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on behalf of the Gfitter group (*)

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Gfitter

http://cern.ch/Gfitter

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

The global electroweak fit and constraints on new physics with Gfitter

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Gfitter

A Generic Fitter Project for HEP Model Testing

- Introduction to the Gfitter program
- Global electroweak fit of the Standard Model

- Oblique parameters
- Constraints on various BSM models
- Two-Higgs-Doublet Model

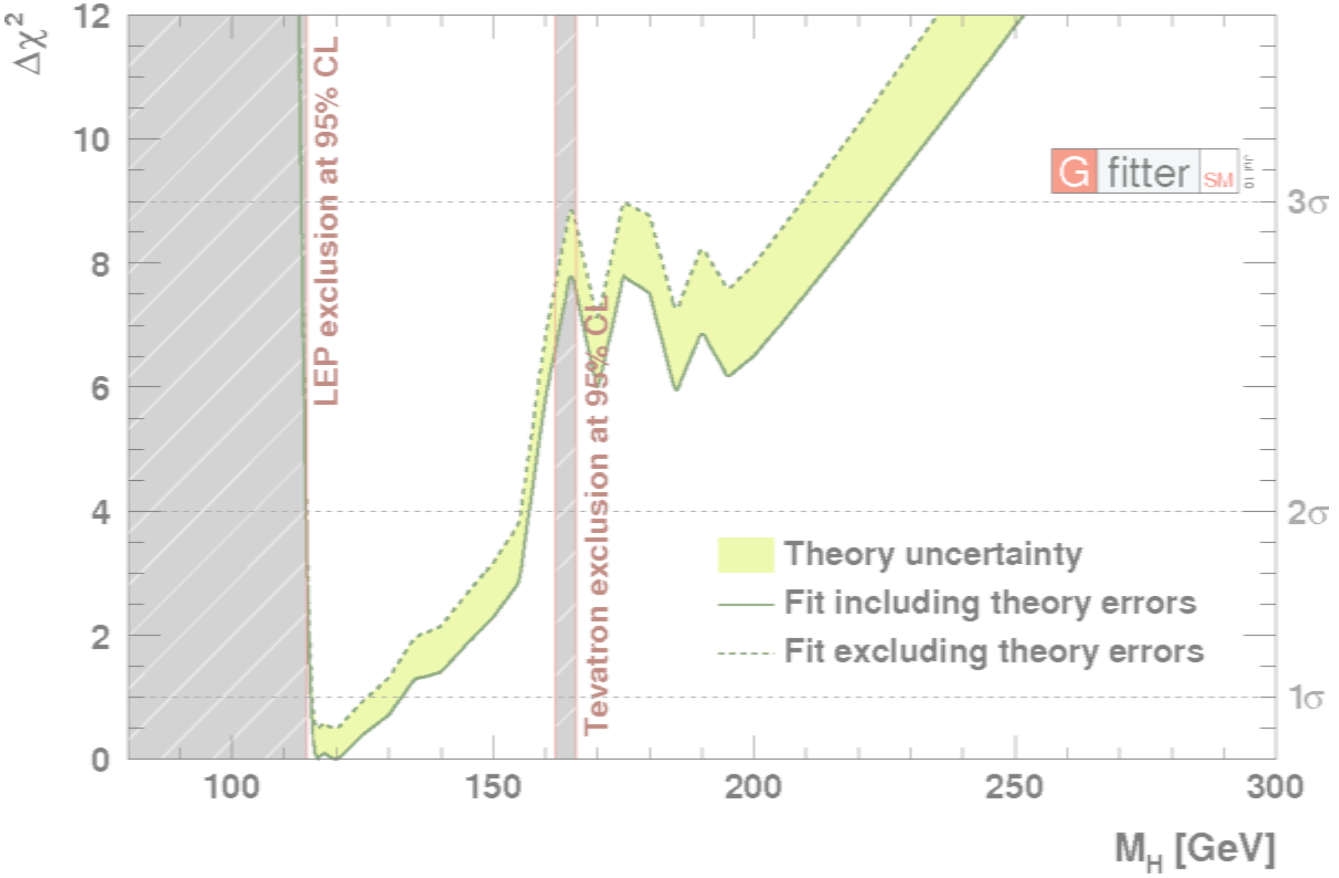
- Conclusion / Prospects

The Gfitter Project – Introduction

Gfitter — A Generic Fitter Project for HEP Model Testing

- Gfitter = state-of-the-art model testing tool for LHC era
- Gfitter software
  - Modular, object-oriented C++, relying on ROOT, XML, python
  - Core package with data-handling, fitting, and statistics tools
  - Independent "plug-in" physics libraries: SM, 2HDM, oblique parameters, SUSY, ...
- Gfitter features
  - Various fitting tools: Minuit (1/2), Genetic Algorithms, Simulated Annealing, etc.
  - Full statistics analysis: goodness-of-fit, p-values, parameter scans, MC analyses.
  - Consistent treatment of statistical, systematic, theoretical uncertainties (Rfit prescription), correlations, and inter-parameter dependencies.
    - Theoretical uncertainties included in χ^2 with flat likelihood in allowed ranges
- Main publication: EPJ C60, 543-583,2009 [arXiv:0811.0009]
  - Also available at: www.cern.ch/Gfitter
  - Today: updates and new results

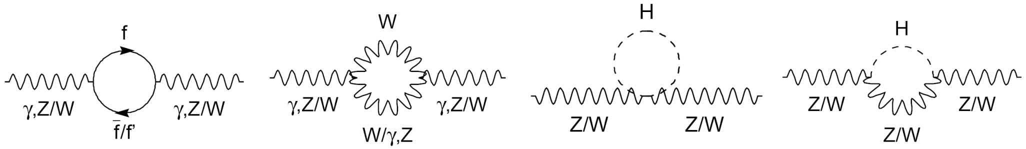
The global electroweak fit of the SM

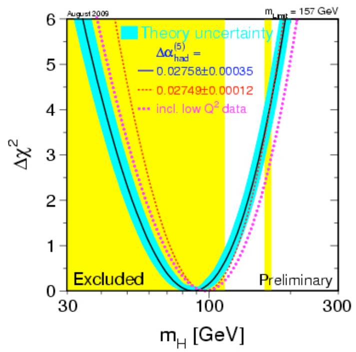


The global electroweak fit with Gfitter

G fitter SM

- A Gfitter package for the global EW fit of the SM
  - Complete reimplementation of SM predictions of EW precision observables
  - Based on huge amount of preparatory work by many people
  - Radiative corrections are important
    - Logarithmic dependence on M_H through virtual corrections



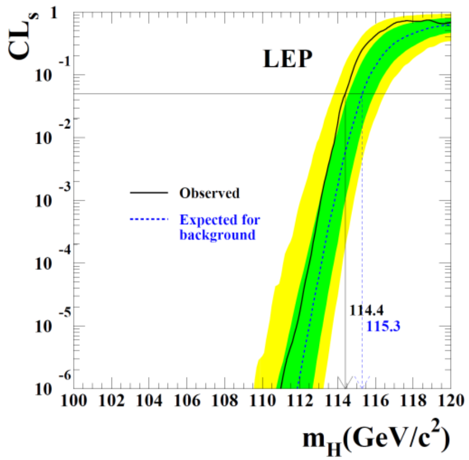


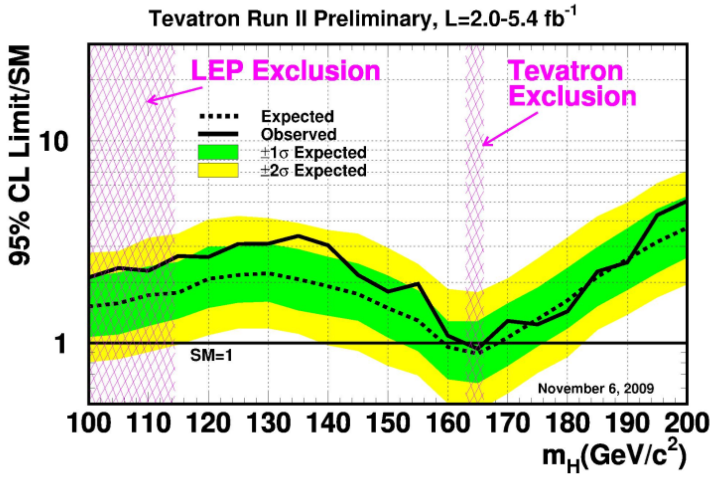
- State-of-the art calculations; in particular:
  - Radiator functions: N^{3}LO of the massless QCD Adler function, used for Z and W hadronic decay widths
    [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]
  - M_W and $\sin^2\theta^f_{eff}$: full two-loop + leading beyond-two-loop correction
    [M. Awramik et al., Phys. Rev D69, 053006 (2004) and ref.][M. Awramik et al., Nucl.Phys.B813:174-187 (2009) and refs.]
    - theoretical uncertainties: M_W (δM_W=4-6MeV), $\sin^2\theta^l_{eff}$ ($\delta\sin^2\theta^l_{eff}$ =$4.7\cdot10^{-5}$)

- Wherever possible, calculations cross-checked against ZFITTER
  → excellent agreement

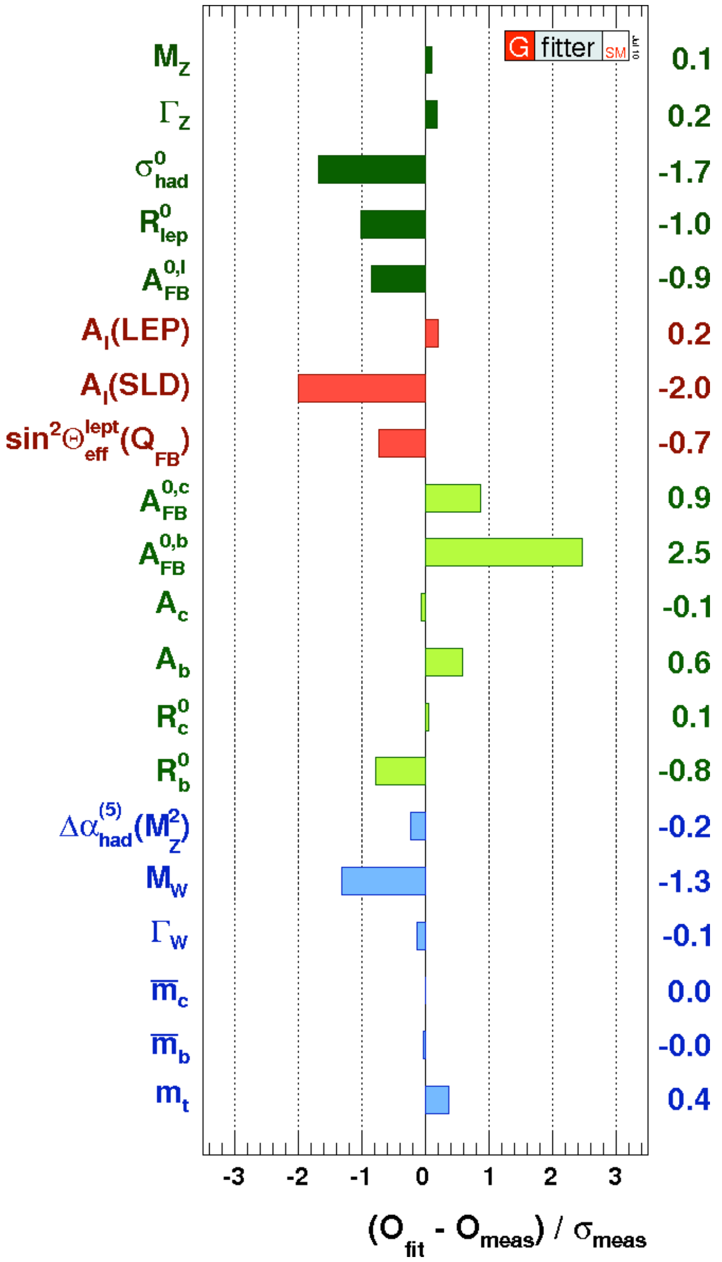
Electroweak Fit – Latest Experimental Input

- Z-pole observables: results from LEP / SLC
  [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
- M_W and Γ_W from LEP/Tevatron [ADLO,CFD+D0: arXiv:0908.1374v1]
- m_{top} latest Tevatron average [CDF&D0: new combination ICHEP'10]
- $\overline{m}_c$, $\overline{m}_b$ world averages [PDG, J. Phys. G33,1 (2006)]
- $\Delta\alpha_{had}^{(5)}(M_Z^2)$ including α_S dependency
  [Hagiwara et al., PLB649,173,'07]
- Direct Higgs searches from LEP/Tevatron
  [ADLO: Phys. Lett. B565, 61 (2003)], [CDF+D0: arXiv:0911.3930]
  - LEP: Higgs strahlung (ee → ZH, H→bb, ττ)
  - Tevatron: gg fusion w/ H → WW, ass. prod., VBF
  - Stat. interpretation in global fit: 2-sided CL_{S+B}





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 $^{(\star)}$	0.1499 ± 0.0018	LEP / 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	LEP / SLC
R^0_b	0.21629 ± 0.00066	LEP / SLC
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	LEP
M_H [GeV] $^{(\circ)}$	Likelihood ratios	LEP & Tevatron
M_W [GeV]	80.399 ± 0.023	LEP & Tevatron
Γ_W [GeV]	2.098 ± 0.048	LEP & Tevatron
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	
m_t [GeV]	173.3 ± 1.1	Tevatron
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2769 ± 22	
$\alpha_s(M_Z^2)$	$-$	



- 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

- Pull values of complete fit
  - No individual value exceeds 3σ
  - FB asymmetry of bottom quarks → largest contribution to χ^2
  - Small contributions from M_Z, $\Delta\alpha_{had}^{(5)}(M_Z^2)$, $\overline{m}_c$, $\overline{m}_b$: input accuracies exceed fit requirements

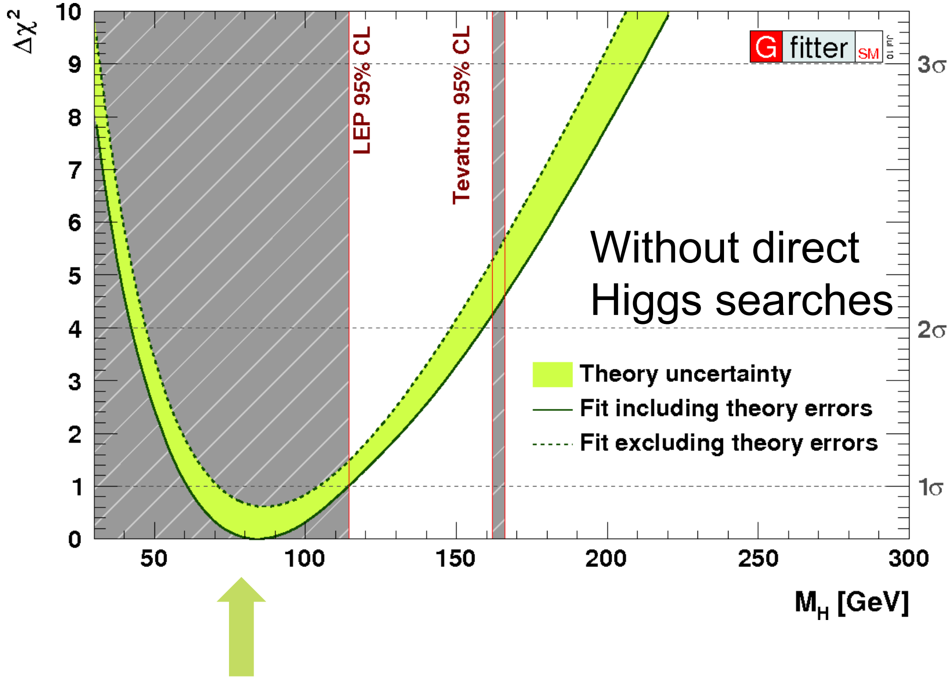
- Goodness of fit – naïve p-value:
  - Excl. direct Higgs searches: χ^2_{min}=16.4
    → Prob(χ^2_{min}, 13) = 0.23
  - Incl. direct Higgs searches: χ^2_{min}=17.8
    → Prob(χ^2_{min}, 14) = 0.22

