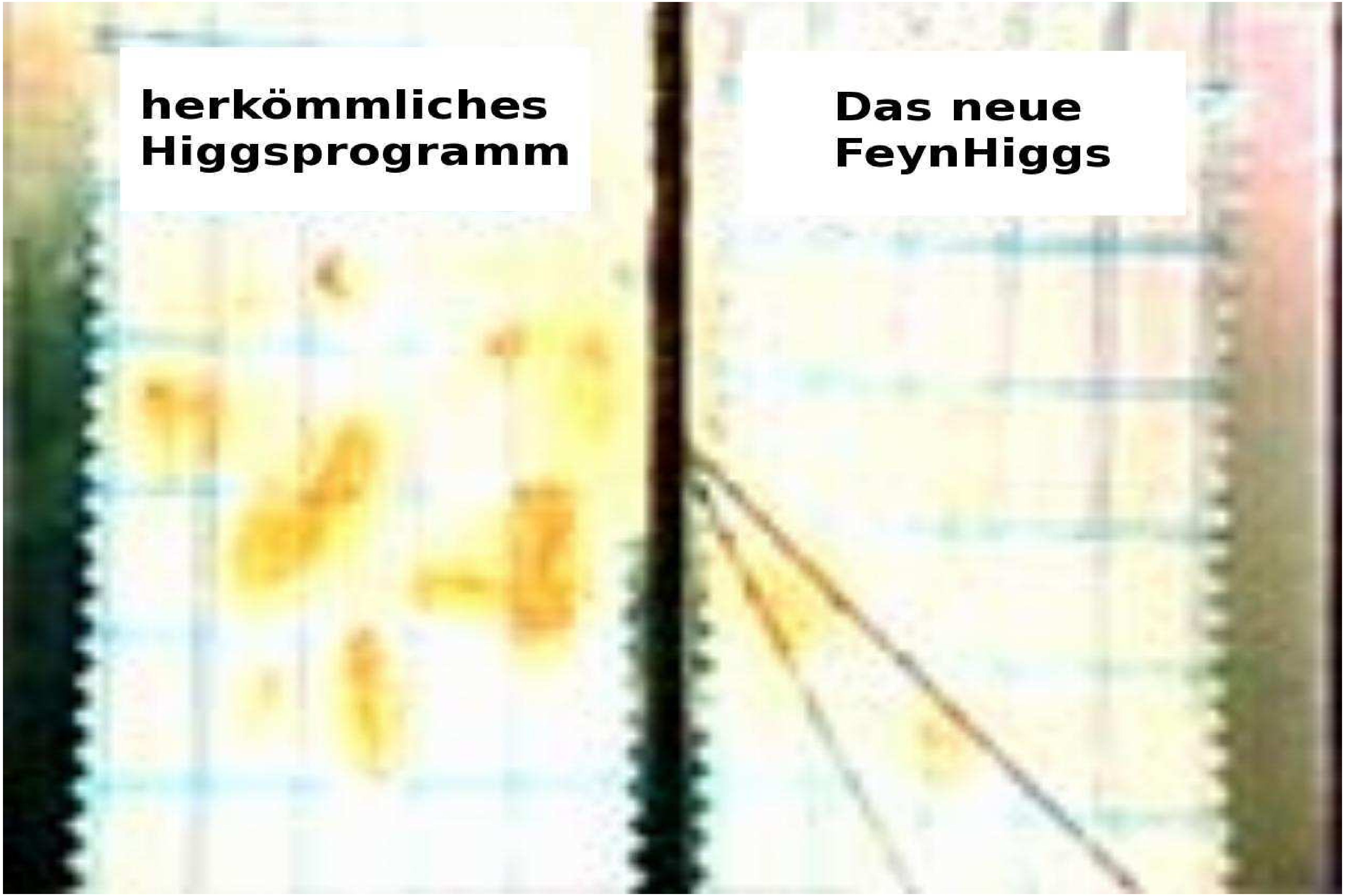
herkömmliches Higgsprogramm
Das neue FeynHiggs

SUSY Predictions for the LHC

Sven Heinemeyer, IFCA (CSIC, Santander)

Bonn, 11/2009

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

1. Introduction and motivation

Q: Which Lagrangian describes the world?

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A: Ummm . . . Let's start differently!

1. Introduction and motivation

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.

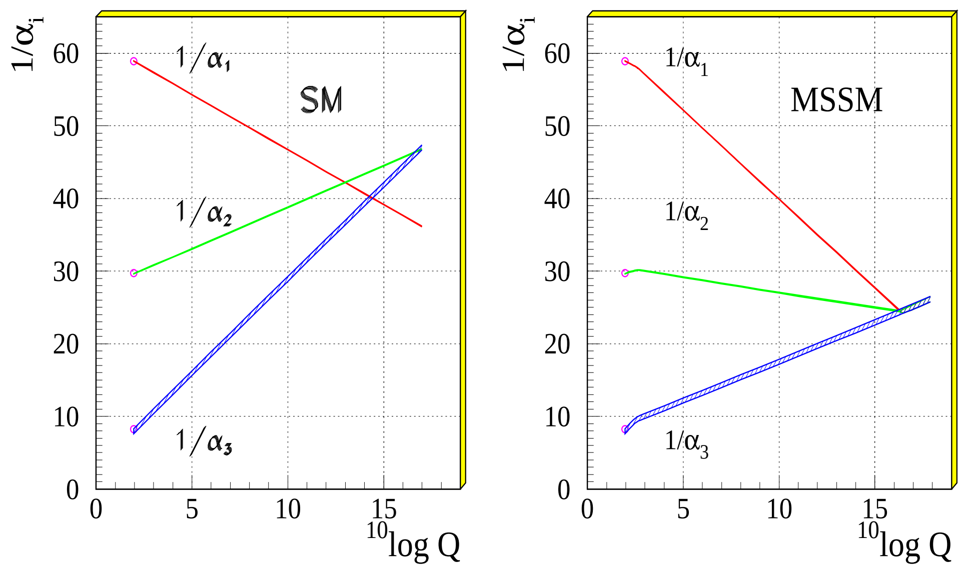
2.) Unification of gauge couplings: Not possible in the SM, but in the MSSM (although it was not designed for it.)

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

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

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

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

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

Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

$\rightarrow$ 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

$SU(2)$ 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)

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

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Q': What describes the world better: SM or MSSM ?

A: Two possible ways:

- Search for new SUSY particles

new SUSY particles found
$\Updownarrow$
SM ruled out

  Problem:
  SUSY particles are too heavy for todays colliders, only lower limits of $\mathcal{O}$(100 GeV).

  $\rightarrow$ waiting for Tevatron (2009/10...?)
  $\rightarrow$ waiting for LHC (2010/11...?)

- Search for indirect effects of SUSY
  via Precision Observables

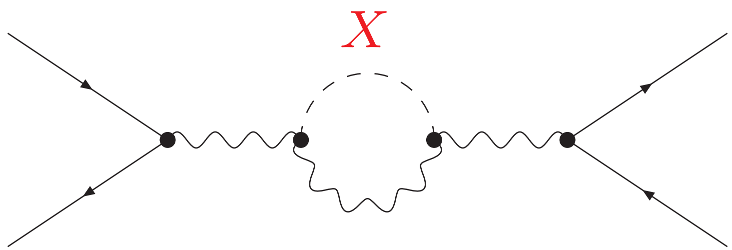
Precision Observables (POs):

Comparison of electro-weak precision observables with theory:

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

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections



$\Downarrow$

Very high accuracy of measurements and theoretical predictions needed

- Which model fits better?
- Does the prediction of a model contradict the experimental data?

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

→ can be approximated with the ρ-**parameter:**

ρ measures the relative strength between

neutral current interaction and charged current interaction

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

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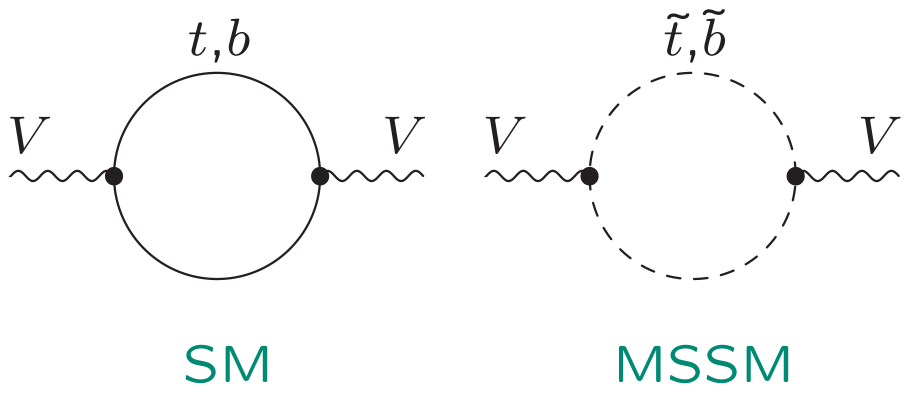

$\Delta\rho^{\text{SUSY}}$ from $\tilde{t}/\tilde{b}$ loops > 0 $\Rightarrow M_W^{\text{SUSY}} \gtrsim M_W^{\text{SM}}$

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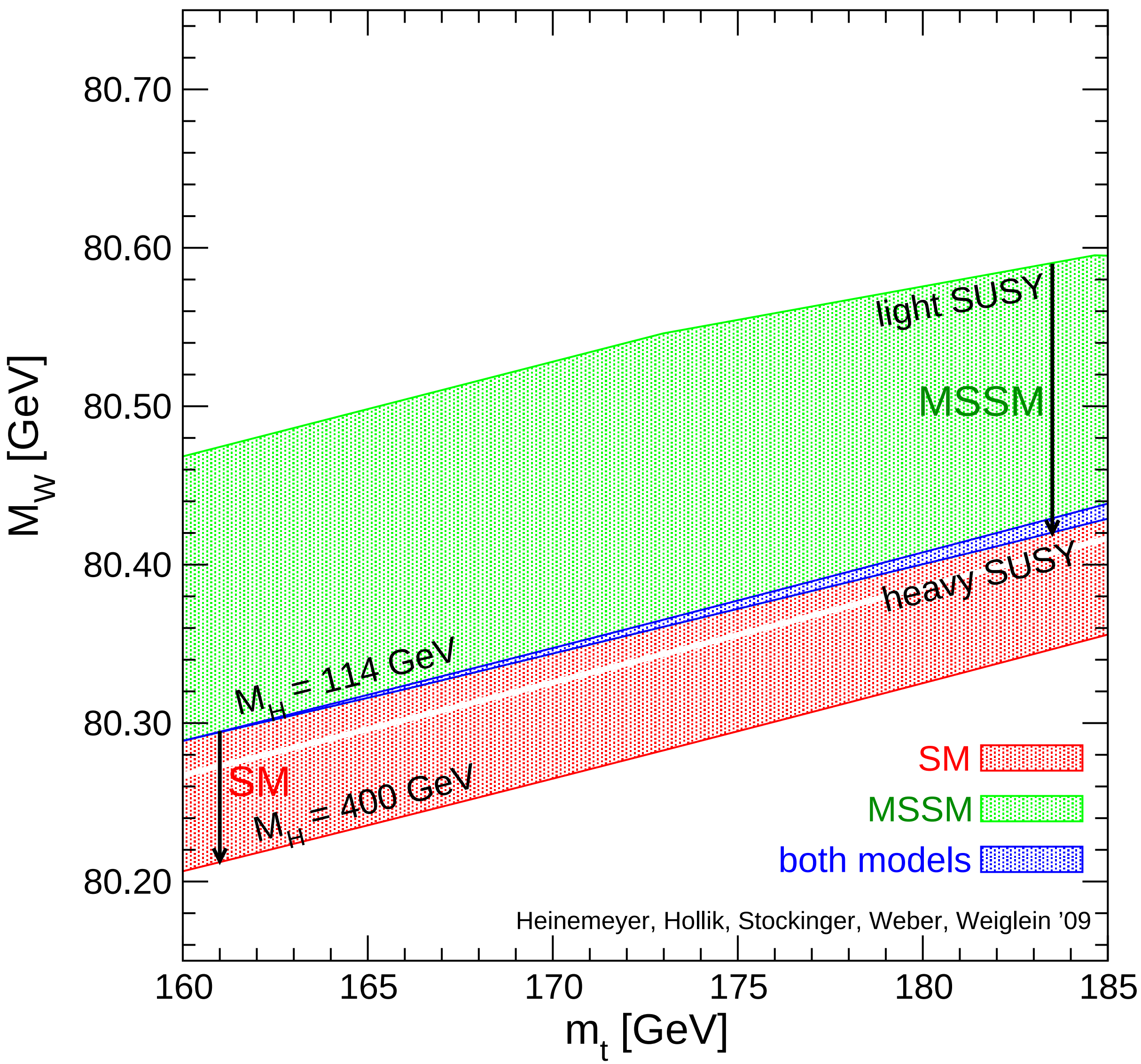
[S.H., W. Hollik, D. Stockinger, A. Weber, G. Weiglein '07]



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scan over
SUSY masses

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

SM band:
variation of M_H^{SM}

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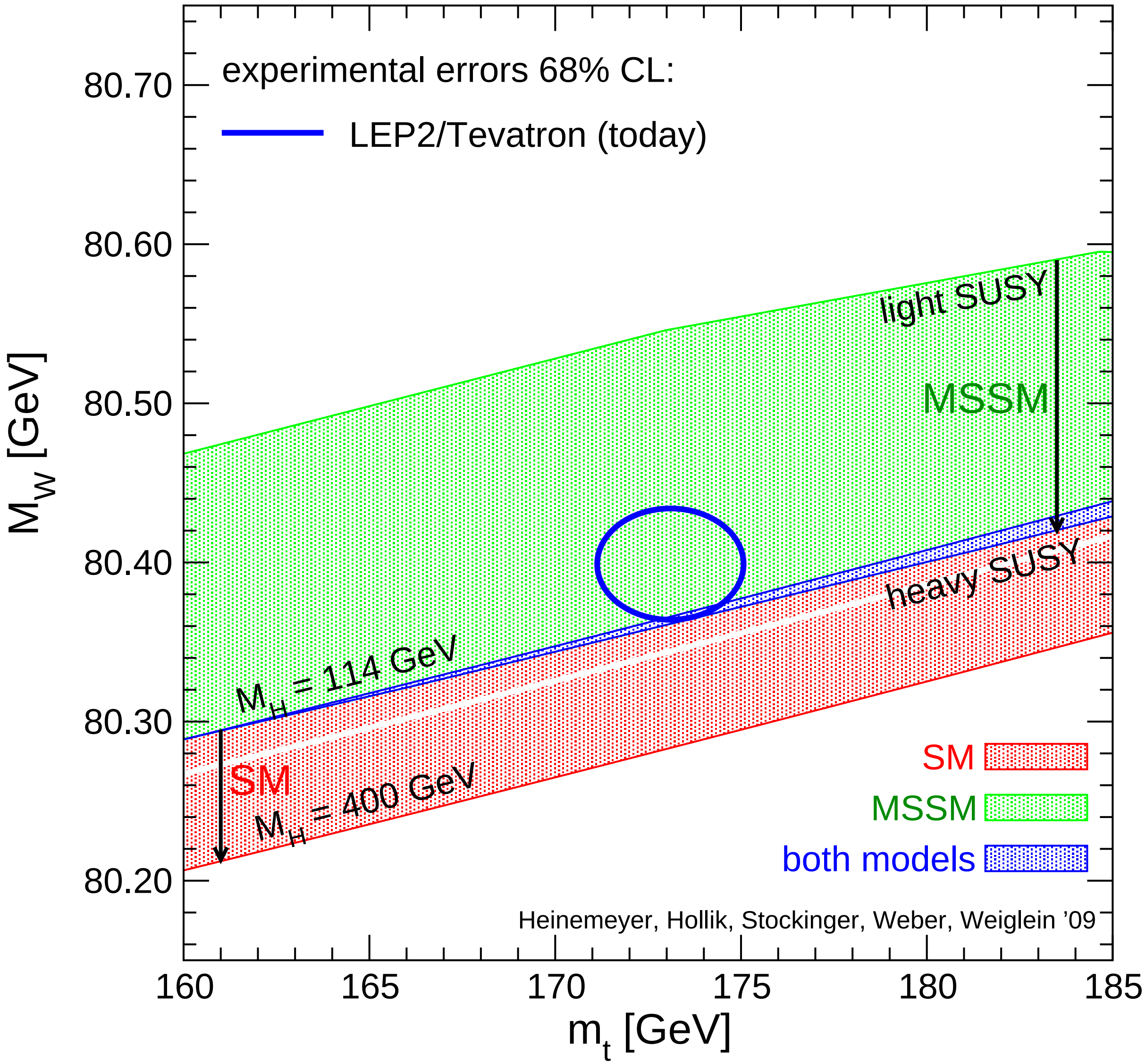

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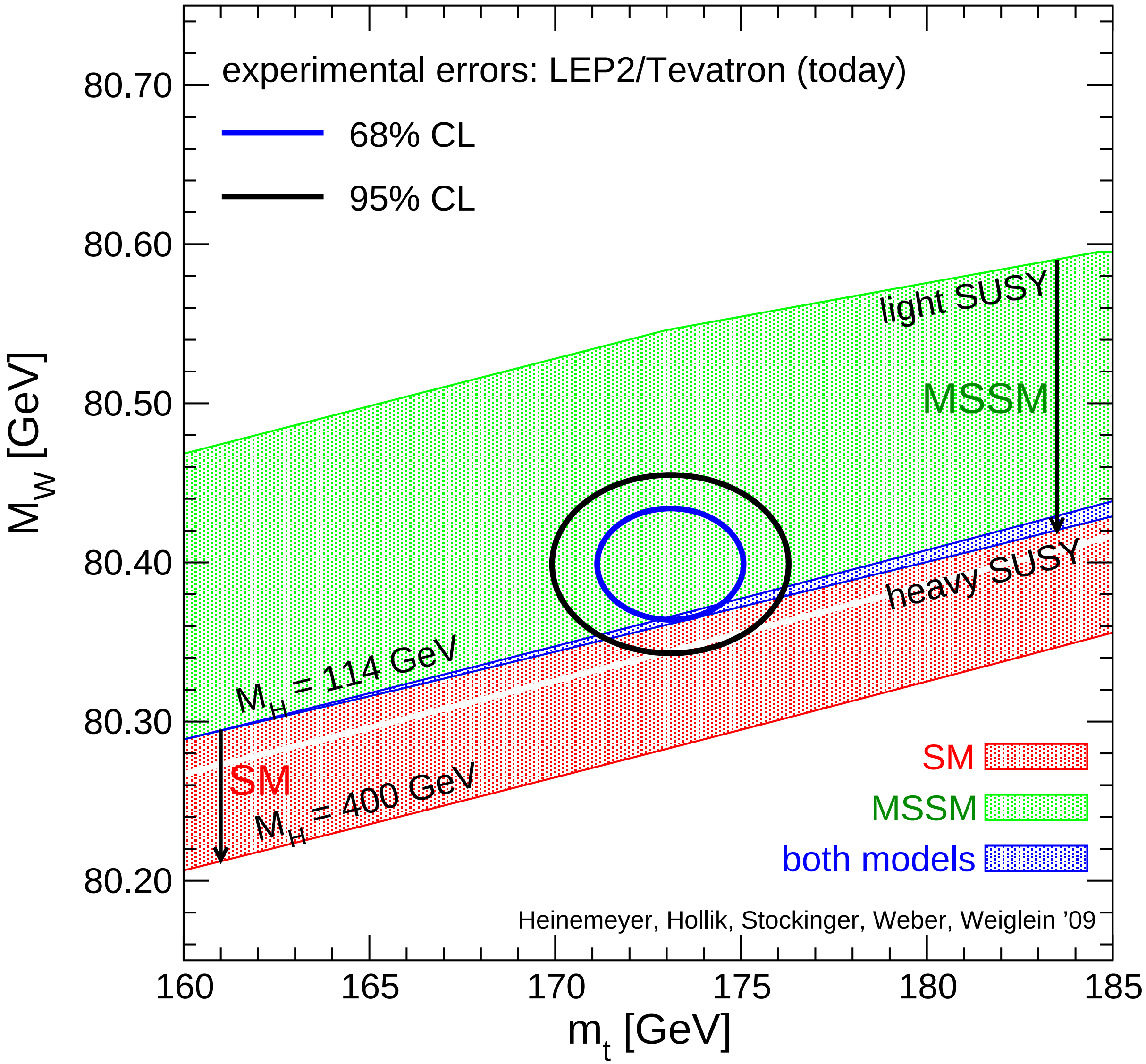

