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Gfitter

Update of the Global Electroweak Fit

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on behalf of the Gfitter collaboration

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Introduction

The electroweak fit combines:

- Measurements of SM observables
- Theoretical relation of observables

$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} \qquad \frac{\mathrm{Re}(g_{V,f})}{\mathrm{Re}(g_{A,f})} = 1 - 4|Q_f|\sin^2\theta_{\mathrm{eff}}^f$$

$$M_W^2 \sin^2\theta_W = \frac{\pi\alpha}{\sqrt{2}\,G_F}$$

→ Consistency check of SM with high precision

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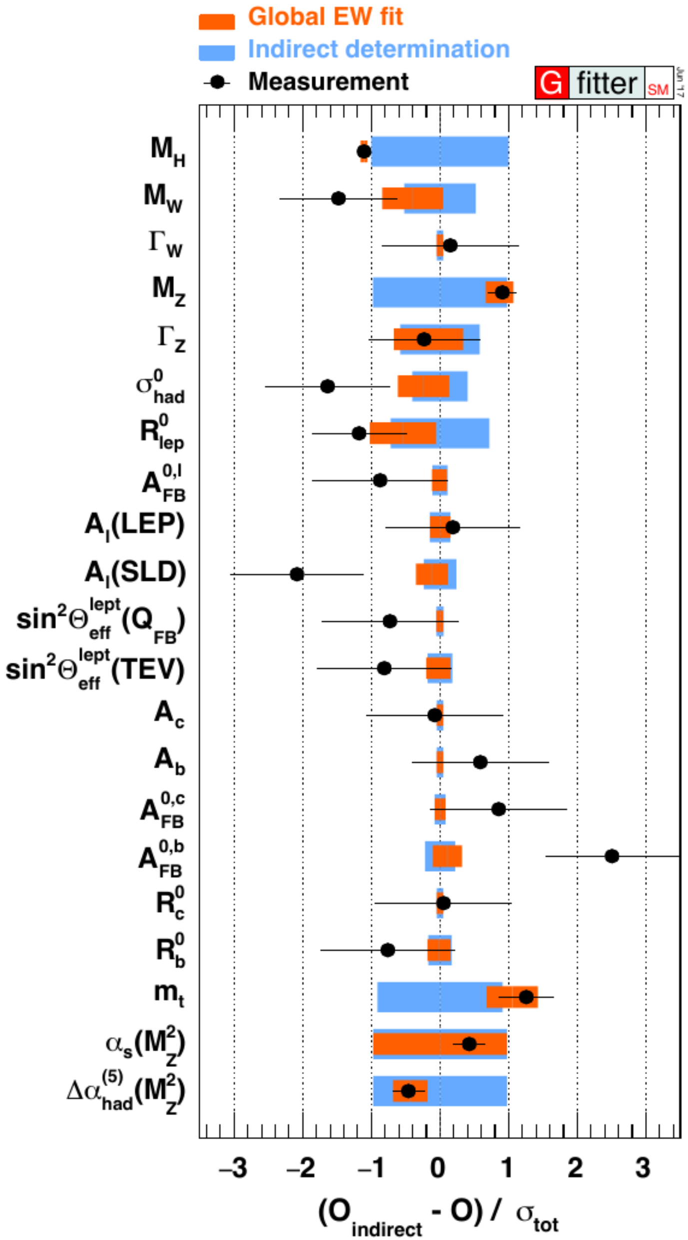
→ Consistency check of SM with high precision

New input:

- ATLAS W mass: M_W = 80370 ± 19 MeV (arXiv:1701.07240)
- Tevatron electroweak mixing angle: $\sin^2\theta_{eff}^{lep}$ = 0.23179±0.00035 (FERMILAB-CONF-16-295-E)
- New top mass measurements from LHC and Tevatron

