SUSY Predictions for the LHC and the ILC

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based on collaboration with
O. Buchmüller, R. Cavanaugh, A. de Roeck, J. Ellis, H. Flächer, G. Isidori, K. Olive, F. Ronga, G. Weiglein

1. Introduction and motivation
2. The models and the tools
3. Prediction of the lightest Higgs boson mass M_h
4. Testing SUSY with m_t and M_W
5. LHC/ILC reach in the CMSSM/NUHM1
6. Conclusions

1. Introduction

The big question:

Which Lagrangian describes the world?

My guess:

It is a supersymmetric one

$\Rightarrow$ concentrate on the MSSM from now on

(other people $\Rightarrow$ other guesses $\Rightarrow$ other priorities . . .)

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⇒ is there any possibility to know what to expect?

Let's see . . .

Supersymmetry (SUSY) : Symmetry between

$$\text{Bosons} \leftrightarrow \text{Fermions}$$

$$Q \; |\text{Fermion}\rangle \rightarrow |\text{Boson}\rangle$$
$$Q \; |\text{Boson}\rangle \rightarrow |\text{Fermion}\rangle$$

Simplified examples:

$$Q \; |\text{top}, \; t\rangle \rightarrow |\text{scalar top}, \; \tilde{t}\rangle$$
$$Q \; |\text{gluon}, \; g\rangle \rightarrow |\text{gluino}, \; \tilde{g}\rangle$$

$\Rightarrow$ each SM multiplet is enlarged to its double size

Unbroken SUSY: All particles in a multiplet have the same mass

Reality: $m_e \neq m_{\tilde{e}} \Rightarrow$ SUSY is broken . . .

. . . via soft SUSY-breaking terms in the Lagrangian (added by hand)

SUSY particles are made heavy: $\boxed{M_{\text{SUSY}} = \mathcal{O}(1 \text{ TeV})}$

Supersymmetry: Motivation

The SM is in a pretty good shape.

Why MSSM? (Is it worth to double the particle spectrum?)

1.) Stability of the Higgs mass against higher-order corr.

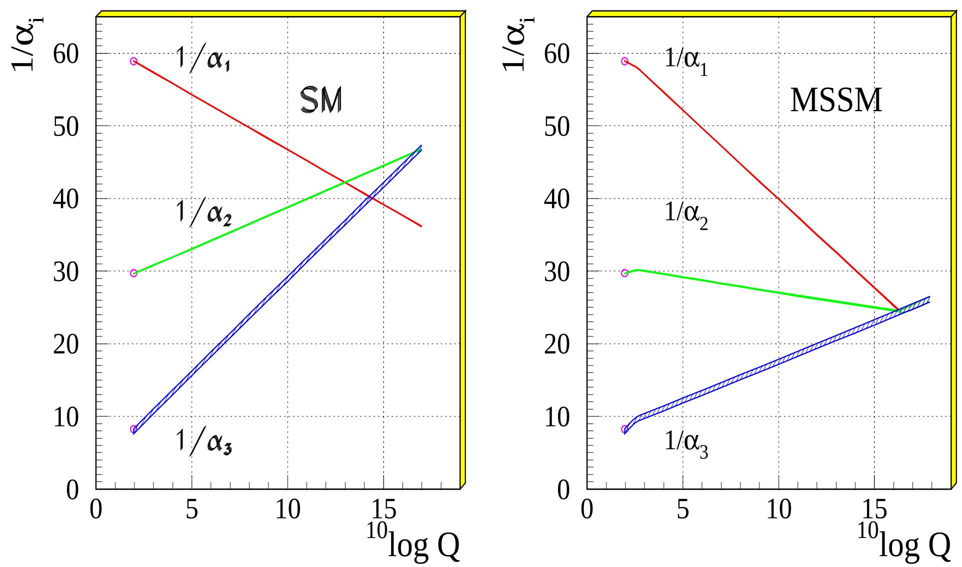
2.) Unification of gauge couplings: Not possible in the SM, but in the MSSM (although it was not designed for it.)

3.) Spontaneous symmetry breaking via Higgs mechanism is automatic in SUSY GUTs

4.) SUSY provides CDM candidate

5.) . . .

Unification of the Coupling Constants
in the SM and the minimal MSSM



[*Amaldi, de Boer, Fürstenau '92*]

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$$\Big[u, d, c, s, t, b\Big]_{L,R} \quad \Big[e, \mu, \tau\Big]_{L,R} \quad \Big[\nu_{e,\mu,\tau}\Big]_L \qquad \text{Spin } \tfrac{1}{2}$$

$$\Big[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\Big]_{L,R} \quad \Big[\tilde{e}, \tilde{\mu}, \tilde{\tau}\Big]_{L,R} \quad \Big[\tilde{\nu}_{e,\mu,\tau}\Big]_L \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^{\pm}, H^{\pm}} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin 1 / Spin 0}$$

$$\tilde{g} \qquad \tilde{\chi}^{\pm}_{1,2} \qquad \tilde{\chi}^0_{1,2,3,4} \qquad \text{Spin } \frac{1}{2}$$

Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

→ CPV will mostly be neglected throughout this talk!

$\tilde{t}/\tilde{b}$ sector of the MSSM: (scalar partner of the top/bottom quark)

Stop, sbottom mass matrices ($X_t = A_t - \mu^*/\tan\beta$, $X_b = A_b - \mu^* \tan\beta$):

$$\mathcal{M}^2_{\tilde{t}} = \begin{pmatrix} M^2_{\tilde{t}_L} + m_t^2 + DT_{t_1} & m_t X_t^* \\ m_t X_t & M^2_{\tilde{t}_R} + m_t^2 + DT_{t_2} \end{pmatrix} \xrightarrow{\theta_{\tilde{t}}} \begin{pmatrix} m^2_{\tilde{t}_1} & 0 \\ 0 & m^2_{\tilde{t}_2} \end{pmatrix}$$

$$\mathcal{M}^2_{\tilde{b}} = \begin{pmatrix} M^2_{\tilde{b}_L} + m_b^2 + DT_{b_1} & m_b X_b^* \\ m_b X_b & M^2_{\tilde{b}_R} + m_b^2 + DT_{b_2} \end{pmatrix} \xrightarrow{\theta_{\tilde{b}}} \begin{pmatrix} m^2_{\tilde{b}_1} & 0 \\ 0 & m^2_{\tilde{b}_2} \end{pmatrix}$$

mixing important in stop sector (also in sbottom sector for large $\tan\beta$)

soft SUSY-breaking parameters A_t, A_b also appear in ϕ-$\tilde{t}/\tilde{b}$ couplings

$$SU(2) \text{ relation} \Rightarrow M_{\tilde{t}_L} = M_{\tilde{b}_L}$$

$\Rightarrow$ relation between $m_{\tilde{t}_1}, m_{\tilde{t}_2}, \theta_{\tilde{t}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}, \theta_{\tilde{b}}$

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$

$$+ \underbrace{\frac{g'^2 + g^2}{8}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}} |H_1 \bar{H}_2|^2$$

gauge couplings, in contrast to SM

physical states: $h^0, H^0, A^0, H^\pm$

Goldstone bosons: $G^0, G^\pm$

Input parameters: (to be determined experimentally)

$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2(\tan\beta + \cot\beta)$$

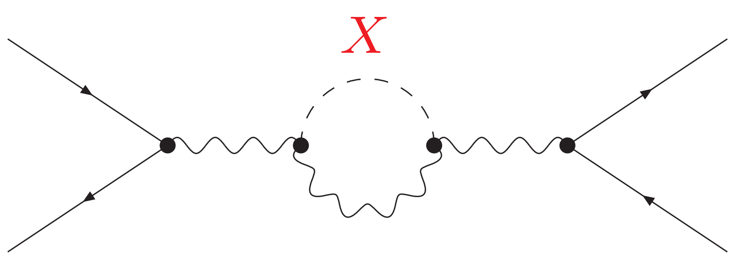
How to make a prediction?

Comparison of precision observables with theory:

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

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections



$\Downarrow$

$\Rightarrow$ Information about unknown parameters

Very high accuracy of measurements and theoretical predictions needed

Example: Prediction for M_W in the SM and the MSSM :

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

$\rightarrow$ can be approximated with the ρ-**parameter:**

ρ measures the relative strength between

neutral current interaction and charged current interaction

$$\rho = \frac{1}{1 - \Delta\rho}, \qquad \Delta\rho = \frac{\Sigma_Z(0)}{M_Z^2} - \frac{\Sigma_W(0)}{M_W^2}, \qquad \Delta M_W \approx \frac{M_W}{2}\frac{c_\mathrm{W}^2}{c_\mathrm{W}^2 - s_\mathrm{W}^2}\Delta\rho$$

(leading, process independent terms)

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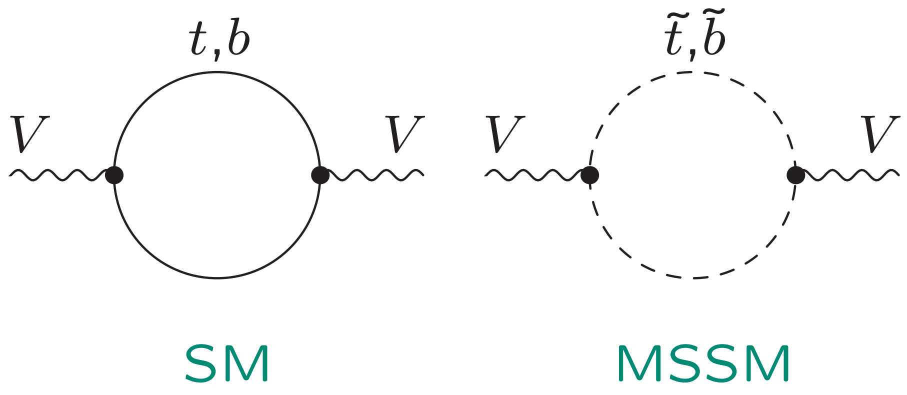

$\Delta\rho^{\text{SUSY}}$ from $\tilde{t}/\tilde{b}$ loops > 0 $\Rightarrow M_W^{\text{SUSY}} \gtrsim M_W^{\text{SM}}$

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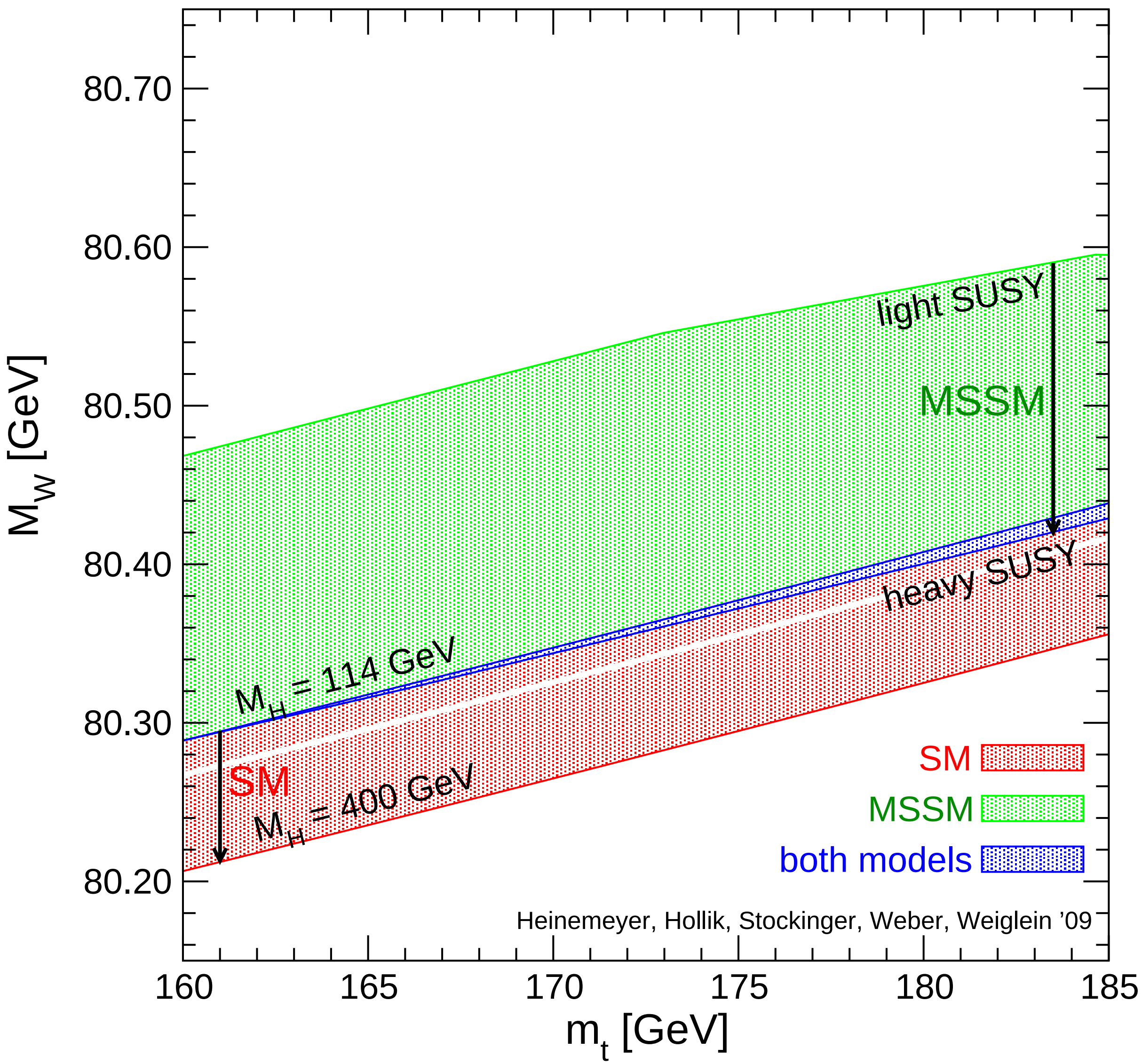
[S.H., W. Hollik, D. Stockinger, A. Weber, G. Weigleín '07]



MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}

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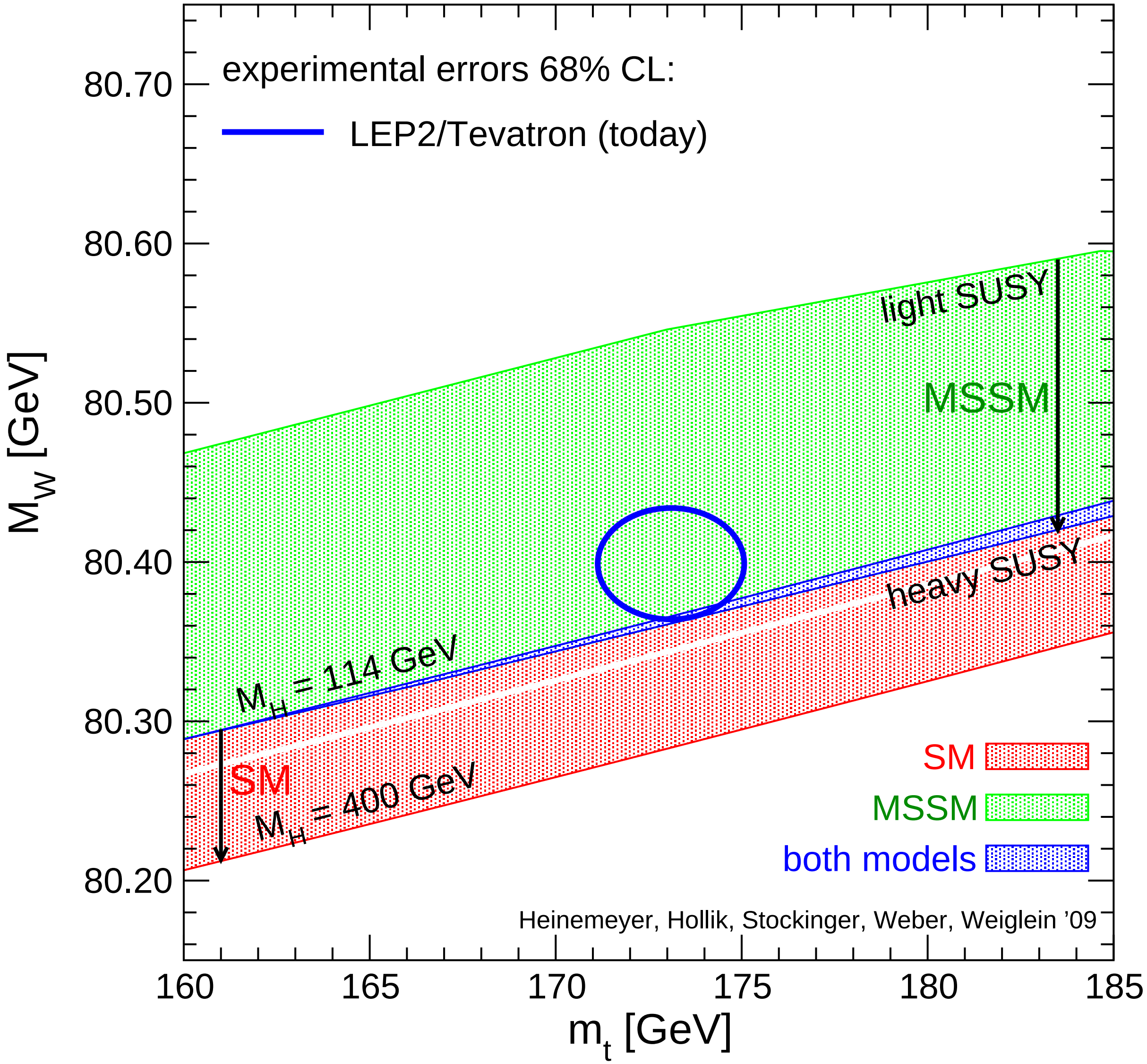

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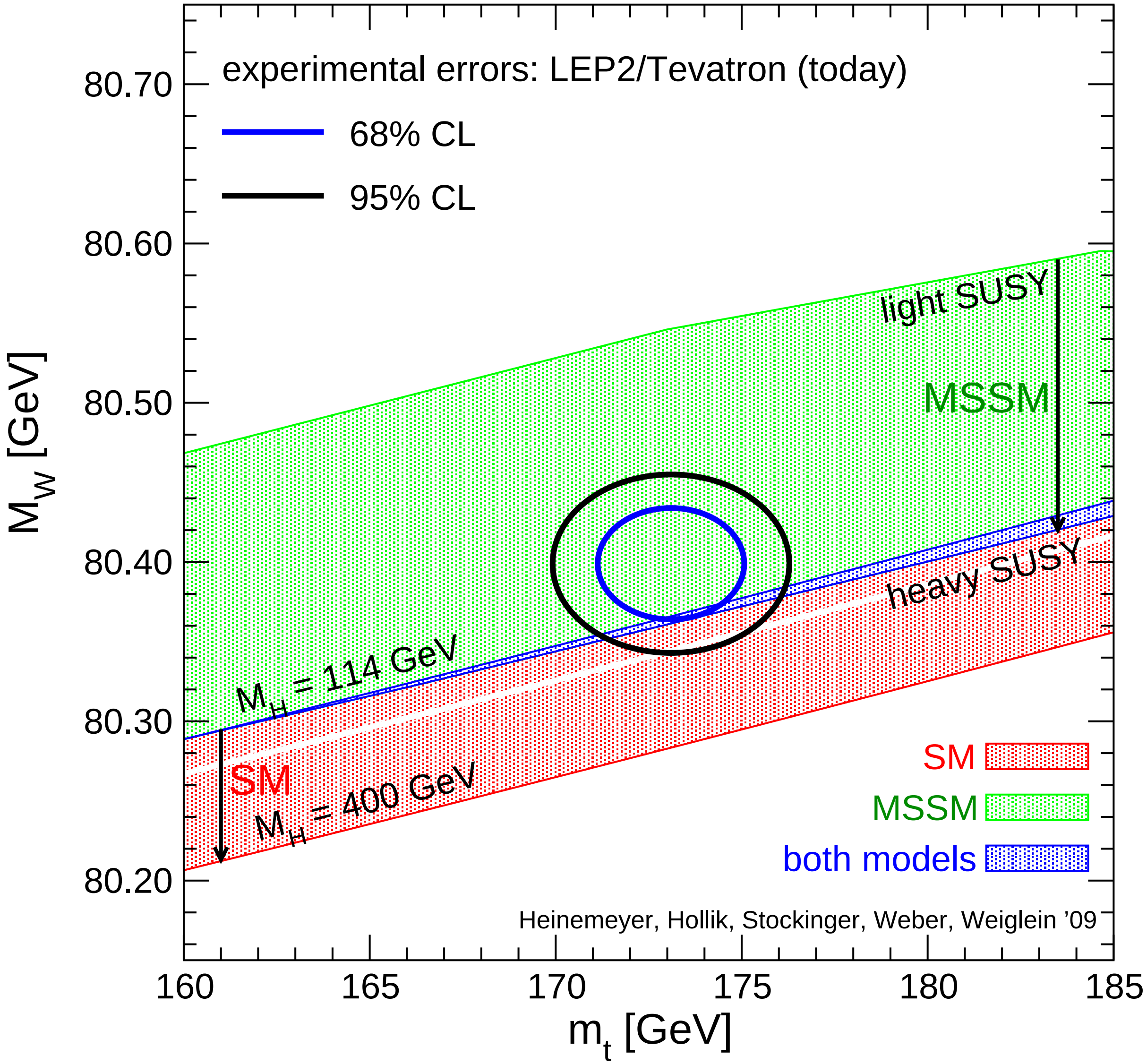

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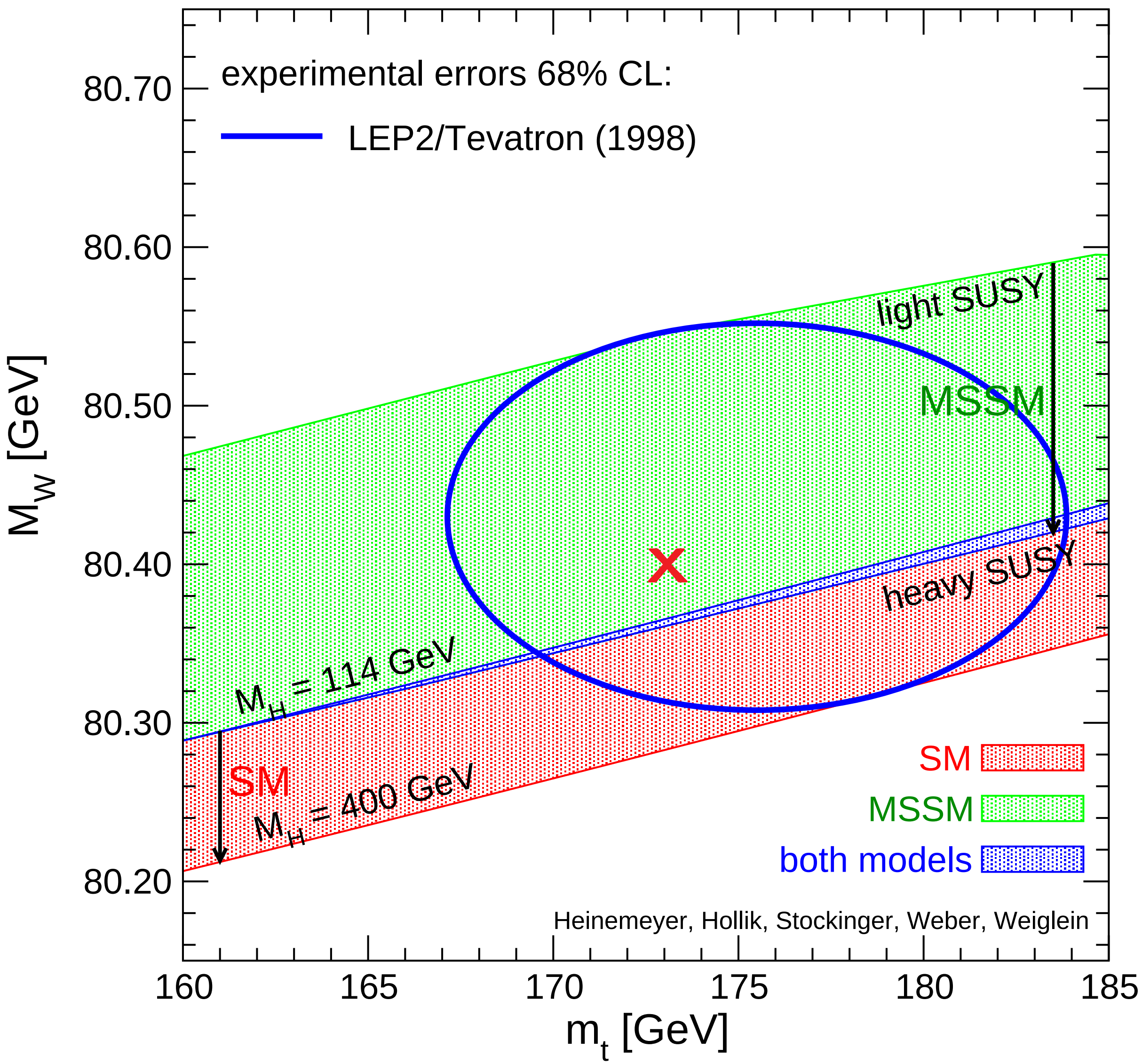

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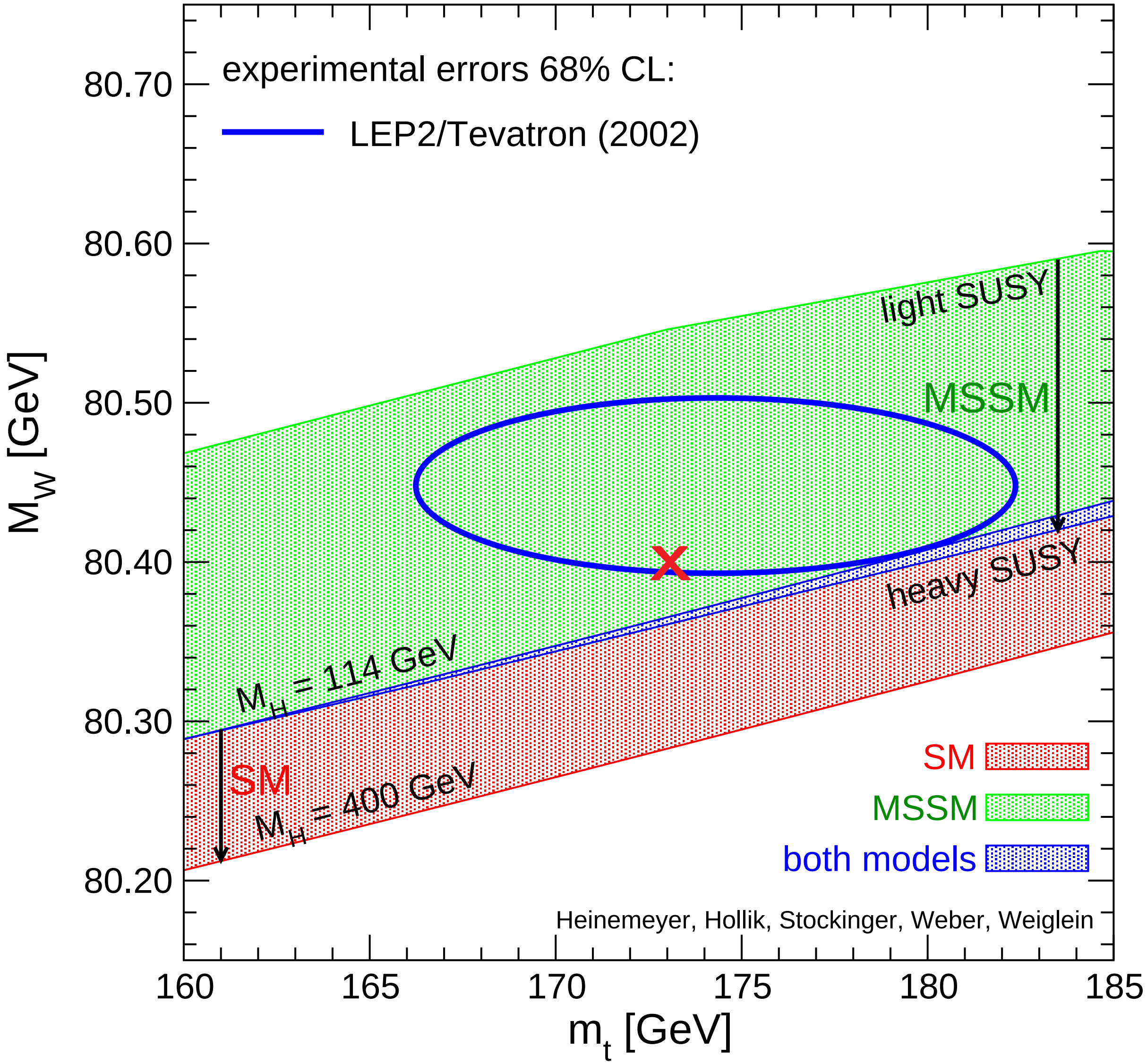