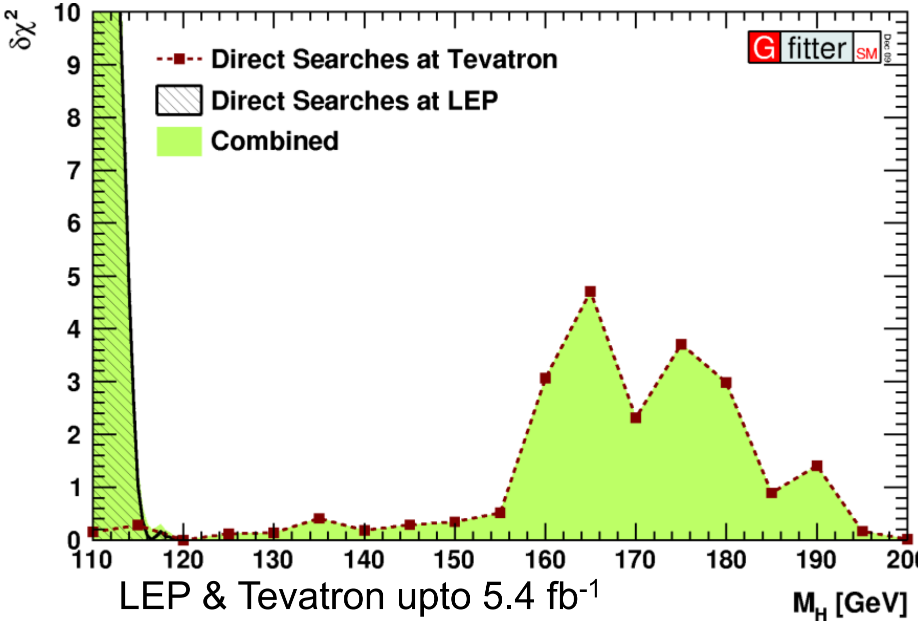
- No indication for new physics

The Electroweak Fit II – Higgs Mass Constraints

- M_H from fit including all data except results from direct Higgs searches at LEP, Tevatron:
  - Central value $\pm 1\sigma$: $M_H = 80^{+30}_{-23}$ GeV
  - 2σ interval: [42,159] GeV

- M_H from fit including results from direct Higgs searches at LEP, Tevatron:
  - Resulting contributions added to χ^2 during fit
  - Stat. interpretation: 2-sided CL_{S+B}

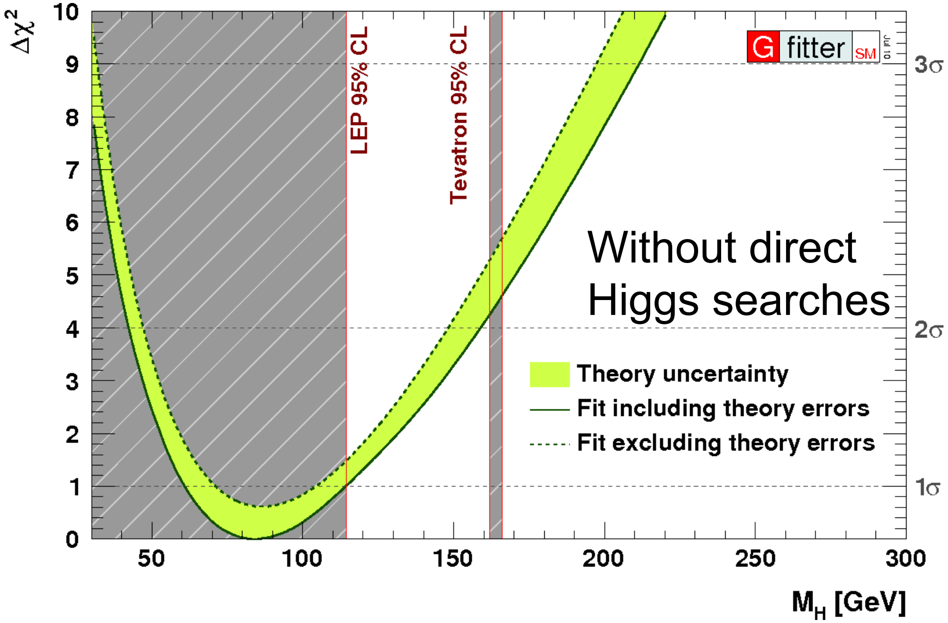


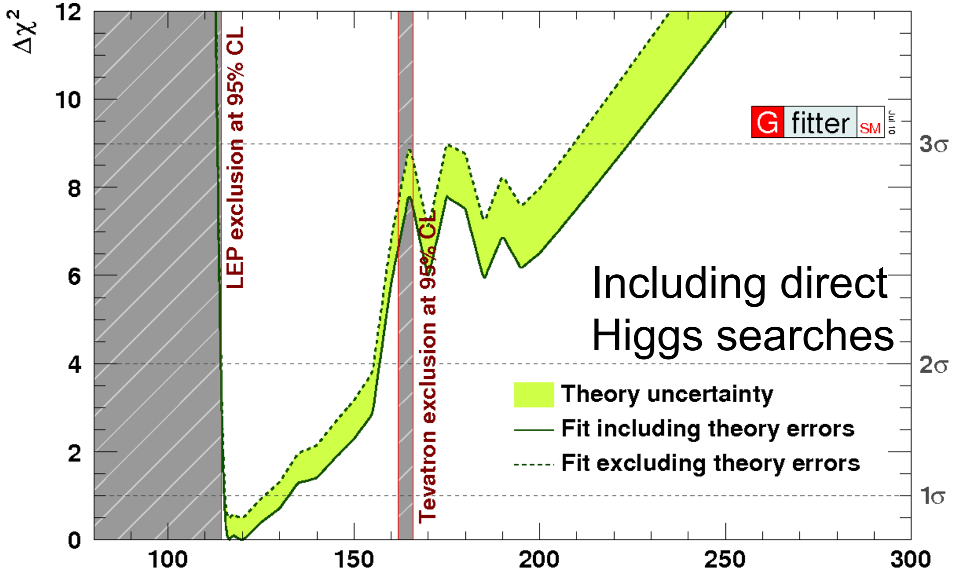


- green error band from including / excluding theoretical errors in fit
  - Theoretical errors included in χ^2 with "flat likelihood term"

The Electroweak Fit II – Higgs Mass Constraints

- M_H from fit including all data except results from direct Higgs searches at LEP, Tevatron:
  - Central value ±1σ: $M_H = 80^{+30}_{-23}$ GeV
  - 2σ interval: [42,159] GeV
- M_H from fit including results from direct Higgs searches at LEP, Tevatron:
  - Central value ±1σ: $M_H = 119.1^{+13.5}_{-4.0}$ GeV
  - 2σ interval: [114,157] GeV

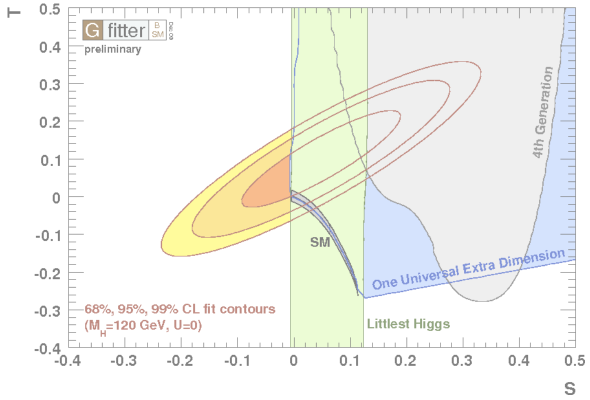


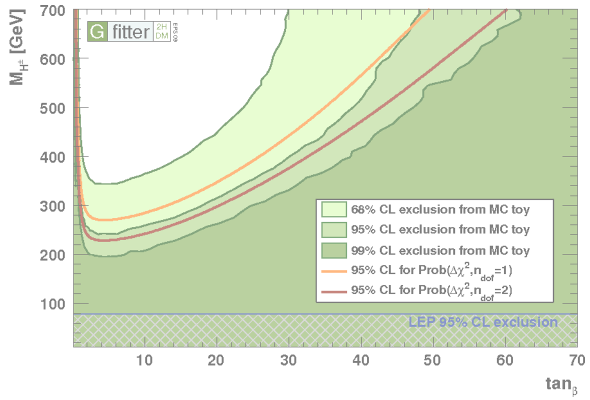


LEP & Tevatron upto 5.4 fb^{-1}

- green error band from including / excluding theoretical errors in fit
  - Theoretical errors included in χ^2 with “flat likelihood term”

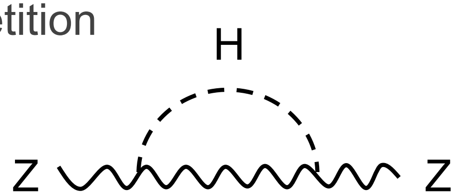
Constraints on New Physics Models





A Gfitter package for Oblique Corrections

- At low energies, BSM physics appears dominantly through vacuum polarization corrections
  - Aka, 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 : New Physics contributions to neutral currents
- T : Difference between neutral and charged current processes – sensitive to weak 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 obtained from fit to EW observables
  - SM_{ref} chosen at: M_H = 120 GeV and m_t = 173.1 GeV
  - This defines (S,T,U) = (0,0,0)

- Results for STU:

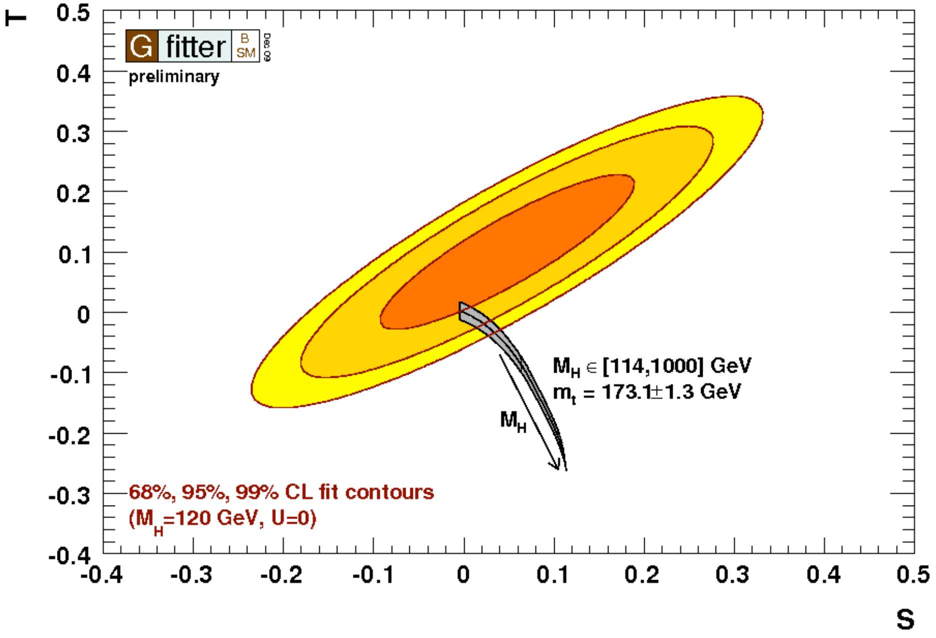
  S = 0.02 ± 0.11

  T = 0.05 ± 0.12

  U = 0.07 ± 0.12

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

ST-plane for *U*=0



- S, T: logarithmically dependent on M_H

- Grey area: SM prediction

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

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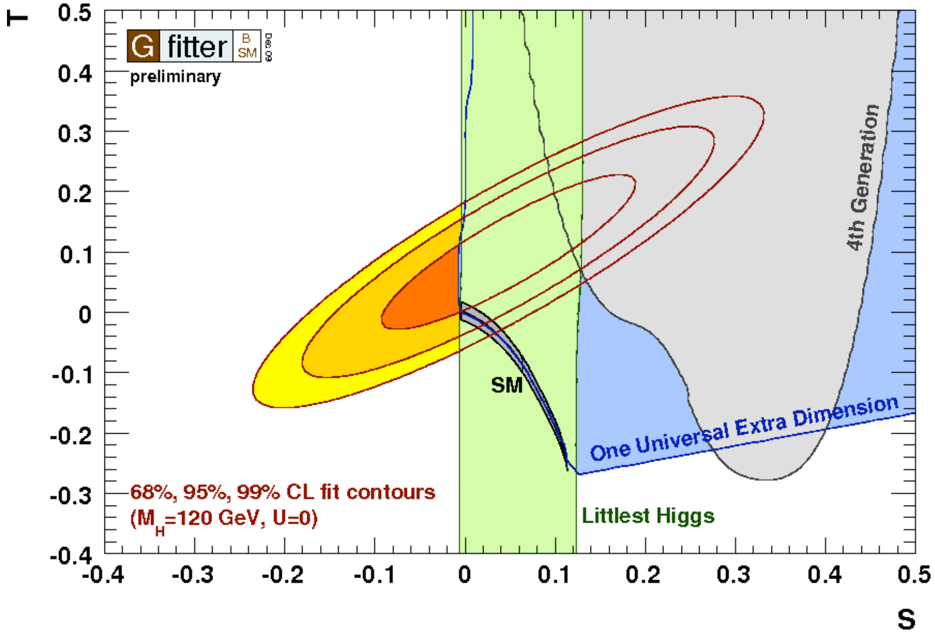

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- Comparison of EW data w/ SM prediction:
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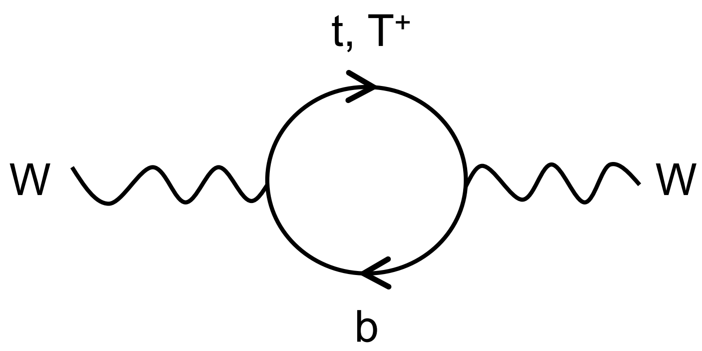
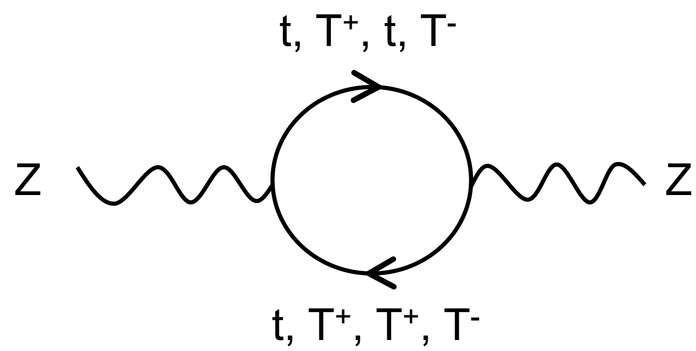
- Many new physics models also compatible with the EW data:
  - Variation of model parameters often allows for large area in ST-plane.
  - Tested: UED, 4th fermion generation, Littlest Higgs, SUSY, etc.

