Impact of LHC bounds on the W-boson mass prediction in SUSY models

based on work in collaboration
with Sven Heinemeyer and Georg Weiglein

Lisa Zeune

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DESY

W-boson mass

- Electroweak precision observables

$$M_W, \; \sin^2\theta_{\text{eff}}, \; a_\mu \ldots$$

- Highly sensitive to quantum effects of 'new physics'
- Precise measurement & precise theoretical calculation needed

→ Test models

→ Constrain model parameters

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Outline of this talk

- Theoretical prediction of the W-boson mass in the MSSM
- Analyze effect of SUSY particles on the M_W prediction
- Effects of LHC results on the M_W prediction

Experimental measurement of the W-boson mass

- Most accurate measurement from Tevatron

Further improvement possible
→ See talk by T. Kurca

- Combination with LEP ⟶ World average:

$$M_W^{\text{exp}} = 80.385 \pm 0.015\text{GeV}$$

Tevatron Electroweak Working Group April '12

- Improvement at the LHC possible but very challenging

→ See talk by A. Vicini

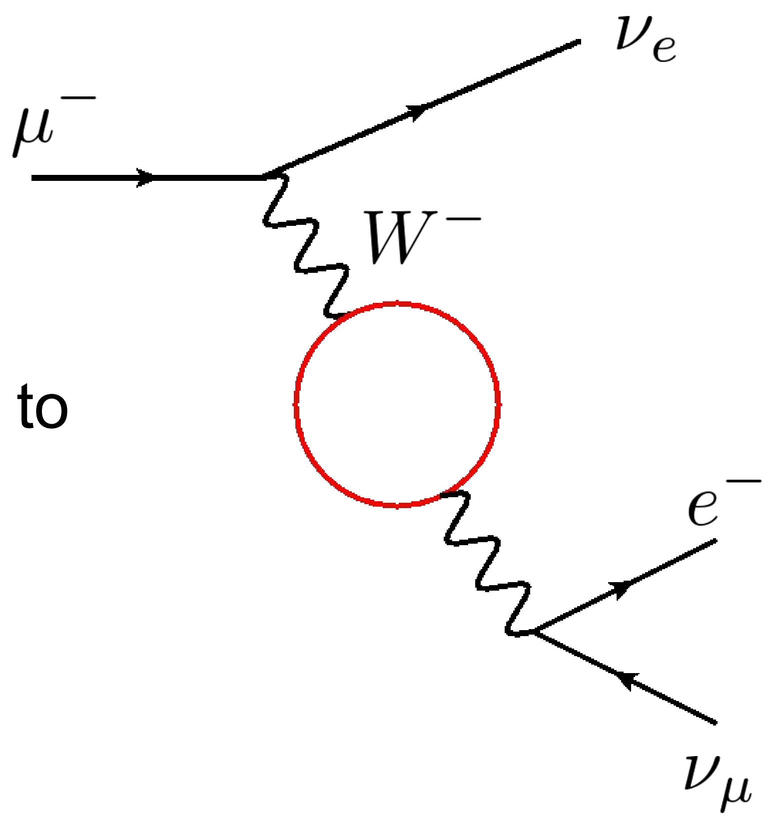
- Great improvement possible at a linear collider
  - ⟶ Measurement with ~7 MeV uncertainty plausible at LC
- Improvement in the top mass measurement
  - ⟶ LC goal: 100 MeV precision
  - ⟶ Higher accuracy of theoretical M_W prediction

Determination of the W-boson mass

- Comparison of muon decay in SM and Fermi model gives:

$$\frac{G_F}{\sqrt{2}} = \frac{e^2}{8 s_W^2 M_W^2}\left(1 + \Delta r(M_W, M_Z, m_t, \ldots X)\right)$$

- $G_F,\ e,\ s_W$ known with high precision
- X model dependent!
- Precise calculation of Δr needed to test model and constrain model parameters!



Calculation of Δr

- 1-loop calculation of Δr in the MSSM and the NMSSM
  - General (N)MSSM, complex phases, CKM mixing (MFV)
- Incorporation of all known SM and SUSY higher order corrections
- To make use of advanced SM calculation:

$$\Delta r^{\mathrm{(N)MSSM}} = \Delta r^{\mathrm{SM}} + \Delta r^{\mathrm{SUSY}}$$

- Most precise MSSM prediction for the W-boson mass
- Easy to extend to other models

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SM contributions to W-boson mass

$$\Delta r^{SM} = \Delta r^{(\alpha)} + \Delta r^{(\alpha\alpha_s)} + \Delta r^{(\alpha\alpha_s^2)} + \Delta r^{(\alpha^2)}_{\text{ferm}} + \Delta r^{(\alpha^2)}_{\text{bos}} + \Delta r^{(G_\mu^2 \alpha_s m_t^4)} + \Delta r^{(G_\mu^3 m_t^6)} + \Delta r^{(G_\mu m_t^2 \alpha_s^3)}$$

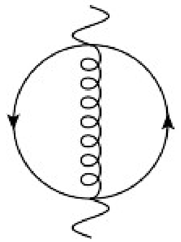
- $\Delta r^{(\alpha)}$: 1-loop contribution
- $\Delta r^{(\alpha\alpha_s)} + \Delta r^{(\alpha\alpha_s^2)}$: 2- and 3-loop QCD correction

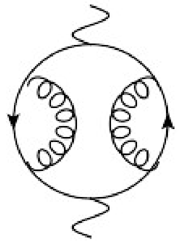
  Chetyrkin, Kuhn, Steinhauser '95, Djouadi, Verzegnassi '88, ...
- $\Delta r^{(\alpha^2)}_{\text{ferm}} + \Delta r^{(\alpha^2)}_{\text{bos}}$: fermionic and bosonic electroweak 2-loop corrections (fitting formula)

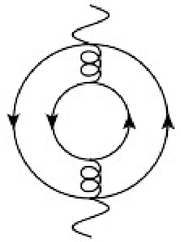
  Awramik, Czakon, Freitas '06, Awramik, Czakon, Freitas, Weiglein '03
- $\Delta r^{(G_\mu^2 \alpha_s m_t^4)} + \Delta r^{(G_\mu^3 m_t^6)}$: 3-loop top quark contributions

  Faisst, Kuhn, Seidensticker, Veretin '03
- $\Delta r^{(G_\mu m_t^2 \alpha_s^3)}$: 4-loop QCD correction Boughezal '06
- QCD corrections enter at 2-loop level:

  → Large corrections beyond 1-loop order







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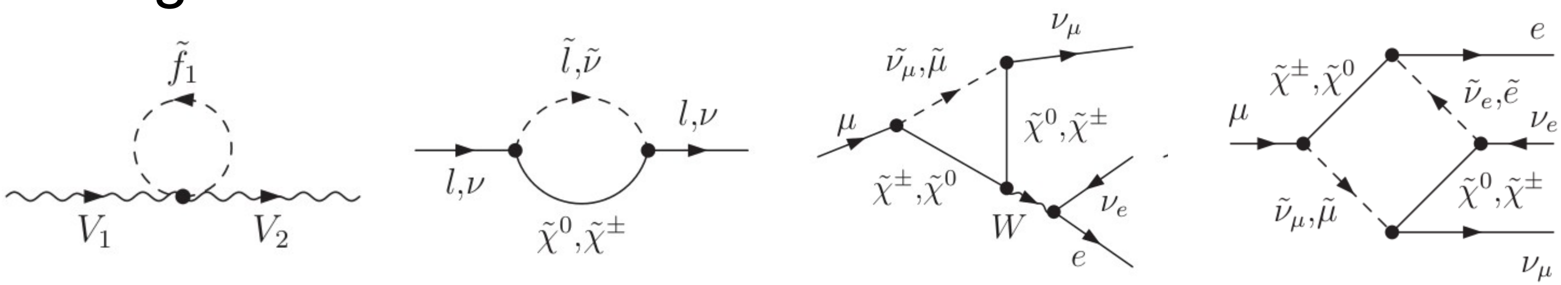
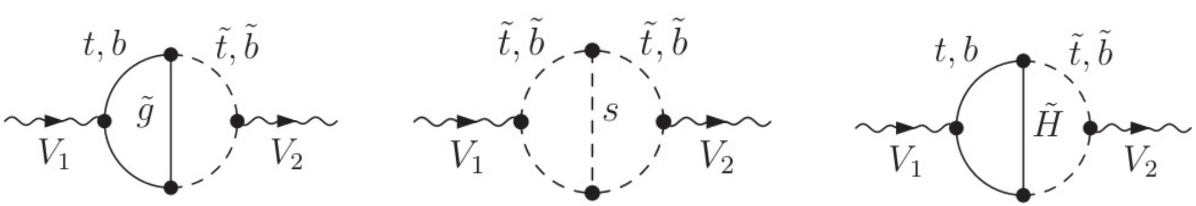
SUSY contributions to W-boson mass

- 1-loop contributions from MSSM Higgs, sfermions, charginos and neutralinos



- Supersymmetric two-loop contributions:
  - SUSY QCD corrections of $O(\alpha\alpha_s)$ Djouadi et. al '98
    (S)quark loops with gluon and gluino exchange
  - Yukawa contributions
    (S)quark loops with Higgs and Higgsino exchange

    Haestier, Heinemeyer, Stoeckinger, Weiglein '05
- Leading reducible two-loop corrections Consoli, Hollik, Jegenlehner '89

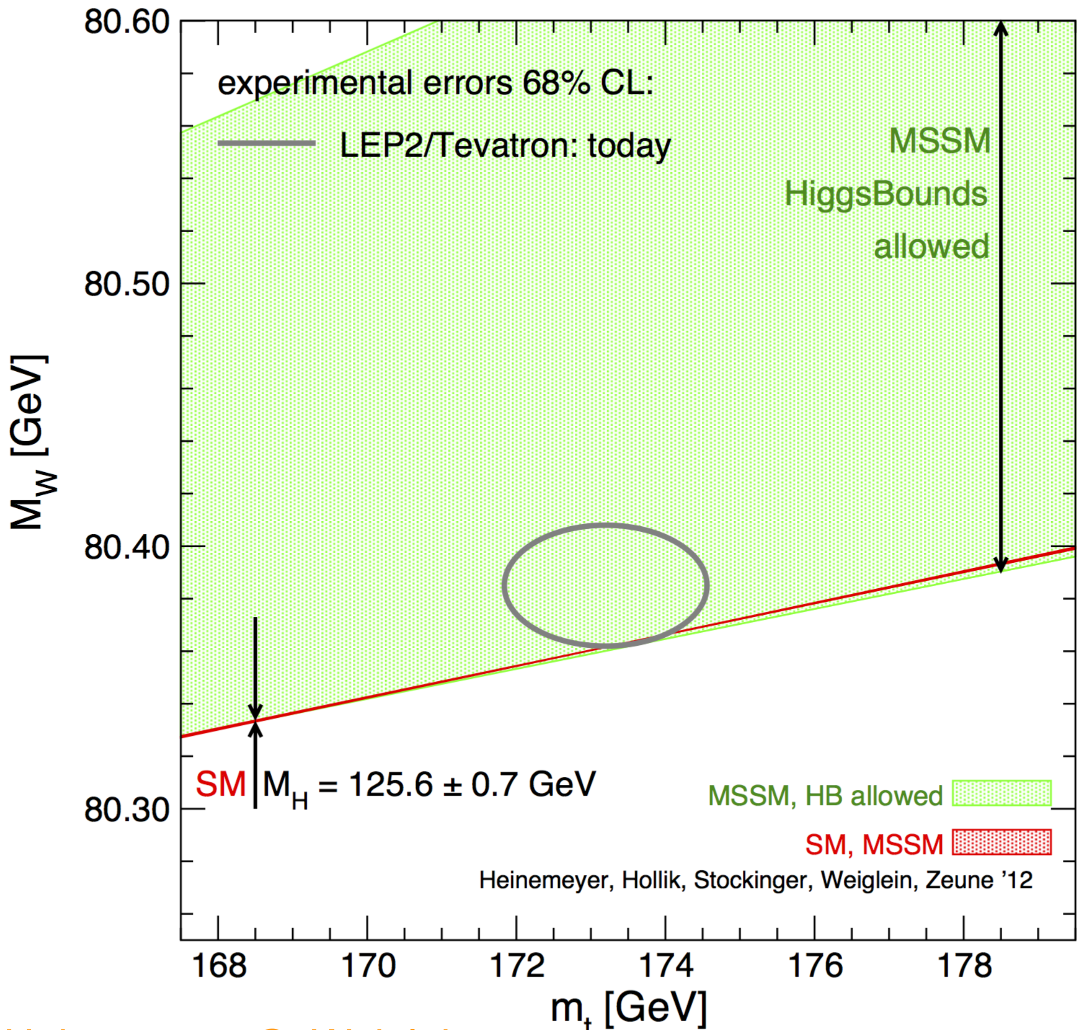


Detailed parameter scan

Parameter	Minimum	Maximum
μ	-2000	2000
$M_{\tilde{E}_{1,2,3}} = M_{\tilde{L}_{1,2,3}}$	100	2000
$M_{\tilde{Q}_{1,2}} = M_{\tilde{U}_{1,2}} = M_{\tilde{D}_{1,2}}$	500	2000
$M_{\tilde{Q}_3}$	100	2000
$M_{\tilde{U}_3}$	100	2000
$M_{\tilde{D}_3}$	100	2000
$A_e = A_\mu = A_\tau$	-3 $M_{\tilde{E}}$	3 $M_{\tilde{E}}$
$A_u = A_d = A_c = A_s$	-3 $M_{\tilde{Q}_{12}}$	3 $M_{\tilde{Q}_{12}}$
A_b	-3 $\max(M_{\tilde{Q}_3}, M_{\tilde{D}_3})$	3 $\max(M_{\tilde{Q}_3}, M_{\tilde{D}_3})$
A_t	-3 $\max(M_{\tilde{Q}_3}, M_{\tilde{U}_3})$	3 $\max(M_{\tilde{Q}_3}, M_{\tilde{U}_3})$
$\tan\beta$	1	60
M_3	500	2000
M_A	90	1000
M_2	100	1000

$M_1 \approx 1/2\, M_2$

W-boson mass prediction in the MSSM



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MSSM region:
allowed by
HiggsBounds*
and PDG limits on
SUSY particles,
neutralino LSP

Overlap region
(SM and MSSM):
After Higgs
discovery SM band
very narrow

* P. Bechtle, O. Brein, S. Heinemeyer, O. Stål,
T. Stefaniak, G. Weiglein and K. Williams