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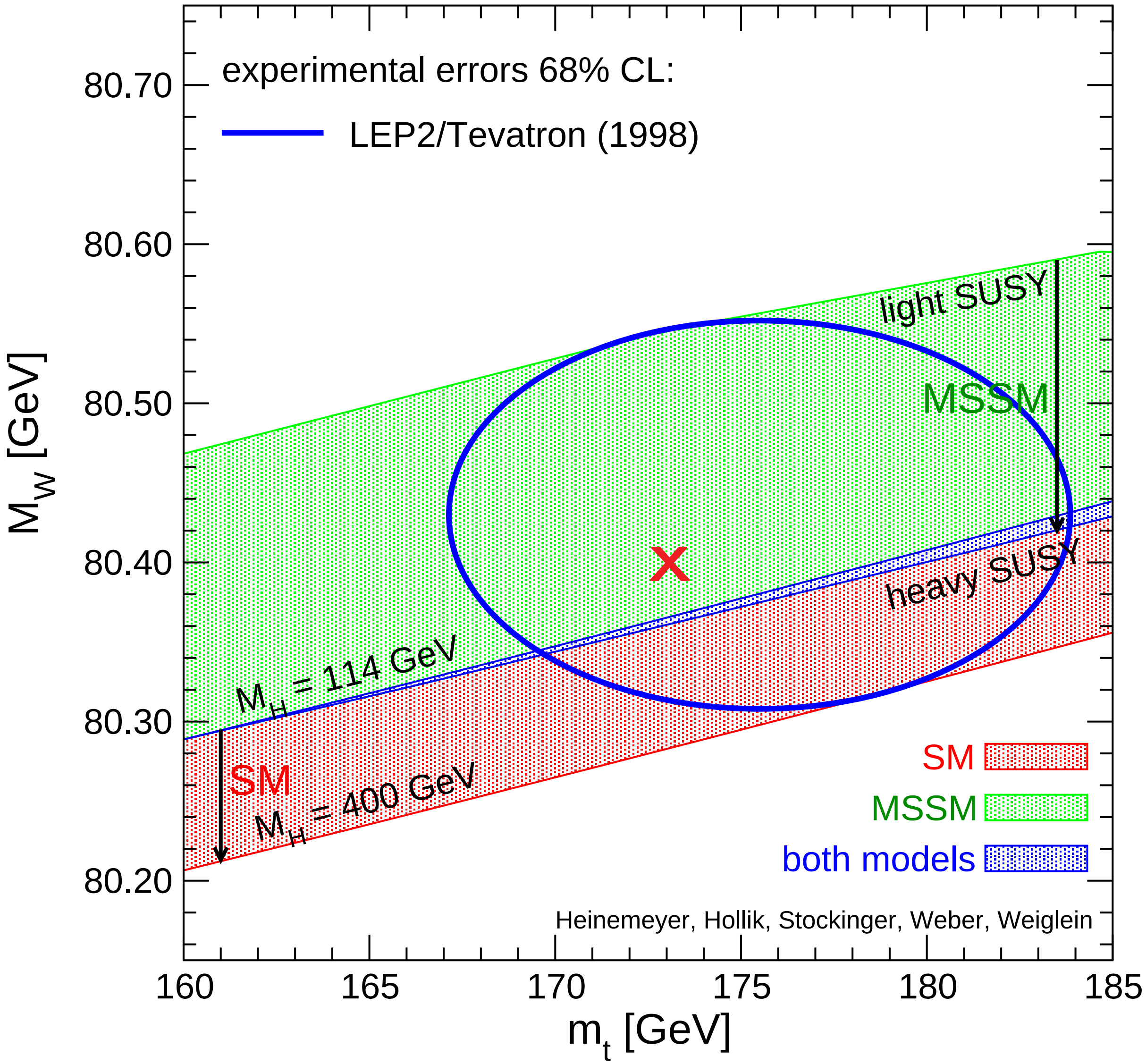

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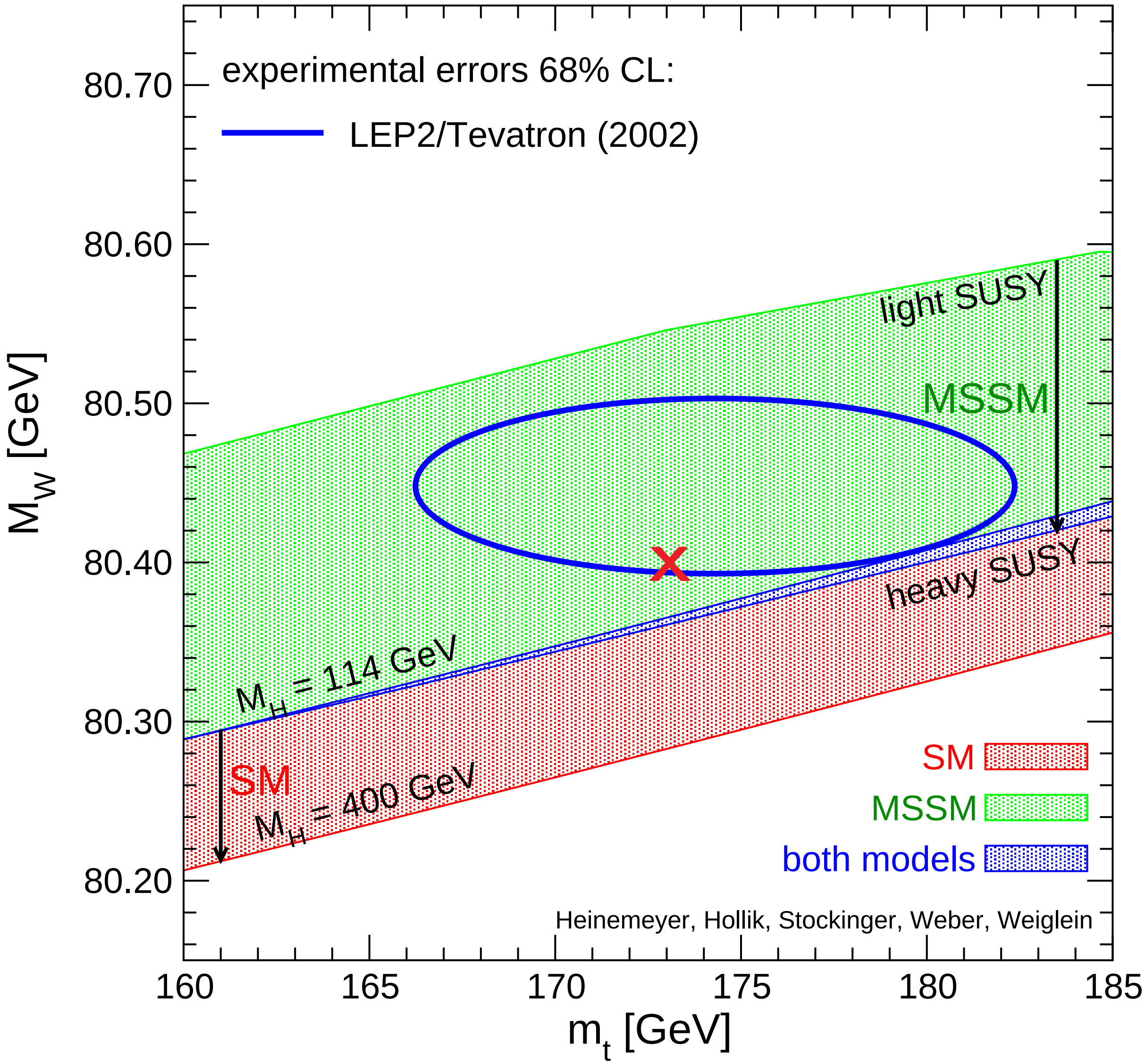

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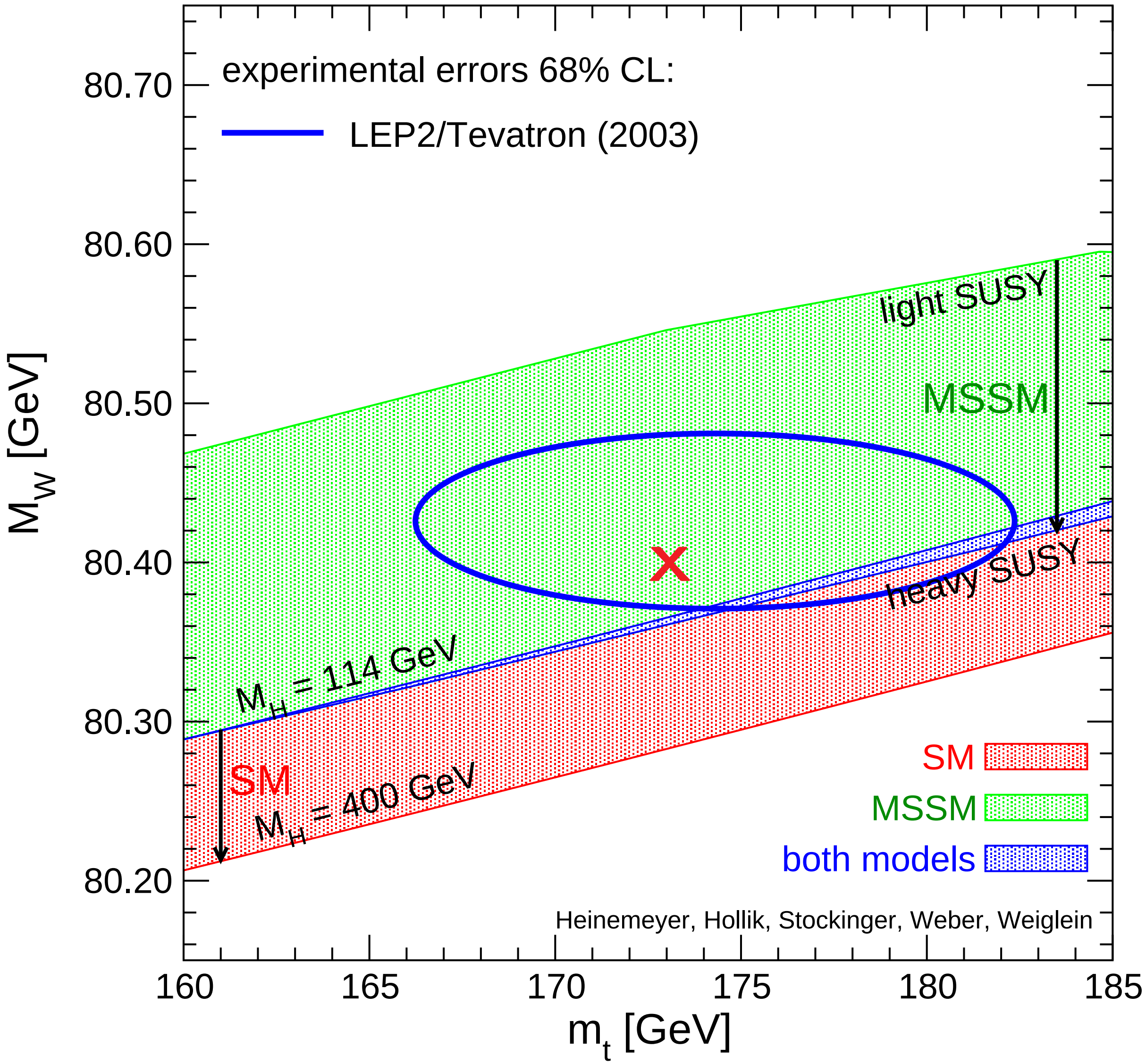

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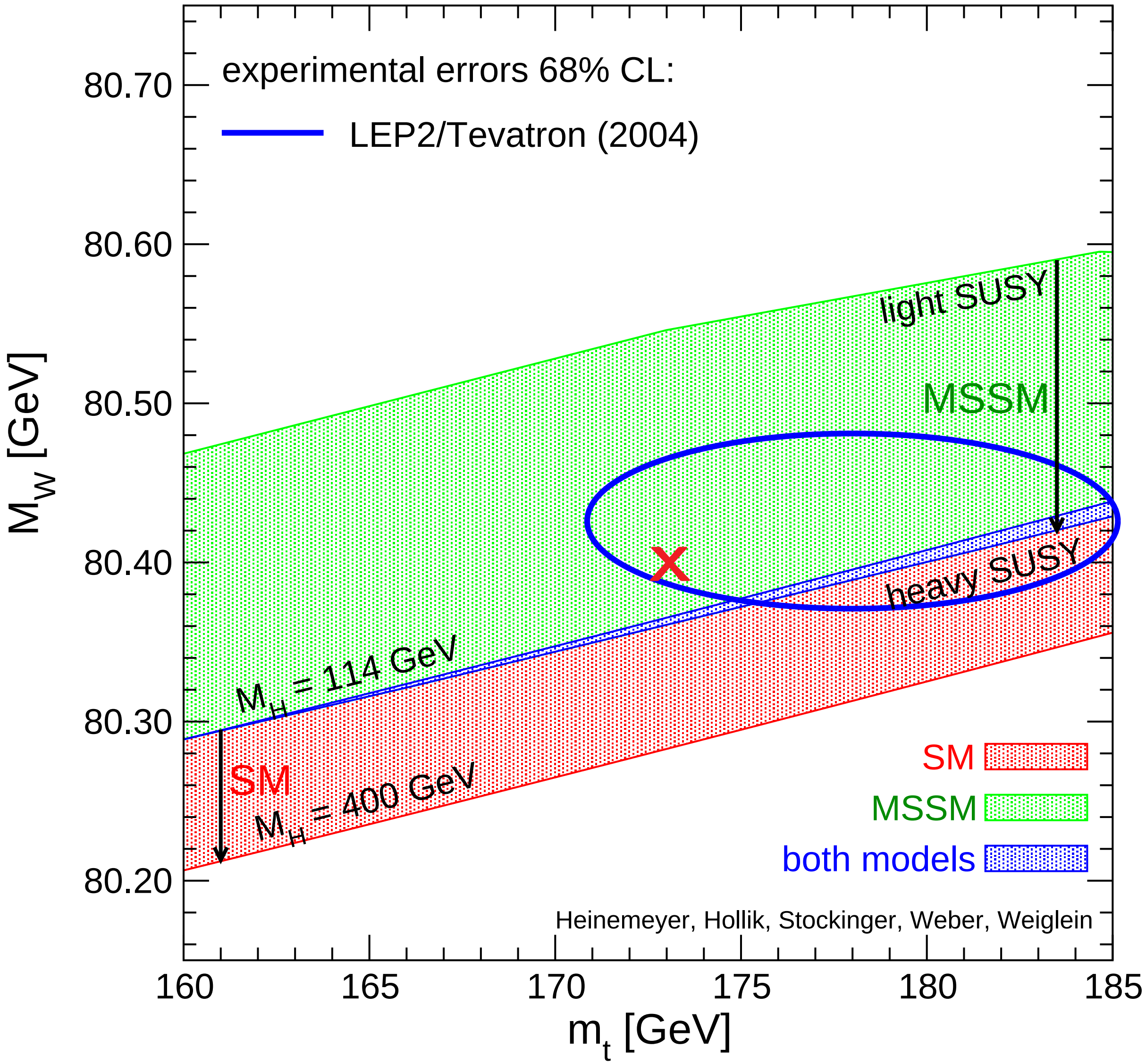

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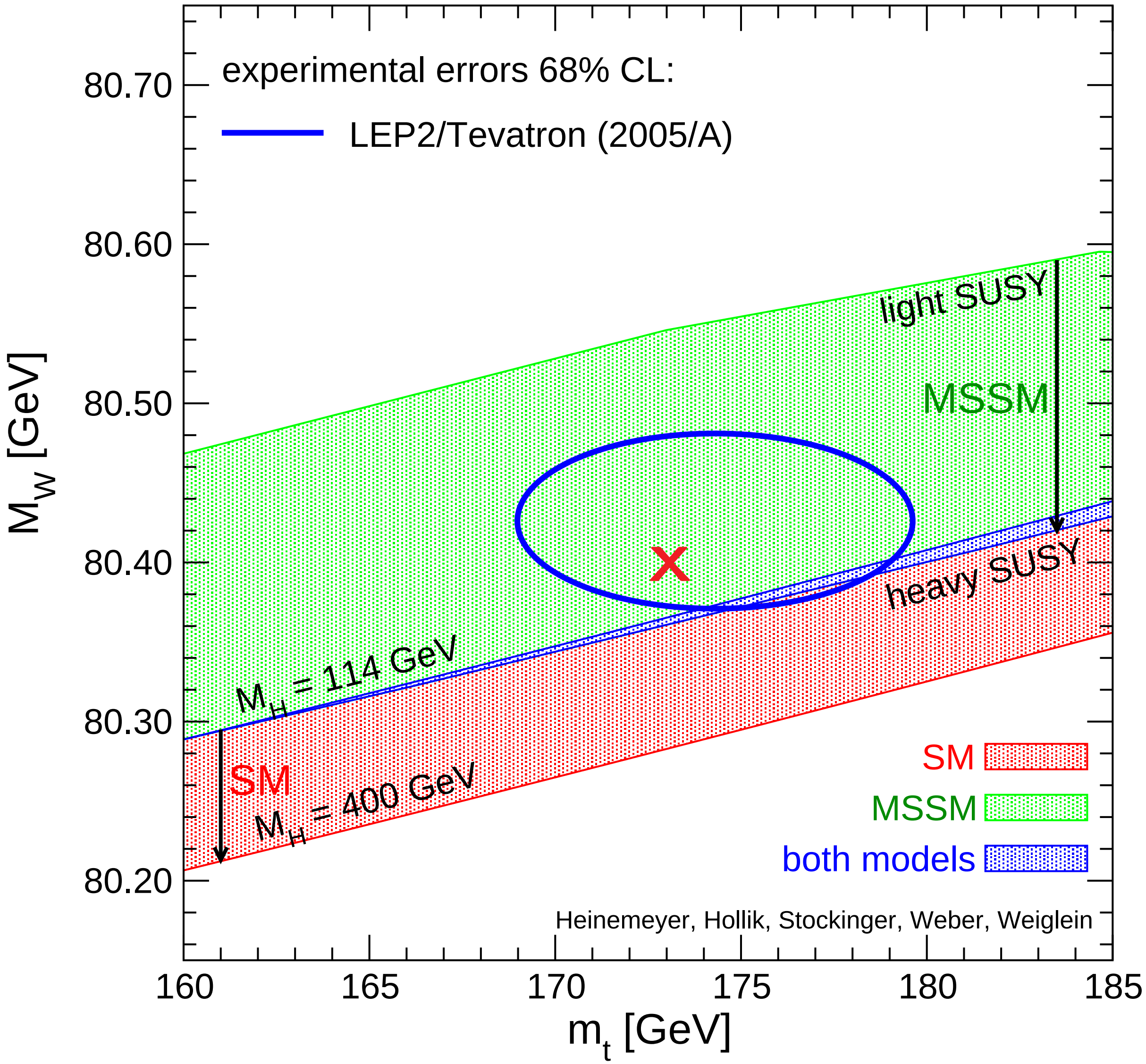

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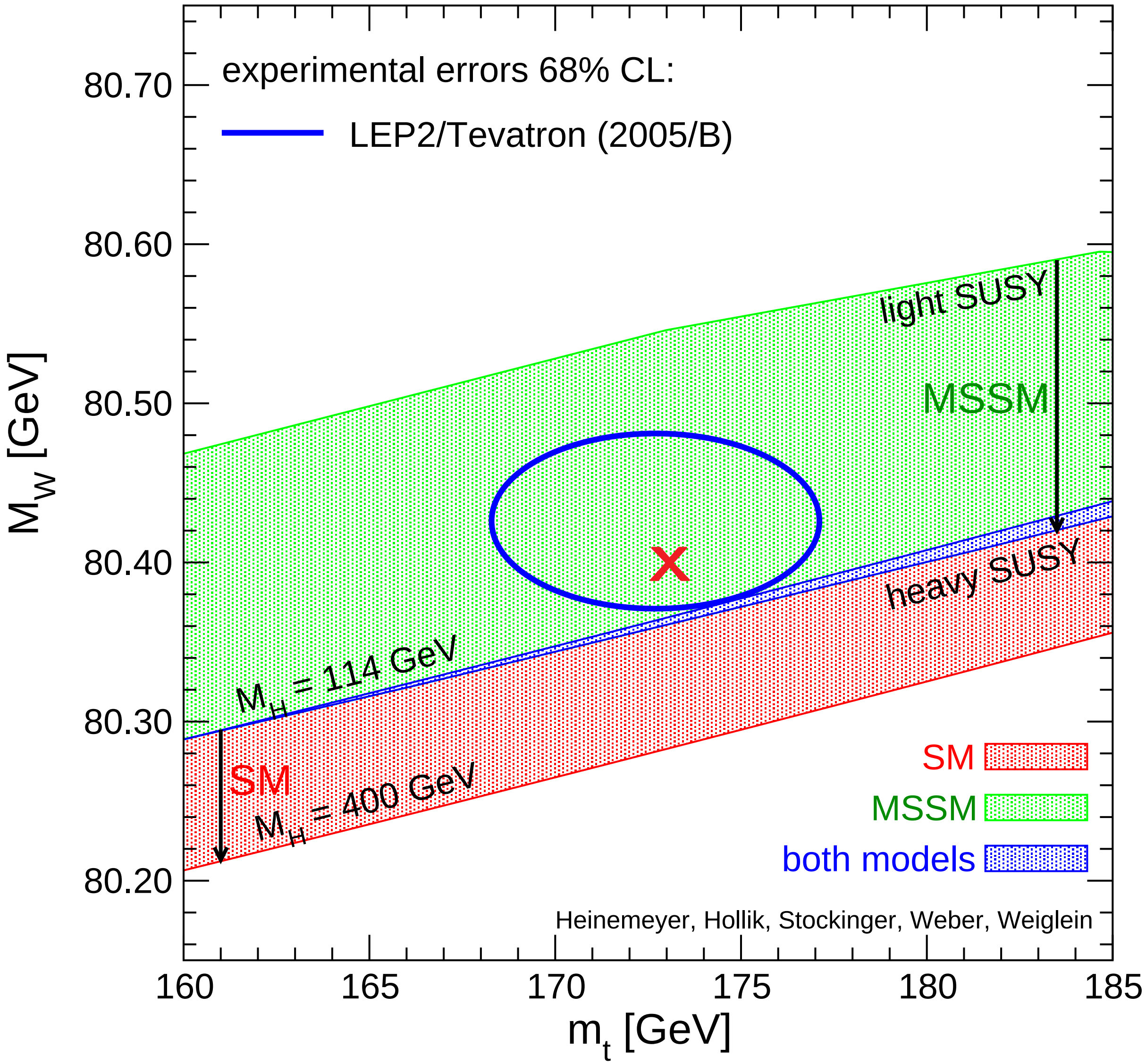