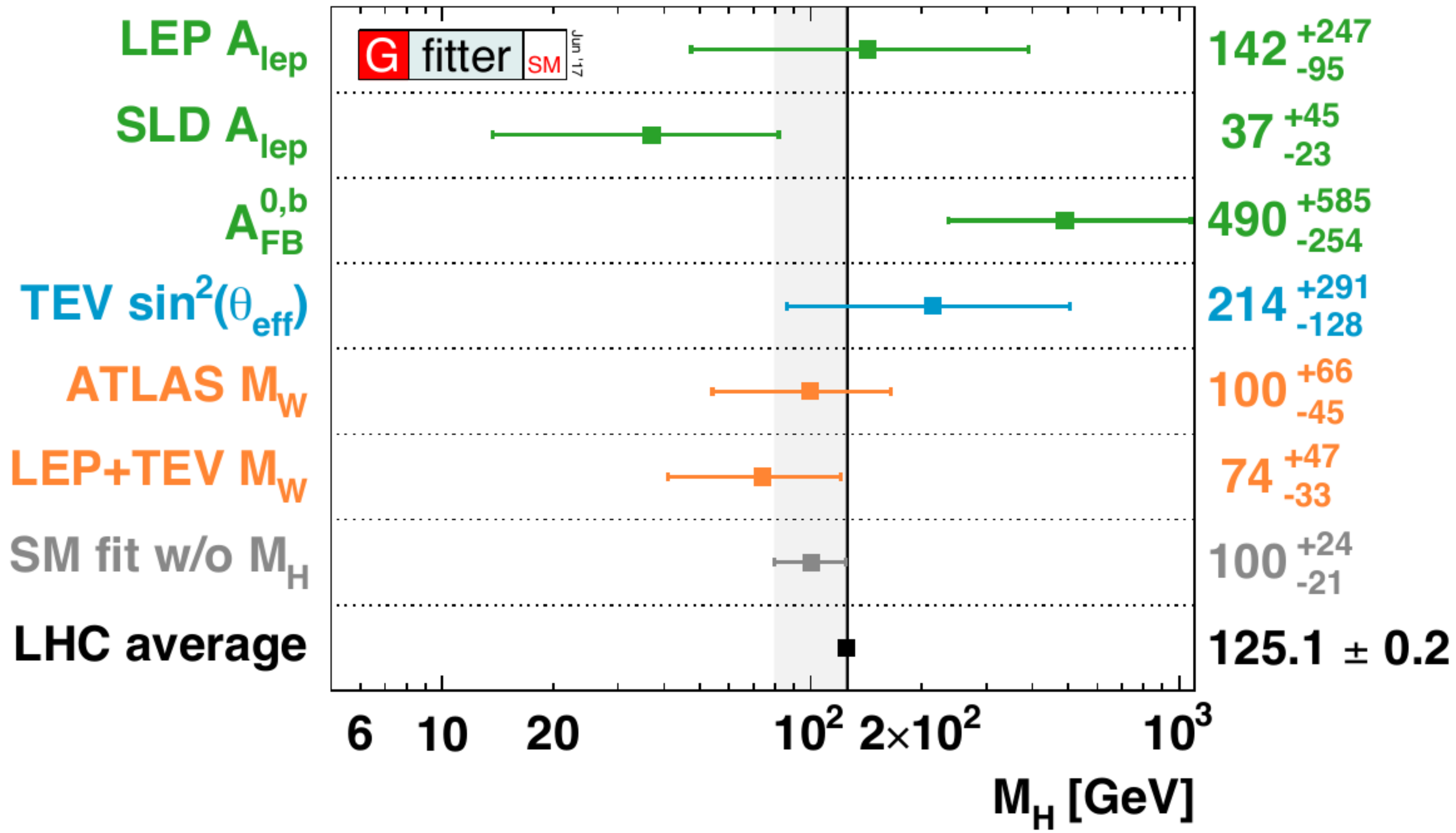
Results



- Global χ^2=18.15 (for ndof = 15), p-value=0.25
- Predictions consistent with measurements
- Largest deviation for $A_{FB}^{0,b}$ ~ 2.5σ

Higgs Mass

Indirect Higgs mass determination from single observables



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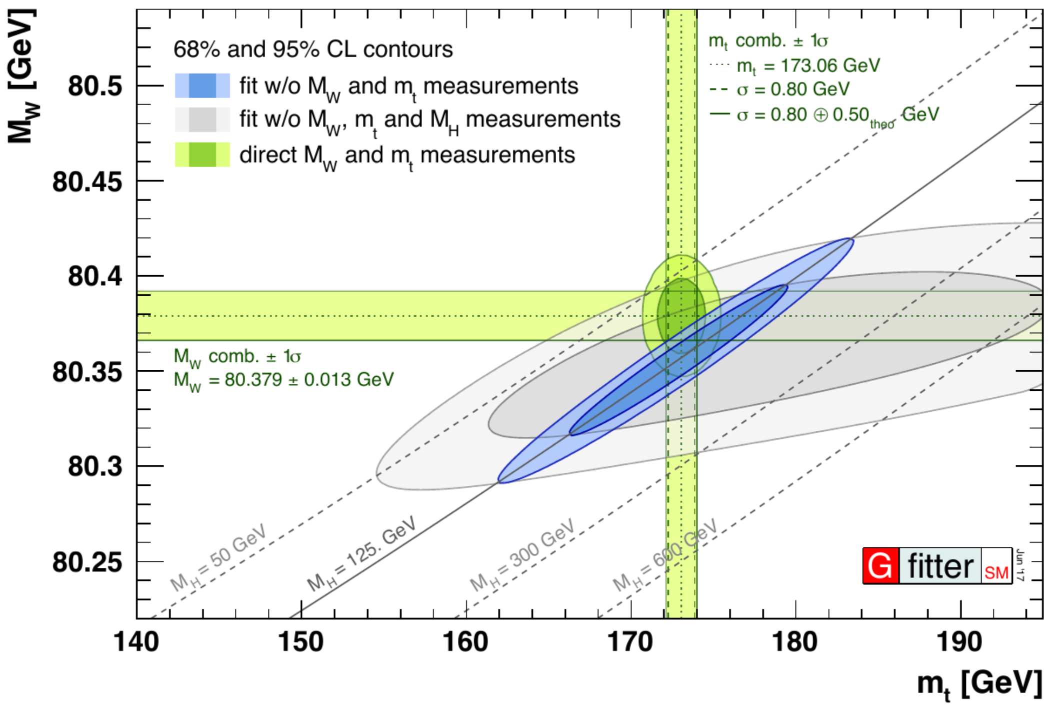
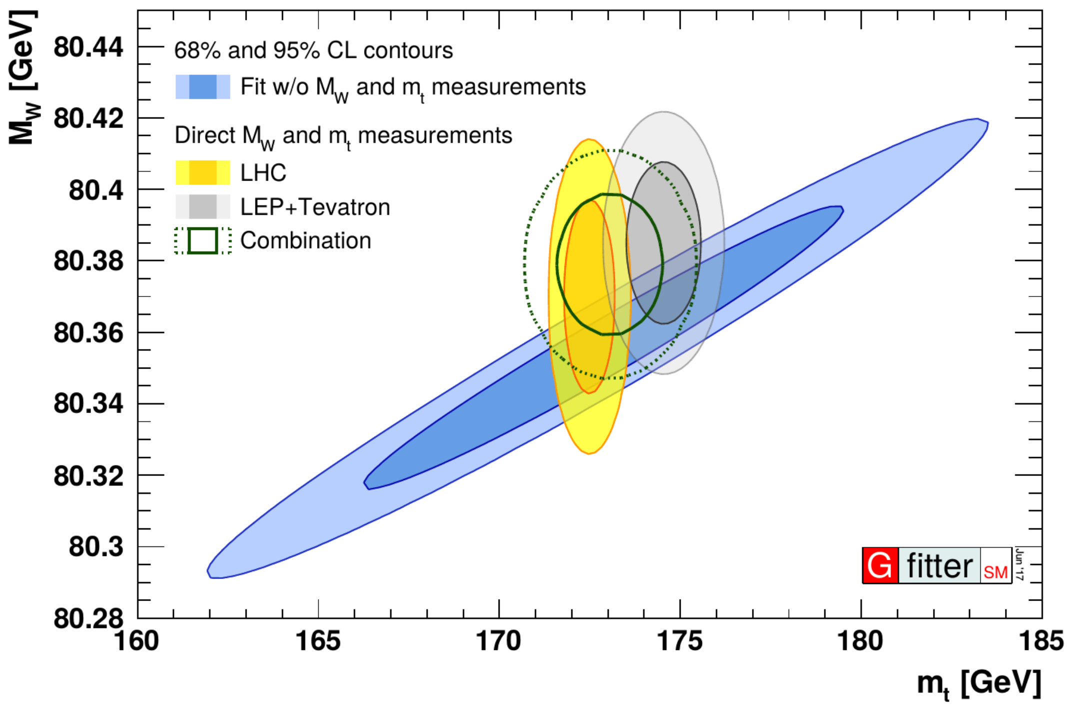
2D Mass Scans

