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Gfitter

http://cern.ch/Gfitter

Gfitter paper published in Eur. Phys. J. C 60, 543 (2009)

Constraints on New Physics theories with Gfitter

- Introduction: Gfitter, the SM fit
- Oblique parameters
- Littlest Higgs model
- Two Higgs doublet model (Type-II)

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The Gfitter Project

G fitter

A Generic Fitter Project
for HEP Model Testing

- Flexible framework for involved fitting problems in the LHC era (and beyond)
  - Based on ROOT framework (math libraries, drawing)
- Modular design: Physics plug-in packages
  - Library for the Standard Model fit to the electroweak precision data
  - Library for SM extensions via the oblique parameters
  - Library for the 2HDM extension of the SM
- Consistent treatment of: correlations and inter-parameter dependencies, statistical, systematic, theoretical uncertainties
  - Theoretical uncertainties: Rfit prescription [CKM fitter, EPJ C21, 225 (2002)]
    - Conservative approach. Included in χ^2 estimator with flat likelihood in allowed ranges
- Advanced statistical analysis methods:
  - E.g. goodness-of-fit, p-value, parameter scans, MC toy analyses, etc.
  - Frequentist approach

Gfitter SM

A Gfitter Package for the Global Electroweak Fit

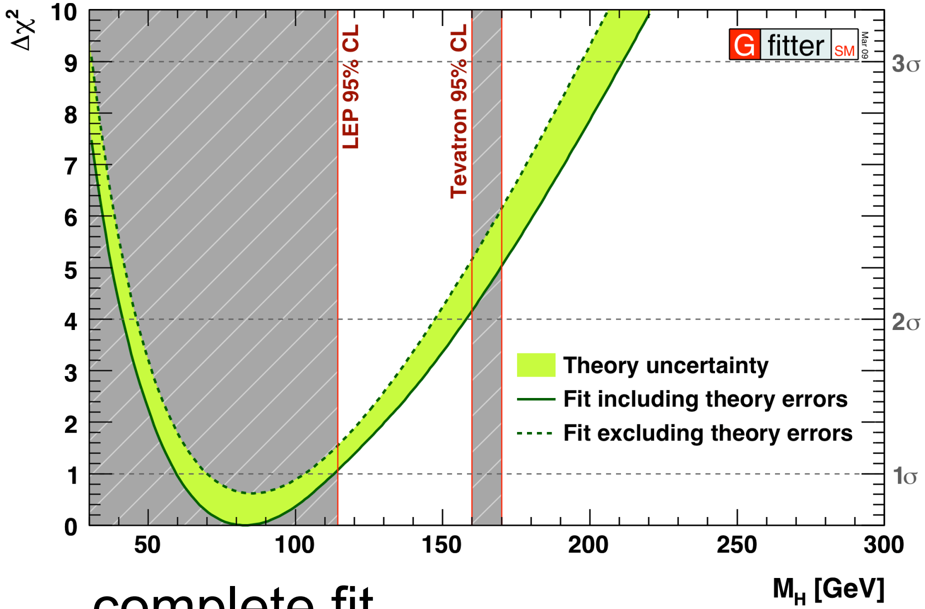
- Complete re-implementation of electroweak theory
  - SM predictions of electroweak precision observables
  - Excellent agreement with ZFitter
- State-of-the art calculations in OMS scheme
  - Radiator functions: N^3LO of the massless QCD Adler function
    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]
  - 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., Nucl.Phys.B813:174-187 (2009) and refs.]
- Two electroweak fits performed
  - Standard Fit: All data except results from direct Higgs searches
  - Complete Fit: All data including results from direct Higgs searches at LEP and Tevatron
    [ADLO: Phys. Lett. B565, 61 (2003)] [CDF+D0: arXiv:0903.4001]

SM Fit Results – Higgs Mass Constraints

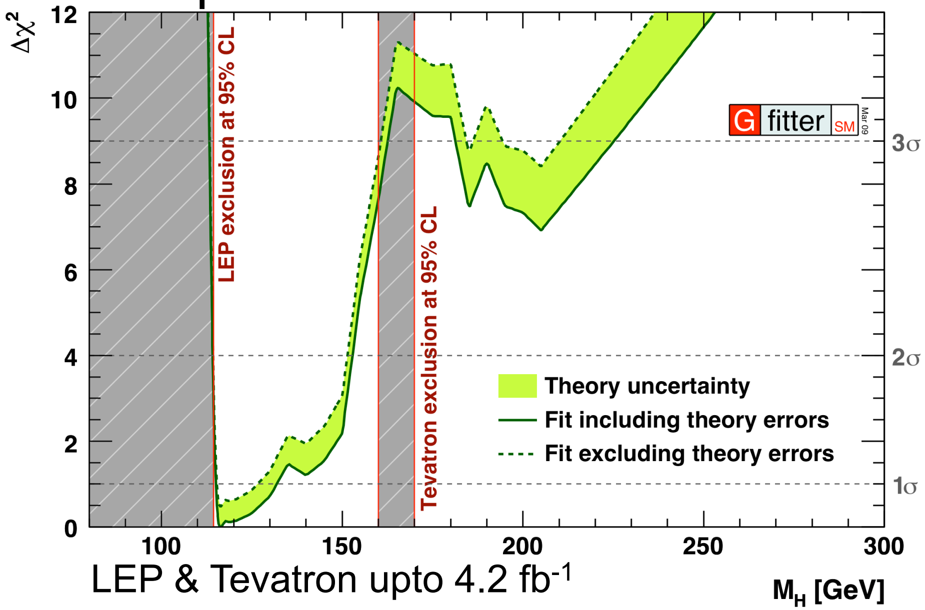
- See talk A. Hoecker for details on SM fit!
- M_H from standard fit:
  - Central value $\pm 1\sigma$: $M_H = 83^{+30}_{-23}$ GeV
  - 2σ interval: [41,158] GeV
  - 3σ interval: [28,211] GeV
- green error band from theoretical errors
  - Included in χ^2 with "flat likelihood term"
- M_H from complete fit:
  - Central value $\pm 1\sigma$: $M_H = 116.4^{+15.6}_{-1.3}$ GeV
  - 2σ interval: [114,153] GeV