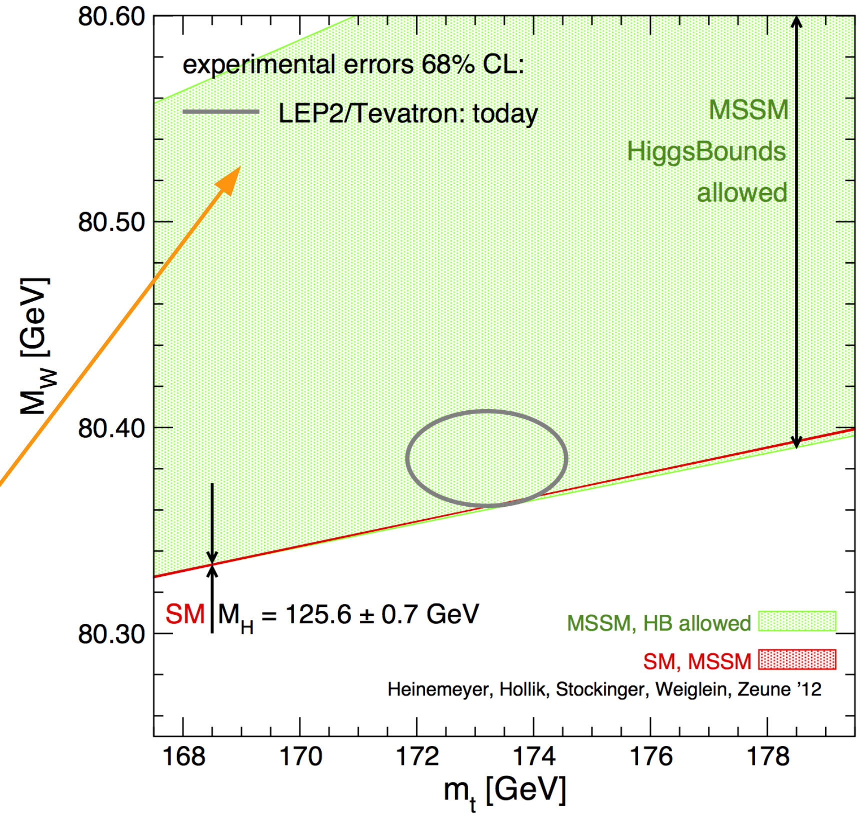
W-boson mass prediction in the MSSM

$$\Delta r^{\text{1-loop}} = \Delta\alpha - \frac{c_W^2}{s_W^2}\Delta\rho + \Delta r_{\text{rem}}$$

- Largest SUSY contribution: $\tilde{t}, \tilde{b}$ contribution to

$$\Delta\rho = \frac{\Sigma_T^Z(0)}{M_Z^2} - \frac{\Sigma_T^W(0)}{M_W^2}$$

- Sensitive to mass splitting between stops and sbottoms
- Very large values for M_W possible for
  - Large mixing in $\tilde{t}, \tilde{b}$ sector
  - $\tilde{t}_1$ or $\tilde{b}_1$ relatively light
  - Restriction: $m_{\tilde{t}_2}/m_{\tilde{t}_1} < 2.5, \;\; m_{\tilde{b}_2}/m_{\tilde{b}_1} < 2.5$



