

# $M_W$ in the MSSM

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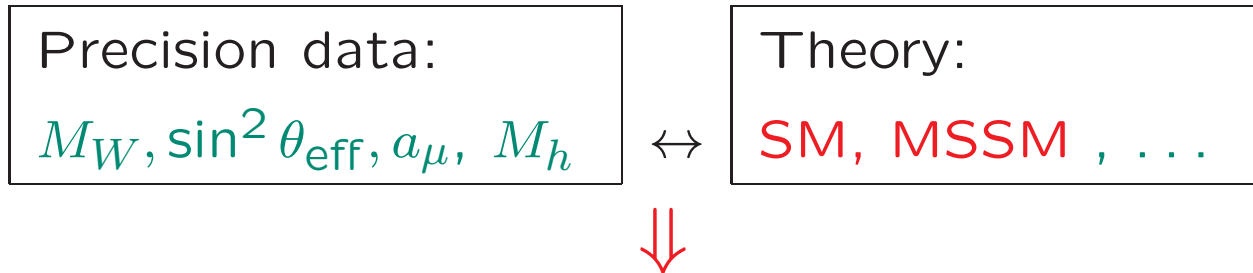
Tokyo, 11/2013

Based on a collaboration with  
*W. Hollik, G. Weiglein, L. Zeune*

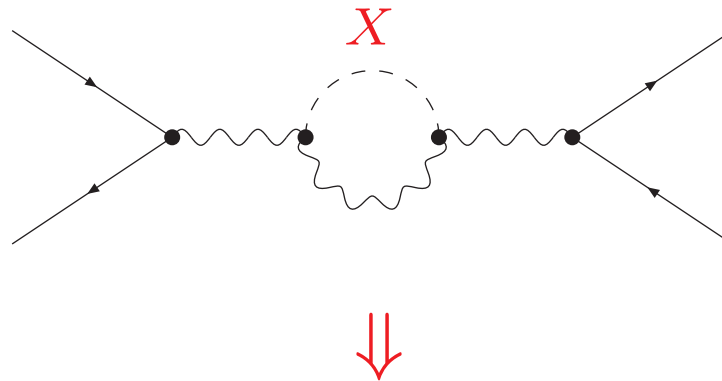
1. Introduction
2.  $M_W$  in the MSSM: current data
3.  $M_W$  in the MSSM: future data
4. Conclusions

# 1. Introduction

Comparison of observables with theory:



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

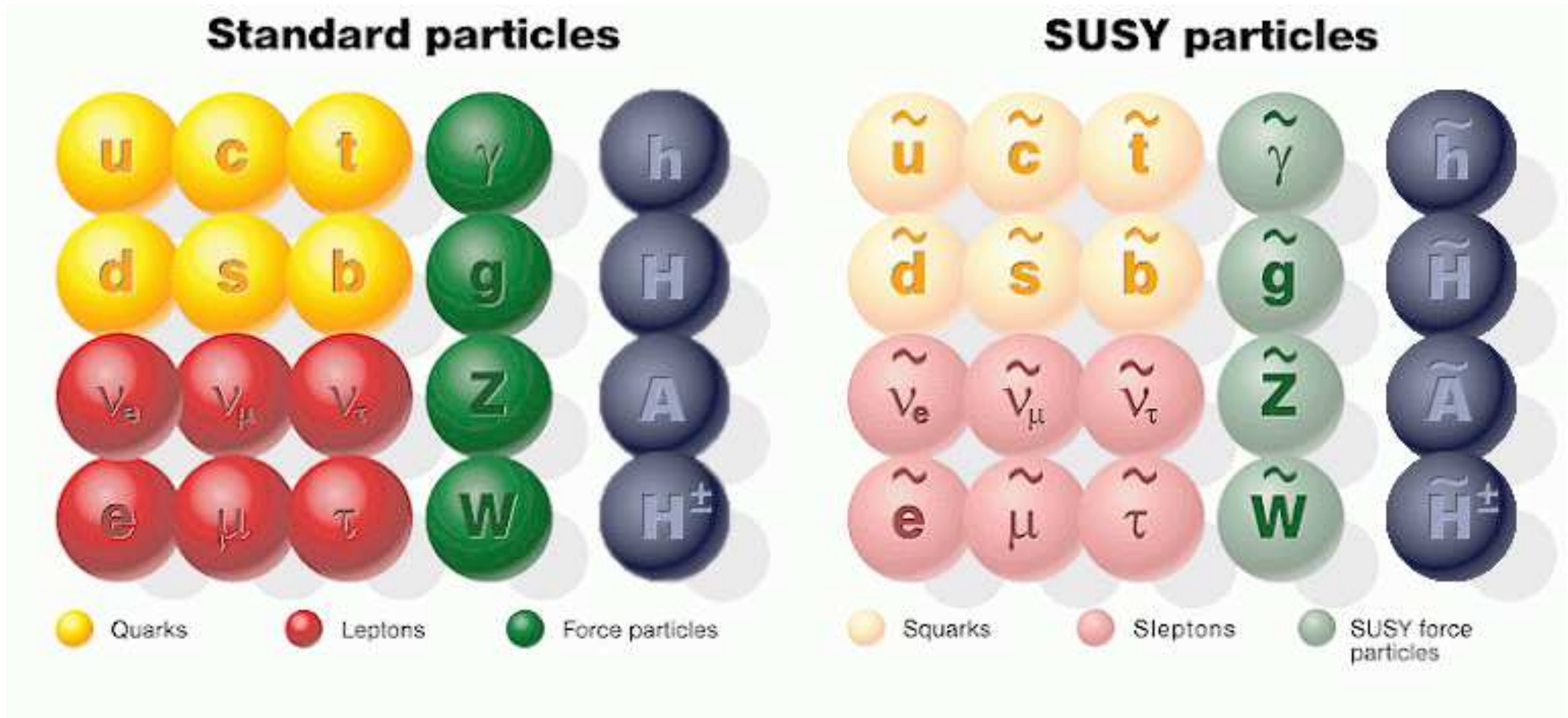


BSM: limits on  $M_X$

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

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



loop corrections

Evaluate  $\Delta r$  from  $\mu$  decay  $\Rightarrow M_W$

One-loop result for  $M_W$  in the SM:

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

$$\begin{aligned} \Delta r_{1\text{-loop}} = & \quad \Delta\alpha & - & \quad \frac{c_W^2}{s_W^2} \Delta\rho & + & \quad \Delta r_{\text{rem}}(M_H) \\ & \sim \log \frac{M_Z}{m_f} & & \sim m_t^2 & & \log(M_H/M_W) \\ & \sim 6\% & & \sim 3.3\% & & \sim 1\% \end{aligned}$$

## Precision observables in the SM and the MSSM

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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:

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

## Corrections to $M_W$ , $\sin^2 \theta_{\text{eff}}$ $\rightarrow$ approximation via the $\rho$ -parameter:

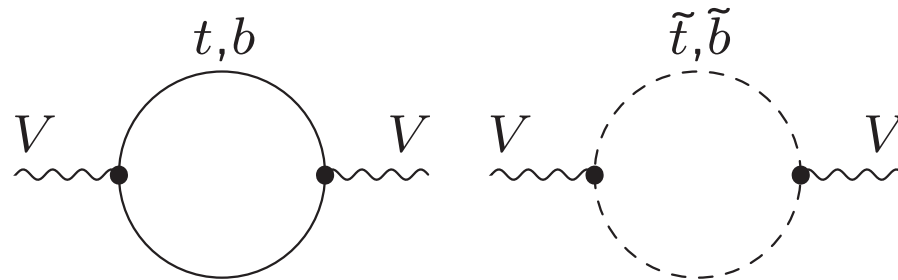
$\rho$  measures the relative strength between  
neutral current interaction and charged current interaction

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

(leading, process independent terms)

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

$$\Delta M_W \approx \frac{M_W}{2} \frac{c_W^2}{c_W^2 - s_W^2} \Delta\rho, \quad \Delta \sin^2 \theta_W^{\text{eff}} \approx -\frac{c_W^2 s_W^2}{c_W^2 - s_W^2} \Delta\rho$$



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

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

- ILC:** – polarized threshold scan  
– kinematic reconstruction of  $W^+W^-$   
– hadronic mass (single  $W$ )