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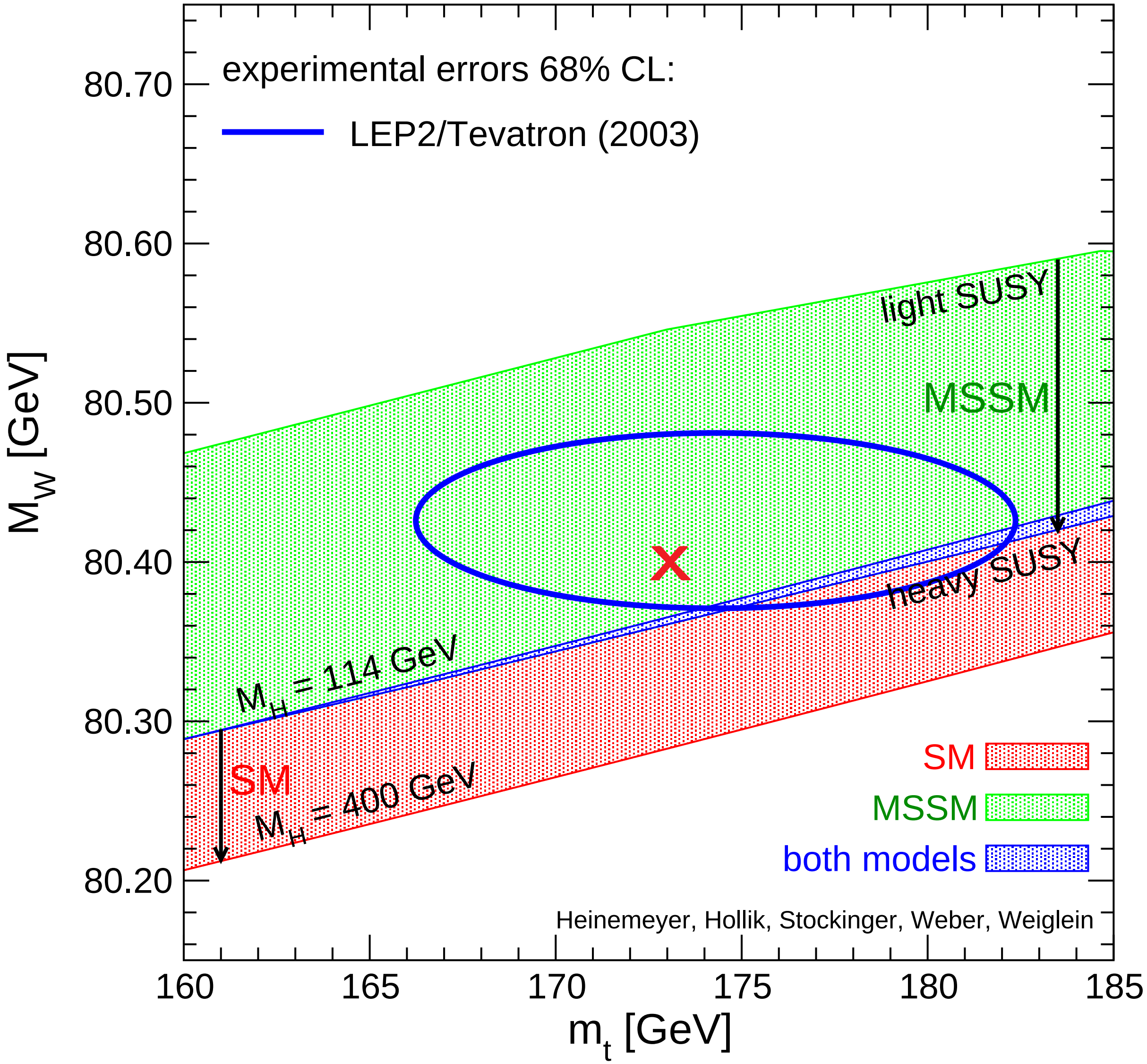

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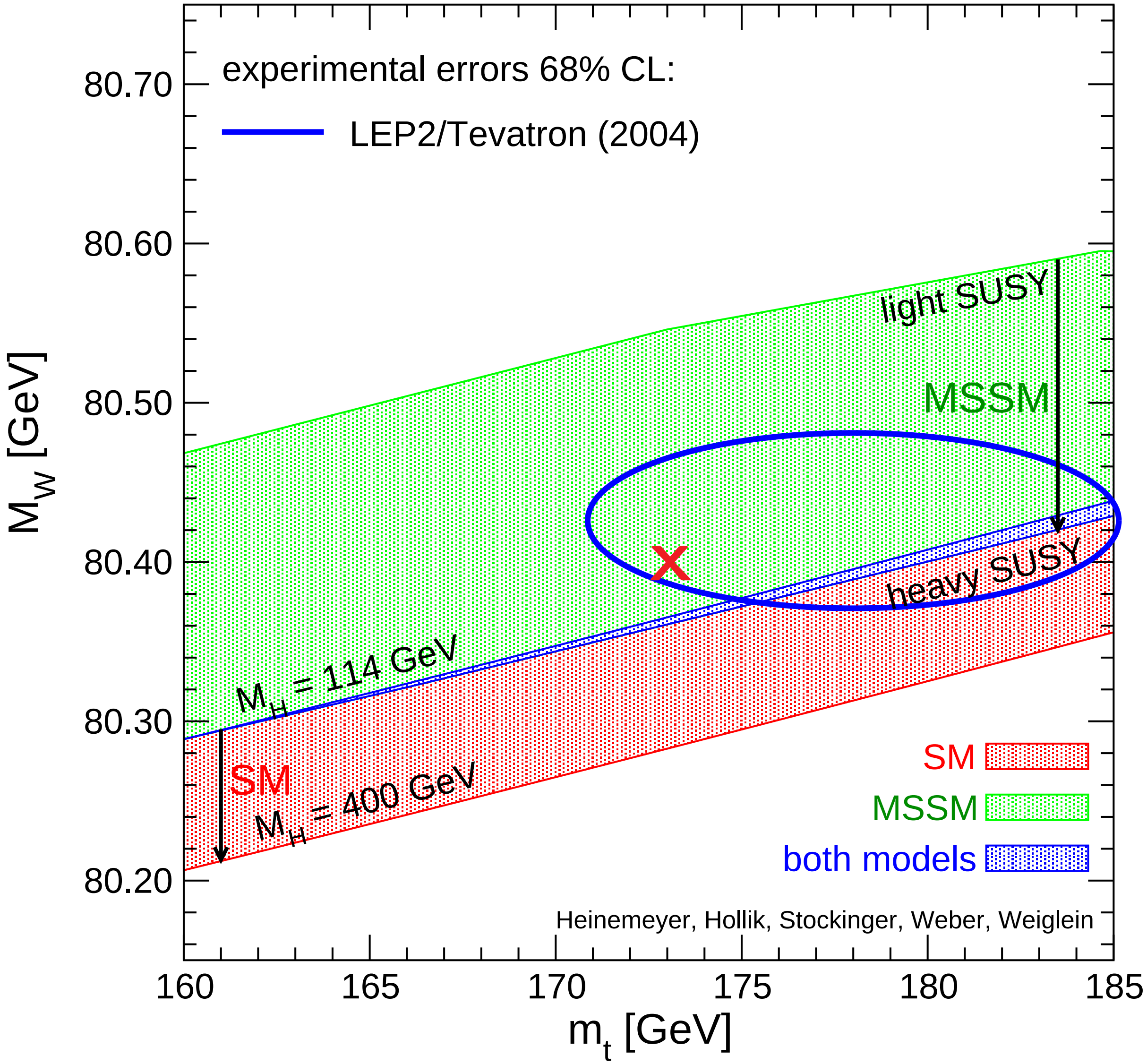

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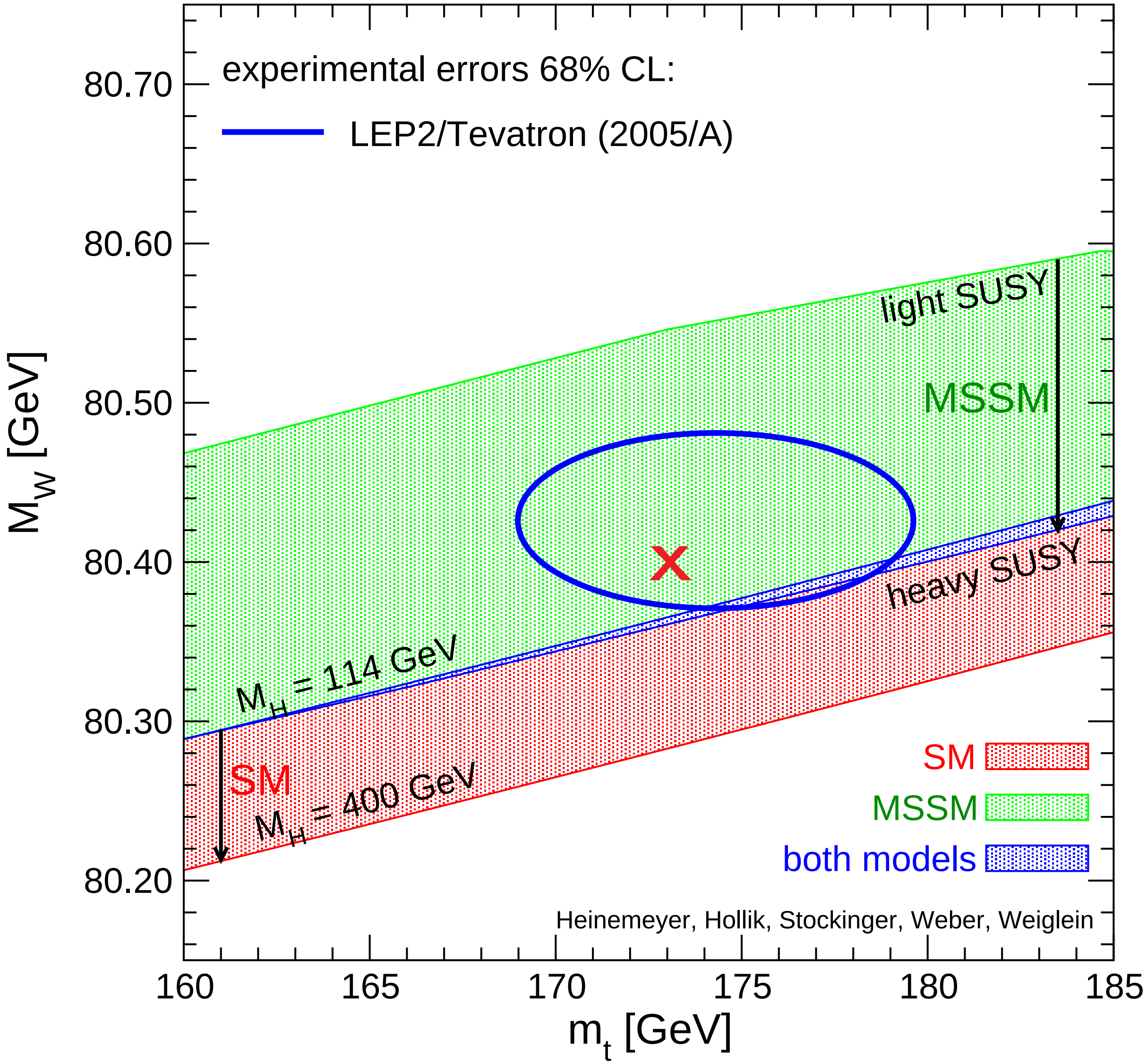

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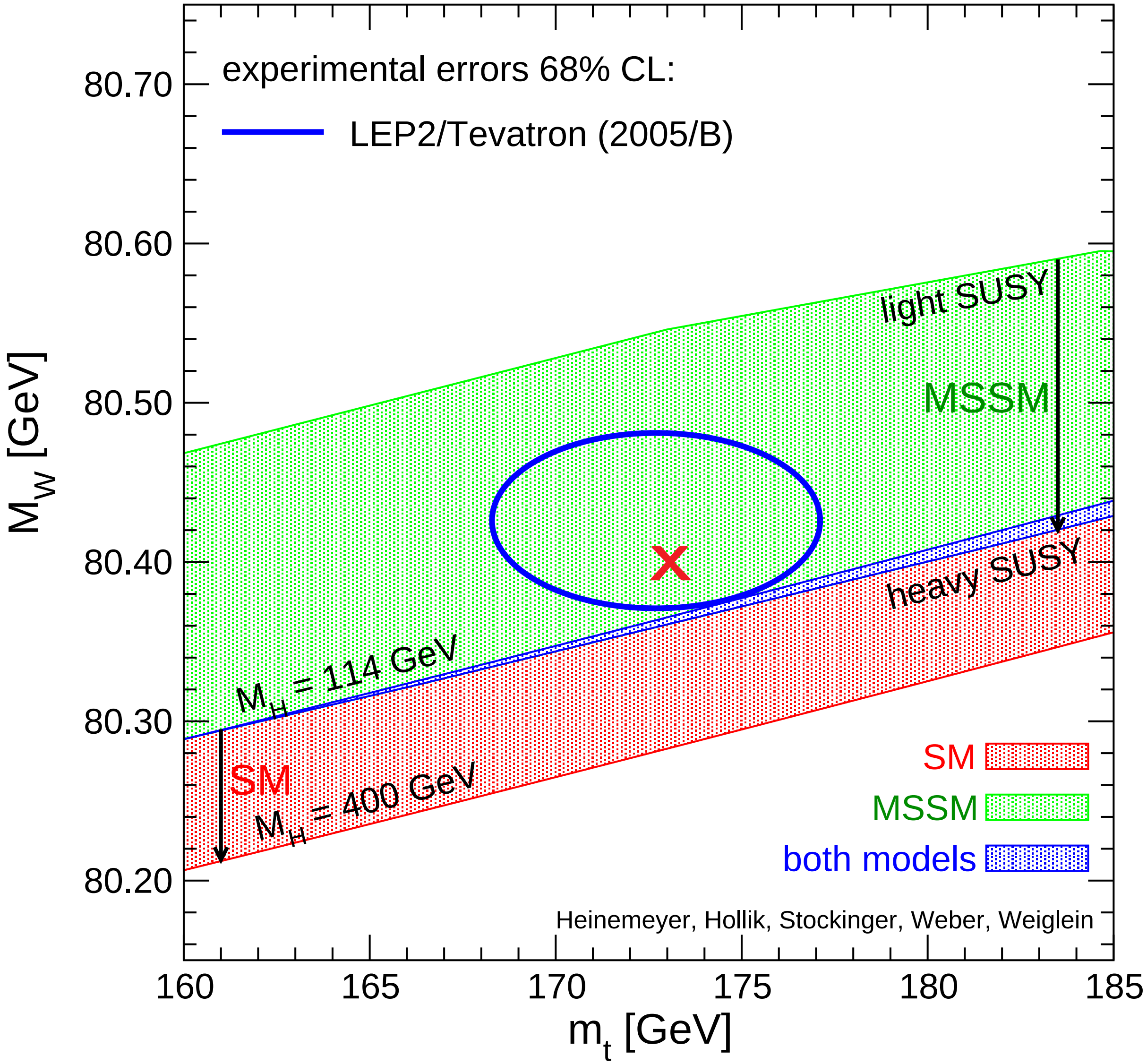

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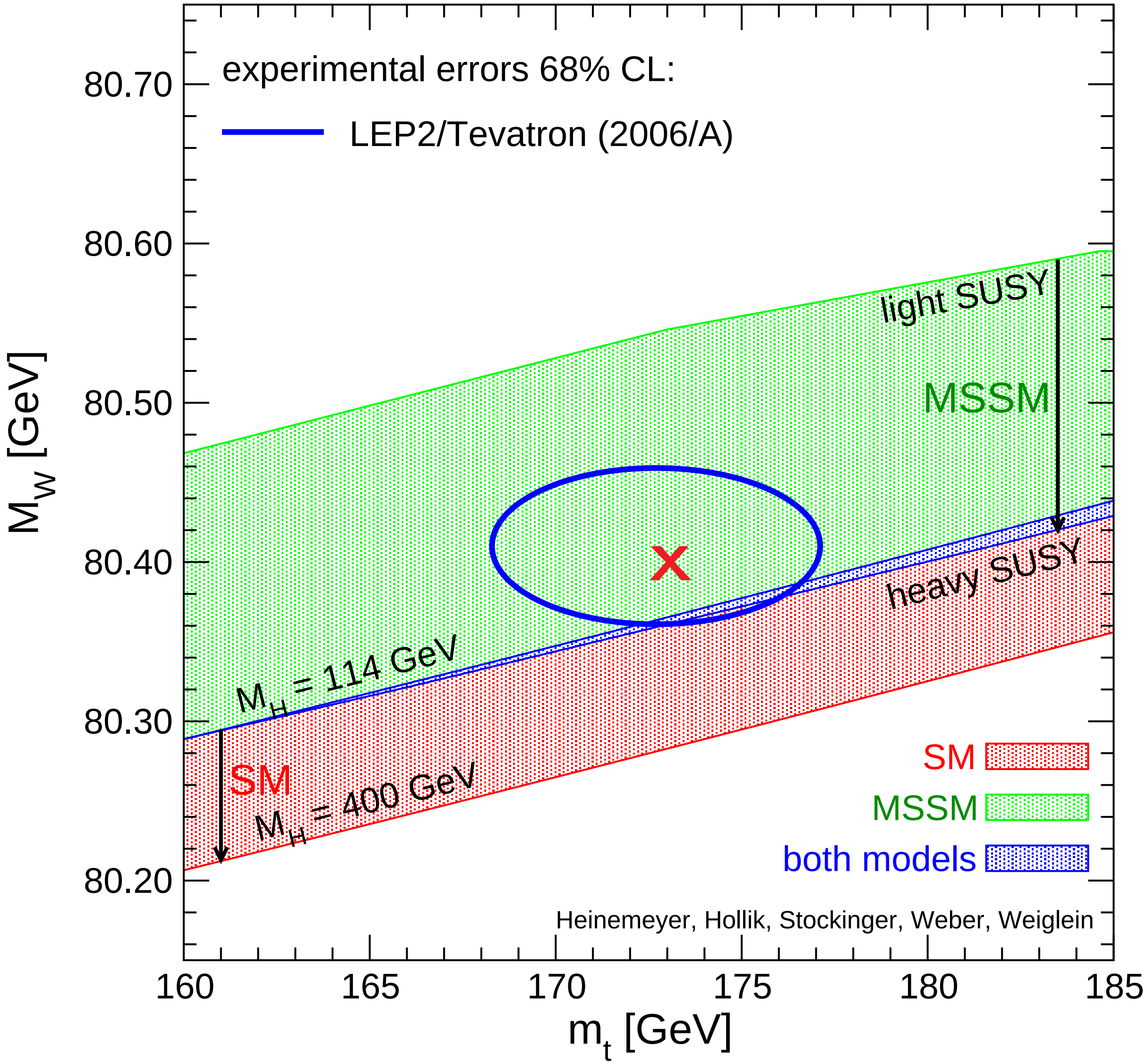

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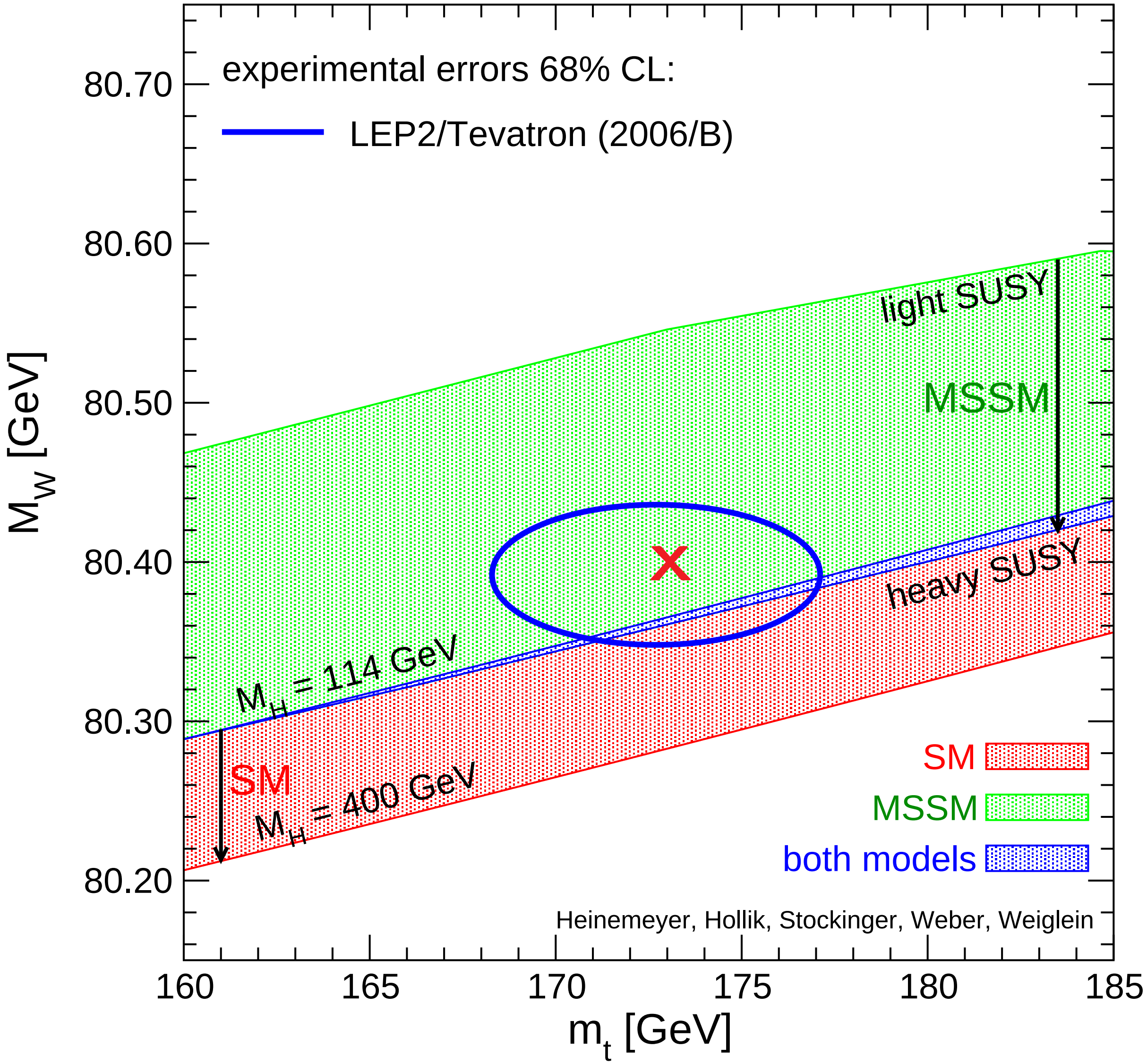

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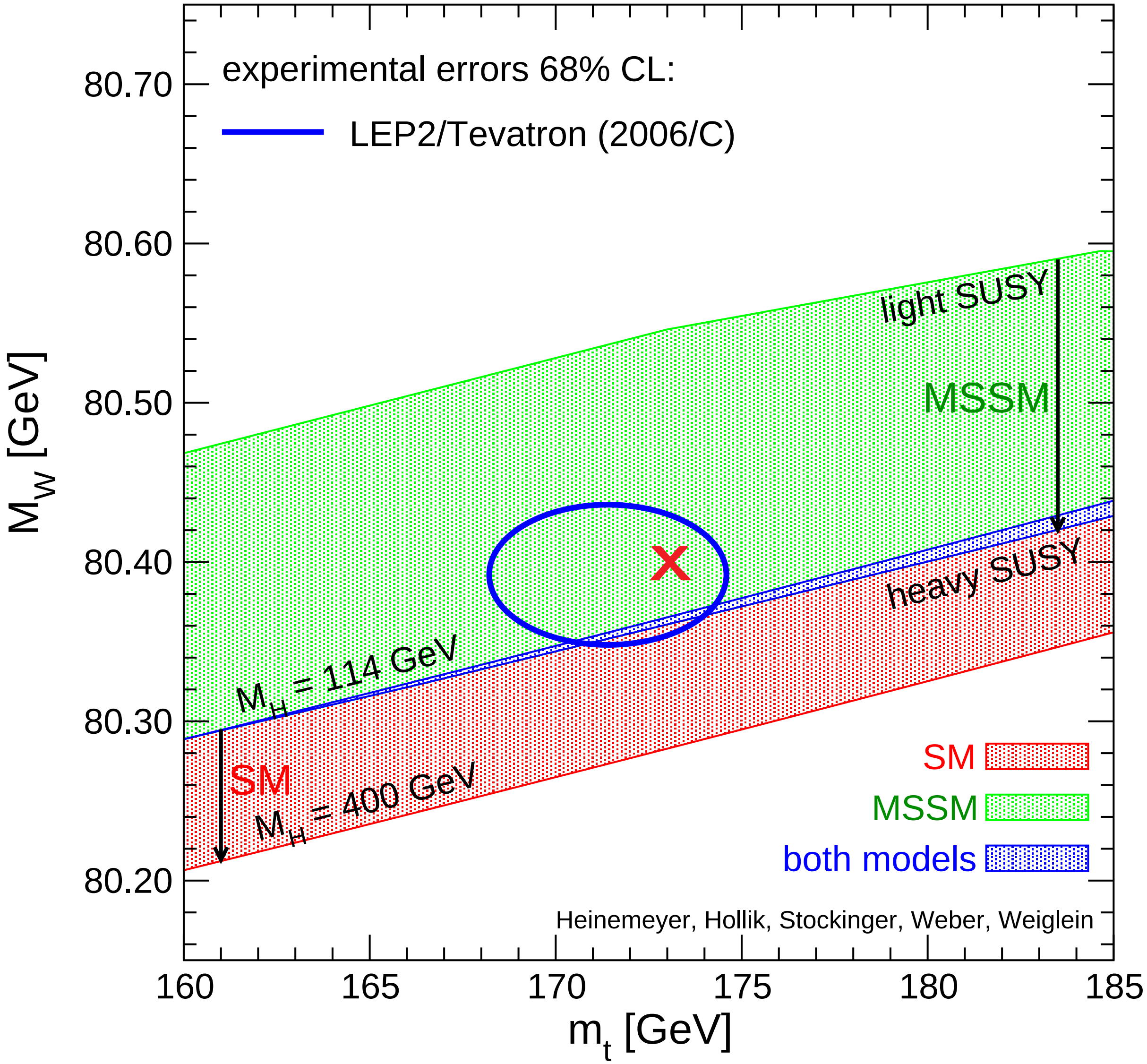