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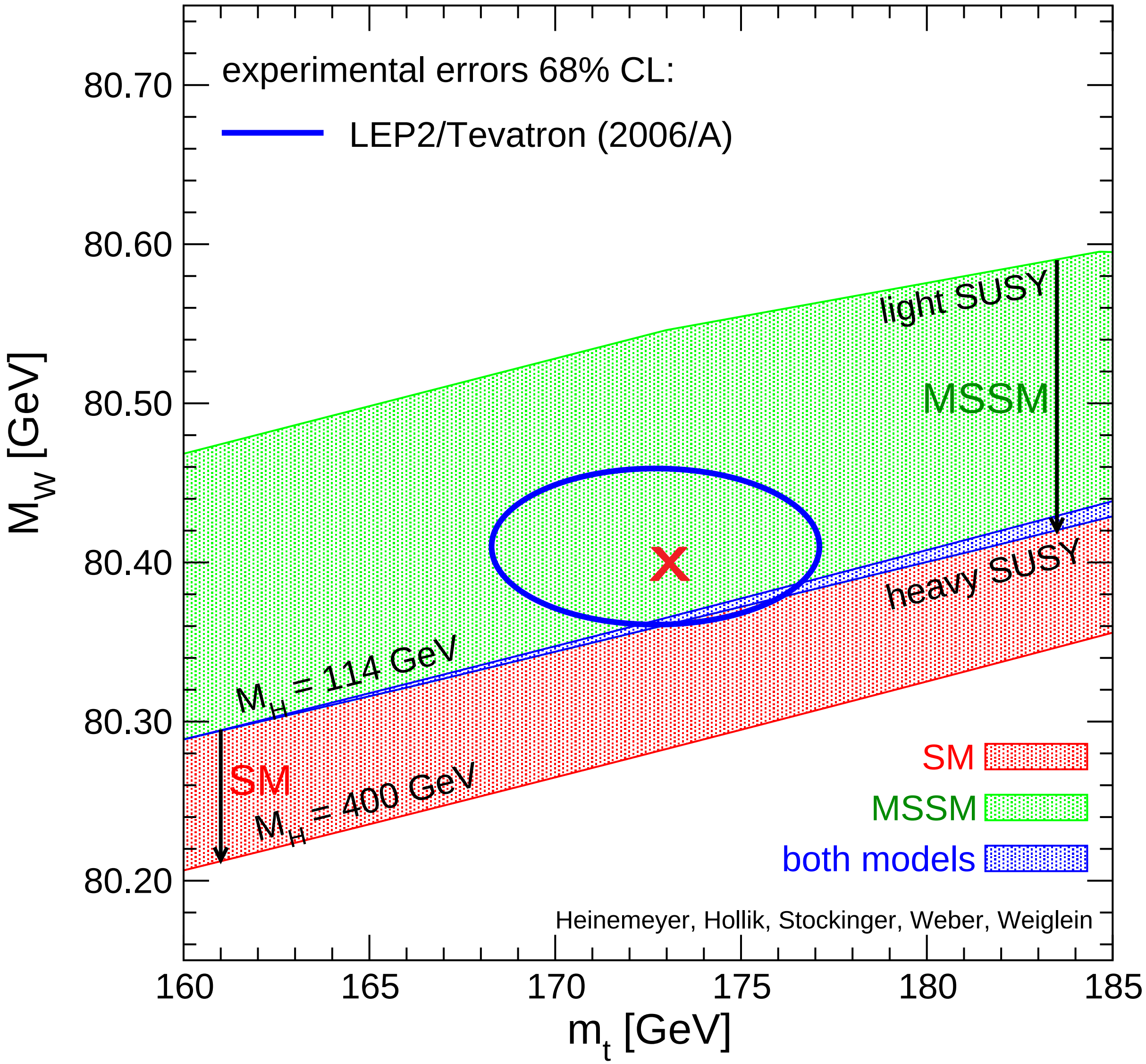

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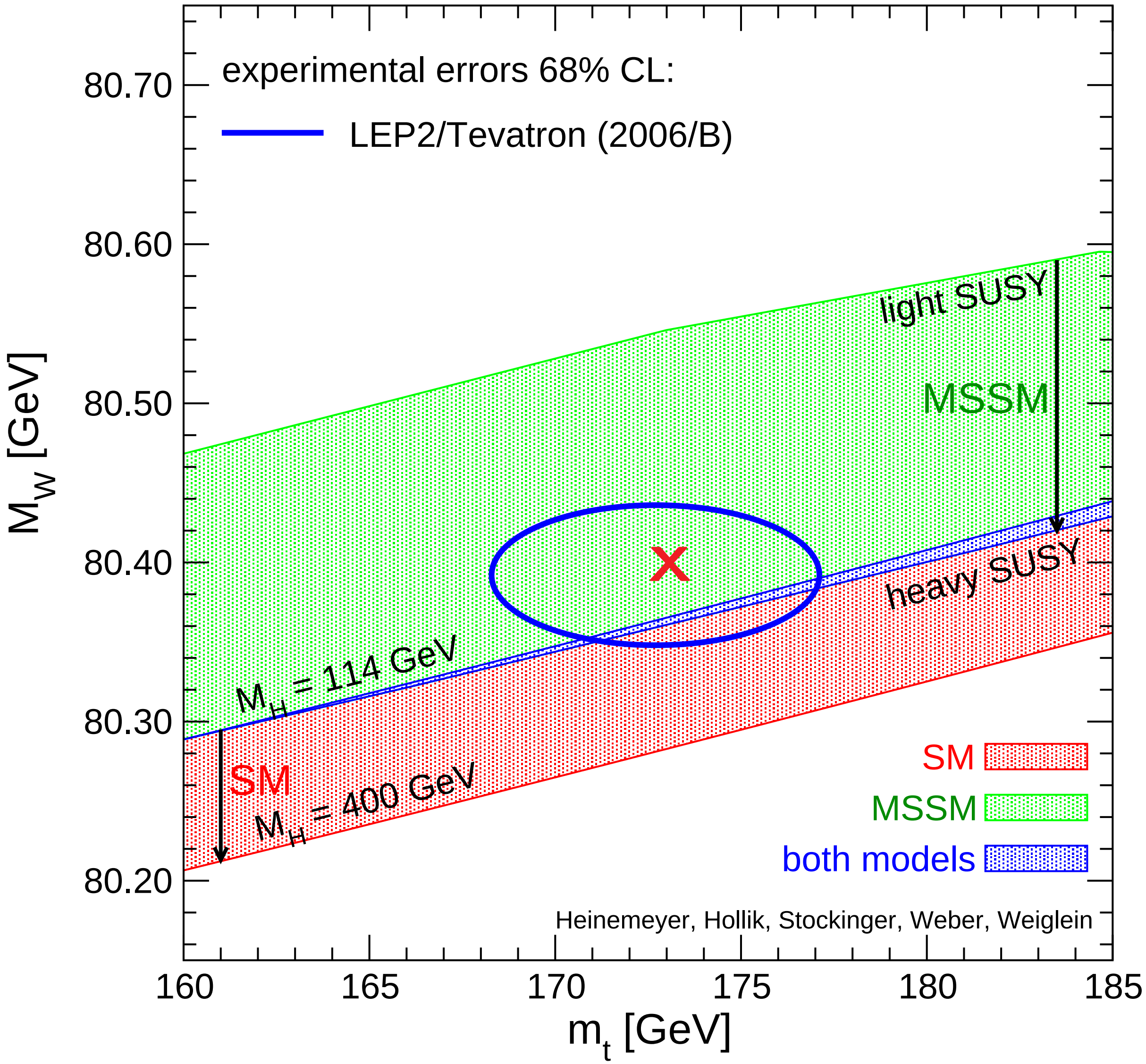

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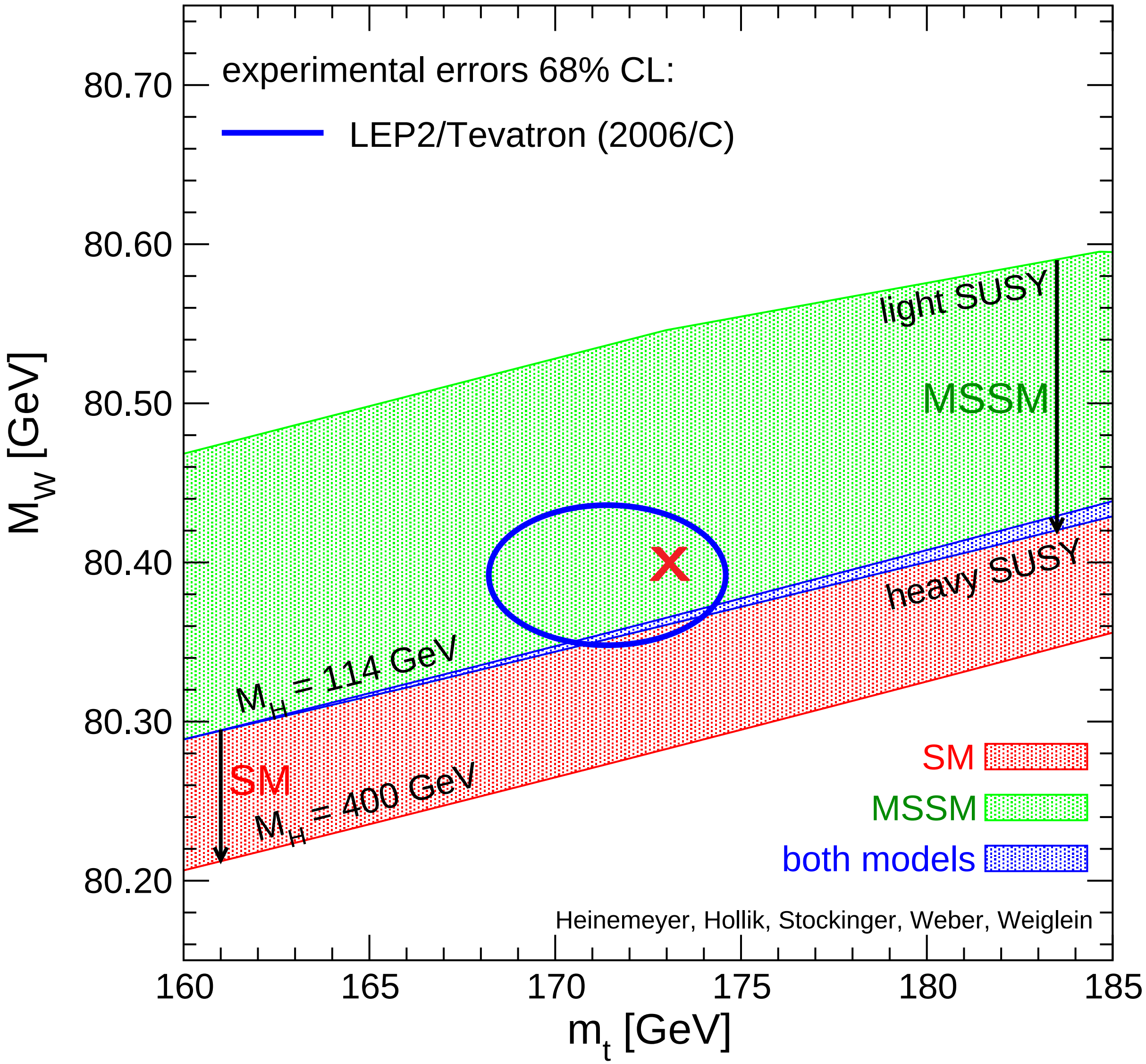

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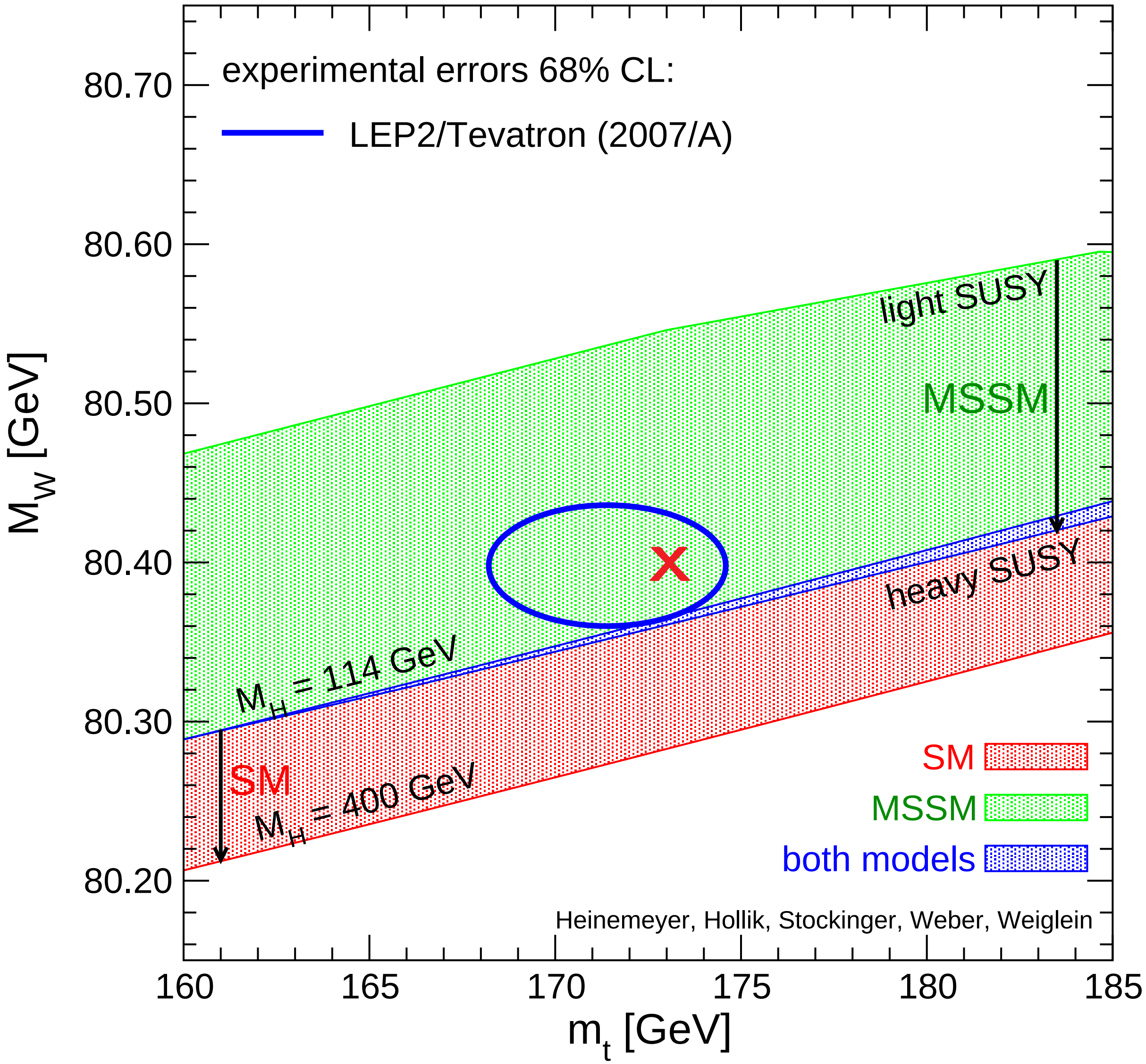

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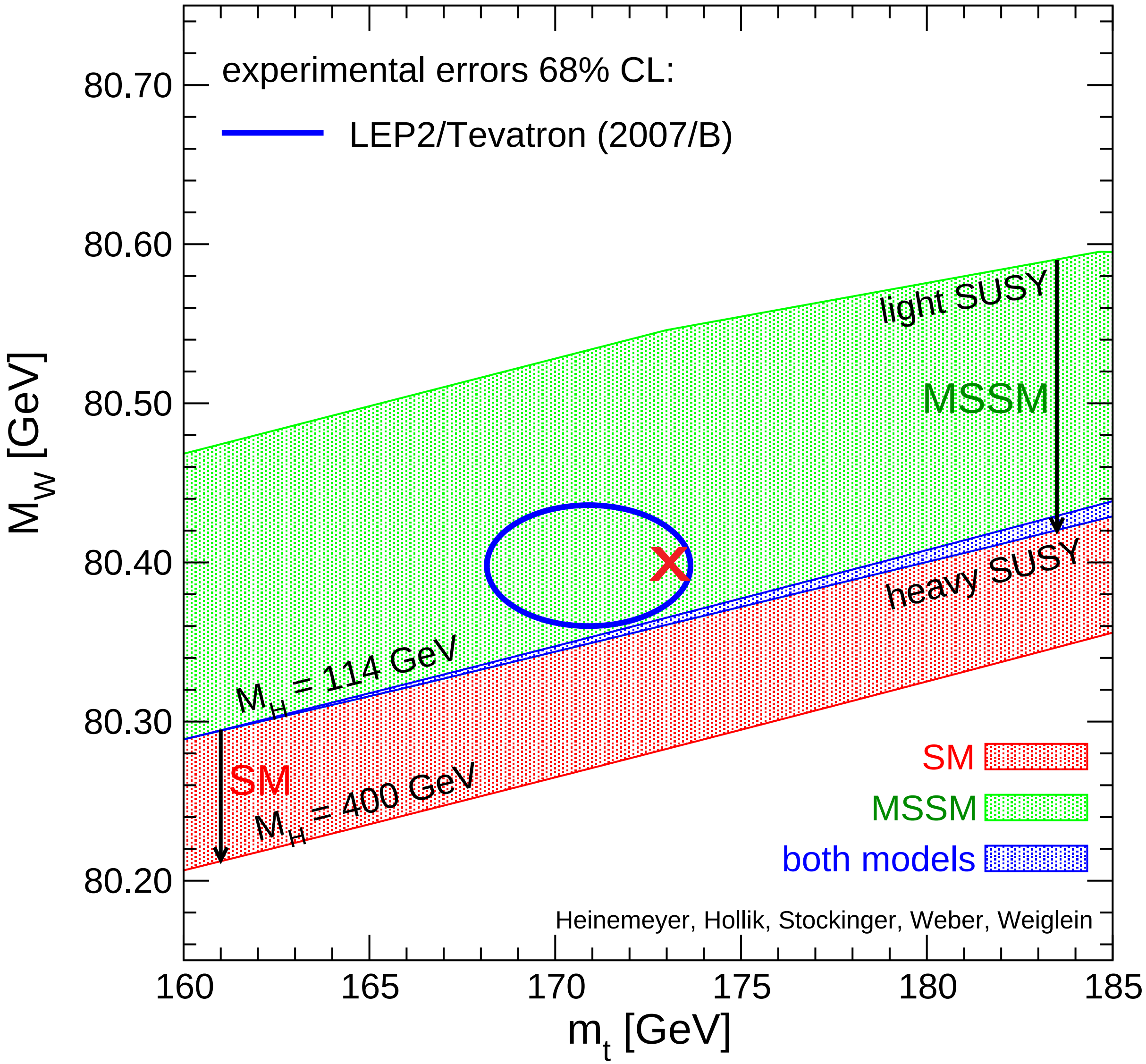

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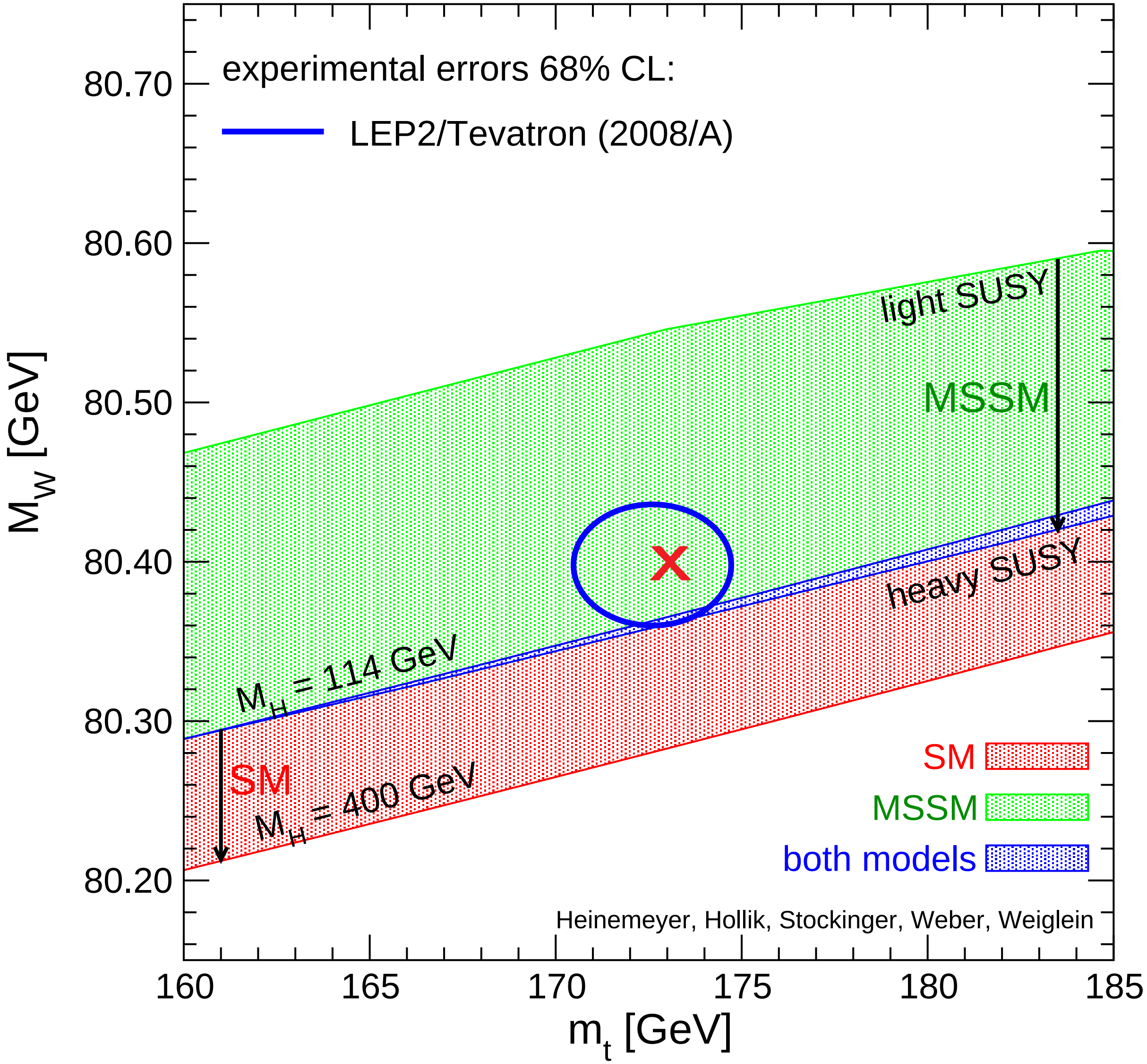

