

**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

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

1. Introduction and motivation

Supersymmetry (SUSY) : Symmetry between

Bosons \leftrightarrow Fermions

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

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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: $M_{\text{SUSY}} = \mathcal{O}(1 \text{ TeV})$

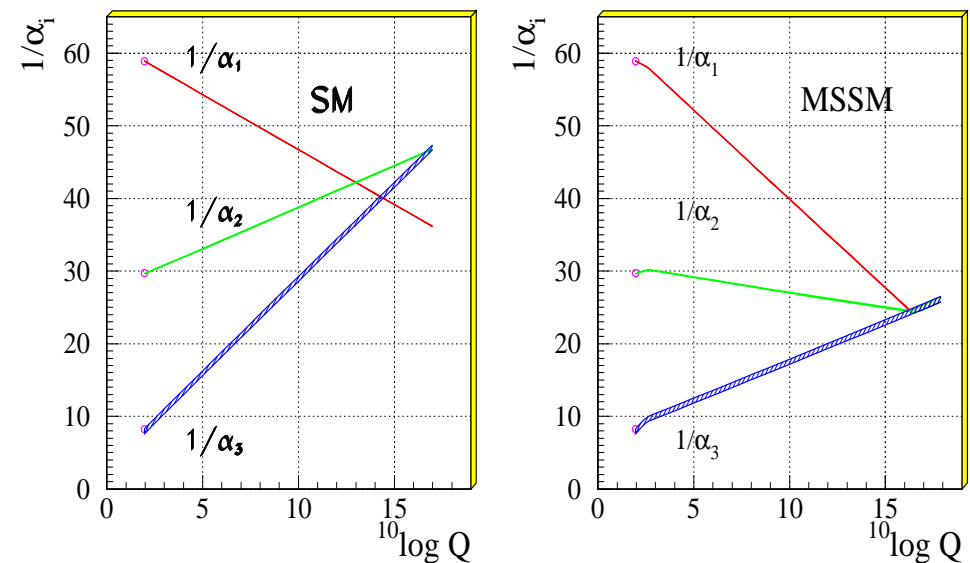
Supersymmetry: Motivation

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, Fürstenauf '92]

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$$\begin{array}{llll} [u, d, c, s, t, b]_{L,R} & [e, \mu, \tau]_{L,R} & [\nu_{e,\mu,\tau}]_L & \text{Spin } \frac{1}{2} \\ [\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}]_{L,R} & [\tilde{e}, \tilde{\mu}, \tilde{\tau}]_{L,R} & [\tilde{\nu}_{e,\mu,\tau}]_L & \text{Spin } 0 \\ g & \underbrace{W^\pm, H^\pm}_{\text{Spin } 1} & \underbrace{\gamma, Z, H_1^0, H_2^0}_{\text{Spin } 0} & \text{Spin } 1 / \text{Spin } 0 \\ \tilde{g} & \tilde{\chi}_{1,2}^\pm & \tilde{\chi}_{1,2,3,4}^0 & \text{Spin } \frac{1}{2} \end{array}$$

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

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

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

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

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$
$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$
$$+ \underbrace{\frac{g'^2 + g^2}{8}}_{\text{gauge couplings, in contrast to SM}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}}_{\text{gauge couplings, in contrast to SM}} |H_1 \bar{H}_2|^2$$

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

Goldstone bosons: G^0, G^\pm

Input parameters: (to be determined experimentally)

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

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A: Two possible ways:

- Search for new SUSY particles

new SUSY particles found



SM ruled out

Problem:

SUSY particles are too heavy for today's colliders, only lower limits of $\mathcal{O}(100 \text{ GeV})$.

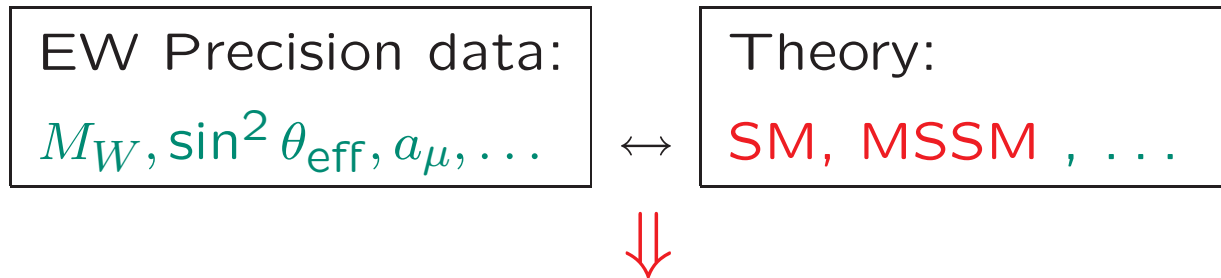
→ waiting for Tevatron (2009/10...?)

→ waiting for LHC (2010/11...?)

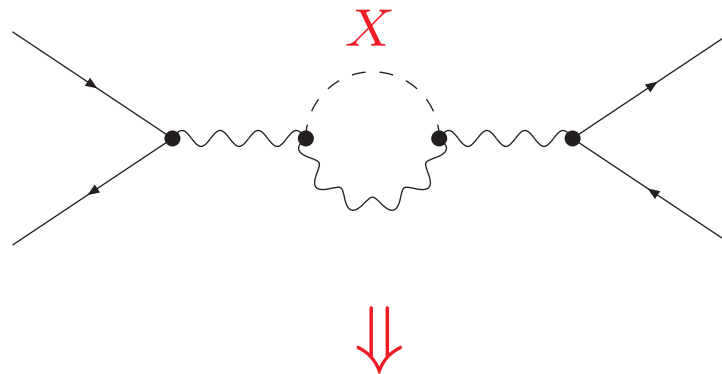
- Search for indirect effects of SUSY
via Precision Observables

Precision Observables (POs):

Comparison of electro-weak precision observables with theory:



