Precise Prediction for M_W in the MSSM

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Based on a collaboration with

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1. Introduction

2. M_W in the MSSM: current data

3. M_W in the MSSM: future data

4. Conclusions

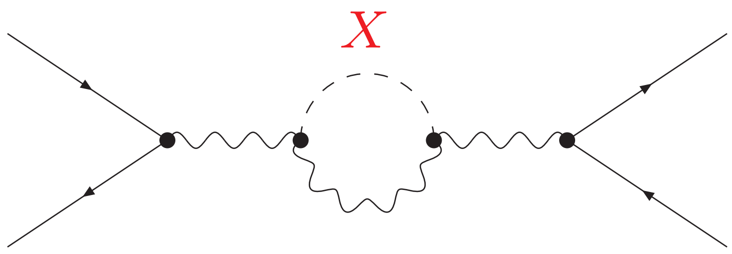
1. Introduction

Comparison of observables with theory:

Precision data:		Theory:
$M_W, \sin^2\theta_{\rm eff}, a_\mu,\ M_h$	$\leftrightarrow$	SM, MSSM , . . .

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections, e.g. X



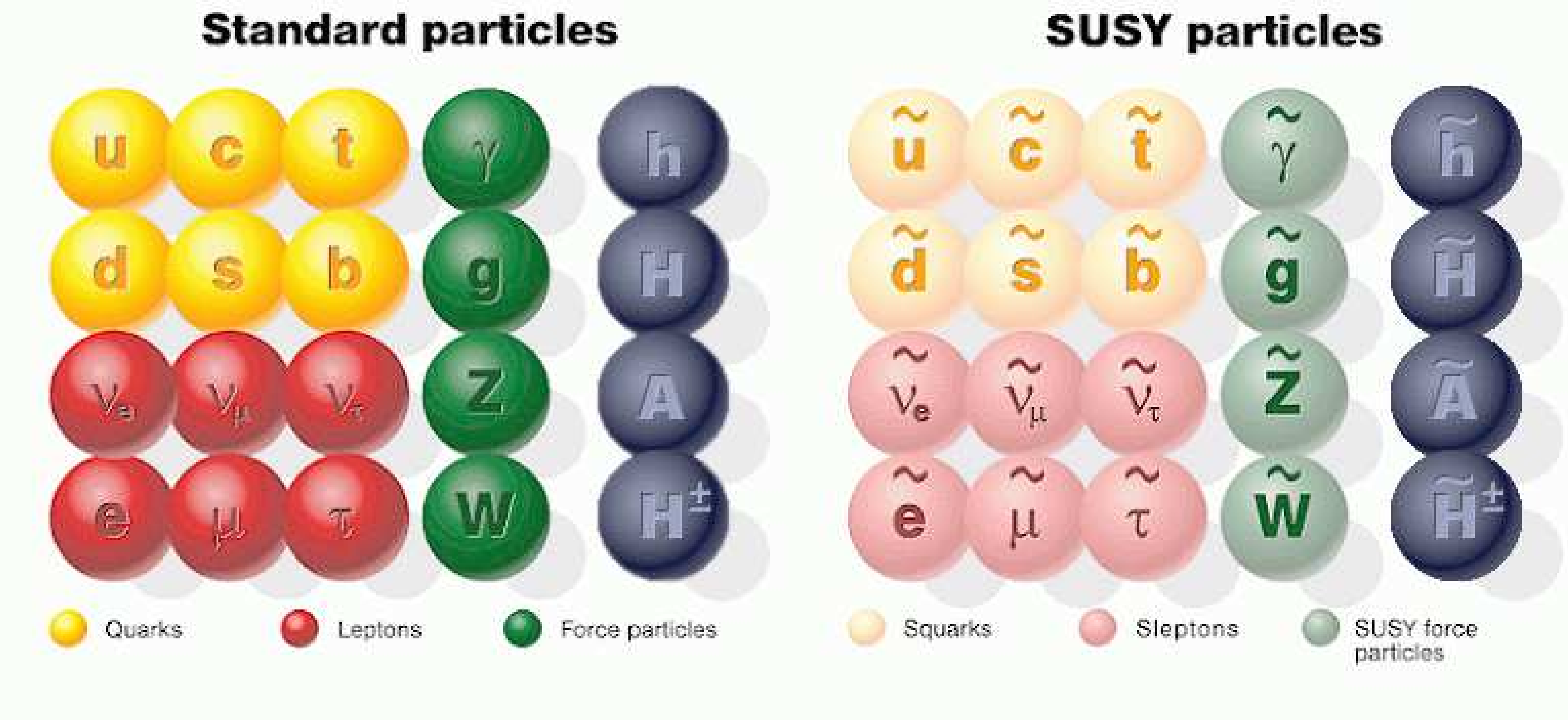
$\Downarrow$

BSM: limits on M_X

Very high accuracy of measurements and theoretical predictions needed

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles



Problem in the MSSM: more than 100 free parameters

Luckily not all are relevant for our calculation/analysis!

Precision observables in the SM and the MSSM

M_W, $\sin^2\theta_{\text{eff}}$, M_h, $(g-2)_\mu$, b physics, . . .

A) Theoretical prediction for M_W in terms

of $M_Z, \alpha, G_\mu, \Delta r$:

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

$\Updownarrow$

loop corrections

Evaluate Δr from μ decay $\Rightarrow M_W$

One-loop result for M_W in the SM:

[*A. Sirlin '80*] , [*W. Marciano, A. Sirlin '80*]

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

$$\sim \log\frac{M_Z}{m_f} \qquad \sim m_t^2 \qquad \log(M_H/M_W)$$

$$\sim 6\% \qquad \sim 3.3\% \qquad \sim 1\%$$

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$\Updownarrow$

loop corrections

B) Effective mixing angle:

$$\sin^2\theta_{\text{eff}}=\frac{1}{4\,|Q_f|}\left(1-\frac{\text{Re}\,g_V^f}{\text{Re}\,g_A^f}\right)$$

Higher order contributions:

$$g_V^f \to g_V^f+\Delta g_V^f, \quad g_A^f \to g_A^f+\Delta g_A^f$$

Corrections to M_W, $\sin^2\theta_{\rm eff}$ → approximation via the ρ-parameter:

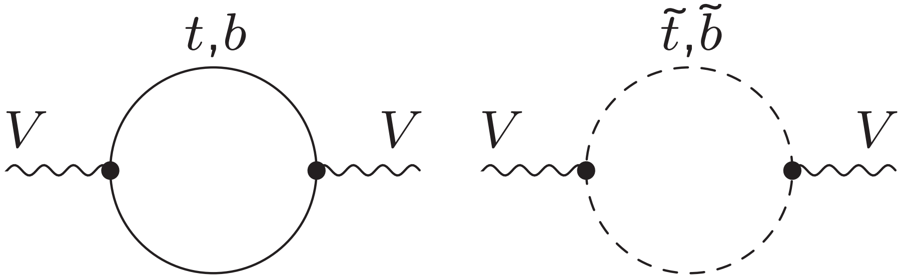
ρ measures the relative strength between
neutral current interaction and charged current interaction

$$\rho = \frac{1}{1 - \Delta\rho} \qquad \Delta\rho = \frac{\Sigma_Z(0)}{M_Z^2} - \frac{\Sigma_W(0)}{M_W^2}$$

(leading, process independent terms)

$\Delta\rho$ gives the main contribution to EW observables:

$$\Delta M_W \approx \frac{M_W}{2}\frac{c_{\rm W}^2}{c_{\rm W}^2 - s_{\rm W}^2}\Delta\rho, \qquad \Delta\sin^2\theta_W^{\rm eff} \approx -\frac{c_{\rm W}^2 s_{\rm W}^2}{c_{\rm W}^2 - s_{\rm W}^2}\Delta\rho$$



$\Delta\rho^{\rm SUSY}$ from $\tilde{t}/\tilde{b}$ loops > 0 $\quad \Rightarrow M_W^{\rm SUSY} \gtrsim M_W^{\rm SM}$, $\sin^2\theta_{\rm eff}^{\rm SUSY} \lesssim \sin^2\theta_{\rm eff}^{\rm SM}$

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SM result for M_W and $\sin^2\theta_{\text{eff}}$:

– full one-loop
– full two-loop
– leading 3-loop via $\Delta\rho$
– leading 4-loop via $\Delta\rho$

Our MSSM result for M_W and $\sin^2\theta_{\text{eff}}$:

– full SM result (via fit formel)
– full MSSM one-loop (incl. complex phases)
– all existing two-loop $\Delta\rho$ contributions

$\Rightarrow$ non-$\Delta\rho$ one-loop and $\Delta\rho$ two-loop contributions sometimes non-negligible!