[G. Wilson '13]

$$\delta M_W^{\text{exp,ILC}} \lesssim 5 \text{ MeV}$$

### Theoretical accuracies:

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

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

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

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

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

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

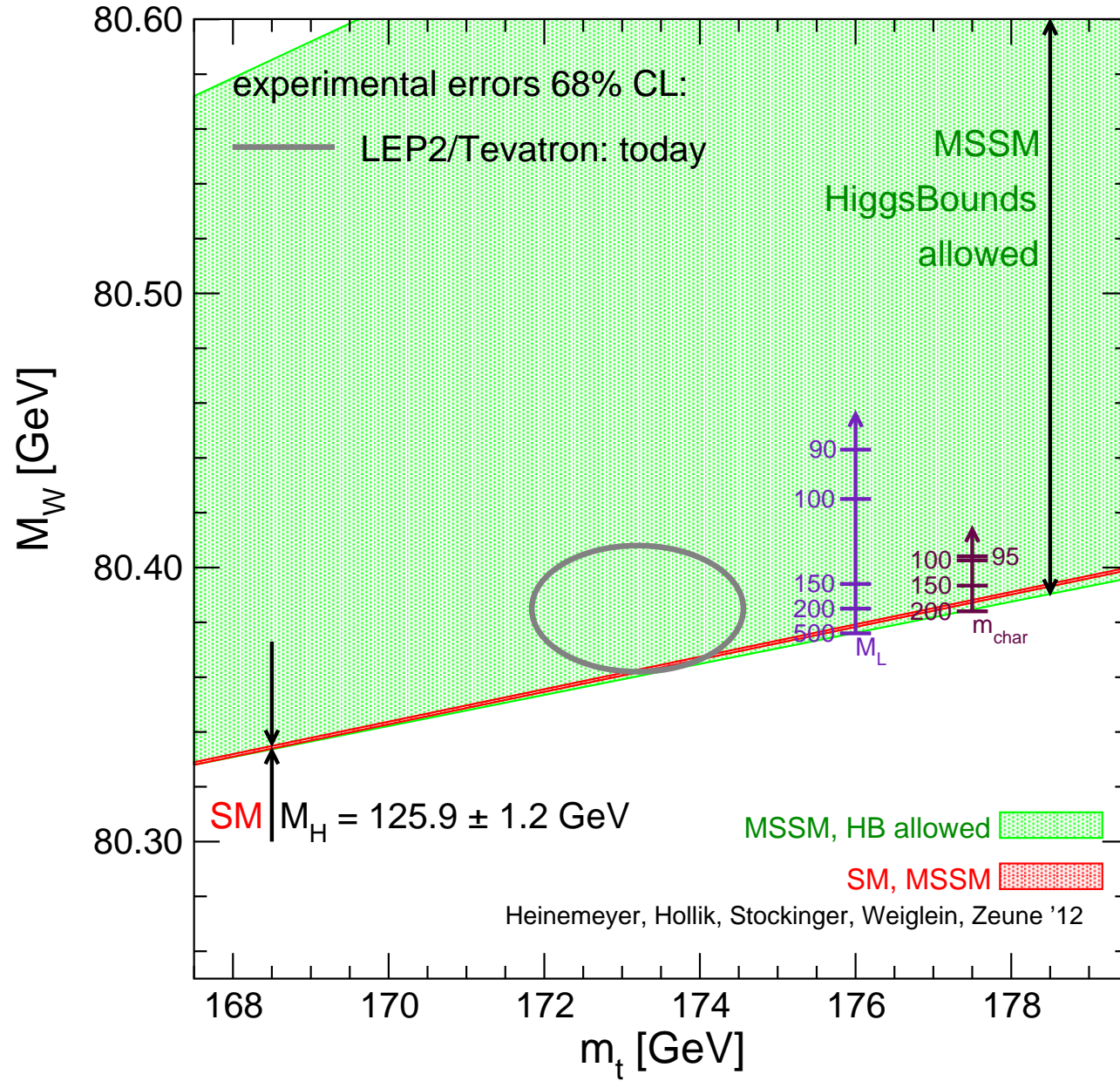


## 2. $M_W$ in the MSSM: current data

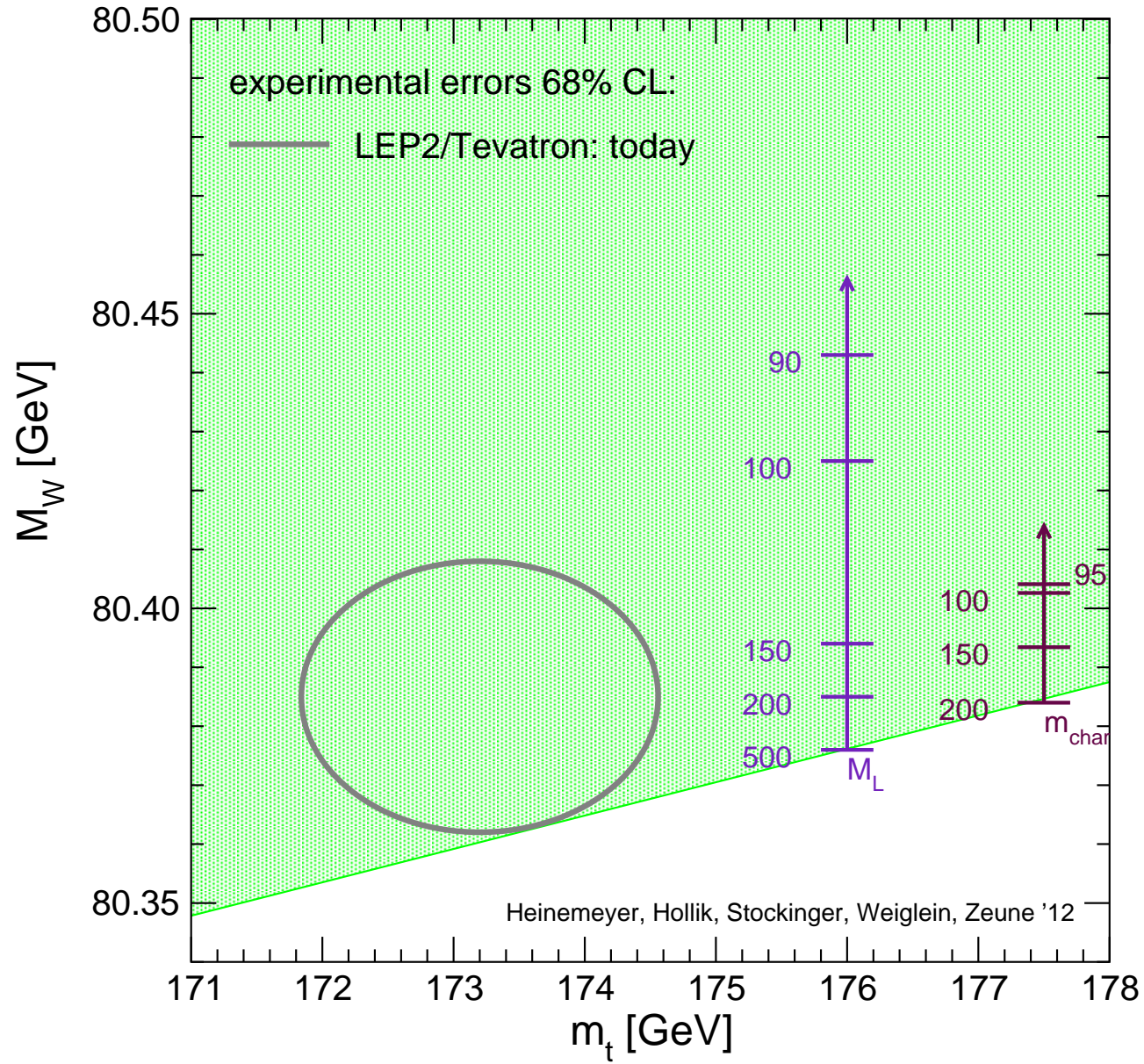
⇒ extensive parameter scan:

Parameter	Minimum	Maximum
$\mu$	-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