Test of theory at quantum level: Sensitivity to loop corrections



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

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

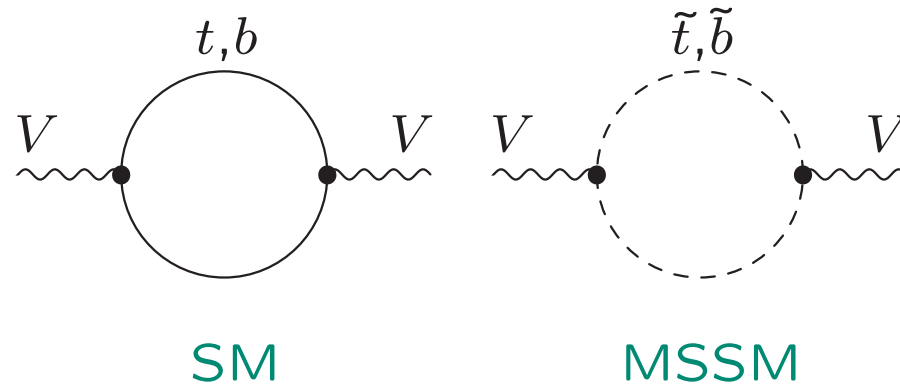
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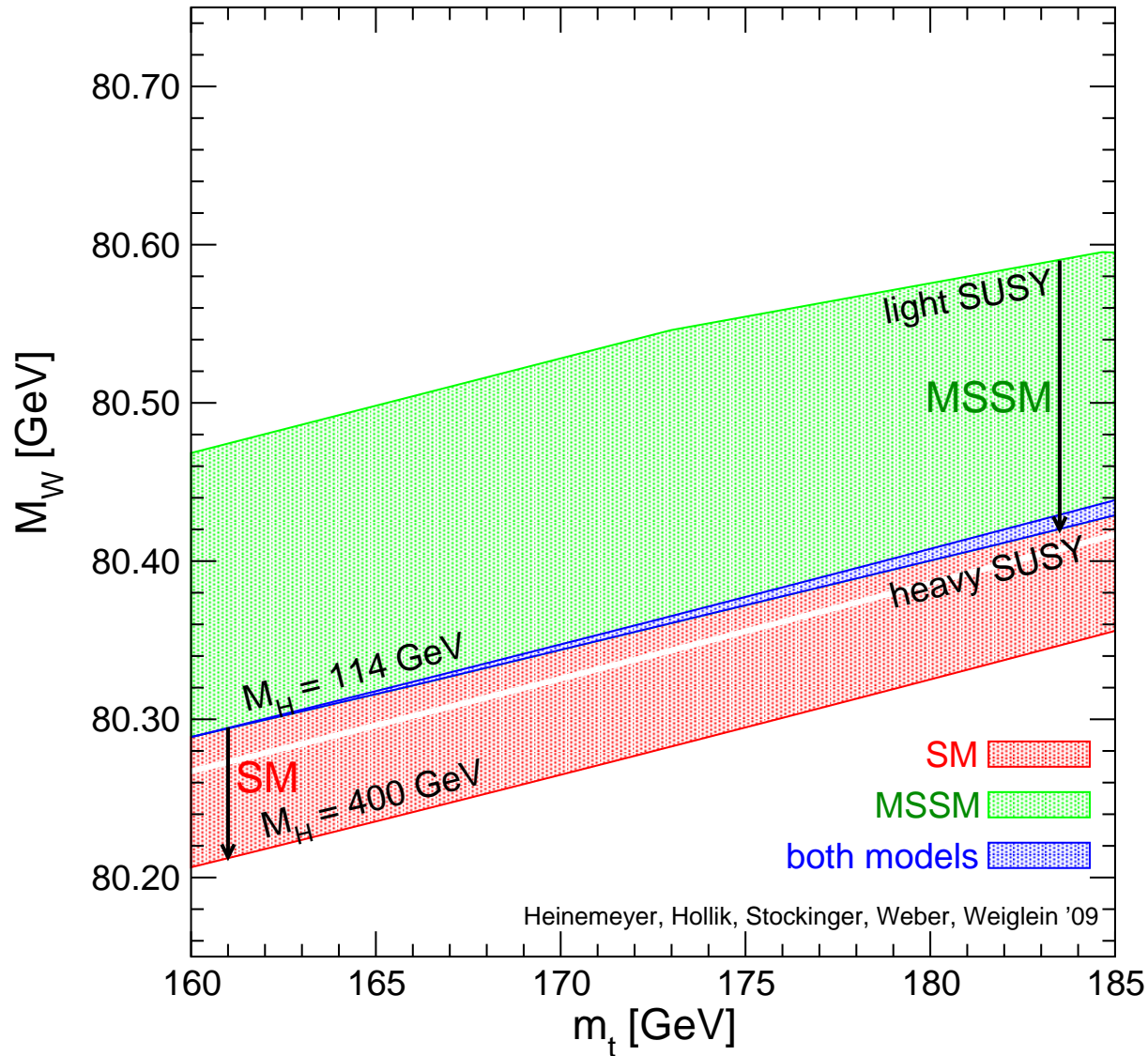
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$$\Delta\rho^{\text{SUSY}} \text{ from } \tilde{t}/\tilde{b} \text{ loops} > 0 \quad \Rightarrow \quad M_W^{\text{SUSY}} \gtrsim M_W^{\text{SM}}$$

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

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



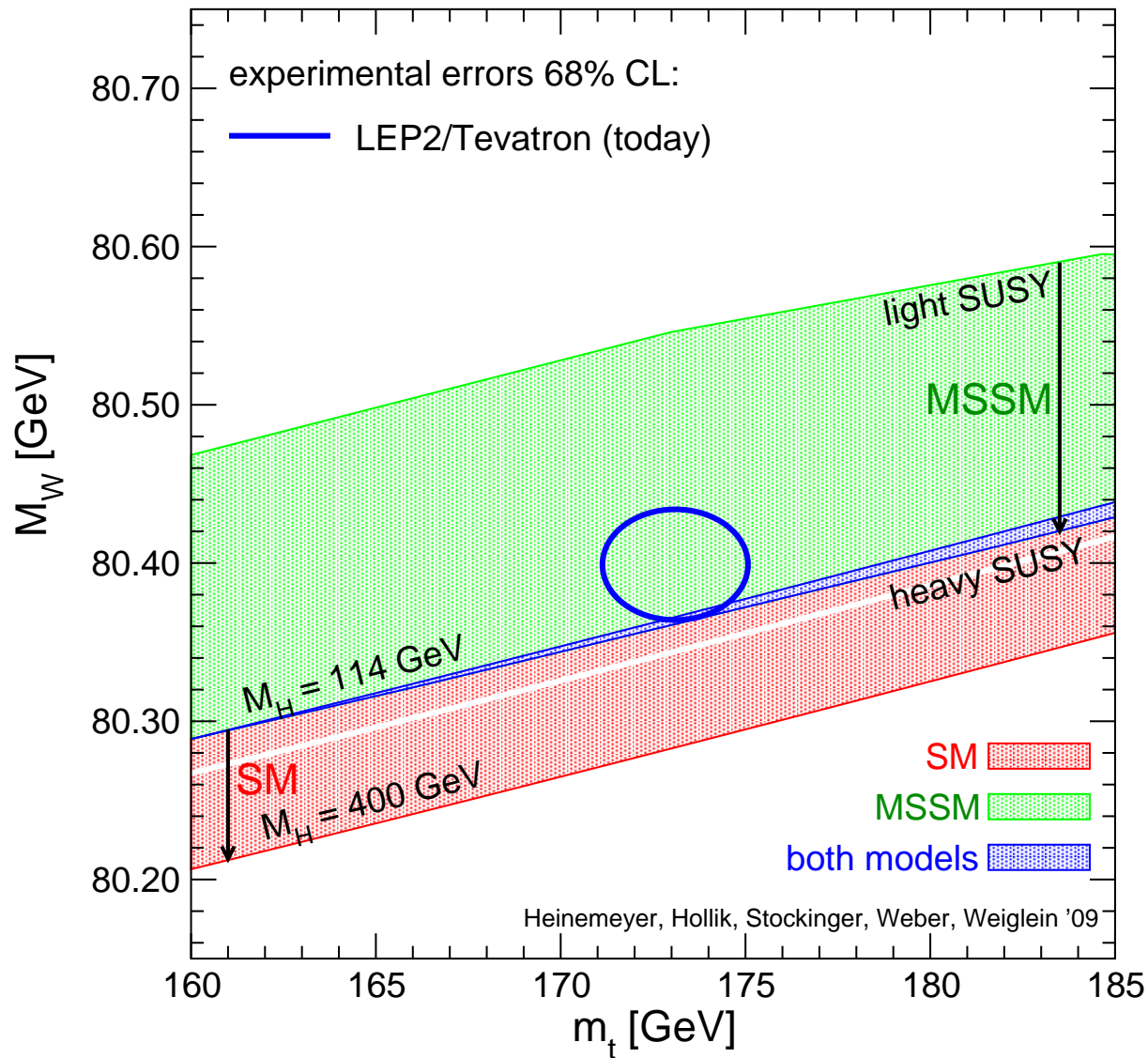
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scan over
SUSY masses