Littlest Higgs Model with T-Parity

- LHM: solves hierarchy problem, possible explanation for EWSM
  - SM contributions to Higgs mass cancelled by new particles
- Non-linear sigma model, broken Global SU(5)/SO(5) symmetry
  - Higgs = lightest pseudo-Nambu-Goldstone boson
  - New SM-like fermions and gauge bosons at TeV scale
- T-parity = symmetry like susy R-parity (not time-invariance)
  - Symmetry forbids direct couplings of new gauge bosons (T-odd) to SM particles (T-even)
  - LHM provides natural dark matter candidate
- Two new top states: T-even m_{T+} and T-odd m_{T-}
- Dominant oblique corrections from weak isospin violation:



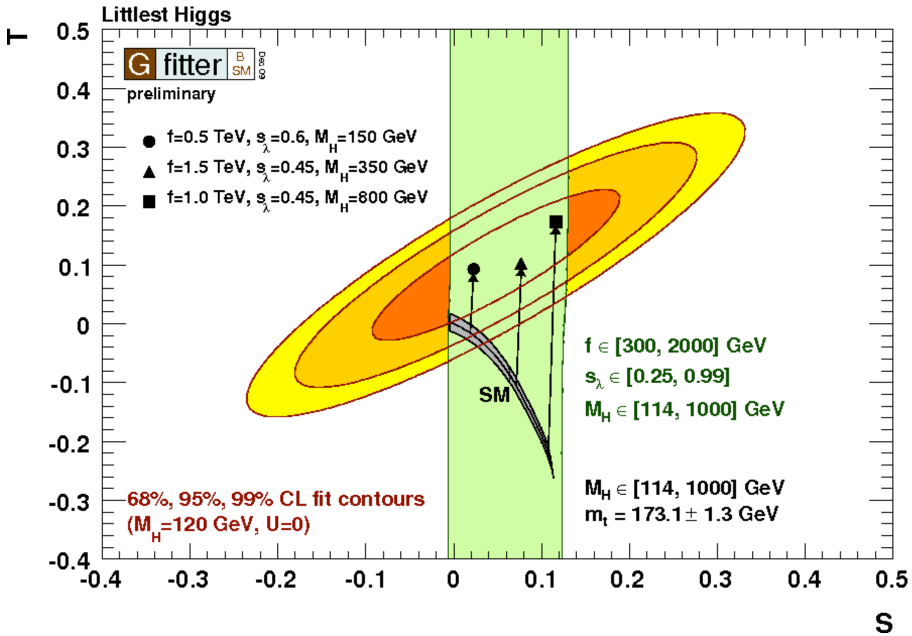


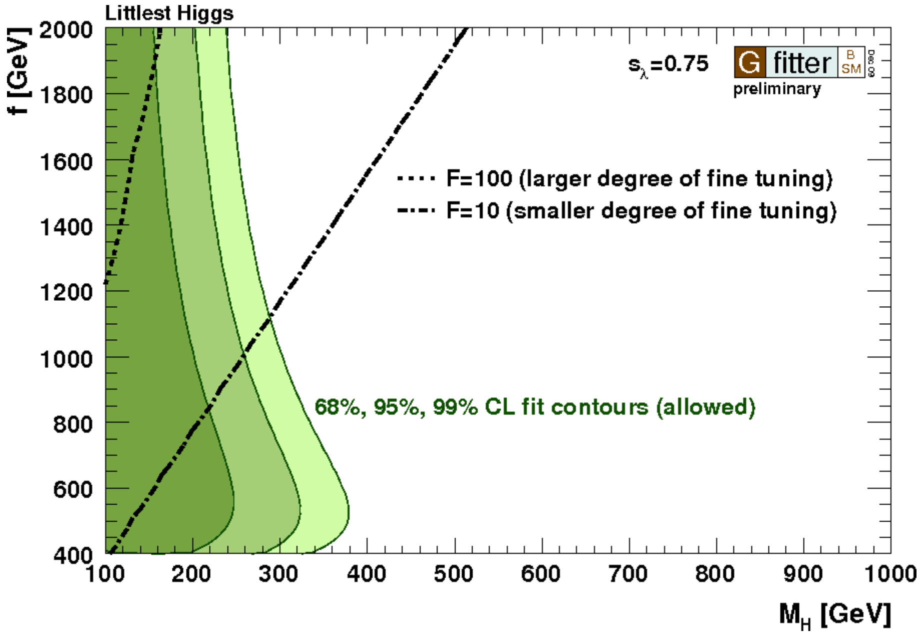
Littlest Higgs with T-Parity

- 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





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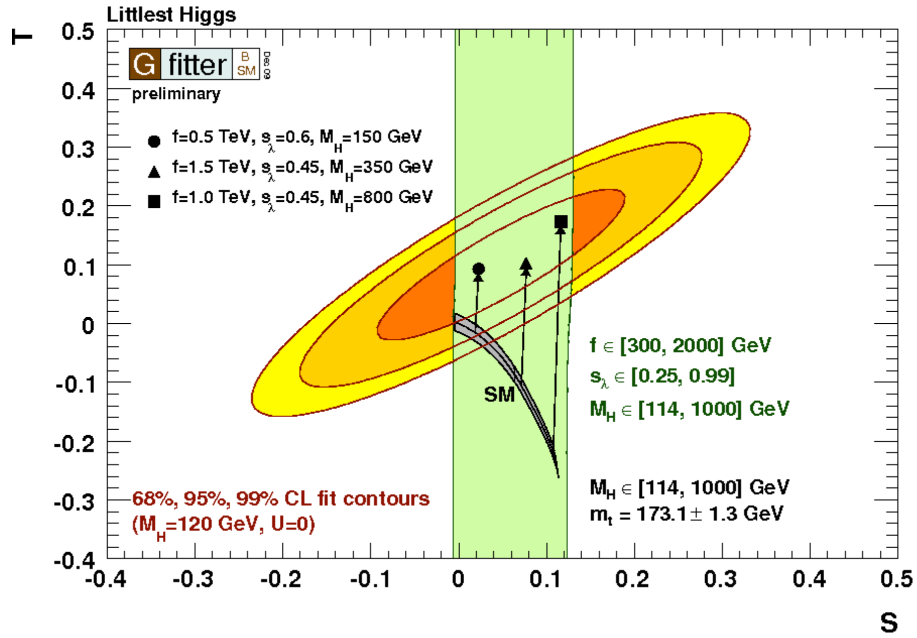

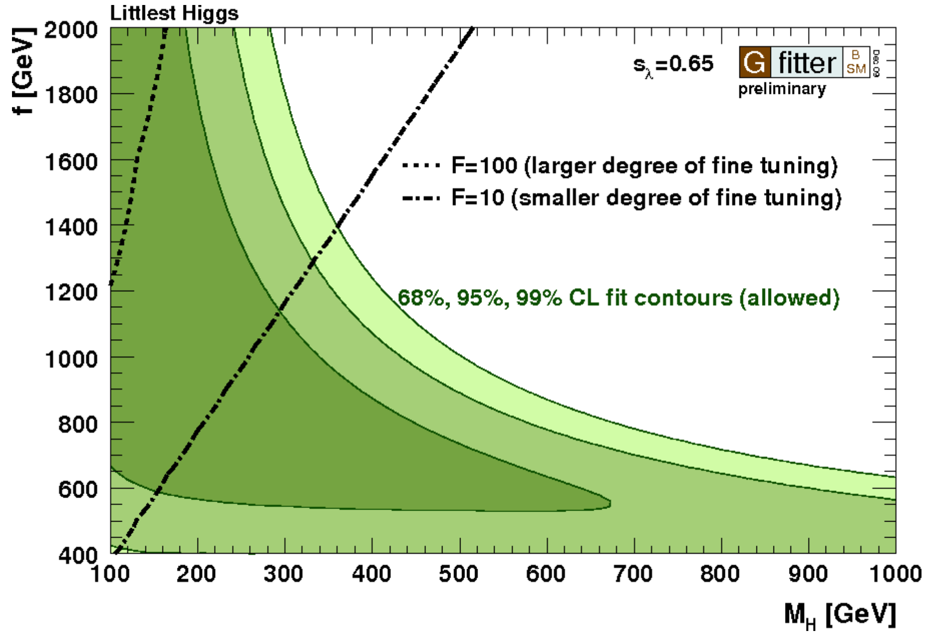

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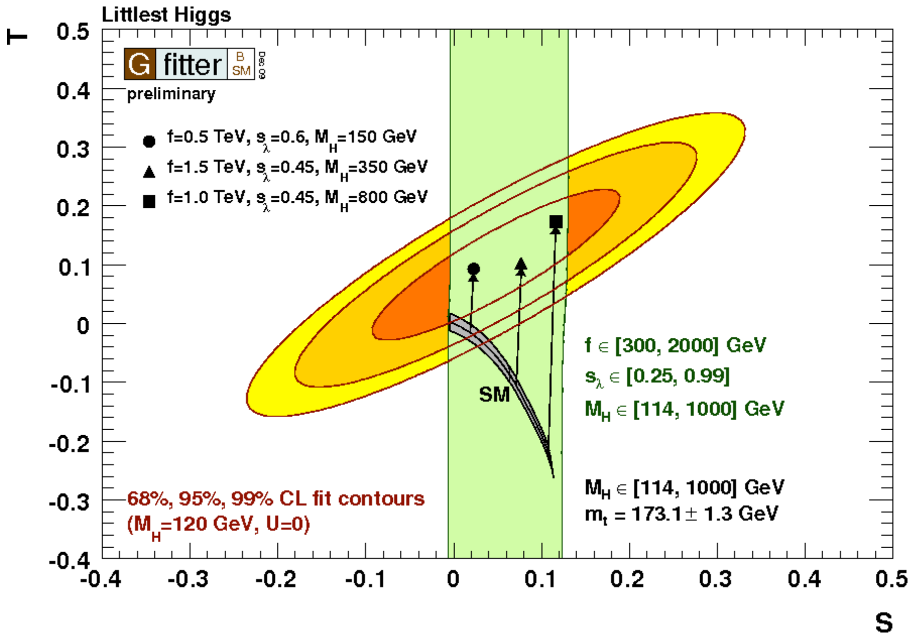
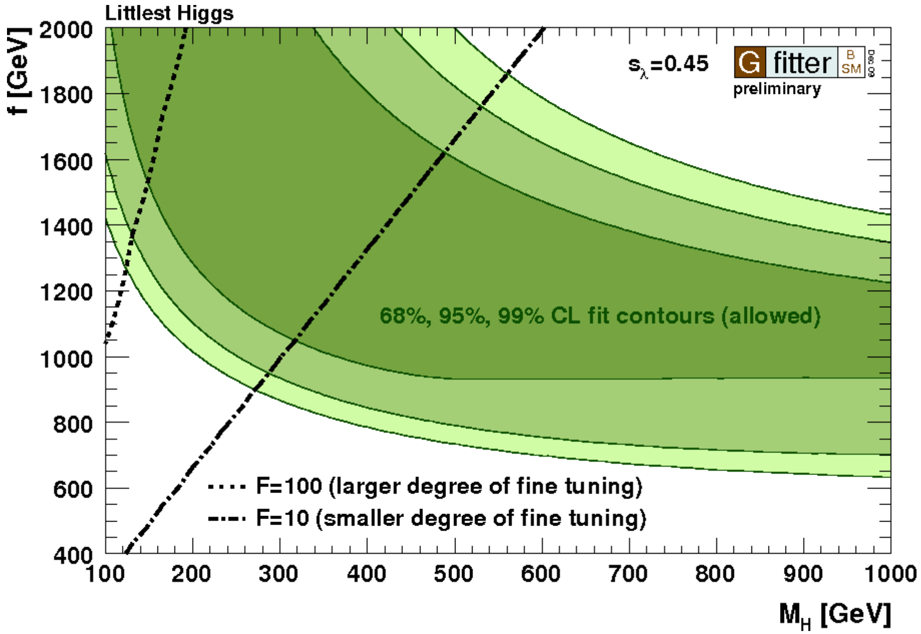
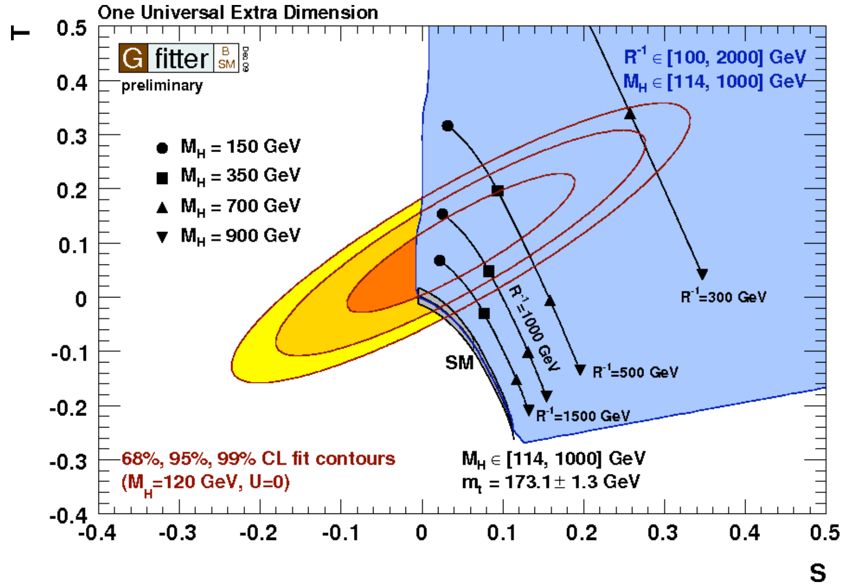