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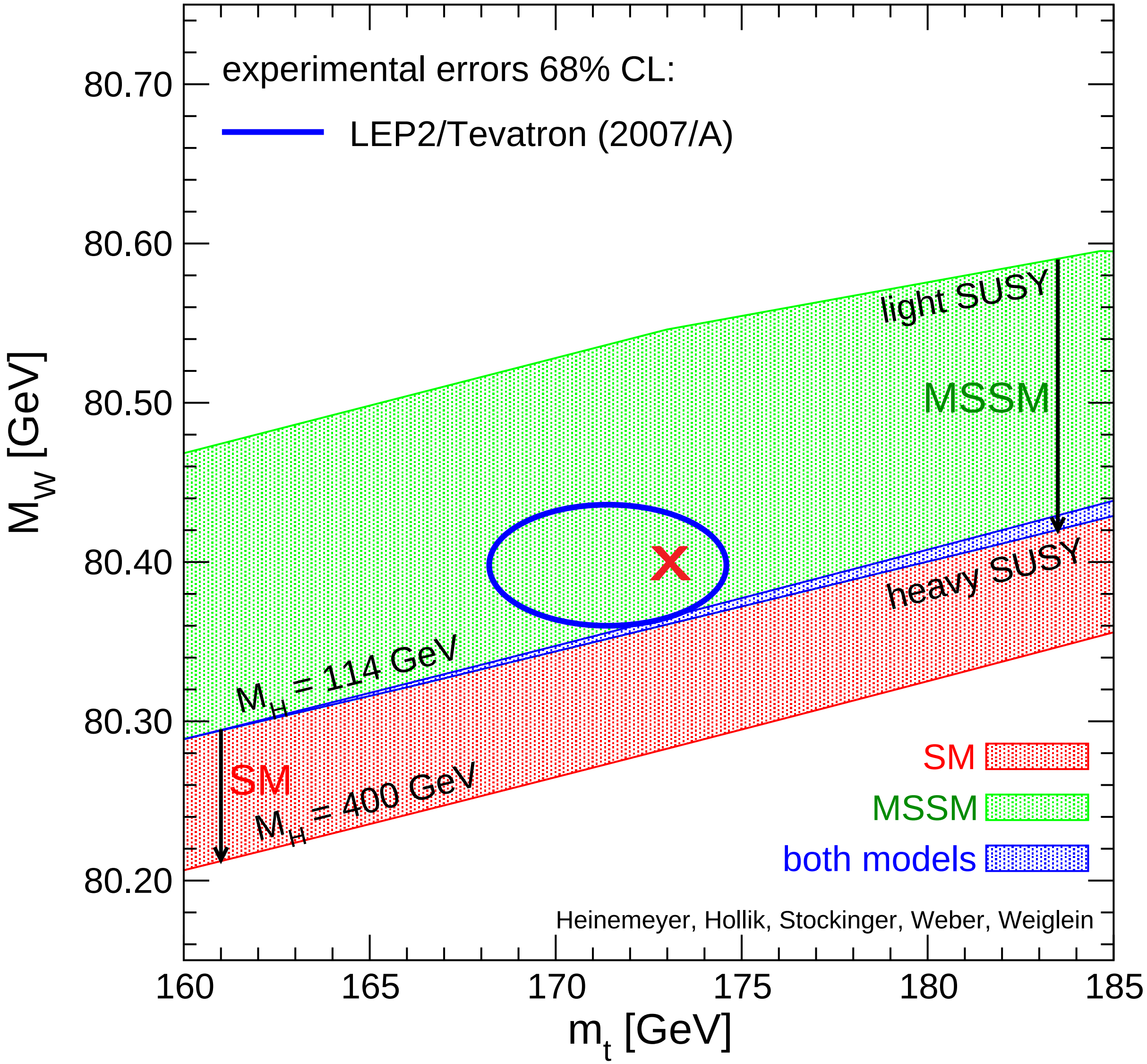

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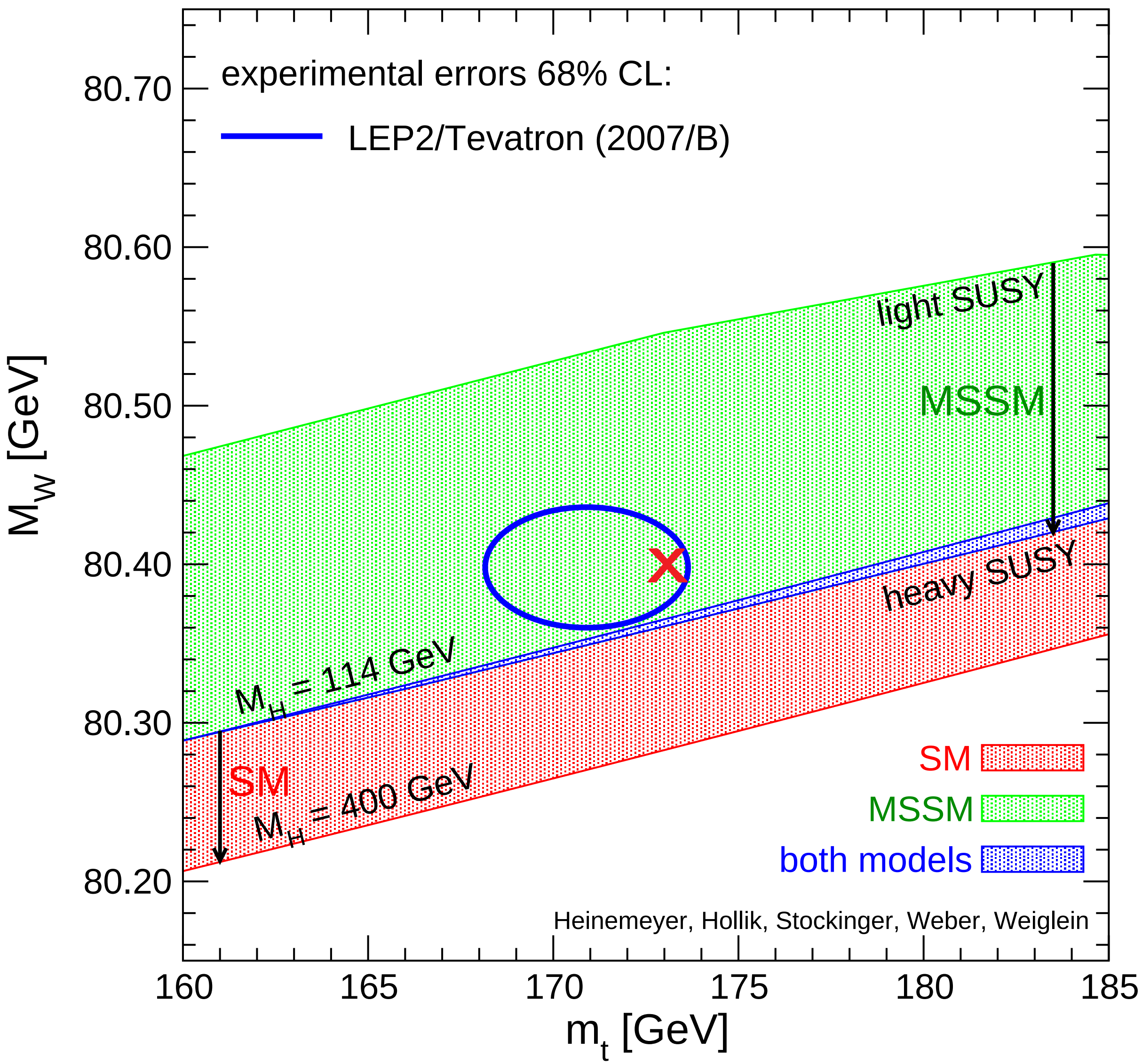

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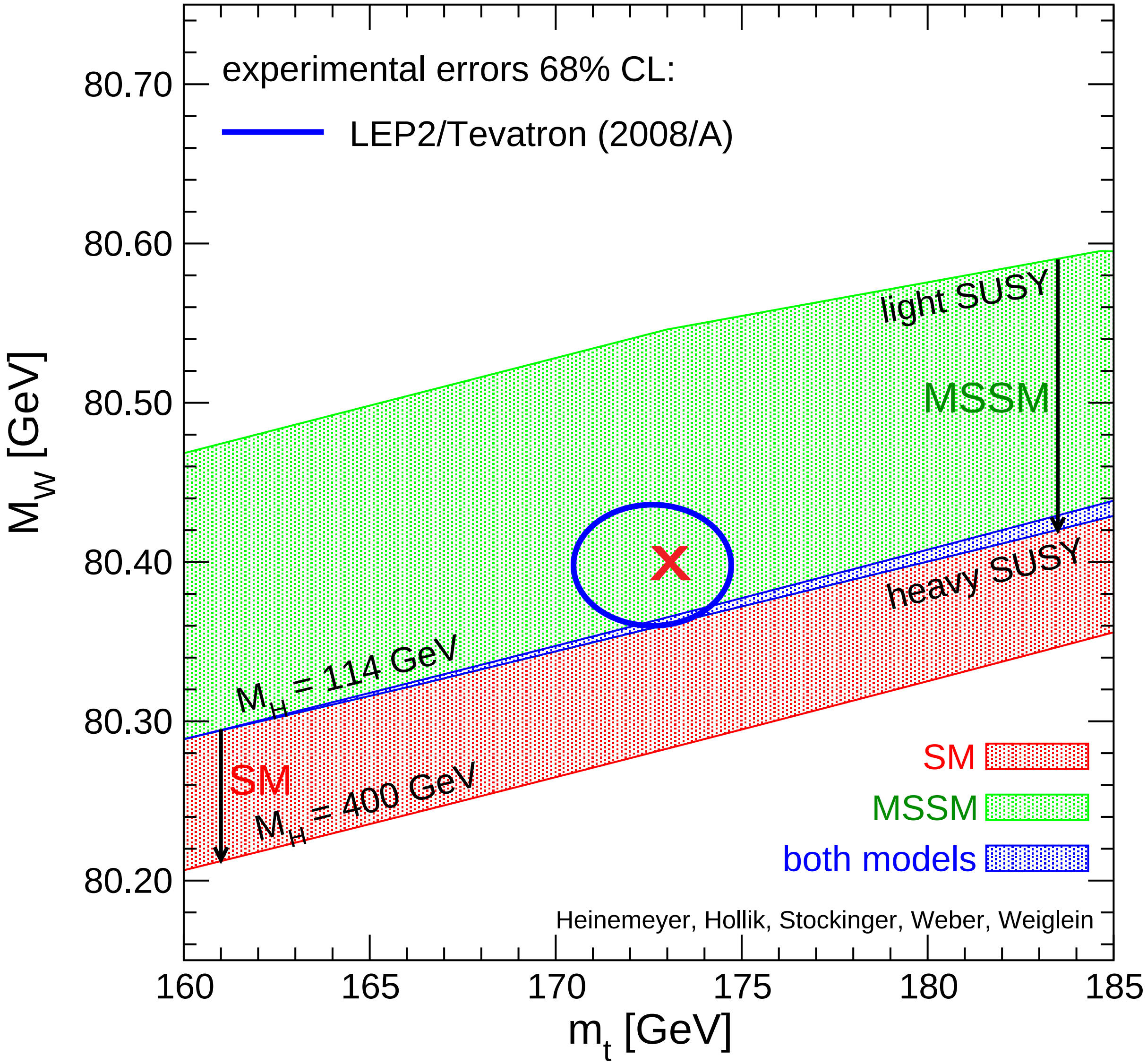

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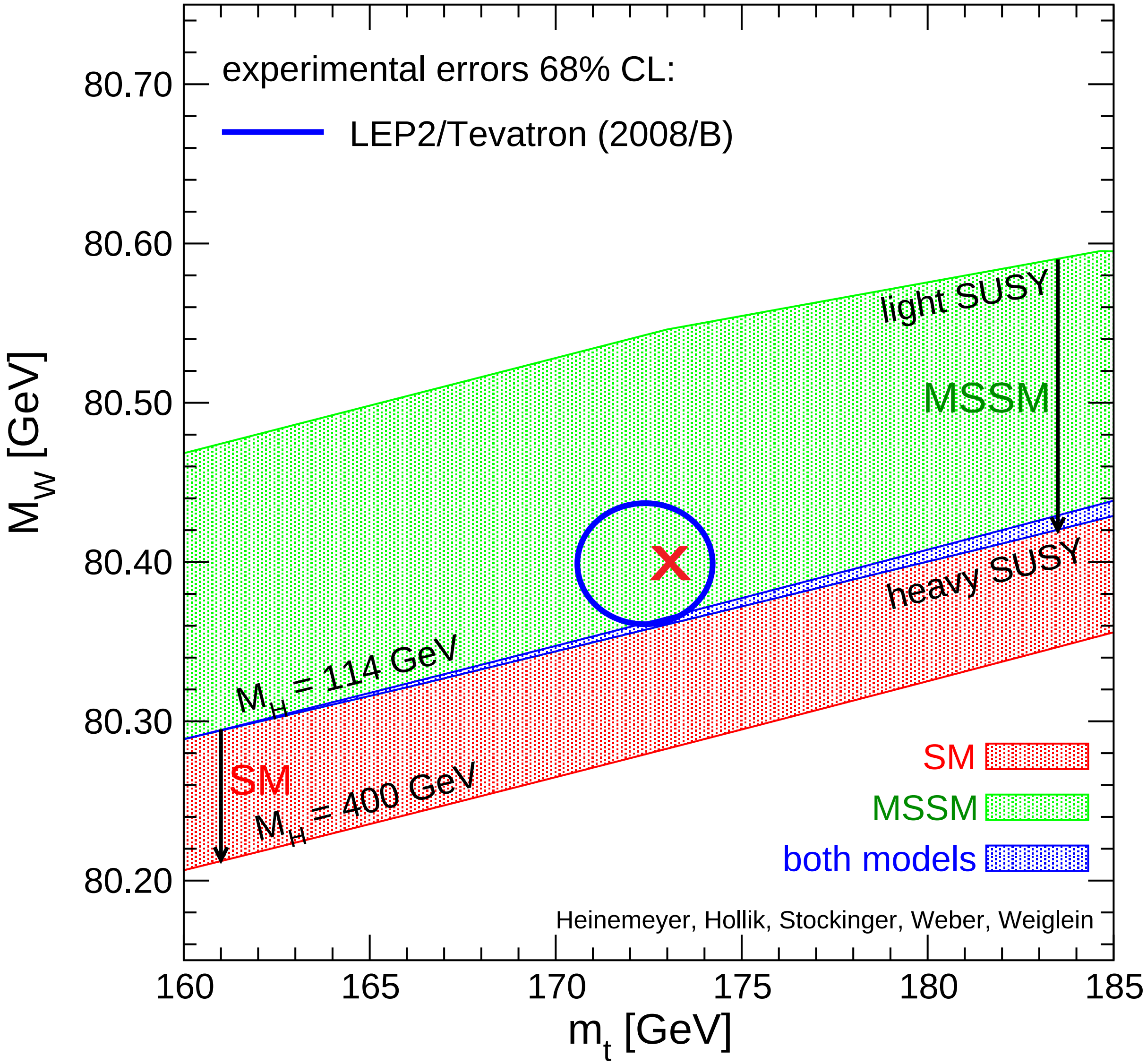

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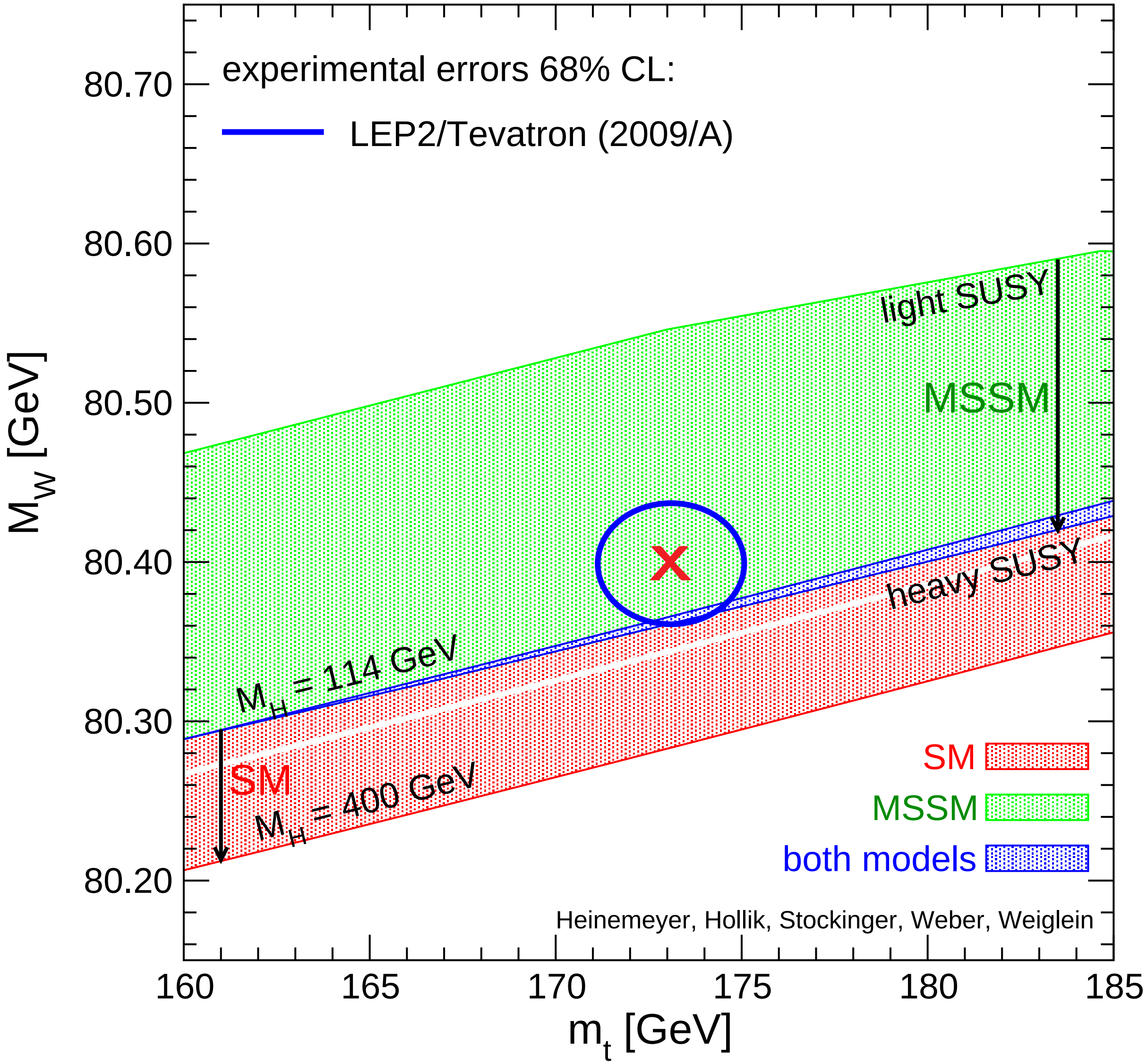

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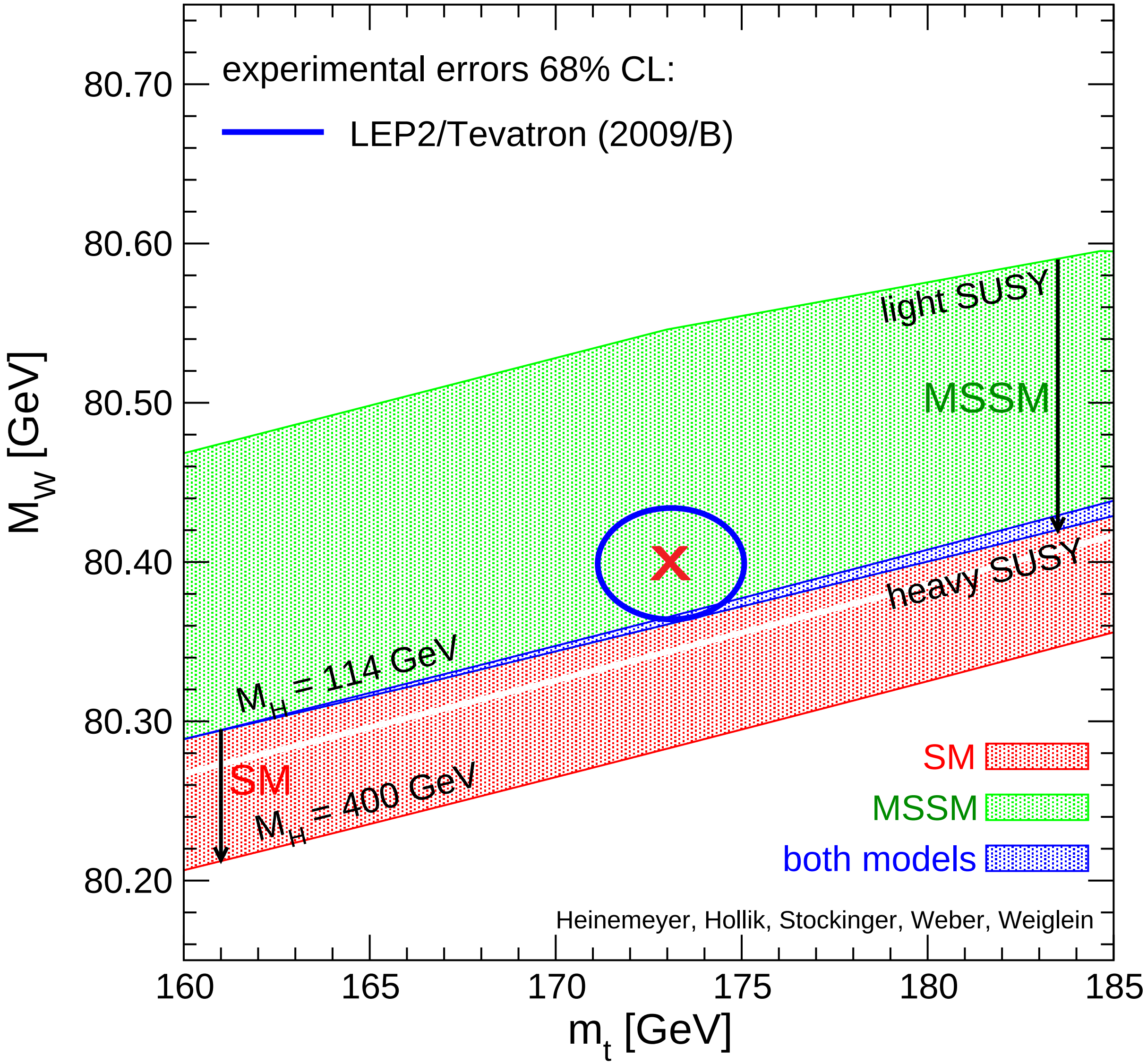

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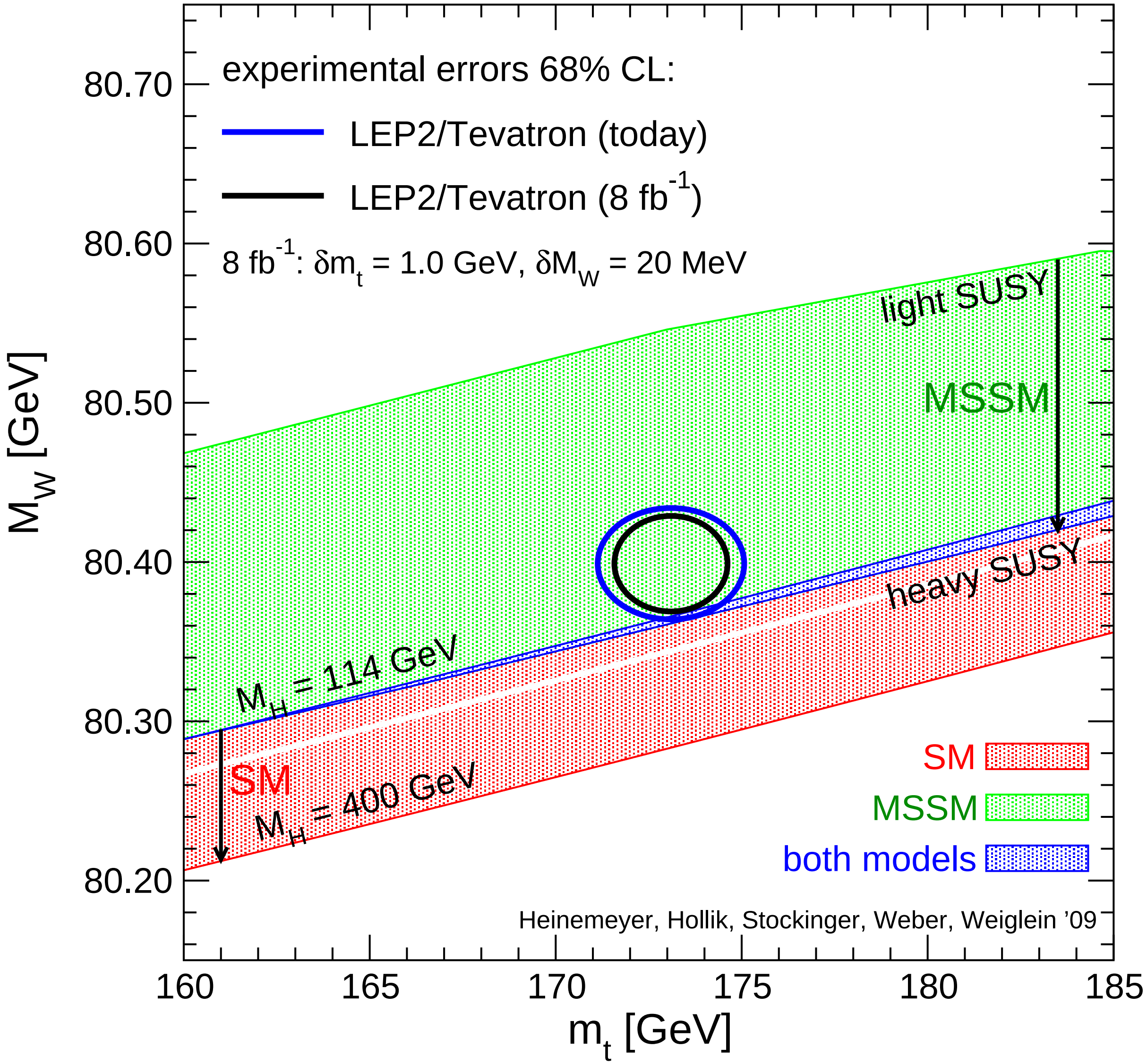

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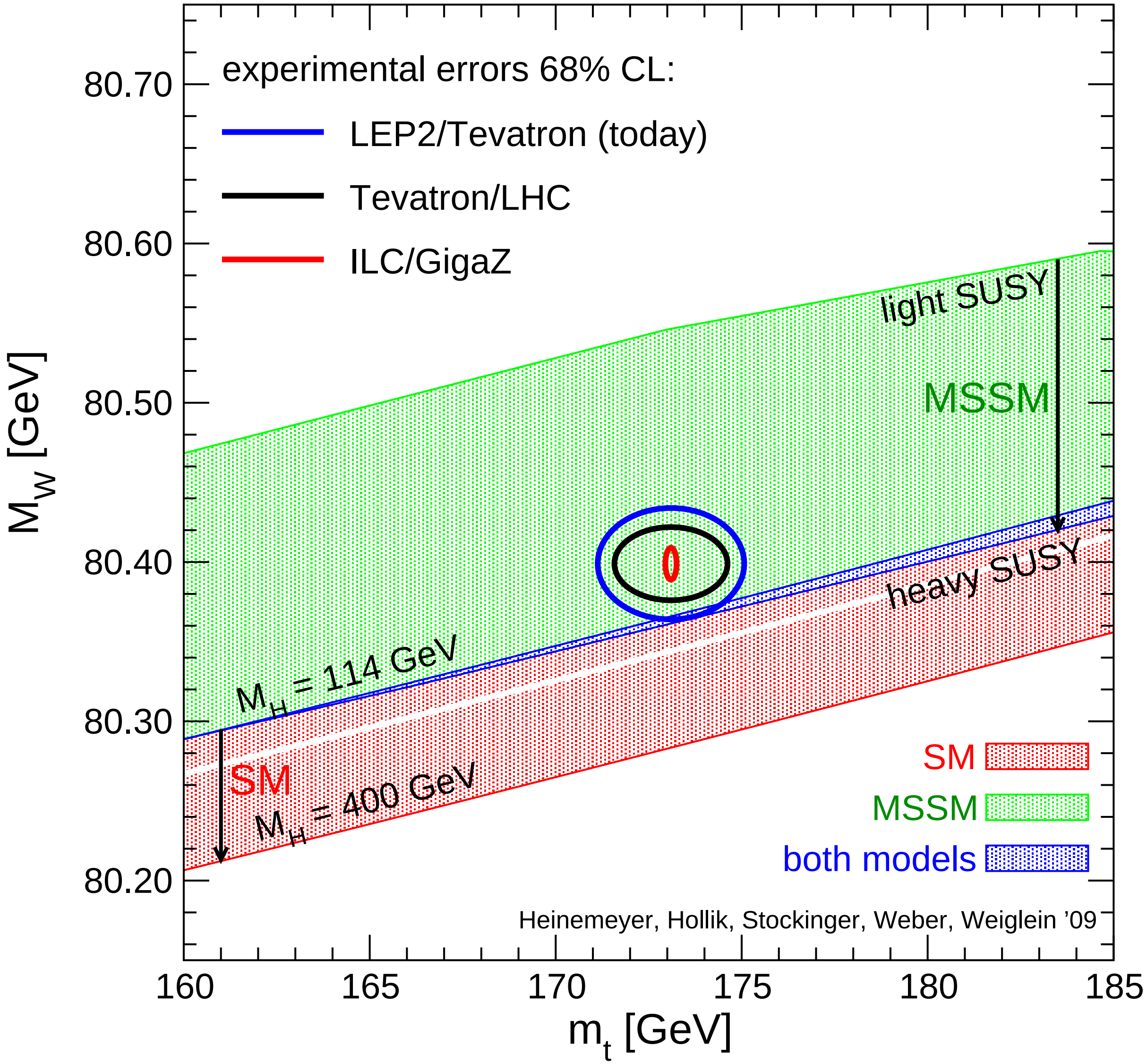