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

SM band:
variation of M_H^{SM}

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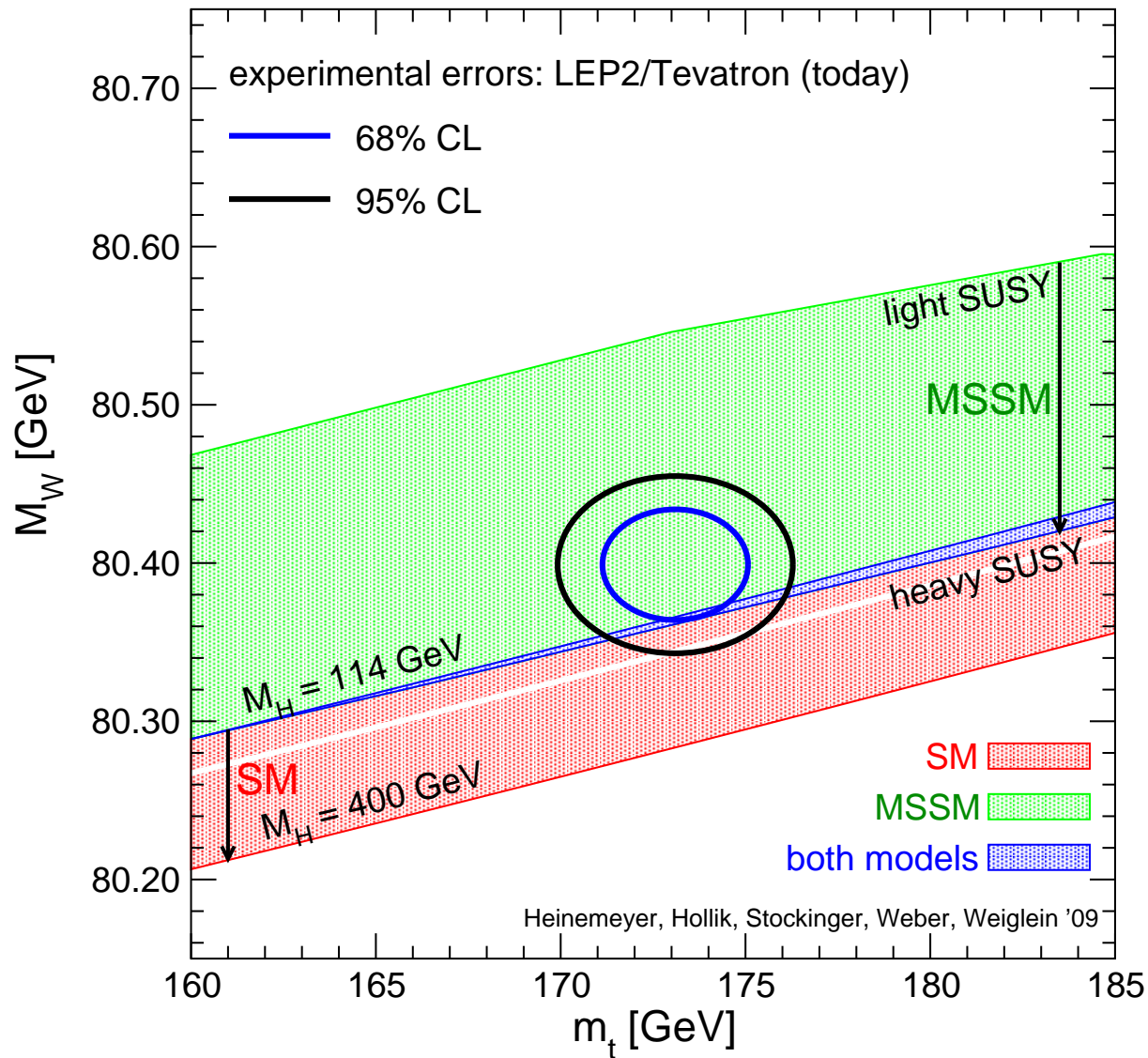
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