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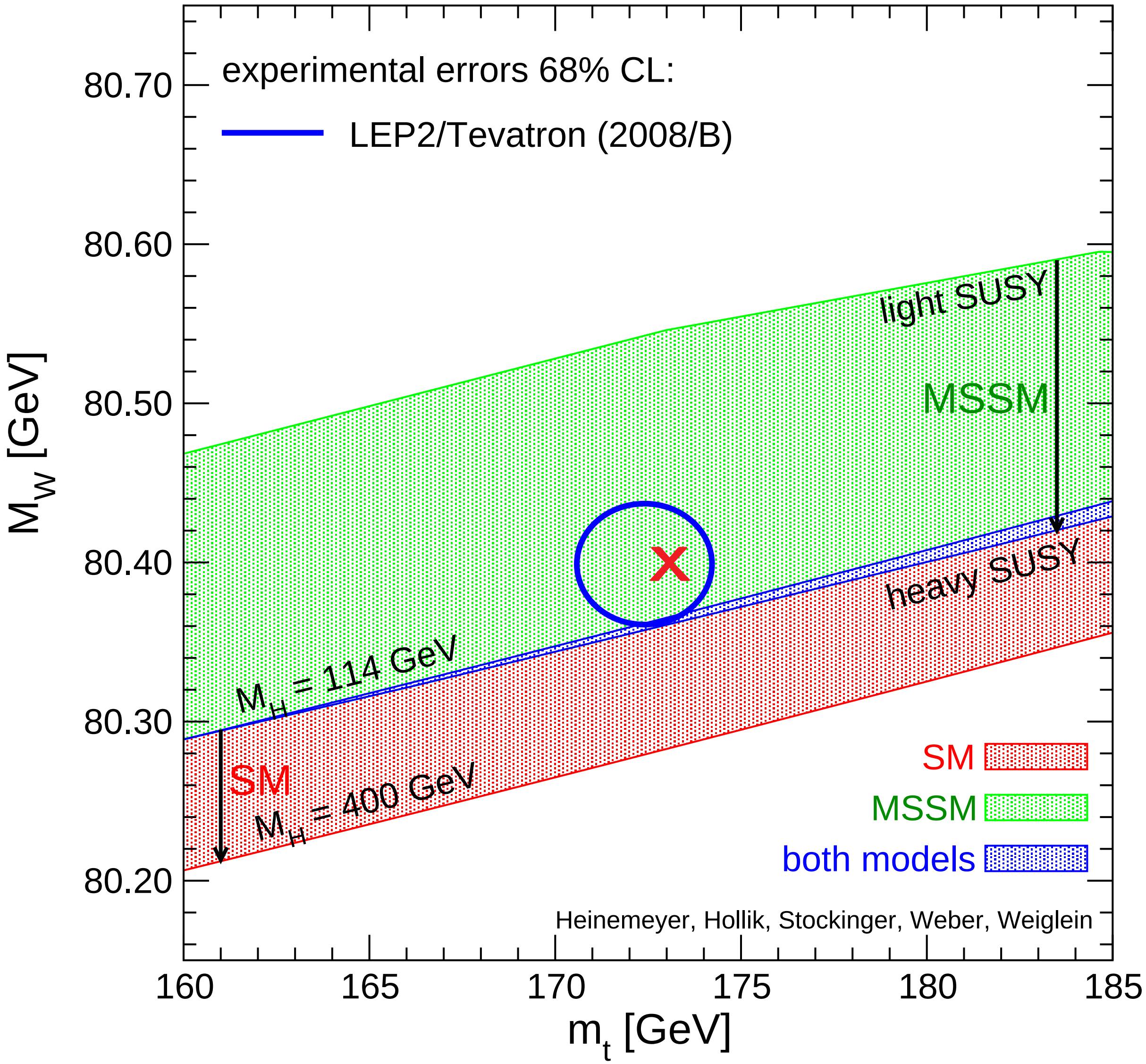

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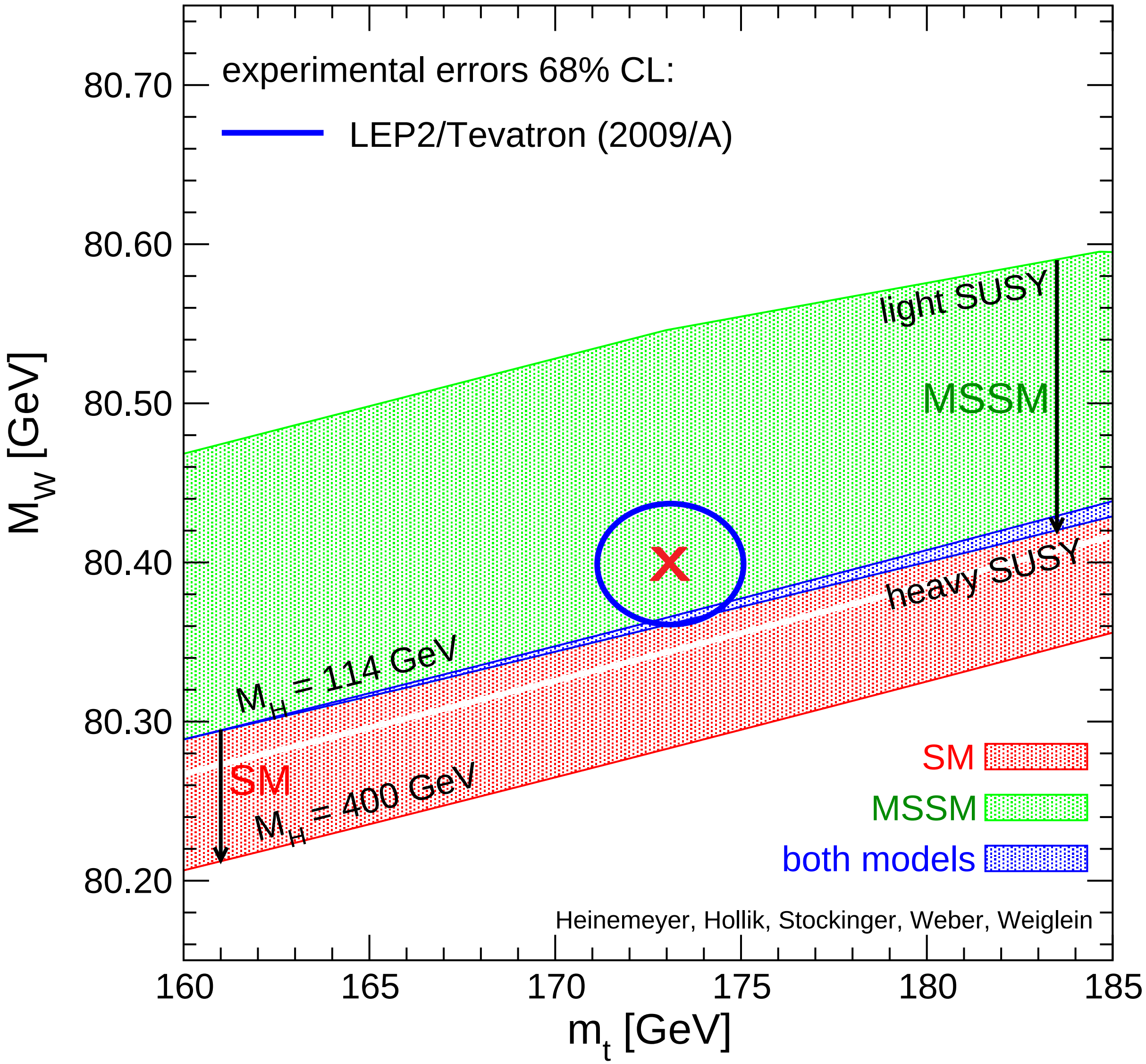

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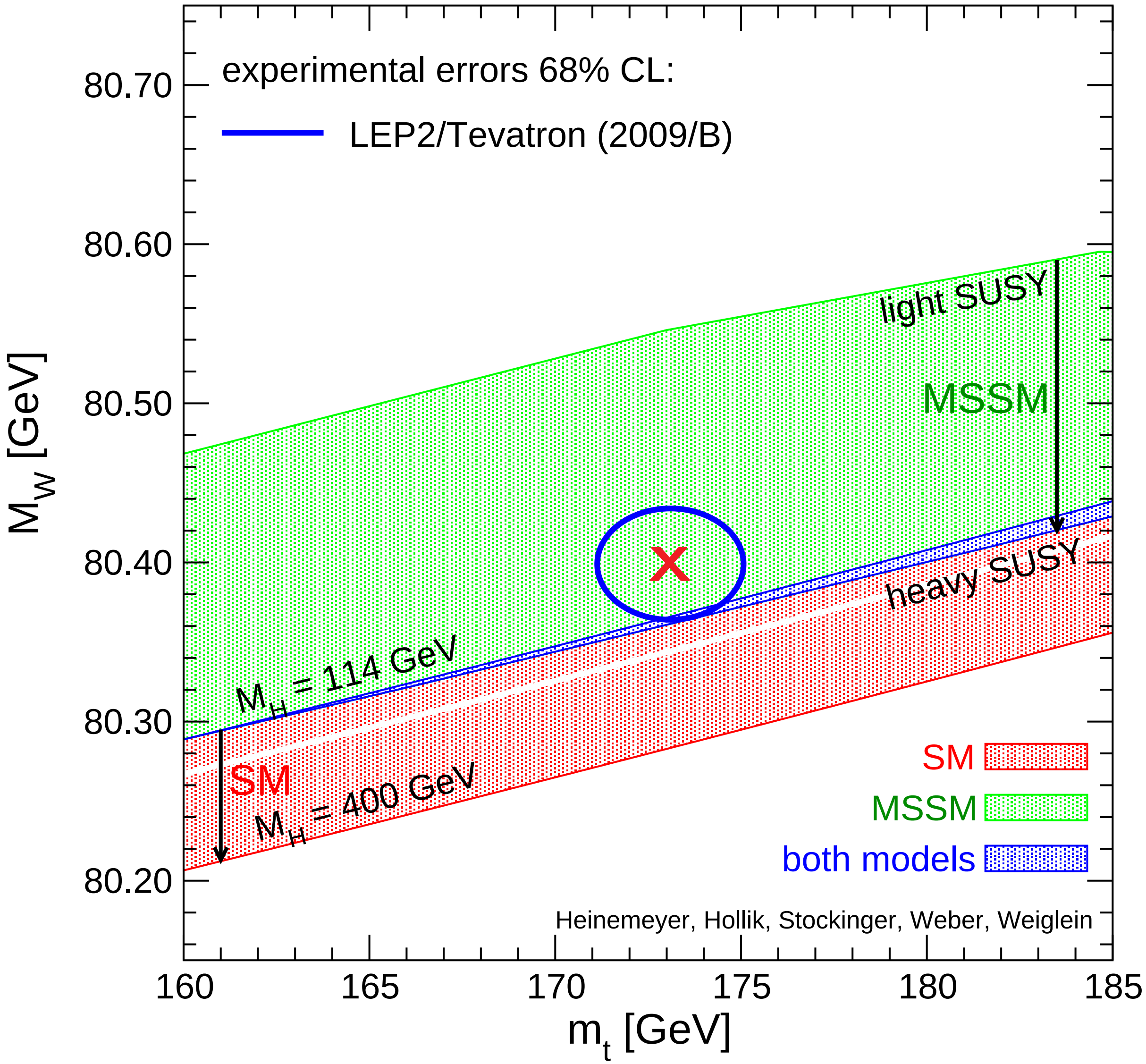

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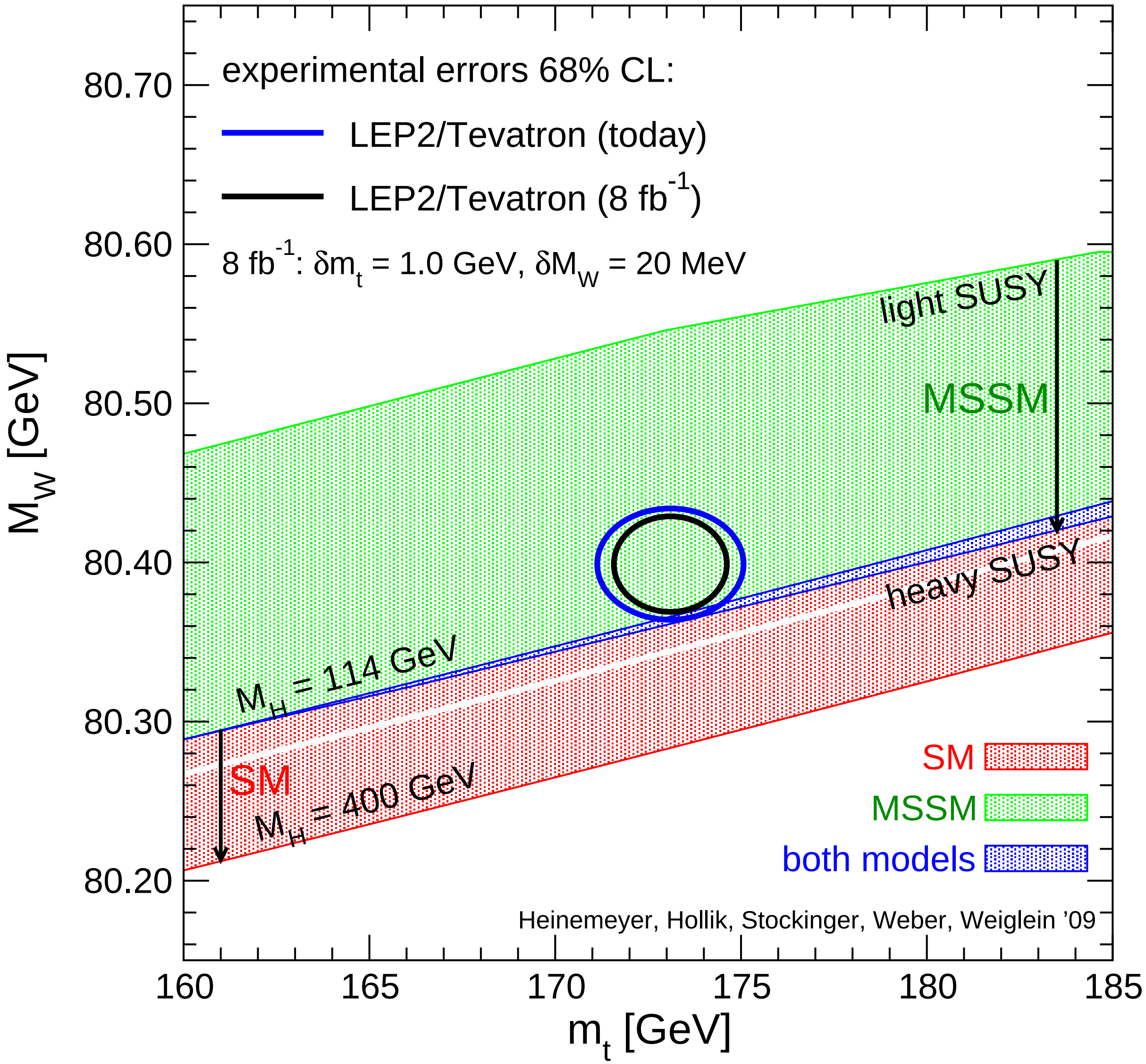

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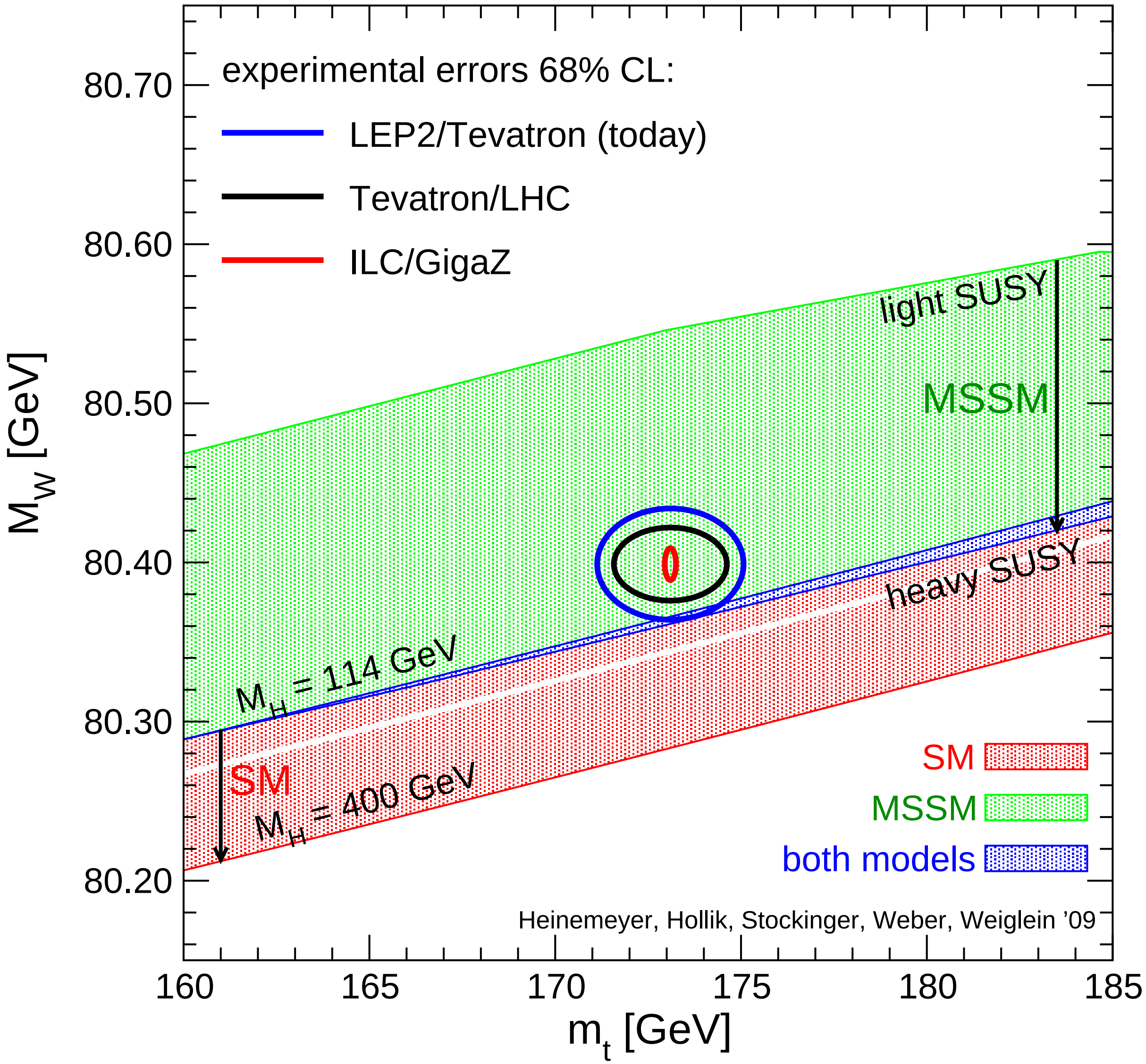