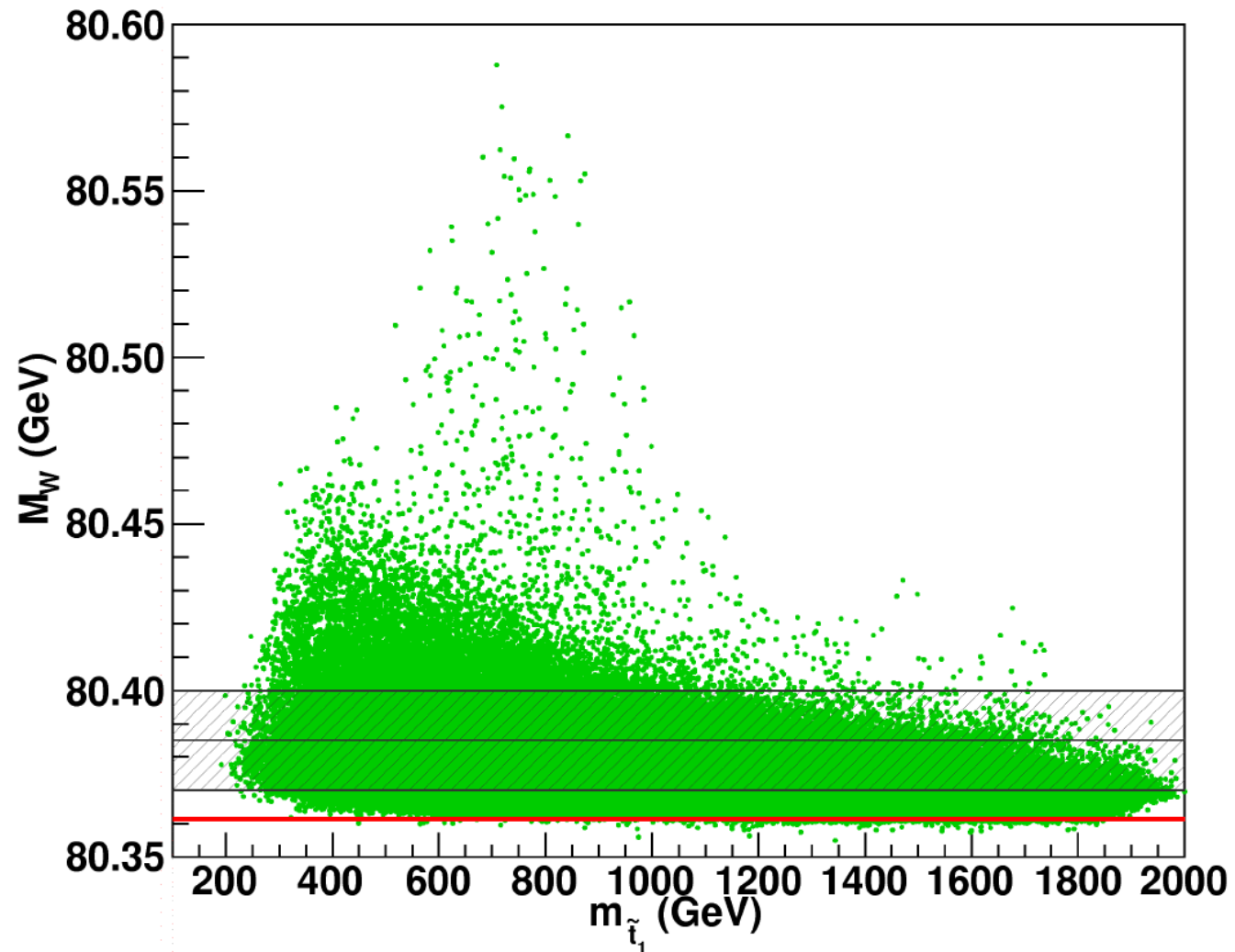
# Effects of charginos and staus:



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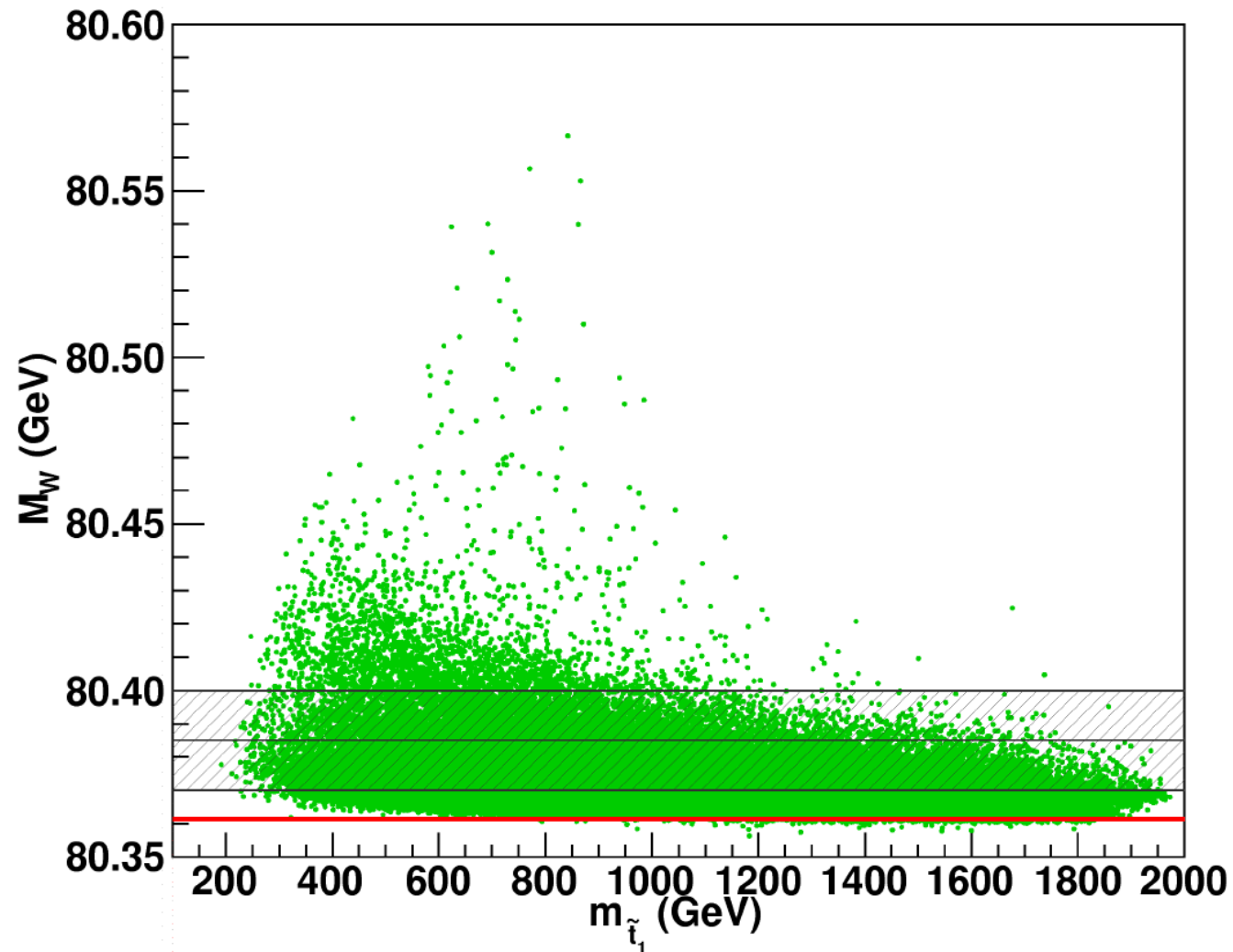