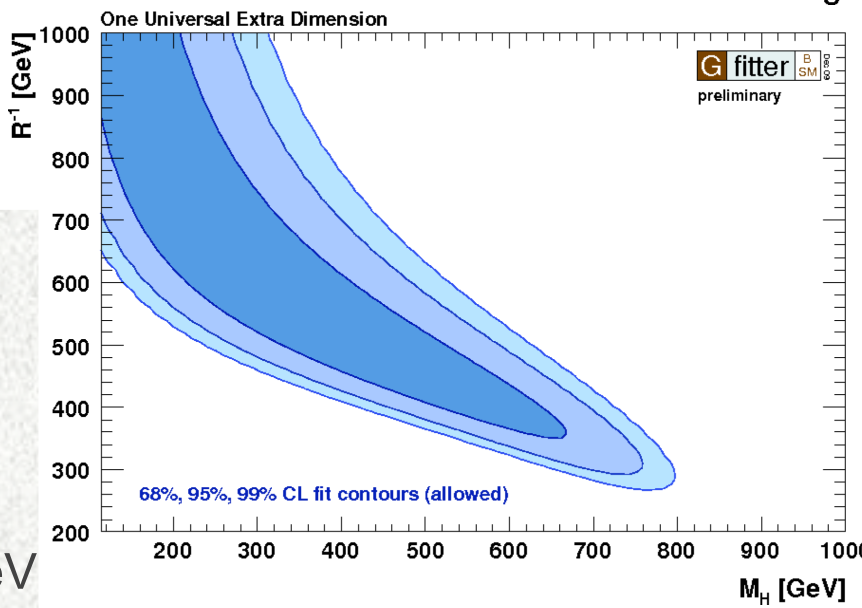
Universal Extra Dimensions

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

- UED:
  - All SM particles can propagate into 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)

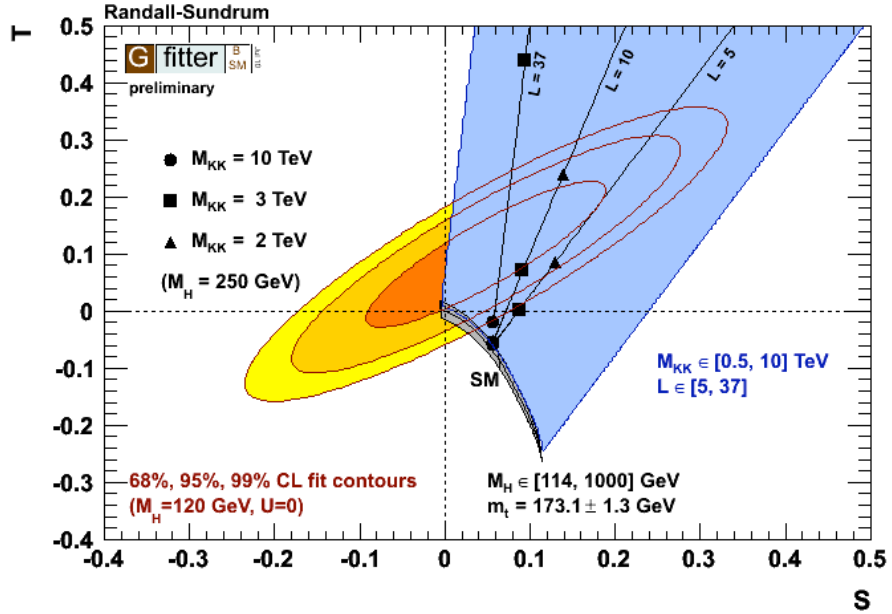


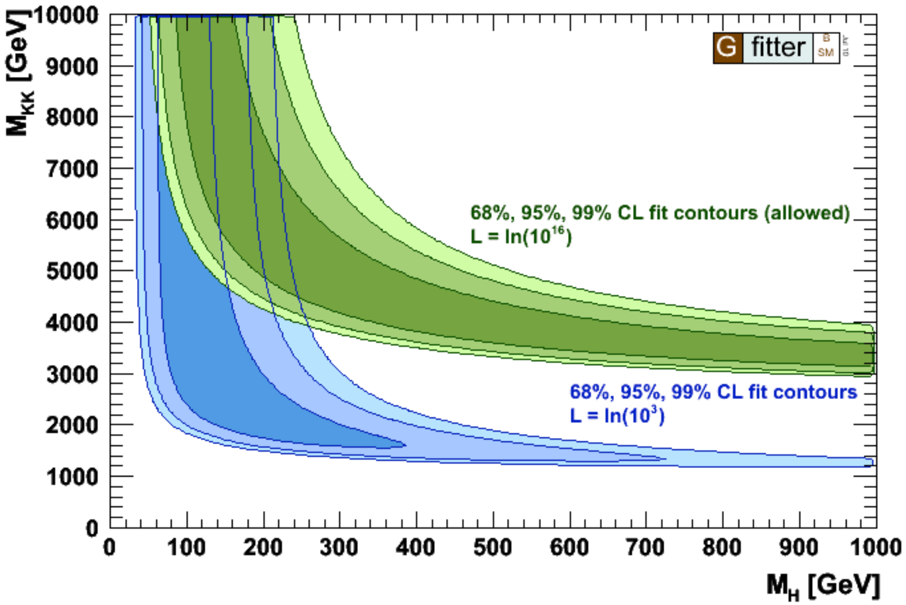
- Results:
  - Large R^{-1}: UED approaches SM (exp.)
    - Only small M_H allowed
  - Small R^{-1}: UED contribution compensated by large M_H
  - Excluded: R^{-1}< 300 GeV and M_H > 800 GeV

Warped Extra Dimensions (Randall-Sundrum)

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

- Introduction of one extra dimension (ED) to 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:
  - Excessive values of T possible
  - Large *L* forces large M_{KK} (several TeVs)
  - Some compensation if M_H is large





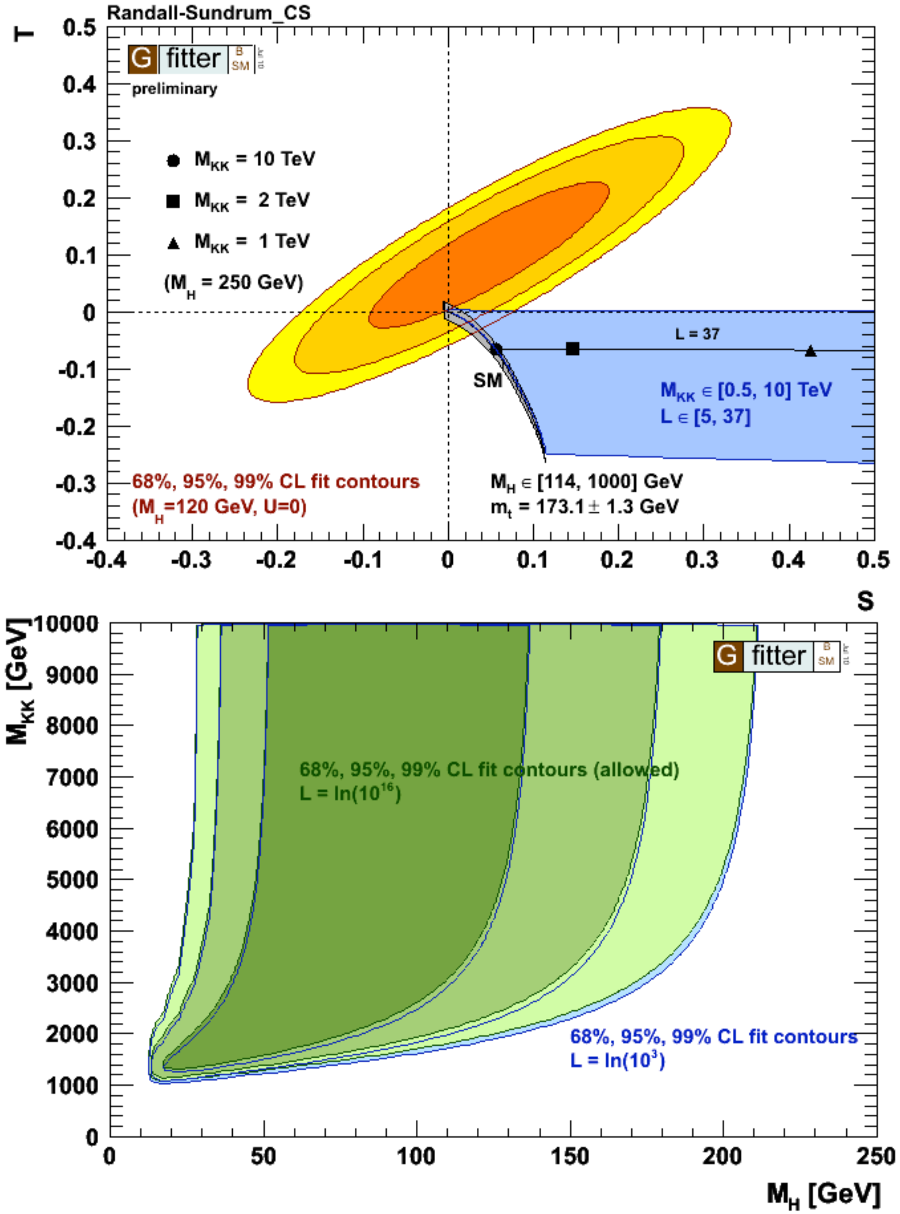
Warped Extra Dimensions w/ custodial symmetry

[K. Agashe, A. Delgado, M. May, R. Sundrum, hep-ph/0308036v2]

- Goal: "cure" WED with large T values
- Introduction of so-called **custodial isospin gauge symmetry** in the bulk

- Extension of hypercharge group to $SU(2)_R \times U(1)_X$
  - Bulk symmetry group: $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X$
- Broken to SM $SU(3)_C \times SU(2)_L \times U(1)_Y$ on "UV" brane
- IR brane $SU(2)_R$ symmetric
- Right-handed fermionic fields occur in doublets

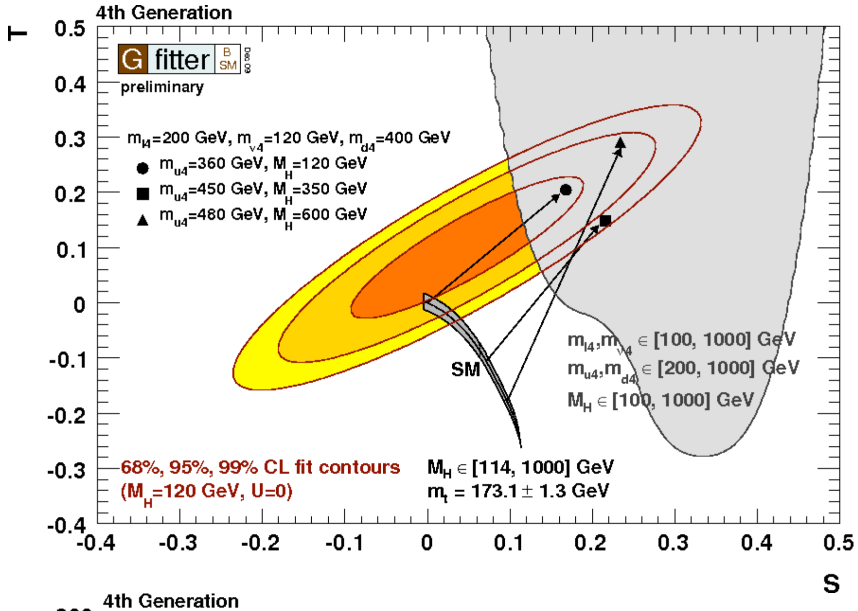
- Results:
  - Almost completely ruled out
  - Only small M_H allowed

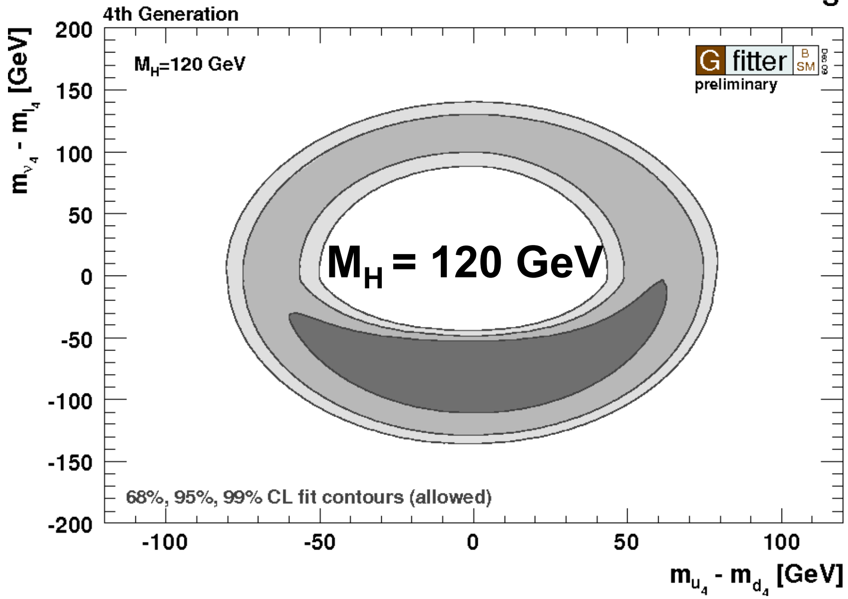


4th fermion generation

- 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
    - 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)
- Results:
  - With appropriate mass differences: 4th fermion model consistent with EW data
    - In particular a 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 (2001)]