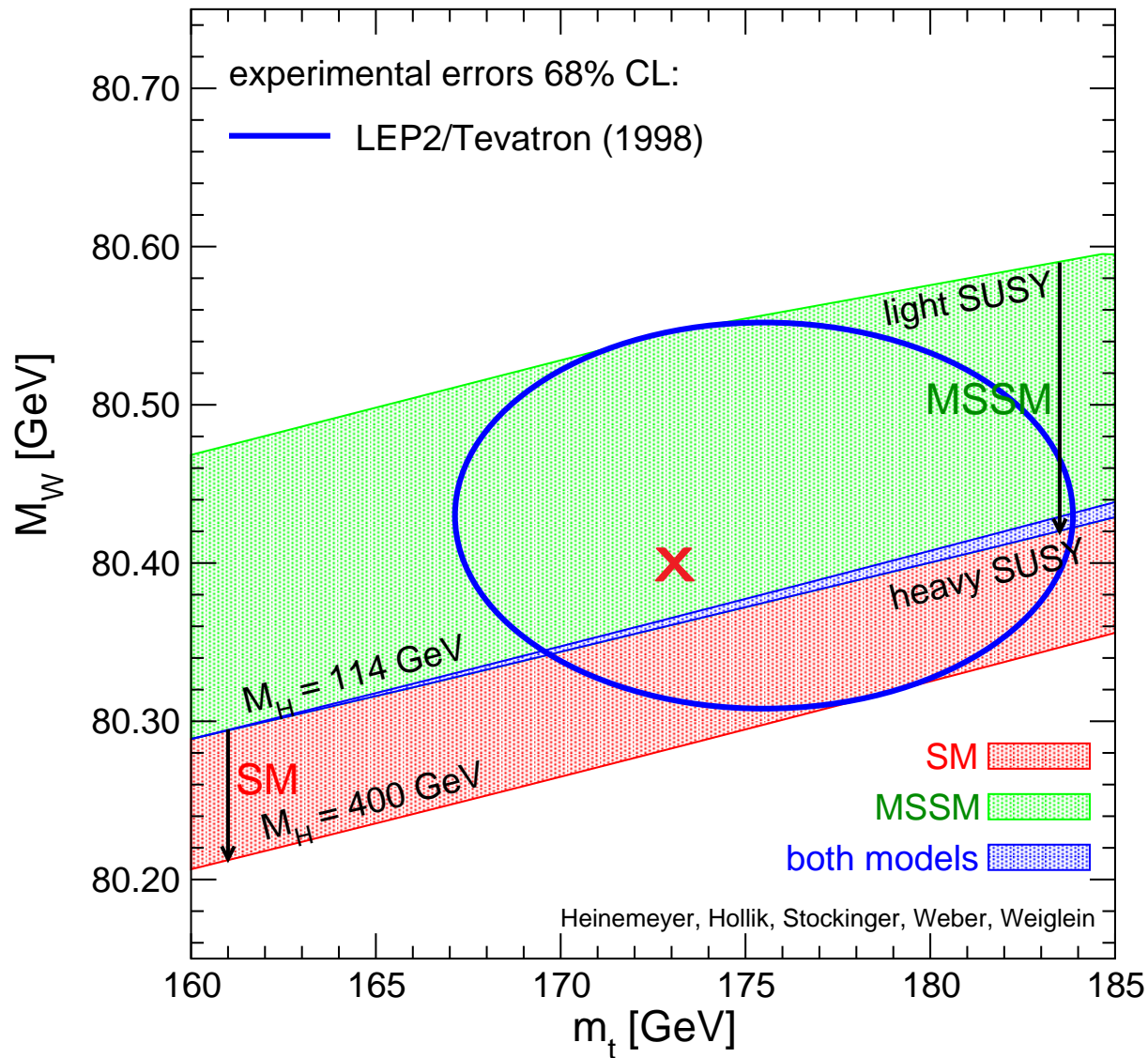
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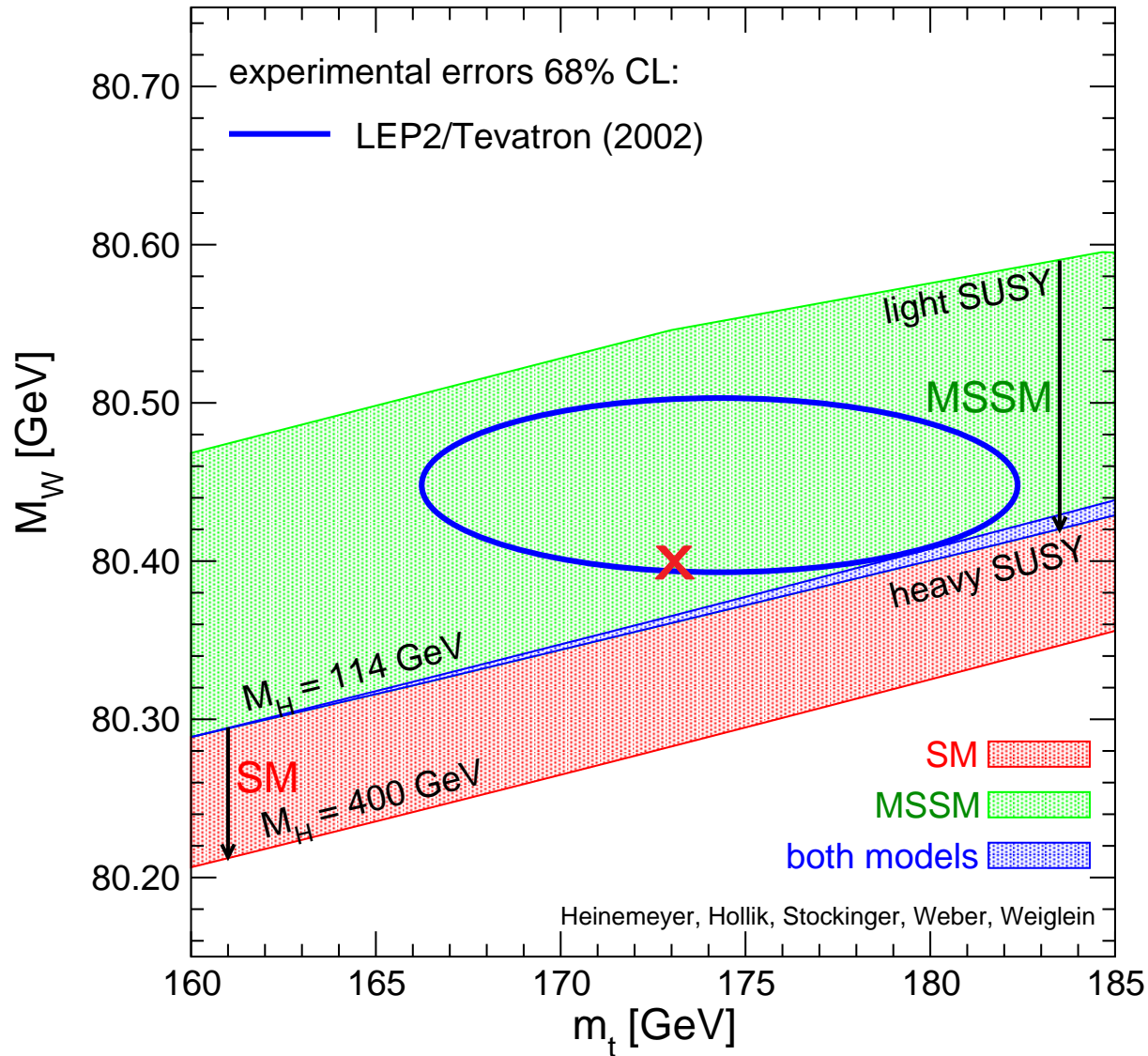
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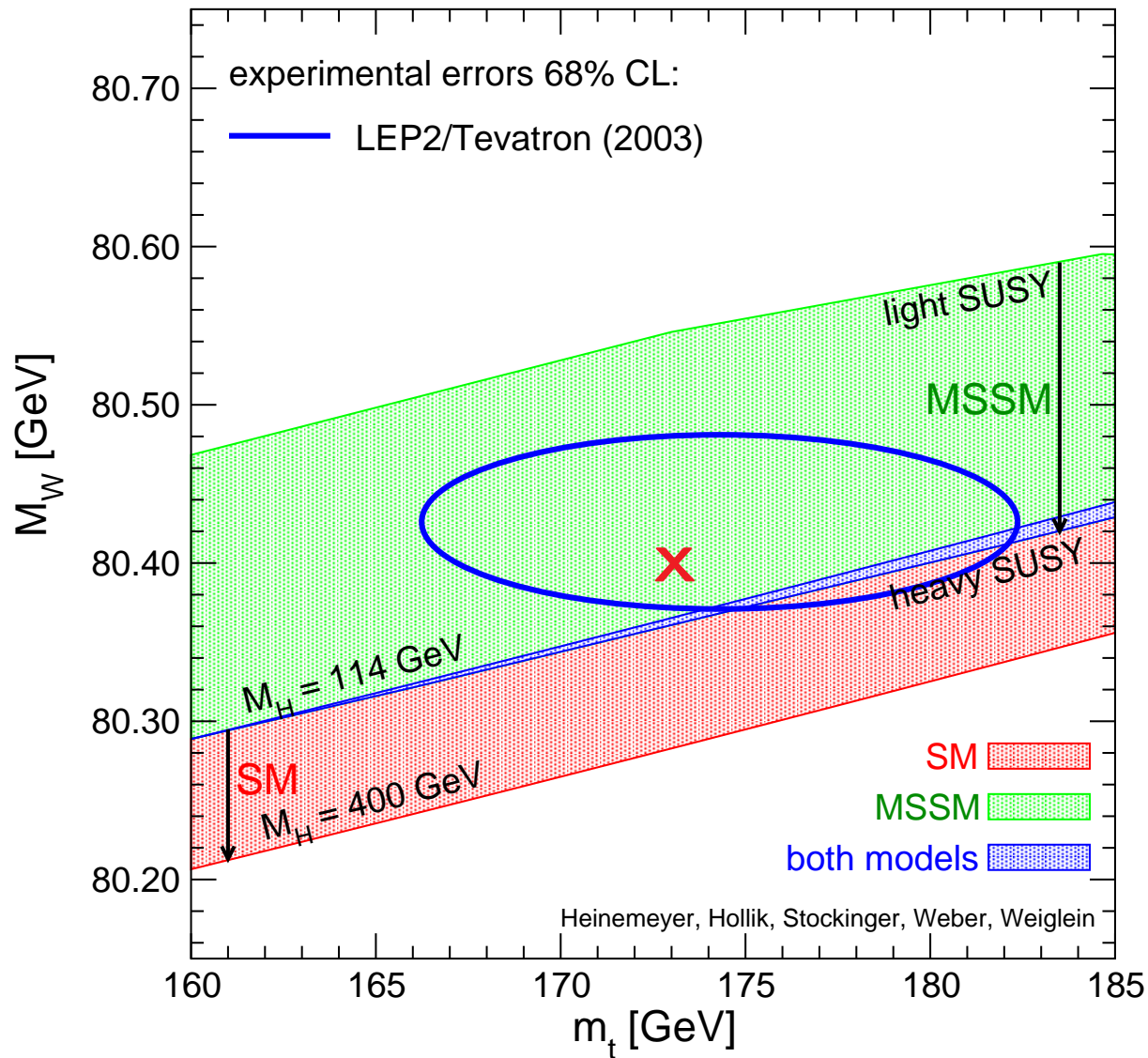