## Effects of stops:



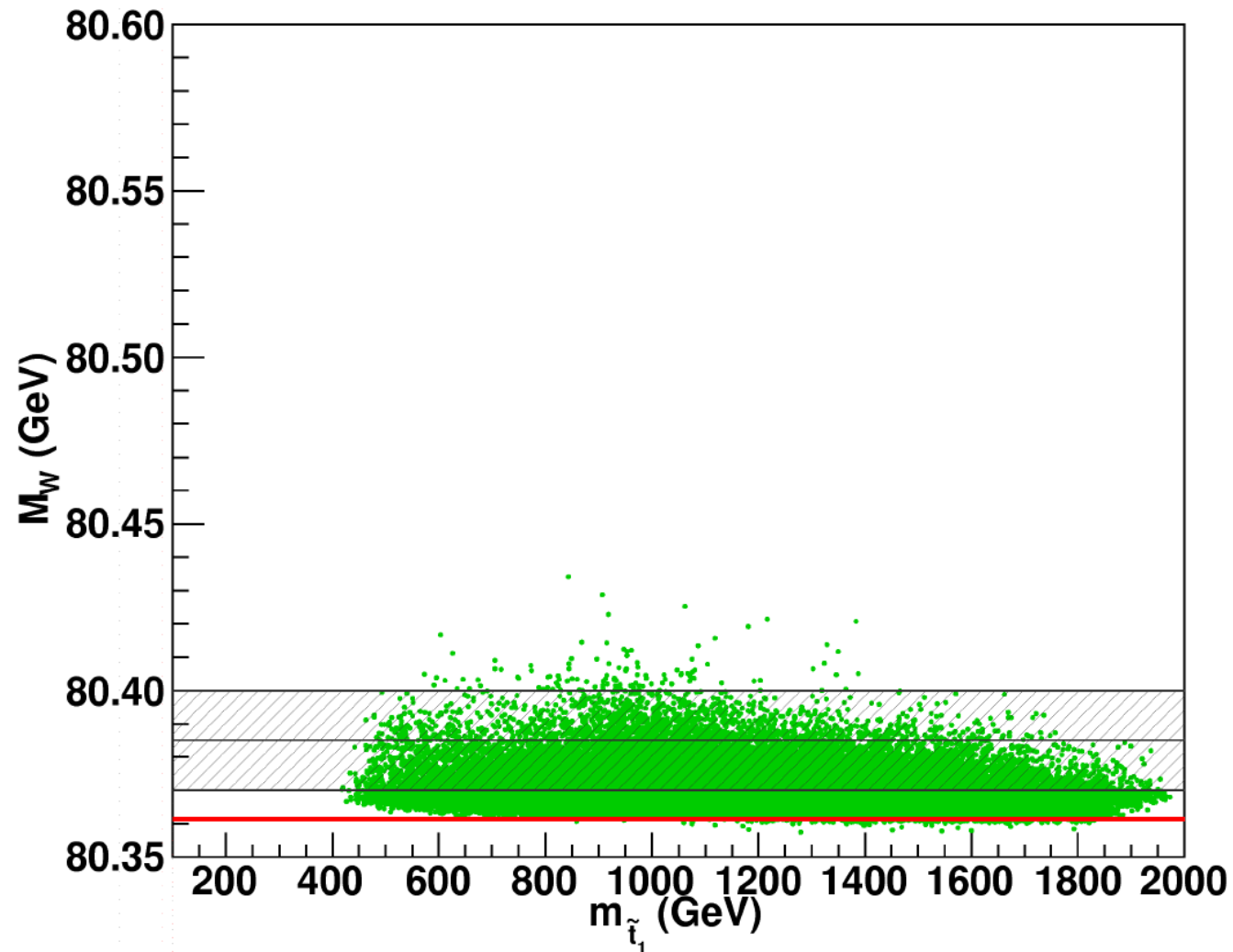
All points HiggsBounds allowed

Effects of stops:



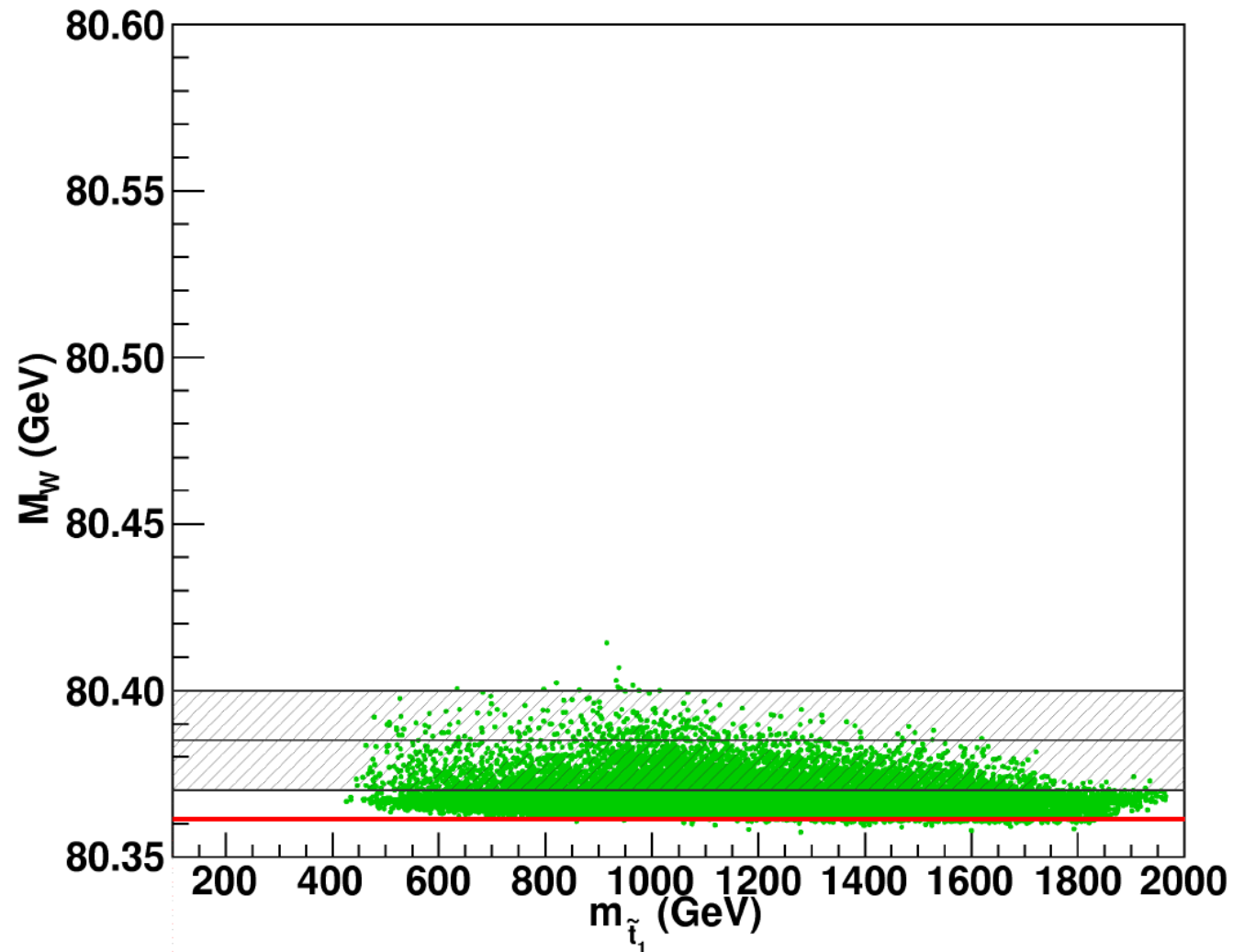
...  $\oplus m_{\tilde{q}_{1,2}}, m_{\tilde{g}} > 1200$  GeV

## Effects of stops:



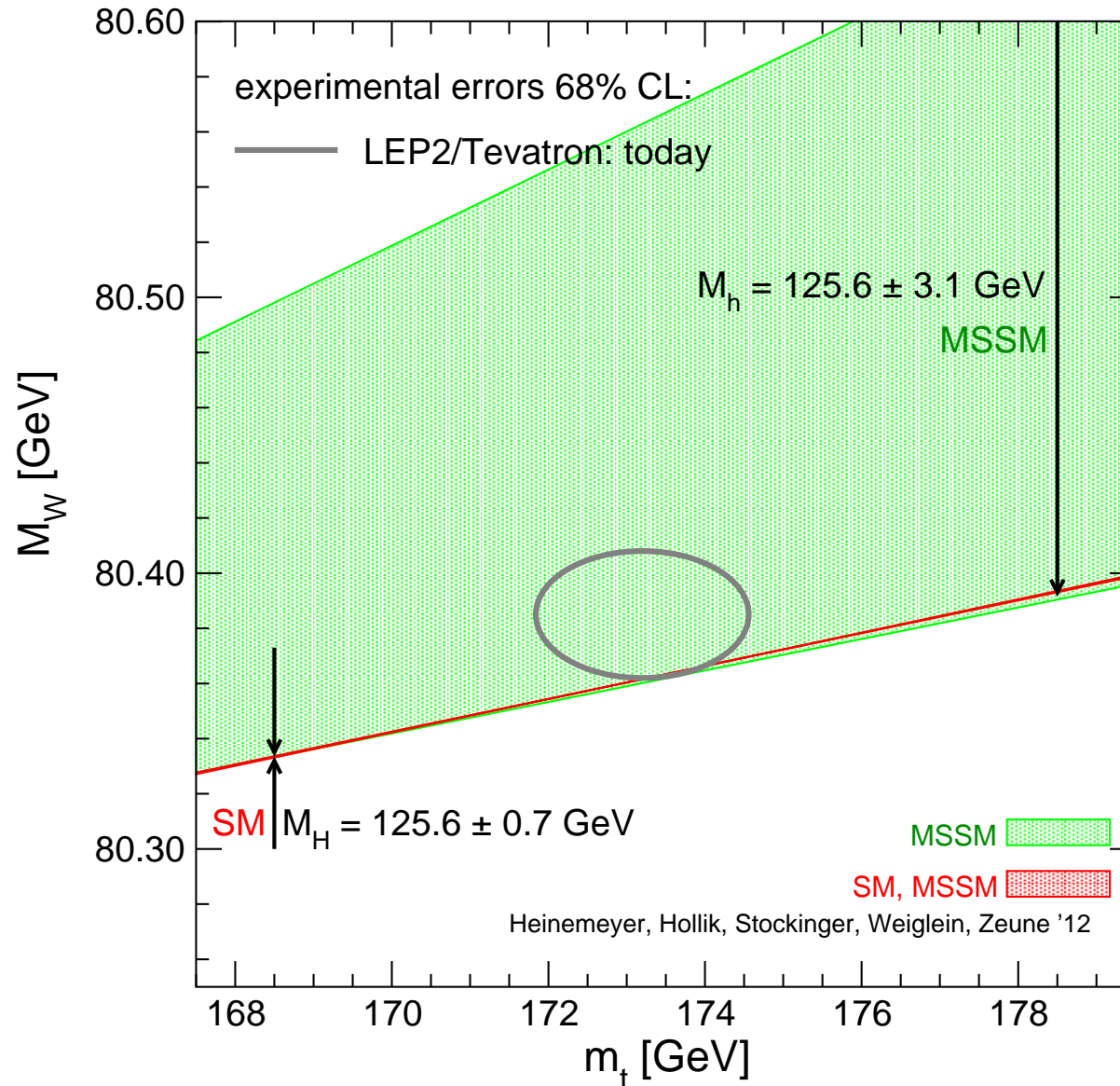
...  $\oplus m_{\tilde{b}_i} > 500$  GeV