- Scan of M_W and M_t
- Determine χ^2 for each point in 2D space
- Individual top and W mass combinations for LHC and Tevatron
- Full combination of latest top and W mass measurements (PDG scaling method)





The 2HDM

- Simple extension of the SM Higgs sector

$$\phi = \begin{pmatrix} a+ib \\ c+id \end{pmatrix} \qquad \phi_1 = \begin{pmatrix} a+ib \\ c+id \end{pmatrix}, \phi_2 = \begin{pmatrix} e+if \\ g+ih \end{pmatrix}$$

SM: 4 degrees of freedom **2HDM**: 8 degrees of freedom

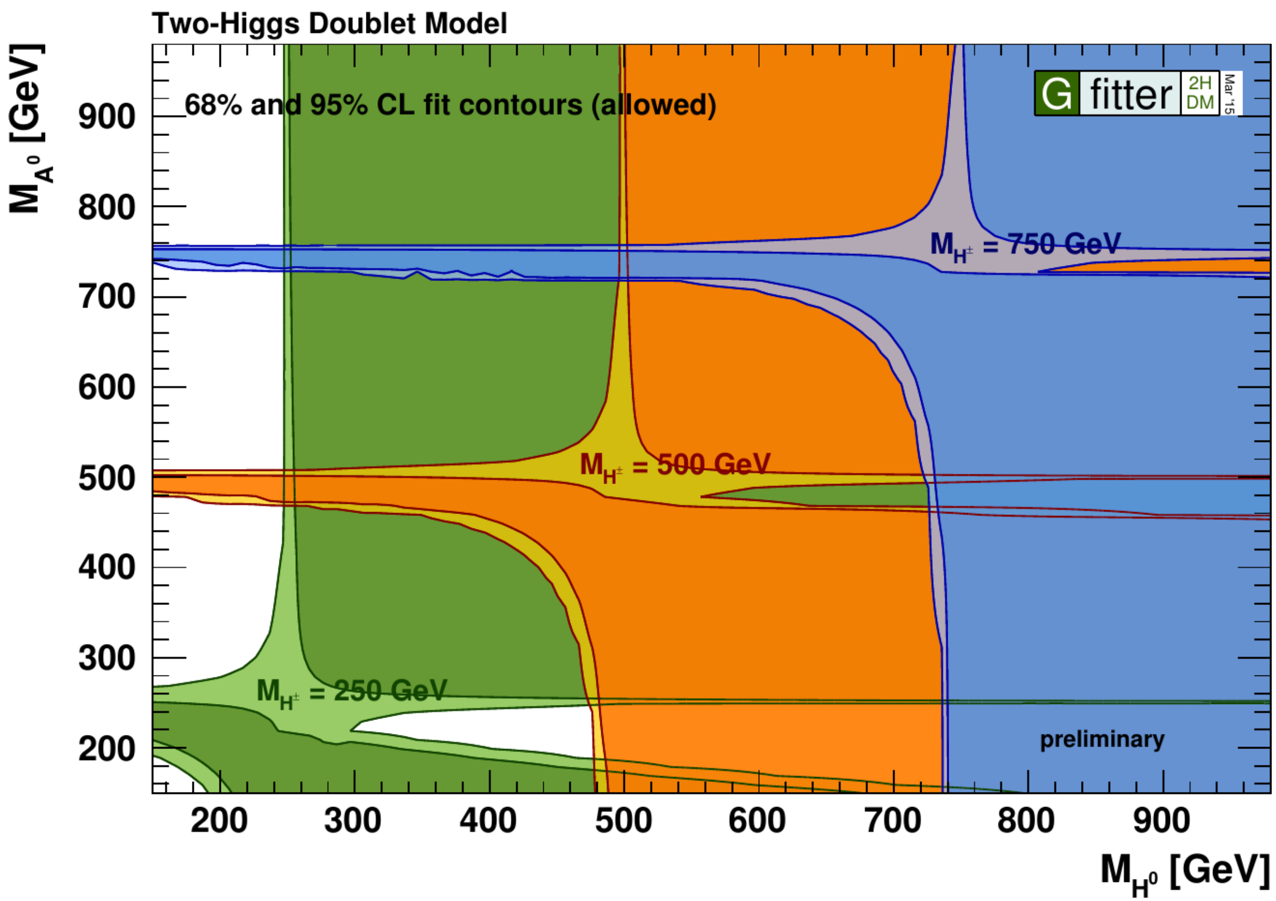
3 degrees "eaten" by W and Z boson masses

→ 1 observable Higgs boson → 5 Higgs bosons h_0, H_0, A_0, H^+, H^-

- Additional free parameters:
  - $\tan\beta = v_2/v_1$
  - α: mixing angle of the neutral Higgs fields
  - M_{12}^2: mass parameter of the mixed term $\Phi_1^\dagger\Phi_2$, soft breaking scale
  - 4 types of Yukawa couplings

EW Constraints

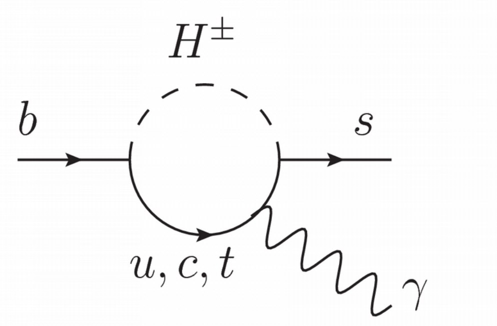
- Use STU formalism to constrain 2HDM
- Assume: discovered 125 GeV Higgs boson is light h_0
- Keep tan β and α free (not constraint by EW data)