- Goodness of fit:
  - Standard fit: $\chi^2/n_{dof} = 16.4/13$
  - Complete fit: $\chi^2/n_{dof} = 17.8/14$
- Probability of falsely rejecting SM ('p-value') evaluated using toy-MC
  - $(20.4 \pm 0.4_{-0.2})\%$
- No requirement for new physics

standard fit



complete fit

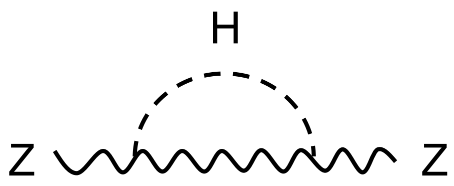


LEP & Tevatron upto 4.2 fb^{-1}

Test of SM extensions via Oblique Corrections

G fitter BSM

- At low energies, BSM physics appears dominantly through vacuum polarization corrections



  - Aka, oblique corrections

- Oblique corrections reabsorbed into electroweak 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)]

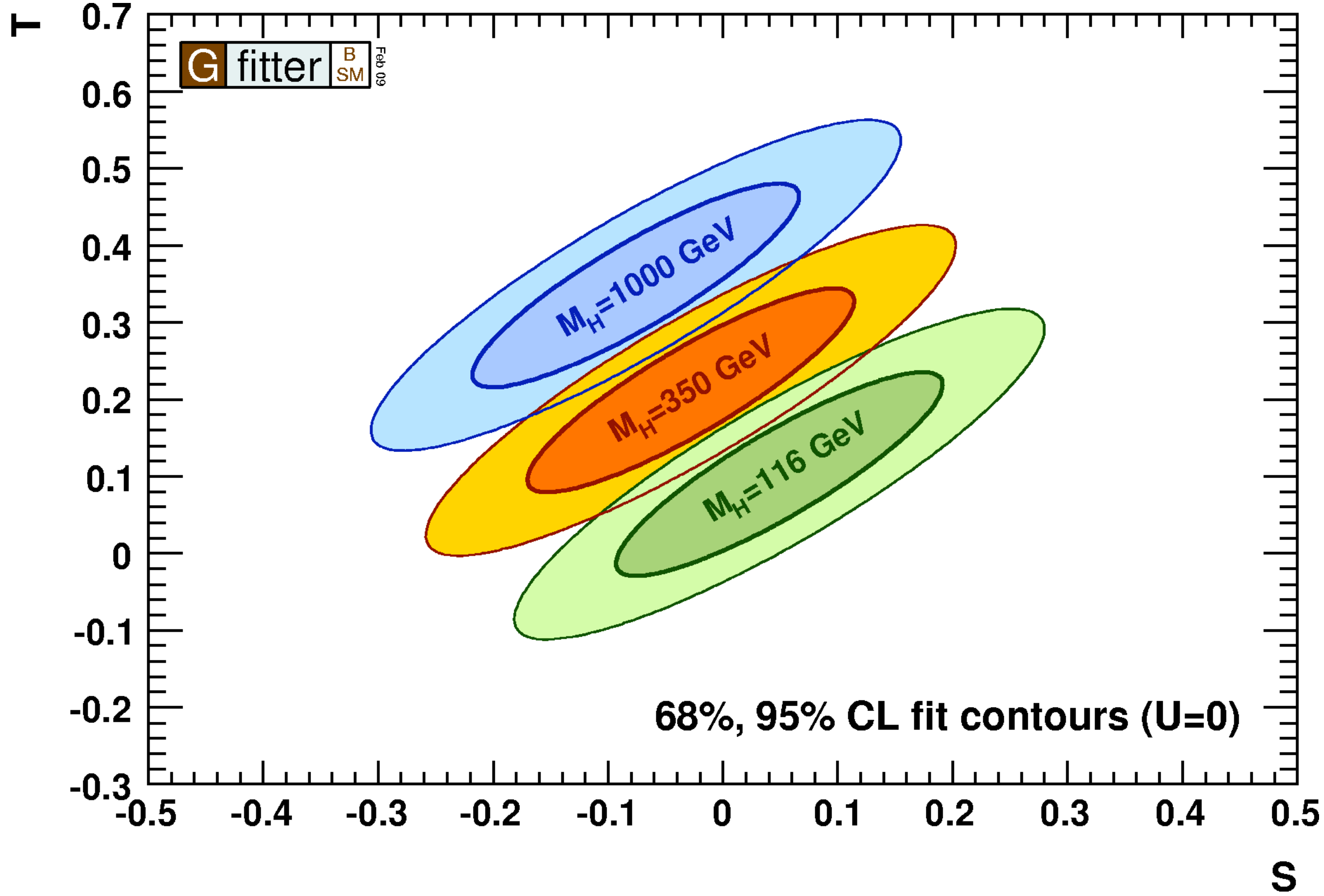
$$\boxed{O_{meas} = O_{SM,REF}(m_H,m_t) + c_S S + c_T T + c_U U}$$

- S : New Physics contributions to neutral currents
- T : Difference between neutral and charged current processes (sensitive to isospin violation)
- U : (+S) New Physics contributions to charged currents. U only sensitive to W mass and width. [Usually very small in NP 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 derived from fit to electroweak observables (see global SM fit)
  - Other floating fit parameters: M_Z, $\alpha_s(M_Z^2)$, $\Delta\alpha_{had}^{(5)}(M_Z^2)$
- 68%, 95% CL ellipses for various M_H values, and m_t = 173.1 GeV (fixed)



M_H=116 (350) GeV
S=0.02(-0.06) ± 0.11
T=0.05(0.15) ± 0.12
U=0.07(0.08) ± 0.12

Higgs corrections to STU:

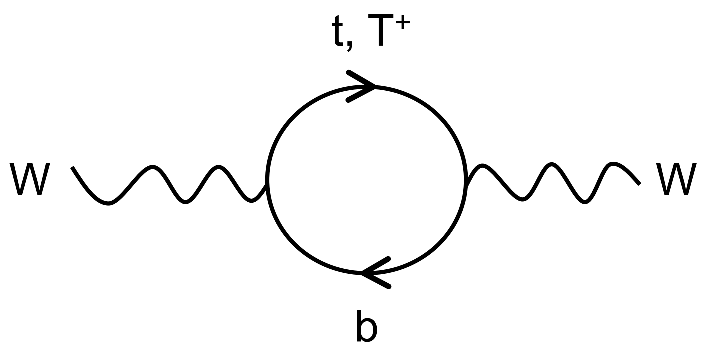
$$S = -\frac{1}{12\pi}\log\frac{m_H^2}{m_{H,\mathrm{ref}}^2}$$

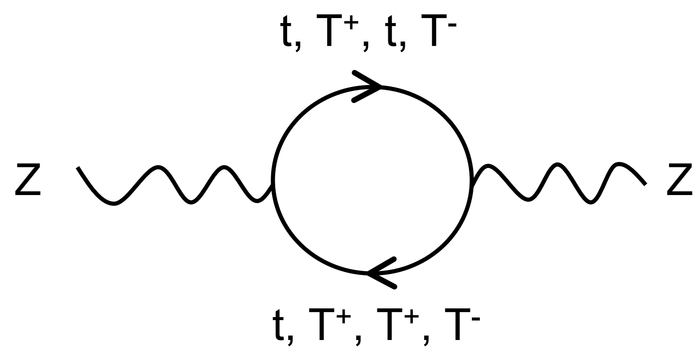
$$T = \frac{3}{16\pi c_W^2}\log\frac{m_H^2}{m_{H,\mathrm{ref}}^2}$$

$$U = 0$$

Littlest Higgs Model, with T-Parity

- LHM solves hierarchy problem, non-linear sigma model
- 'Littlest' HM: broken Global SU(5)/SO(5) symmetry
  - Higgs = lightest pseudo-Nambu-Goldstone boson
  - New SM-like fermions and gauge bosons at TeV scale
  - SM contributions to Higgs mass cancelled by new particles
- T-parity = symmetry like R-parity (not time-invariance)
  - Symmetry forbids direct couplings of new gauge bosons to SM particles
  - Provides natural dark matter candidate
- Two new heavy top-quark states: T-even m_{T+} and T-odd m_{T-}
- Dominant oblique corrections:



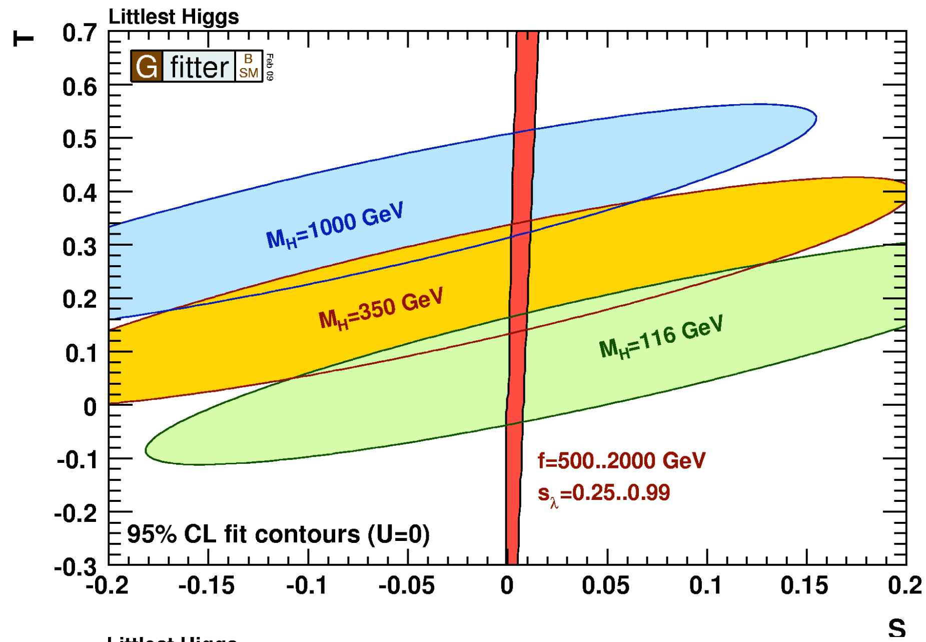


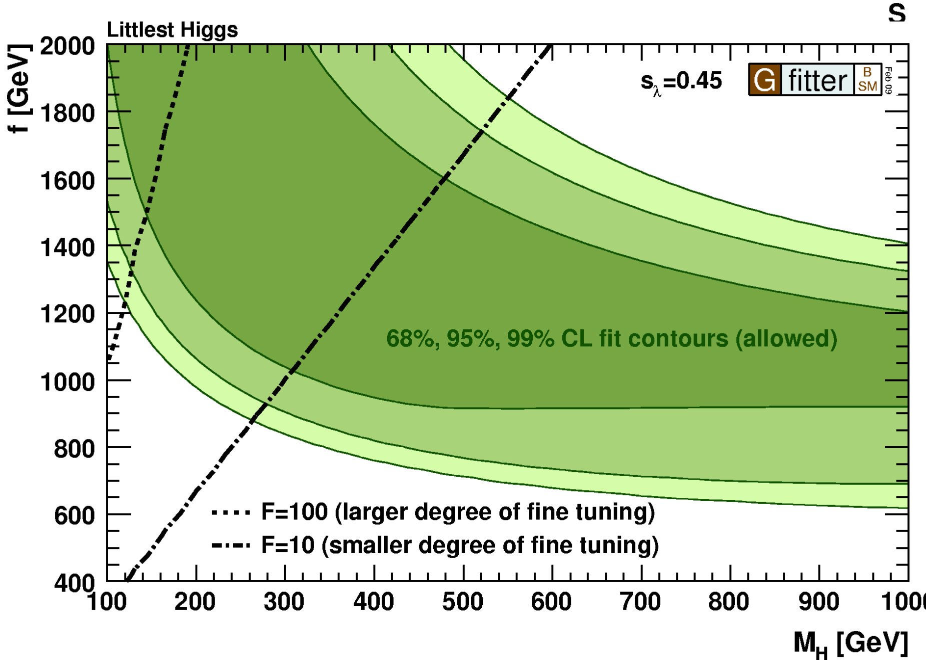
Littlest Higgs with T-Parity

- STU predictions (oblique corrections) inserted for Littlest Higgs model
  [Hubisz et al., JHEP 0601:135 (2006)]