## Effects of stops:



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

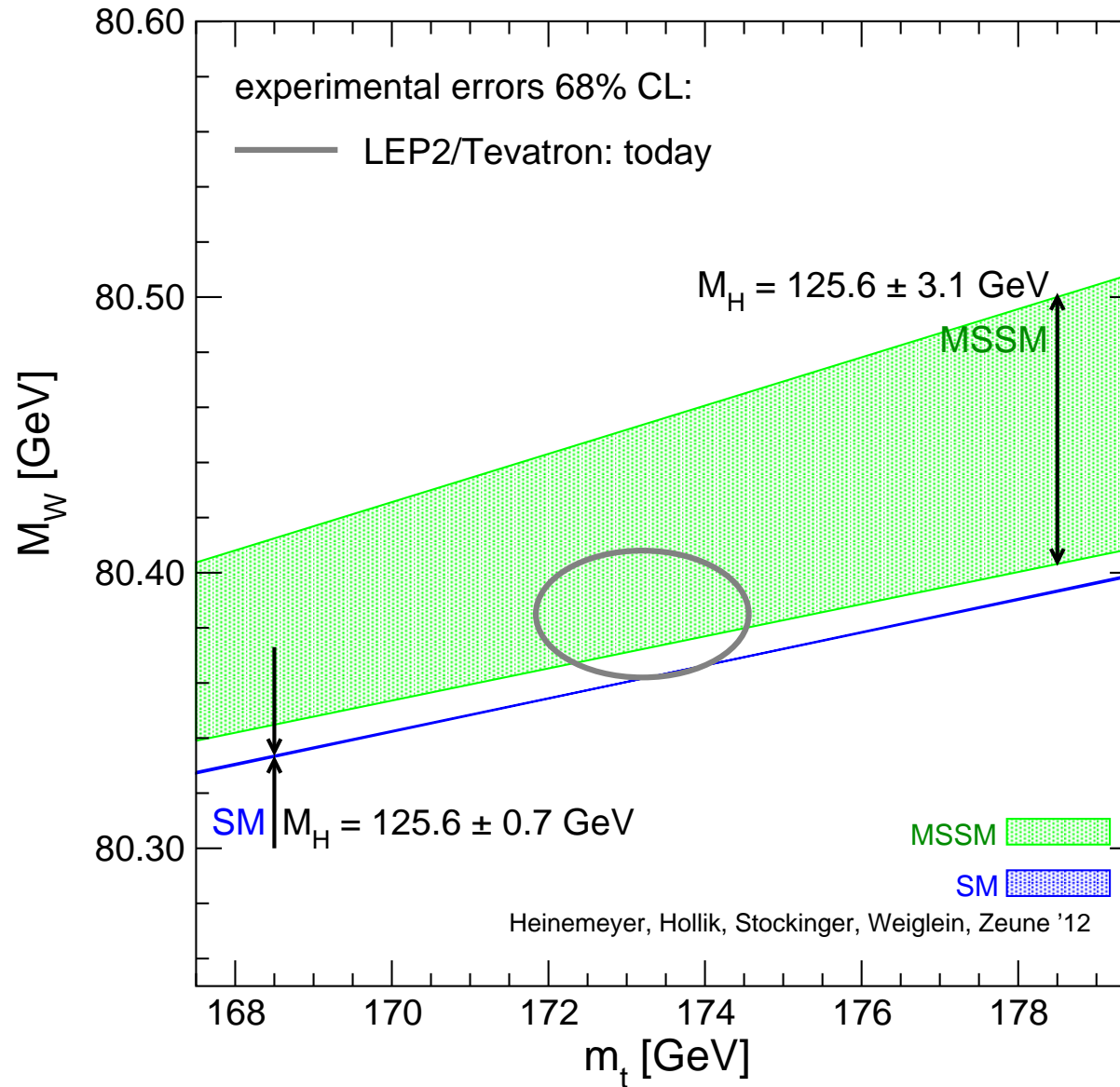
# Interpreting the Higgs discovery in the MSSM:



⇒ agreement better than with SM



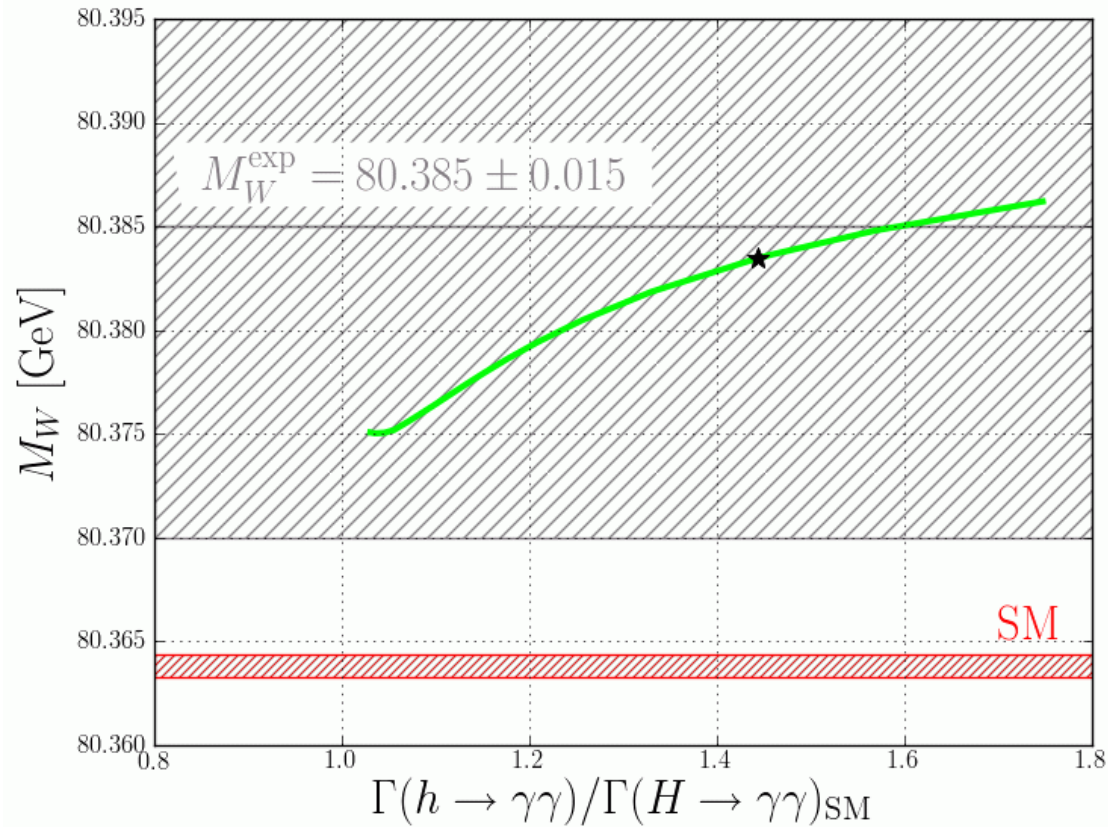
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## Effect of light scalar taus:

- can enhance  $\Gamma(h \rightarrow \gamma\gamma)$
- 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