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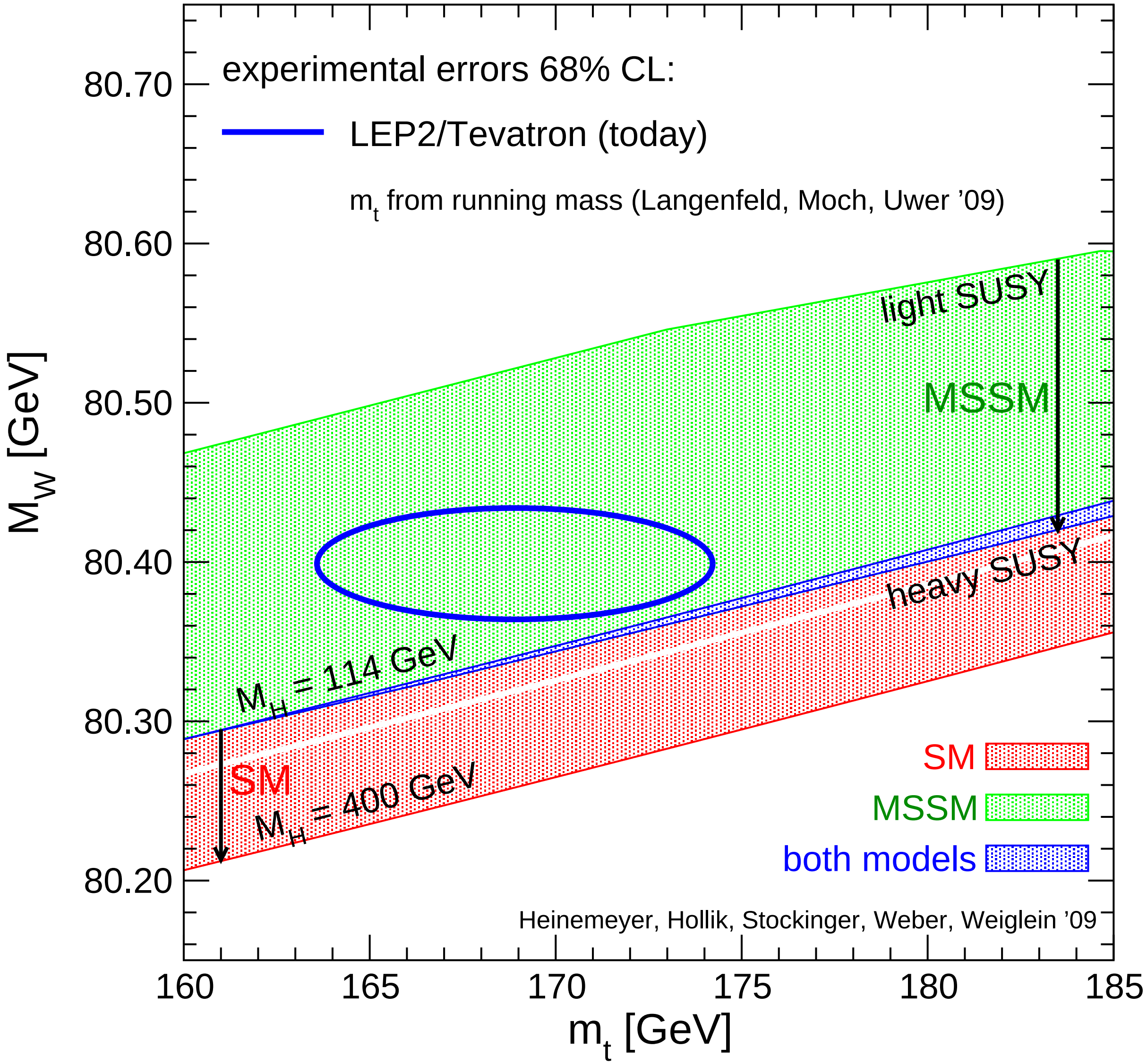

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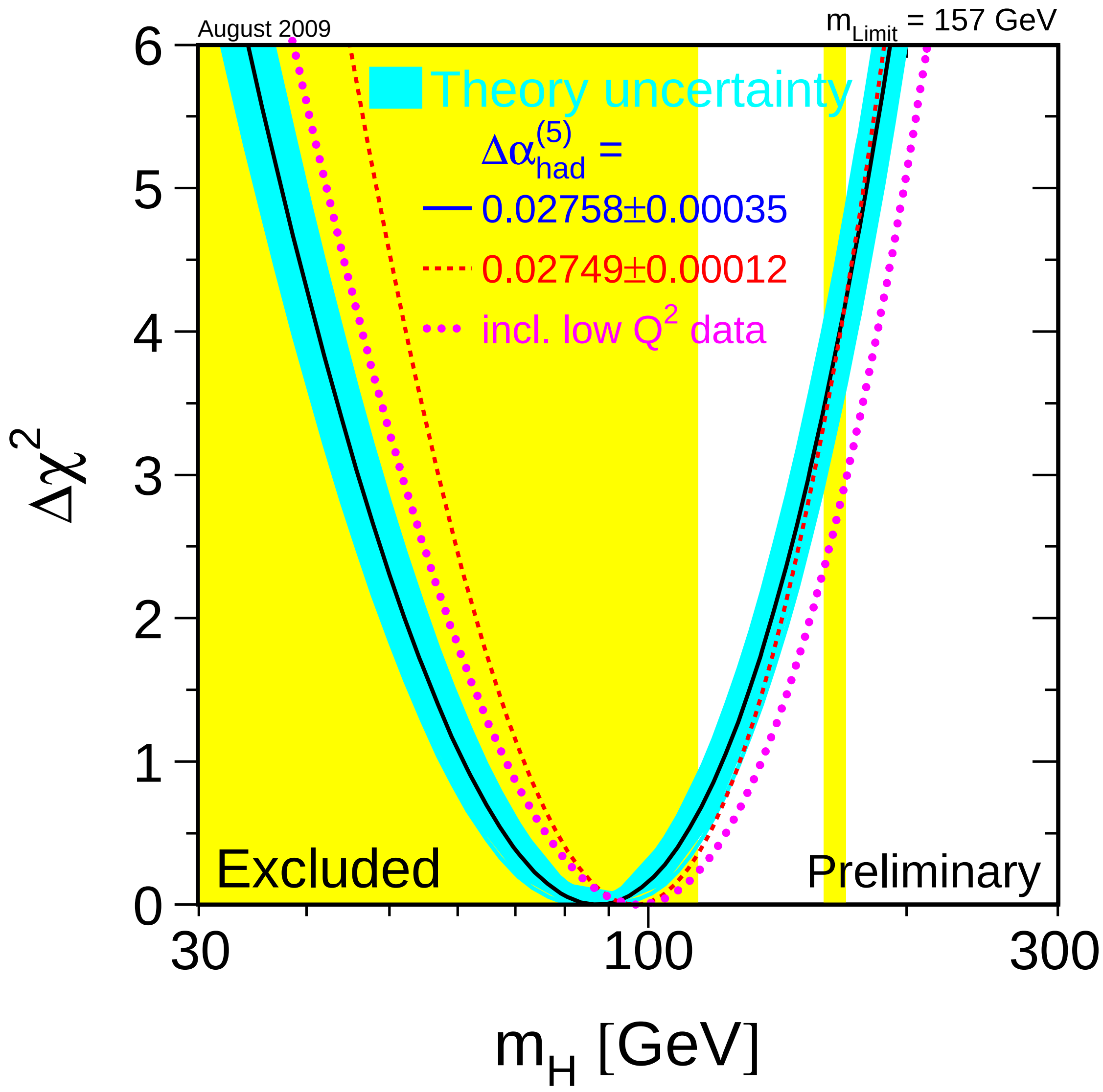
Global fit to all SM data:

[*LEPEWWG '09*]

$\Rightarrow M_H = 87^{+35}_{-26}$ GeV

$M_H < 157$ GeV, 95% C.L.



Assumption for the fit:
SM incl. Higgs boson

$\Rightarrow$ no confirmation of
Higgs mechanism

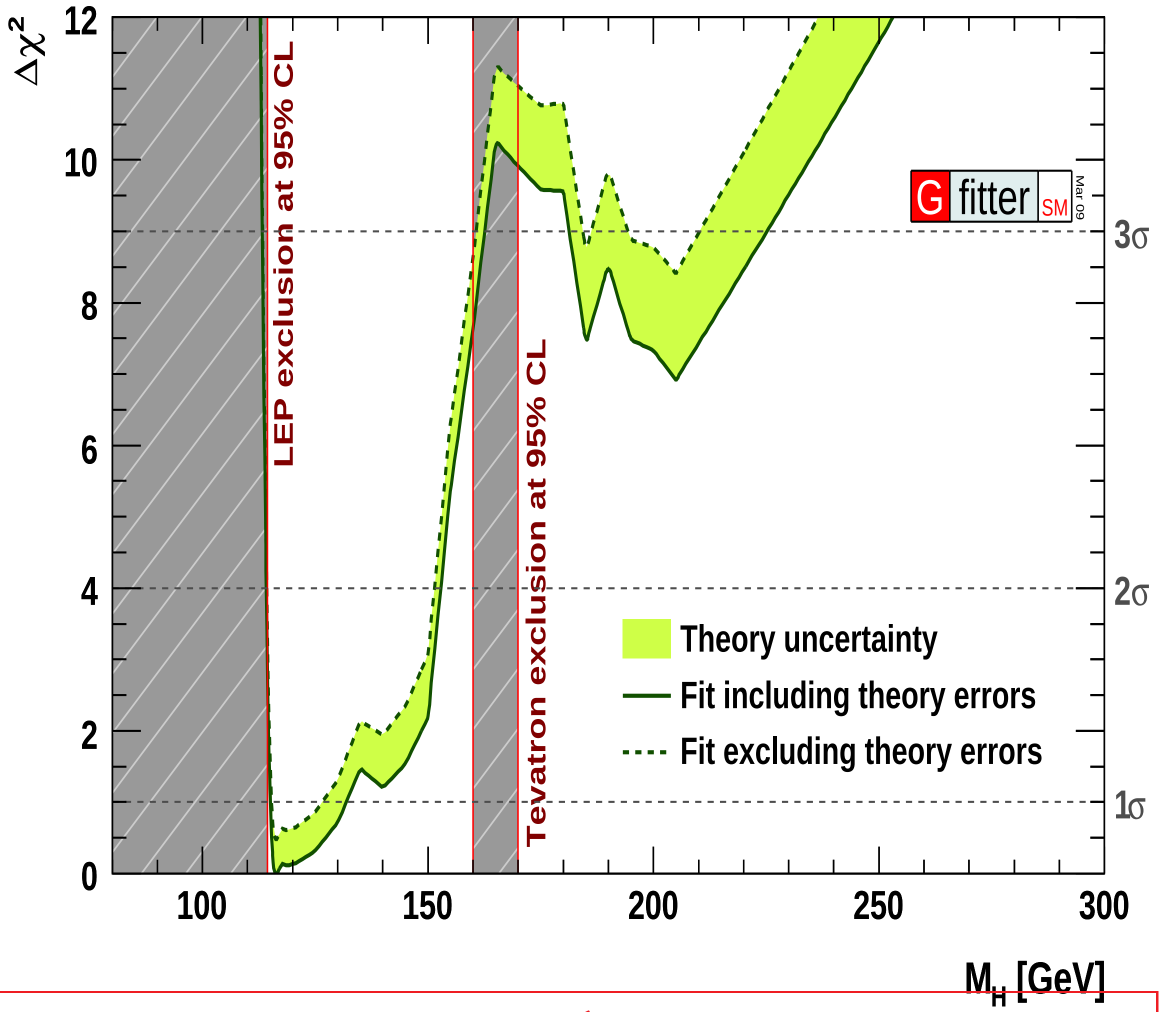
$\Rightarrow$ Higgs boson seems to be light, $M_H \lesssim 160$ GeV

Global fit to all SM data incl. direct searches:

[GFitter '09]

$\Rightarrow M_H = 116.4^{+18.3}_{-1.4}$ GeV

$M_H < 152$ GeV, 95% C.L.



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Main idea of analysis:

Combine all existing precision data:

- Electroweak precision observables (EWPO)
- B physics observables (BPO)
- Cold dark matter (CDM)
- ...

Predict:

- best-fit points
- ranges for Higgs masses
- ranges for SM parameters
- ranges for SUSY masses ⇒ LHC/ILC reach

2. The models and the tools

Indirect constraints on M_{SUSY} from existing data?

- Electroweak precision observables (EWPO) ?
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  $\Rightarrow$ combination of EWPO, BPO, CDM ?

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EWPO M_W : information on $m_{\tilde{t}}$, $m_{\tilde{b}}$ or M_A, $\tan\beta$ or . . .

EWPO $(g-2)_\mu$: information on $\tan\beta$ and/or $m_{\tilde{\chi}^0}$, $m_{\tilde{\chi}^\pm}$ and/or $m_{\tilde{\mu}}$, $m_{\tilde{\nu}_\mu}$

BPO BR$(b \to s\gamma)$: information on $\tan\beta$ and/or $M_{H^\pm}$ and/or $m_{\tilde{t}}$, $m_{\tilde{\chi}^\pm}$

CDM (LSP gives CDM) : information on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}}$ or M_A or . . .

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EWPO $(g-2)_\mu$: information on $\tan\beta$ and/or $m_{\tilde{\chi}^0}$, $m_{\tilde{\chi}^\pm}$ and/or $m_{\tilde{\mu}}$, $m_{\tilde{\nu}_\mu}$

BPO BR$(b \to s\gamma)$: information on $\tan\beta$ and/or $M_{H^\pm}$ and/or $m_{\tilde{t}}$, $m_{\tilde{\chi}^\pm}$

CDM (LSP gives CDM) : information on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}}$ or M_A or ...

$\Rightarrow$ combination makes only sense if all parameters are connected!
$\Rightarrow$ GUT based models, ...

Existing analyses for GUT based models: (involving precision observables)

CMSSM/mSUGRA:

[J. Ellis, S.H., K. Olive, G. Weiglein '04, '06, '07] *[J. Ellis, S.H., K. Olive, A. Weber, G. Weiglein '07]*

[E. Baltz, P. Gondolo '04] *[R. Ruiz de Austri, R. Trotta and L. Roszkowski '06, '07]*

[B. Allanach, C. Lester and A. Weber '06, '07]

[F. Feroz, M. Hobson, L. Roszkowski and R. Ruiz de Austri, R. Trotta '08]

[O. Buchmueller et al. '07] *[O. Buchmueller et al. '08]* *[O. Buchmueller et al. '09]*

[M. Cabrera, A. Casas, R. Ruiz de Austri '09] *[Y. Akrami, P. Scott, J. Edsjo, J. Conrad, L. Bergstrom '09]*

NUHM (Non-Universal Higgs Mass model):

[J. Ellis, S.H., K. Olive, G. Weiglein '06] *[J. Ellis, S.H., K. Olive, A.M. Weber, G. Weiglein '07]*

[J. Ellis, T. Hahn, S.H., K. Olive, G. Weiglein '07]

[O. Buchmueller et al. '08] *[O. Buchmueller et al. '09]*

VCMSSM (Very Constrained MSSM):

[J. Ellis, S.H., K. Olive, G. Weiglein '06]

[L. Roszkowski, R. Ruiz de Austri, R. Trotta, Y. Tsai, T. Varley '09]

mSUGRA (GDM) (Gravitino Dark Matter): *[J. Ellis, S.H., K. Olive, G. Weiglein '06]*

CMSSM, mGMSB, mAMSB: *[S.H., X. Miao, S. Su, G. Weiglein '08]*

CNMSSM: *[D. Lopez-Fogliani, L. Roszkowski, R. Ruiz de Austri, T. Varley '09]*

Finite Unified Theories: *[S.H., M. Mondragón, G. Zoupanos '07]*

Different methods:

1.) Scanning:

– 3-dim scans (possibly with CDM fixing one dimension)
– multi-dim scans
– multi-dim scans (with Markov Chain Monte Carlo technique)

$\Rightarrow$ here: results using last two

2.) Fitting:

– Frequentist
– Bayesian

$\Rightarrow$ focus on Frequentist here

$\Rightarrow$ χ^2 function to include all experimental results

3.) Priors . . . (none)

χ^2 calculation:

$\rightarrow$ global χ^2 likelihood function
combines all theoretical predictions with experimental constraints:

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f_{\mathrm{SM}_i}^{\mathrm{obs}} - f_{\mathrm{SM}_i}^{\mathrm{fit}})^2}{\sigma(f_{\mathrm{SM}_i})^2}$$

N: number of observables studied
M: SM parameters: $\Delta\alpha_{\mathrm{had}}, m_t, M_Z$
C_i: experimentally measured value (constraint)
P_i: MSSM parameter-dependent prediction for the corresponding constraint

Assumption: measurements are uncorrelated - fulfilled to a high degree

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→ global χ^2 likelihood function
combines all theoretical predictions with experimental constraints:

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C_i: experimentally measured value (constraint)
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Assumption: measurements are uncorrelated - fulfilled to a high degree

What to do if only a lower/upper bound exists?

→ especially important: M_h → backup

The models: 1.) CMSSM (or mSUGRA):

⇒ Scenario characterized by

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}\,\mu$$

m_0 : universal scalar mass parameter

$m_{1/2}$: universal gaugino mass parameter

A_0 : universal trilinear coupling

} at the GUT scale

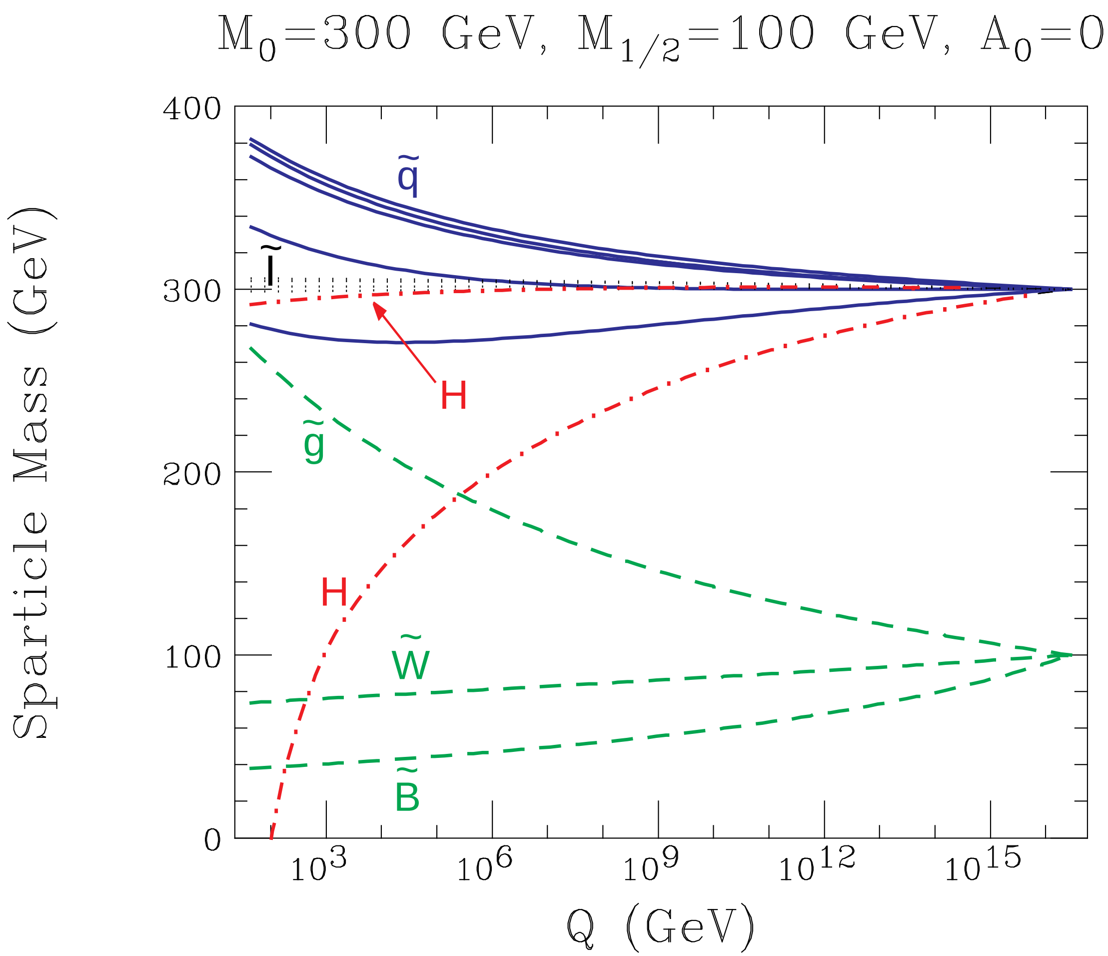
$\tan\beta$: ratio of Higgs vacuum expectation values

$\mathrm{sign}(\mu)$: sign of supersymmetric Higgs parameter

⇒ particle spectra from renormalization group running to weak scale

⇒ Lightest SUSY particle (LSP) is the lightest neutralino

⇒ particle spectra from renormalization group running to weak scale



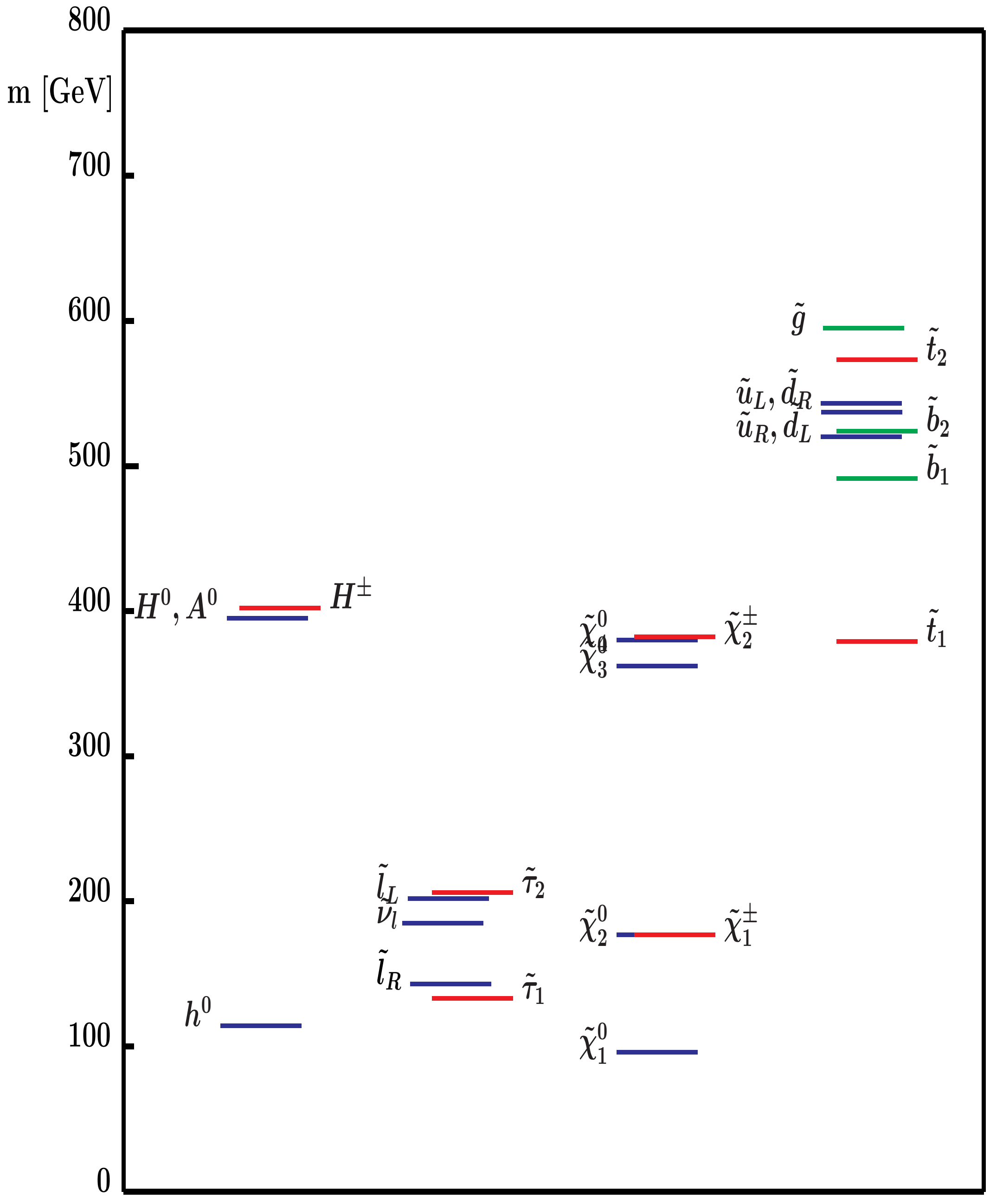
⇒ one parameter turns negative ⇒ Higgs mechanism for free

“Typical” CMSSM scenario

(SPS 1a benchmark scenario):

SPS home page:

`www.ippp.dur.ac.uk/∼georg/sps`



The models: 2.) NUHM1: (Non-universal Higgs mass model)

Assumption: no unification of scalar fermion and scalar Higgs parameter at the GUT scale

⇒ effectively M_A or μ as free parameters at the EW scale

⇒ besides the CMSSM parameters

M_A or μ

Further extension: NUHM2:

Assumption: no unification of the Higgs parameters at the GUT scale

⇒ effectively M_A and μ as free parameters at the EW scale

⇒ besides the CMSSM parameters

M_A and μ

Our tool:

The "MasterCode"

⇒ collaborative effort of theorists and experimentalists

[*Buchmüller, Cavanaugh, De Roeck, Ellis, Flächer, Hahn, SH, Isidori, Olive, Ronga, Weiglein*]

Über-code for the combination of different tools:

- tools are included as subroutines
- compatibility ensured by collaboration of authors of "MasterCode" and authors of "sub tools" /SLHA(2)
- one "MasterCode" for one model . . .