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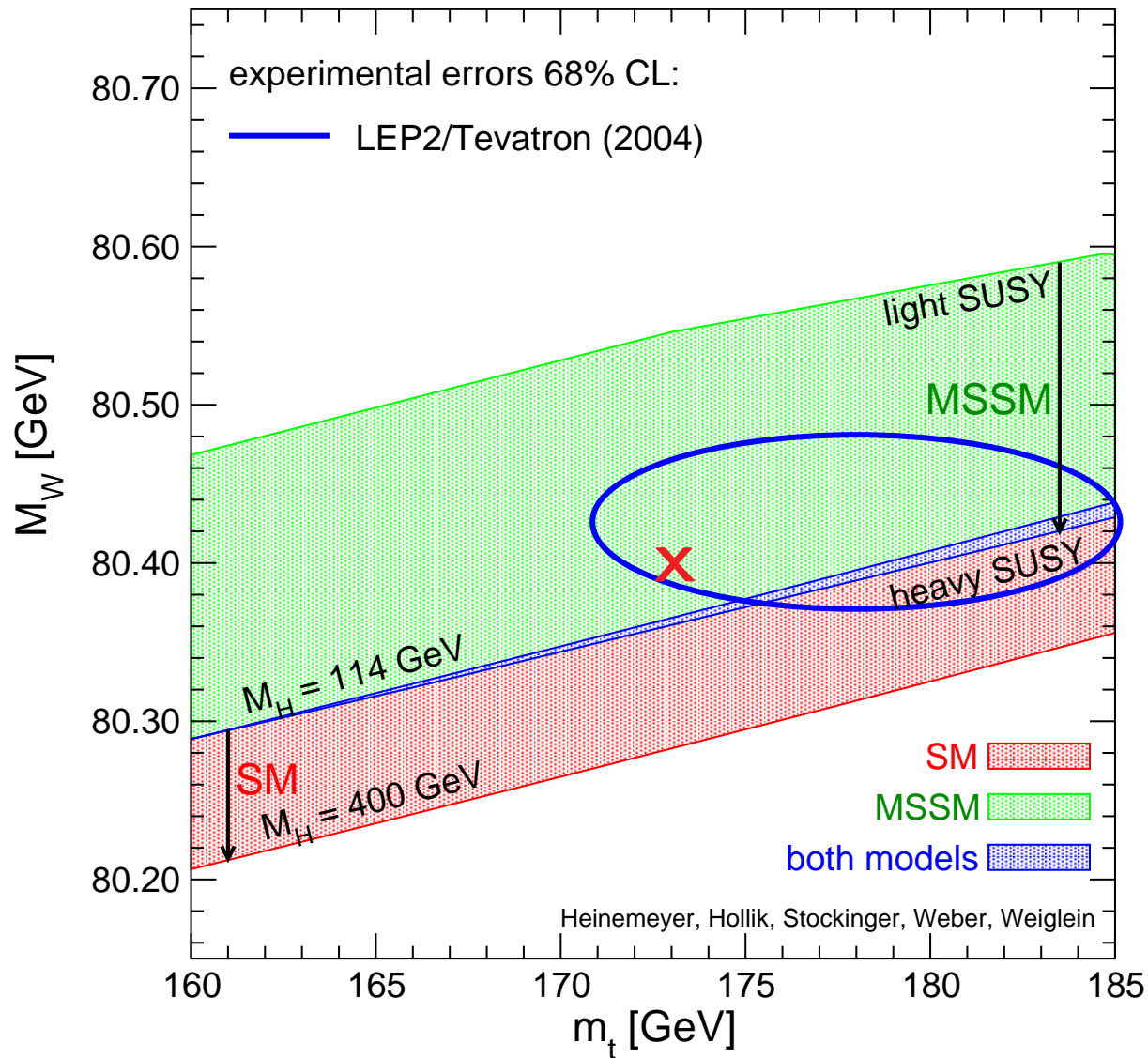
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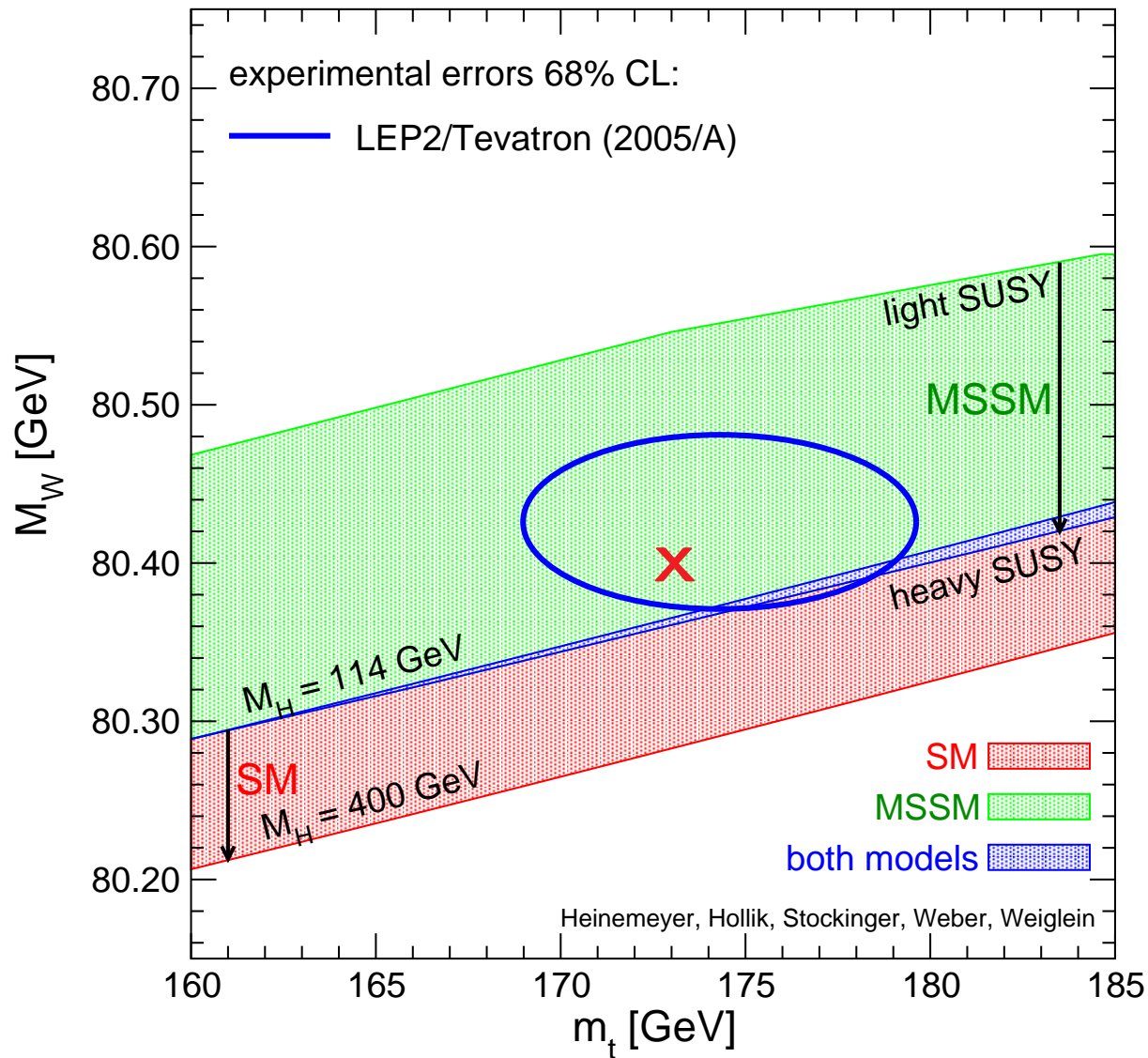