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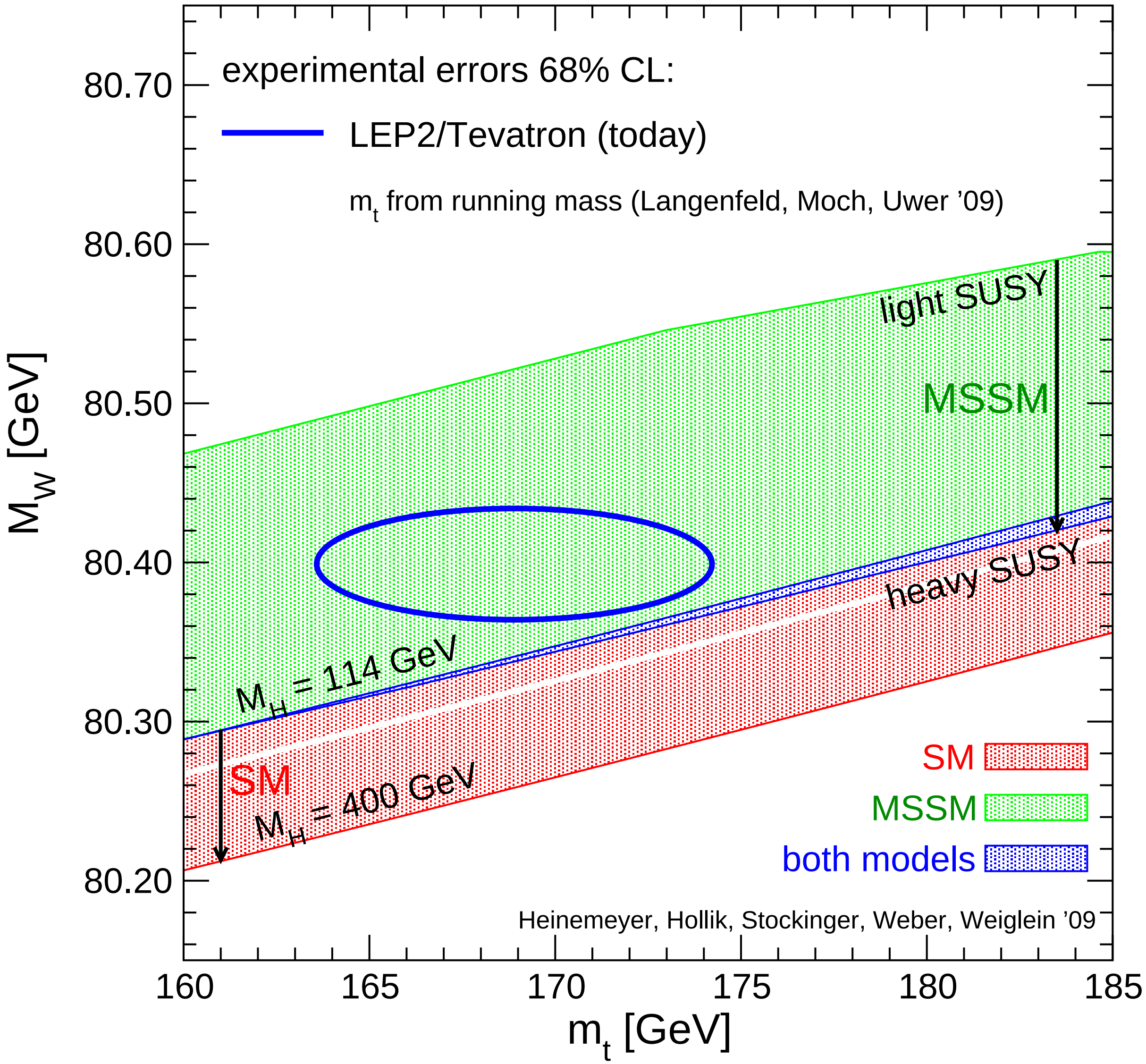

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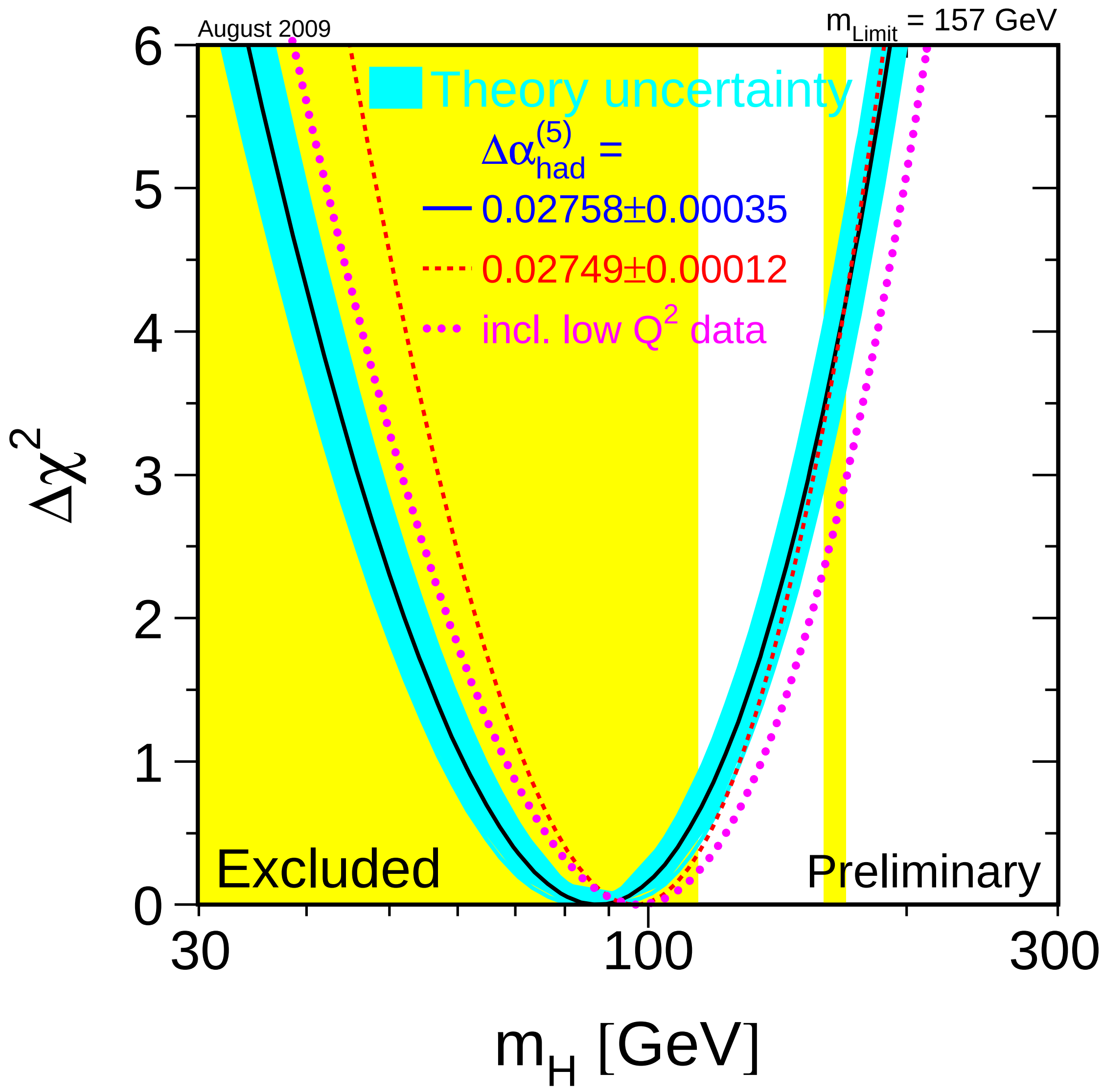
Global fit to all SM data:

[*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

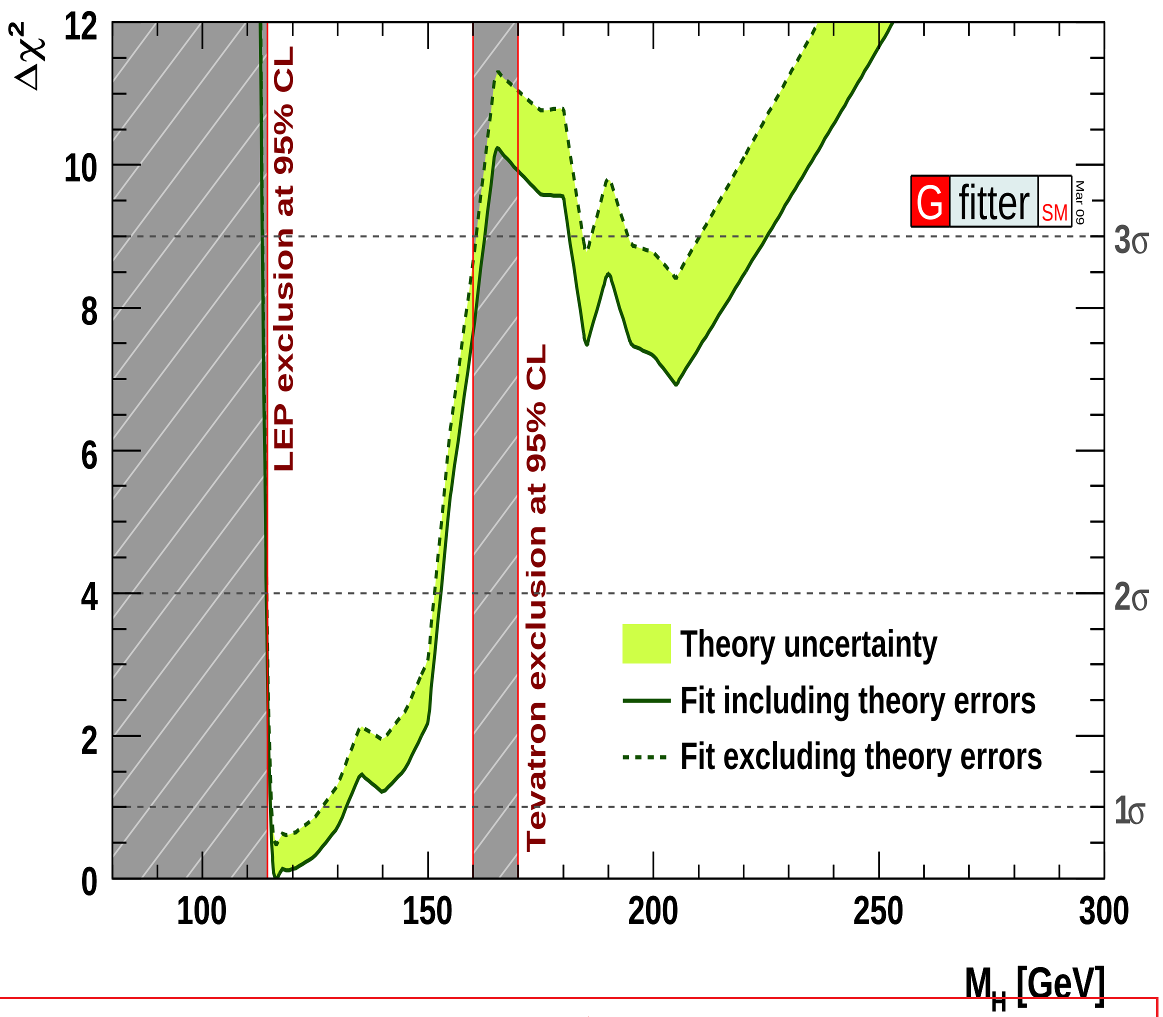
$\Rightarrow$ Higgs boson seems to be light, $M_H \lesssim 160$ GeV

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.



Assumption for the fit:
SM incl. Higgs boson

$\Rightarrow$ no confirmation of Higgs mechanism

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2. The models and the tools

Indirect constraints on M_{SUSY} from existing data?

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

$\Rightarrow$ 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*]

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*]

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*]

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

Different methods:

1.) Scanning:

– 3-dim scans (possibly with CDM fixing one dimension)

[J. Ellis, T. Hahn, SH, K. Olive, A. Weber, G. Weiglein '04, '06, '07]

– multi-dim scans

[O. Buchmueller et al. '07] *[S.H., X. Miao, S. Su, G. Weiglein '08]*

– multi-dim scans (with Markov Chain Monte Carlo technique)

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

[B. Allanach, C. Lester and A. Weber '06, '07] *[O. Buchmueller et al. '08]*

⇒ here: results using last one

2.) Fitting:

– Frequentist

[J. Ellis, T. Hahn, SH, K. Olive, A. Weber, G. Weiglein '04, '06, '07]

[O. Buchmueller et al. '07, '08] *[S.H., X. Miao, S. Su, G. Weiglein '08]*

– Bayesian

[R. de Austri, R. Trotta and L. Roszkowski '06, '07]

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

⇒ focus on Frequentist here

3.) Priors . . . (none)

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

⇒ Scenario characterized by

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

m_0 : universal scalar mass parameter

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

A_0 : universal trilinear coupling

} at the GUT scale

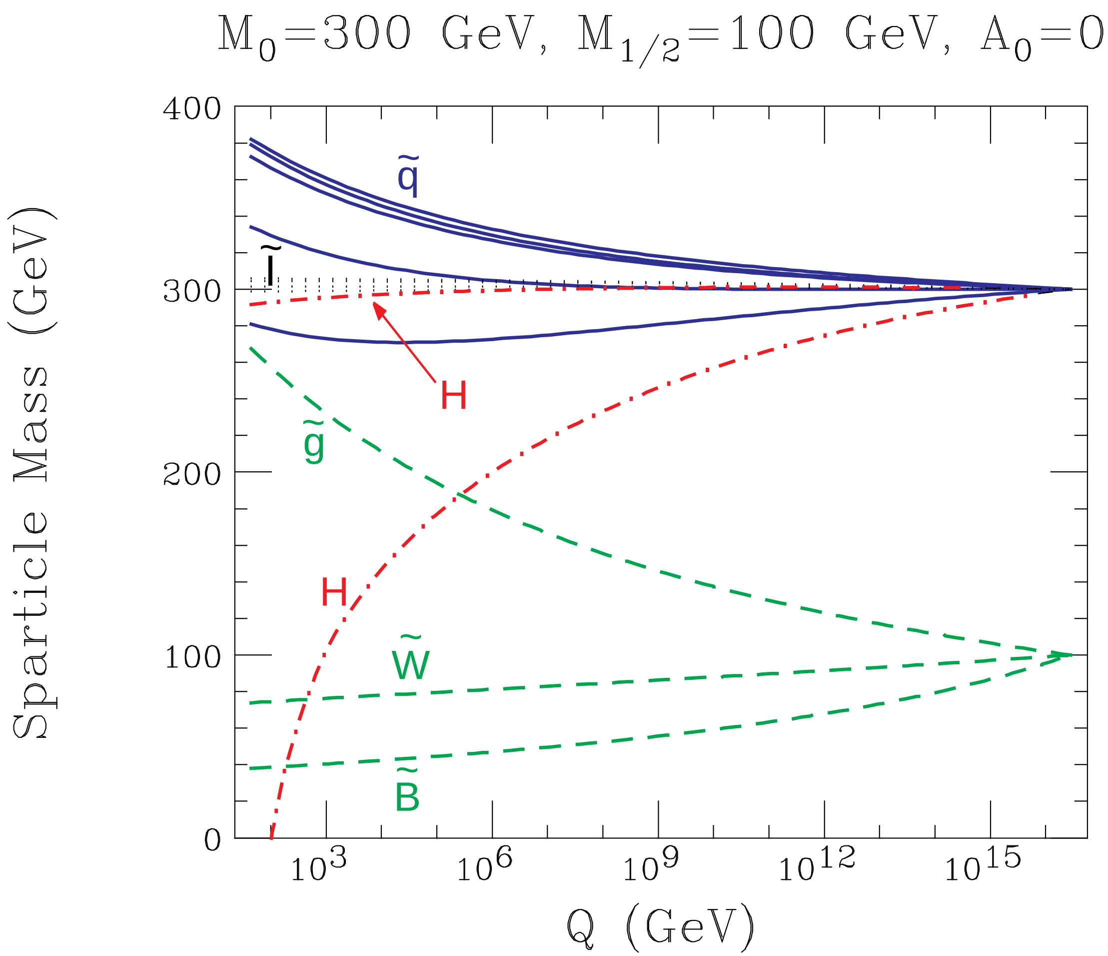
$\tan\beta$: ratio of Higgs vacuum expectation values

sign(μ) : sign of supersymmetric Higgs parameter

⇒ particle spectra from renormalization group running to weak scale

⇒ Lightest SUSY particle (LSP) is the lightest neutralino

$\Rightarrow$ particle spectra from renormalization group running to weak scale



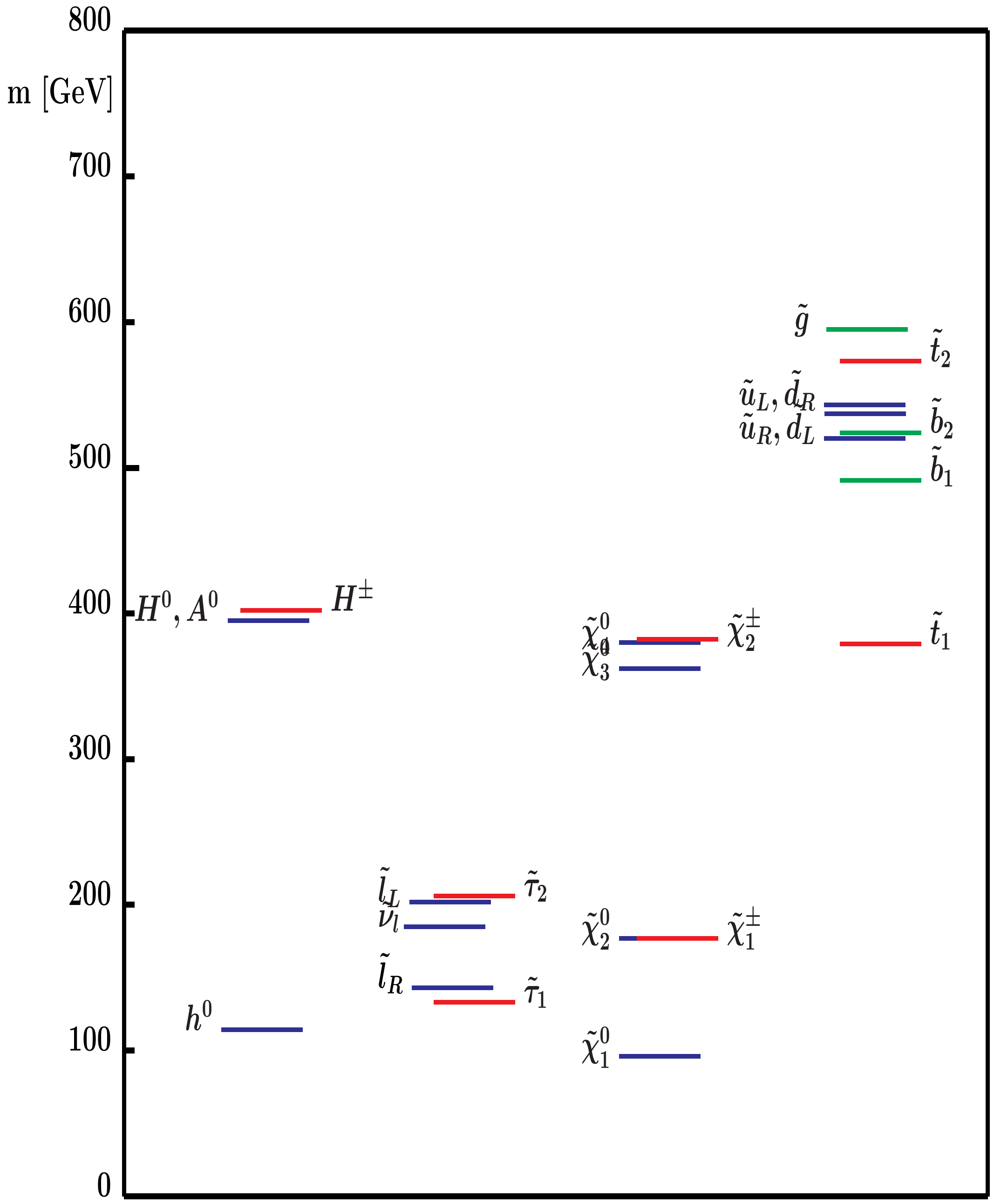
$\Rightarrow$ one parameter turns negative $\Rightarrow$ Higgs mechanism for free

“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
>
> $$M_A \text{ or } \mu$$

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
>
> $$M_A \text{ and } \mu$$

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

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

Example: B/K physics observables in the MasterCode

1. $\mathrm{BR}(b \to s\gamma)$
2. $\mathrm{BR}(B_s \to \mu^+\mu^-)$
3. ΔM_s
4. $\mathrm{R}(\Delta M_s/\Delta M_d)$
5. $\mathrm{BR}(B_u \to \tau\nu_\tau)$
6. $\mathrm{BR}(B \to X_x\ell^+\ell^-)$
7. $\mathrm{R}(K \to \ell\nu)$
8. $\mathrm{R}(\Delta M_K)$

⇒ largest impact: (1) and (2)

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

How does this work in Supersymmetry?

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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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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

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
– combine with B physics observables
– combine with CDM and $(g-2)_\mu$
– include SM parameters with their errors: m_t, ...