⇒ evaluate observables of one parameter point consistently with various tools

cern.ch/mastercode

Status of the "MasterCode":

- one model: (MFV) MSSM
- tools included:
  - B-physics observables [*SuFla*]
  - more B-physics observables [*SuperIso*]
  - Higgs related observables, $(g-2)_\mu$ [*FeynHiggs*]
  - Electroweak precision observables [*FeynWZ*]
  - Dark Matter observables [*MicrOMEGAs, DarkSUSY*]
  - for GUT scale models: RGE running [*SoftSusy*]
- added: χ^2 analysis code

  (→ similar directions as SFitter, Fittino)
- currently being implemented:
  - Higgs constraints (for χ^2 contributions . . .) [*HiggsBounds*]
- planned: inclusion of more tools

  inclusion of more models

3. Constraining the lightest MSSM Higgs mass M_h

Contrary to the SM: M_h is not a free parameter

MSSM tree-level bound: $M_h < M_Z$, excluded by LEP Higgs searches

Large radiative corrections:

Dominant one-loop corrections:

$$\Delta M_h^2 \sim G_\mu m_t^4 \log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right)$$

The MSSM Higgs sector is connected to all other sector via loop corrections (especially to the scalar top sector)

Measurement of M_h, Higgs couplings $\Rightarrow$ test of the theory

LHC: $\Delta M_h \approx 0.2$ GeV
ILC: $\Delta M_h \approx 0.05$ GeV

$\Rightarrow$ M_h will be (the best?) electroweak precision observable

Fit of M_h in Supersymmetry?

Fit of M_h in Supersymmetry?

Advantages of fits in the MSSM vs. SM

- $(g-2)_\mu$ can be used as a constraint
- Cold Dark Matter can be used as a constraint
- BR($B_s \to \mu^+\mu^-$) can be used as a constraint
- M_h can be predicted from other parameters
  $\Rightarrow$ stronger constraints possible

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Fit of M_h in Supersymmetry?

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  $\Rightarrow$ stronger constraints possible

Disadvantages of fits in the MSSM vs. SM

– many independent mass scales
– M_h can be predicted from other parameters
  $\Rightarrow$ more difficult to disentangle effects

Note: LEP limits on M_h are not included in this (part of the) fit

Prediction of M_h in the CMSSM/NUHM1

[Buchmüller, Cavanaugh, De Roeck, Ellis, Flächer, S.H., Isidori, Olive, Ronga, Weiglein '09]

General idea:

Take the most simple MSSM version: CMSSM/NUHM1
$\rightarrow$ just three/four GUT scale parameters + $\tan\beta$

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– combine all electroweak precision data as in the SM (i.e. not M_h)
– combine with B physics observables
– combine with CDM and $(g-2)_\mu$
– include SM parameters with their errors: $m_t, \ldots$

– scan over the full CMSSM/NUHM1 parameter space

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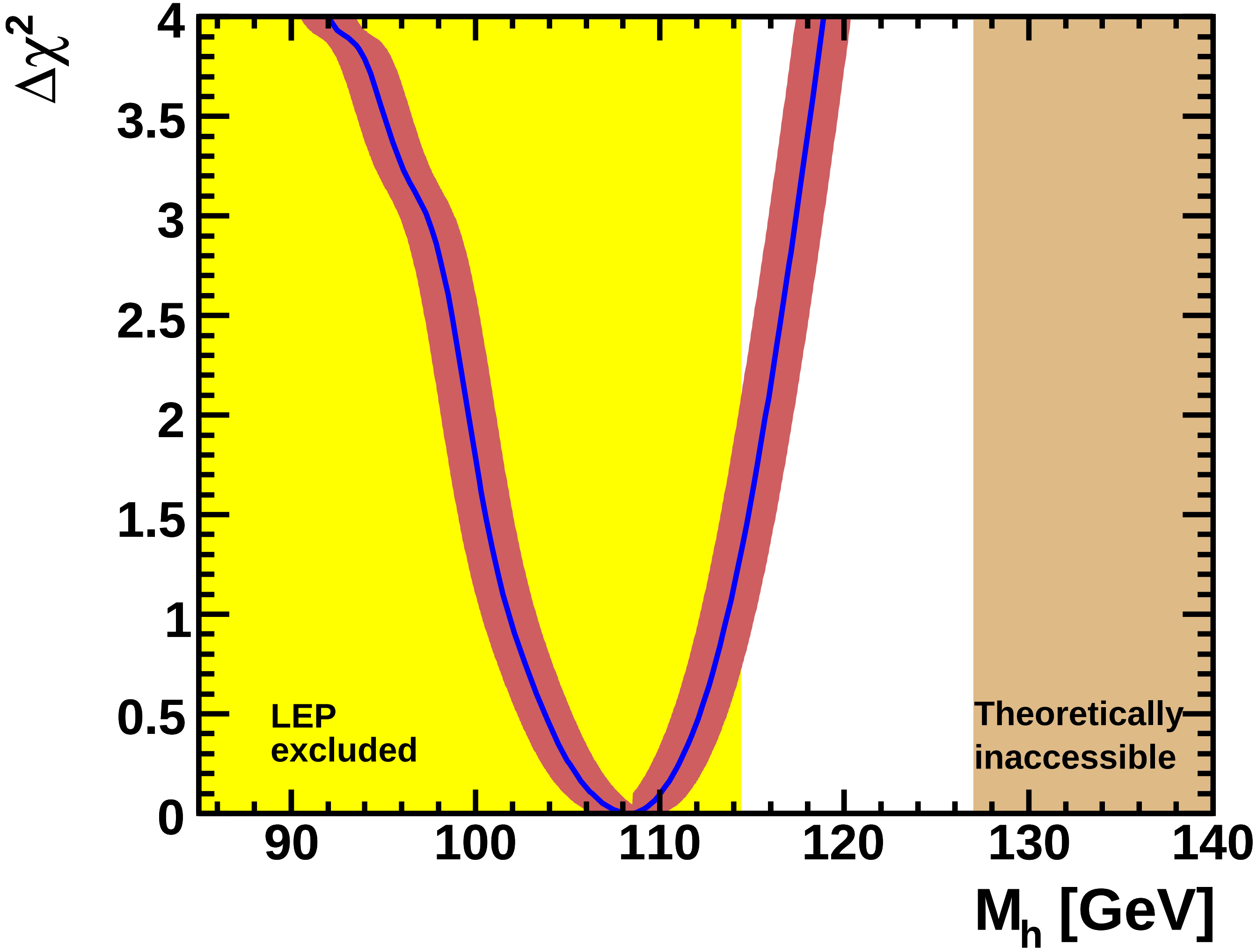
– include SM parameters with their errors: $m_t, \ldots$

– scan over the full CMSSM/NUHM1 parameter space

$\Rightarrow$ preferred M_h values

CMSSM: red band plot:

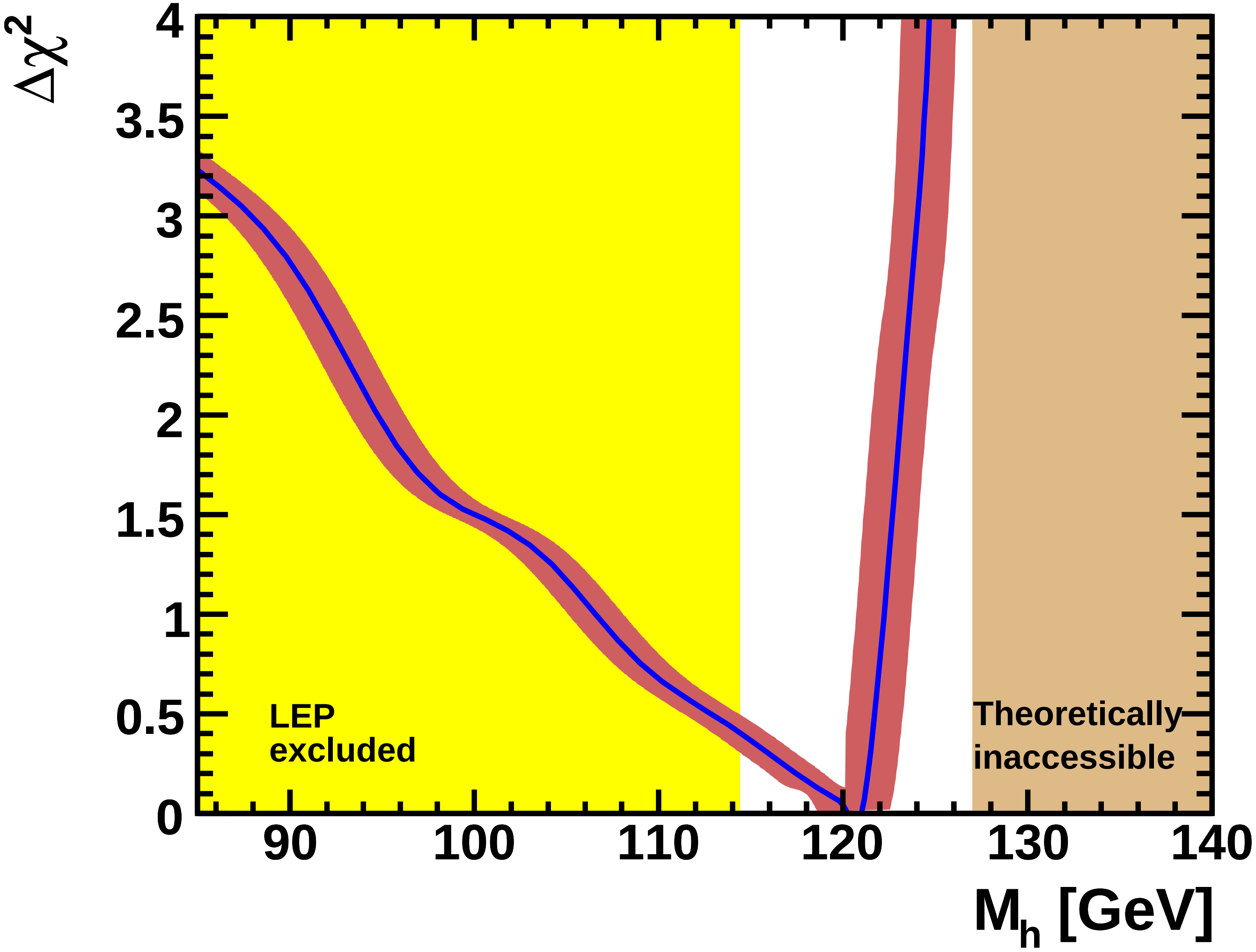
[2009]



$M_h = 108 \pm 6\,(\text{exp}) \pm 1.5(\text{theo})$ GeV

NUHM1: red band plot:

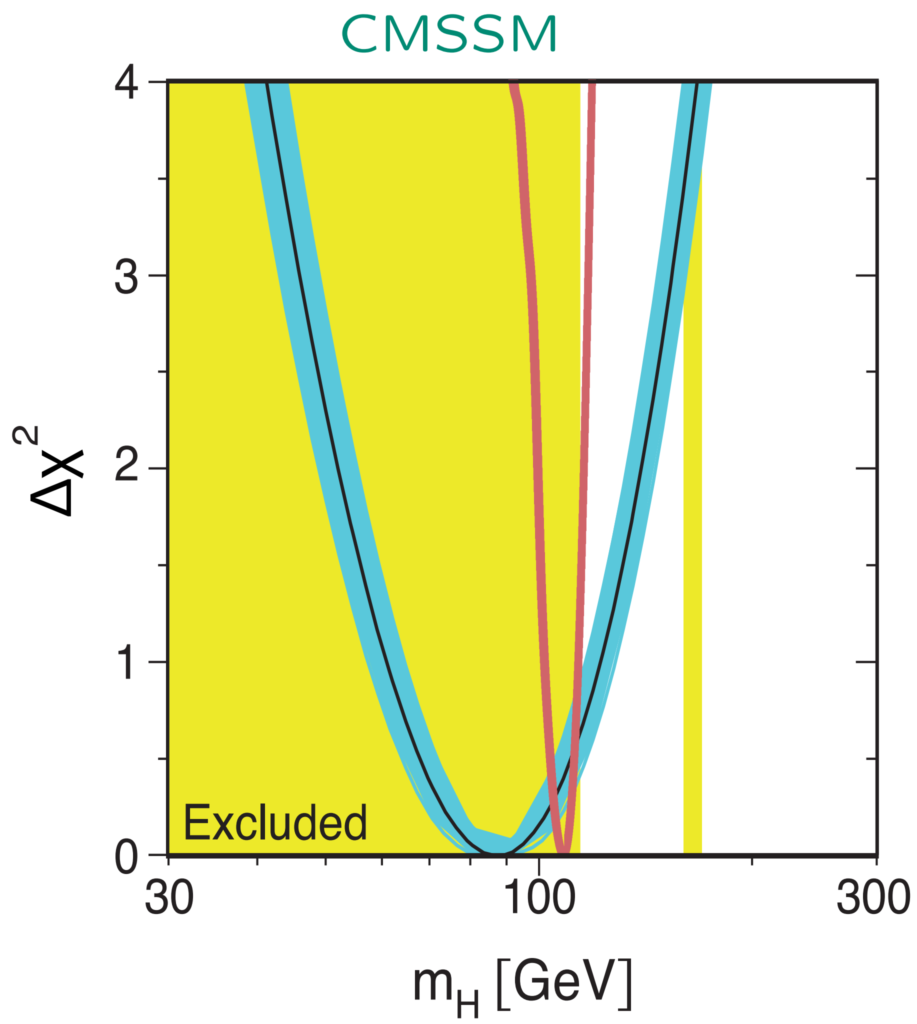
[2009]



$M_h = 121^{+1}_{-14}$ (exp) $\pm$ 1.5(theo) GeV $\Rightarrow$ naturally above LEP limit

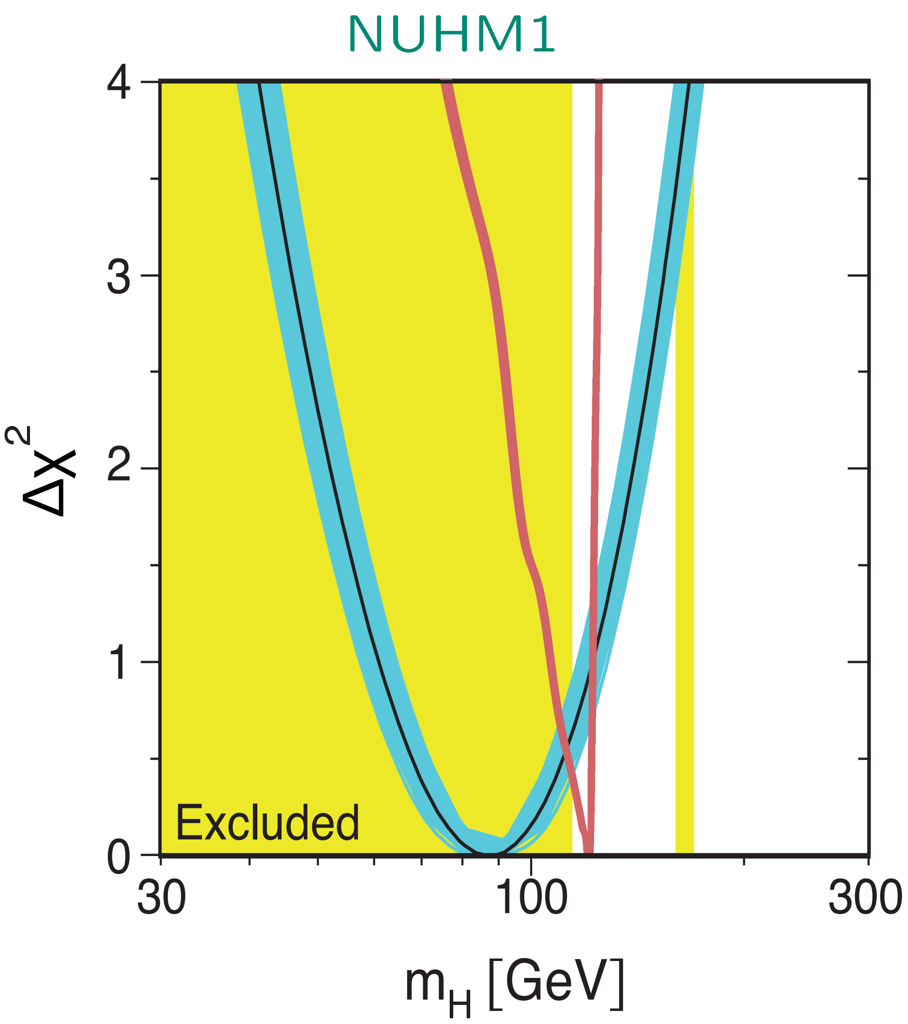
Prediction of M_H^{SM} (blue band) and M_h in the MSSM (red band):

[2009]



$M_h^{\text{CMSSM}} = 108 \pm 6 \pm 1.5$ GeV

⇒ as good as the SM



$M_h^{\text{NUHM1}} = 121^{+1}_{-14} \pm 1.5$ GeV

⇒ above the LEP limit

4. Testing SUSY with m_t and M_W

Sensitive test of any model:

Fit m_t and/or M_W and compare with experimental values:

$$\begin{aligned} m_t^{\text{exp}} &= 173.1 \pm 1.3 \text{ GeV} \\ M_W^{\text{exp}} &= 80.399 \pm 0.023 \text{ GeV} \end{aligned}$$

[*LEPEWWG '09*]

[*TevEWWG '09*]

$$m_t^{\text{fit,SM,excl.}\, M_W} = 172.6^{+13.3}_{-10.2} \text{ GeV}$$

$$m_t^{\text{fit,SM,incl.}\, M_W} = 179.3^{+11.6}_{-8.5} \text{ GeV}$$

$$M_W^{\text{fit,SM,excl.}\, m_t} = 80.363 \pm 0.032 \text{ GeV}$$

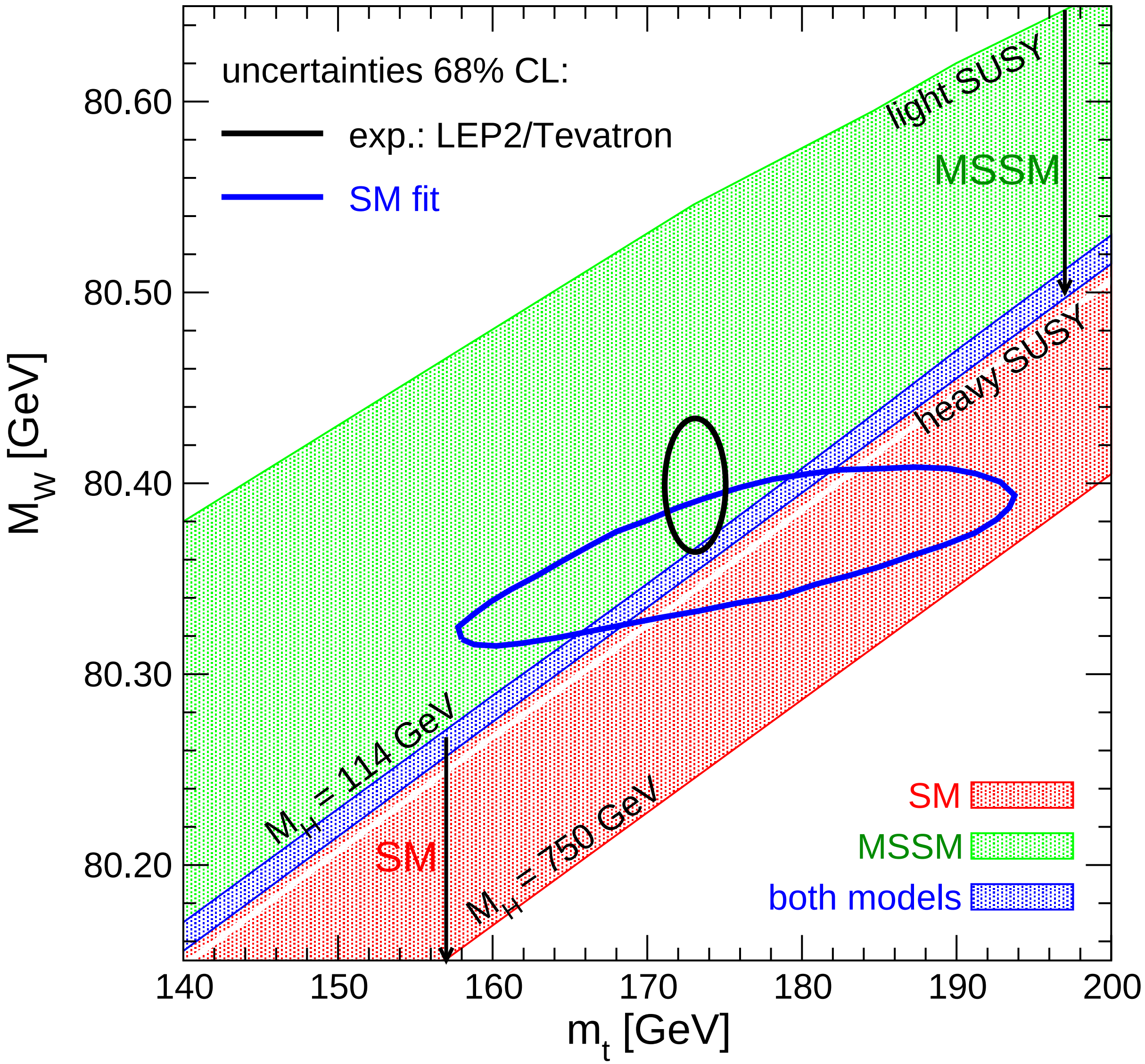
$$M_W^{\text{fit,SM,incl.}\, m_t} = 80.364 \pm 0.020 \text{ GeV}$$

⇒ non-trivial success of the SM

⇒ quantum corrections up to two-loop needed

Comparison of direct and indirect determination of m_t and M_W in the SM and the MSSM :

[2009]



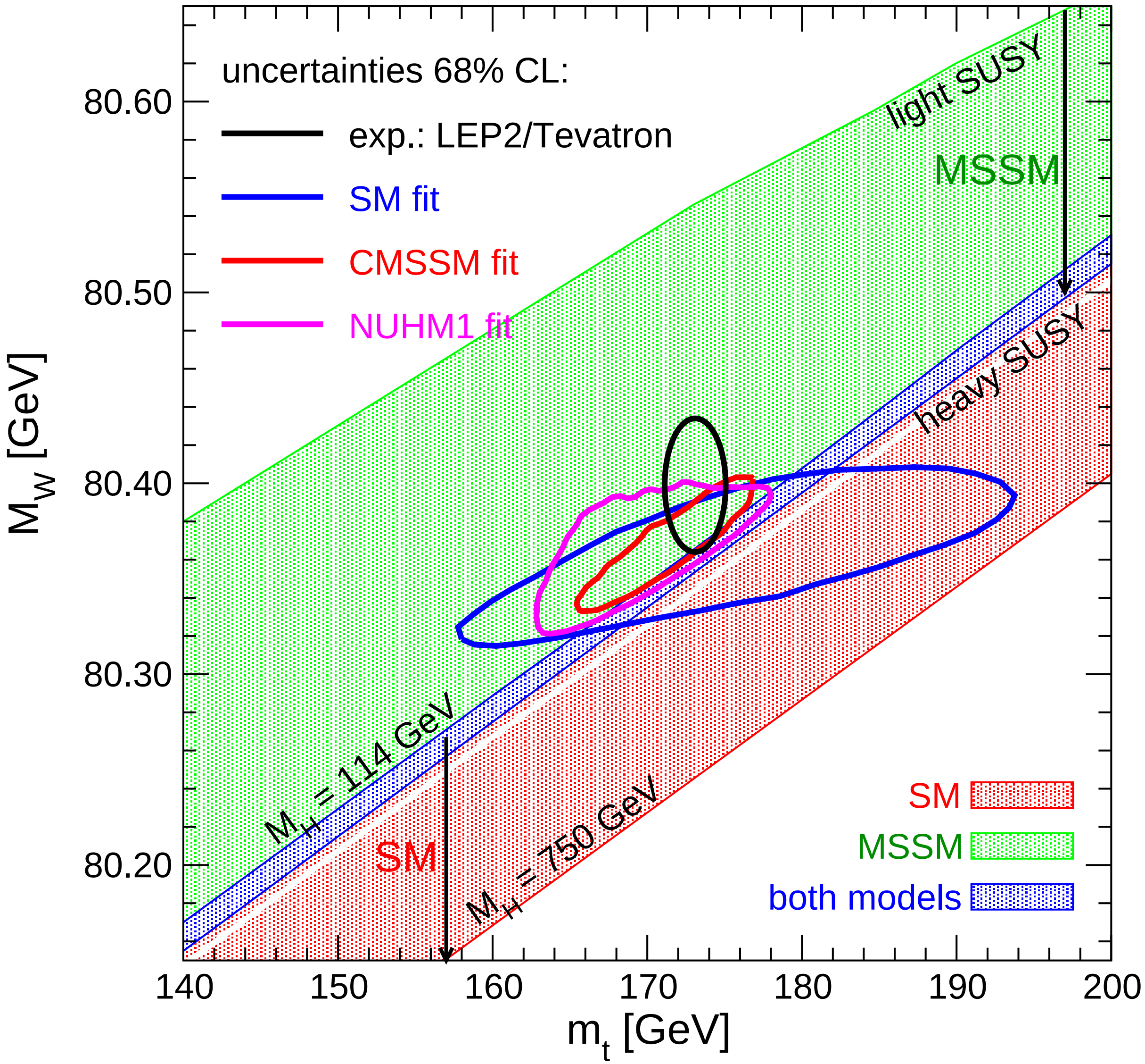
MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}

Comparison of direct and indirect determination of m_t and M_W in the SM and the MSSM :

[2009]



MSSM band:
scan over
SUSY masses

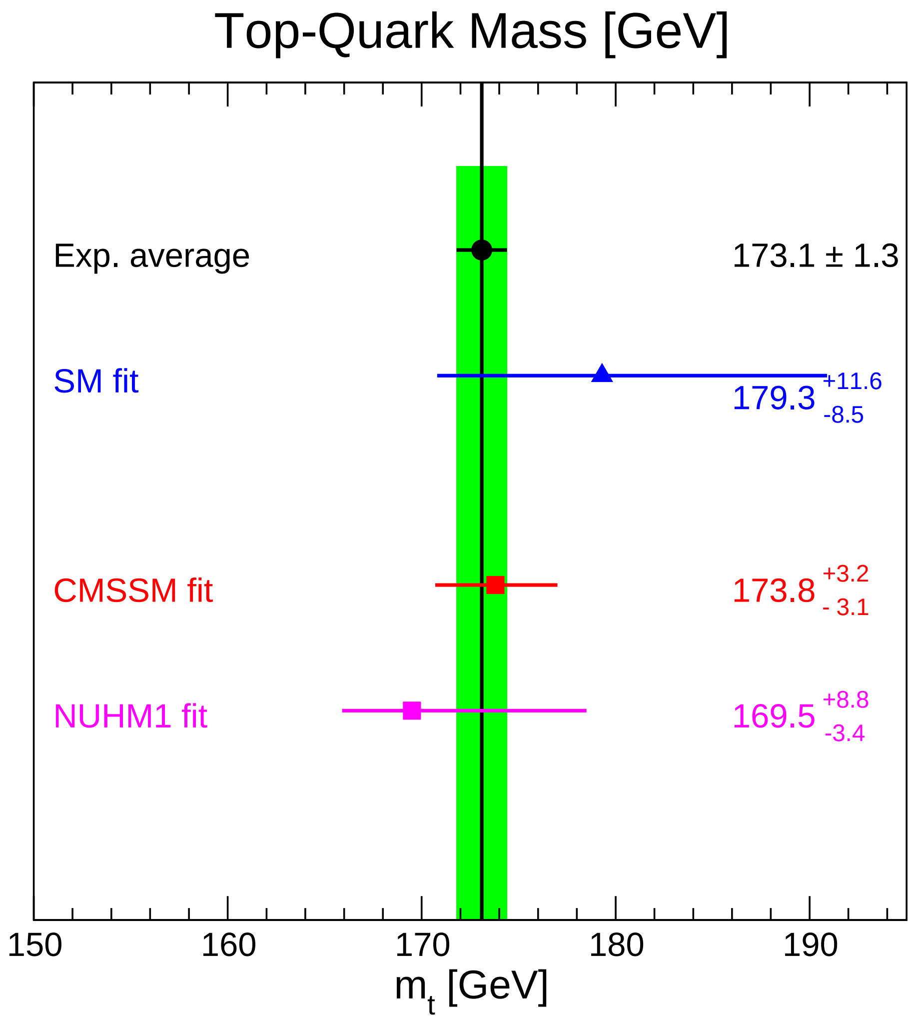
overlap:
SM is MSSM-like
MSSM is SM-like