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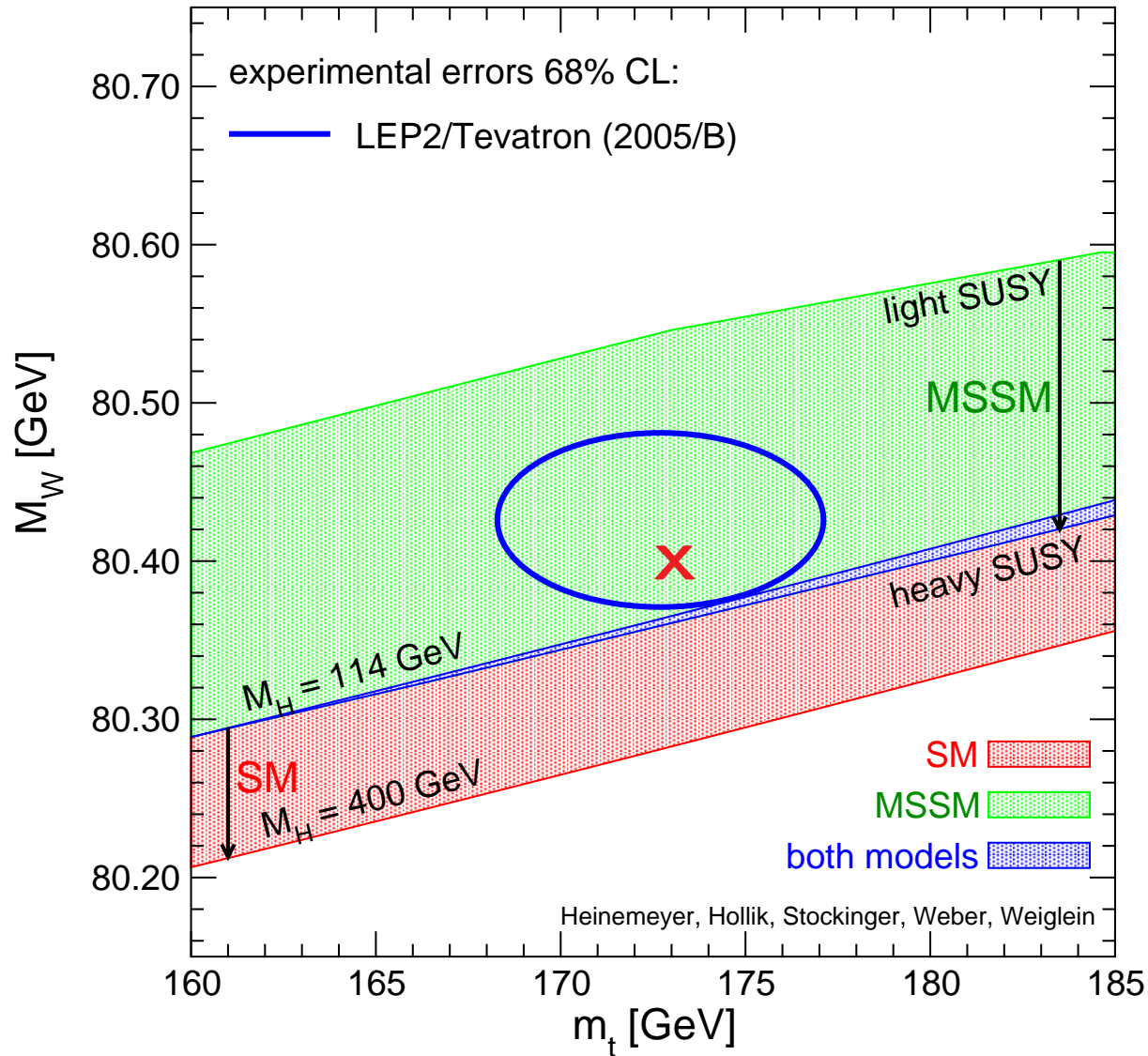
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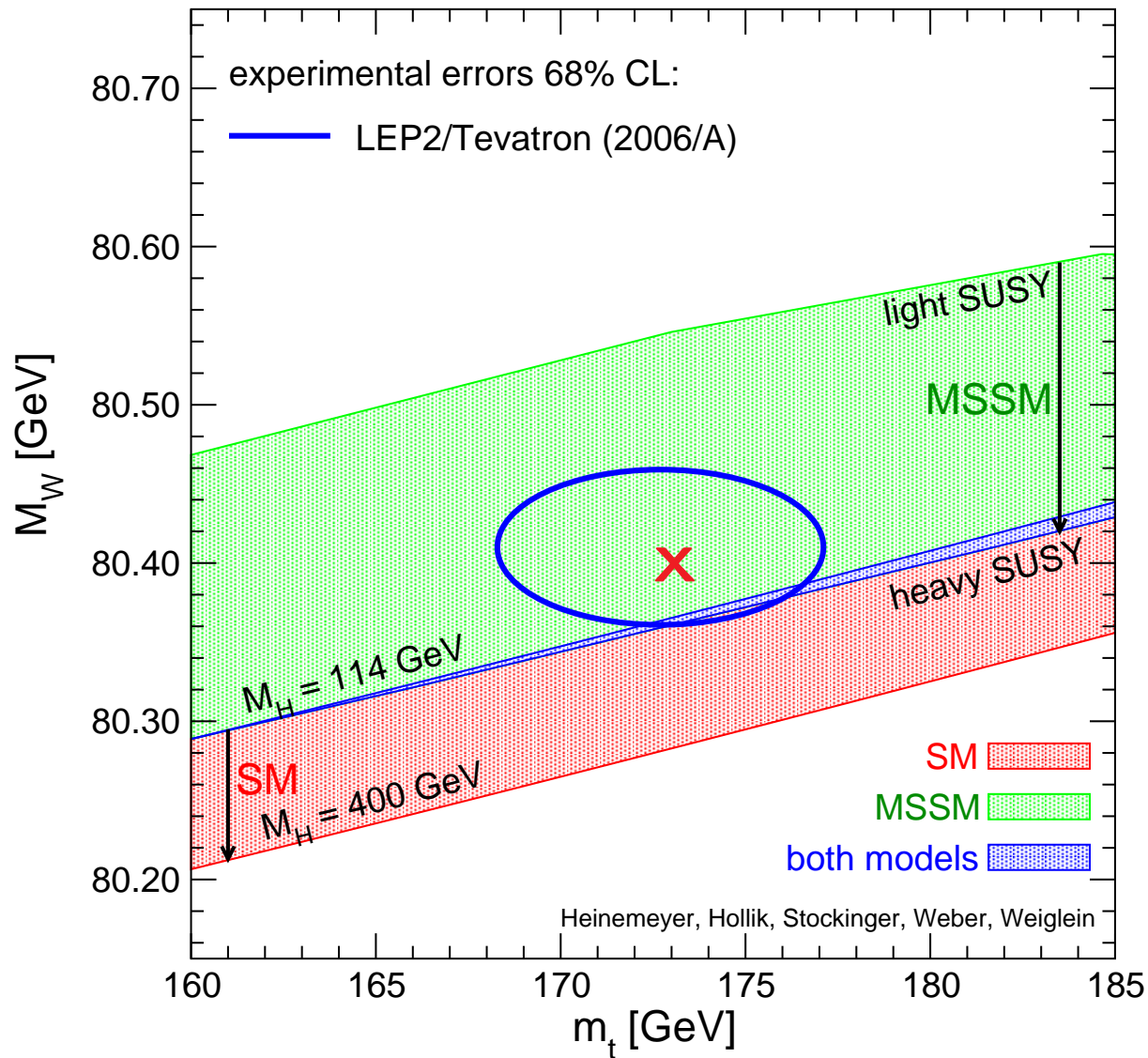
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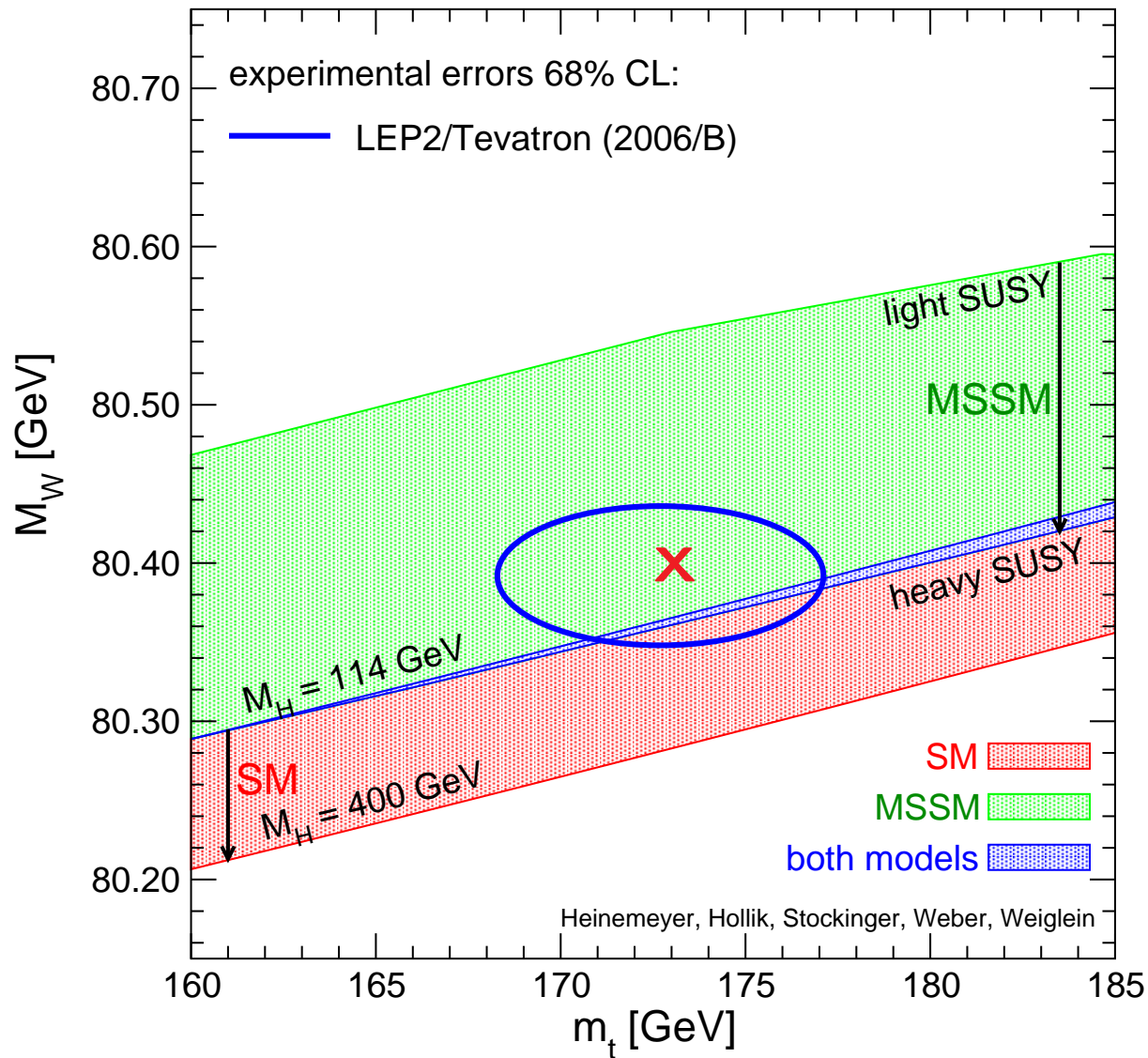