- Parameters of LH model
  - f : symmetry breaking scale (scale of new particles)
  - $s_\lambda \cong m_{T-} / m_{T+}$: ratio of T-odd/-even masses in top sector
  - Order one-coefficient δ_c (value depends on detail of UV physics)
    - Treated as theory uncertainty in fit (Rfit) : δ_c= [-5,5]
- F: degree of fine-tuning

- LH model prefers large Higgs mass, with only small degree of fine-tuning





G fitter 2HDM

A Gfitter Package for 2HDM SM Extensions

- Two Higgs Doublet Model (Type-II)
  - SM extended by additional Higgs doublet (2HDM)
  - One Higgs doublet couples to up-type fermions, other doublet couples to down-type fermions
  - Five Higgs bosons: 3 neutral (A^0, h^0, H^0), two charged ($H^\pm$)
  - 6 Free parameters → $M_{H\pm}$, M_{A0}, M_{H0}, M_h, $\tan\beta$, $|\alpha|$
  - [Type-II 2HDM resembles Higgs sector in MSSM]

Two Higgs Doublet Model

- We have looked at processes sensitive to charged Higgs interactions

$$\mathcal{L}_{H^\pm ff} = \frac{g}{2\sqrt{2}m_W}\left\{H^+\bar{U}\left[M_U V_{CKM}(1-\gamma_5)\cot\beta + V_{CKM}M_D(1+\gamma_5)\tan\beta\right]D + \text{h.c.}\right\}$$

- Interaction has similar structure as W-boson
  - Left-handed coupling: $1/\tan\beta$, right-handed coupling: $\tan\beta$
- Sensitive parameters $\rightarrow$ $M_{H\pm}$, $\tan\beta$
- LEP limit: $M_{H\pm}$>78.6 GeV (95%CL), for any value of $\tan\beta$

- Measurements of interest from B-physics

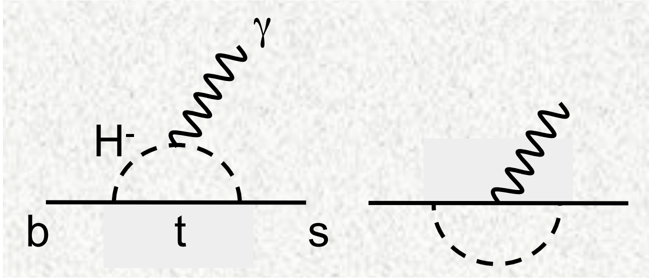
Observable	Input value	Exp. Ref.	Calculation
R_b^0	0.21629 ± 0.00066	[ADLO, Phys. Rept. 427, 257 (2006)]	[H. E. Haber and H. E. Logan, Phys. Rev. D62, 015011 (2000)]
BR ($B \to X_s\gamma$)	$(3.52\pm0.23\pm0.09)\cdot10^{-4}$	[HFAG, latest update]	[M. Misiak et al., Phys. Rev. Lett. 98, 022002 (2007)]
BR ($B \to \tau\nu$)	$(1.73\pm0.33)\cdot10^{-4}$	[P.Chang, Talk at ICHEP 2008]	[W. S. Hou, Phys. Rev. D48, 2342 (1993)]
BR ($B \to \mu\nu$)	$(-5.7\pm6.8\pm7.1)\cdot10^{-4}$	[E. Baracchini, Talk at ICHEP 2008]	[W. S. Hou, Phys Rev. D48, 2342 (1993)]
BR ($K \to \mu\nu$)/ BR($\pi \to \mu\nu$)	1.004±0.007	[FlaviaNet,, arXiv: 0801.1817]	[FlaviaNet, arXiv: 0801.1817]
BR($B \to D\tau\nu$)/ BR($B \to De\nu$)	0.416±0.117±0.052	[Babar, Phys. Rev. Lett 100, 021801 (2008)]	[J. F. Kamenik and F. Mescia, arXiv:0802.3790]