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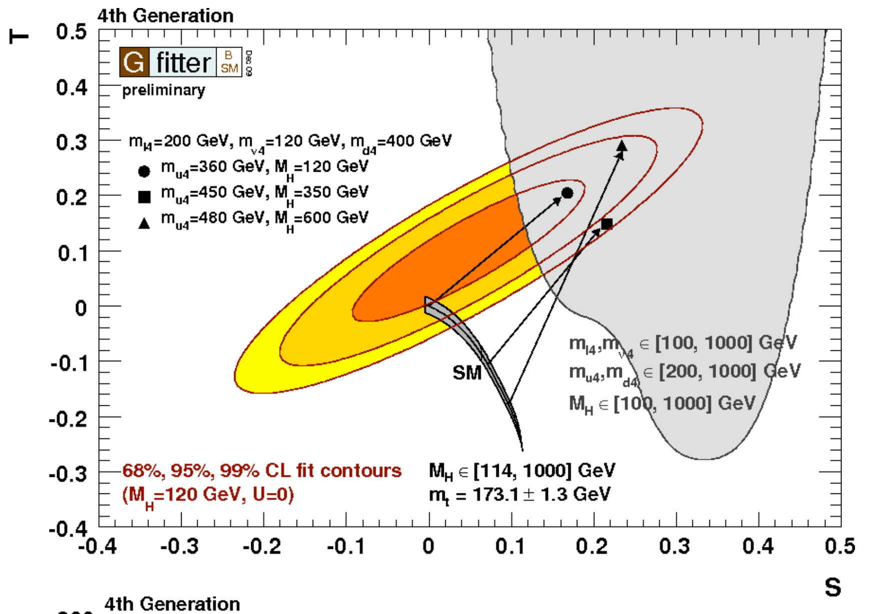
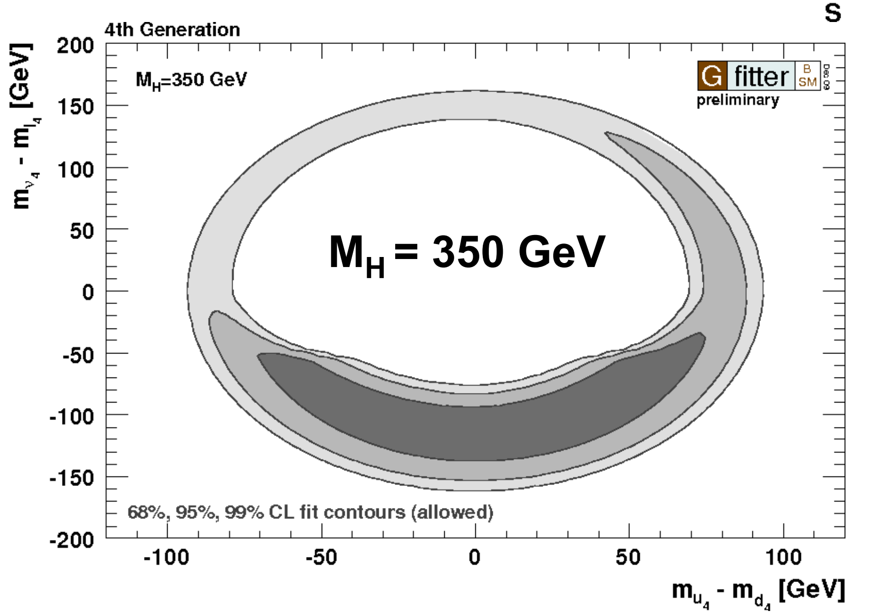
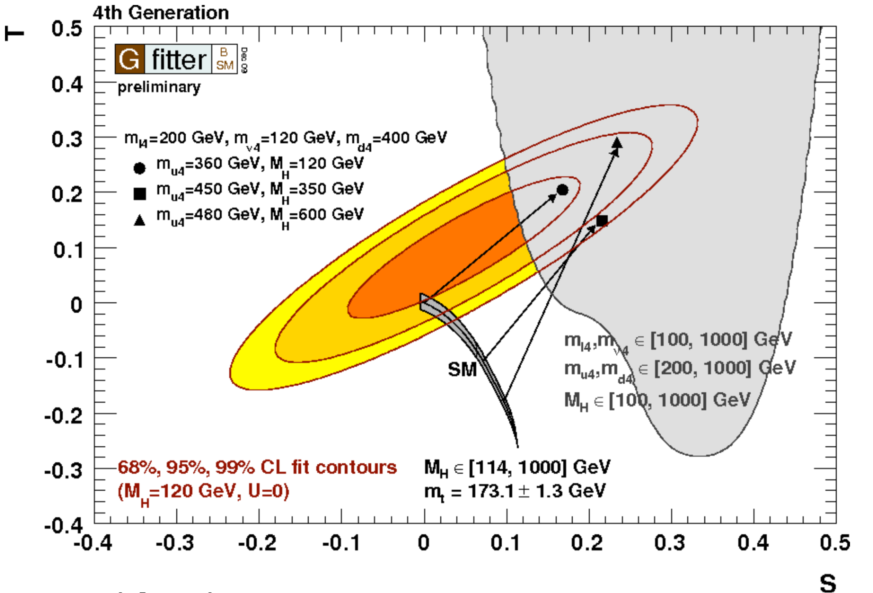


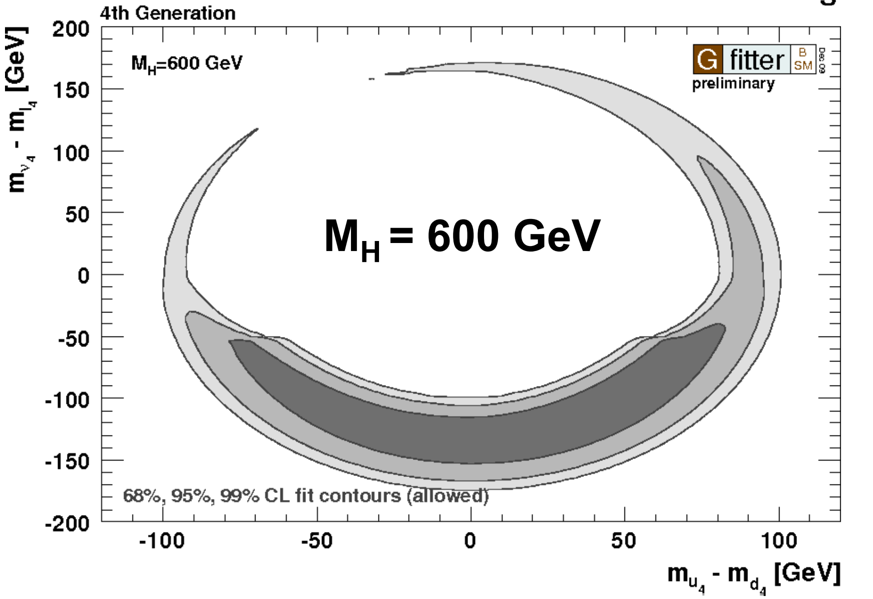


4th fermion generation

- 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
    - 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)
- Results:
  - With appropriate mass differences: 4th fermion model consistent with EW data
    - In particular a 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 (2001)]



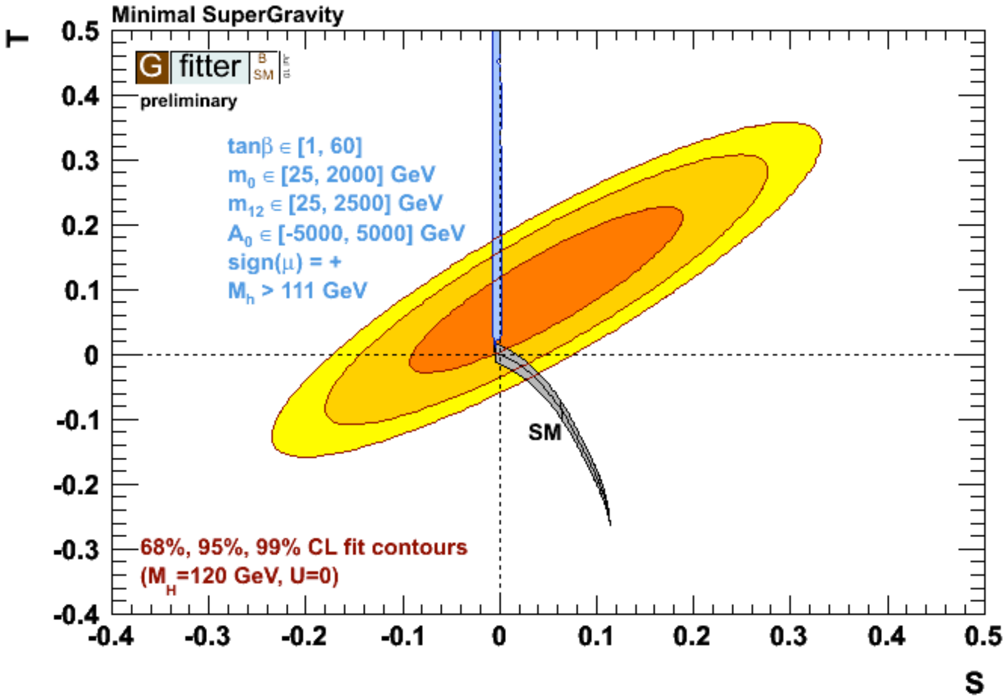


Minimal SuperGravity (preliminary)

[G. Weiglein: arXiv:hep-ph/9712226v1][S. Heinemeyer, W. Hollik, G. Weiglein: arXiv:hep-ph/0412214v1]

- Supersymmetry solves many short-comings of SM: hierarchy problem, unification of coupling constants, DM candidate, …
- mSUGRA: highly constrained breaking mechanism at GUT scale
  - SUSY breaking mediated by **gravitational interaction**
- mSUGRA determined by 5 parameters:
  - $m_{1/2}$: mass of fermions at GUT scale
  - m_0: mass of scalars at GUT scale
  - $\tan\beta$: ratio of two Higgs vacuum expectation values
  - A_0: trilinear coupling of the Higgs
  - sgn(μ): sign of Higgsino mass term

- Oblique corrections dominated by weak isospin violation between $m_{\tilde{b}1}$, $m_{\tilde{t}1}$, and $m_{\tilde{t}1}$,$m_{\tilde{t}2}$
  - $\delta M_W \lesssim 35$ MeV, $\delta\sin^2\theta^l_{eff} \lesssim 2\times10^{-4}$
- By construction of the oblique parameters → T parameter has dominant contribution



Additional constraints on mSUGRA

Gfitter B SM

- Extra constraints on top of EW precision observables
  - LEP limits on Higgs mass, neutralinos, sleptons
  - Kaon-, B-physics
  - (g_μ-2)
  - relic density

Parameter	Input value	meas. error	theoretical error
Ωh^2	0.1131	0.0034	0.012
$a_\mu(\text{meas}) - a_\mu(\text{SM})$	20.5×10^{-10}	8.2×10^{-10}	2.0×10^{-10}
$\text{BF}(B \to X_s\gamma)_{\text{meas}}/\text{BF}(B \to X_s\gamma)_{\text{SM}}$	1.117	0.076	0.096
$\Delta m_s(\text{meas})/\Delta m_s(\text{SM})$	1.015	0.122	
$\text{BF}(B_s \to \mu\mu)$	$< 4.7 \times 10^{-8}$		
$\text{BF}(B \to \tau\nu)_{\text{meas}}/\text{BF}(B \to \tau\nu)_{\text{SM}}$	2.16	$^{+0.62}_{-0.53}$	
Rl_{23}	1.004	0.007	
$\text{BF}(B \to D\tau\nu)/\text{BF}(B \to De\nu)$	0.42	0.13	
M_h [GeV]	> 114		3
M_{χ_0} [GeV]	> 50		
$M_{\chi_1^+}$ [GeV]	> 103		
$M_{\tilde{e}_R}$ [GeV]	> 90		
$M_{\tilde{\mu}_R}$ [GeV]	> 90		
$M_{\tilde{\tau}_R}$ [GeV]	> 90		

Average of e^+e^- and τ predictions for a_μ^{had} [$\pi\pi$], with scaled error.
arXiv:0908.4300v2, 0906.5443

- Using theoretical predictions by:
  - microMegas
  - FeynHiggs
  - SuperIso
  - SoftSUSY

- Dedicated C++ interfaces to Gfitter
  - No exchange of Les Houches files

SoftSUSY - [B.C. Allanach, Comp. Phys. Com. 143 (2002) 305-331], Feynhiggs - [M. Frank et al., JHEP0702:047, 2007], SuperIso - [F. Mahmoudi, JHEP12 (2007), 026], microMegas - [G. B´elanger et al., IRFU-10-24, LAPTH-012-10]

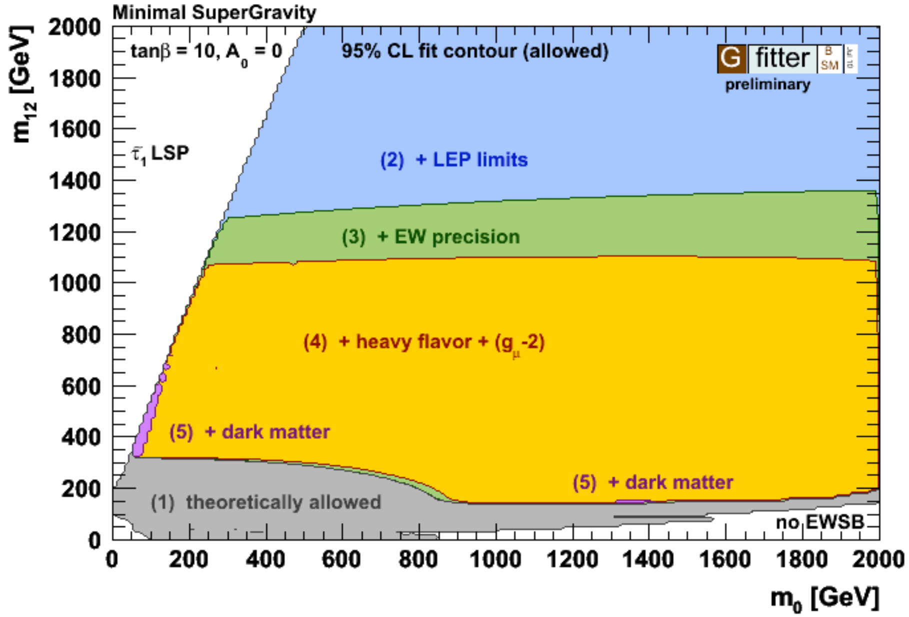
mSUGRA: Parameter Scans

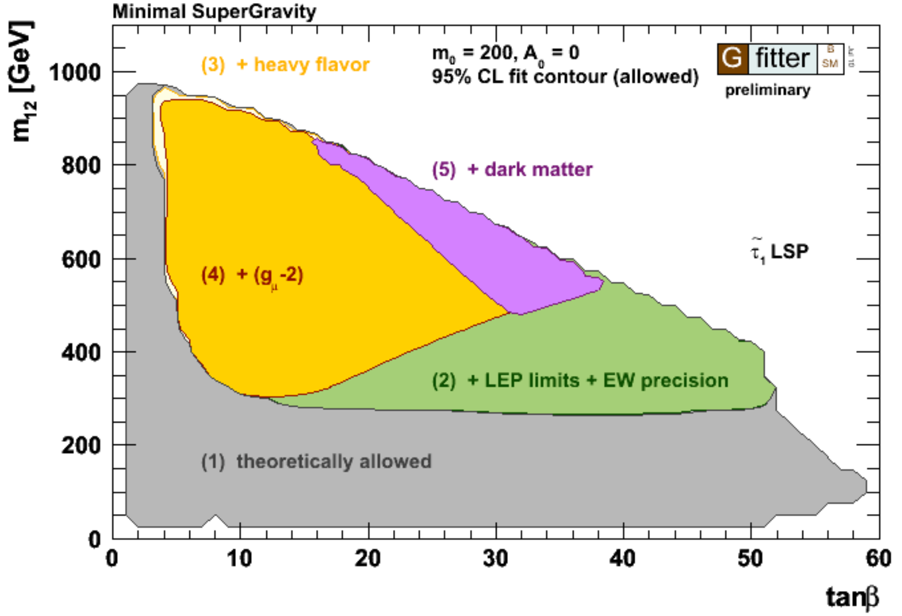
[G. Weiglein: arXiv:hep-ph/9712226v1][S. Heinemeyer, W. Hollik, G. Weiglein: arXiv:hep-ph/0412214v1]

- Low m_0 area excluded by requiring a non-charged LSP.