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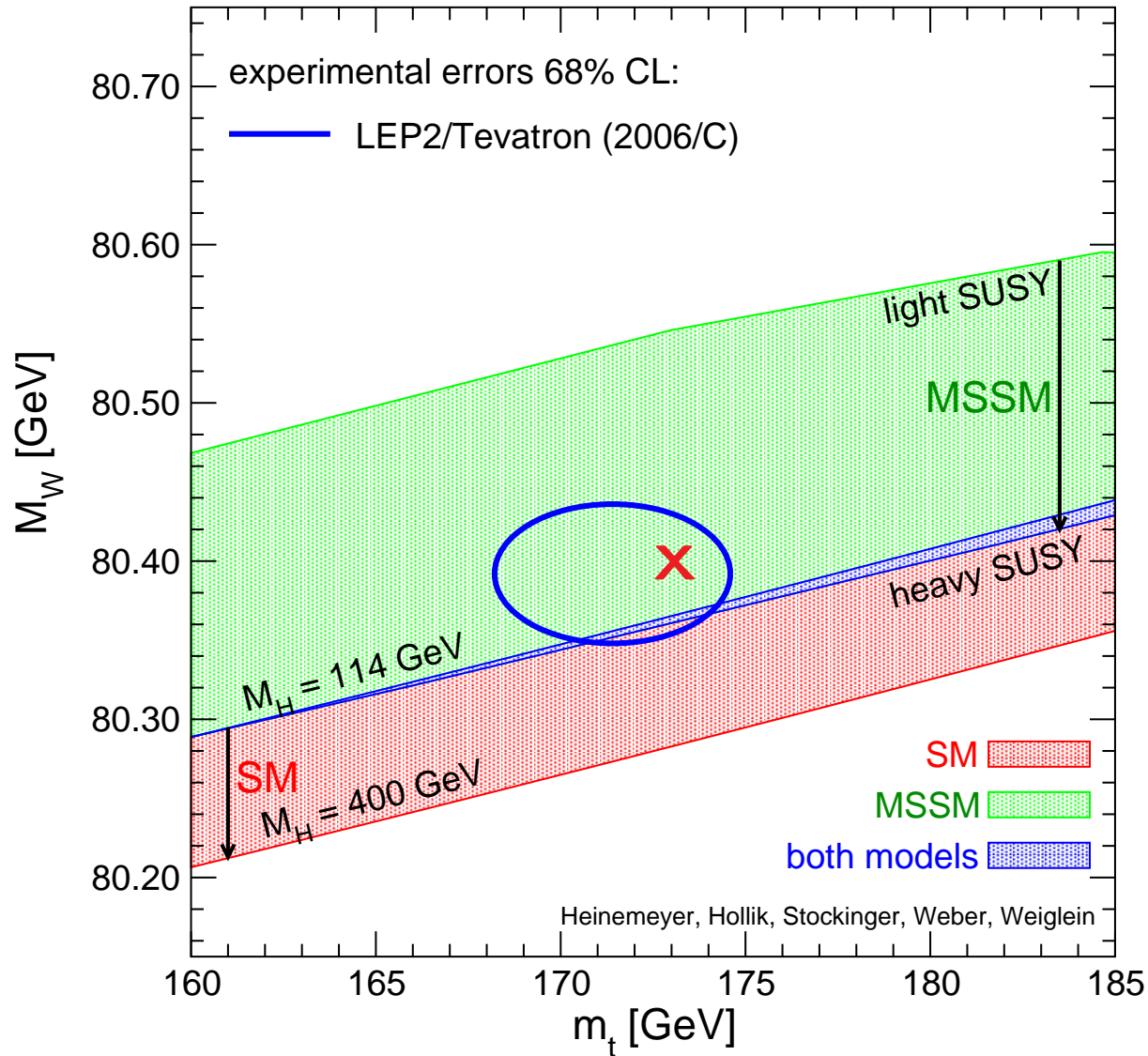
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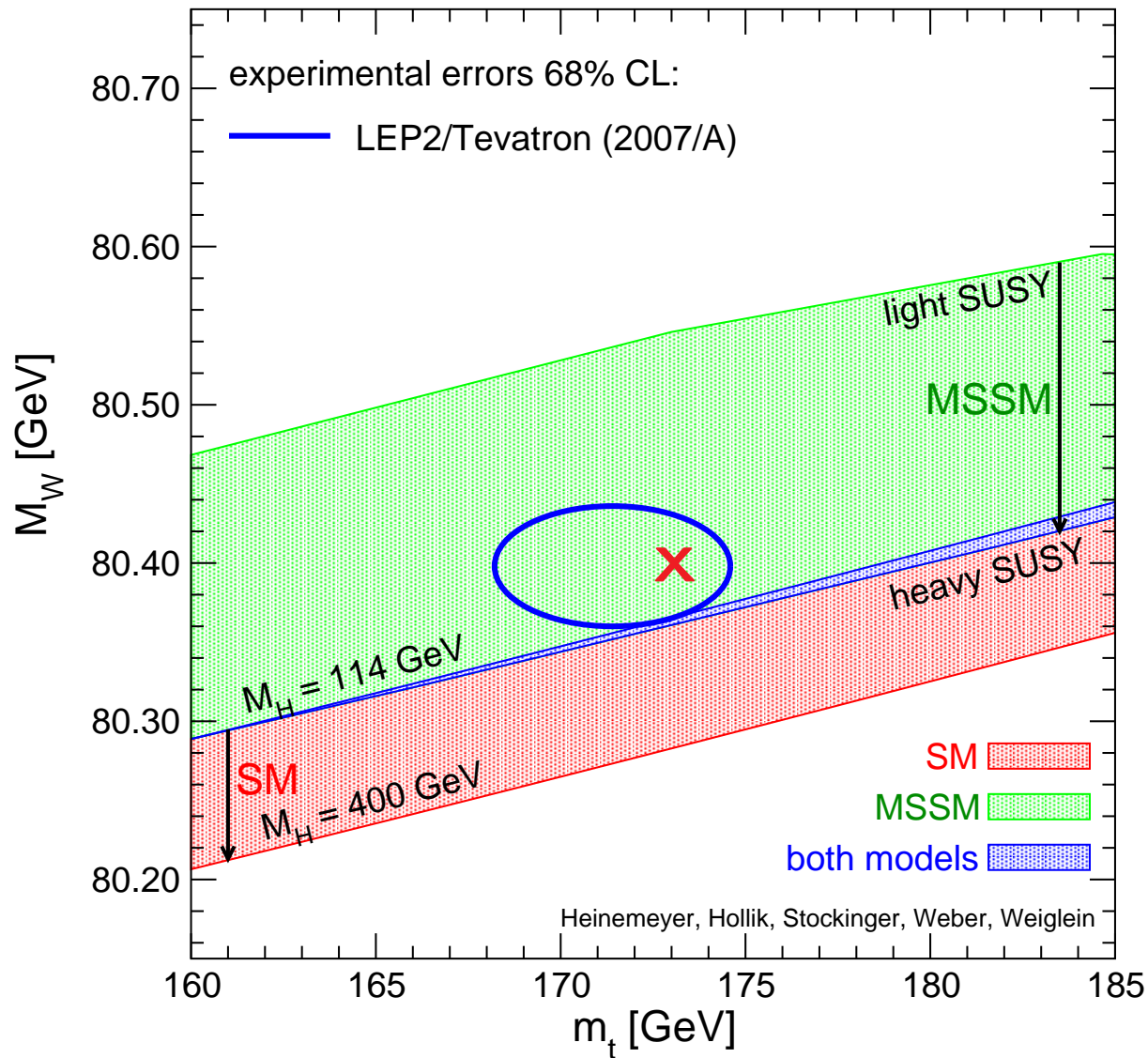