– scan over the full CMSSM/NUHM1 parameter space

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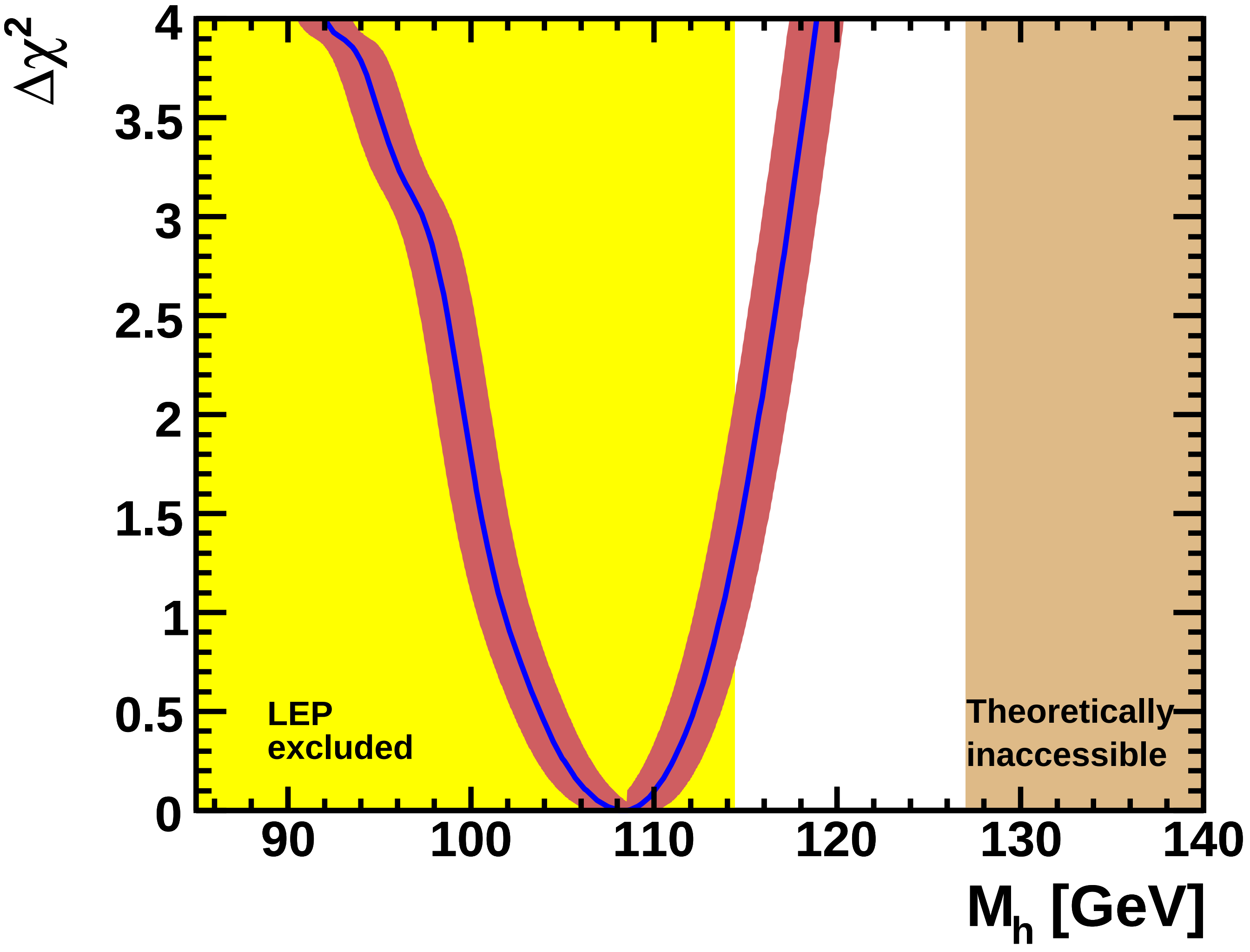
$\Rightarrow$ preferred M_h values

CMSSM: red band plot:

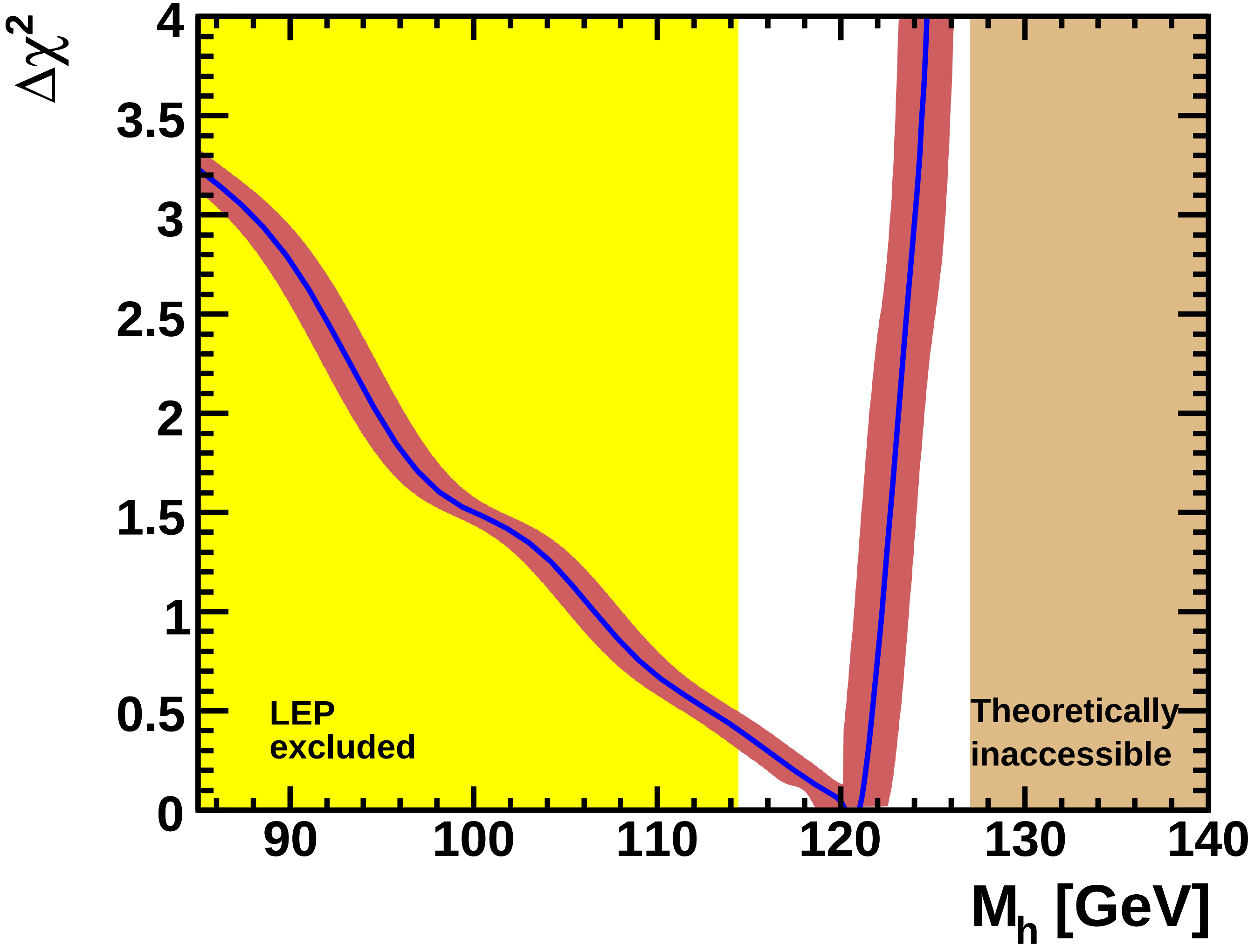
[*MasterCode '09*]



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

NUHM1: red band plot:

[*MasterCode '09*]



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

4. 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

$\longrightarrow$ 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)

$\longrightarrow$ final minimum: Minuit

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

$\Rightarrow$ preferred CMSSM/NUHM1 parameters
$\Rightarrow$ LHC/ILC reach

Best-fit points:

CMSSM:

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

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

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

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

NUHM1:

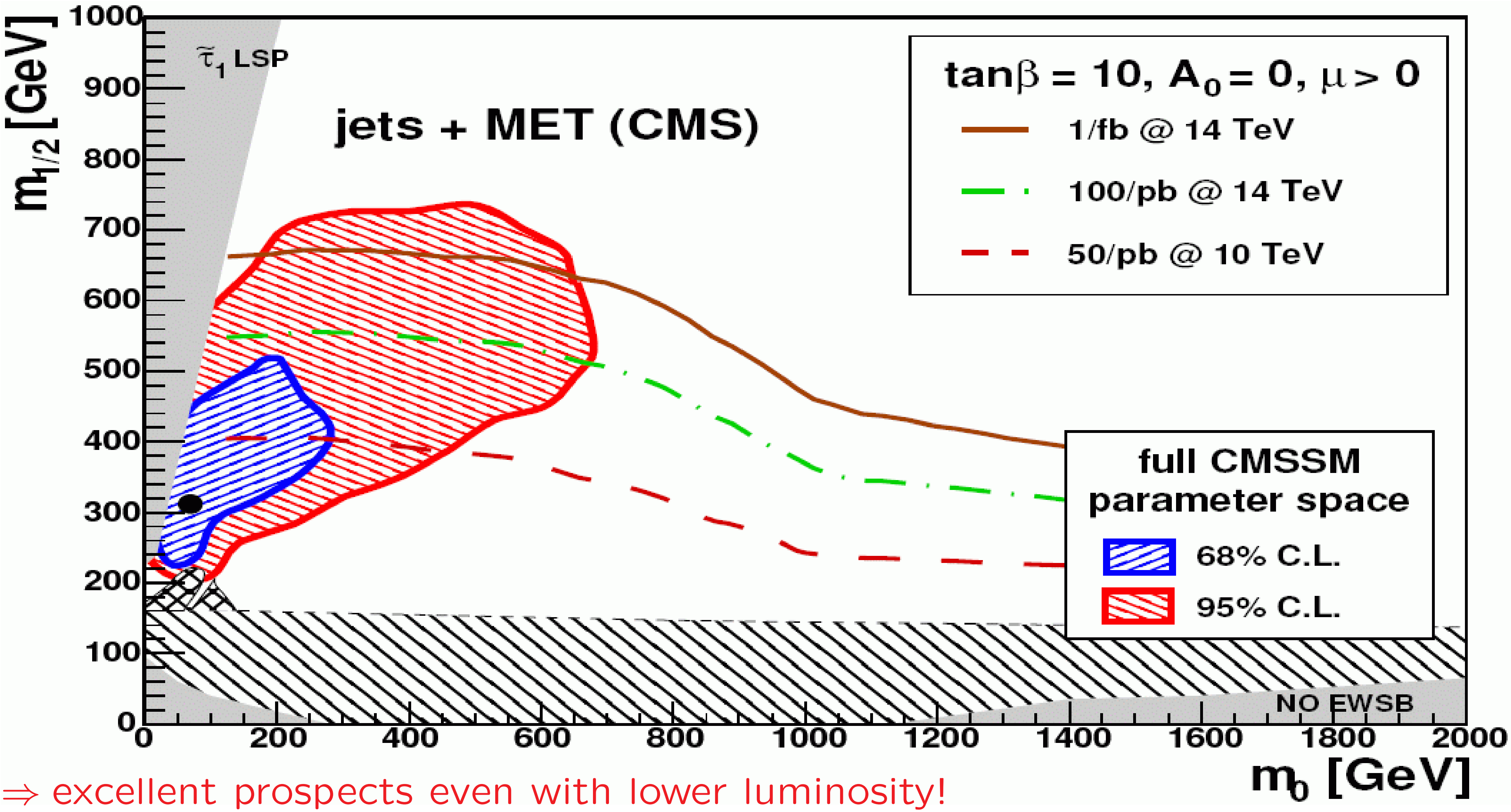
$m_{1/2} = 270$ GeV, $m_0 = 150$ GeV, $A_0 = -1300$ GeV,

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

(similar probability)

LHC (CMS):

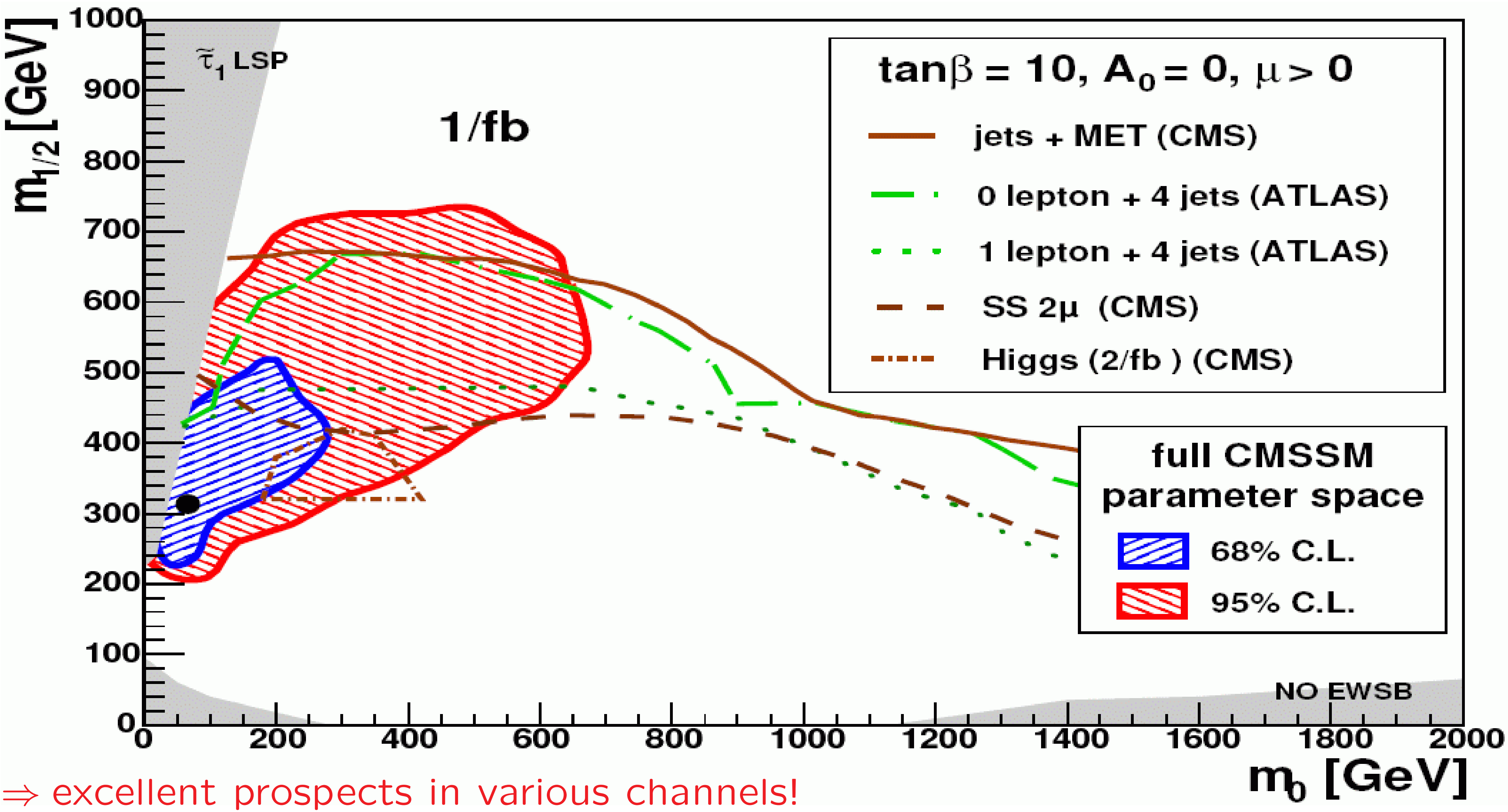
[*MasterCode '08*] [*CMS '07*]



⇒ excellent prospects even with lower luminosity!

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

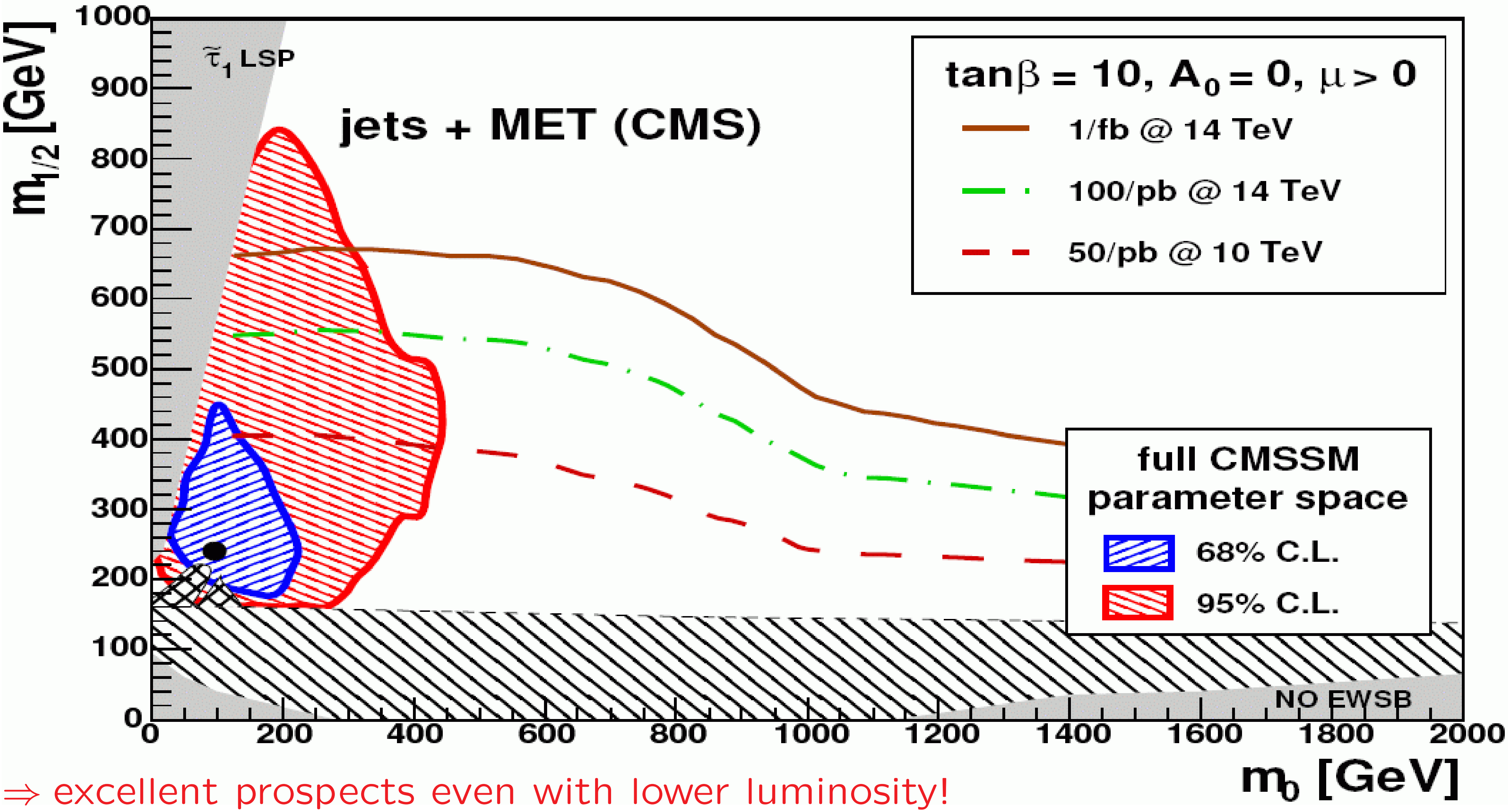
[*MasterCode '08*] [*CMS '07*]



⇒ excellent prospects in various channels!

LHC (CMS): NUHM1 analysis

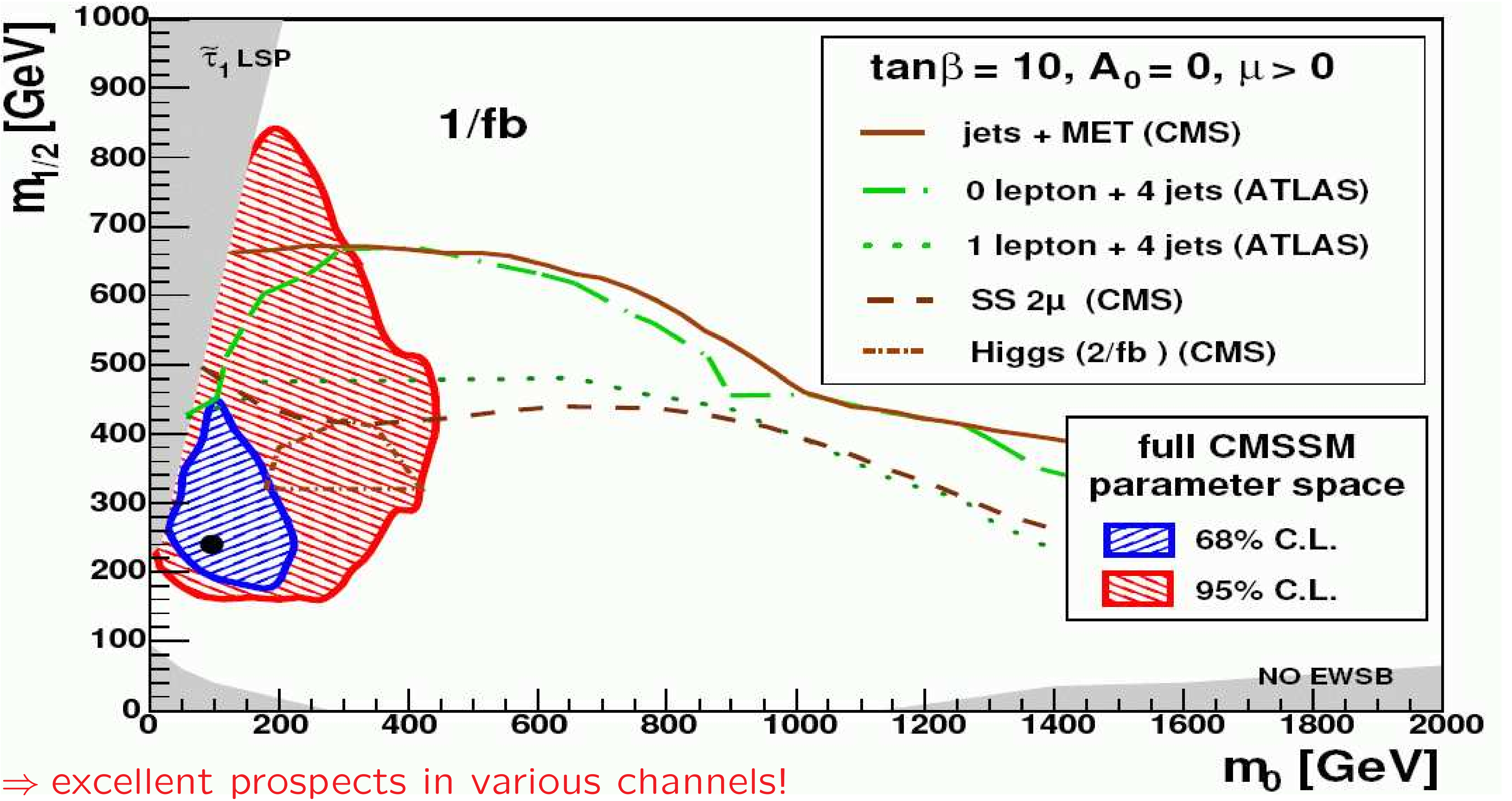
[*MasterCode '08*] [*CMS '07*]



⇒ excellent prospects even with lower luminosity!