The W boson mass

Experimental accuracy:

Today: LEP2, Tevatron: $M_W^{\text{exp}} = 80.385 \pm 0.015$ GeV

ILC: – polarized threshold scan
– kinematic reconstruction of W^+W^- [G. Wilson '13]
– hadronic mass (single W)

$$\delta M_W^{\text{exp,ILC}} \lesssim 3 \text{ MeV}$$

Theoretical accuracies:

intrinsic today: $\delta M_W^{\text{SM,theo}} = 4$ MeV, $\delta M_W^{\text{MSSM,today}} = 5 - 10$ MeV

intrinsic future: $\delta M_W^{\text{SM,theo,fut}} = 2$ MeV, $\delta M_W^{\text{MSSM,today}} = 3 - 5$ MeV

parametric today: $\delta m_t = 0.9$ GeV, $\delta(\Delta\alpha_{\text{had}}) = 10^{-4}$, $\delta M_Z = 2.1$ MeV

$\delta M_W^{\text{para},m_t} = 5.5$ MeV, $\delta M_W^{\text{para},\Delta\alpha_{\text{had}}} = 2$ MeV, $\delta M_W^{\text{para},M_Z} = 2.5$ MeV

parametric future: $\delta m_t^{\text{ILC}} = 0.1$ GeV, $\delta(\Delta\alpha_{\text{had}})^{\text{fut}} = 5 \times 10^{-5}$

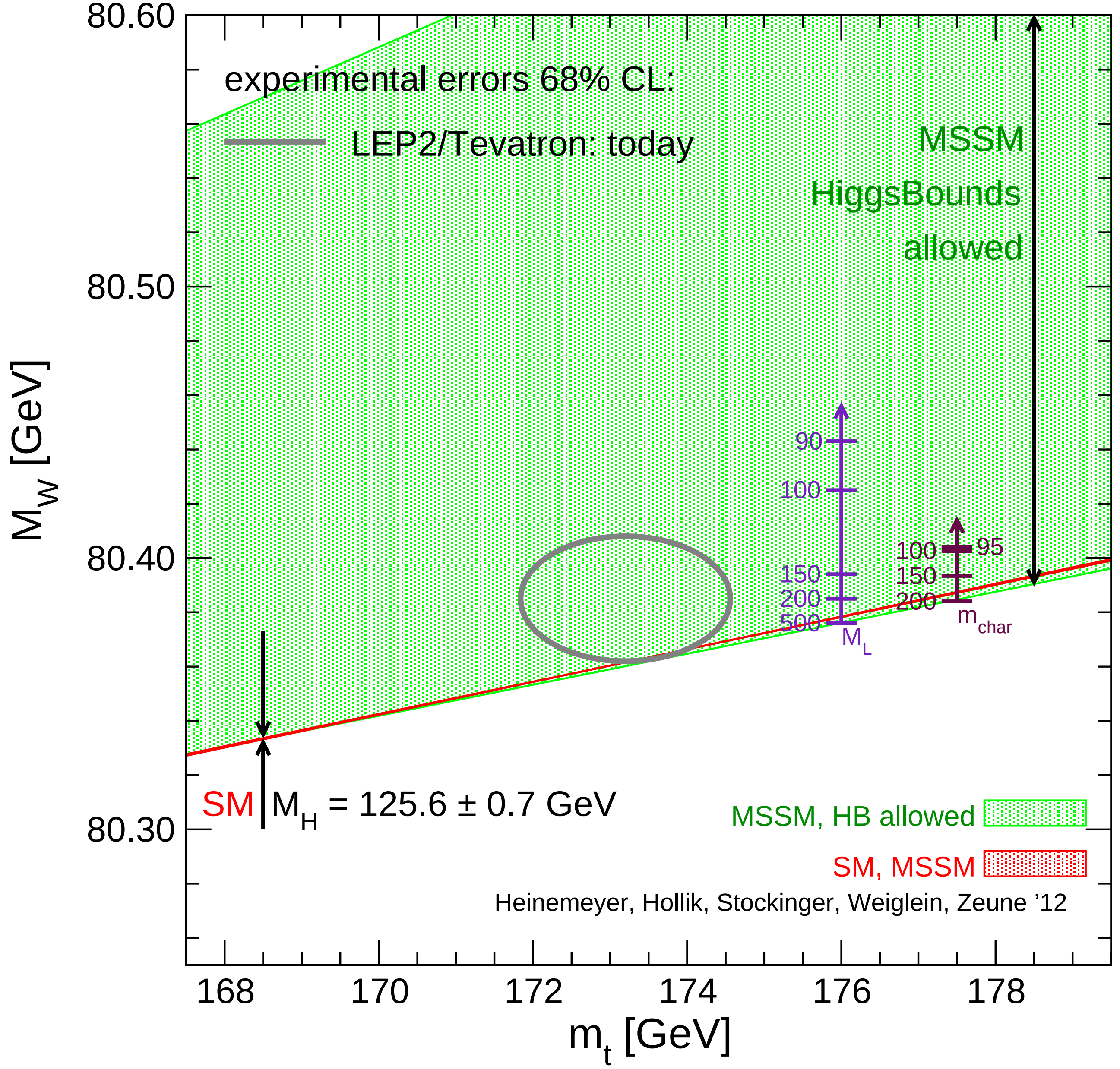
$$\Delta M_W^{\text{para,fut},m_t} = 1 \text{ MeV}, \quad \Delta M_W^{\text{para,fut},\Delta\alpha_{\text{had}}} = 1 \text{ MeV}$$

2. M_W in the MSSM: current data

$\Rightarrow$ extensive 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

Effects of charginos and staus:



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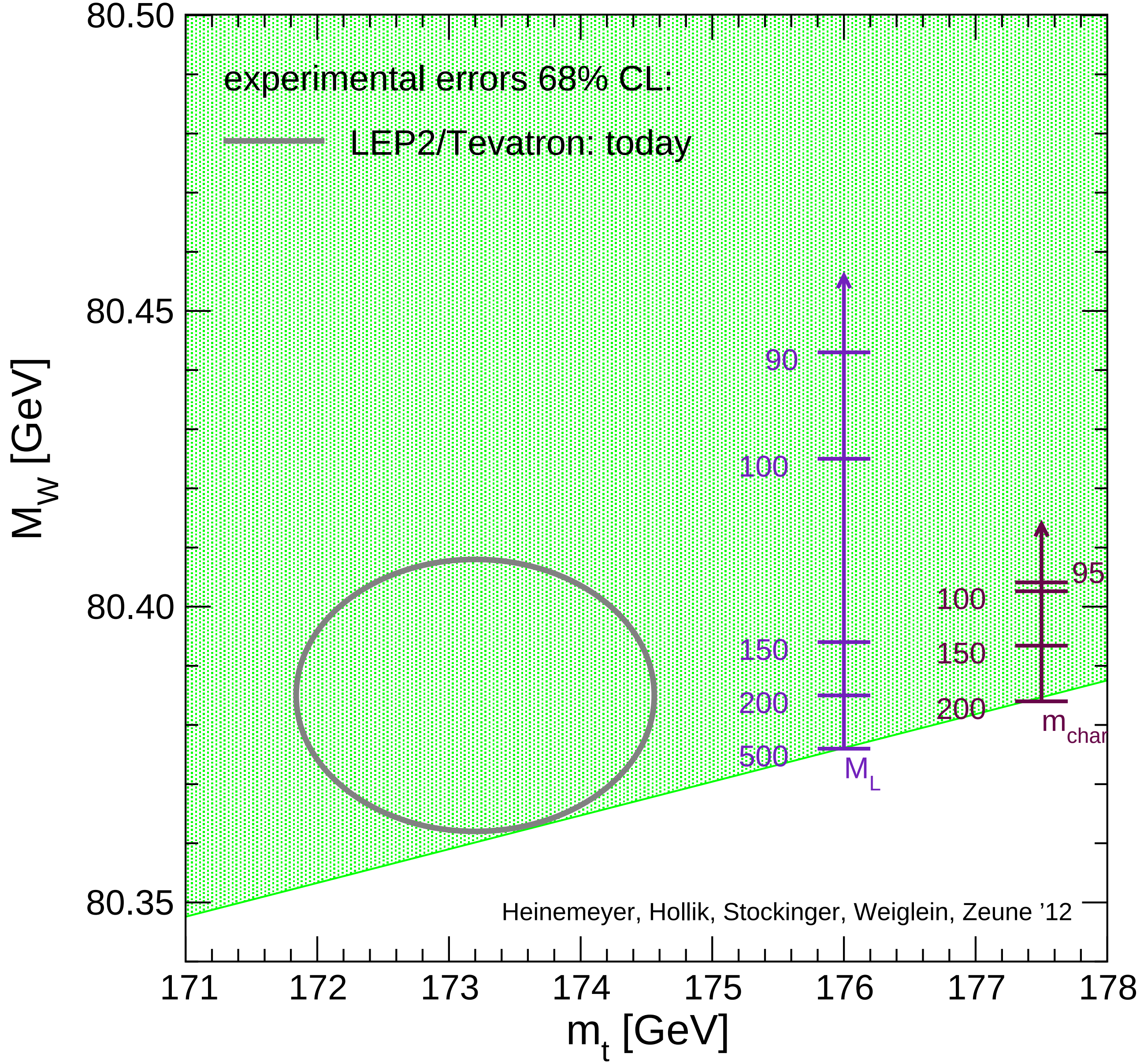
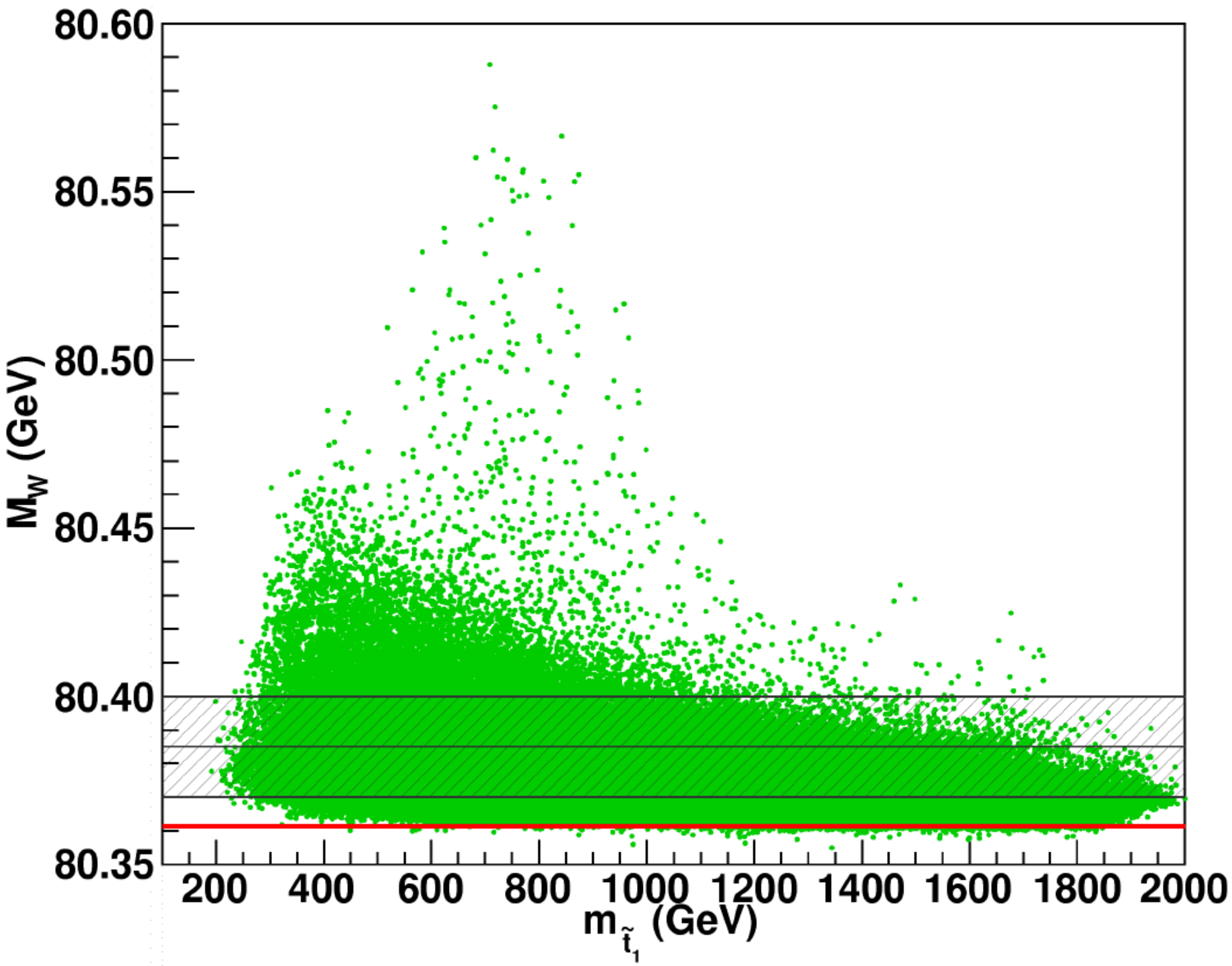
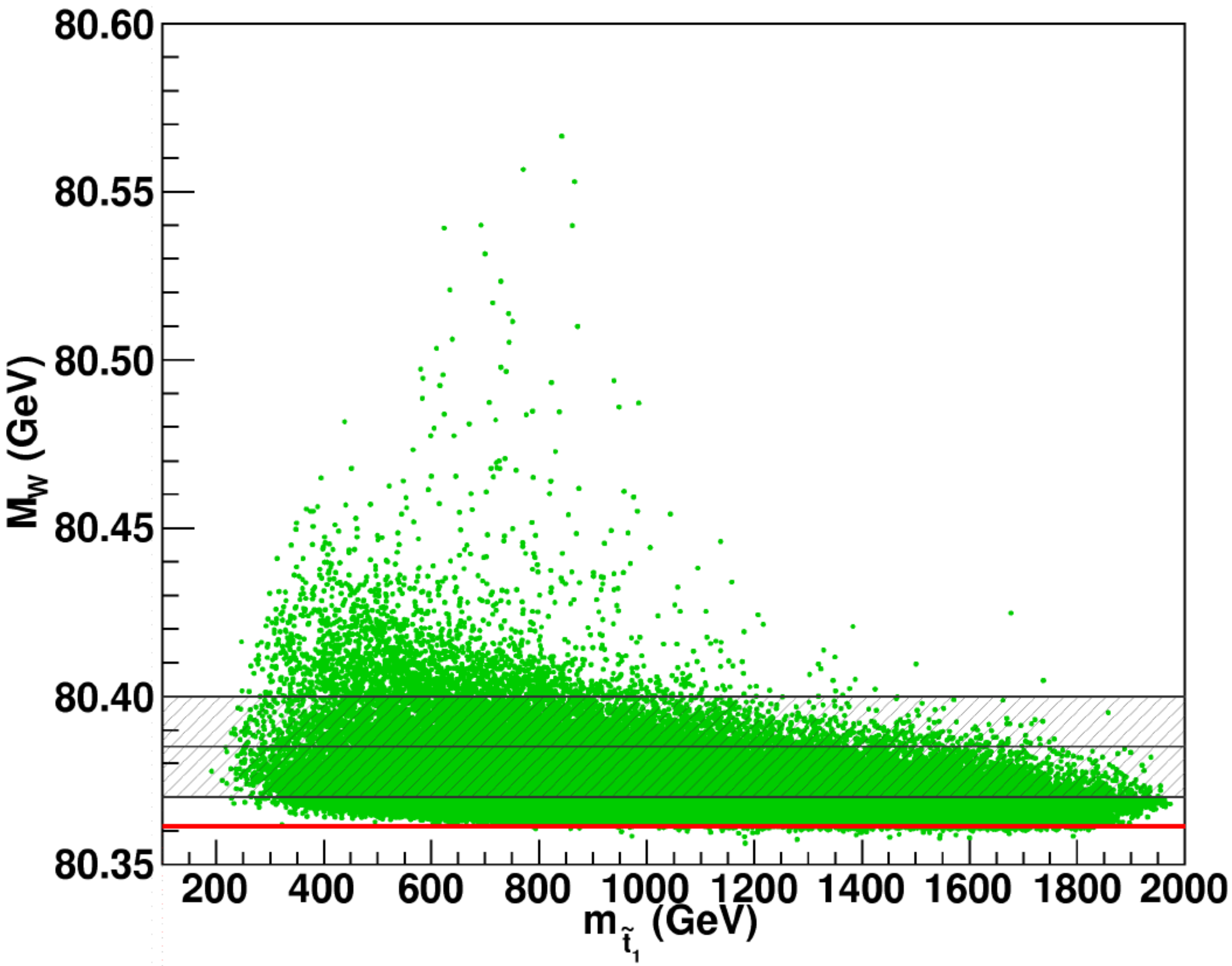