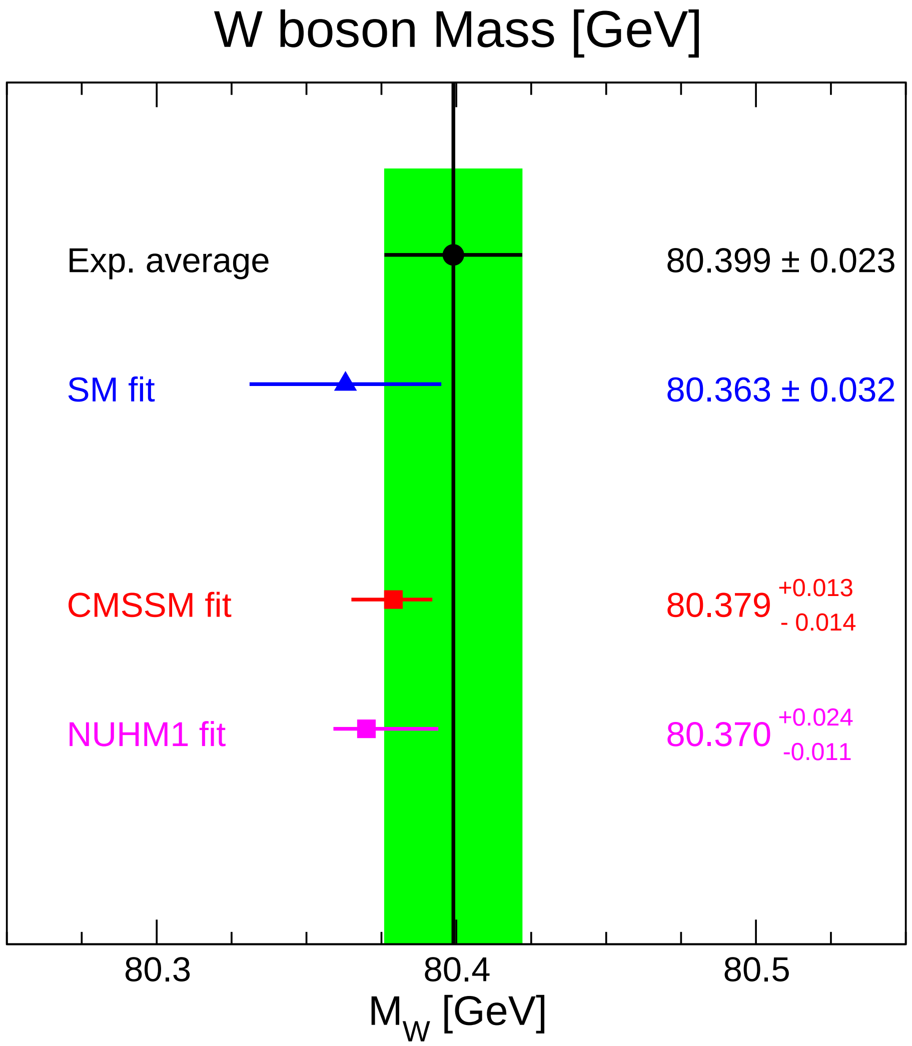
SM band:
variation of M_H^{SM}

M_W fit: M_W not included, m_t fit: m_t not included

(SM fit: M_H not included – CMSSM/NUHM1 fit: M_h included)

[2009]





⇒ CMSSM and NUHM1 fit amazingly well m_t and M_W

⇒ better than the SM: smaller errors, better best-fit points

5. LHC/ILC reach in the CMSSM/NUHM1

[*Buchmüller, Cavanaugh, De Roeck, Ellis, Flächer, S.H., Isidori, Olive, Ronga, Weiglein '09*]

- combine all electroweak precision data as in the SM
- combine with B physics observables
- combine with CDM and $(g-2)_\mu$
- include SM parameters with their errors: m_t, M_Z, $\Delta\alpha_{\rm had}$

$\Rightarrow$ χ^2 function

$\rightarrow$ scan over the full CMSSM/NUHM1 parameter space

$\sim 2.5\ 10^7$ points samples with MCMC

statistical measure: χ^2 function (Frequentist, no priors)

$\rightarrow$ final minimum: Minuit

$\Delta\chi^2$: 68, 95% C.L. contours

$\Rightarrow$ preferred CMSSM/NUHM1 parameters $\Rightarrow \mathcal{L}_{\rm SUSY}$

$\Rightarrow$ LHC/ILC reach

Best-fit points:

[2008]

CMSSM:

$m_{1/2} = 310$ GeV, $m_0 = 60$ GeV, $A_0 = 130$ GeV,

$\tan\beta = 11$, $\mu = 400$ GeV, $M_A = 450$ GeV

$\chi^2/N_{\rm dof} = 20.6/19$ (36 % probability)

$\Rightarrow$ very similar to SPS 1a :-)

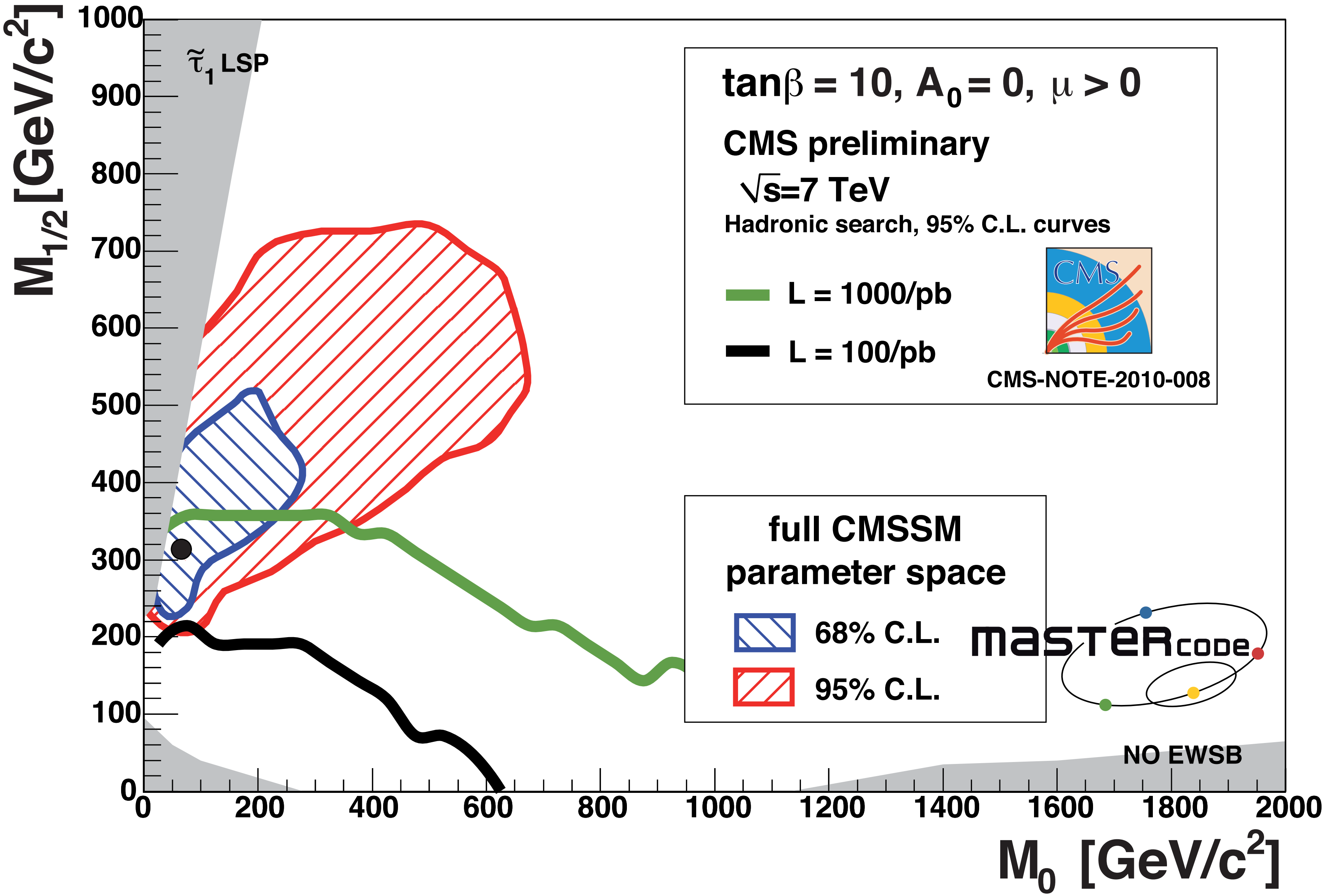
NUHM1:

$m_{1/2} = 270$ GeV, $m_0 = 150$ GeV, $A_0 = -1300$ GeV,

$\tan\beta = 11$, $\mu = 1140$ GeV, $M_A = 310$ GeV

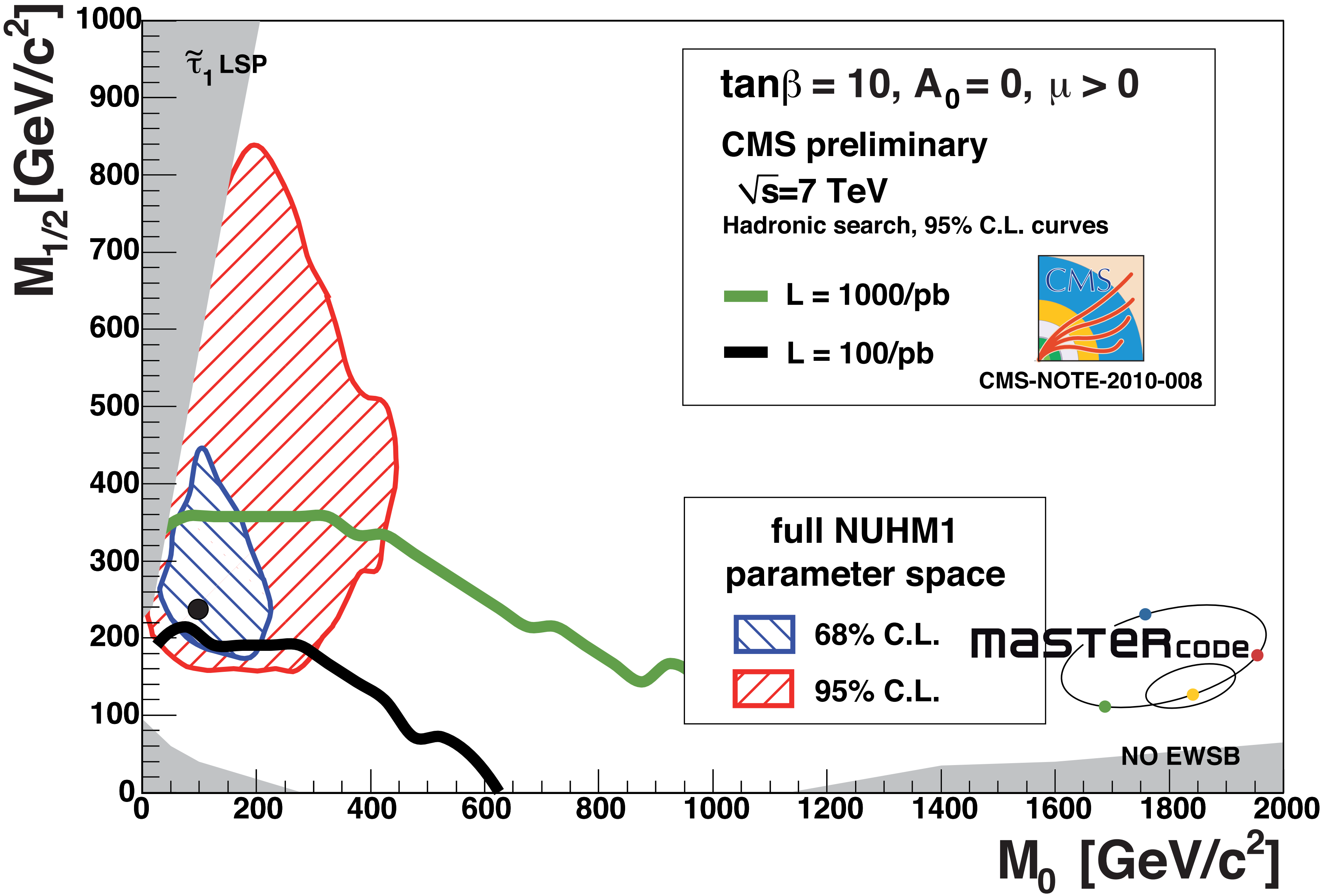
(similar probability)

LHC (CMS) ⊕ CMSSM analysis:



⇒ best-fit point and part of 68% C.L. are can be tested in 2011

LHC (CMS) ⊕ NUHM1 analysis:



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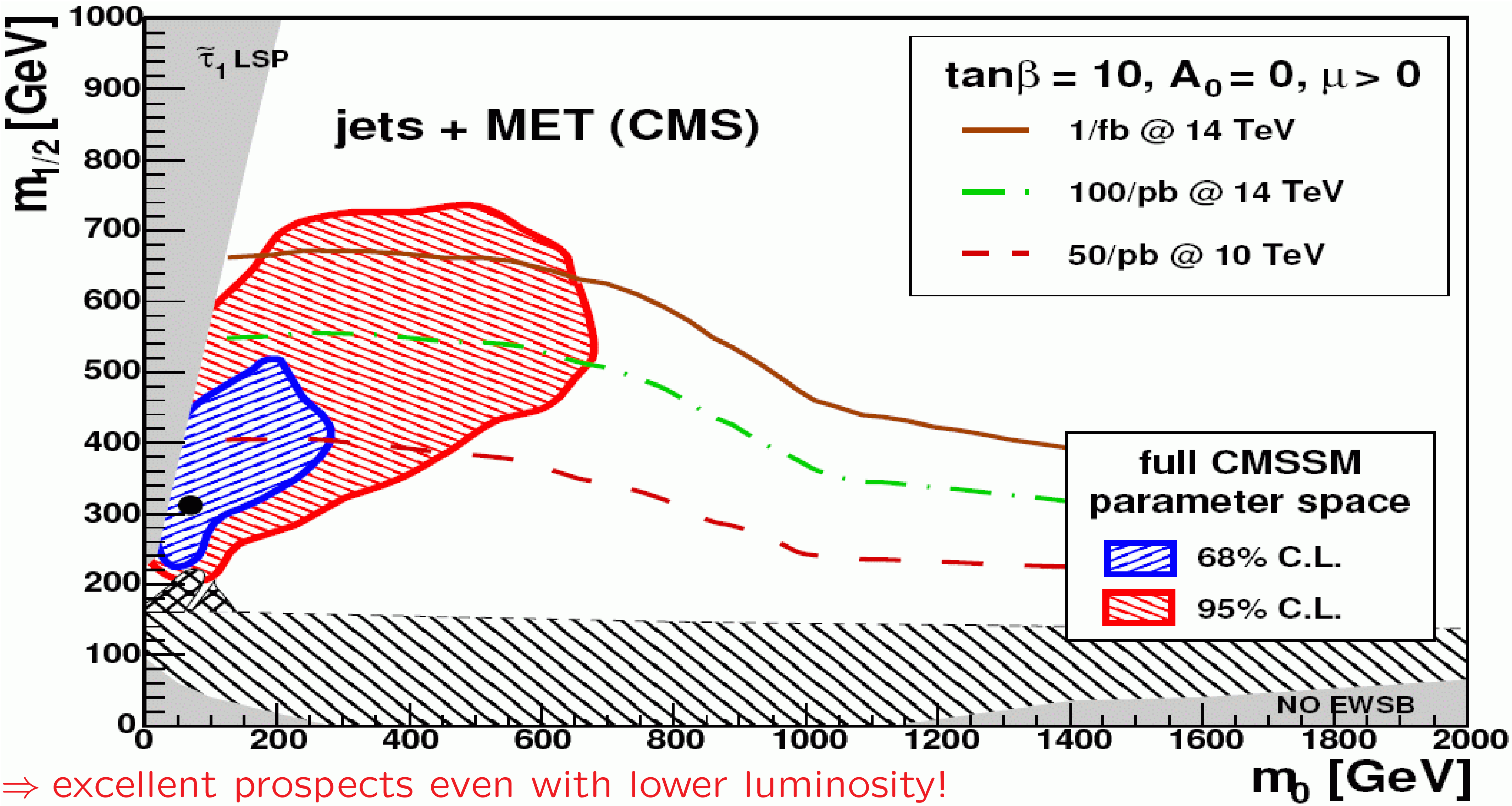
LHC (CMS) ⊕ CMSSM analysis:

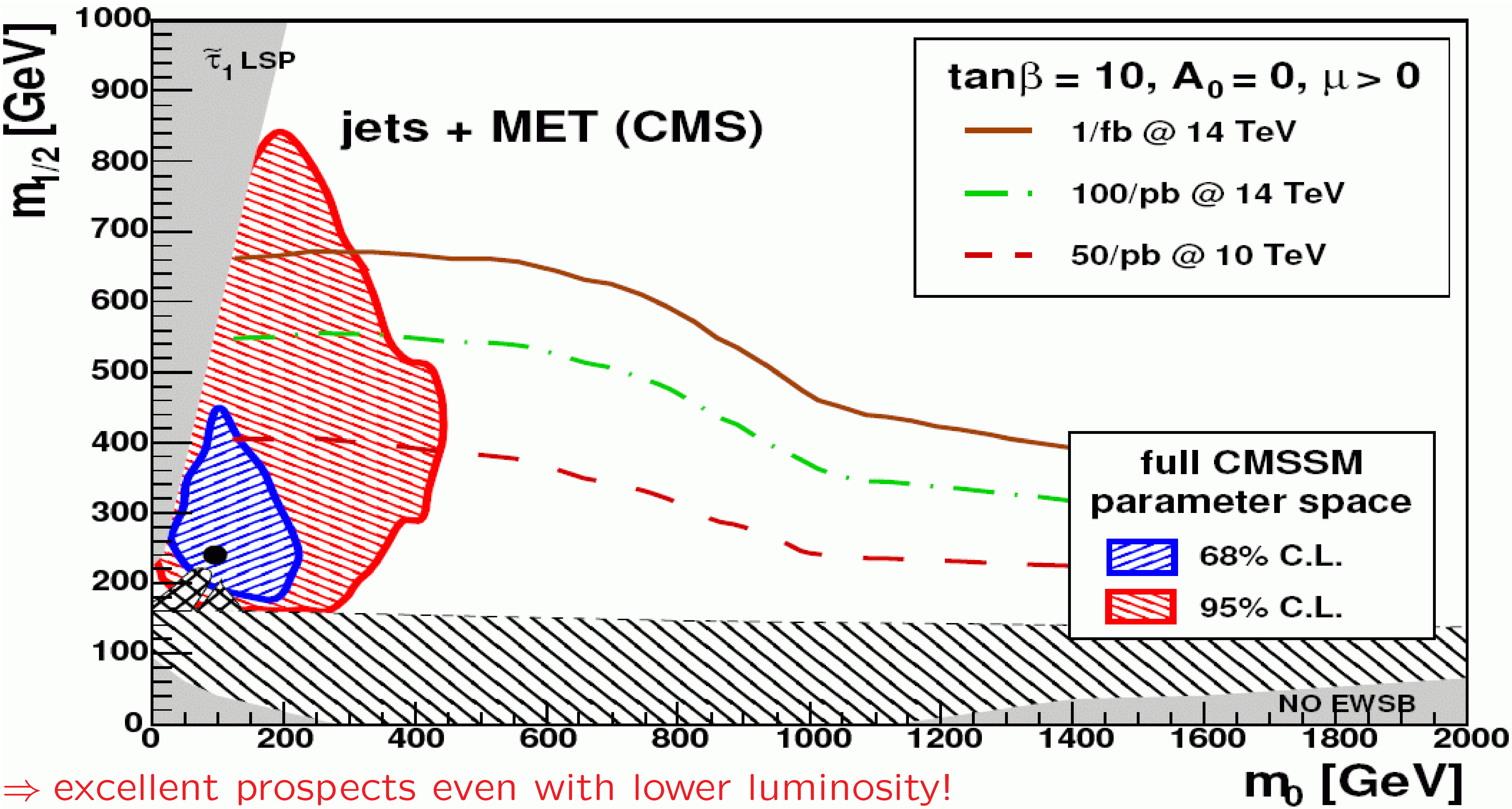
[*CMS '07*] [*2008*]



⇒ excellent prospects even with lower luminosity!

LHC (CMS) ⊕ NUHM1 analysis:

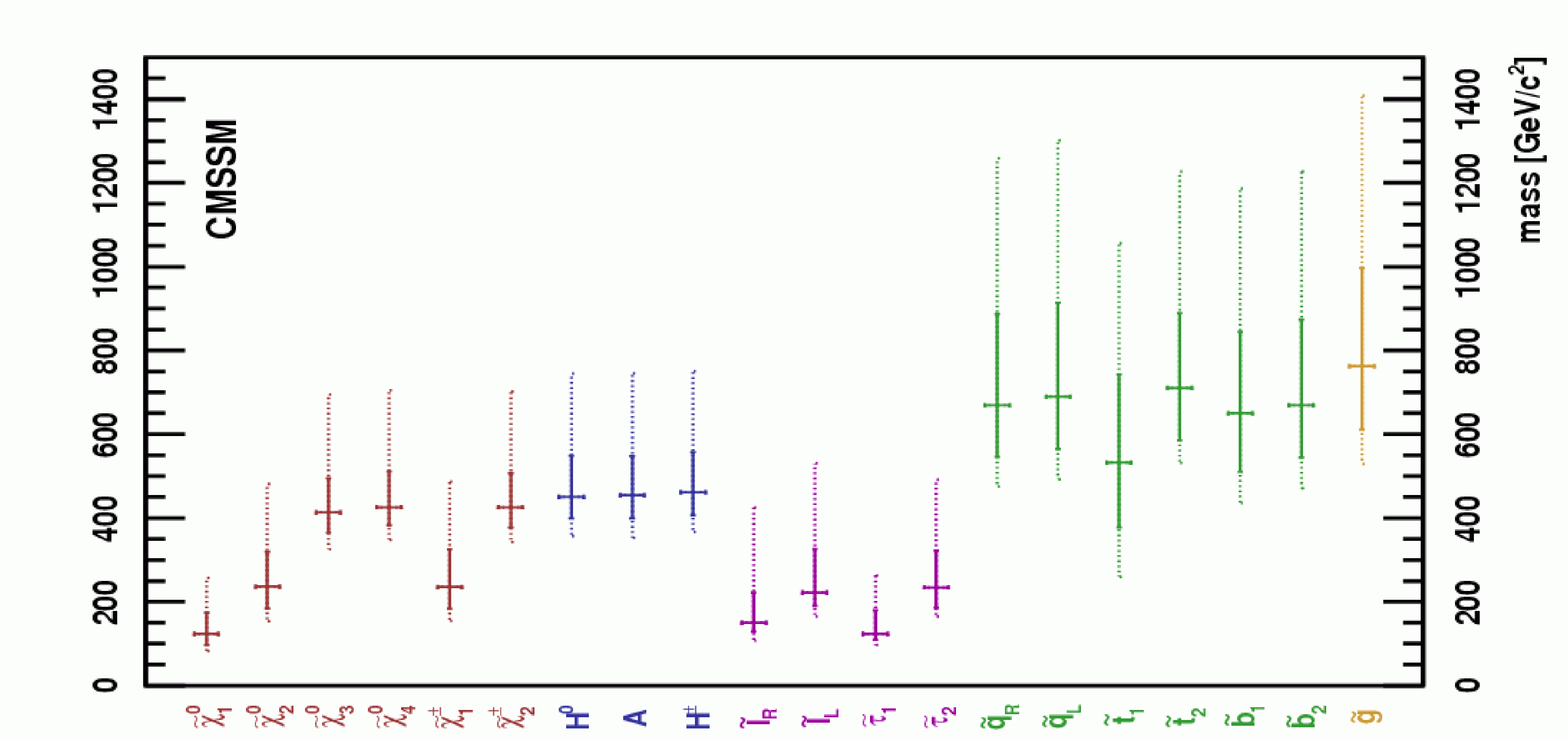
[*CMS '07*] [*2008*]



⇒ excellent prospects even with lower luminosity!