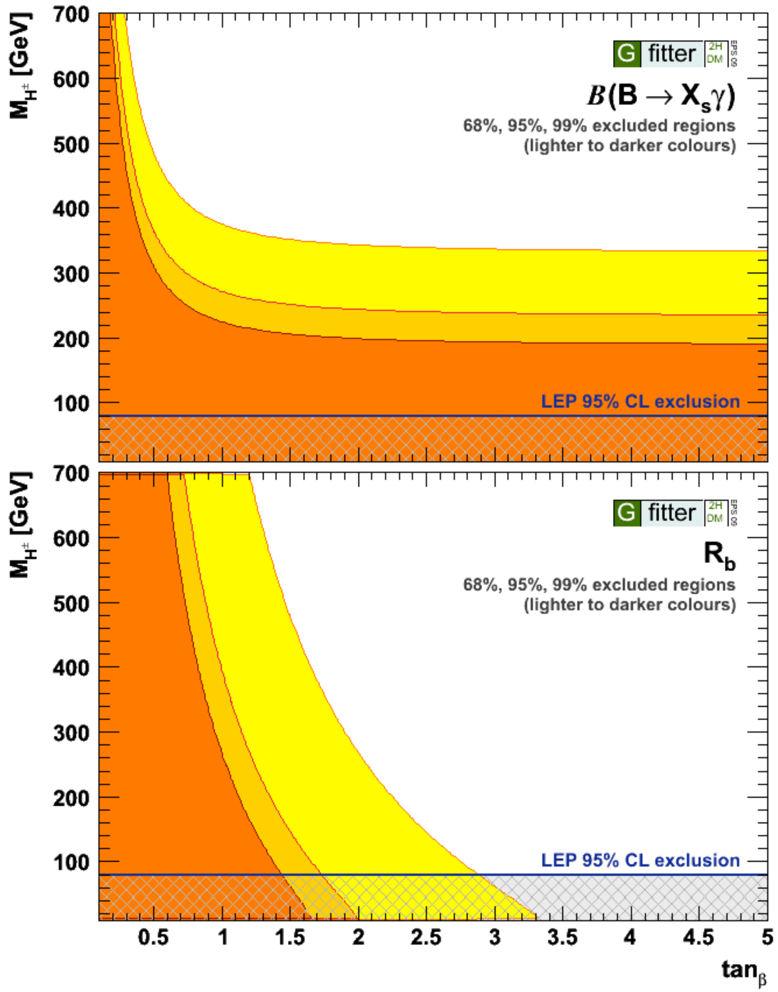
b→sγ and R^0_b

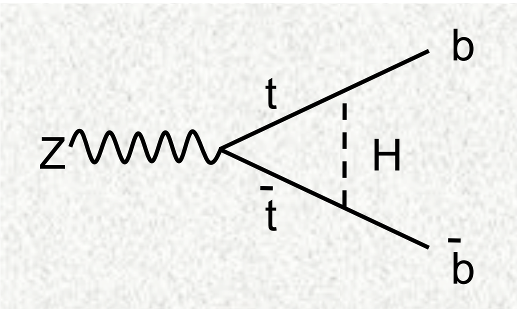
- Penguin dipole-moment of b→sγ allows combination of left- and right-handed Higgs couplings.
- Wilson coefficient:

$$C_7^H \approx -\frac{m_t^2}{2M_H^2}\left(\frac{7}{36}\frac{1}{\tan^2\beta}+\frac{2}{3}\ln\frac{m_H^2}{m_t^2}+\frac{1}{2}\right)$$

- $B \to X_s\gamma$: $M_H > 200$ GeV for $\tan\beta > 1$





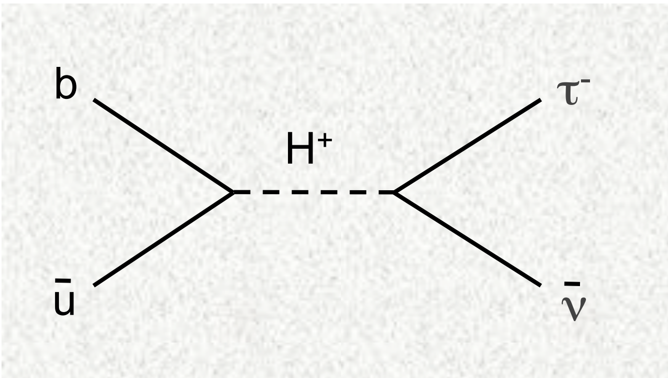


- Z vertex contribution suppressed by $1/\tan^2\beta$
- R^0_b sensitive to small $\tan\beta$ only

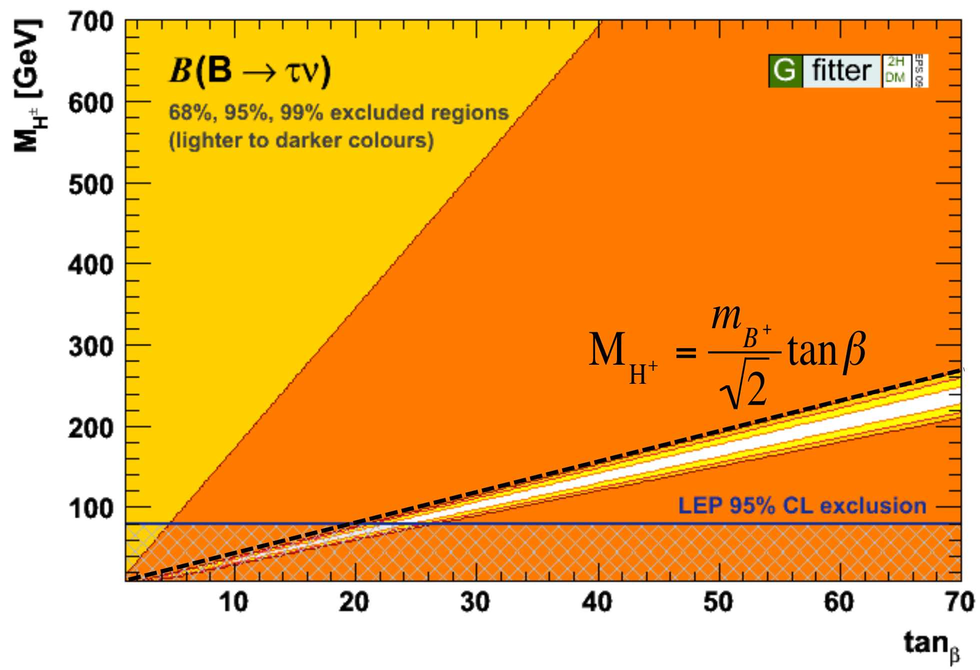
Strongest constraint: $B \rightarrow \tau\nu$

$(BR\times10^{-4})$	Oct '08	EPS '09	Reference
$BR(B\to\tau\nu)_{meas}$	1.51 ± 0.33	1.73 ± 0.35	FPCP 2009
$BR(B\to\tau\nu)_{SM}$	$1.20^{+0.36}_{-0.30}$	$0.87^{+0.21}_{-0.18}$	(Vub direct-measurements.)
V_{ub} $(\times10^{-3})$	3.81 ± 0.47	3.70 ± 0.33	Gambino,Giordano, Ossola,Uraltsev
f_B (MeV)	216 ± 22	190 ± 13	HPQCD '09 using NRQCD, Davies at FPCP'09
$BR(B\to\tau\nu)_{CKM}$	$0.83^{+0.27}_{-0.10}$	$0.80^{+0.15}_{-0.09}$	CKM Fitter '09, indirect Vub