Effects of stops:



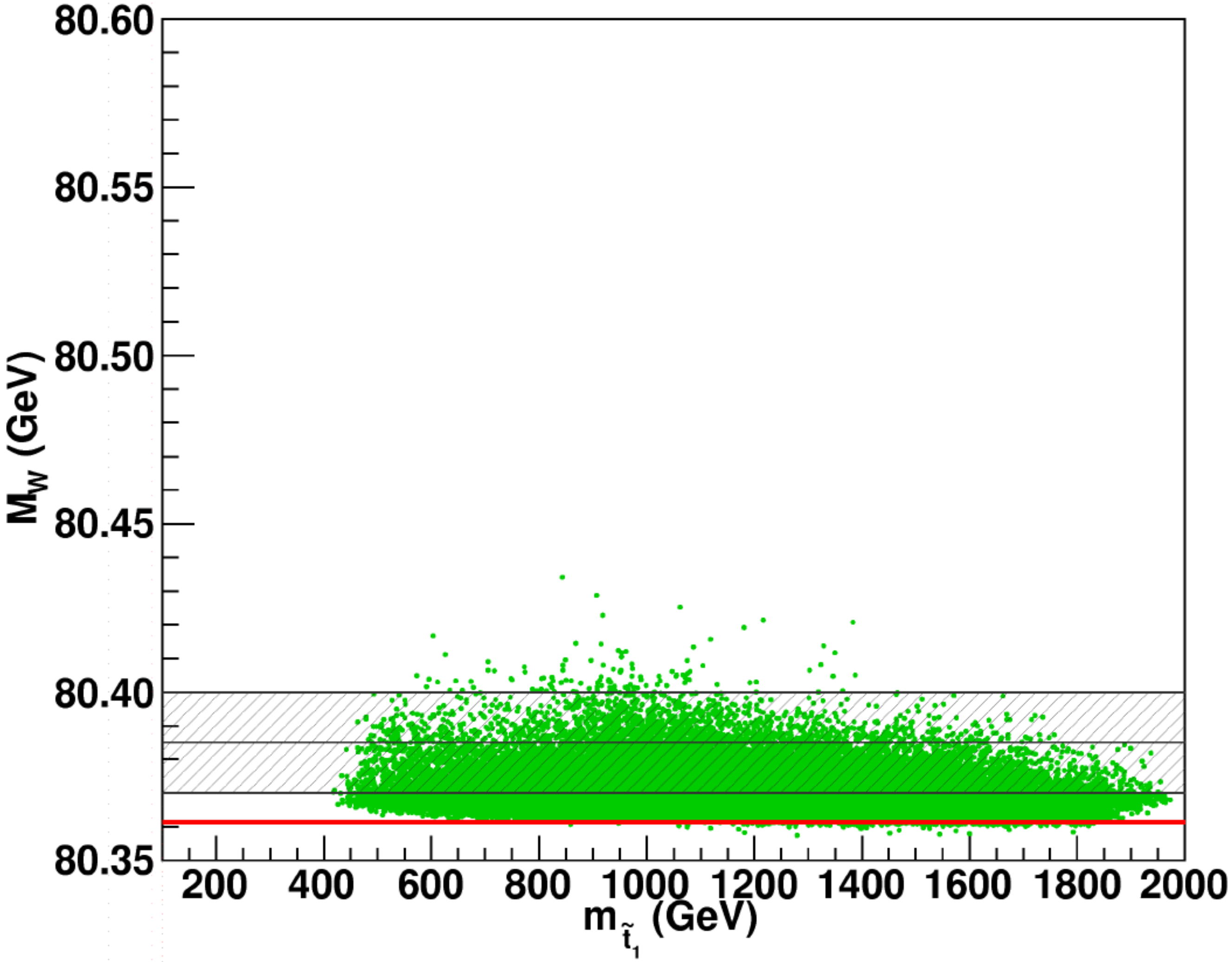
All points HiggsBounds allowed

Effects of stops:



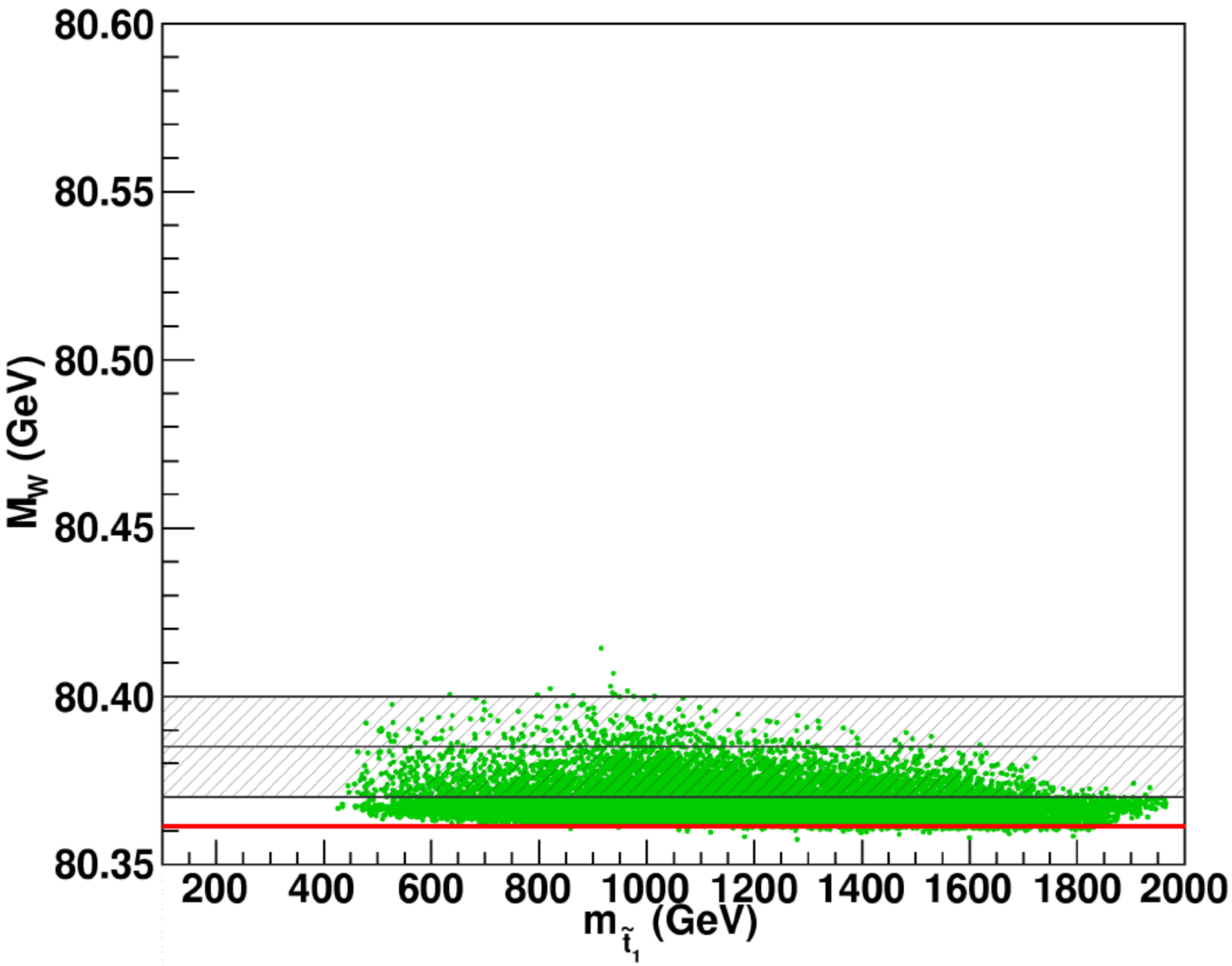
$\ldots \oplus\ m_{\tilde{q}_{1,2}}, m_{\tilde{g}} > 1200$ GeV