Impact of a Higgs at 125 GeV

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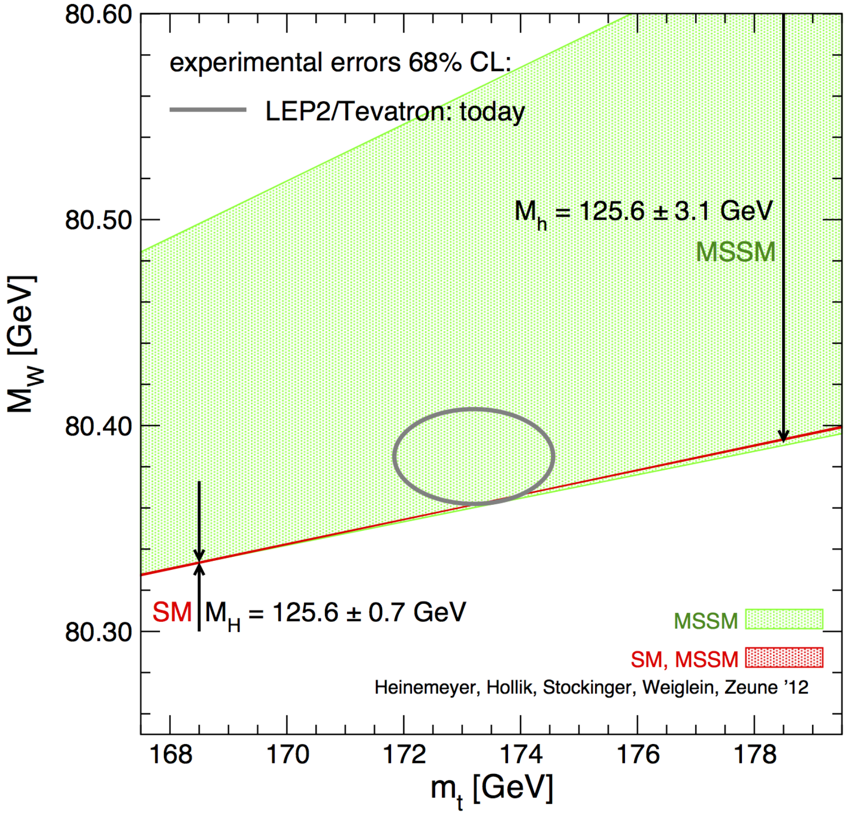
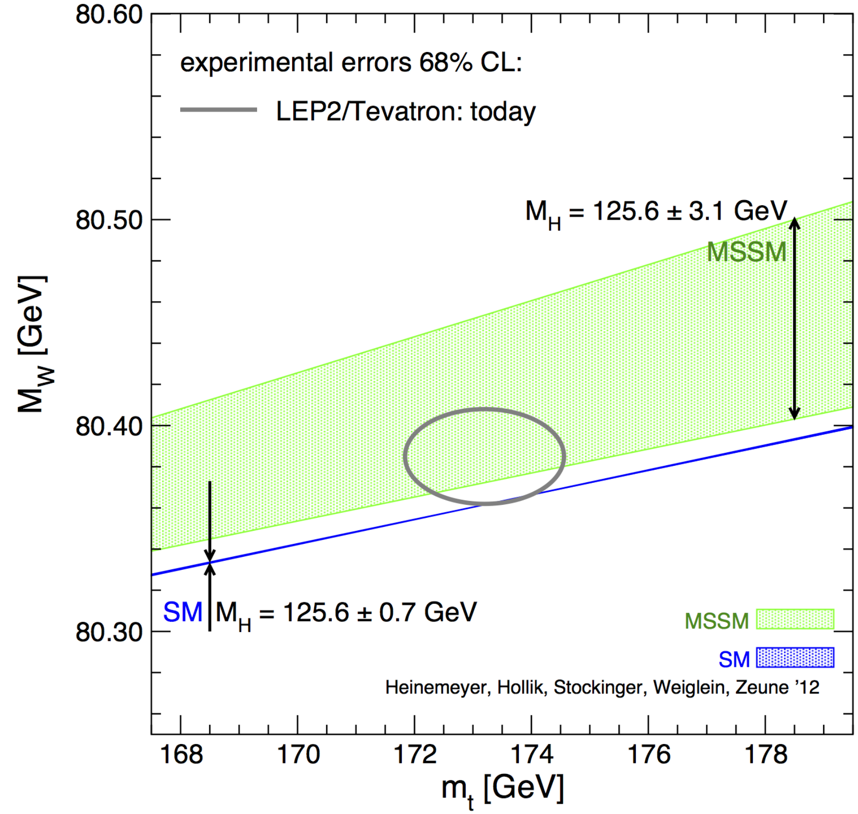
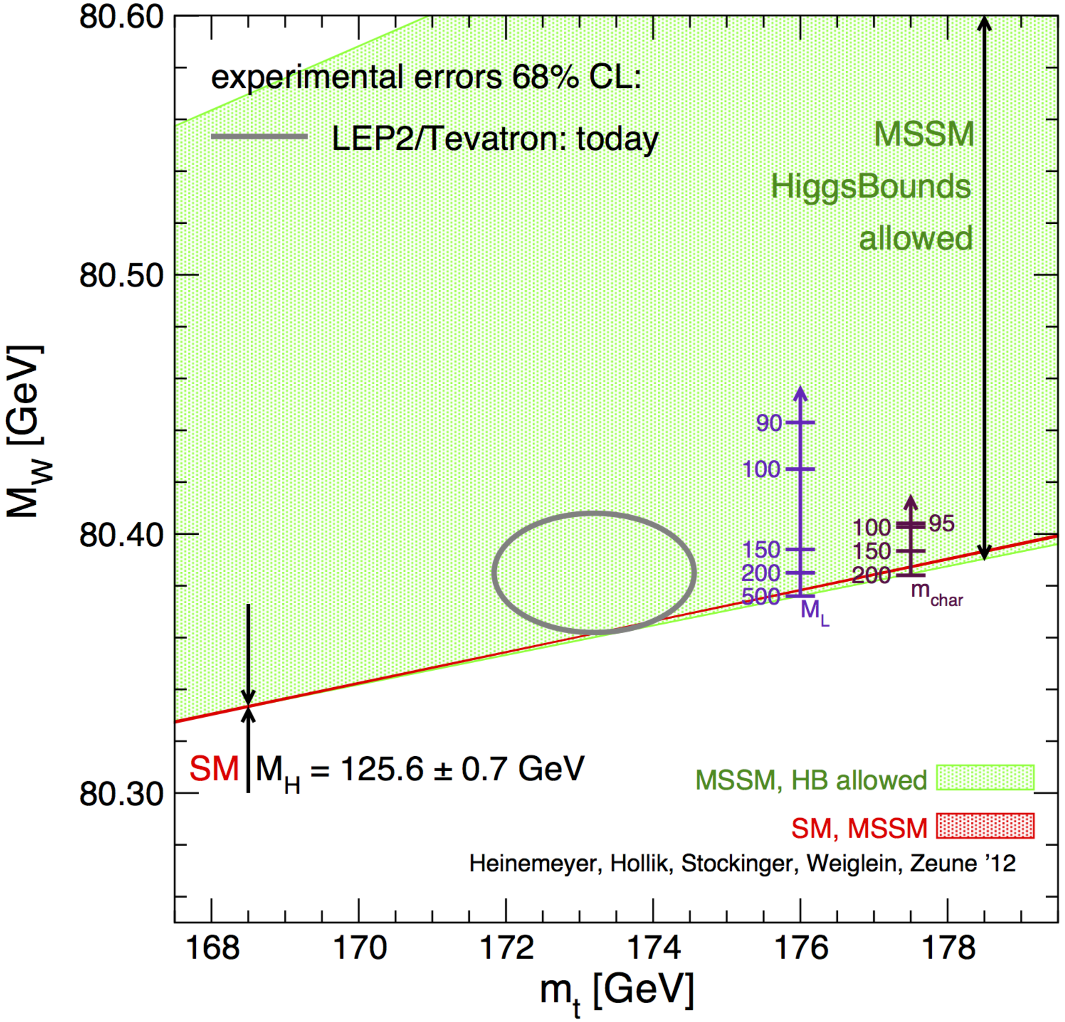




- The discovered Higgs boson can in the MSSM be interpreted both as the light or heavy CP-even Higgs
- In both cases M_W prediction in good agreement with current measurement

Contribution from SUSY particles

- Effects from charginos, neutralinos and sleptons:



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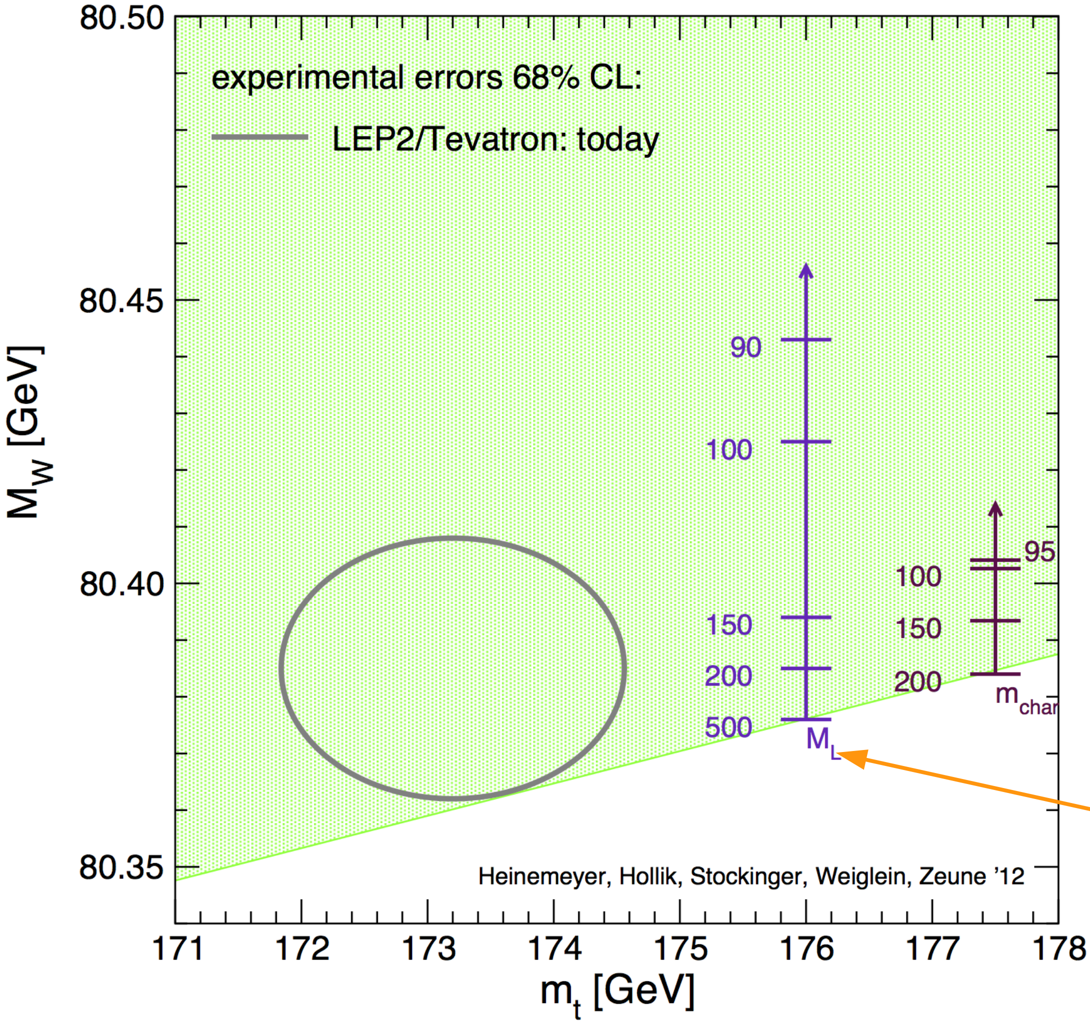
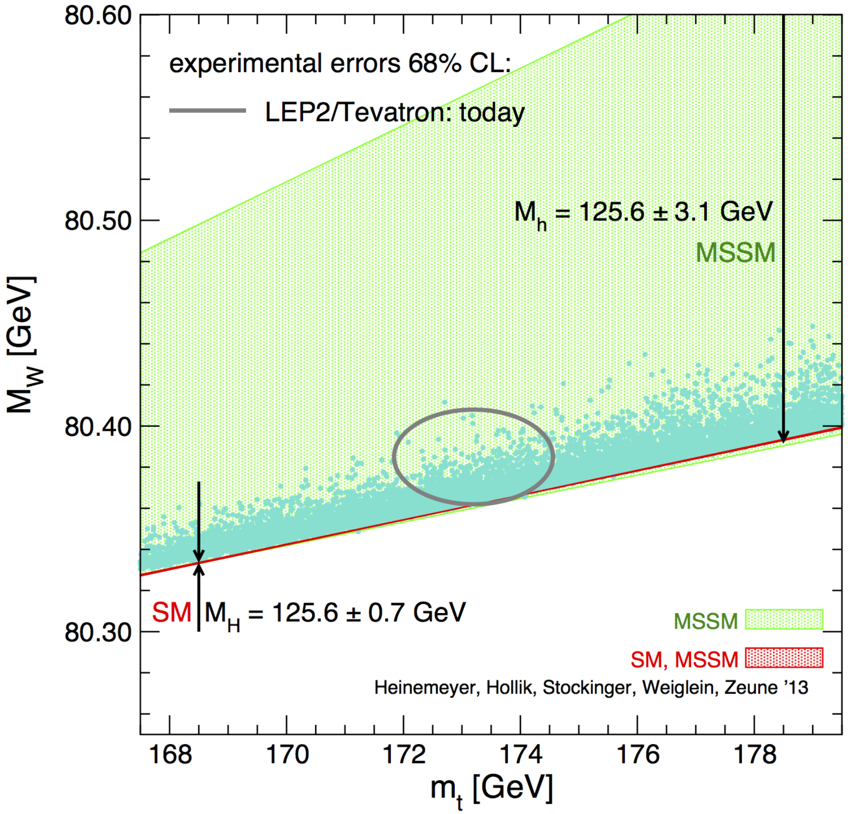


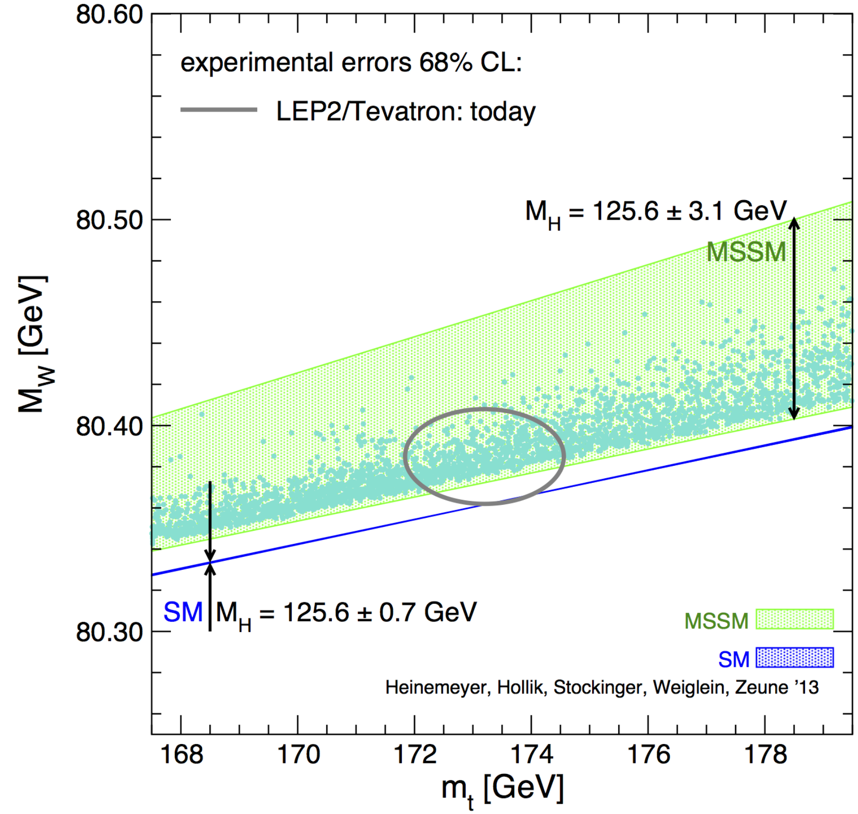
- Contribution from light sleptons ≳ 60 MeV (mainly from mass splitting between charged sleptons and sneutrinos)
- Contribution from charginos and neutralinos ≈ 20 MeV

All other SUSY particles heavy

Impact of stop and sbottom mass limit

Blue points:
Stop, sbottoms heavier than 500 GeV,
squarks and gluinos heavier than 1200 GeV





- Limits on stop and sbottom masses would decrease the possible size of the SUSY contributions
- M_W prediction in good agreement with exp. measurement

Conclusions

- Precise prediction of W-boson mass in the MSSM
- Size of SUSY contributions:
  - Largest contribution from stops and sbottoms
    $\rightarrow$ Limits on 3rd generation squarks have large impact on M_W
    $\rightarrow$ No restriction possible
  - Light sleptons and charginos, neutralinos give sizable contributions $\rightarrow$ sizable shift compared to SM even for very heavy squarks
- Both MSSM interpretations of a Higgs at 125 GeV give W-boson mass prediction in good agreement with measurement
- Current value favors non-zero SUSY contribution
- Higher precision needed to distinguish between models