- Latest measurements used
- We use prediction based on direct measurements of V_{ub}.
- [2.1σ deviation between measurement and SM prediction for $BR(B\to\tau\nu)$]

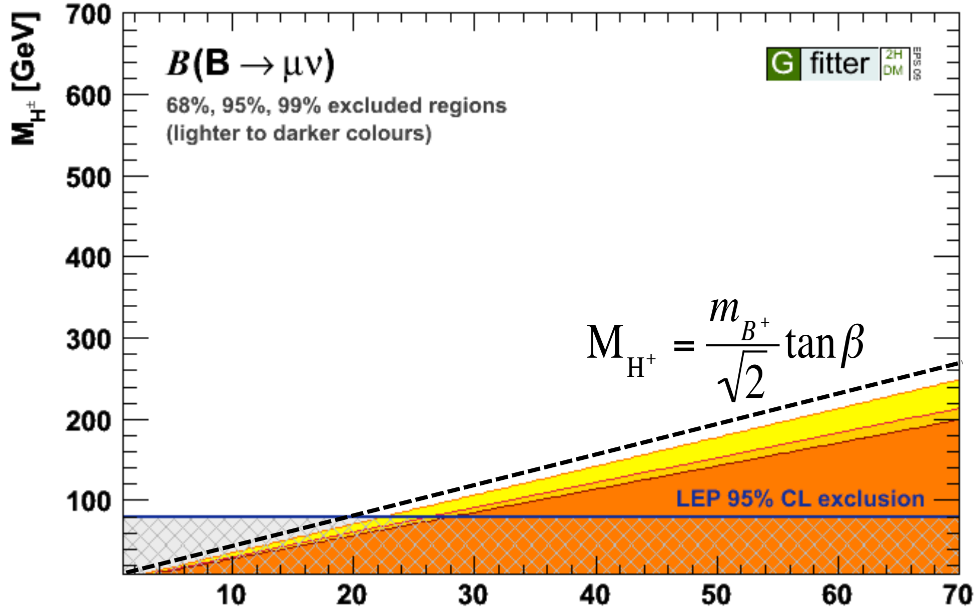


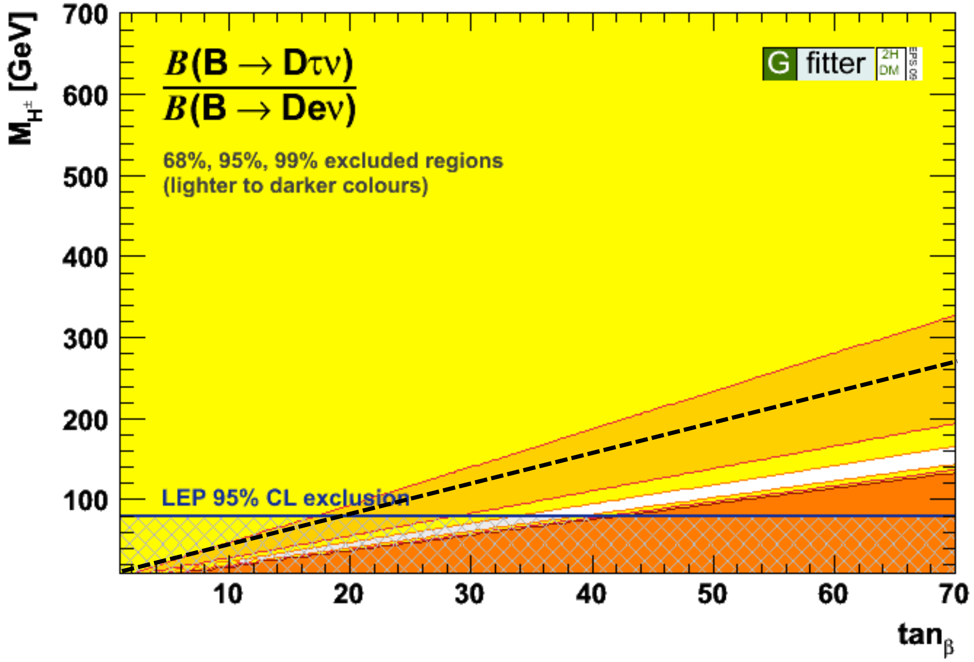
$$\frac{BR(B\to\tau\nu)_{\rm 2HDM}}{BR(B\to\tau\nu)_{\rm SM}} = \left[1 - m_B^2\frac{\tan^2\beta}{M_{H^\pm}^2}\right]^2$$