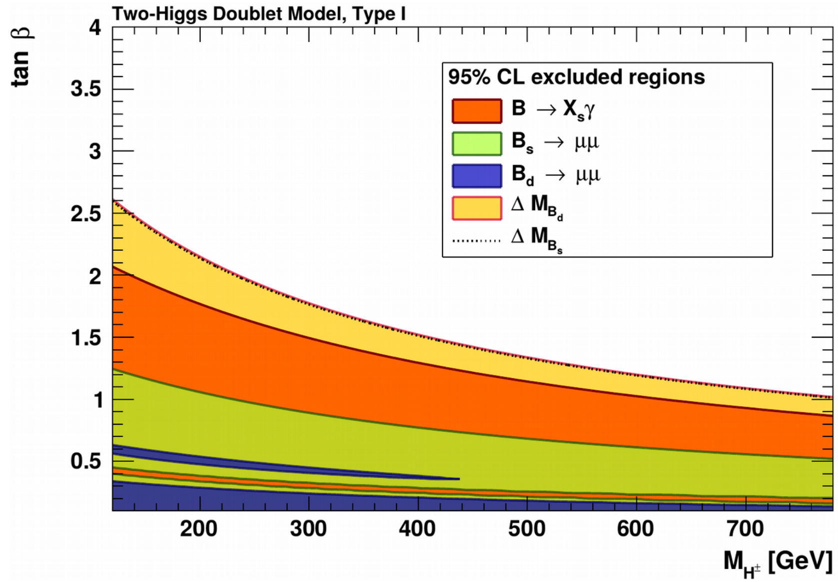


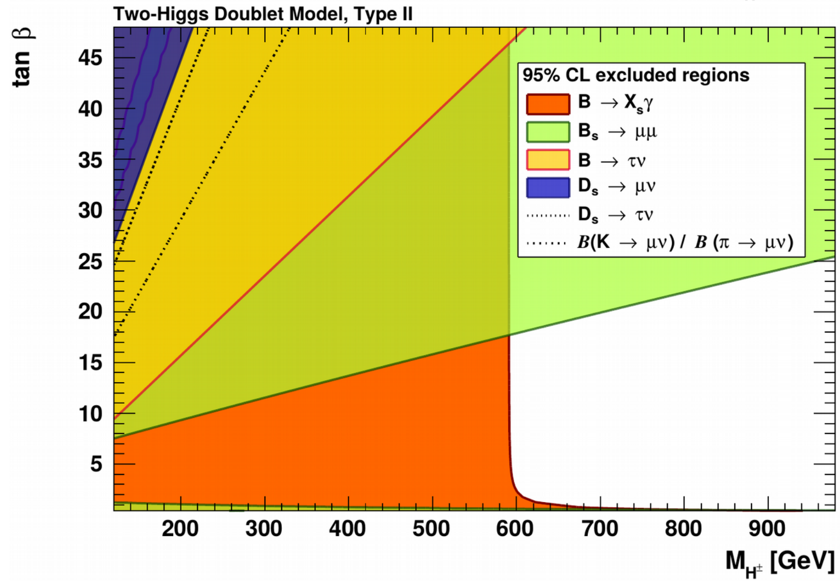
Only weak constraints on masses from electroweak data

Flavor Observables

- Branching fractions of B and D mesons sensitive to H^+ contributions
  - $b \to s\gamma$
  - $B \to \tau\nu$
  - $B_s \to \mu\mu$
  - $B_d \to \mu\mu$
  - $D_s \to \mu\nu$
  - $D_s \to \tau\nu$
  - $BR(K \to \mu\nu)/BR(\pi \to \mu\nu)$
  - B_s mixing parameter $\Delta M(B_s)$
  - B_d mixing parameter $\Delta M(B_d)$
  - Muon g-2







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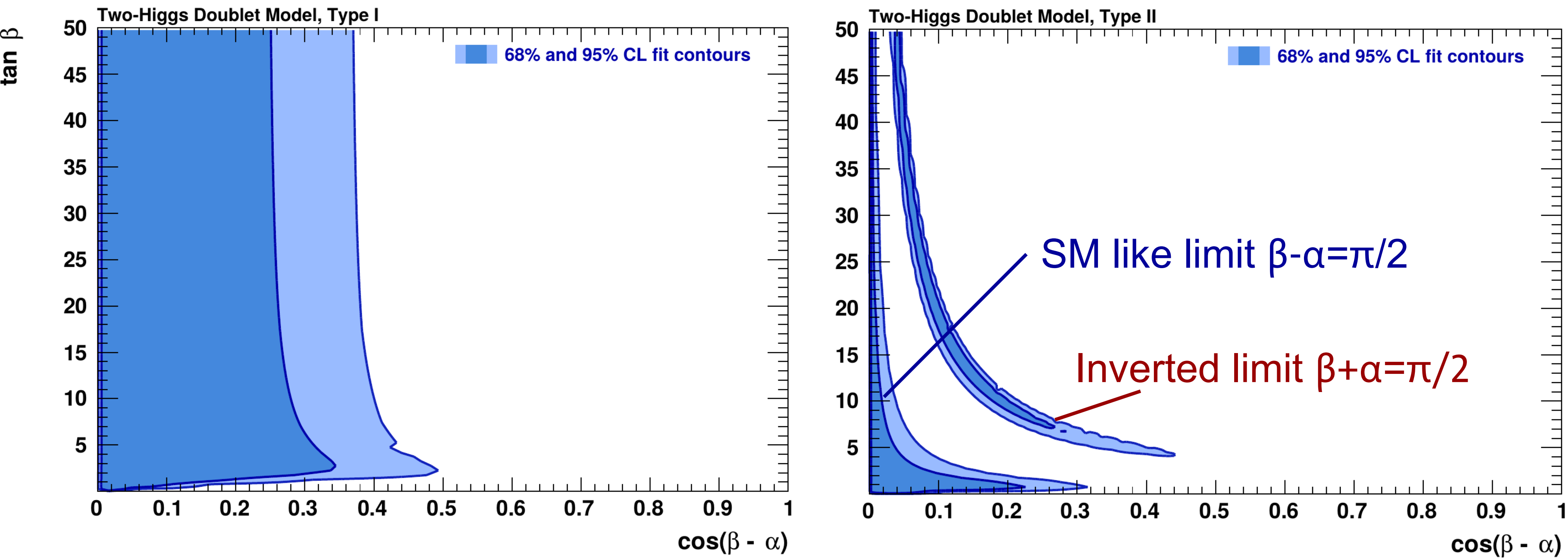
Higgs BRs