Effects of stops:



$\ldots \oplus m_{\tilde{b}_i} > 500$ GeV

Effects of stops:

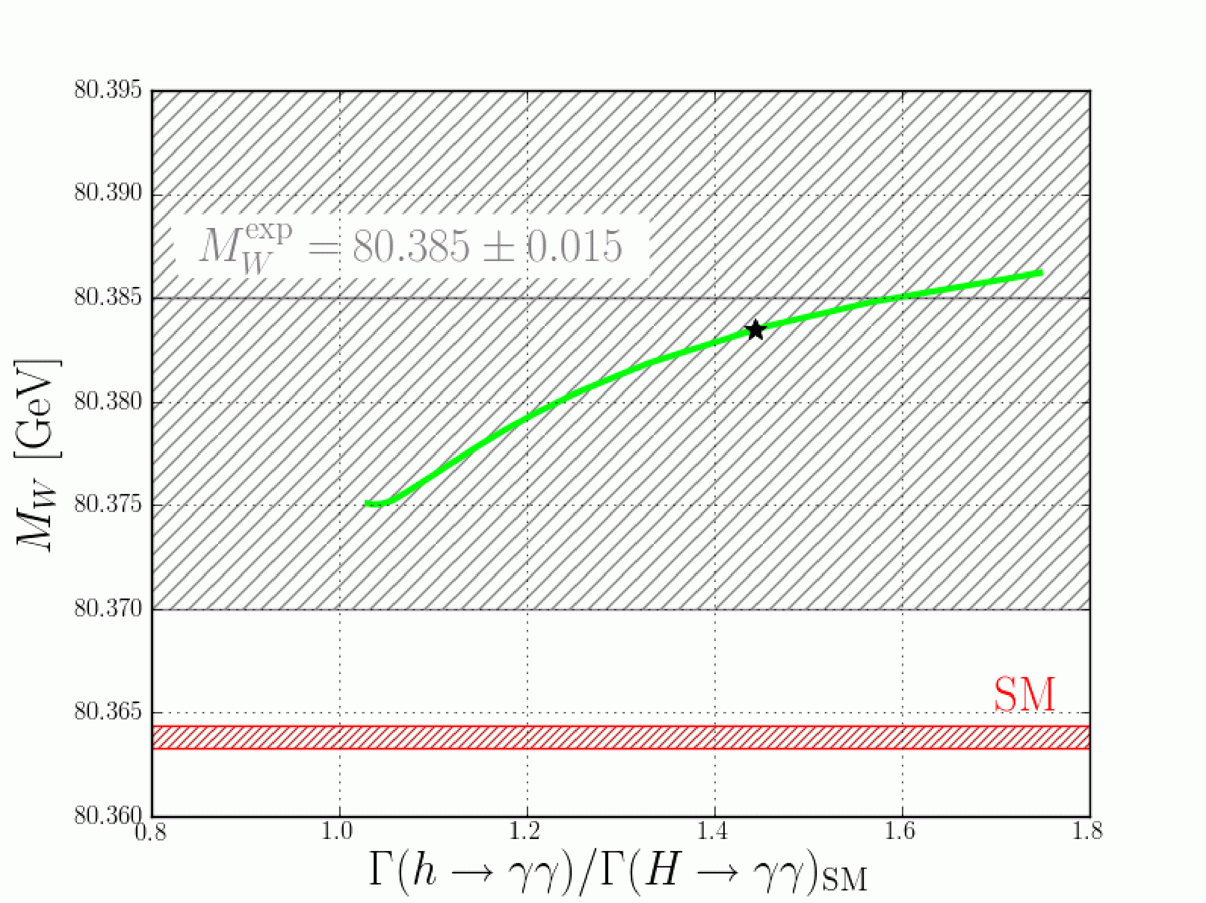


$\ldots \oplus\ m_{\tilde{l}}, m_{\tilde{\chi}_i^\pm}, m_{\tilde{\chi}_j^0} > 500$ GeV

Effect of light scalar taus:

– can enhance $\Gamma(h \to \gamma\gamma)$

– can give contribution to M_W



Szenario: pMSSM-7 best fit point
with $M_{\tilde{E}_3} = M_{\tilde{L}_3}$ varied from 280 GeV to 500 GeV

3. M_W in the MSSM: future data

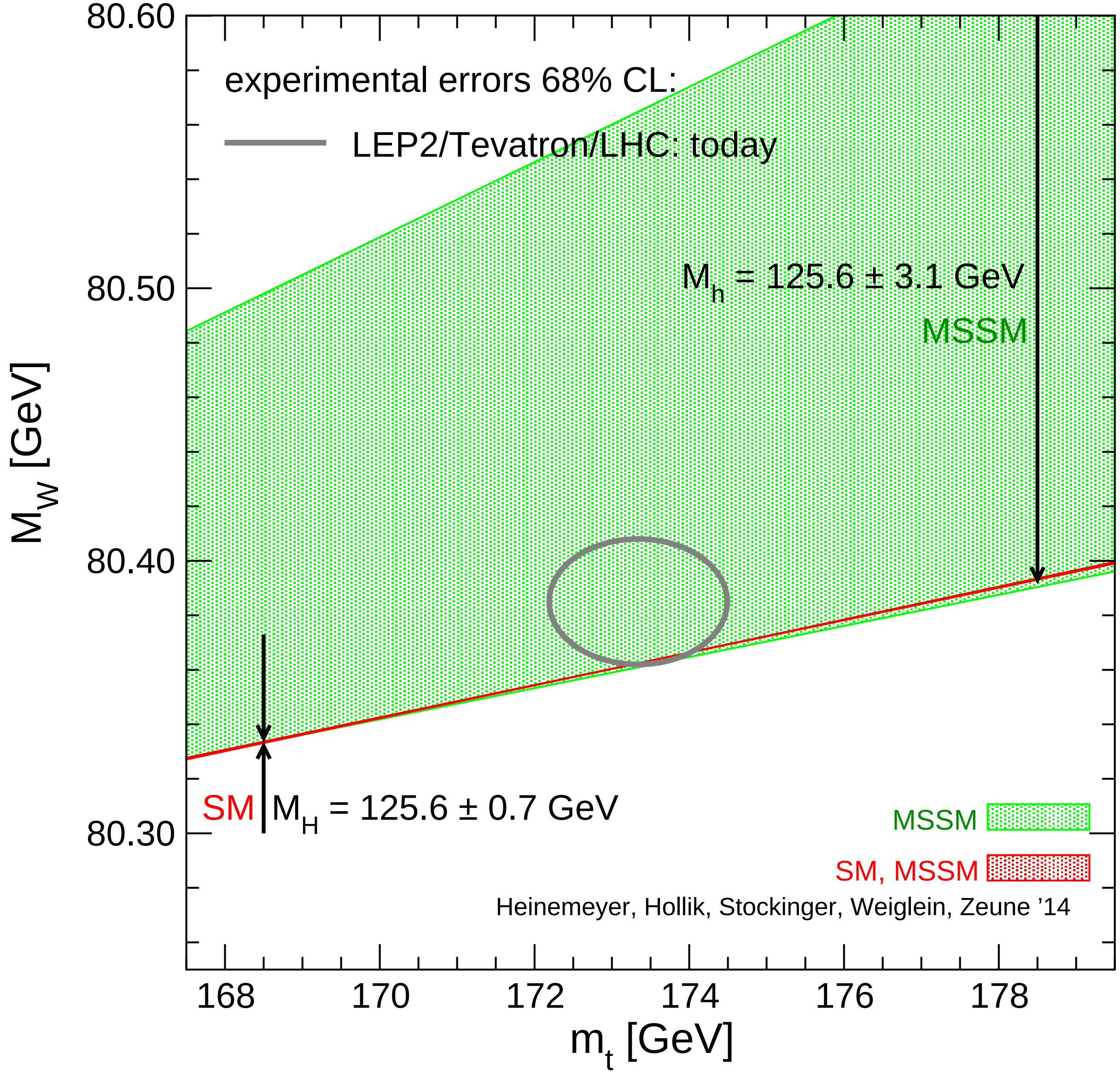
$\Rightarrow$ extensive parameter scan as before

Szenarios:

1. Assume lower limits on parameters
   $\Rightarrow$ analyze agreement between MSSM prediction and data

2. Assume some measurement: $m_{\tilde{t}_1} = 400 \pm 40$ GeV
   and lower limits for everything else
   $\Rightarrow$ prediction for other SUSY particles?