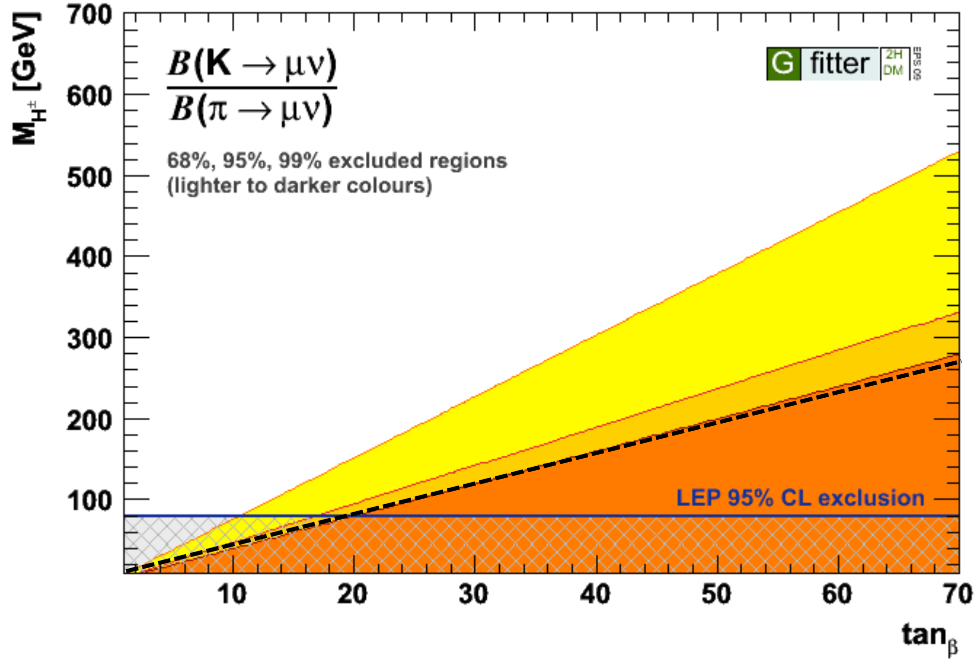


Other measurements w/ tree-level contributions

- Weak upper-limit on BR(B→μν)
- Favored solution of BR(B→τν) excluded by combination of:
  - BR(K→μν) / BR(π→μν)
  - BR(B→Dτν) / BR(B→Deν)
  - $B \to X_s \gamma$

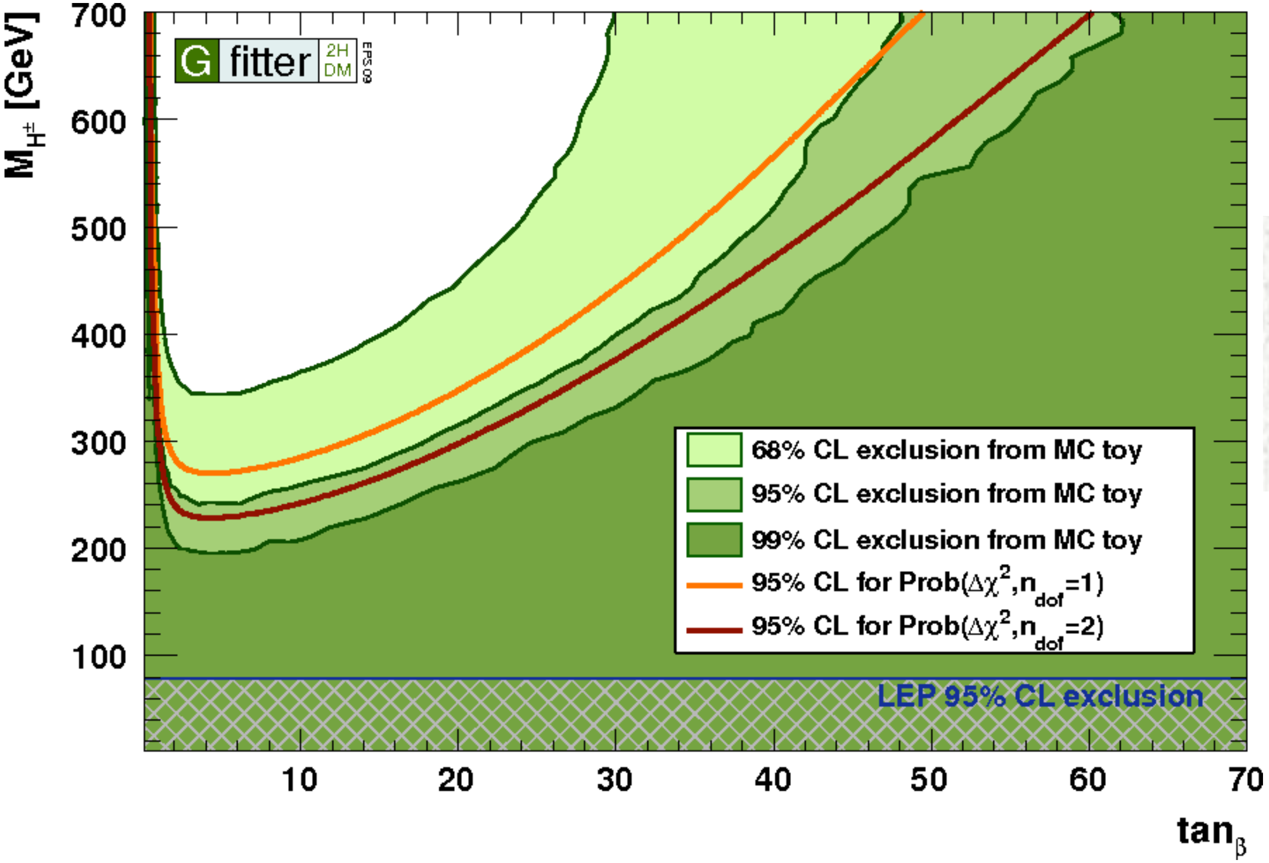






2HDM: Combined Fit

- Combined exclusion area depends on assumption on number of dof.
  - n_{dof}=1 : where single constraint dominates.
  - n_{dof}=2 : several observables contribute.
- MC toy study to resolve exclusion area
- [Combined limit not necessarily stronger than single constraint due to increasing n_{dof}]



- Excluded at 95% CL
  - Small tanβ
  - M_H < 240 GeV for all tanβ
  - M_H < 780 GeV for tanβ=70

Conclusion & Prospects

- Gfitter = powerful framework for involved HEP model fit problems
  - w/ advanced studies of statistical fit properties
- Results of SM electroweak fit
  - → See talk by Andreas Hoecker
  - No requirement for physics beyond SM (large p-value)
- Tests of New Physics models through oblique corrections
  - Constraints on Littlest Higgs model
- Constraints on Two-Higgs-Doublet Model (Type II)
  - Excluded @ 95% CL: $M_H < 240$ GeV for all $\tan\beta$

- Expect to see more NP models tested by Gfitter in near future!

