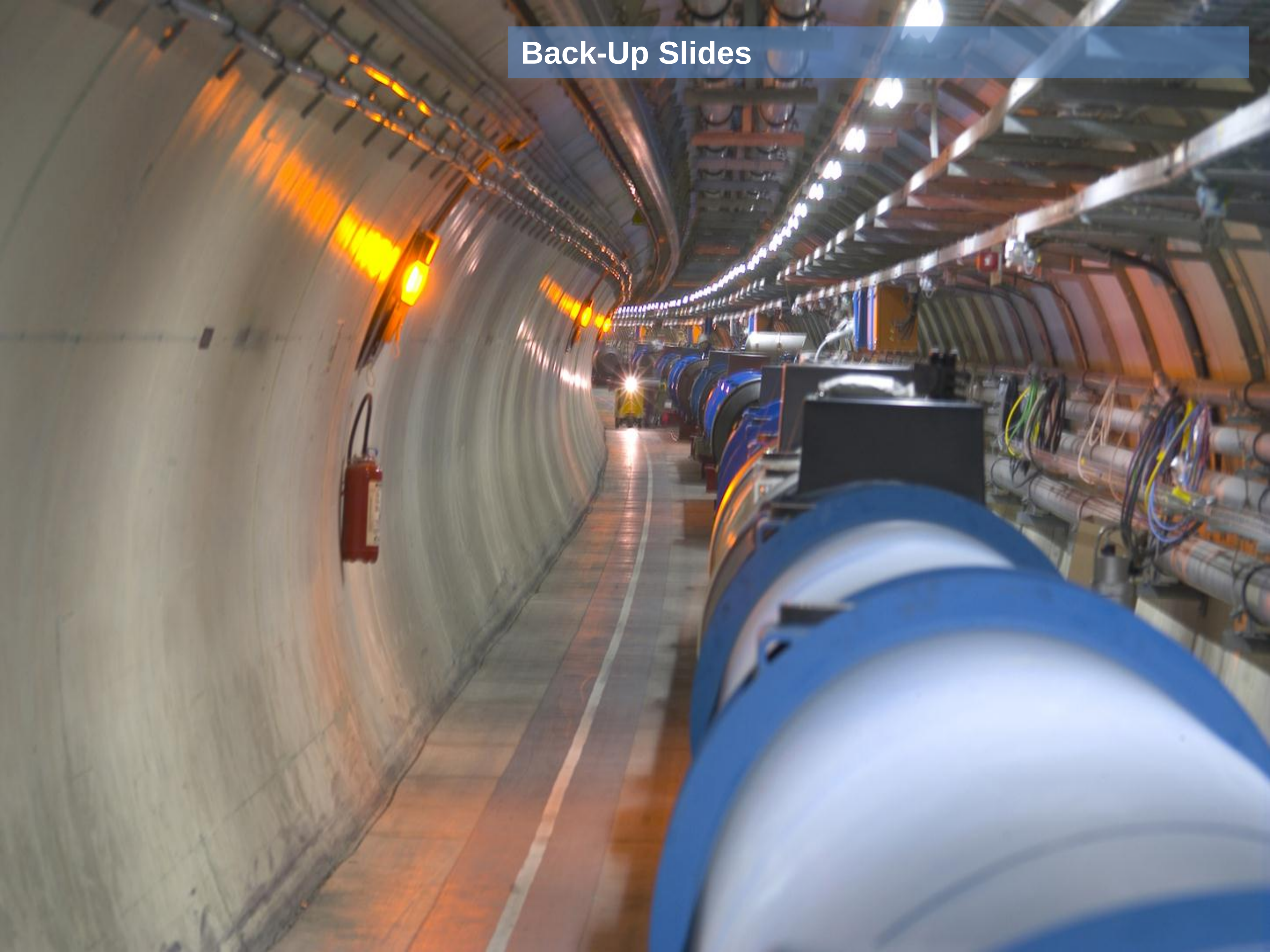
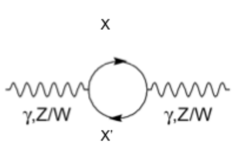
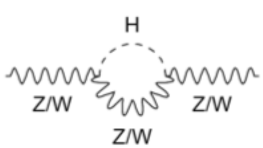