Interpreting the Higgs discovery in the MSSM:



$\Rightarrow$ agreement better than with SM

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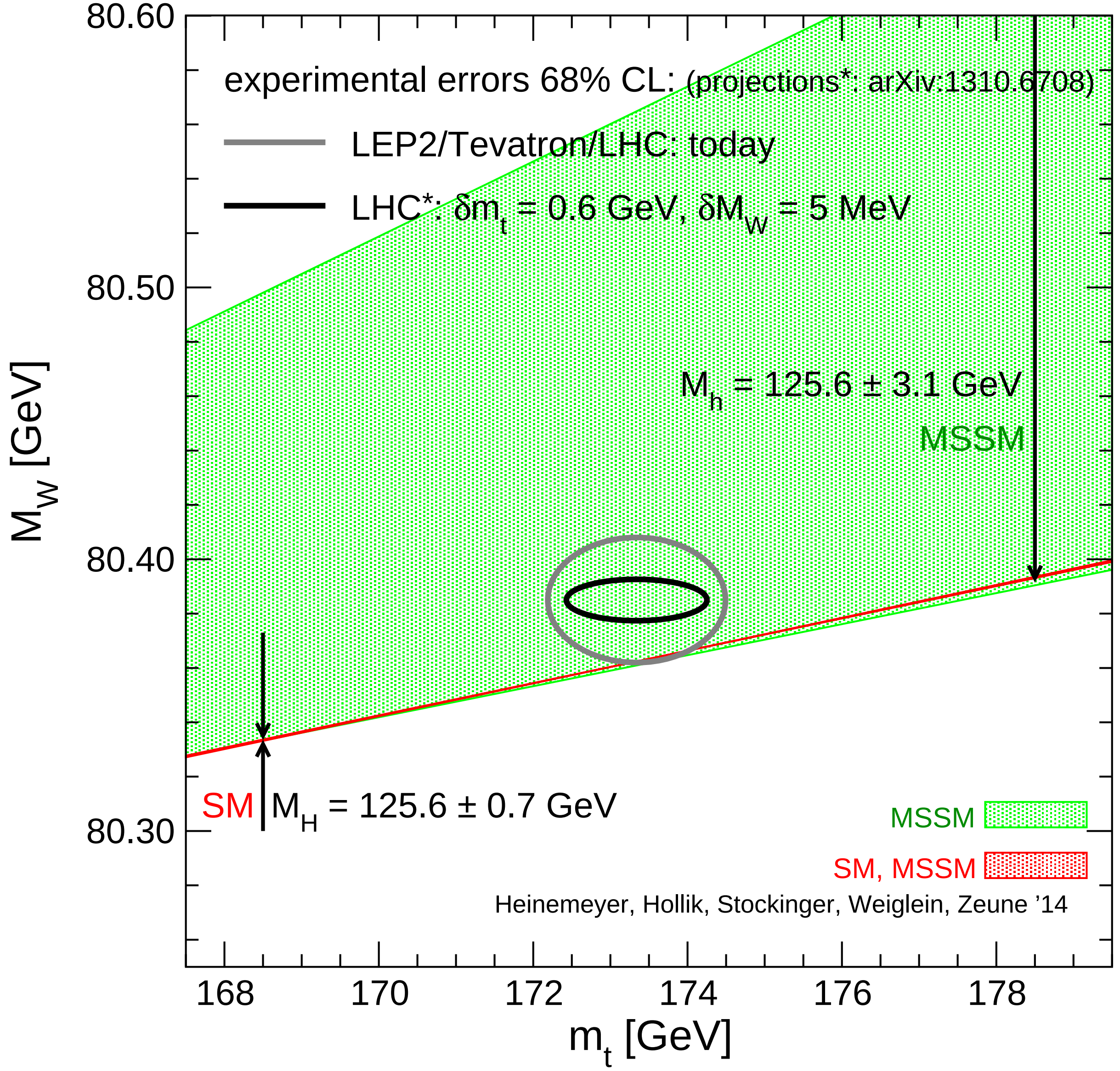

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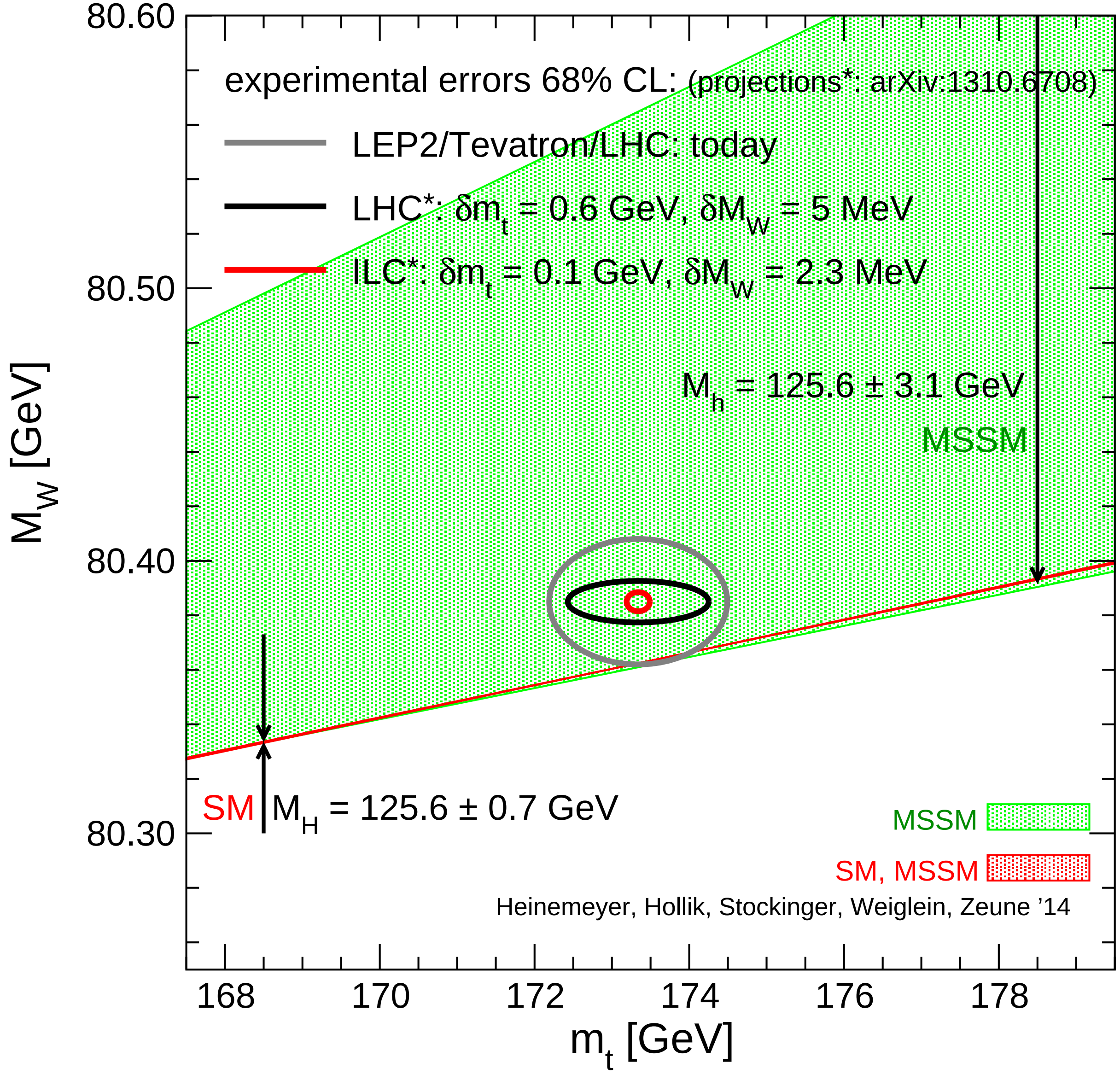