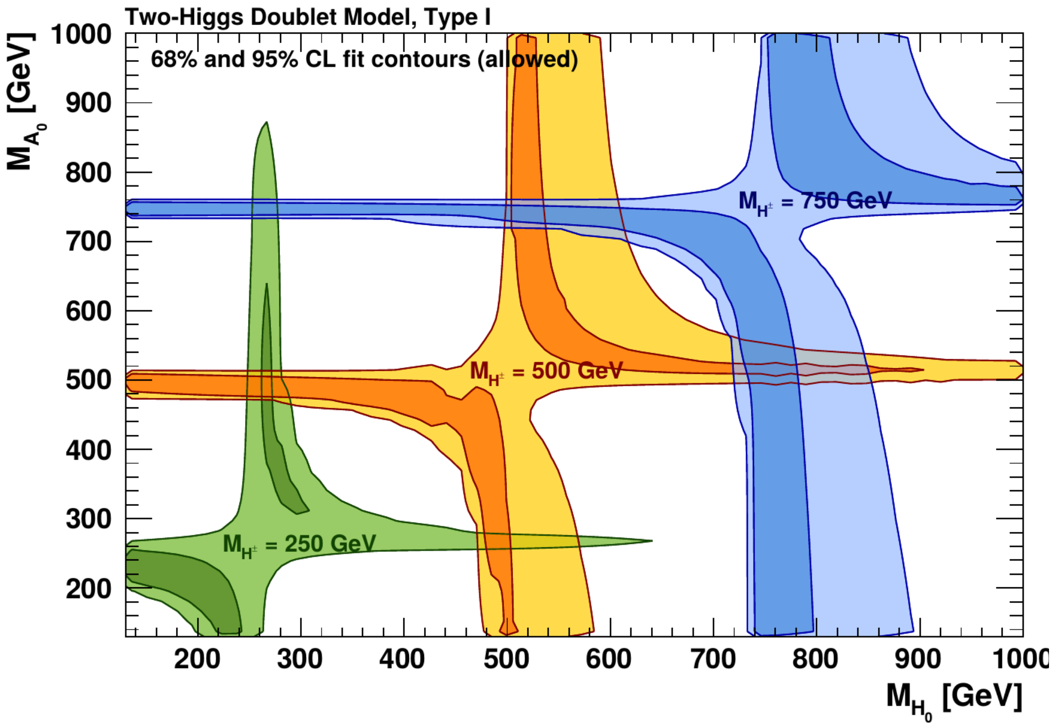
- Higgs branching ratios measured by ATLAS and CMS (J. High Energy Phys. 08 (2016) 045)
- Yukawa couplings would change in case of 2HDM
- Higgs BRs constrain angles α and β

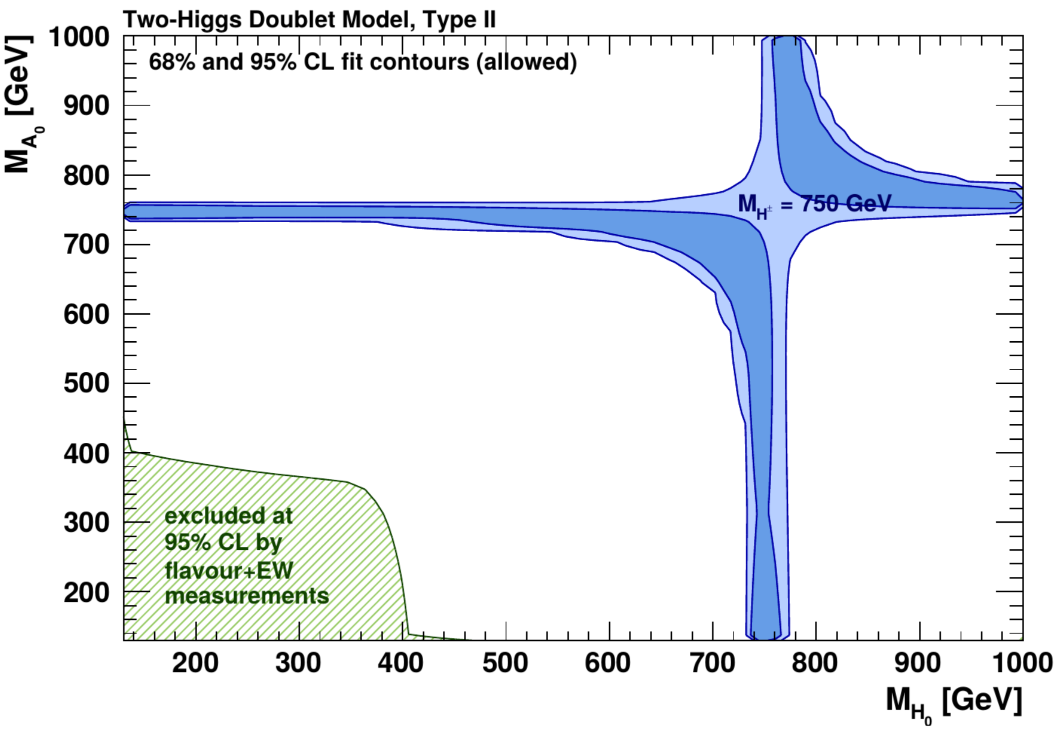


- Similar limits in lepton specific and flipped models as in Type II

Mass limits

- Mass scans with constraints from Higgs BRs, flavor and EW data



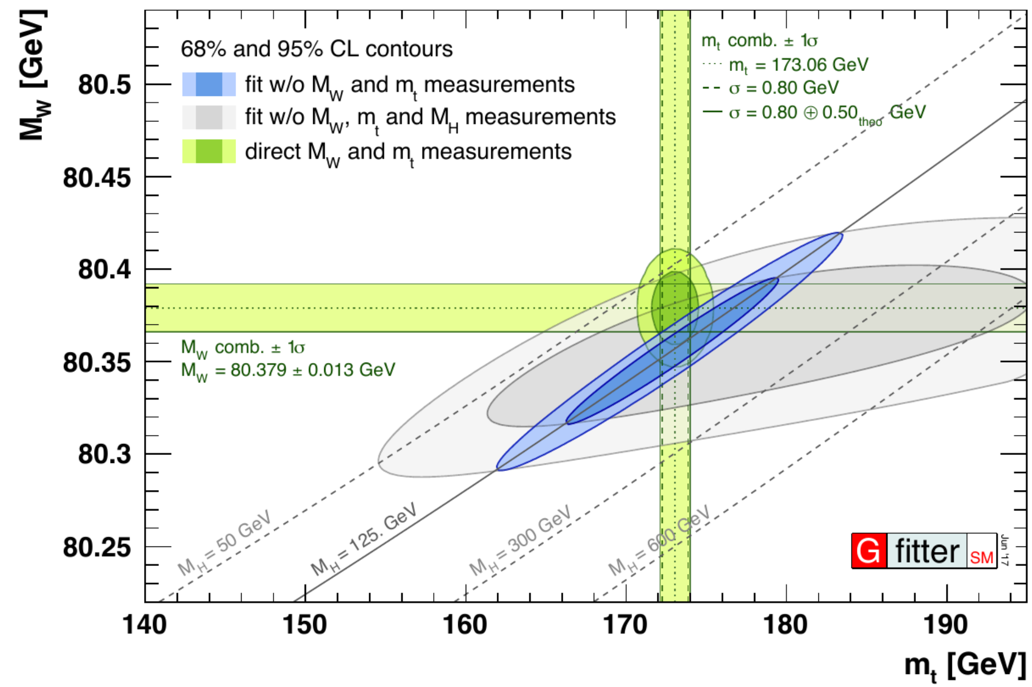


- One neutral Higgs boson mass should be close to M_{H+}
- Limit on M_{H+} from flavor measurements in Type II transferred into limits on neutral Higgs boson masses