Oblique Corrections

- 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

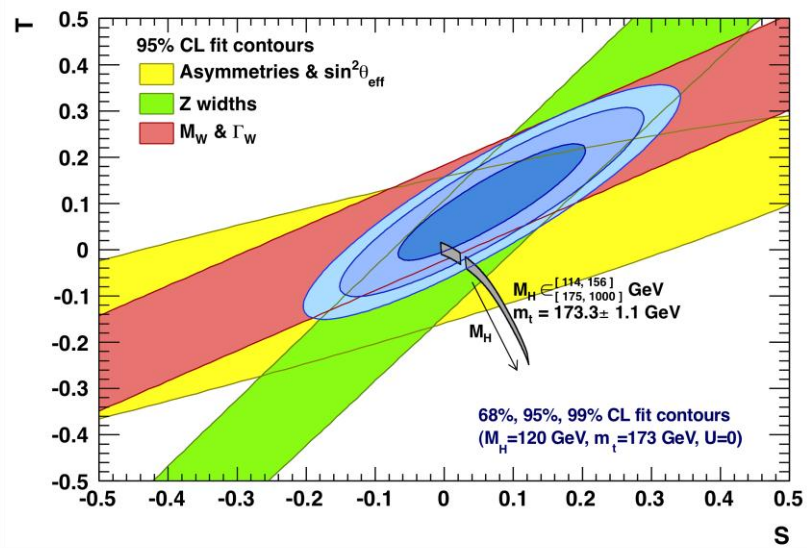
- S,T,U obtained from fit to EW observables

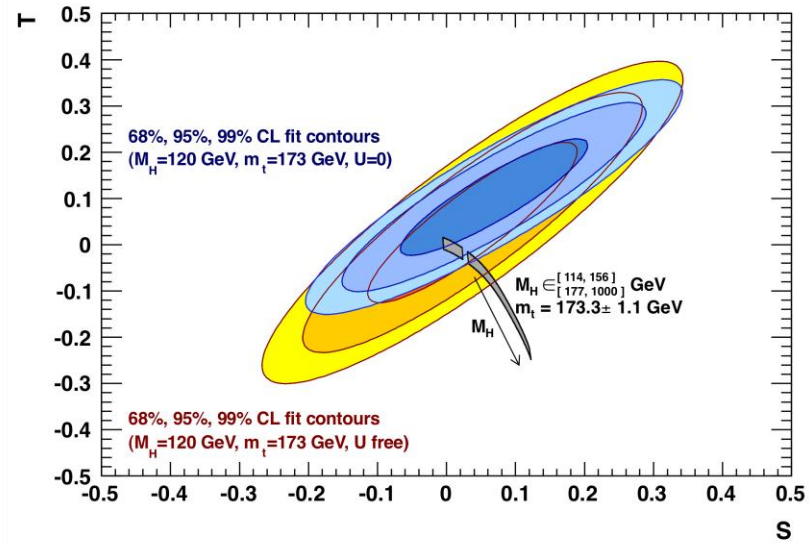
- Results for STU:
- $S = 0.04 \pm 0.10$
- $T = 0.05 \pm 0.11$
- $U = 0.08 \pm 0.11$

- 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.





4^{th} fermion generation

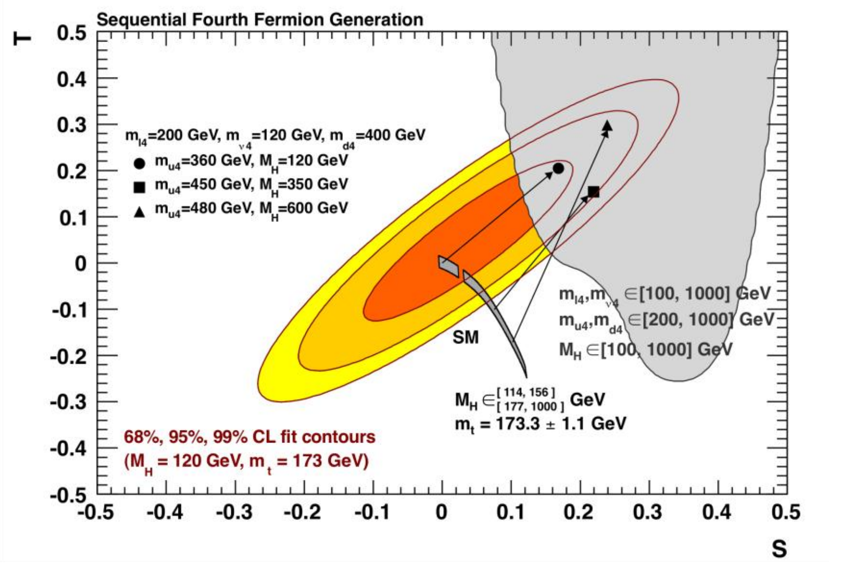
- Models with a fourth generation
  - No explanation for *n=3* generations
  - Intr. new states for leptons and quarks
    -
  - Free parameters:
    - masses of new quarks and leptons
    - assume: no mixing of extra fermions