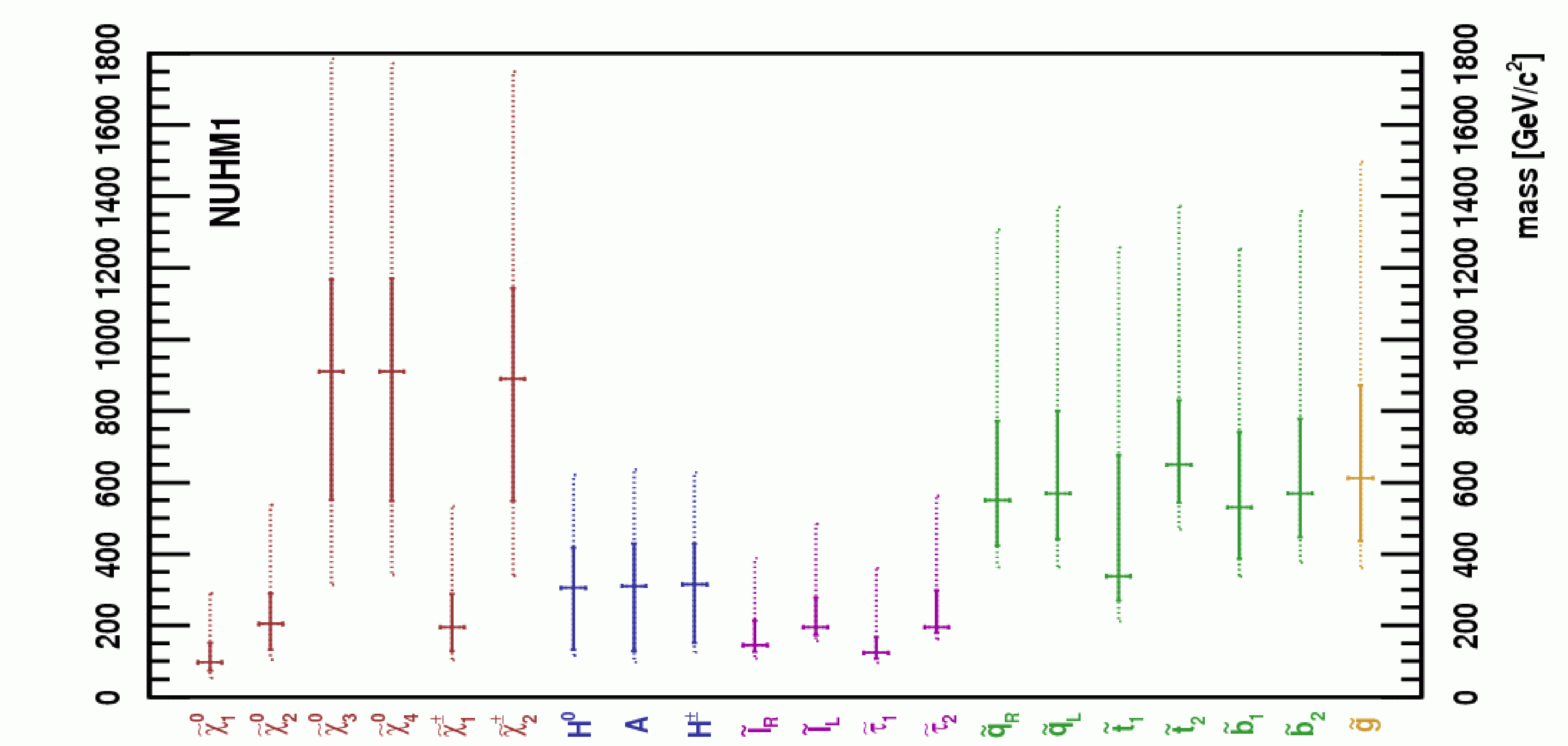
Masses for best-fit points: CMSSM

[2009]



⇒ largely accessible spectrum for LHC and ILC

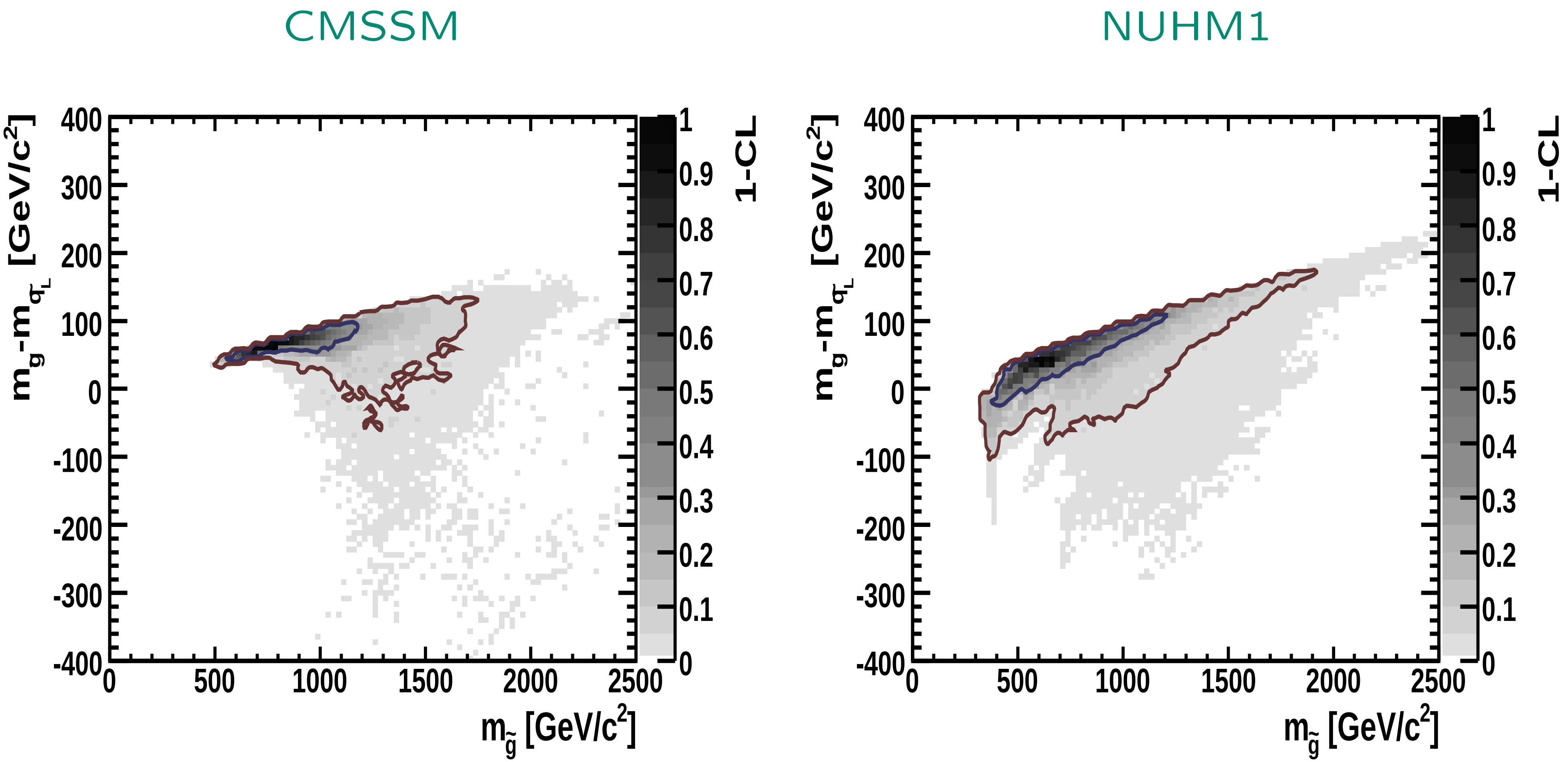
Masses for best-fit points: NUHM1



$\Rightarrow$ largely accessible spectrum for LHC and ILC

Some more predictions: $m_{\tilde{g}} - m_{\tilde{q}_L}$

[2009]

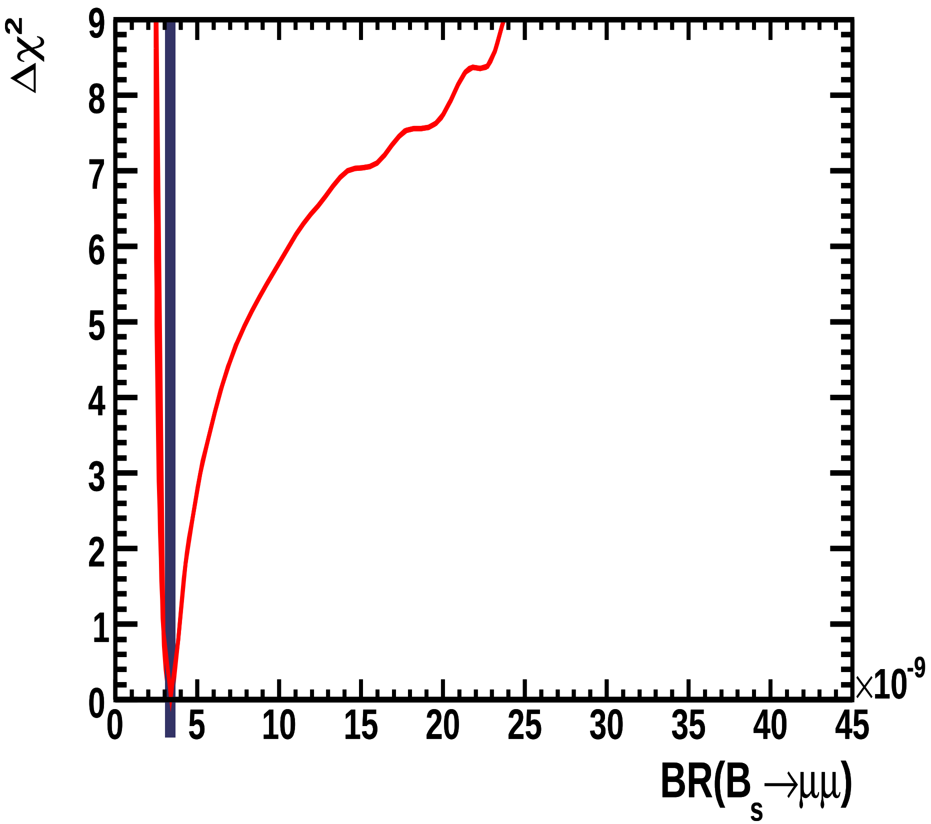


$\Rightarrow m_{\tilde{g}}$ often largest mass, but exceptions are possible

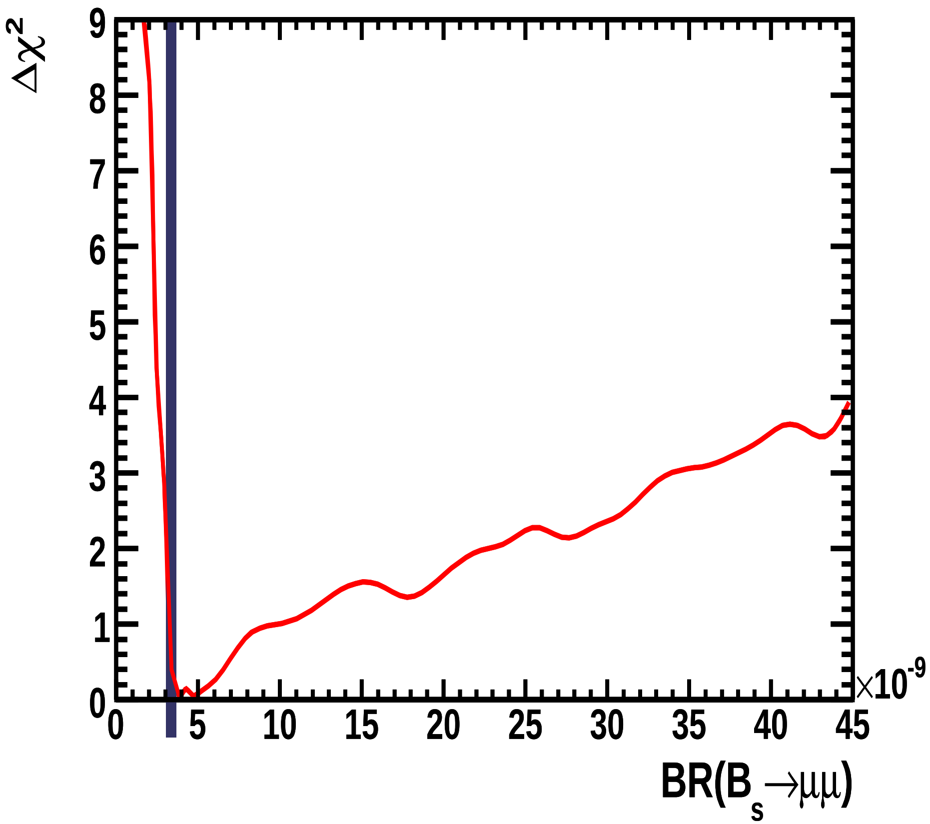
Some more predictions: $\mathrm{BR}(B_s \to \mu^+\mu^-)$

[2009]

CMSSM



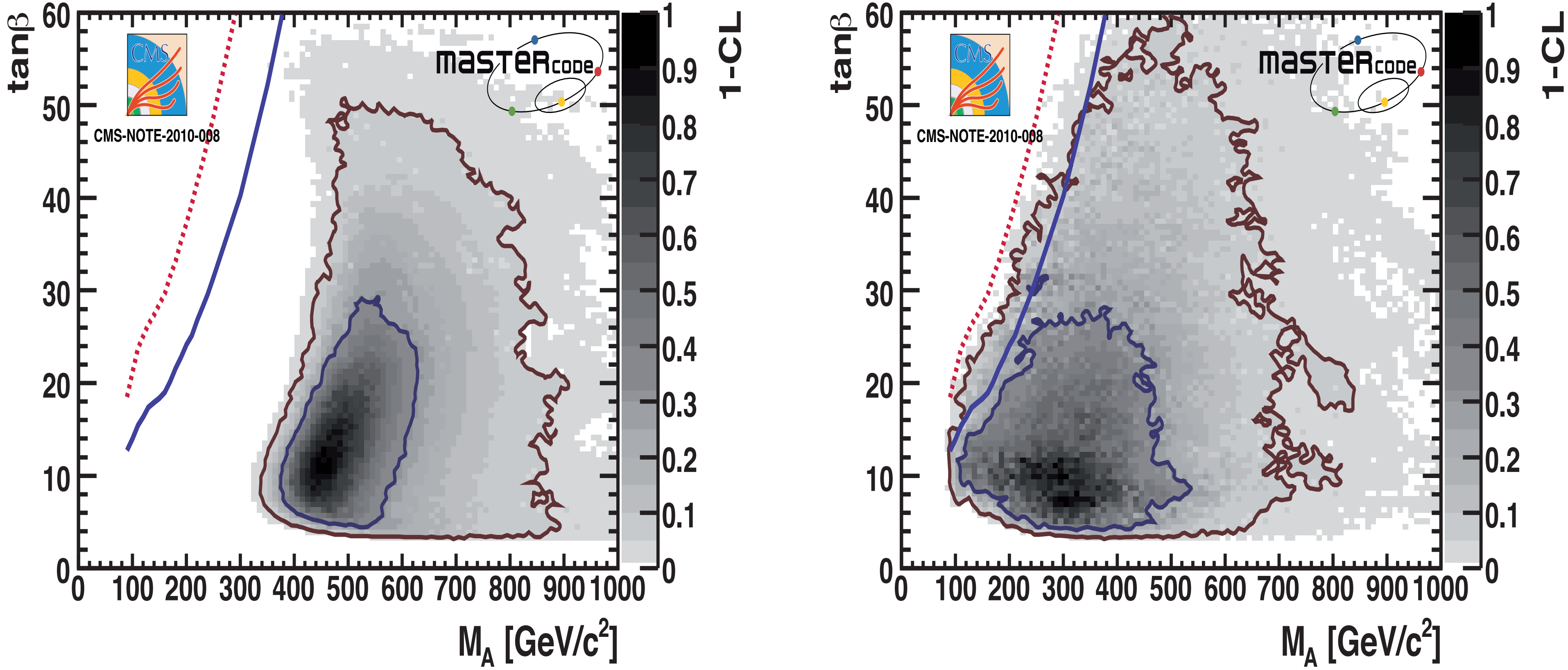
NUHM1



⇒ best-fit similar to SM, larger value would favor NUHM1

Some more predictions: preferred M_A–$\tan\beta$ parameter space

CMSSM NUHM1



red dotted: discovery with 1 fb^{-1} @ 7 TeV

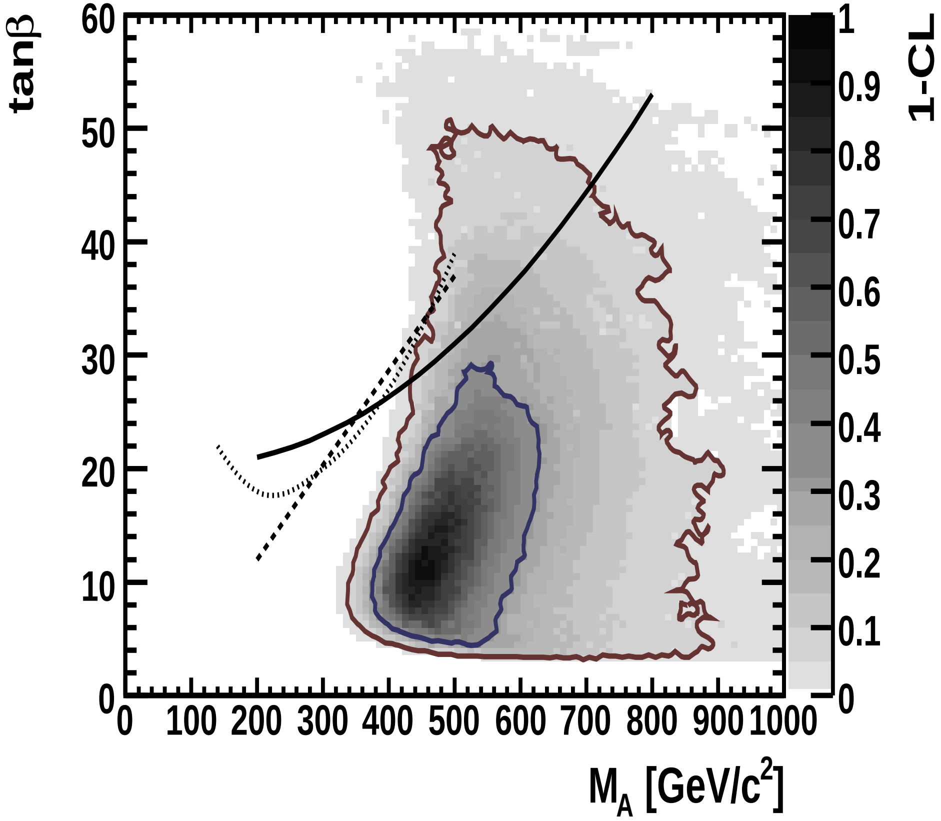
blue solid: 95% C.L. exclusion with 1 fb^{-1} @ 7 TeV

⇒ preferred regions missed in 2010-2011 run

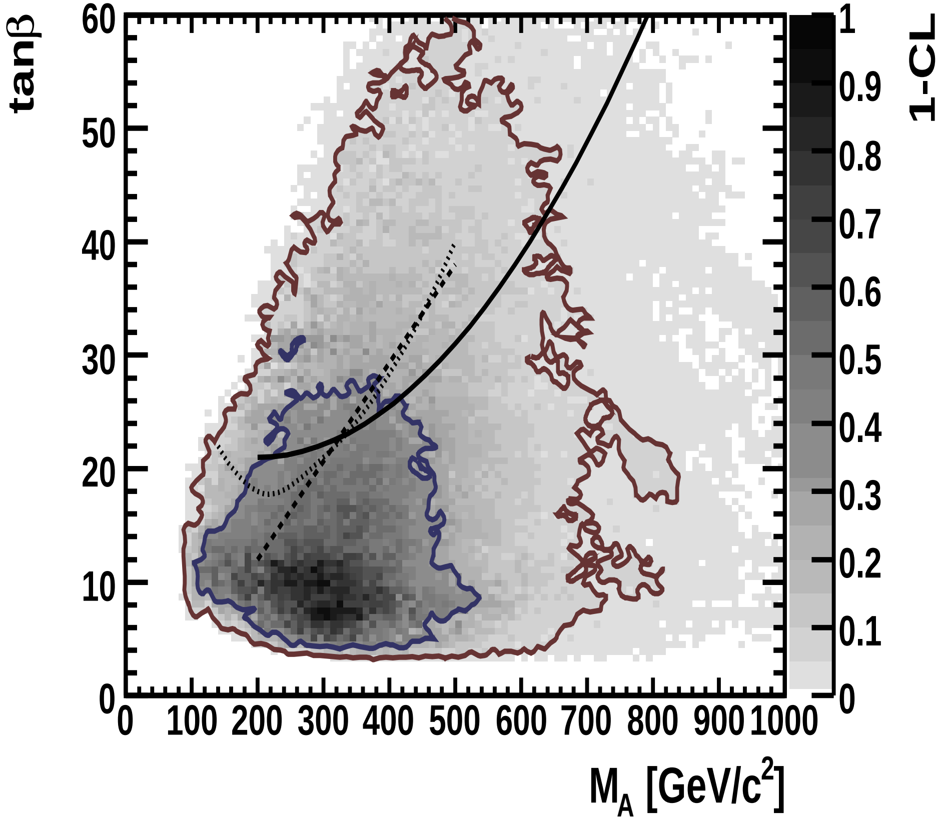
Some more predictions: preferred M_A–$\tan\beta$ parameter space

[2009]

CMSSM



NUHM1



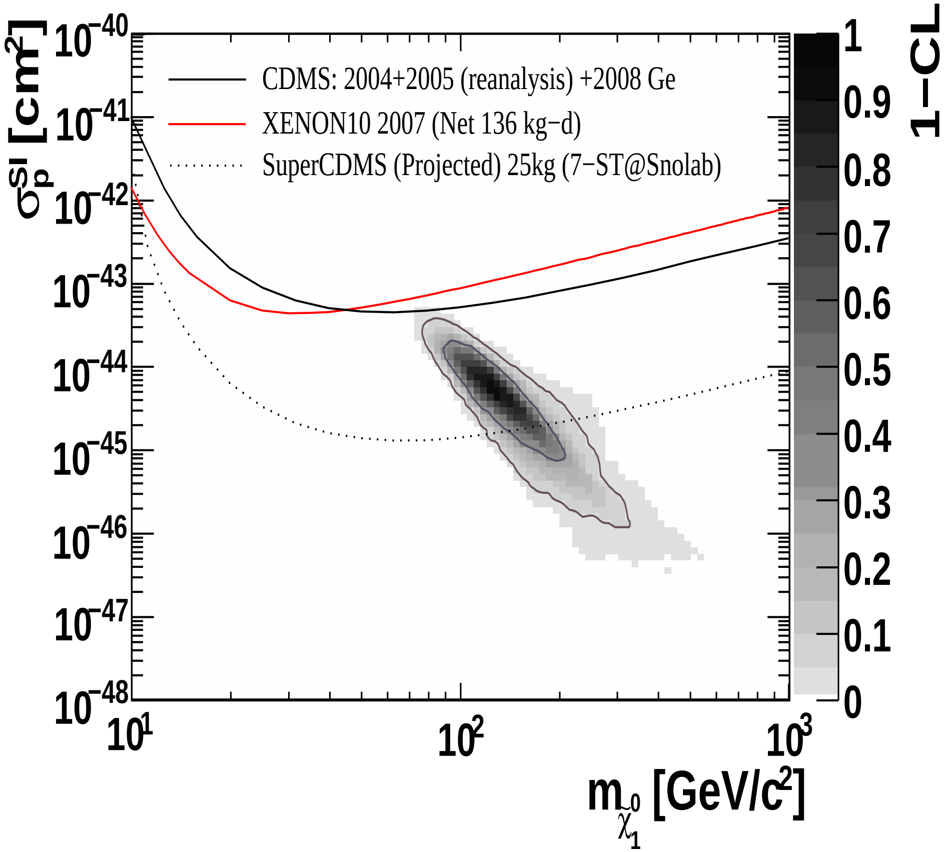
CMS analysis for 30 fb^{-1} @ 14 TeV

⇒ still best-fit regions missed by LHC, better for ILC(1000)

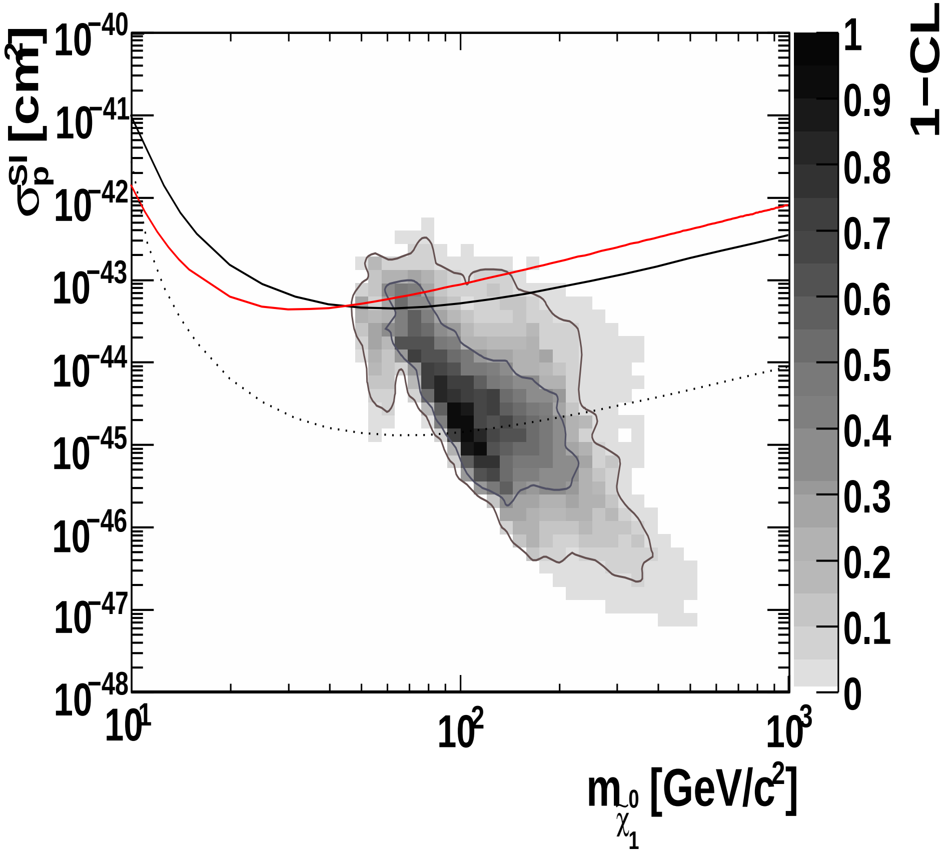
Some more predictions: direct search for dark matter

[2009]

CMSSM



NUHM1



⇒ only partially covered by future experiments

6. Conclusinos

- Idea: Predict most probable MSSM parameter regions
  using existing data: EWPO, BPO, CDM, . . .
- Models: CMSSM, NUHM1
- statistical measure: χ^2 function (Frequentist, no priors)
  $\sim 2.5\ 10^7$ points samples with MCMC
  $\Delta\chi^2$: 68, 95% C.L. contours
- Best-fit points:
  CMSSM: $m_{1/2} = 310$ GeV, $m_0 = 60$ GeV, $A_0 = 240$ GeV,
  $\tan\beta = 11$, $\mu = 380$ GeV, $M_A = 410$ GeV
  $\Rightarrow$ very similar to SPS 1a :-)
  Prediction of M_h (no LEP bound): $M_h = 108 \pm 6 \pm 1.5$ GeV
  NUHM1: $m_{1/2} = 270$ GeV, $m_0 = 150$ GeV, $A_0 = -1300$ GeV,
  $\tan\beta = 11$, $\mu = 1140$ GeV, $M_A = 310$ GeV
  Prediction of M_h (no LEP bound): best fit: $M_h \approx 121$ GeV
- 68% C.L. areas: partially covered with $\sim 1\ \text{fb}^{-1}$ @ 7 TeV (u.d.!)
  $\Rightarrow$ early LHC data could be very conclusive!

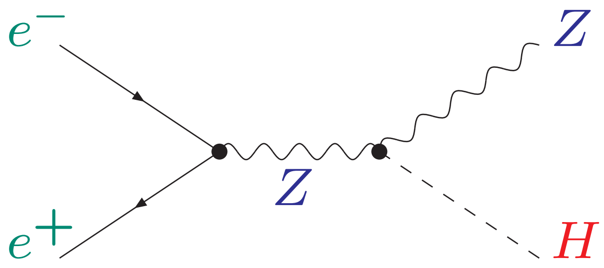

Higgs Days at Santander 2010
Theory meets Experiment
13.-16. October
HEPTOOLS
I F C A
Instituto de Física de Cantabria
CSIC
UC
UNIVERSIDAD DE CANTABRIA
contact: Sven.Heinemeyer@cern.ch
http://www.ifca.es/HDays10
Photo: Philip Bechtle HDays09

Back-up

SM Higgs search at LEP:

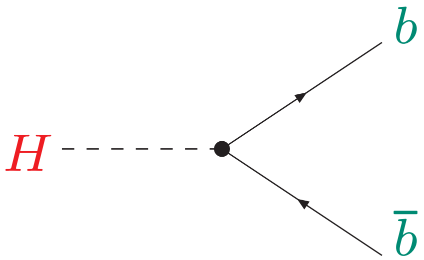
Dominant SM production process:

$e^+e^- \to ZH$:



Dominant decay process:

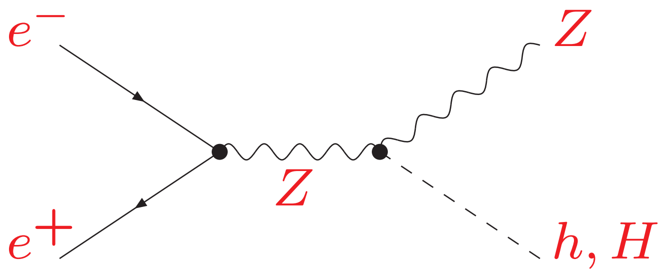
$H \to b\bar{b}$:



Bounds valid in the CMSSM? NUHM1? MSSM?