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

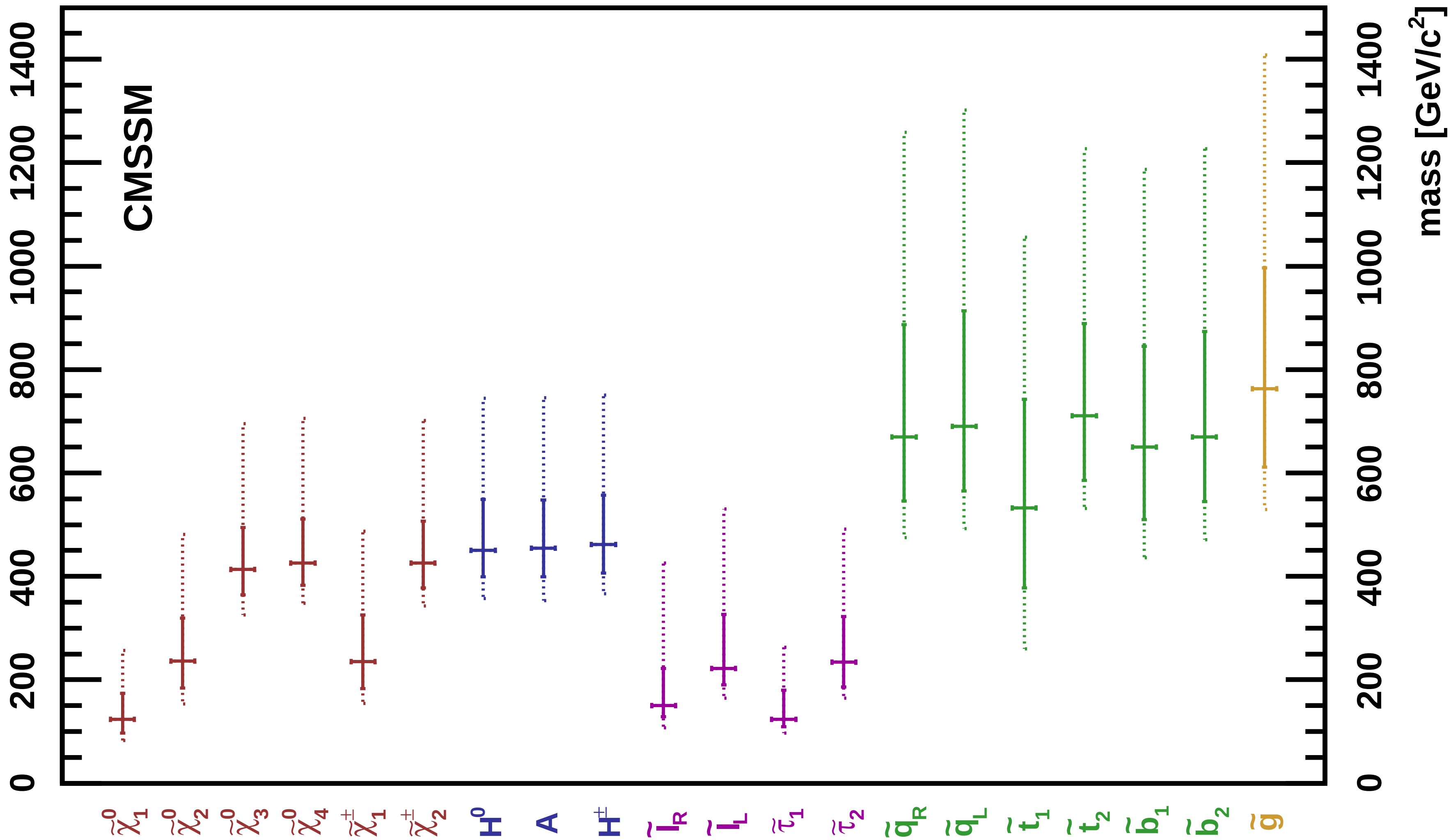
[*MasterCode '08*] [*CMS '07*]



⇒ excellent prospects in various channels!

Masses for best-fit points: CMSSM

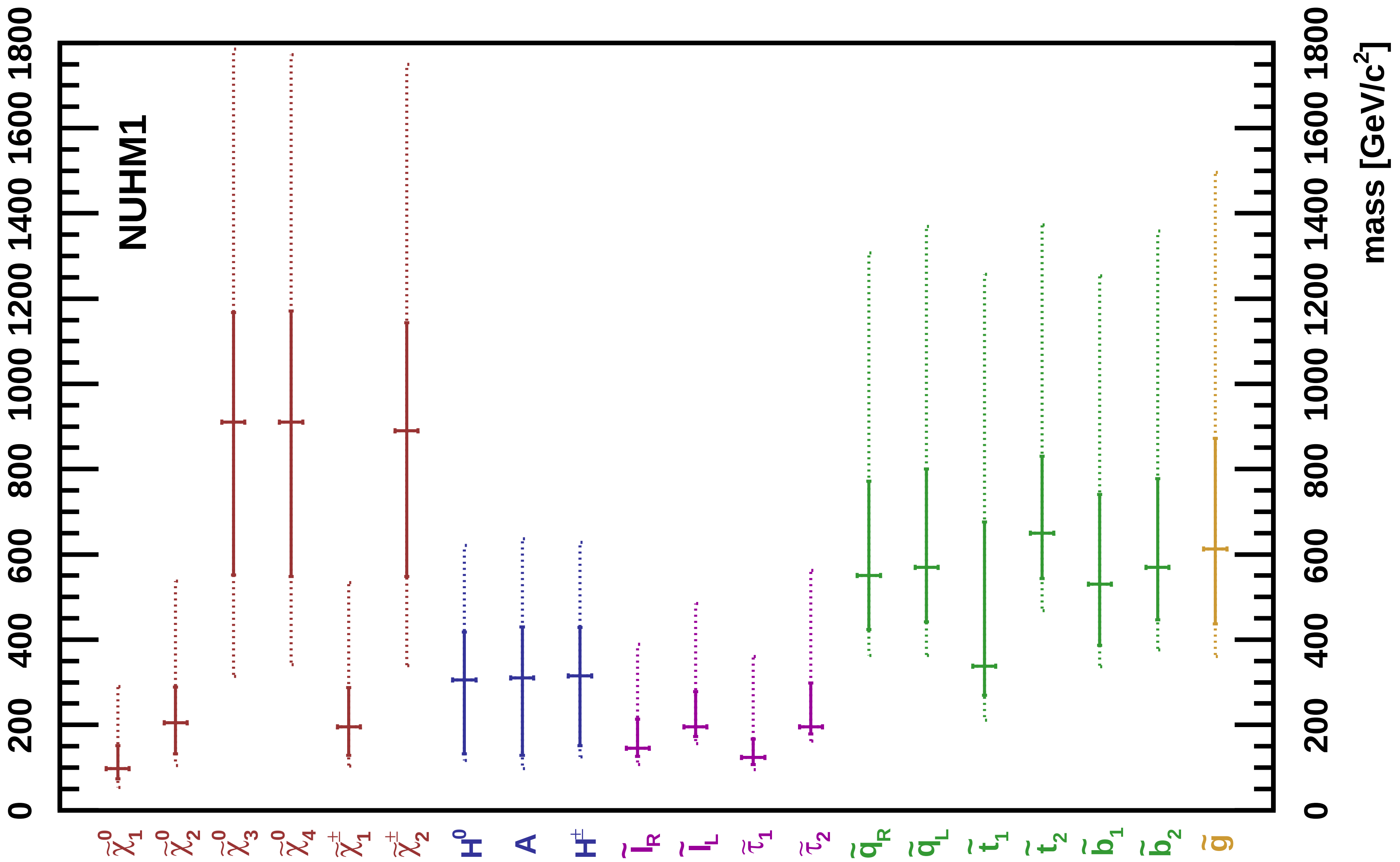
[*MasterCode '09*]



⇒ largely accessible spectrum for LHC and ILC

Masses for best-fit points: CMSSM

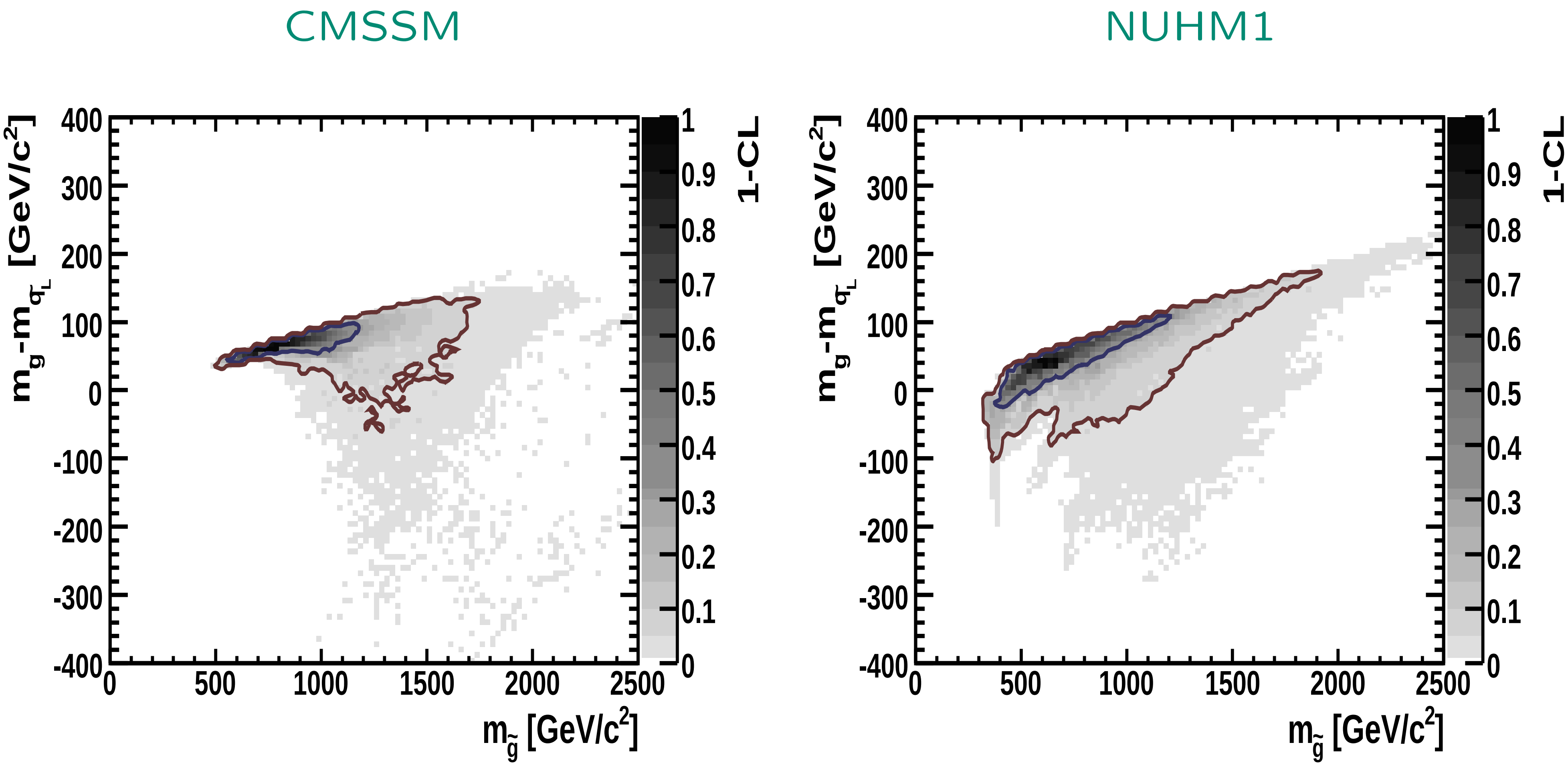
[*MasterCode '09*]



⇒ largely accessible spectrum for LHC and ILC

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

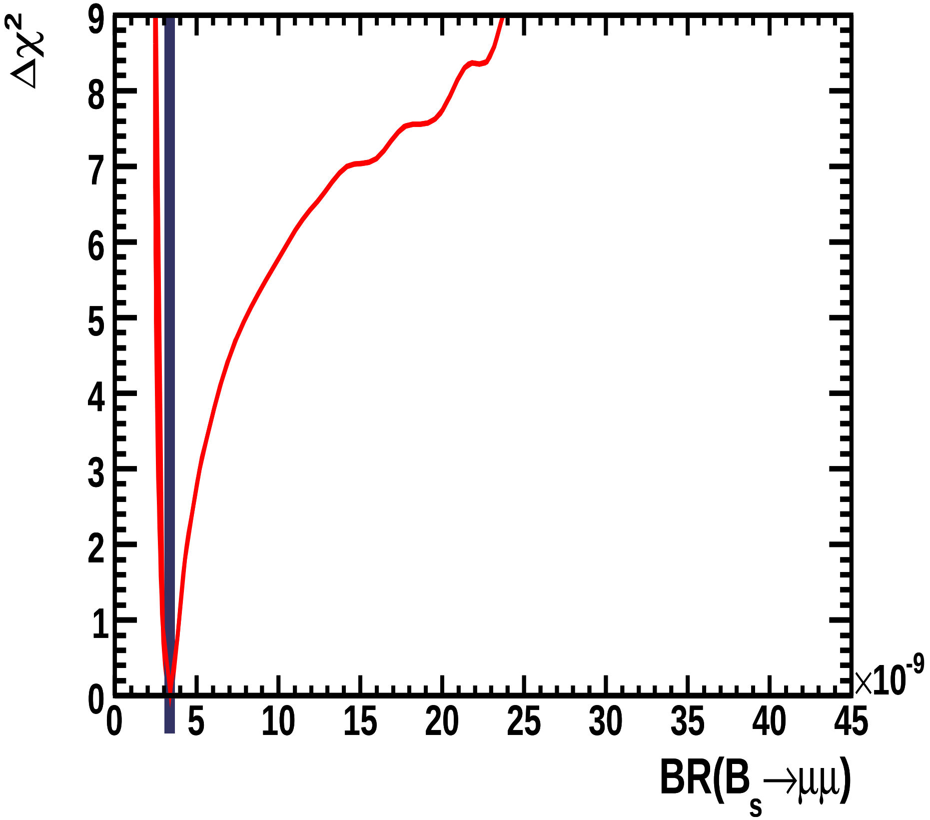
[*MasterCode '09*]



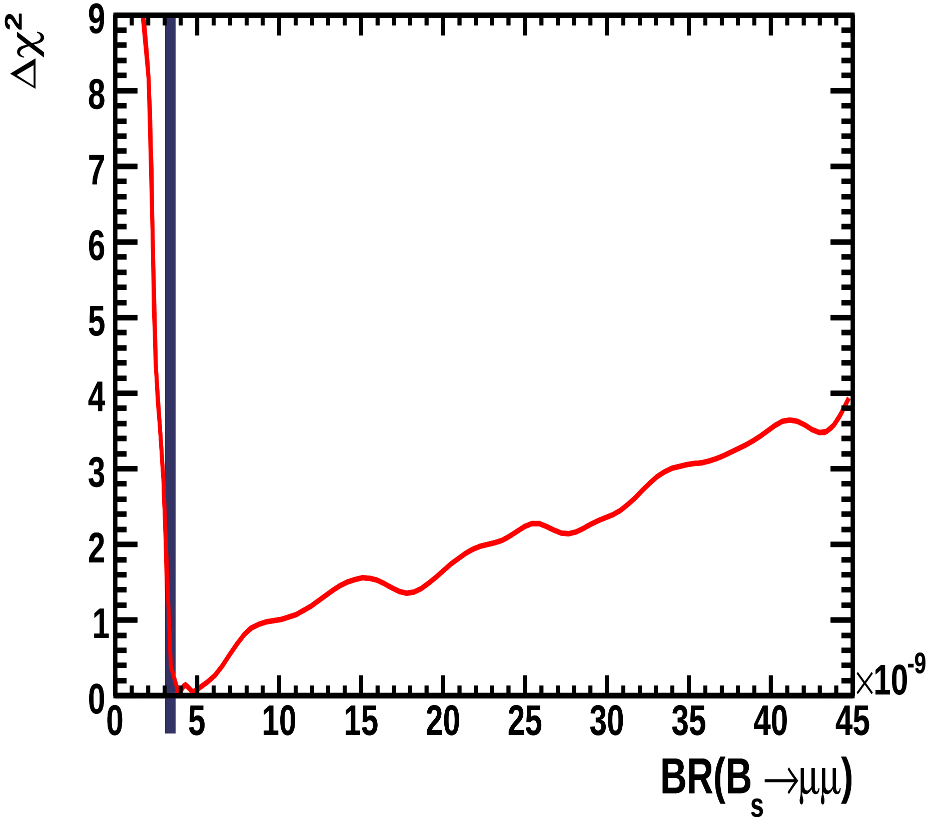
$\Rightarrow$ $m_{\tilde{g}}$ often largest mass, but exceptions are possible

Some more predictions: BR($B_s \to \mu^+\mu^-$) [MasterCode '09]

CMSSM



NUHM1

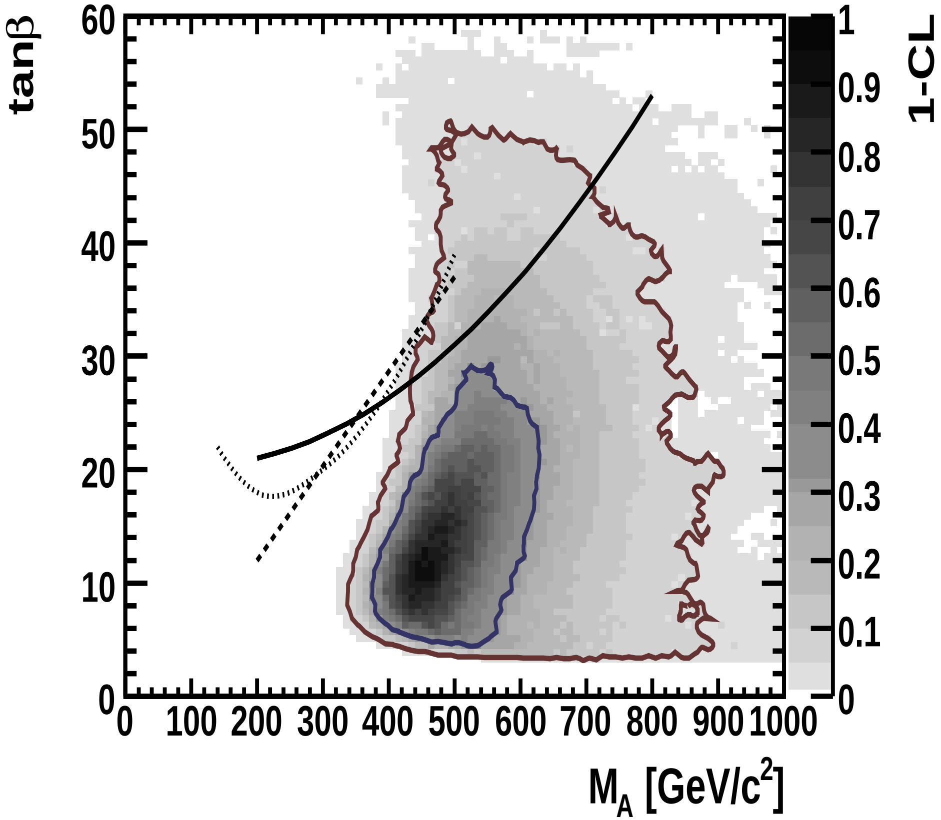


$\Rightarrow$ best-fit similar to SM, larger value would favor NUHM1

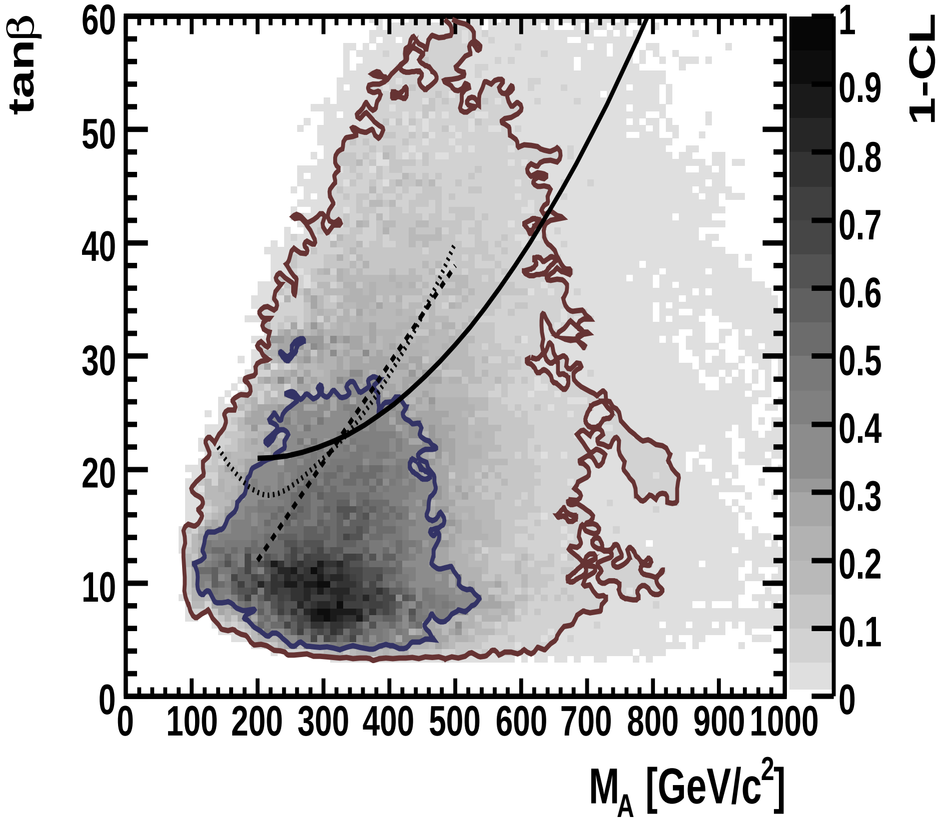
Some more predictions: preferred M_A–$\tan\beta$ parameter space