- 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



Gfitter

Full SM-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	$91.1983^{+0.0133}_{-0.0155}$
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4959 ± 0.0015	2.4955 ± 0.0014	$2.4951^{+0.0017}_{-0.0016}$
σ^0_{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	–	20.743 ± 0.018	20.741 ± 0.018	$20.718^{+0.027}_{-0.026}$
$A^{0,\ell}_{\mathrm{FB}}$	0.0171 ± 0.0010	–	0.01641 ± 0.0002	$0.01620^{+0.0002}_{-0.0001}$	0.01606 ± 0.0001
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–	0.1479 ± 0.0010	$0.1472^{+0.0009}_{-0.0006}$	–
A_c	0.670 ± 0.027	–	$0.6683^{+0.00044}_{-0.00043}$	$0.6680^{+0.00040}_{-0.00028}$	$0.6679^{+0.00042}_{-0.00025}$
A_b	0.923 ± 0.020	–	$0.93470^{+0.00009}_{-0.00008}$	$0.93463^{+0.00008}_{-0.00005}$	$0.93463^{+0.00007}_{-0.00005}$
$A^{0,c}_{\mathrm{FB}}$	0.0707 ± 0.0035	–	0.0741 ± 0.0005	$0.0737^{+0.0005}_{-0.0004}$	0.0738 ± 0.0004
$A^{0,b}_{\mathrm{FB}}$	0.0992 ± 0.0016	–	0.1037 ± 0.0007	$0.1035^{+0.0003}_{-0.0004}$	$0.1038^{+0.0003}_{-0.0005}$
R^0_c	0.1721 ± 0.0030	–	0.17226 ± 0.00006	0.17226 ± 0.00006	0.17226 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	$0.21578^{+0.00005}_{-0.00008}$	$0.21577^{+0.00005}_{-0.00008}$	$0.21577^{+0.00005}_{-0.00007}$
$\sin^2\theta^\ell_{\mathrm{eff}}(Q_{\mathrm{FB}})$	0.2324 ± 0.0012	–	0.23141 ± 0.00012	$0.23150^{+0.00008}_{-0.00011}$	$0.23152^{+0.00006}_{-0.00013}$
M_H [GeV] $^{(\circ)}$	Likelihood ratios	yes	$95^{+30[+74]}_{-24[-43]}$	$125^{+8[+21]}_{-10[-11]}$	$95^{+30[+74]}_{-24[-43]}$
M_W [GeV]	80.399 ± 0.023	–	$80.382^{+0.014}_{-0.015}$	$80.368^{+0.007}_{-0.010}$	$80.360^{+0.012}_{-0.011}$
Γ_W [GeV]	2.085 ± 0.042	–	2.093 ± 0.001	2.092 ± 0.001	$2.091^{+0.002}_{-0.001}$
$\overline{m}_c$ [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]	173.2 ± 0.9	yes	173.3 ± 0.9	173.5 ± 0.9	$177.2^{+2.9}_{-3.1}$ $^{(\bigtriangledown)}$
$\Delta\alpha^{(5)}_{\mathrm{had}}(M^2_Z)$ $^{(\dagger\triangle)}$	2749 ± 10	yes	2750 ± 10	2748 ± 10	2716^{+60}_{-45}
$\alpha_s(M^2_Z)$	–	yes	0.1192 ± 0.0028	0.1193 ± 0.0028	0.1193 ± 0.0028
$\delta_{\mathrm{th}} M_W$ [MeV]	$[-4,4]_{\mathrm{theo}}$	yes	4	4	–
$\delta_{\mathrm{th}} \sin^2\theta^\ell_{\mathrm{eff}}$ $^{(\dagger)}$	$[-4.7,4.7]_{\mathrm{theo}}$	yes	4.7	4.7	–

$^{(\star)}$Average of LEP ($A_\ell = 0.1465 \pm 0.0033$) and SLD ($A_\ell = 0.1513 \pm 0.0021$) measurements. The fit w/o the LEP (SLD) measurement but with the direct Higgs searches gives $A_\ell = 0.1471^{+0.0010}_{-0.0005}$ ($A_\ell = 0.1467^{+0.0007}_{-0.0004}$). $^{(\circ)}$In brackets the 2σ. $^{(\dagger)}$In units of 10^{-5}. $^{(\triangle)}$Rescaled due to α_s dependency. $^{(\bigtriangledown)}$Ignoring a second less significant minimum, *cf.* fig. ?? and the result of eq. (??).