Conclusion

Status of the electroweak fit:

- Latest top and W mass measurements included and combined
- Fully consistent with SM predictions



New Physics interpretation: The 2HDM

- Combination of EW, flavour and Higgs measurements
- Strong constraints on mass parameters

BACKUP

Theoretical Input

- Consistent set of full EW 2-loop calculations is available:
  - $\sin^2\Theta^f_{\rm eff}$: effective weak mixing angle (from ratio g_V/g_A)
    (M. Awramik et al., PRL 93, 201805 (2004), JHEP 11, 048 (2006), Nucl. Phys. B813, 174 (2009))
  - M_W: mass of the W boson, includes QCD corrections at 4-loop level
    (M. Awramik et al., PRD 69, 053006 (2004), PRL 89, 241801 (2002))
  - Γ_f: partial widths of the Z boson (A. Freitas, JHEP 04, 070 (2014))
  - Radiator functions to Γ_f: QED and QCD corrections up to N^3LO
    (Baikov et al., PRL 108, 222003 (2012))
  - (Γ_W: width of the W boson, only 1-loop EW corrections included
    (Cho et al., JHEP 1111, 068 (2011)))
- Estimate uncertainties due to unknown higher orders (using a geometric series):

$\delta_{\rm theo} M_W$	4 MeV	$\delta_{\rm theo}\Gamma_{u,c}$	0.12 MeV
$\delta_{\rm theo}\sin^2\theta^f_{\rm eff}$	$4.7\cdot10^{-5}$	$\delta_{\rm theo}\Gamma_b$	0.21 MeV
$\delta_{\rm theo}\Gamma_{e,\mu,\tau}$	0.012 MeV	$\delta_{\rm theo}\sigma^0_{\rm had}$	6 pb
$\delta_{\rm theo}\Gamma_\nu$	0.014 MeV	$\delta_{\rm theo}\mathcal{R}_{V,A}$	$\sim\mathcal{O}(\alpha_s^4)$
$\delta_{\rm theo}\Gamma_{d,s}$	0.09 MeV	$\delta_{\rm theo} m_t$	0.5 GeV

Uncertainty on m_t:
Relation between m_{pole} and measured mass

The Electroweak Fit

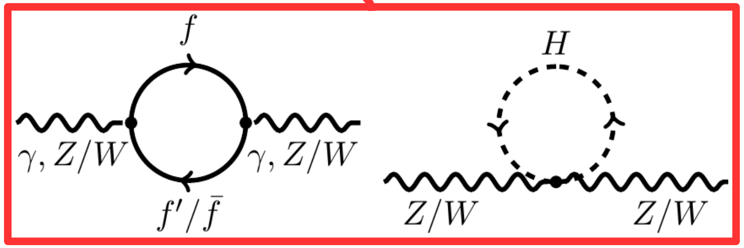
- Gauge & scalar sector is determined by 4 parameters (choose α, G_F, M_Z, M_H)
- Other parameters and observables related by theory

$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} \qquad M_W^2 \sin^2\theta_W = \frac{\pi\alpha}{\sqrt{2}\,G_F}$$

→ over-constrained theory

- Other SM parameters (quark masses, M_H, α_S) enter by radiative corrections

$$M_W^2 = \frac{M_Z^2}{2}\left(1 + \sqrt{1 - \frac{\sqrt{8}\,\pi\alpha(1+\Delta r)}{G_F M_Z^2}}\right)$$



$$\sin^2\theta_{\text{eff}}^f = \kappa_Z^f \sin^2\theta_W \qquad g_{V,f} = \sqrt{\rho_Z^f}\left(I_3^f - 2Q^f \sin^2\theta_{\text{eff}}^f\right) \qquad g_{A,f} = \sqrt{\rho_Z^f}\, I_3^f$$

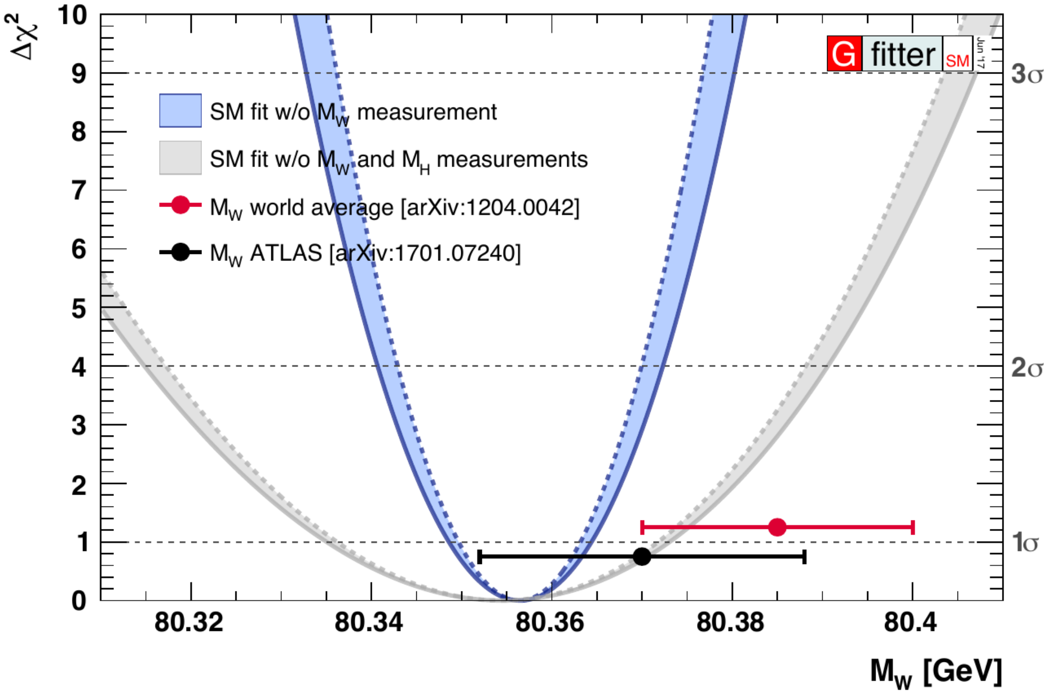
- G_F known with high precision → not varied in the fit