- More information / all results:
  - http://cern.ch/Gfitter
  - Continuous support & updates
  - Paper published in Eur. Phys. J. C 60, 543 (2009)

Gfitter

A Generic Fitter Project for HEP Model Testing

Backup

The Electroweak Fit – Experimental Input

- Z-pole precision cross-section and asymmetry measuments from LEP / SLC(*):
  - M_Z, Γ_Z [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
  - Hadronic x-section at Z pole σ^0_{had}
  - Leptonic ratio R^0_l
  - Hadronic ratios R^0_c, R^0_b (*)
  - FB asymmetries $A_{FB}^{0,l,c,b}$ (f.s. angular distributions) (*)
  - LR asymmetries (*)
    - SLC A_l, A_c, A_b (IS polarization), LEP A_l (τ polarization)
  - FB charge asymmetry Q_{FB}
- M_H in complete fit: likelihood ratios from LEP/Tevatron
- M_W and Γ_W from LEP/Tevatron [ADLO,CFD+D0: arXiv:0811.4682]
- $\overline{m}_c$, $\overline{m}_b$ world averages [PDG, J. Phys. G33,1 (2006)]
- m_t latest Tevatron average [arXivx:0808.1089 [hep-ex]]
- $\Delta\alpha_{had}^{(5)}(M_Z^2)$ including α_S dependency [Hagiwara et al., PLB649,173,'07]
- Theoretical uncertainties
  - M_W (δM_W=4-6MeV), $\sin^2\theta^l_{eff}$ ($\delta\sin^2\theta^l_{eff}$ =$4.7\cdot10^{-5}$)
- Floating fit parameters
  - M_Z, $\Delta\alpha_{had}^{(5)}(M_Z^2)$, $\alpha_S(M_Z^2)$, $\overline{m}_c$, $\overline{m}_b$, m_t, M_H

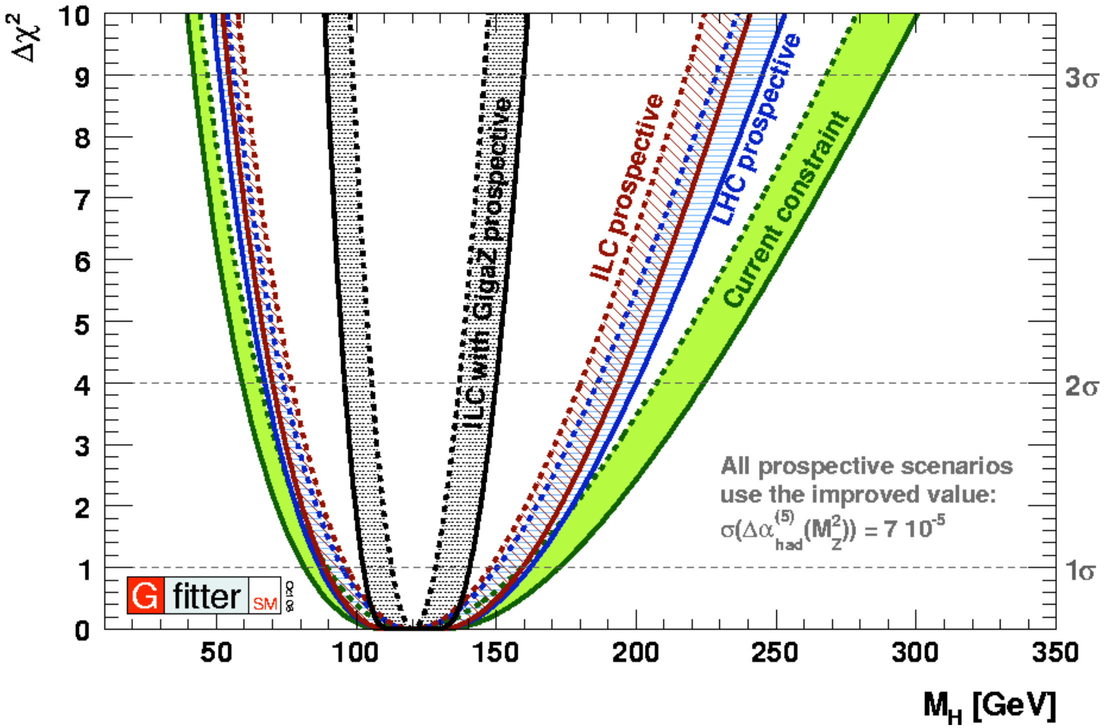
M_Z [GeV]	91.1875 ± 0.0021
Γ_Z [GeV]	2.4952 ± 0.0023
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037
R^0_ℓ	20.767 ± 0.025
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010
A_ℓ $^{(\star)}$	0.1499 ± 0.0018
A_c	0.670 ± 0.027
A_b	0.923 ± 0.020
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016
R^0_c	0.1721 ± 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
M_W [GeV]	80.399 ± 0.023
Γ_W [GeV]	2.098 ± 0.048
$\overline{m}_c$ [GeV]	1.25 ± 0.09
$\overline{m}_b$ [GeV]	4.20 ± 0.07
m_t [GeV]	173.1 ± 1.3
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2768 ± 22
$\alpha_s(M_Z^2)$	–
$\delta_{\rm th}M_W$ [MeV]	$[-4, 4]_{\rm theo}$
$\delta_{\rm th}\sin^2\theta^\ell_{\rm eff}$ $^{(\dagger)}$	$[-4.7, 4.7]_{\rm theo}$
$\delta_{\rm th}\rho^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$
$\delta_{\rm th}\kappa^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$

† in units of 10^{-5}

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]	25	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]	${}^{+56}_{-40}$ $({}^{+52}_{-39})$ $[{}^{+39}_{-31}]$	${}^{+45}_{-35}$ $({}^{+42}_{-33})$ $[{}^{+30}_{-25}]$	${}^{+42}_{-33}$ $({}^{+39}_{-31})$ $[{}^{+28}_{-23}]$	${}^{+27}_{-23}$ $({}^{+20}_{-18})$ $[{}^{+8}_{-7}]$
$\alpha_s(M_Z^2)$ $[10^{-4}]$	28	28	27	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]