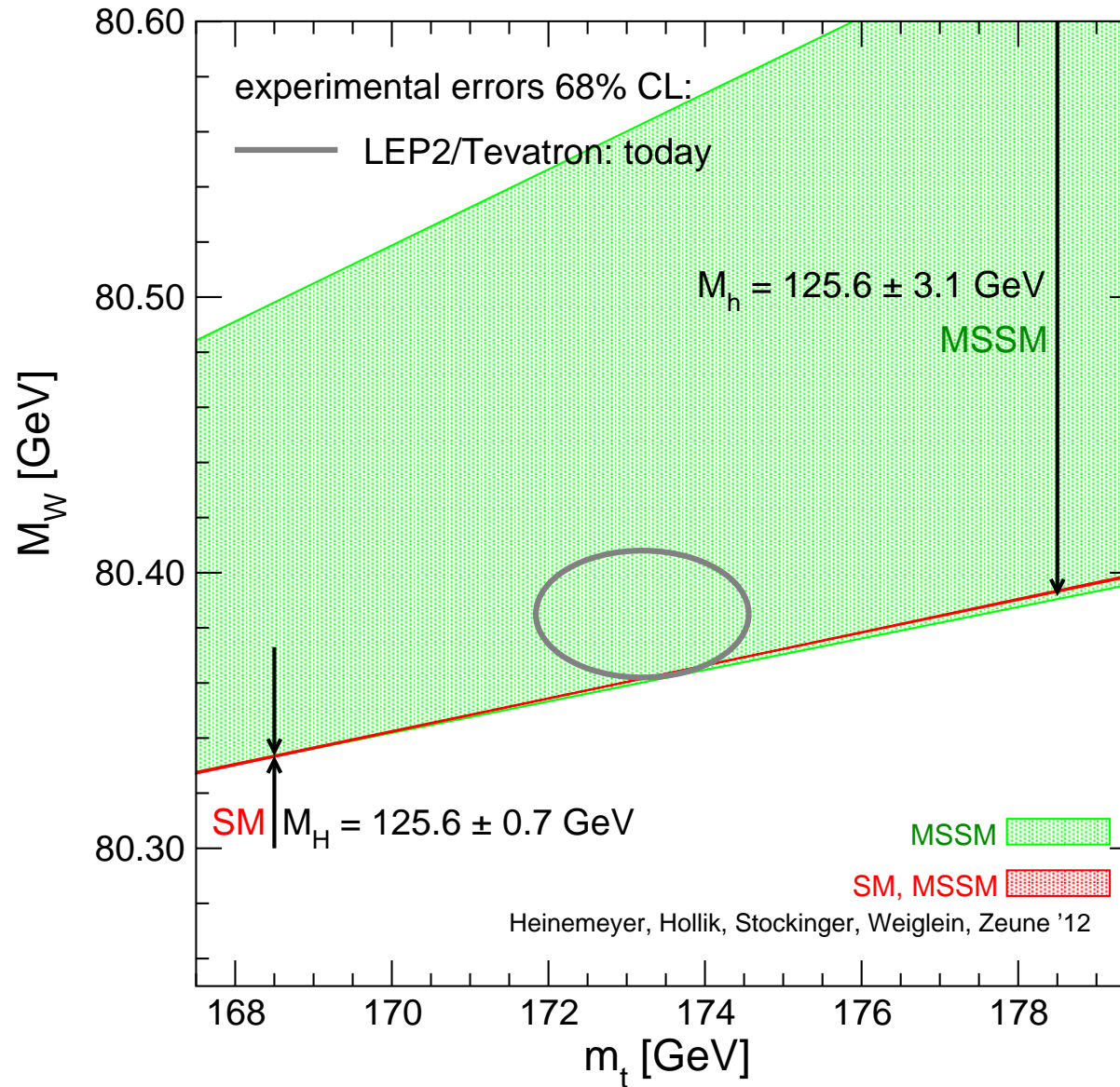
### 3. $M_W$ in the MSSM: future data

⇒ extensive parameter scan as before

#### Szenarios:

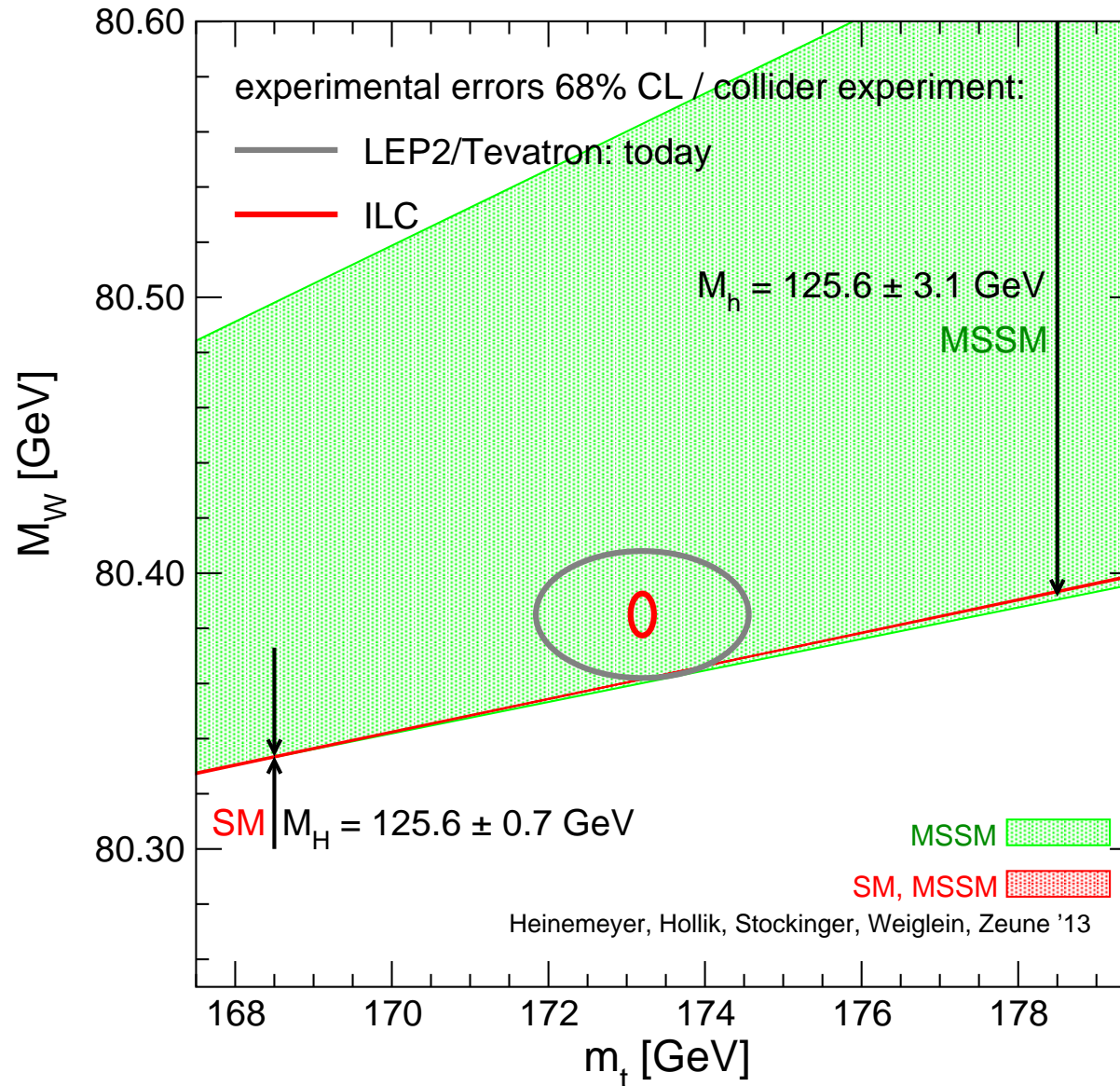
1. Assume lower limits on parameters  
⇒ analyze agreement between MSSM prediction and data
2. Assume some measurement:  $m_{\tilde{t}_1} = 400 \pm 40$  GeV  
and lower limits for everything else  
⇒ prediction for other SUSY particles?