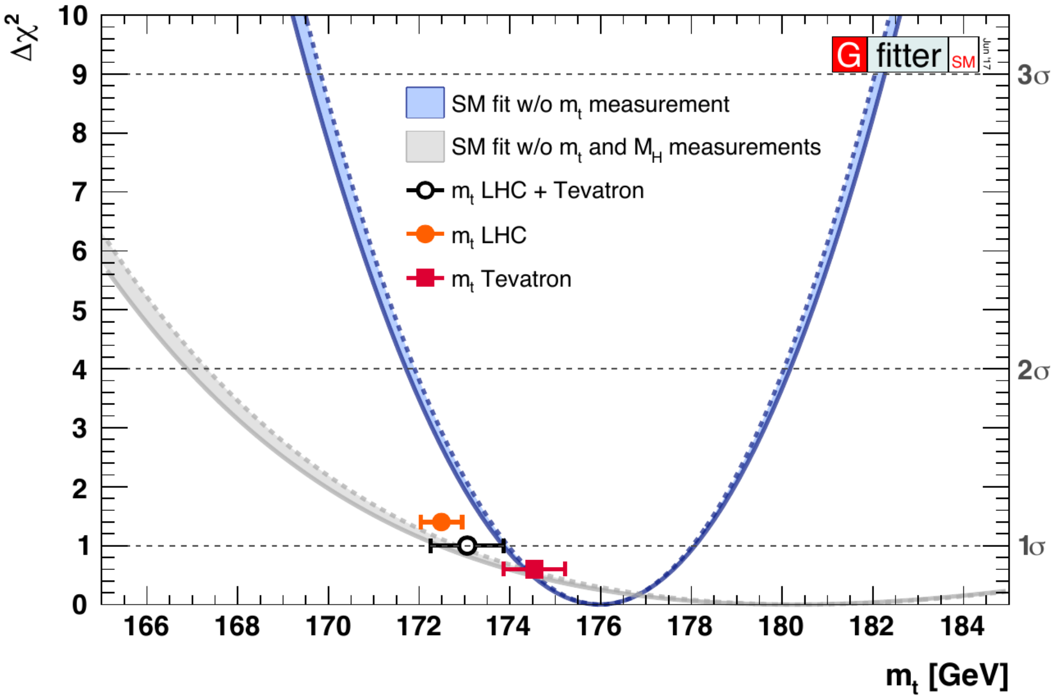
Results

Parameter	Input value	Free in fit	Fit Result	w/o exp. input in line	w/o exp. input in line, no theo. unc
M_H [GeV]	125.1 ± 0.2	yes	$125.1^{+0.2}_{-0.2}$	$100.2^{+24.4}_{-20.6}$	$100.3^{+23.5}_{-19.9}$
M_W [GeV]	80.379 ± 0.013	–	80.363 ± 0.007	80.356 ± 0.008	80.356 ± 0.007
Γ_W [GeV]	2.085 ± 0.042	–	2.091 ± 0.001	2.091 ± 0.001	2.091 ± 0.001
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1879 ± 0.0020	91.1967 ± 0.0099	91.1969 ± 0.0096
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4950 ± 0.0014	2.4945 ± 0.0016	2.4945 ± 0.0016
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	–	41.483 ± 0.015	41.474 ± 0.016	41.474 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.744 ± 0.017	20.725 ± 0.026	20.724 ± 0.026
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	–	0.01623 ± 0.0001	0.01622 ± 0.0001	0.01624 ± 0.0001
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–	0.1471 ± 0.0005	0.1471 ± 0.0005	0.1472 ± 0.0004
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	–	0.23151 ± 0.00006	0.23151 ± 0.00006	0.23150 ± 0.00005
$\sin^2\theta^\ell_{\rm eff}({\rm TEV})$	0.2318 ± 0.0003	–	0.23151 ± 0.00006	0.23150 ± 0.00006	0.23150 ± 0.00005
A_c	0.670 ± 0.027	–	0.6679 ± 0.00022	0.6679 ± 0.00022	0.6680 ± 0.00016
A_b	0.923 ± 0.020	–	0.93475 ± 0.00004	0.93475 ± 0.00004	0.93475 ± 0.00003
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	–	0.0737 ± 0.0003	0.0737 ± 0.0003	0.0737 ± 0.0002
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	–	0.1031 ± 0.0003	0.1033 ± 0.0004	0.1033 ± 0.0003
R^0_c	0.1721 ± 0.0030	–	$0.17226^{+0.00009}_{-0.00008}$	0.17226 ± 0.00008	0.17226 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	0.21579 ± 0.00011	0.21578 ± 0.00012	0.21577 ± 0.00004
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes	$1.27^{+0.07}_{-0.11}$	–	–
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes	$4.20^{+0.17}_{-0.07}$	–	–
m_t [GeV]$^{(\bigtriangledown)}$	173.06 ± 0.94	yes	173.54 ± 0.86	$175.97^{+2.11}_{-2.12}$	$176.00^{+2.03}_{-2.04}$
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2758 ± 10	yes	2756 ± 10	2738 ± 41	2739 ± 39
$\alpha_s(M_Z^2)$	–	yes	$0.1197^{+0.0030}_{-0.0029}$	0.1197 ± 0.0030	0.1198 ± 0.0028

$^{(\star)}$Average of LEP ($A_\ell = 0.1465 \pm 0.0033$) and SLD ($A_\ell = 0.1513 \pm 0.0021$) measurements, used as two measurements in the fit. The fit w/o the LEP (SLD) measurement gives $A_\ell = 0.1471 \pm 0.0005$ ($A_\ell = 0.1469 \pm 0.0005$). $^{(\bigtriangledown)}$Combination of experimental (0.8 GeV) and theory uncertainty (0.5 GeV).$^{(\dagger)}$In units of 10^{-5}. $^{(\triangle)}$Rescaled due to α_s dependency.