[MasterCode '09]

CMSSM



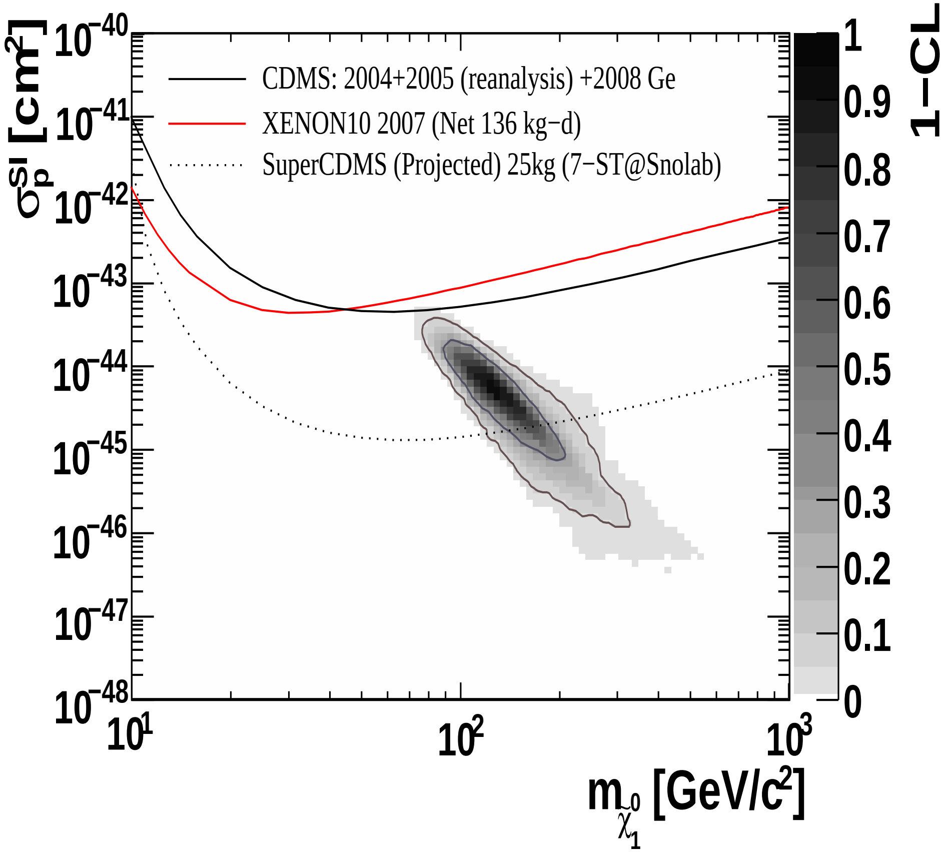
NUHM1



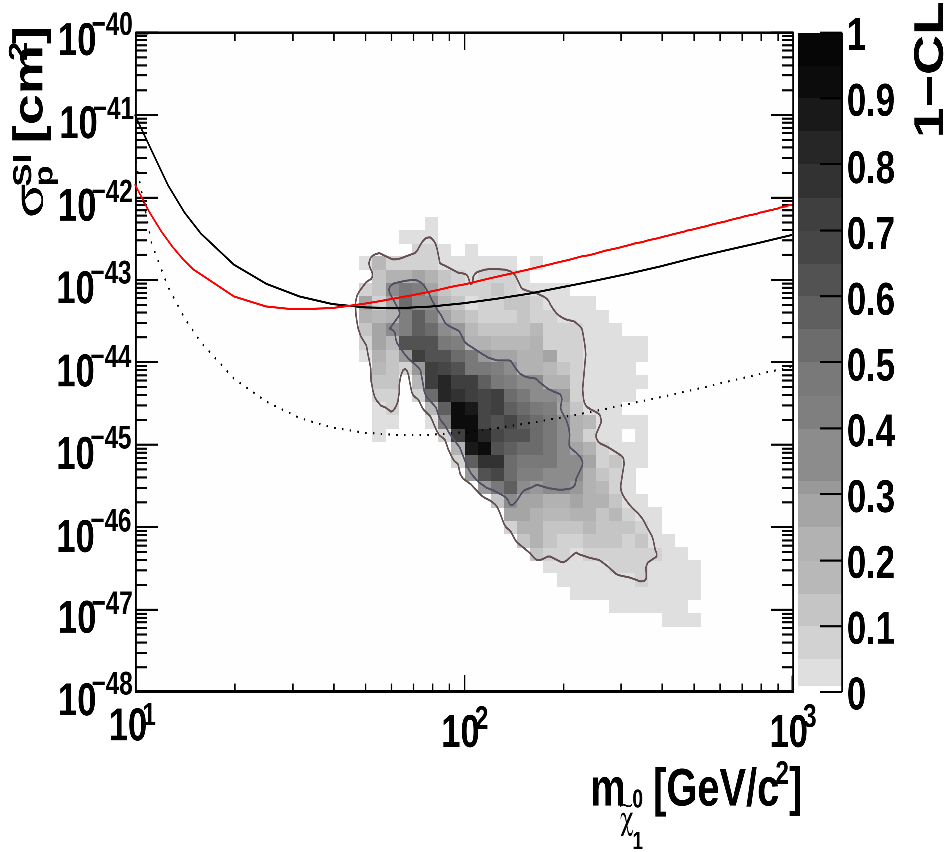
⇒ best-fit regions missed by LHC, better for ILC(1000)

Some more predictions: direct search for dark matter [*MasterCode '09*]

CMSSM



NUHM1



⇒ only partially covered by future experiments

5. Conclusinos

- Precision observables
  - can give valuable information about the "true" Lagrangian
  - can provide bounds on SUSY parameter space

- SM: Blue band plot: $\Rightarrow M_H^{\text{SM}} = 87^{+35}_{-26}$ GeV (too light for LEP bounds?)

- MSSM: investigated model: CMSSM, NUHM1

- M_h determination (without LEP bound):
  CMSSM/NUHM1: Red band plot: $\Rightarrow M_h^{\text{CMSSM}} = 108 \pm 6 \pm 1.5$ GeV
  $\Rightarrow M_h^{\text{NUHM1}} = 121^{+1}_{-14} \pm 1.5$ GeV

- LHC reach in the CMSSM/NUHM1
  - excellent prospects with 1 fb^{-1}: nearly full 95% C.L. covered
  - good prospects for 100 pb^{-1} at 10 GeV: nearly 68 % C.L. covered

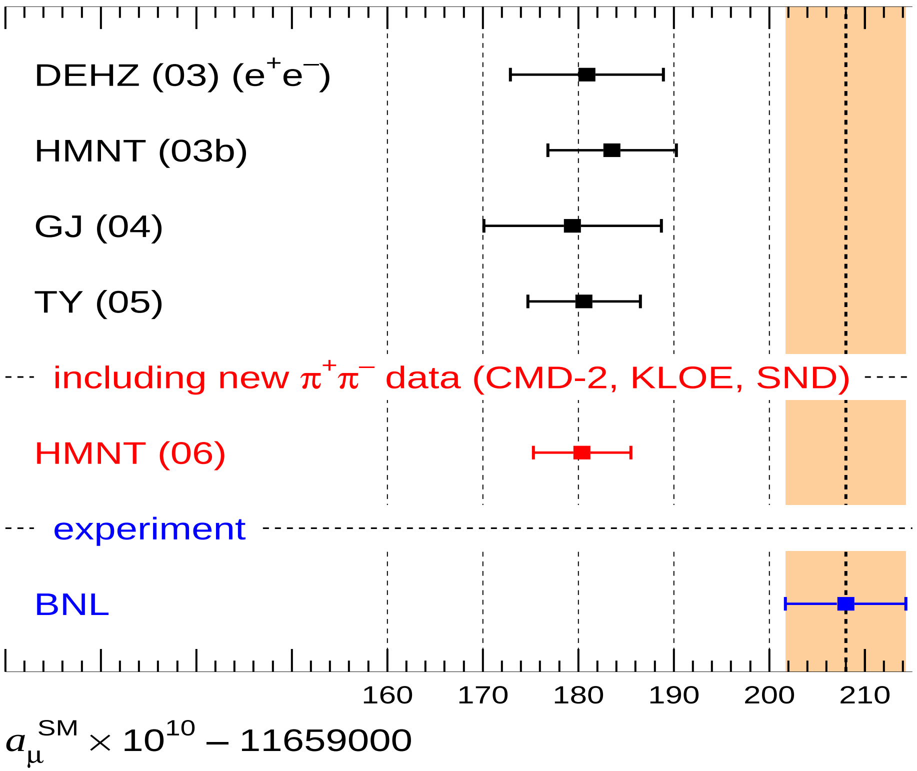
- ILC reach in the CMSSM/NUHM1
  - several particles probably accessible at the ILC(500)
  - very good prospects for the ILC(1000)

Back-up

Another EWPO: the anomalous magnetic moment of the muon

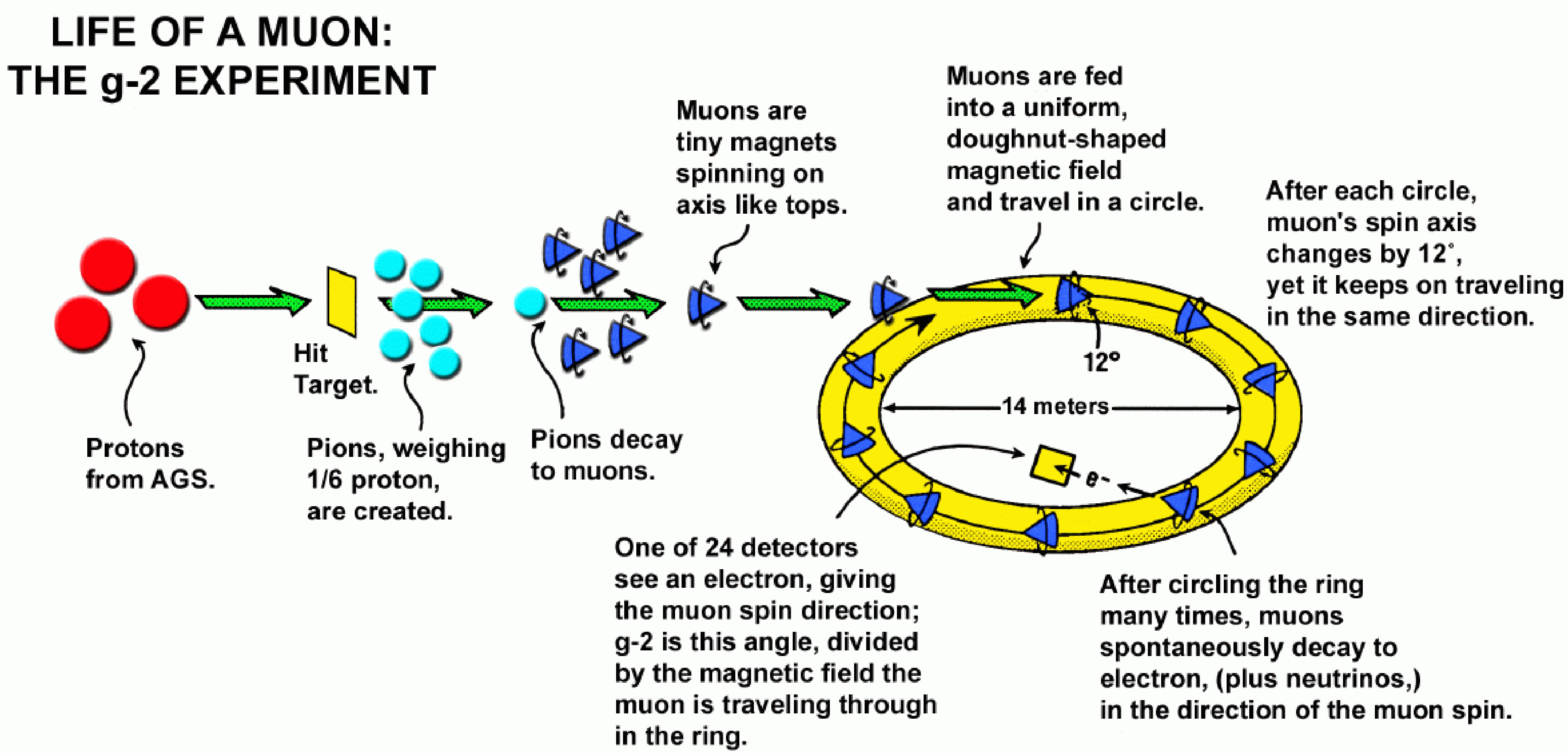
$$a_\mu \equiv (g-2)_\mu/2$$

Overview about the current experimental and SM (theory) result:
[g-2 Collaboration, hep-ex/0602035] → T



$$a_\mu^{\text{exp}} - a_\mu^{\text{theo,SM}} \approx (28 \pm 8) \times 10^{-10} \quad : 3.4\,\sigma$$

The $(g-2)_\mu$ experiment:



Coupling of muon to magnetic field : $\mu - \mu - \gamma$ coupling

$$\bar{u}(p') \left[\gamma^\mu F_1(q^2) + \frac{i}{2m_\mu} \sigma^{\mu\nu} q_\nu F_2(q^2) \right] u(p) A_\mu \qquad F_2(0) = a_\mu$$

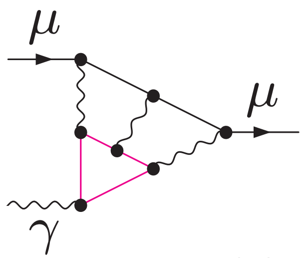
Current status of $(g-2)_\mu$:

Experiment:

– 2001 - 2006: very stable development
– final error: 6×10^{-10} , still statistically dominated

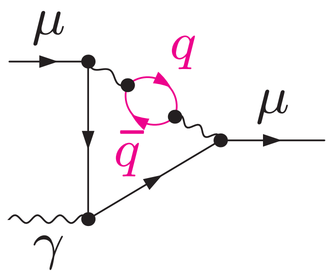
Theory:

– the light-by-light contribution:



2002: sign error discovered; since then stabilized

– the hadronic vacuum contribution:



problems with the τ data $\Rightarrow$ hardly used anymore (status 06/2009)
new 'direct' e^+e^- data from CMD-II and SND
$\Rightarrow$ agrees well (also with old e^+e^- data)
new radiative return data from KLOE and B-factories
$\Rightarrow$ agrees well with e^+e^- data

new SM evaluations, based on new exp e^+e^- data for a_μ^{had} :

$$a_\mu(\text{Exp-SM}) = \left\{ \begin{array}{ll} \text{[HMNT '06]} & 28(8) \\ \text{[DEHZ '06]} & 28(8) \\ \text{[FJ '07]} & 29(9) \\ \text{[MRR '07]} & 29(9) \\ \text{[DH '09]} & 24.6(8.1)^* \end{array} \right\} \times 10^{-10}$$

better agreement between evaluations, more precise,
larger deviation from exp than ever before

$\Downarrow$

3σ deviation has now been definitely established

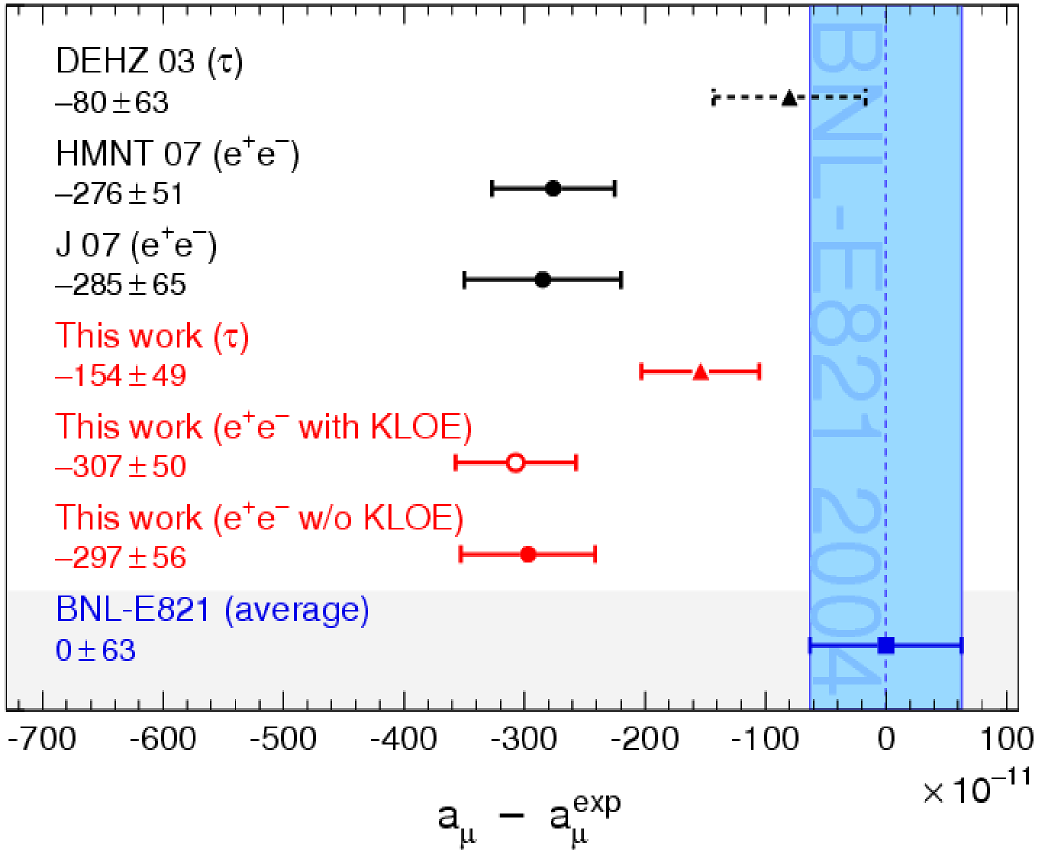
(based on e^+e^- data)

*: including the latest Babar data

New development for τ data:

[*M. Davier, A. Höcker et al. '09*]

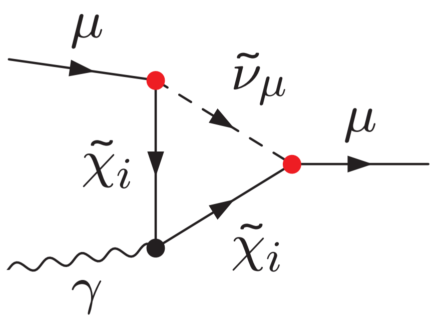
Re-evaluation of τ data: improved evaluation of iso-spin breaking effects
$\Rightarrow$ shift in τ data :

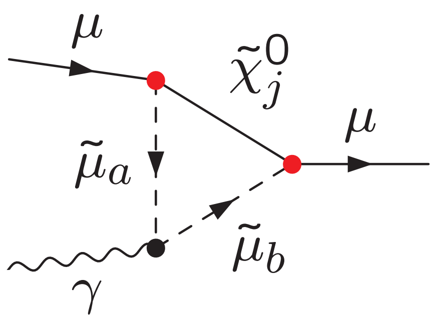


Now: 1.9 σ deviation! $\Rightarrow$ still tbc!
If correct: $\Rightarrow$ new average of all data possible . . .

$(g-2)_\mu$: SUSY can easily explain the deviation:

Feynman diagrams for MSSM 1L corrections:





– Diagrams with chargino/sneutrino exchange

– Diagrams with neutralino/smuon exchange

Enhancement factor as compared to SM:

$$\mu - \tilde{\chi}_i^\pm - \tilde{\nu}_\mu \quad : \quad \sim m_\mu \tan\beta$$

$$\mu - \tilde{\chi}_j^0 - \tilde{\mu}_a \quad : \quad \sim m_\mu \tan\beta$$

SM, EW 1L: $\frac{\alpha}{\pi} \frac{m_\mu^2}{M_W^2}$

MSSM, 1L: $\frac{\alpha}{\pi} \frac{m_\mu^2}{M_{\text{SUSY}}^2} \times \tan\beta$

SUSY corrections at 1L:

$$a_\mu^{\text{SUSY,1L}} \approx 13 \times 10^{-10} \left(\frac{100\ \text{GeV}}{M_{\text{SUSY}}}\right)^2 \tan\beta\, \text{sign}(\mu)$$

$M_{\text{SUSY}} (= m_{\tilde{\mu}} = m_{\tilde{\nu}} = m_{\tilde{\chi}})$: generic SUSY mass scale

$$a_\mu^{\text{SUSY,1L}} = (-100 \ldots +100) \times 10^{-10}$$

$$a_\mu^{\text{exp}} - a_\mu^{\text{theo,SM}} \approx (28 \pm 8) \times 10^{-10}$$

$\Rightarrow$ SUSY could easily explain the "discrepancy"

$\Rightarrow$ a_μ can provide bounds on SUSY parameter space
(by requiring agreement at the 95% C.L.)