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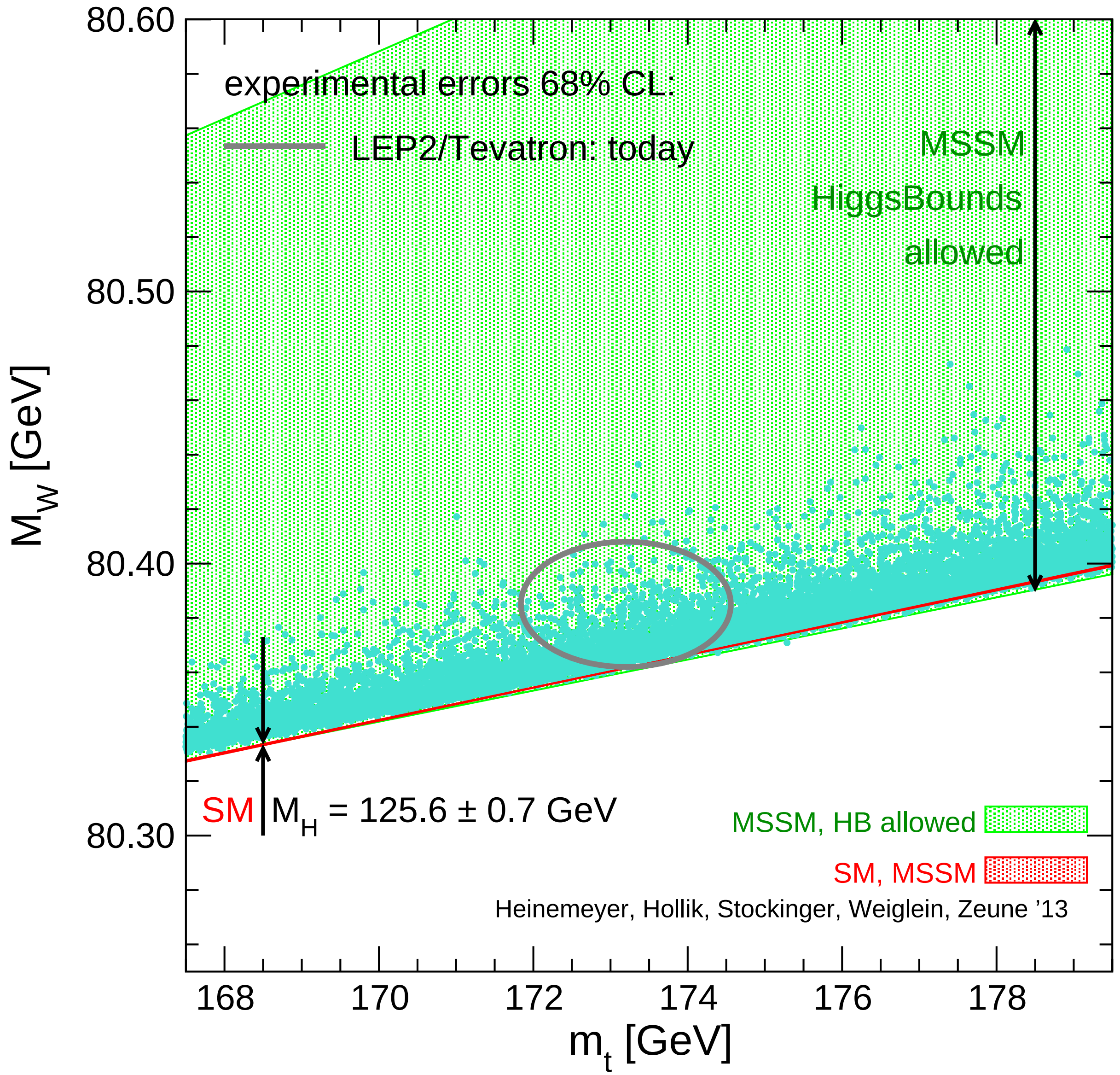
Szenario 1: Effects of stops, sbottoms, M_h:



light blue: $m_{\tilde{t}_i}, m_{\tilde{b}_j} > 500$ GeV, $m_{\tilde{q}_{1,2}}, m_{\tilde{g}} > 1200$ GeV

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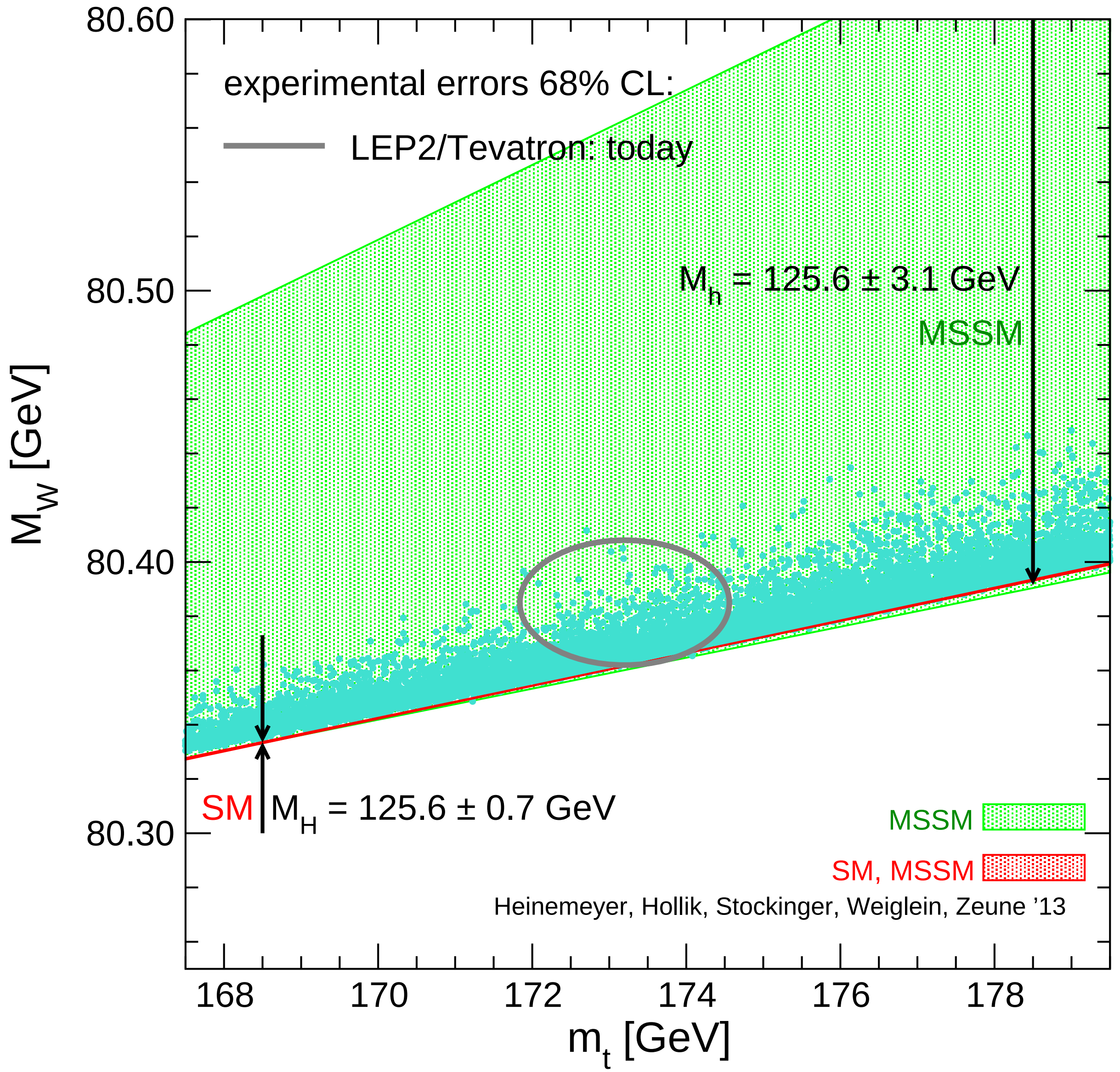
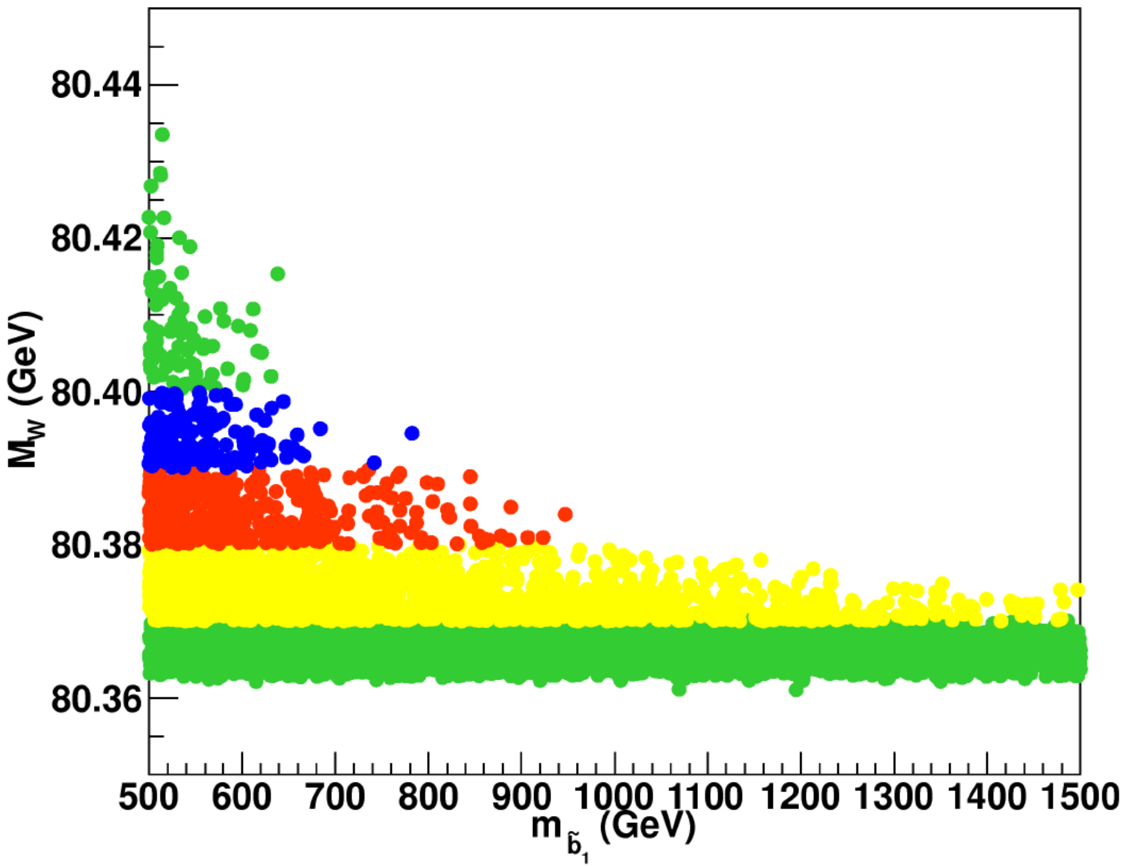