M_W and M_t


Δχ²
G fitter SM
Jun 17
SM fit w/o M_W measurement
SM fit w/o M_W and M_H measurements
M_W world average [arXiv:1204.0042]
M_W ATLAS [arXiv:1701.07240]
3σ
2σ
1σ
80.32
80.34
80.36
80.38
80.4
M_W [GeV]


Δχ²
G fitter SM
Jun 17
SM fit w/o m_t measurement
SM fit w/o m_t and M_H measurements
m_t LHC + Tevatron
m_t LHC
m_t Tevatron
3σ
2σ
1σ
166
168
170
172
174
176
178
180
182
184
m_t [GeV]

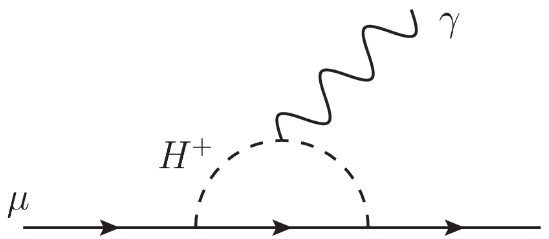
2HDM Types

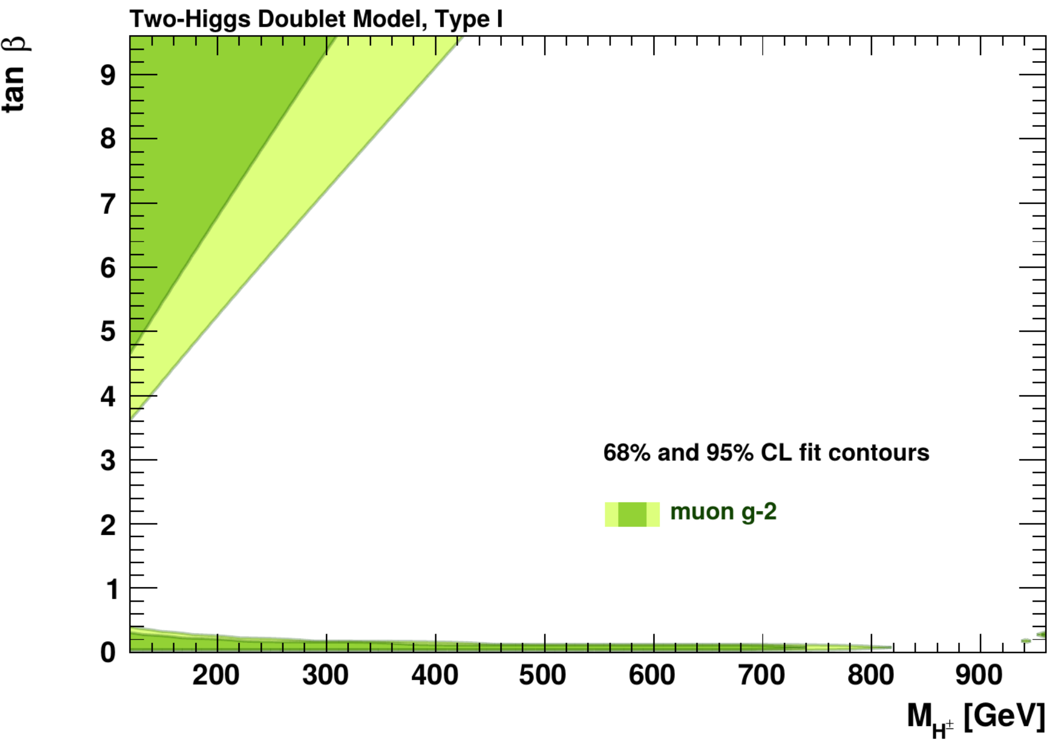
Parameterization for various 2HDMs (taken from arXiv:1106.0034)

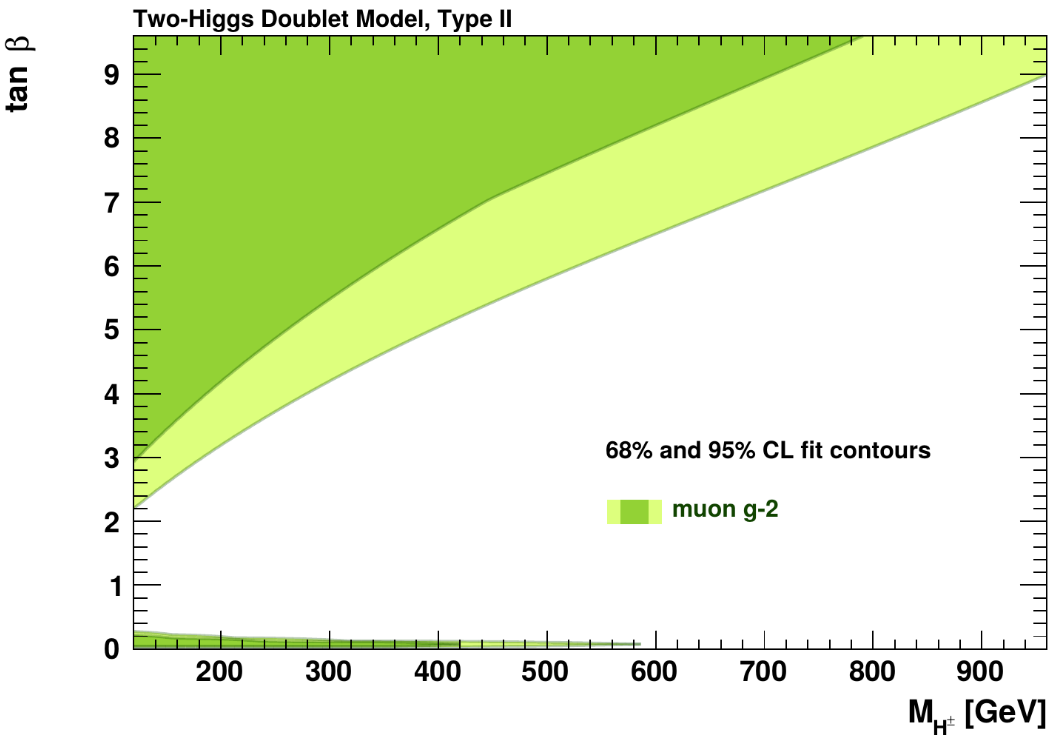
	Type I	Type II	Lepton-specific	Flipped
ξ_h^u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
ξ_h^d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
ξ_h^ℓ	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$
ξ_H^u	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
ξ_H^d	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
ξ_H^ℓ	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$
ξ_A^u	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
ξ_A^d	$-\cot\beta$	$\tan\beta$	$-\cot\beta$	$\tan\beta$
ξ_A^ℓ	$-\cot\beta$	$\tan\beta$	$\tan\beta$	$-\cot\beta$

Muon g-2

- Muon magnetic moment $a_\mu=(g-2)/2$ deviates from SM prediction
- $\Delta a_\mu=(274\pm63\pm42)*10^{-11}$
- Theory prediction from Cherchiglia et al.







- 2HDM can explain discrepancy in some parameter regions