# Interpreting the Higgs discovery in the MSSM:



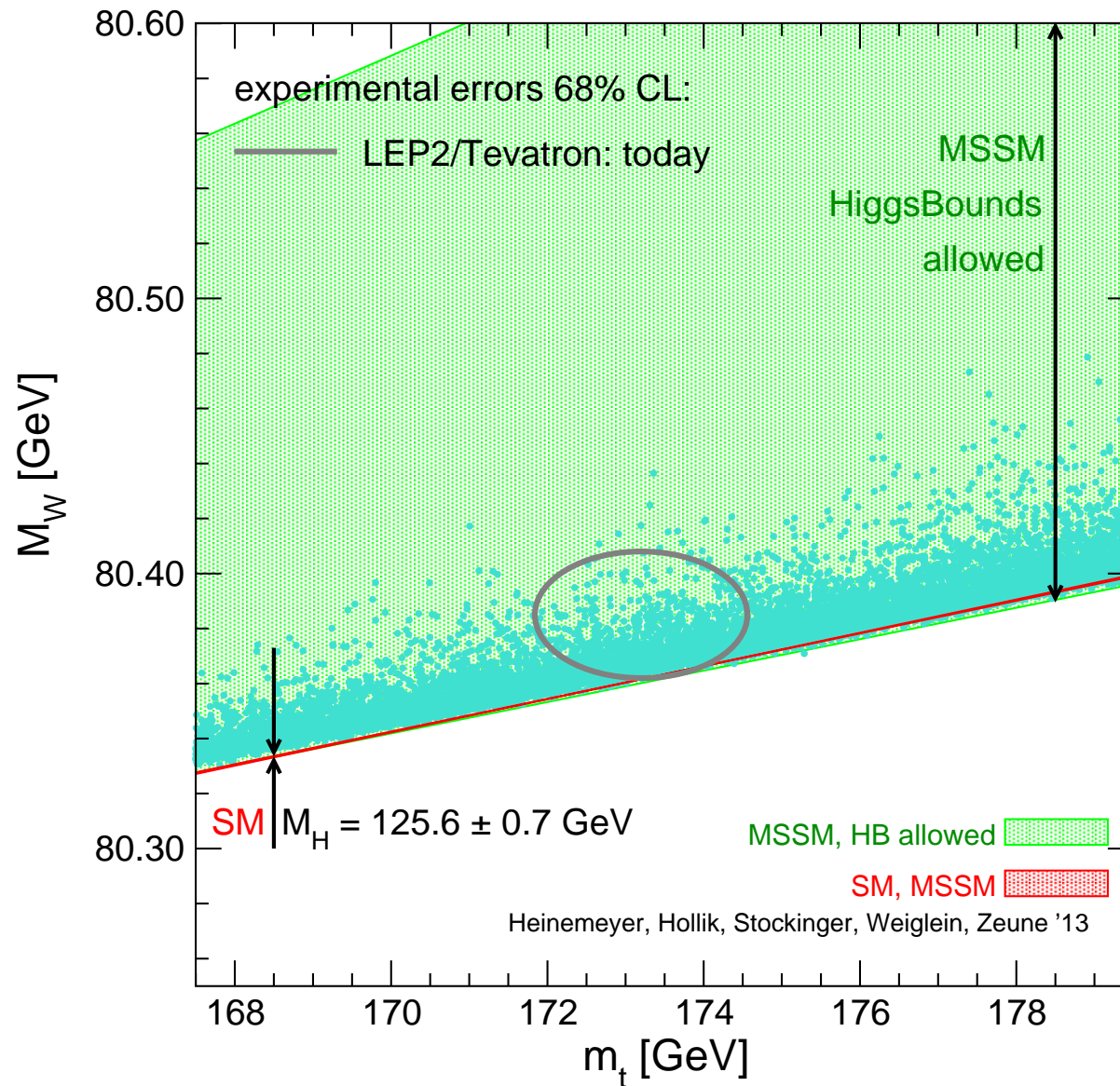
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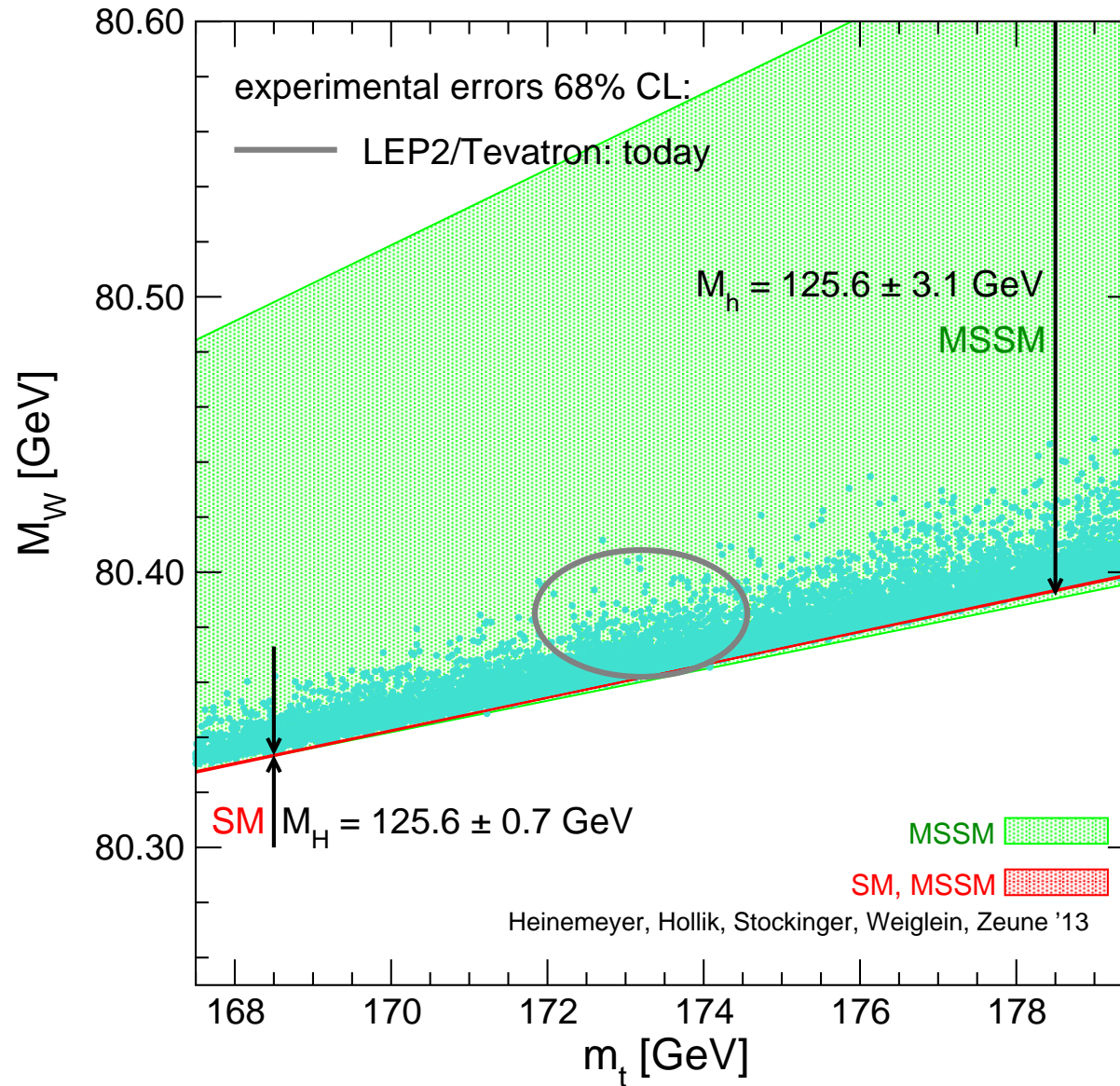
⇒ agreement better than with SM

# Szenario 1: Effects of stops, sbottoms, $M_h$ :



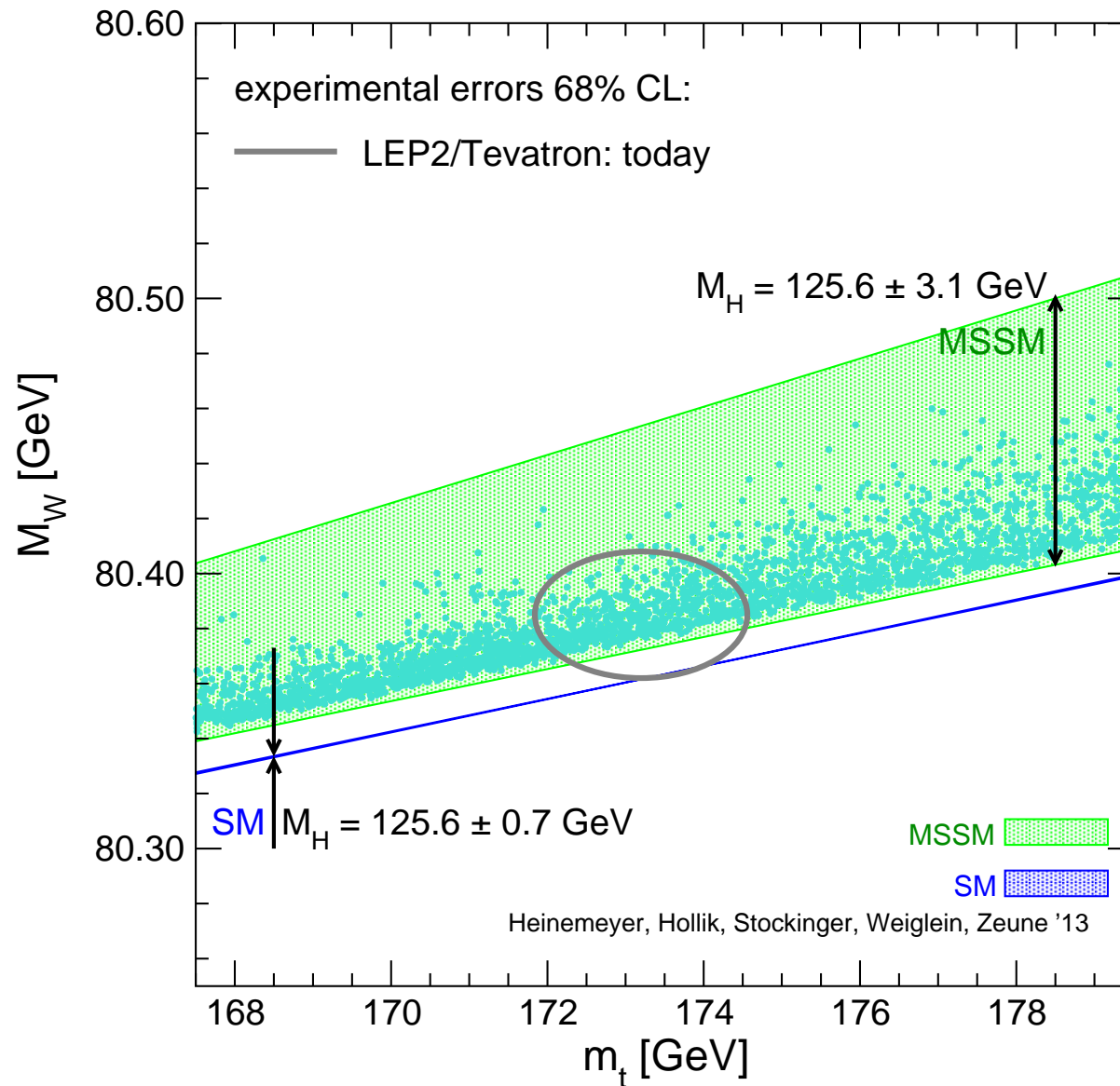
light blue:  $m_{\tilde{t}_i}, m_{\tilde{b}_j} > 500$  GeV,  $m_{\tilde{q}_{1,2}}, m_{\tilde{g}} > 1200$  GeV