light blue: $m_{\tilde{t}_i}, m_{\tilde{b}_j} > 500$ GeV, $m_{\tilde{q}_{1,2}}, m_{\tilde{g}} > 1200$ GeV

Szenario 2:

$m_{\tilde{t}_1} = 400 \pm 40$ GeV, Other masses $\gtrsim 500$ GeV

$M_W^{\rm ILC} = 80.375 \pm 0.005$ GeV, 80.385 ± 0.005 GeV, 80.395 ± 0.005 GeV



⇒ clear prediction for light sbottom mass!

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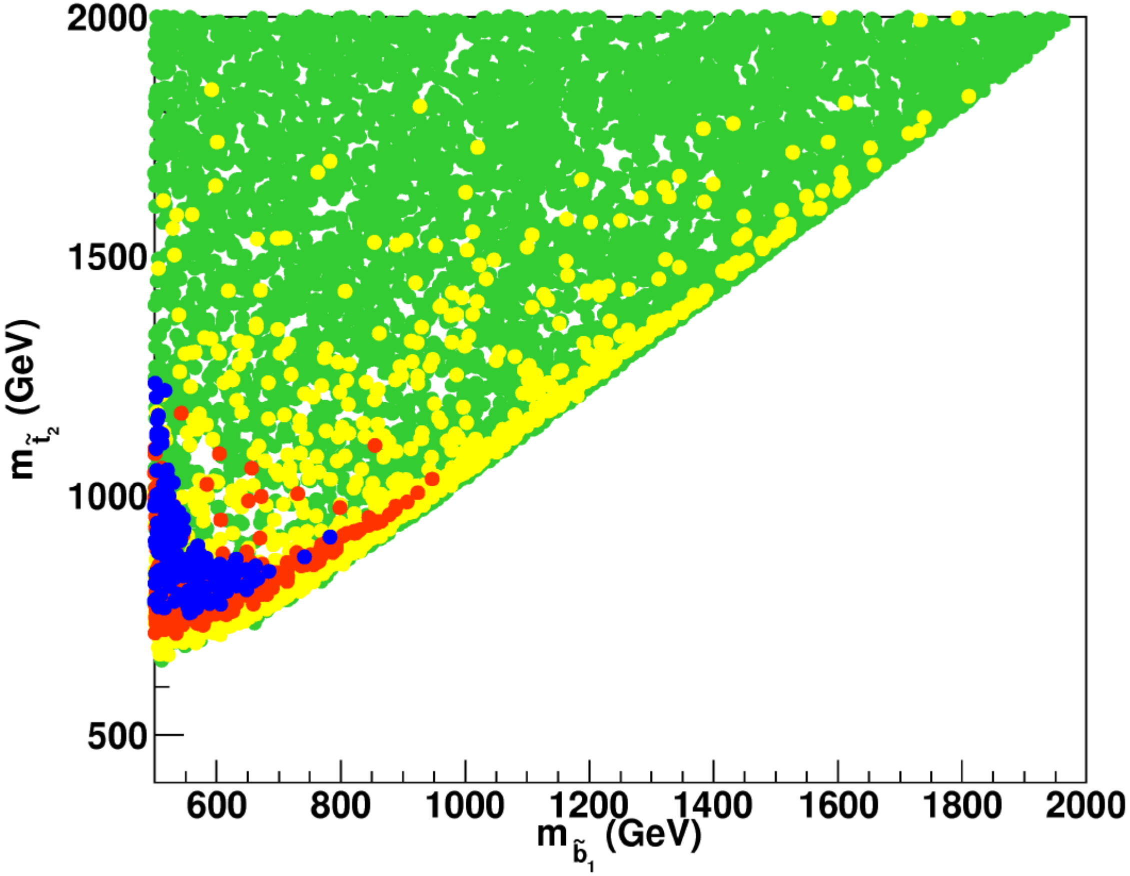

$\Rightarrow$ clear prediction for light sbottom and heavy stop mass!

4. Conclusinos

- EWPO can give valuable information about SM, BSM
  Best: M_W, $\sin^2\theta_{\text{eff}}$, ...

- SUSY corrections mainly via $\Delta\rho$, But also non-$\Delta\rho$ can be relevant

- Best prediction for M_W in the MSSM
  (including complex phases at one-loop)

- Effects of light SUSY particles on M_W:
  – light sleptons: $\sim$ 60 MeV
  – light charginos: $\sim$ 20 MeV
  – $m_{\tilde{t}_1} \lesssim$ 1.5 TeV can give exact M_W value

- Higgs discovery:
  – light Higgs at $\sim$ 125 GeV: very good agreement with M_W)
  – heavy Higgs at $\sim$ 125 GeV: still very good agreement (at least

- Future scenarios:
  – stops and sbottoms heavyer than 500 GeV: very good agreement
  – $m_{\tilde{t}_1} = 400 \pm 40$ GeV $\Rightarrow$ limits an $m_{\tilde{b}_1}$, $m_{\tilde{t}_2}$