- Limits on m_0, $m_{1/2}$, $\tan\beta$, A_0 by including in the fit:
  1. Theoretically allowed region
  2. LEP limits in Higgs mass, neutralinos, sleptons
  3. Electroweak precision observables (STU)
  4. Constraints from K-, B-physics and $(g_\mu\text{-}2)$
  5. From the relic density

- 95% CL contours of allowed regions are shown





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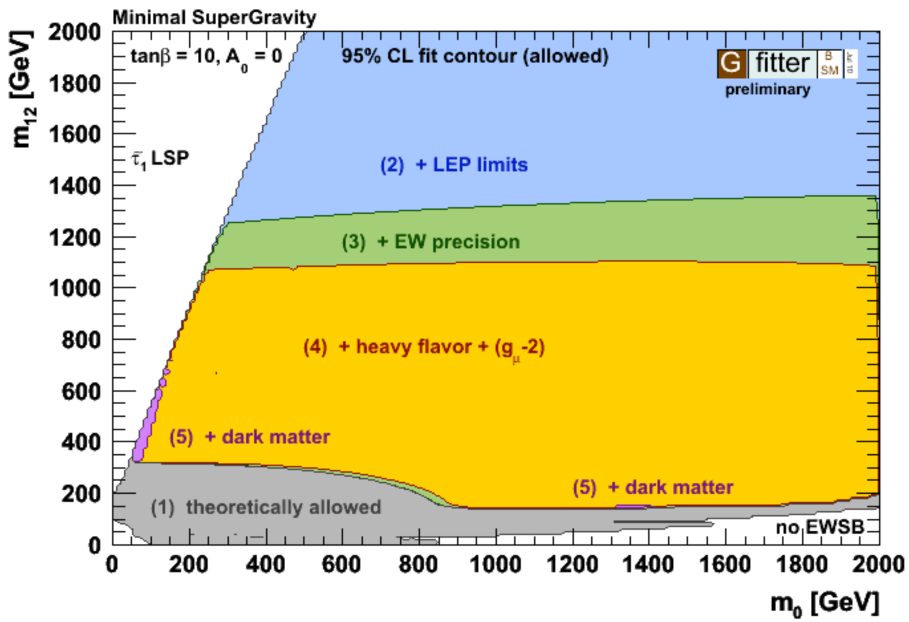
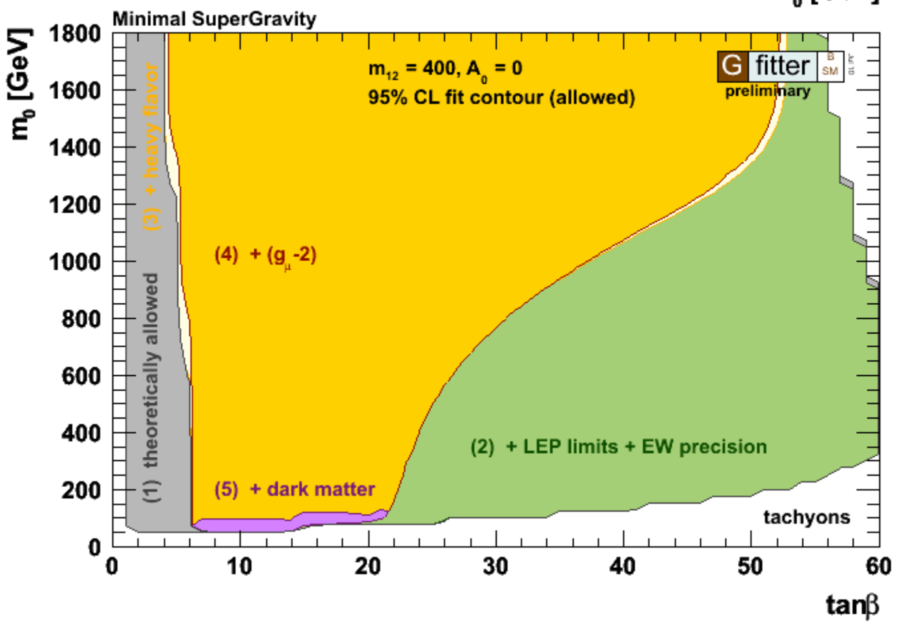




mSUGRA: Fit Strategy

- No fit results shown here yet – still preliminary ;-)
  - Results sofar consistent with MasterCode and Fittino groups.
- Main challenge: finding global mSUGRA minimum in constrained fits
  - Eg. LSP mass-scan: χ^2_{min} when predicted M_{LSP} = 150 GeV?
- Solution: "brute force" fit strategy
  - 1 Fit takes ~15 mins
    - O(1000) Minuit iterations, dominated by calc. of SUSY particle spectrum
  - Parameter scans fully parallelized
- Need lots of computing power …

"brute force" fit strategy:

1 Fit, defined as:

Prefits
- ✧Performed X times (eg. 40)
- ✧Randomized starting values
- ✧Simplex fit → fast

Follow-up fit
- ✧Performed once
- ✧Starting values: best prefit
- ✧Migrad fit → detailed, slow

Fit repeated until global minimum confirmed N times

Two Higgs Doublet Model

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

- 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/tanβ, right-handed coupling: tanβ
- Sensitive parameters → $M_{H\pm}$, tanβ
- LEP limit: $M_{H\pm}$>78.6 GeV (95%CL), for any value of tanβ

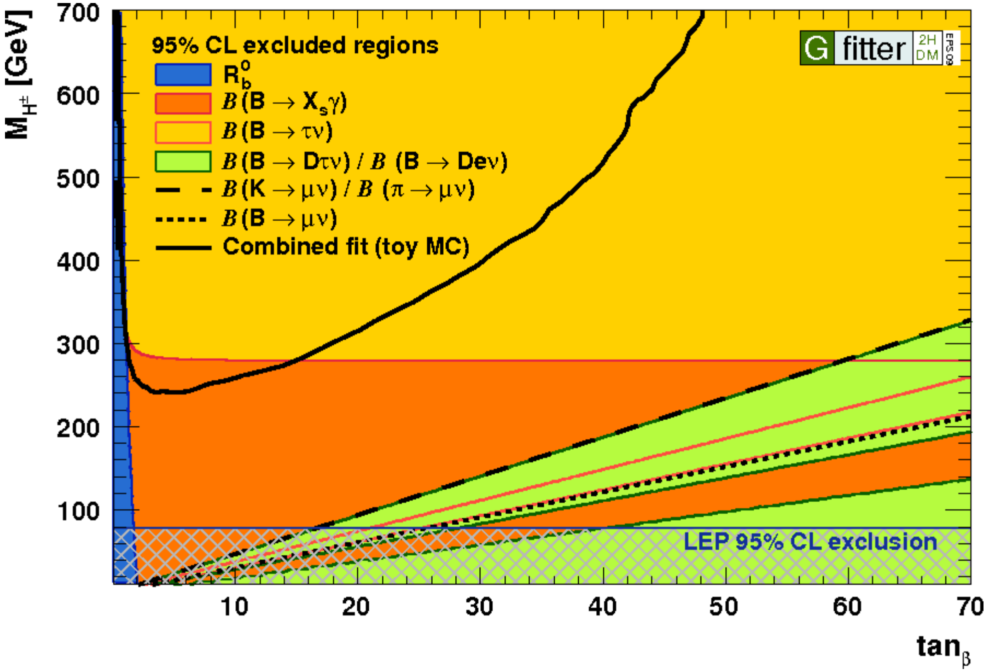
- Measurements of interest from B-physics

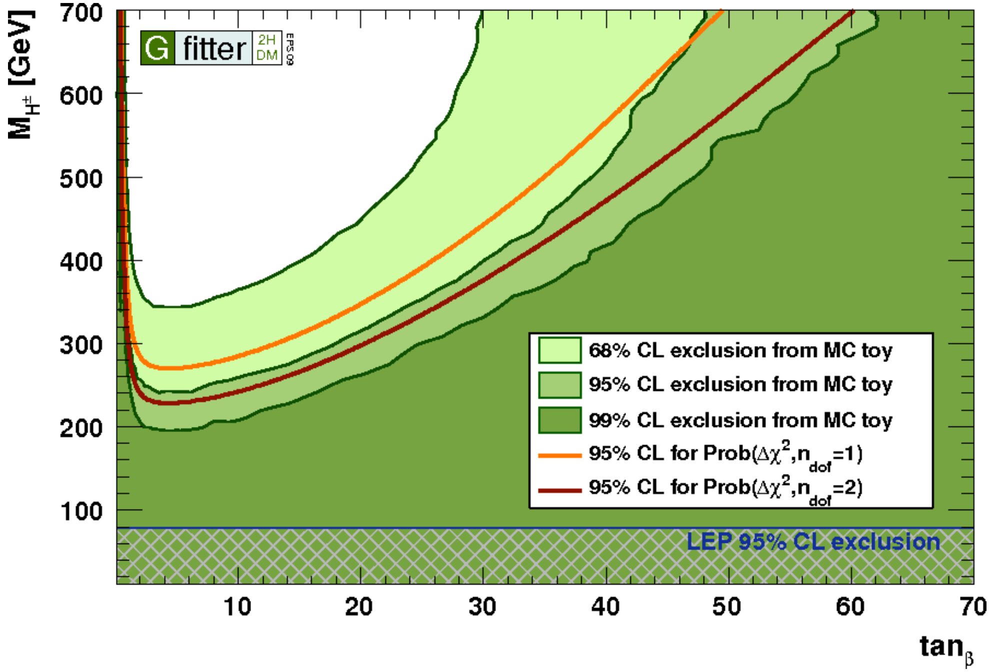
Observable	Input value	Exp. Ref.	Calculation
R_b^0	0.21629 ± 0.00066	[ADLO, Phys. Rept. 427, 257 (2006)]	[H. E. Haber and H. E. Logan, Phys. Rev. D62, 015011 (2000)]
BR ($B \to X_s\gamma$)	$(3.52\pm0.23\pm0.09)\cdot10^{-4}$	[HFAG, latest update]	[M. Misiak et al., Phys. Rev. Lett. 98, 022002 (2007)]
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]

2HDM: Combined Fit

- Below: overlay of individual 95% CL excluded regions
- Combined exclusion area depends on assumption on number of dof.
  - ndof=1 : where single constraint dominates.
  - ndof=2 : several observables contribute.
- MC toy study to resolve exclusion area
  - Assuming n_{dof}=1 and 2-sided limits

- Combined limit not necessarily stronger than single constraint due to increasing n_{dof}
- Fit minimum: χ^2=3.9 for M_H=858 GeV and tanβ=6.8
- Excluded at 95% CL
  - Small tanβ
  - M_H < 240 GeV for all tanβ
  - M_H < 780 GeV for tanβ=70





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 obtained sofar
  - New and updated global fit of the electroweak SM
    - Higgs mass strongly constrained. Light Higgs preferred by SM.
  - Oblique parameters (still!) a powerful method to constrain BSM theories
    - Presented constraints on various BSM theories
    - Heavy Higgs boson allowed in various BSM models
  - Constraints on the Two-Higgs-Doublet-Model

- The future
  - Maintain and extend existing fits.
    - Tevatron updates and of course LHC results
  - More models in preparation for oblique parameters fit (STU)
  - Expect SUSY fit results to come out soon!

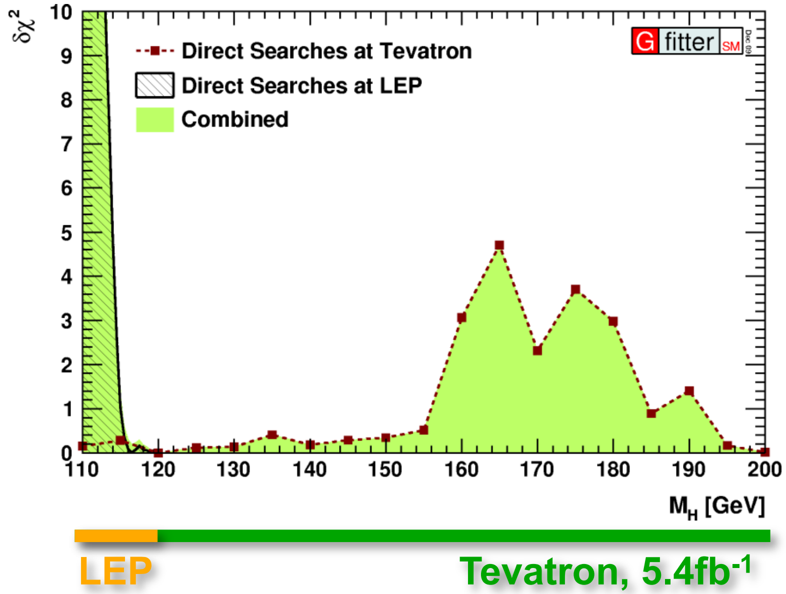
G fitter

A Generic Fitter Project for HEP Model Testing

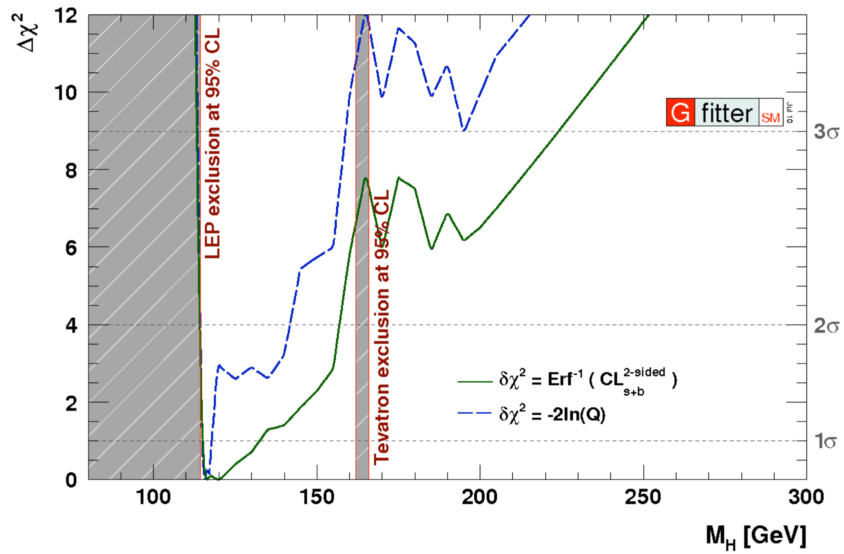
Backup

Statistical interpretation Higgs limits

- Stat. interpretation in global fit: 2-sided CL_{S+B}
  - Experiments measure test statistics: *LLR = -2lnQ*, where $Q=L_{S+B}/L_B$
  - *LLR* is transformed by experiments into one-sided CL_{S+B} using toy-MC experiments
    - Sensitive to too few Higgs-like events
  - We transform 1-sided CL_{S+B} into 2-sided CL^{2s}_{S+B}
    - We measure deviations from the SM.
    - Eg. also interested in too many Higgs-like events.
  - χ^2 contribution calculated via inverse error function, assuming symmetric pdf : $\delta\chi^2=Erf^{-1}(1-CL^{2s}_{S+B})$