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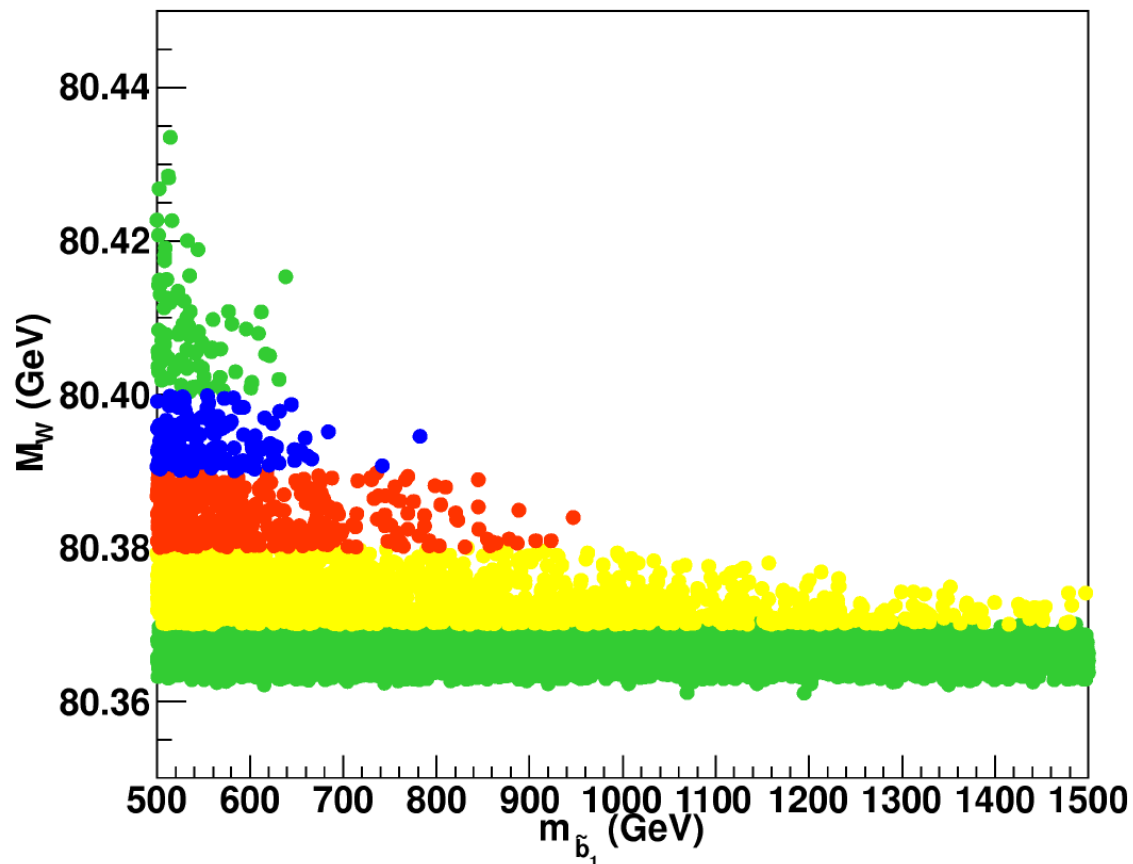
light blue:  $m_{\tilde{t}_i}, m_{\tilde{b}_j} > 500$  GeV,  $m_{\tilde{q}_{1,2}}, m_{\tilde{g}} > 1200$  GeV



## Szenario 2:

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

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

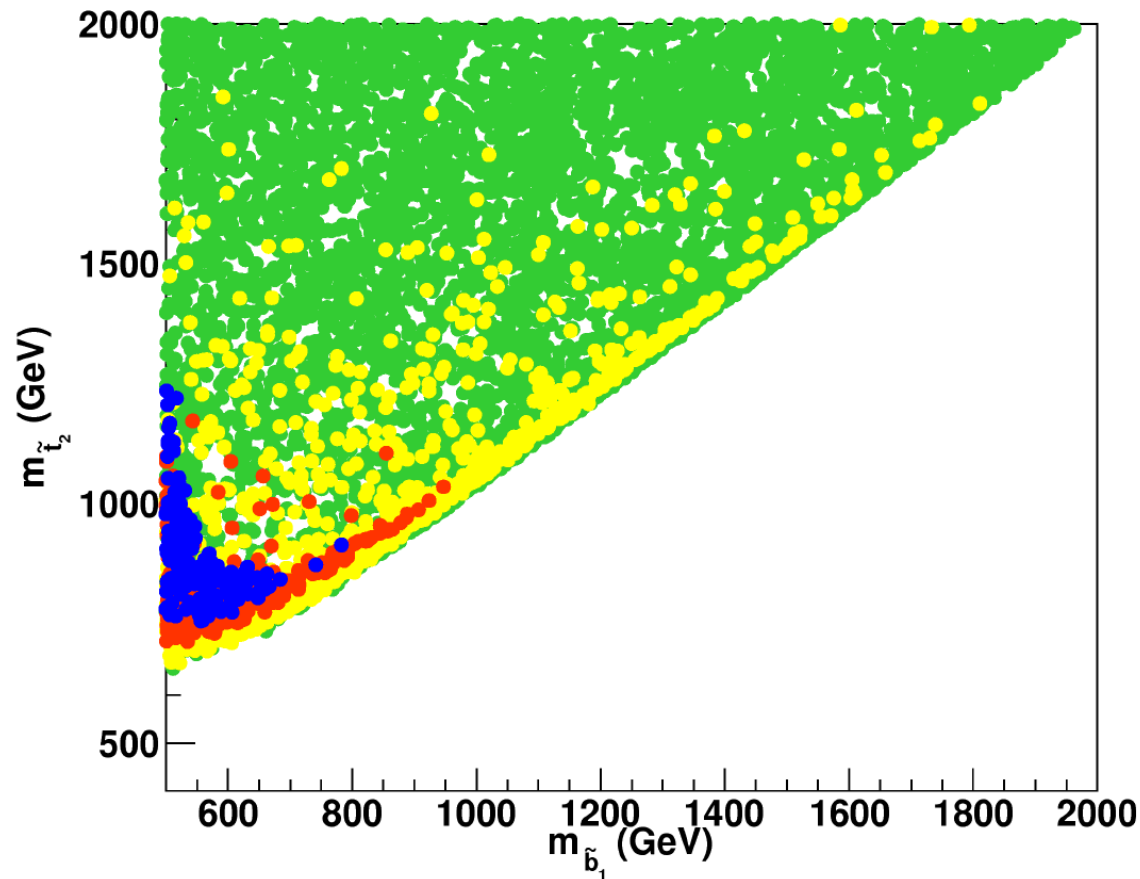


⇒ clear prediction for light sbottom mass!

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⇒ 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
  - heavy Higgs at  $\sim 125$  GeV: still very good agreement
- Future scenarios:
  - stops and sbottoms heavier than 500 GeV: very good agreement
  - $m_{\tilde{t}_1} = 400 \pm 40$  GeV  $\Rightarrow$  limits an  $m_{\tilde{b}_1}$ ,  $m_{\tilde{t}_2}$