Search for neutral SUSY Higgs bosons:

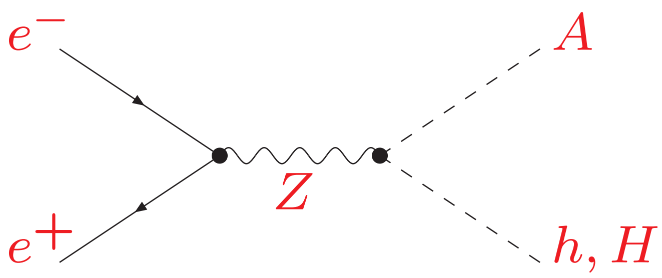
$e^+e^- \to Zh, ZH$



$$\sigma_{hZ} \approx \sin^2(\beta - \alpha_{\rm eff})\sigma^{\rm SM}_{hZ}$$

$$\sigma_{HZ} \approx \cos^2(\beta - \alpha_{\rm eff})\sigma^{\rm SM}_{hZ}$$

$e^+e^- \to Ah, AH$



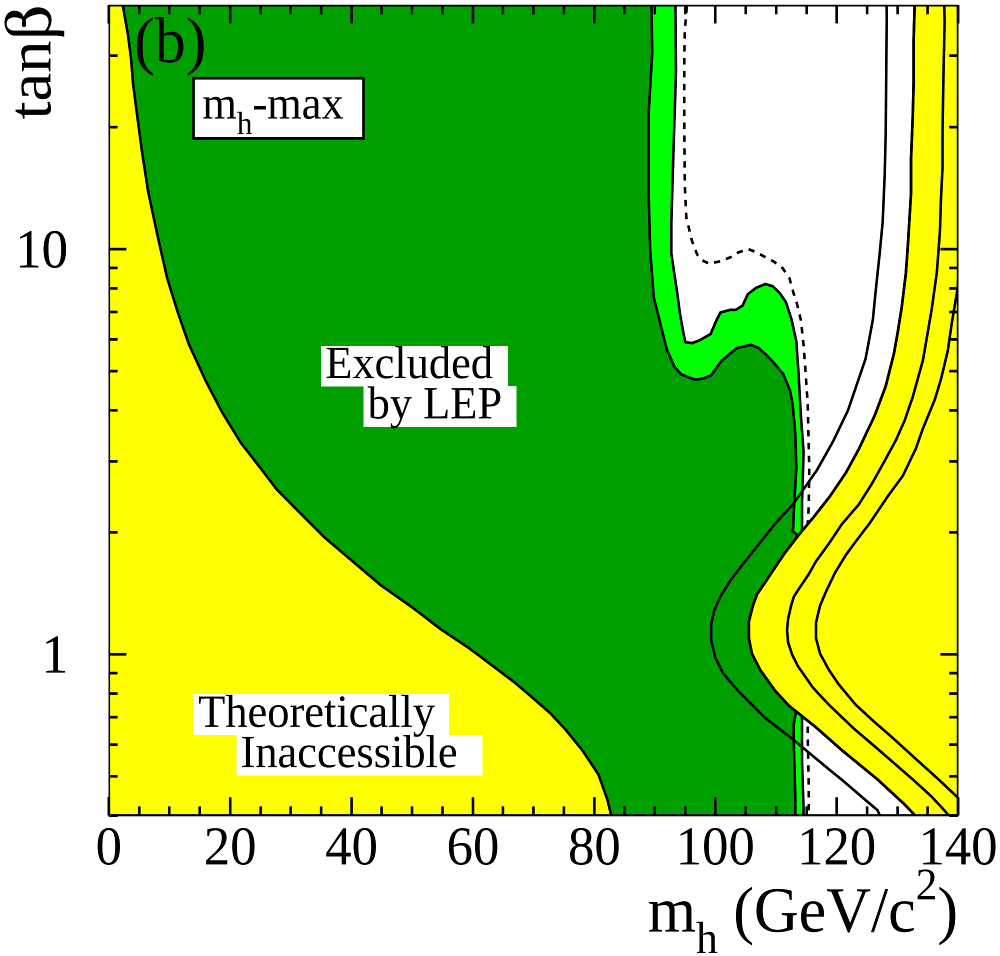
$$\sigma_{hA} \propto \cos^2(\beta - \alpha_{\rm eff})\sigma^{\rm SM}_{hZ}$$

$$\sigma_{HA} \propto \sin^2(\beta - \alpha_{\rm eff})\sigma^{\rm SM}_{hZ}$$

Constraints from the Higgs search at LEP [*LEP Higgs Working Group '06*]

Experimental search vs. upper M_h-bound (*FeynHiggs* 2.0)

m_h^{max}-scenario ($m_t = 174.3$ GeV, $M_{\text{SUSY}} = 1$ TeV):

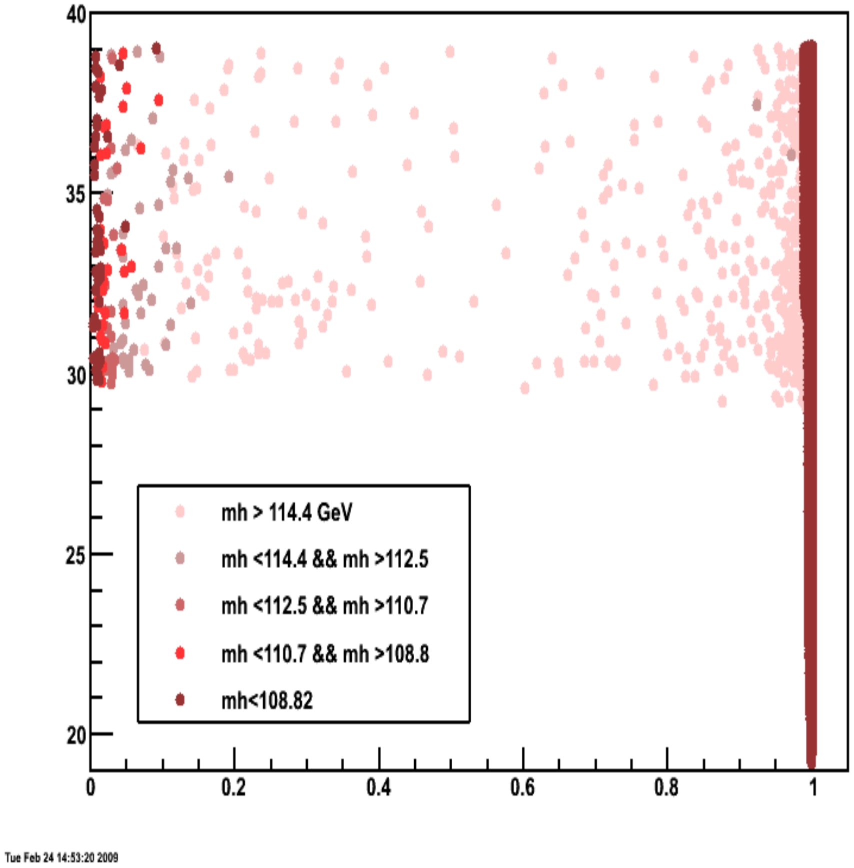


$m_h > 92.8$ GeV
(expected: 94.9 GeV), 95% C.L.

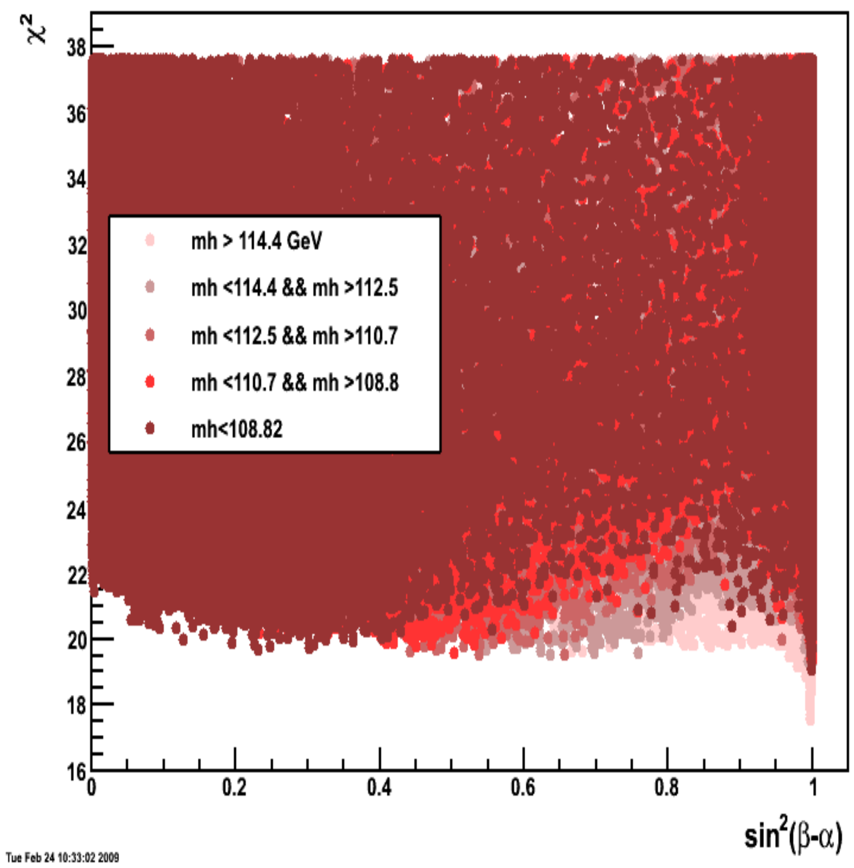
$M_A > 93.4$ GeV
(expected: 95.2 GeV)

$\sin^2(\beta - \alpha_{\rm eff})$ in the CMSSM, NUHM1:

CMSSM

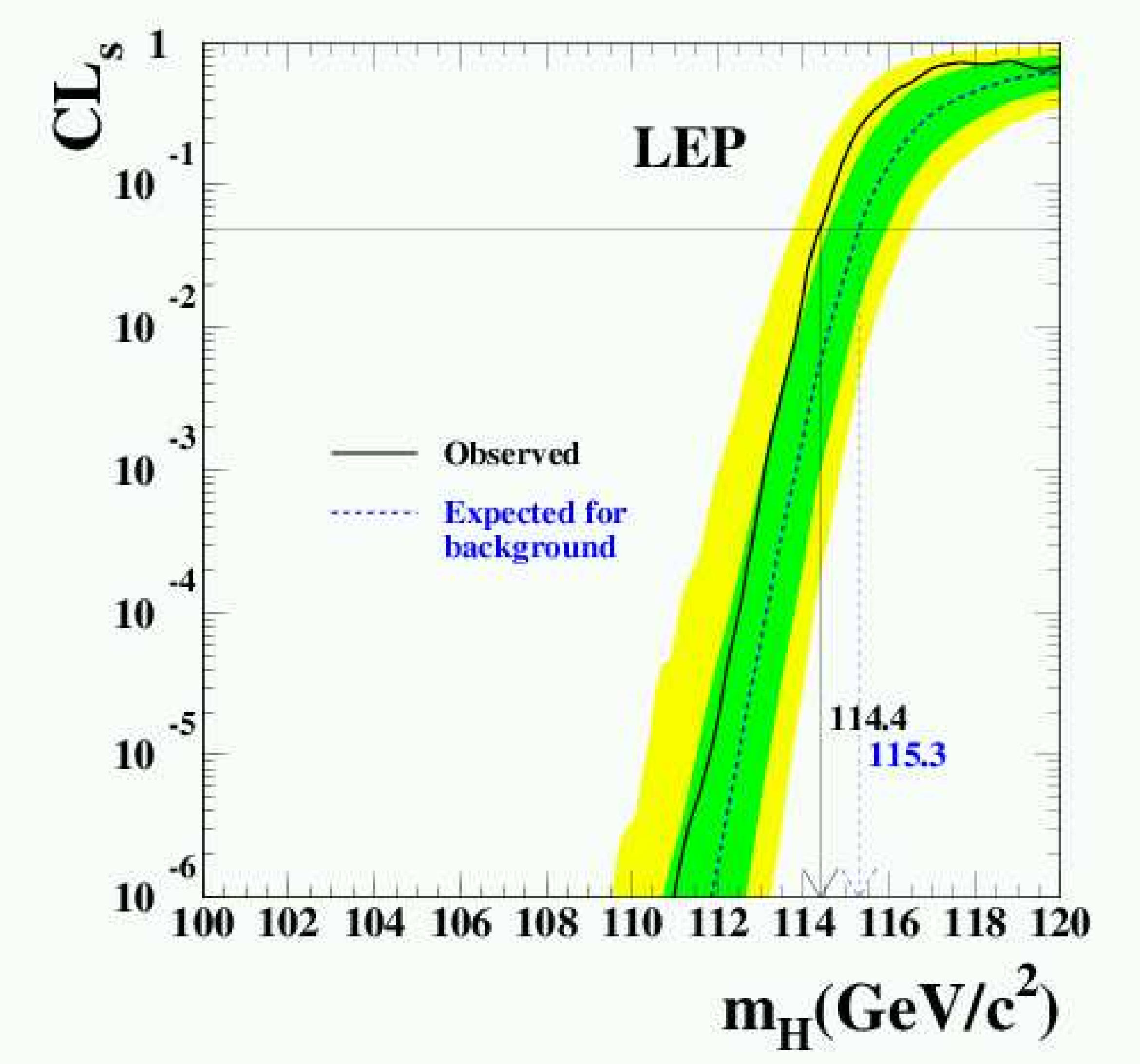


NUHM1



In CMSSM:

SM bound of M_H search can be used [*LEP Higgs Working Group '03*]



CL_s can be used/transformed into χ^2 values

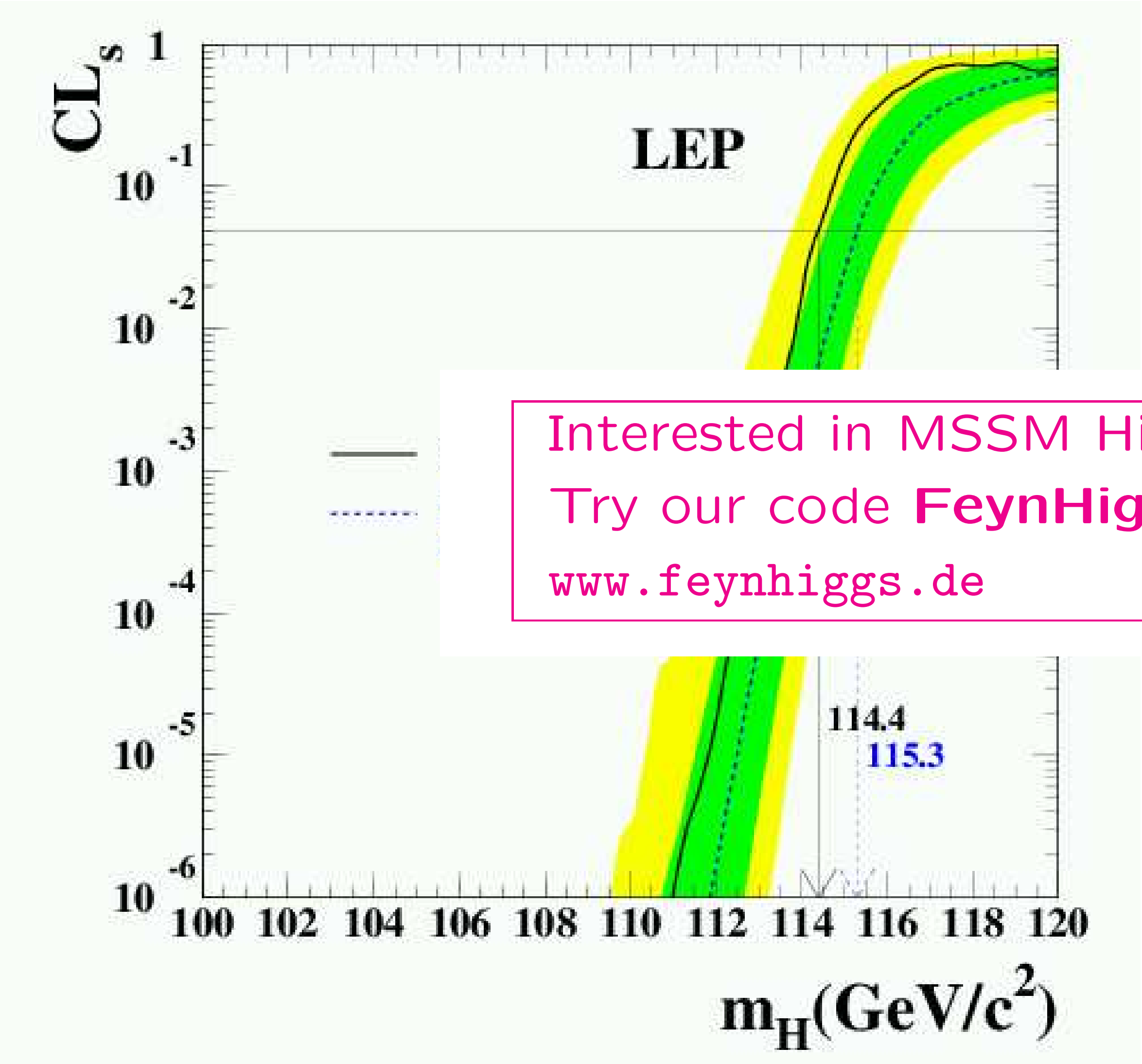
$\Rightarrow$ can be included into χ^2 evaluation

$\delta M_h^{\text{intr.}} \approx 3$ GeV

We use *FeynHiggs*

In CMSSM:

SM bound of M_H search can be used [*LEP Higgs Working Group '03*]



CL_s can be used/transformed into χ^2 values

Interested in MSSM Higgs physics?
Try our code **FeynHiggs**
`www.feynhiggs.de`

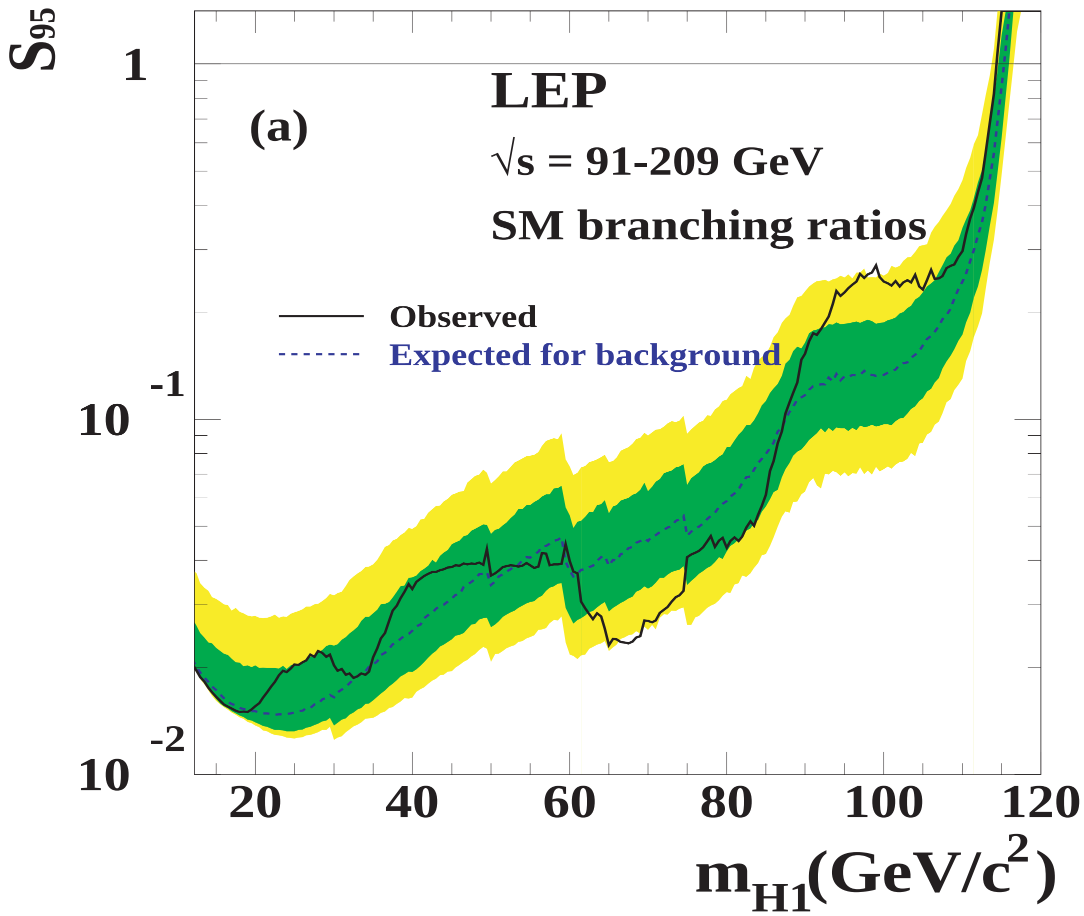
...ed into

$\delta M_h^{\rm intr.} \approx 3$ GeV

We use *FeynHiggs*

In the NUHM1:

SM bound on M_H is reduced: $S_{95} \sim \sin^2(\beta - \alpha_{\rm eff})$

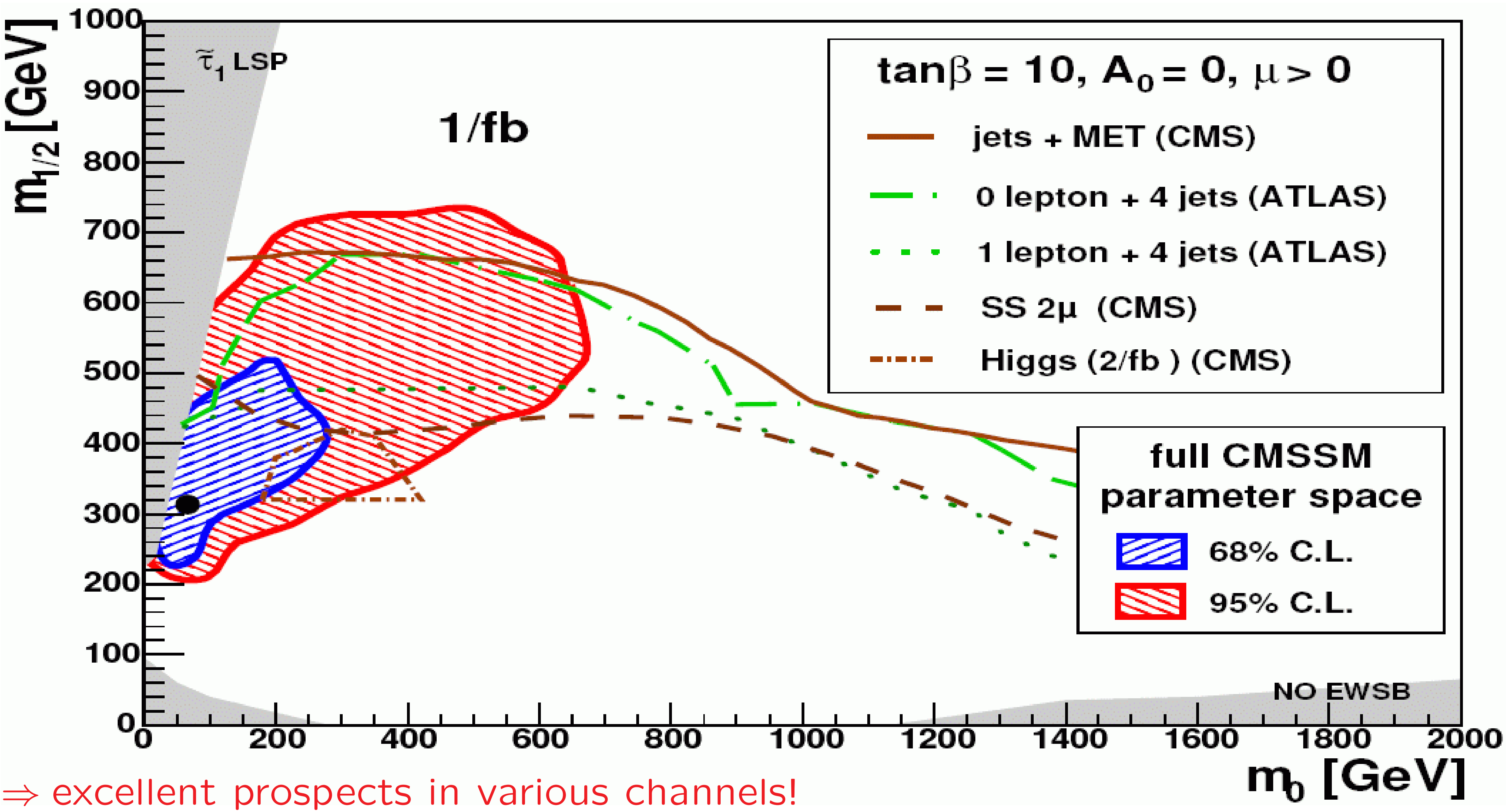


⇒ take into account the LEP SM Higgs bound . . .

. . . but shifted according to the reduced coupling

LHC (CMS) reach with 1 fb^{-1}:

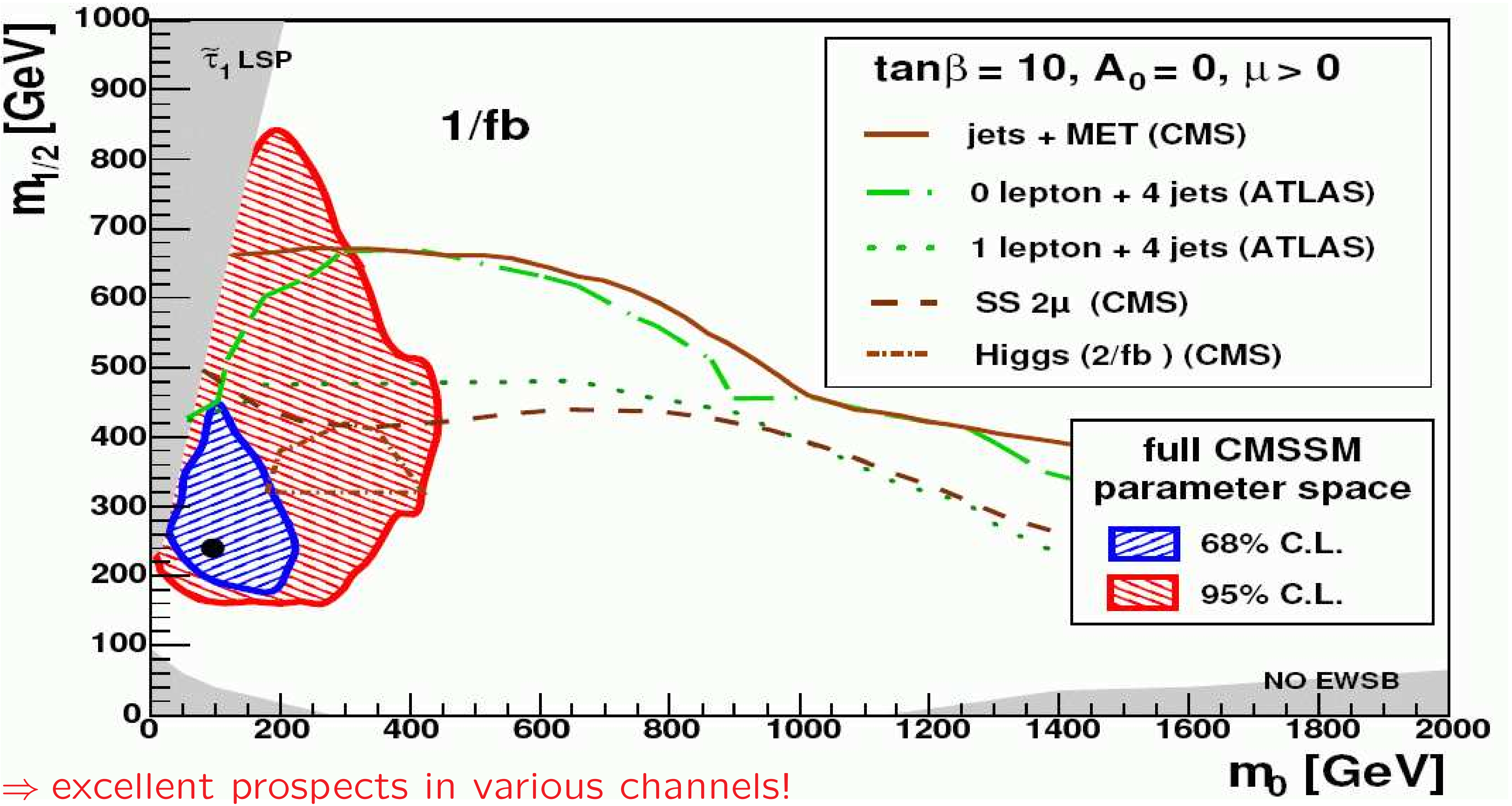
[*MasterCode '08*] [*CMS '07*]



⇒ excellent prospects in various channels!

LHC (CMS) reach with 1 fb^{-1}: NUHM1 analysis

[*MasterCode '08*] [*CMS '07*]



⇒ excellent prospects in various channels!