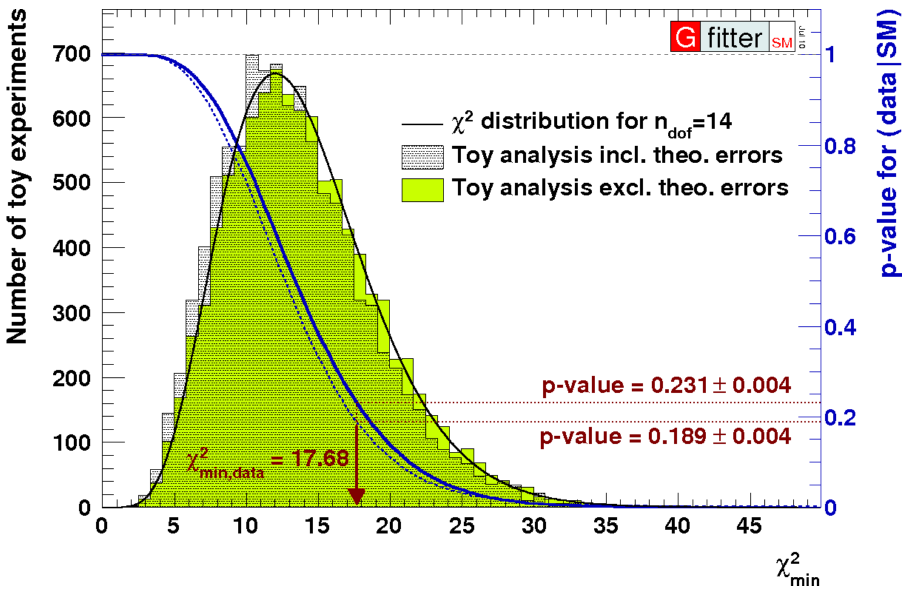


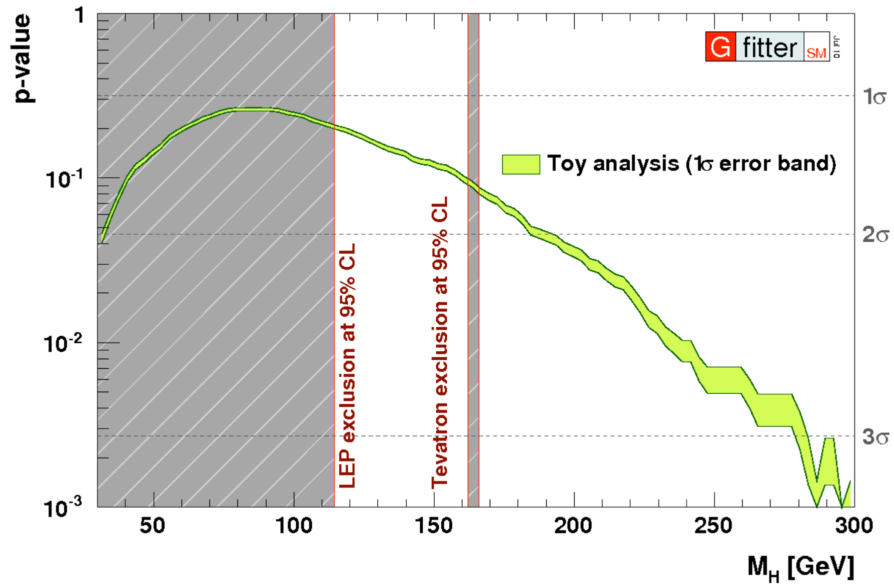
- Alternative treatments (thanks to fruitful discussion with Tevatron people):
  - Use one-sided CL_{S+B}: however, different interpretation – want SM Higgs (not any Higgs)
  - Directly use $\delta\chi^2 \approx$ LLR: Bayesian interpretation, lacks pseudo-MC information



Goodness of Global Fit

- determine p-value by using MC toy experiments
  - p-value: probability for wrongly rejecting the SM
  - p-value: probability for getting a $\chi^2_{min,toy}$ larger than the $\chi^2_{min,data}$ from data





- for each toy complete fit is performed
- p-value = $(23\pm1_{-2})$%
  - no significant requirement for new physics

- derivation of p-value for standard fit as function of M_H
- small p-values for large Higgs masses (M_H~280 GeV)

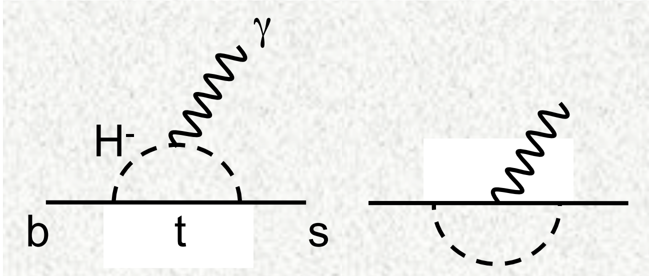
- usually unable to indicate signals for physics beyond SM
  - sensitive observables mixed with insensitive ones

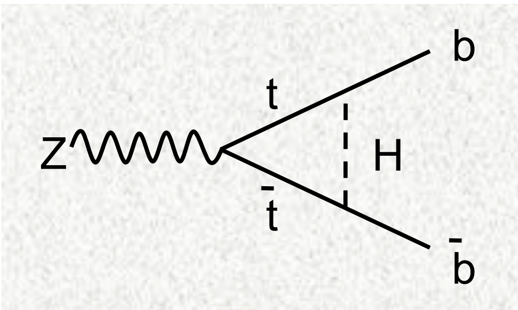
$b \to s\gamma$ and R^0_b

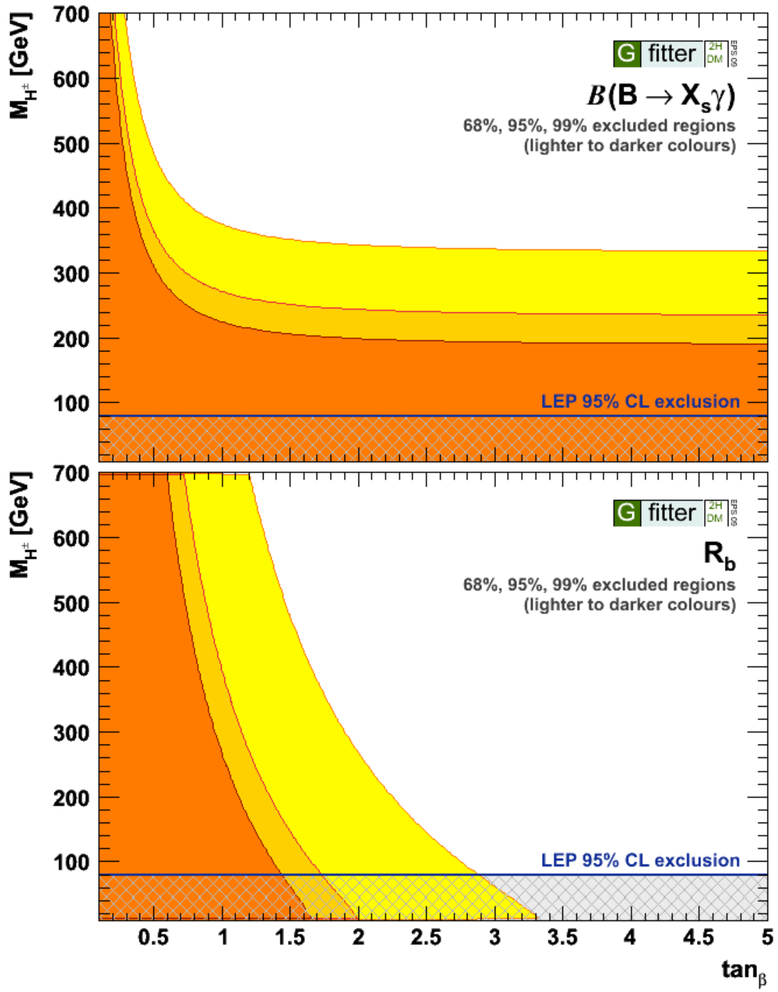
- Penguin dipole-moment of $b \to s\gamma$ allows combination of left- and right-handed Higgs couplings.
- Wilson coefficient:

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

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





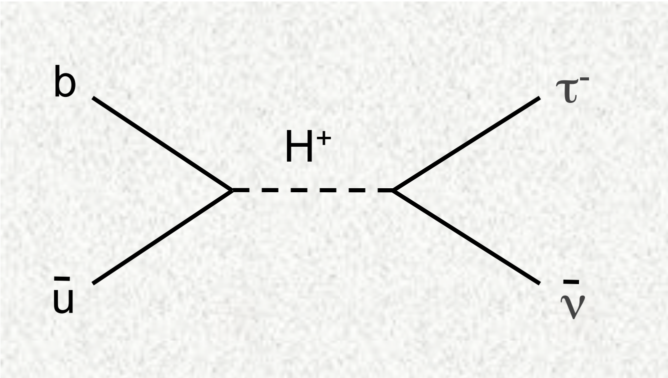


- Z vertex contribution suppressed by $1/\tan^2\beta$
- R^0_b sensitive to small $\tan\beta$ only

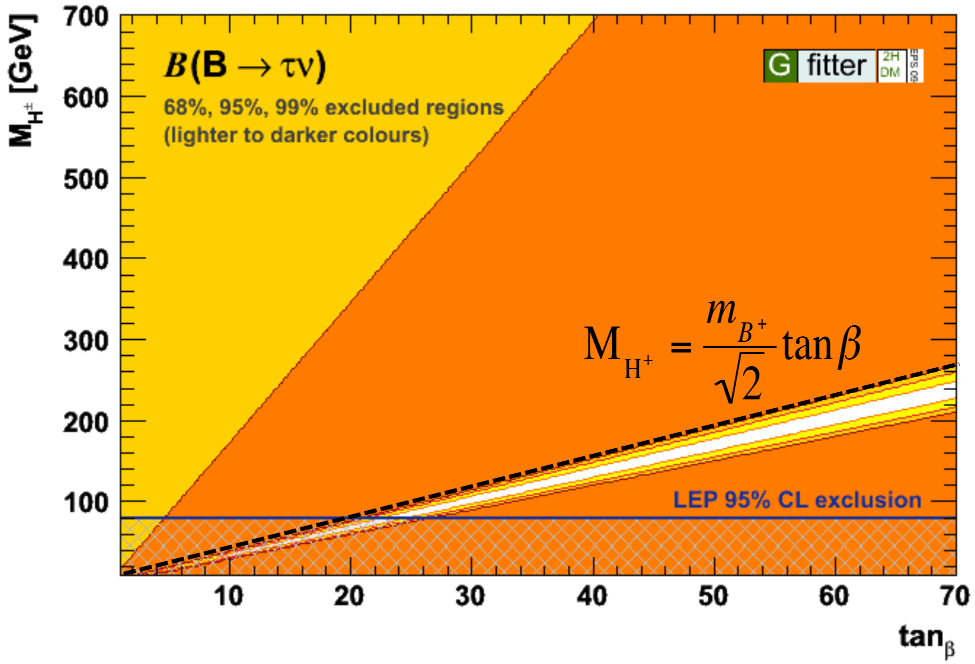
Strongest constraint: B → τν

(BRx10^{-4})	Oct '08	EPS '09	Reference
BR(B->τν)$_{meas}$	1.51 ± 0.33	1.73 ± 0.35	FPCP 2009
BR(B->τν)$_{SM}$	1.53 ± 0.49	1.12 ± 0.25	(Vub direct-measurements.)
V_{ub} (x10^{-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->τν)$_{CKM}$	$0.83^{+0.27}_{-0.10}$	$0.80^{+0.15}_{-0.09}$	CKM Fitter '09, indirect Vub

- We use prediction based on direct measurements of V_{ub}.
- [2.4σ deviation between measurement and CKM-fitter prediction for BR(B->τν)]

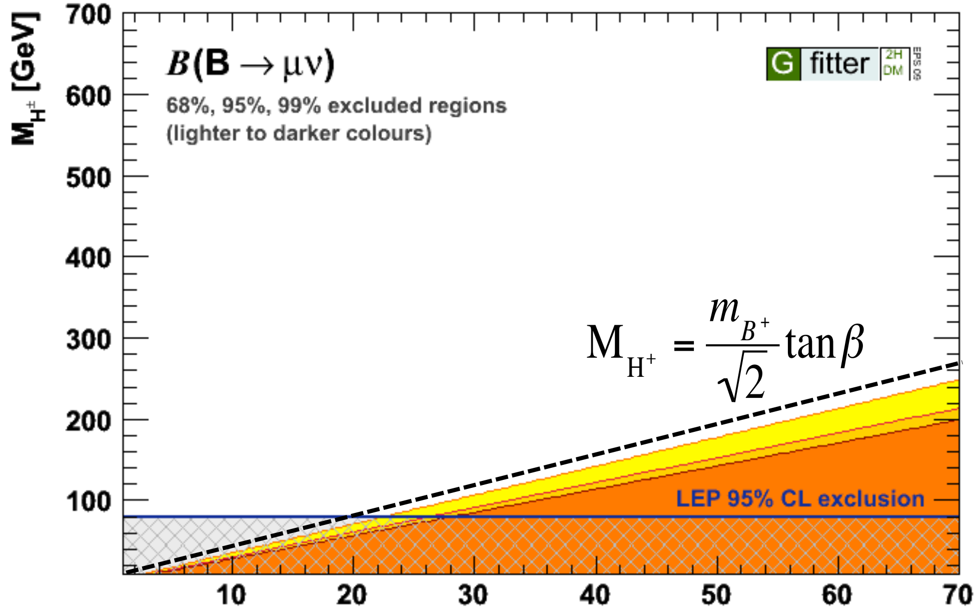


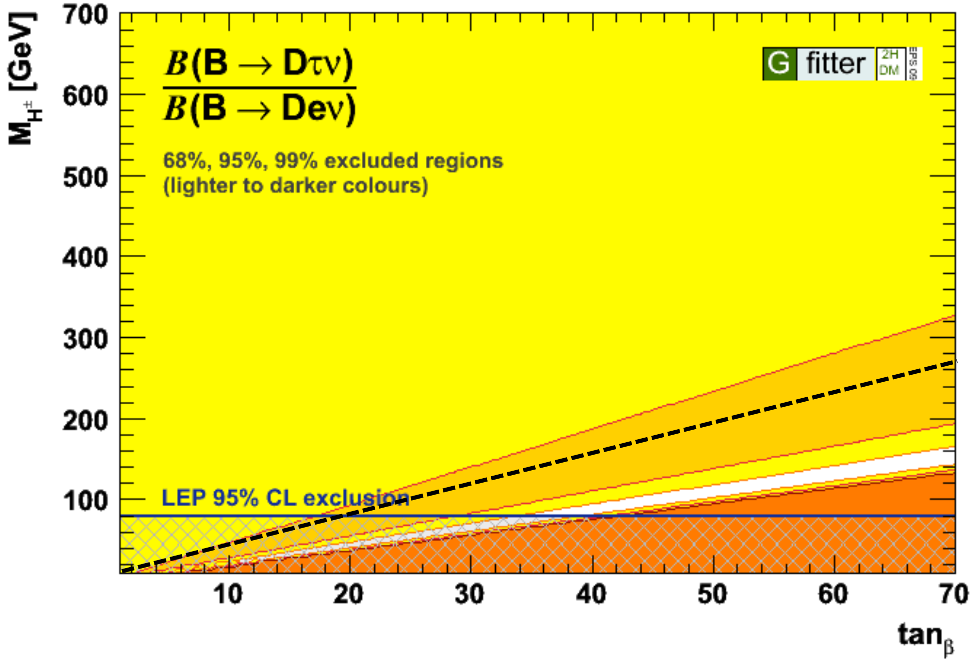
$$\frac{BR(B\to\tau\nu)_{2HDM}}{BR(B\to\tau\nu)_{SM}} = \left[1 - m_B^2\frac{\tan^2\beta}{M_{H^\pm}^2}\right]^2$$