Back-up slides

Stop contribution

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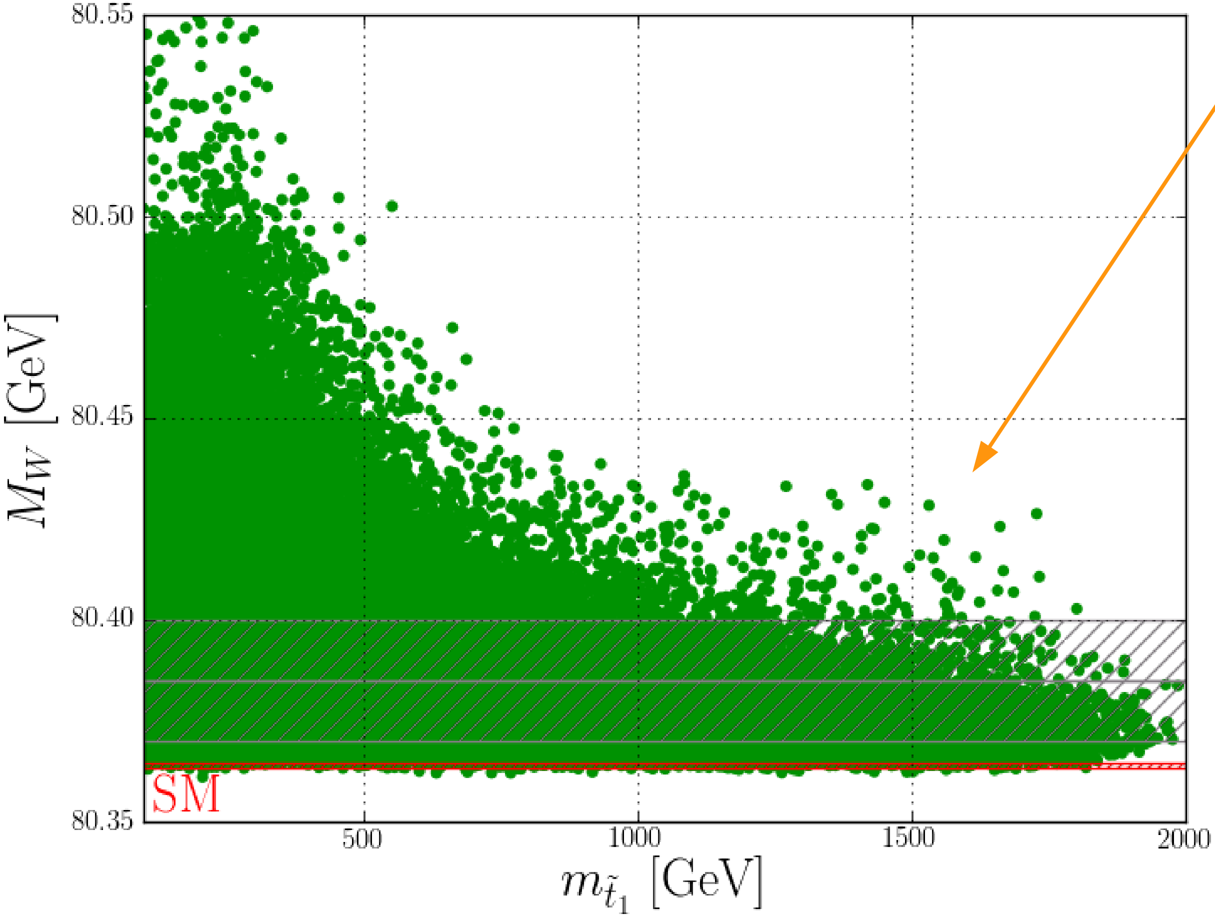


All HiggsBounds allowed points

If stops are heavy:

- Still sizable SUSY contributions from:

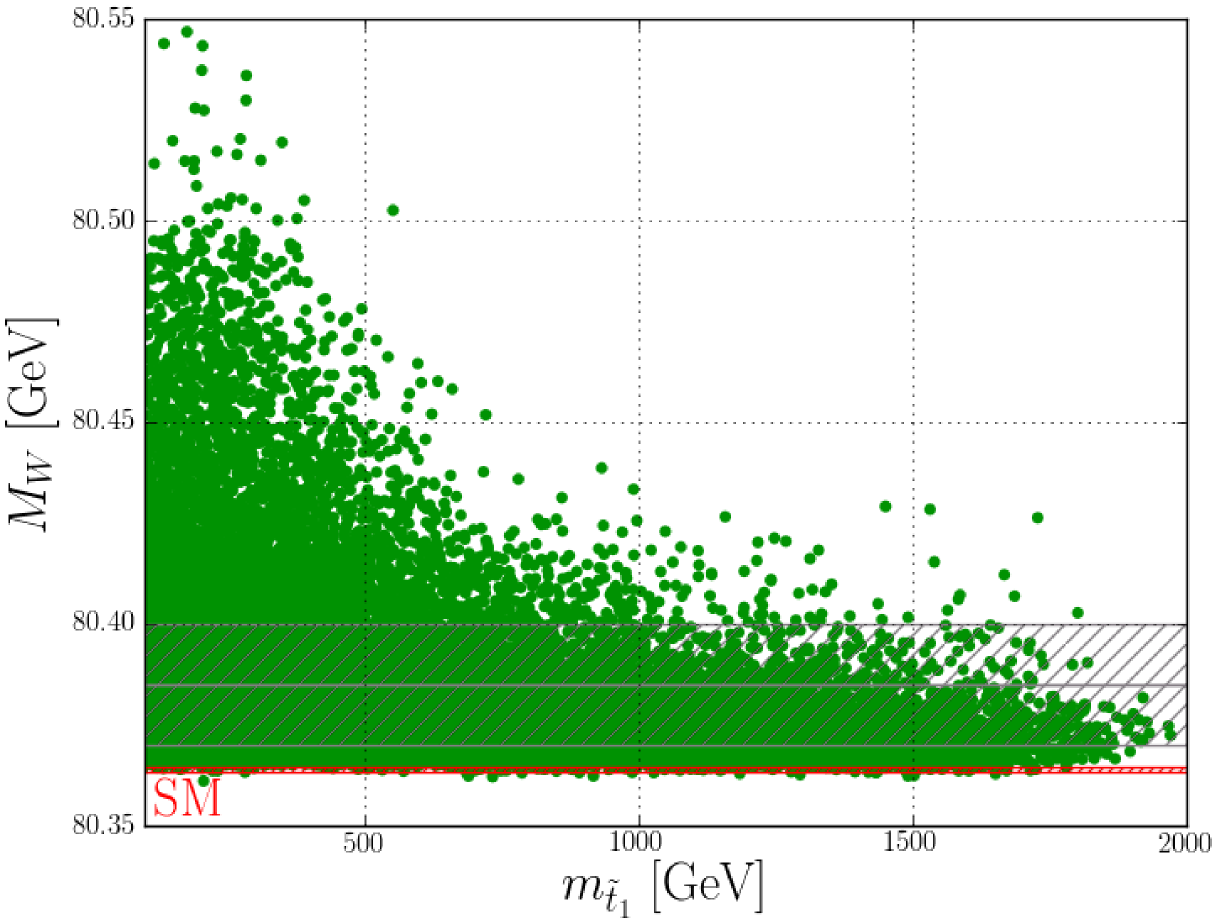
  sleptons

  charginos, neutralinos

  + remaining contributions from stop, sbottoms

Compatible with measurement

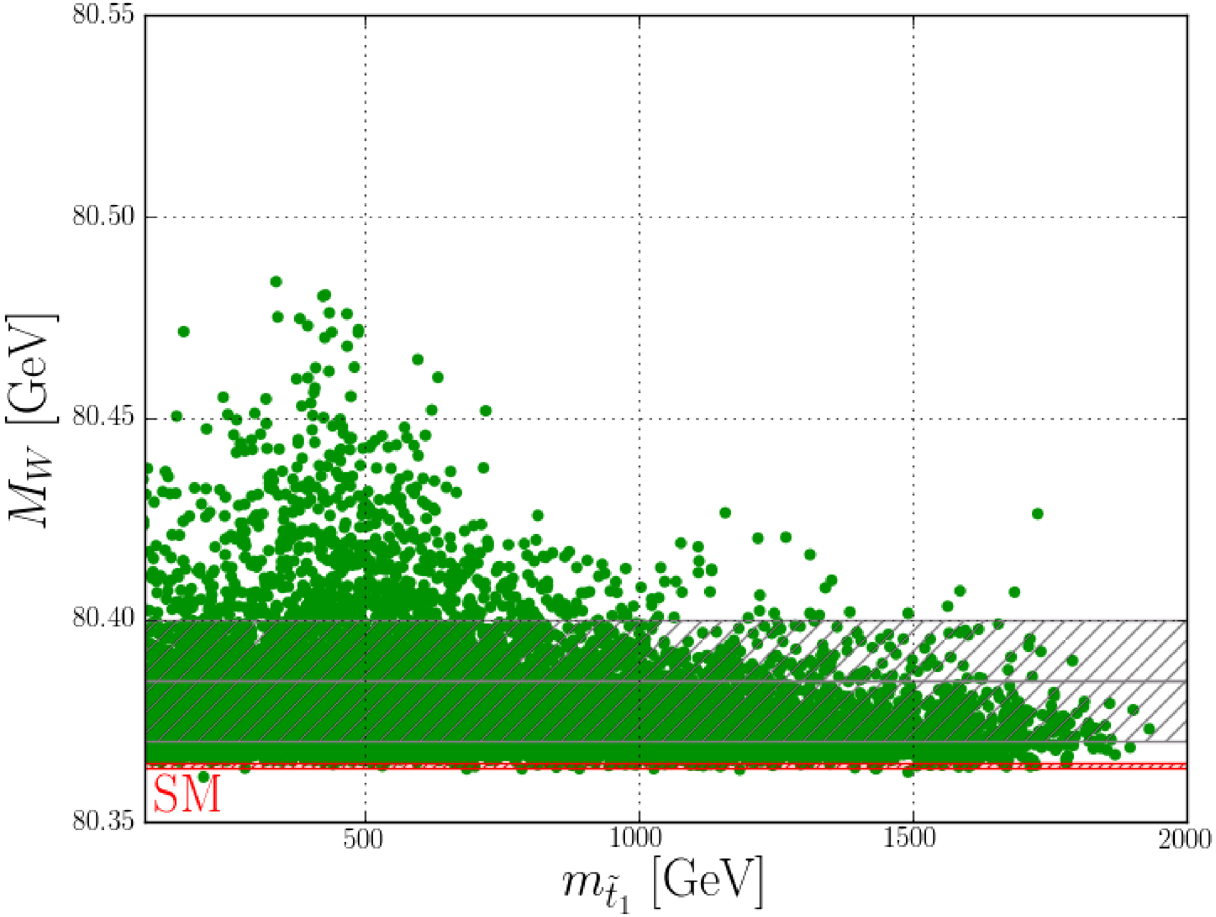
Stop contribution



LHC bounds on squarks and gluinos have very little impact on W-boson mass prediction

+ squarks and gluinos heavier than 1200 GeV

Stop contribution



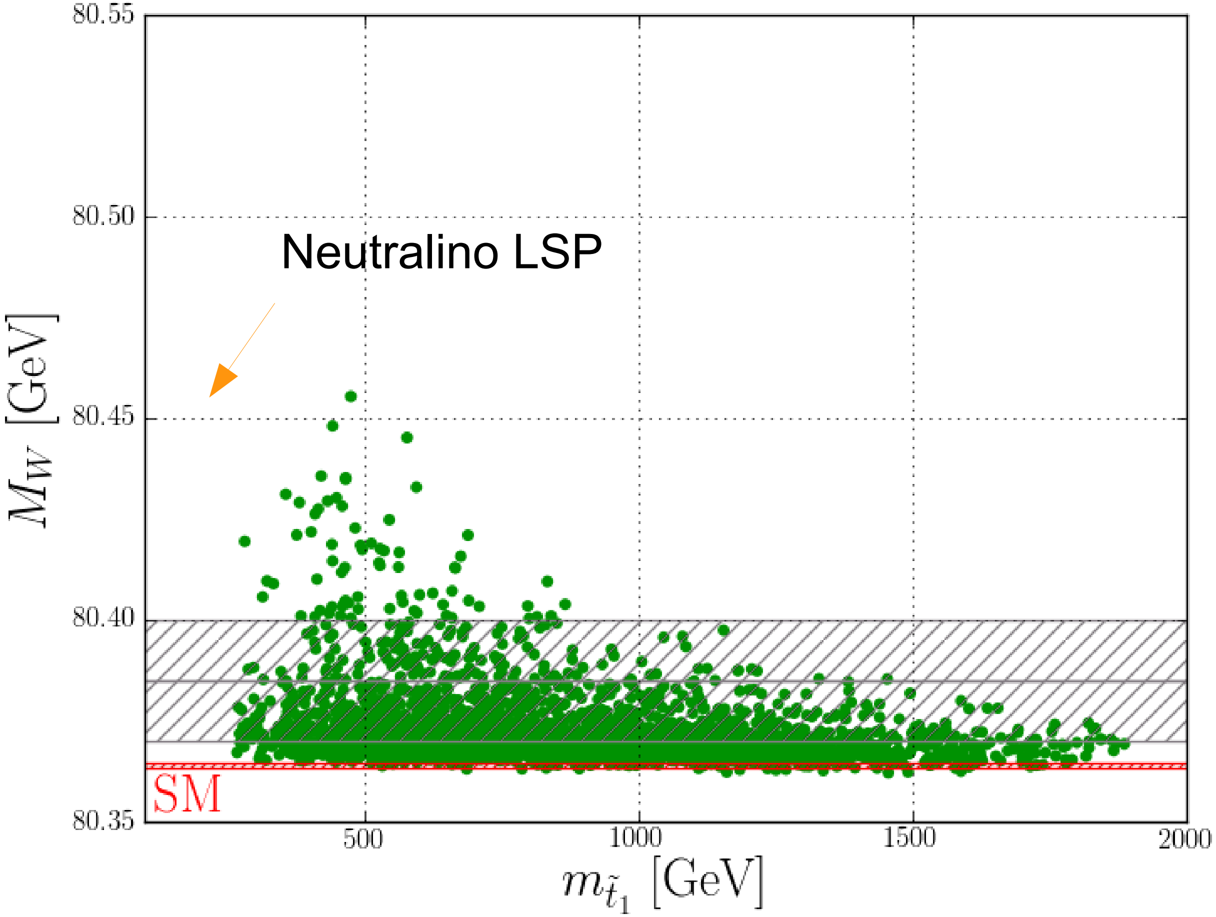
If sbottoms are heavier than 500 GeV:

Very large M_W values impossible

Good compatibility with experimental result

+ sbottoms heavier than 500 GeV

Stop contribution



With

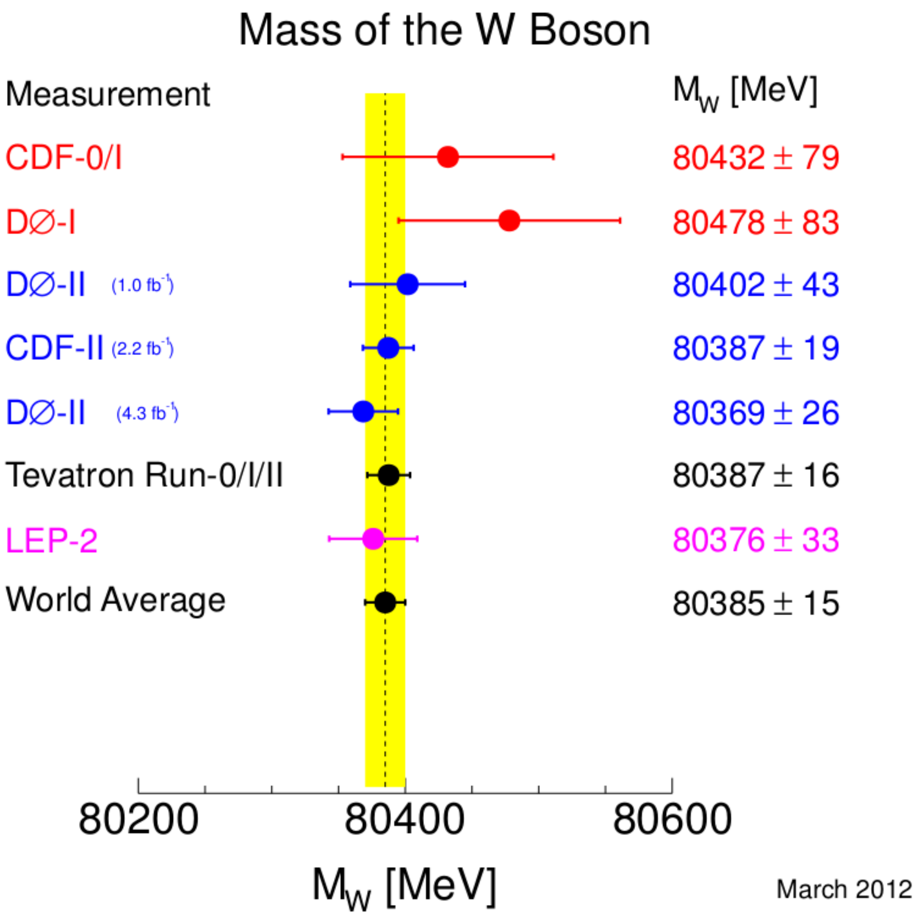
$m_{\tilde{t}_1} \sim 500$ GeV

$m_{\tilde{b}_1} > 500$ GeV

remaining M_W contribution from stop – sbottom sector can still be sizable

+ sleptons and charginos heavier than 500 GeV

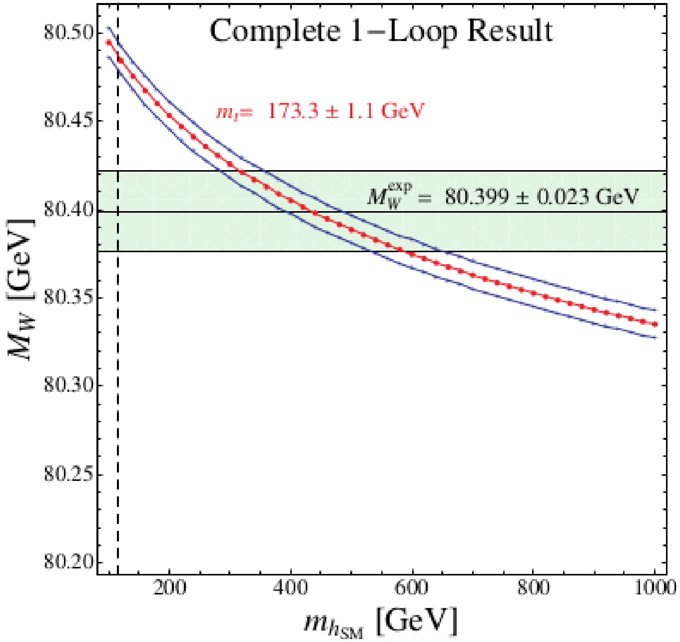
New measurement of the W-boson mass

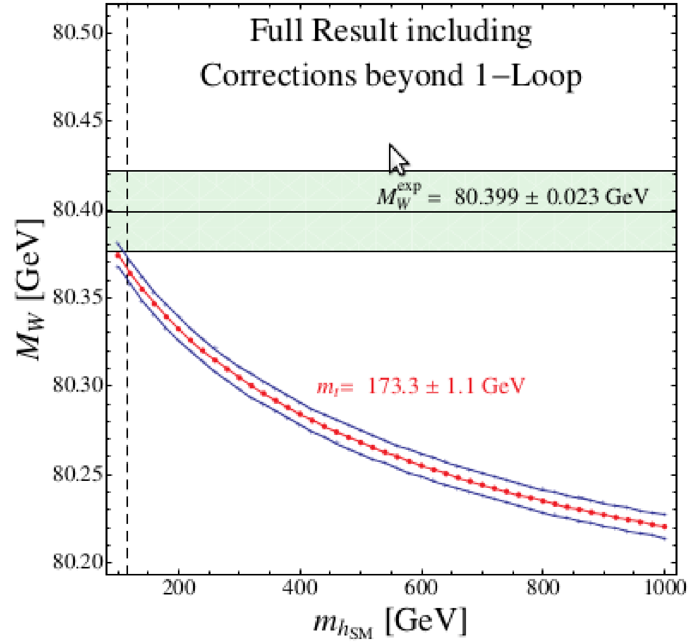


New CDF Result (2.2 fb^{-1})
Transverse Mass Fit Uncertainties (MeV)

	electrons	*muons*	*common*
W statistics	19	16	0
Lepton energy scale	10	7	5
Lepton resolution	4	1	0
Recoil energy scale	5	5	5
Recoil energy resolution	7	7	7
Selection bias	0	0	0
Lepton removal	3	2	2
Backgrounds	4	3	0
pT(W) model	3	3	3
Parton dist. Functions	10	10	10
QED rad. Corrections	4	4	4
Total systematic	18	16	15
Total	26	23	

W boson mass prediction SM





- Corrections beyond one-loop cause downward shift of more than 100 MeV
- Dominant contributions: $\Delta r^{(\alpha\alpha_s)} + \Delta r^{(\alpha\alpha_s^2)}$ ($\approx$ 14% of $\Delta r^{(\alpha)}$)
  $\Delta r^{(\alpha^2)}$ ($\approx$ 9% of $\Delta r^{(\alpha)}$)
- Preference for small SM Higgs masses
- No overlap between 1σ band and theoretical prediction for $m_{h_{SM}} > 114$ GeV
- Dominant theoretical uncertainty from m_t (higher order uncertainty 4 MeV)

Full Δr formula

$$\Delta r = \frac{\Sigma_T^{WW}(0) - \mathrm{Re}\left(\Sigma_T^{WW}(M_W^2)\right)}{M_W^2} + \Pi^{AA}(0) - \frac{c_W^2}{s_W^2}\,\mathrm{Re}\left[\frac{\Sigma_T^{ZZ}(M_Z^2)}{M_Z^2} - \frac{\Sigma_T^{WW}(M_W^2)}{M_W^2}\right]$$

$$+ 2\frac{s_W}{c_W}\frac{\Sigma_T^{AZ}(0)}{M_Z^2} + \mathrm{Vertex} + \mathrm{Box} - \frac{1}{2}\mathrm{Re}\left(\Sigma_L^{e}(0) + \Sigma_L^{\mu}(0) + \Sigma_L^{\nu_e}(0) + \Sigma_L^{\nu_\mu}(0)\right)$$