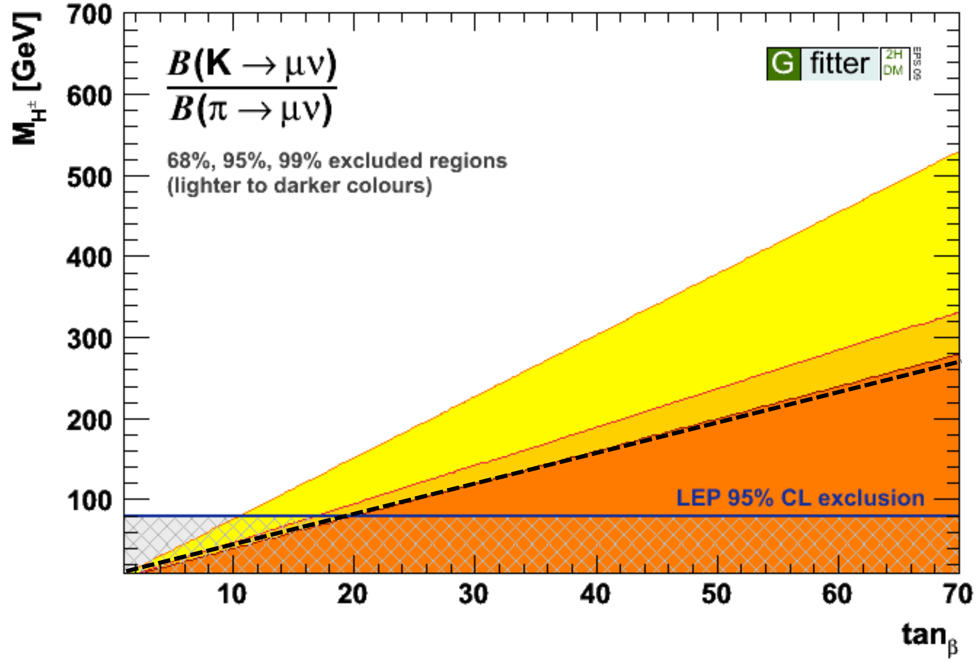


Other measurements w/ tree-level contributions

- Weak upper-limit on BR(B->μν)
- Favored solution of BR(B->τν) excluded by combination of:
  - B→X_sγ
  - BR(K->μν) / BR(π->μν)
  - BR(B->Dτν) / BR(B->Deν)



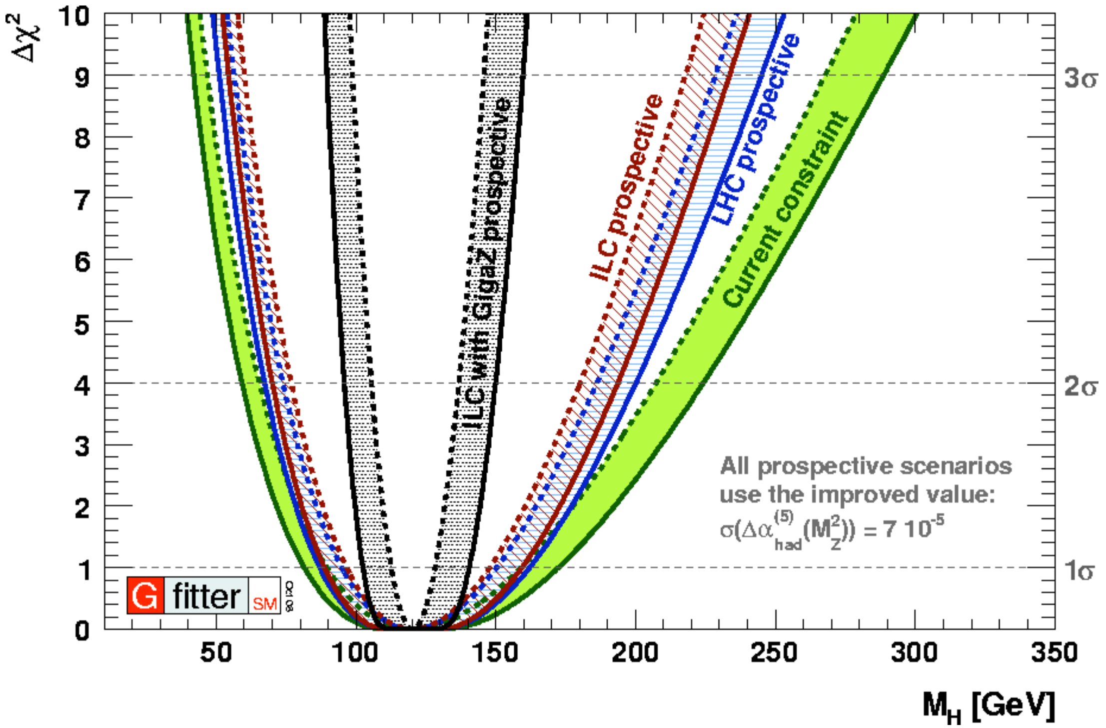




Prospects for LHC and ILC

- 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]

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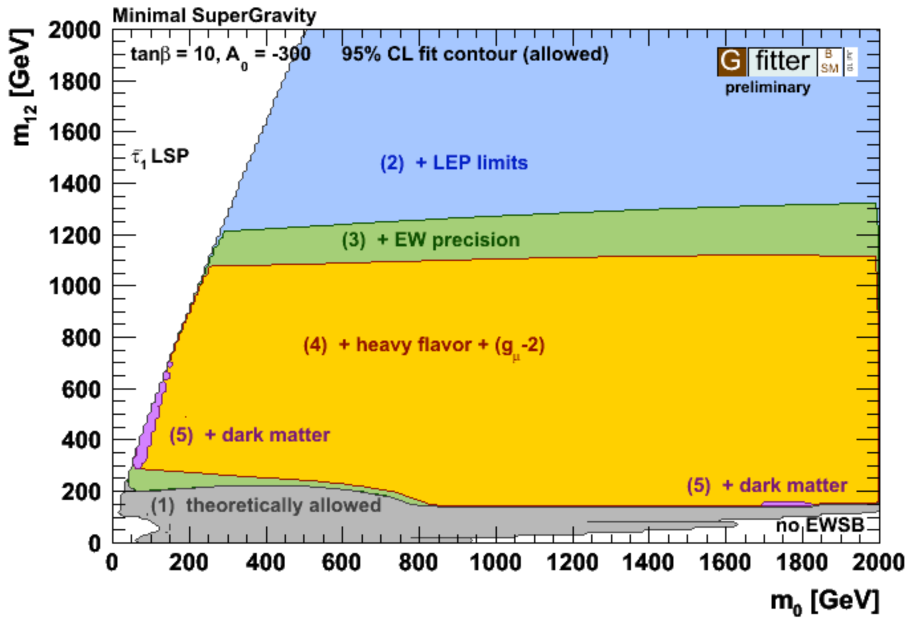

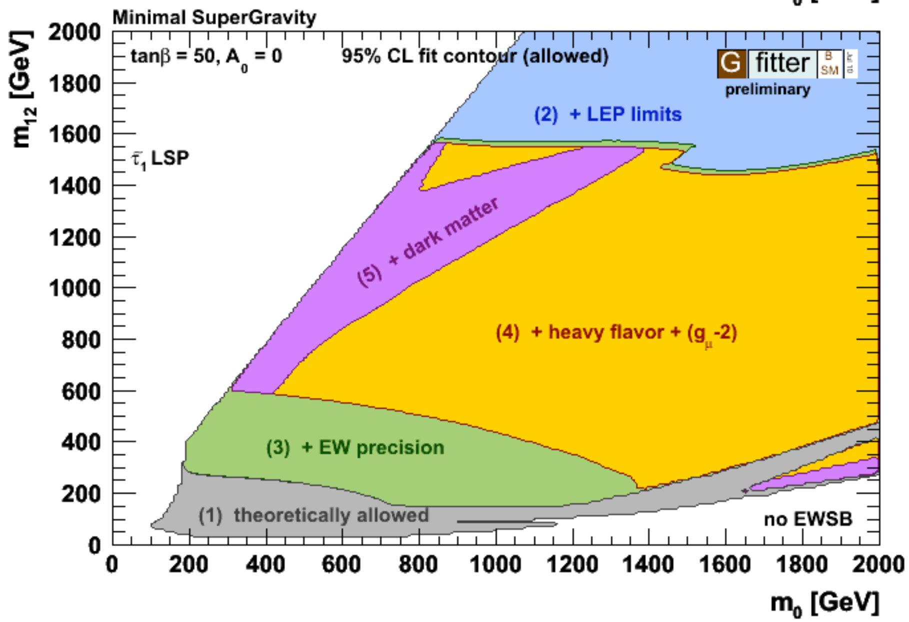

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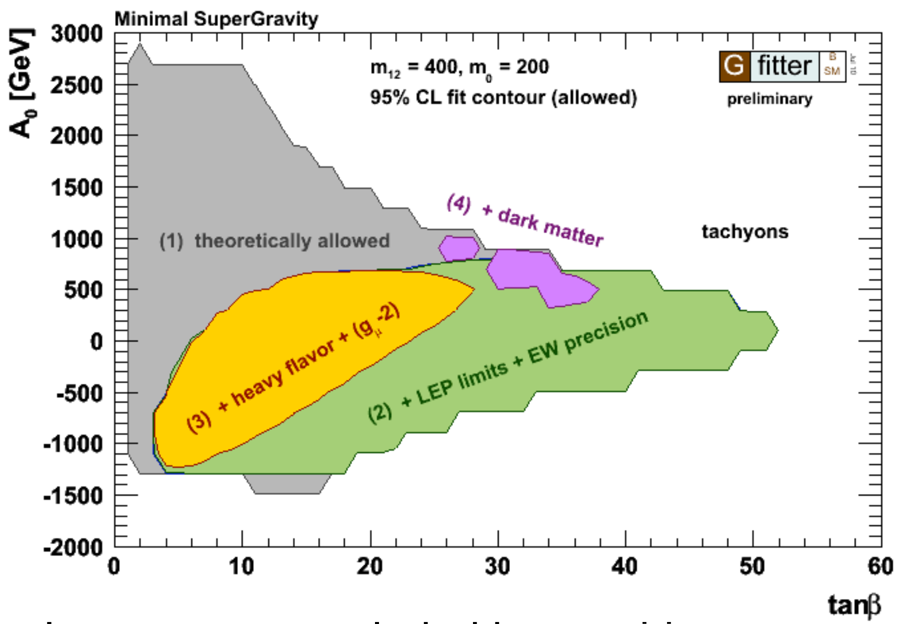

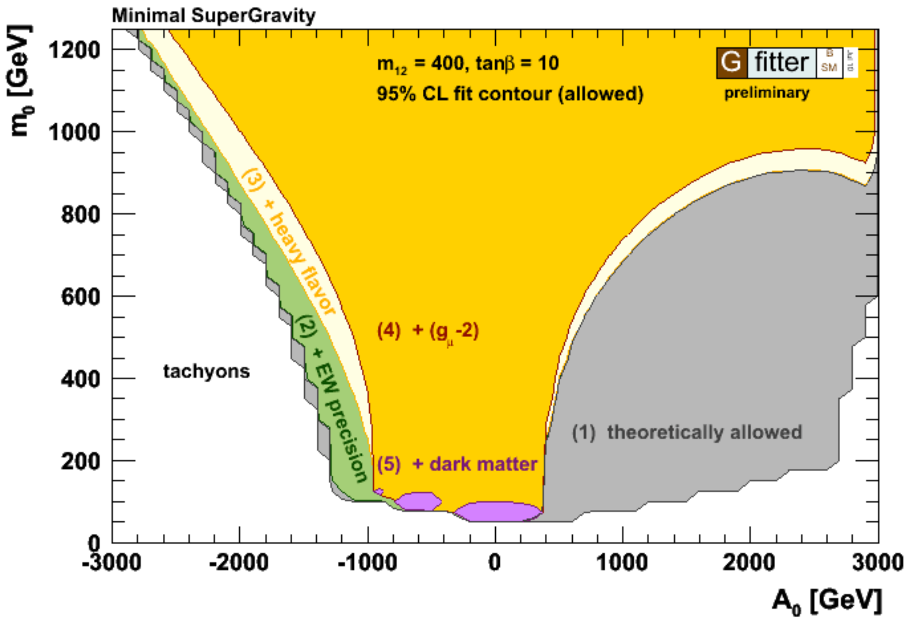

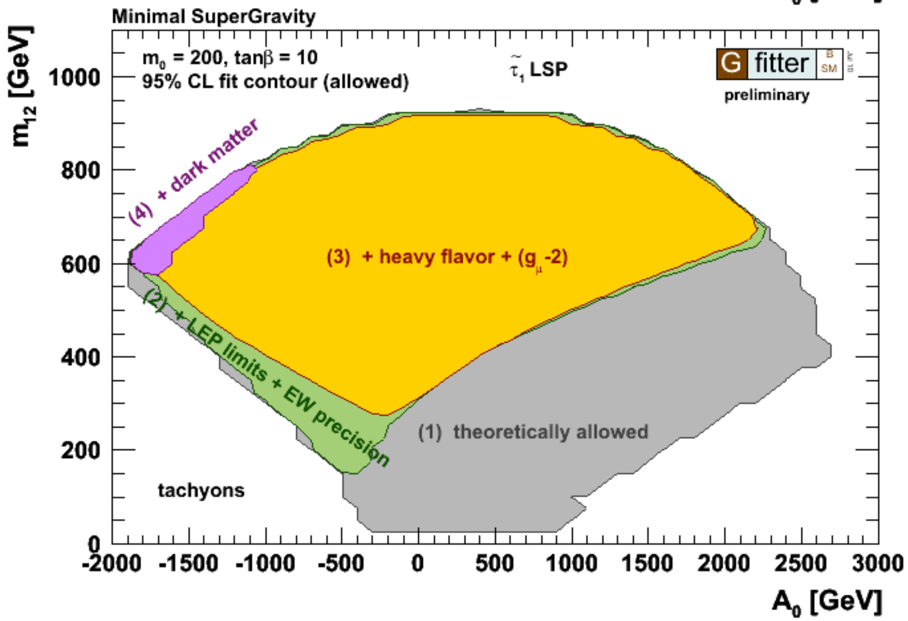

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Electroweak Fit – Latest Experimental Input

- Z-pole observables: results from LEP / SLC
  [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
- M_W and Γ_W from LEP/Tevatron [ADLO,CFD+D0: arXiv:0908.1374v1]
- m_{top} latest Tevatron average [CDF&D0: new combination ICHEP'10]
- $\overline{m}_c$, $\overline{m}_b$ world averages [PDG, J. Phys. G33,1 (2006)]
- $\Delta\alpha_{had}^{(5)}(M_Z^2)$ including α_S dependency
  [Hagiwara et al., PLB649,173,'07]
- Direct Higgs searches from LEP/Tevatron
  [ADLO: Phys. Lett. B565, 61 (2003)], [CDF+D0: arXiv:0911.3930]
  - LEP: Higgs strahlung (ee → ZH, H→bb, ττ)
  - Tevatron: gg fusion w/ H → WW, ass. prod., VBF
  - Stat. interpretation in global fit: 2-sided CL_{S+B}

- 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)

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 $^{(\star)}$	0.1499 ± 0.0018	LEP / 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	LEP / SLC
R^0_b	0.21629 ± 0.00066	LEP / SLC
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	LEP
M_H [GeV] $^{(\circ)}$	Likelihood ratios	LEP & Tevatron
M_W [GeV]	80.399 ± 0.023	LEP & Tevatron
Γ_W [GeV]	2.098 ± 0.048	LEP & Tevatron
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	
m_t [GeV]	173.3 ± 1.1	Tevatron
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2769 ± 22	
$\alpha_s(M_Z^2)$	$-$	