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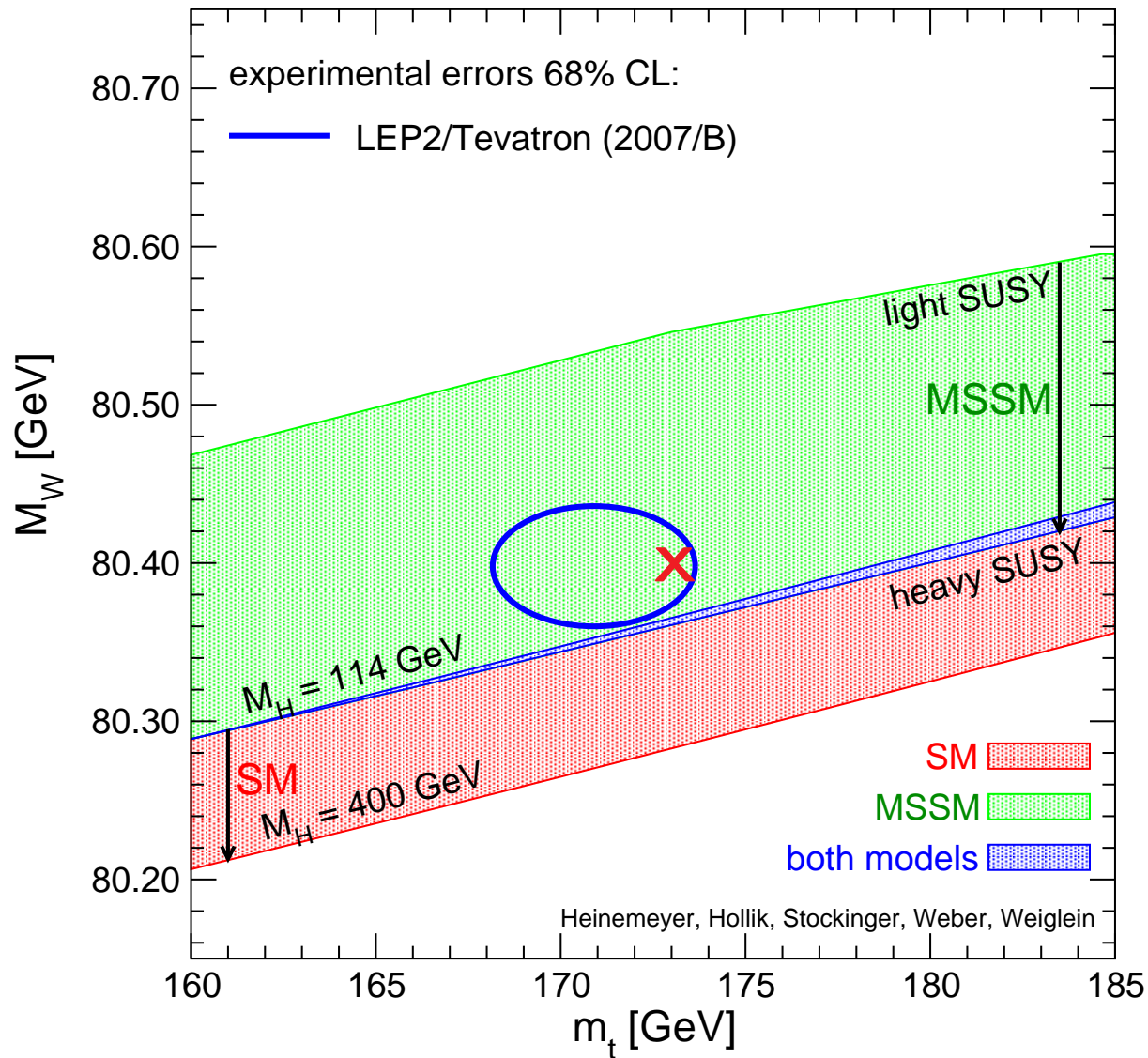
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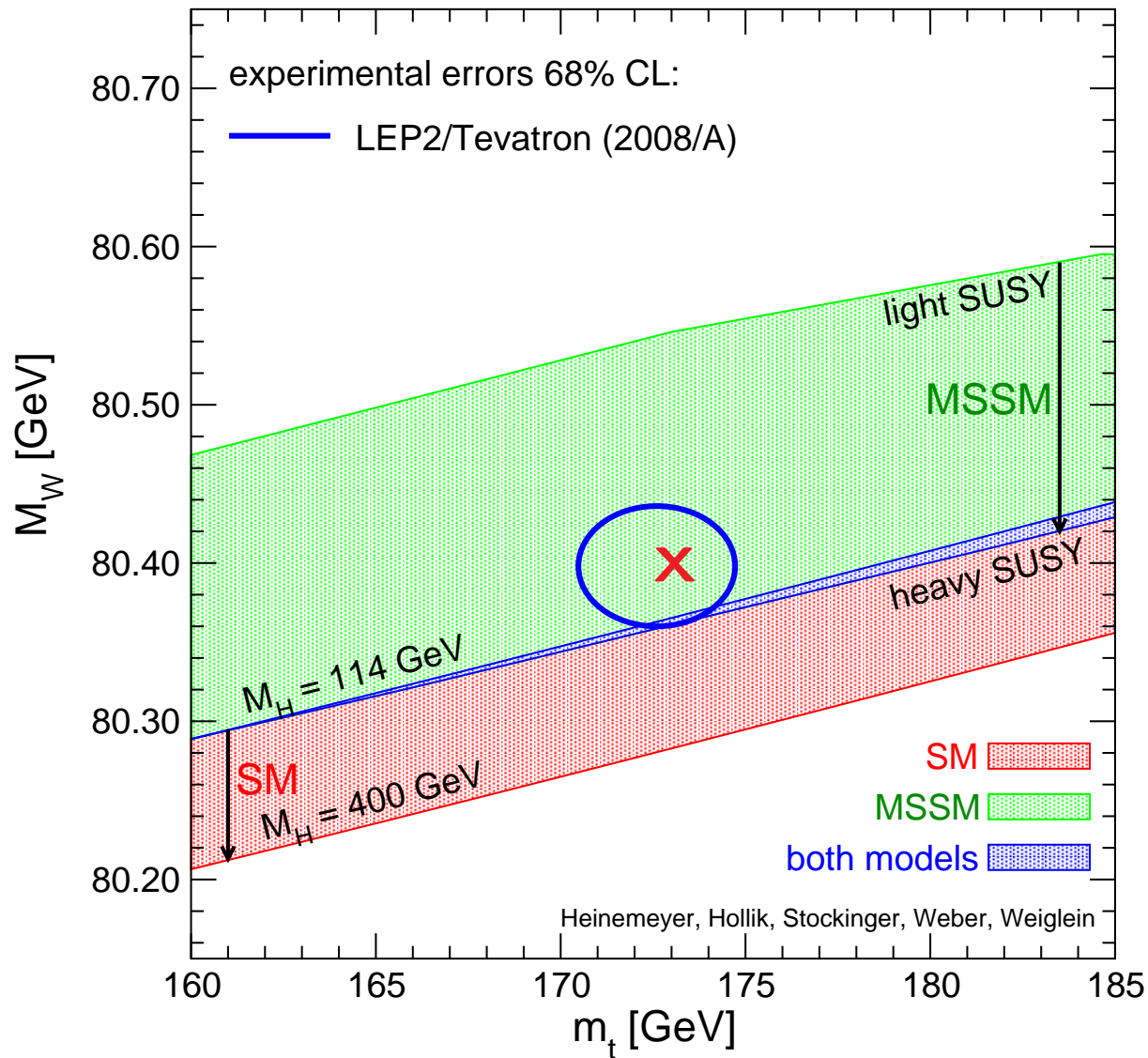
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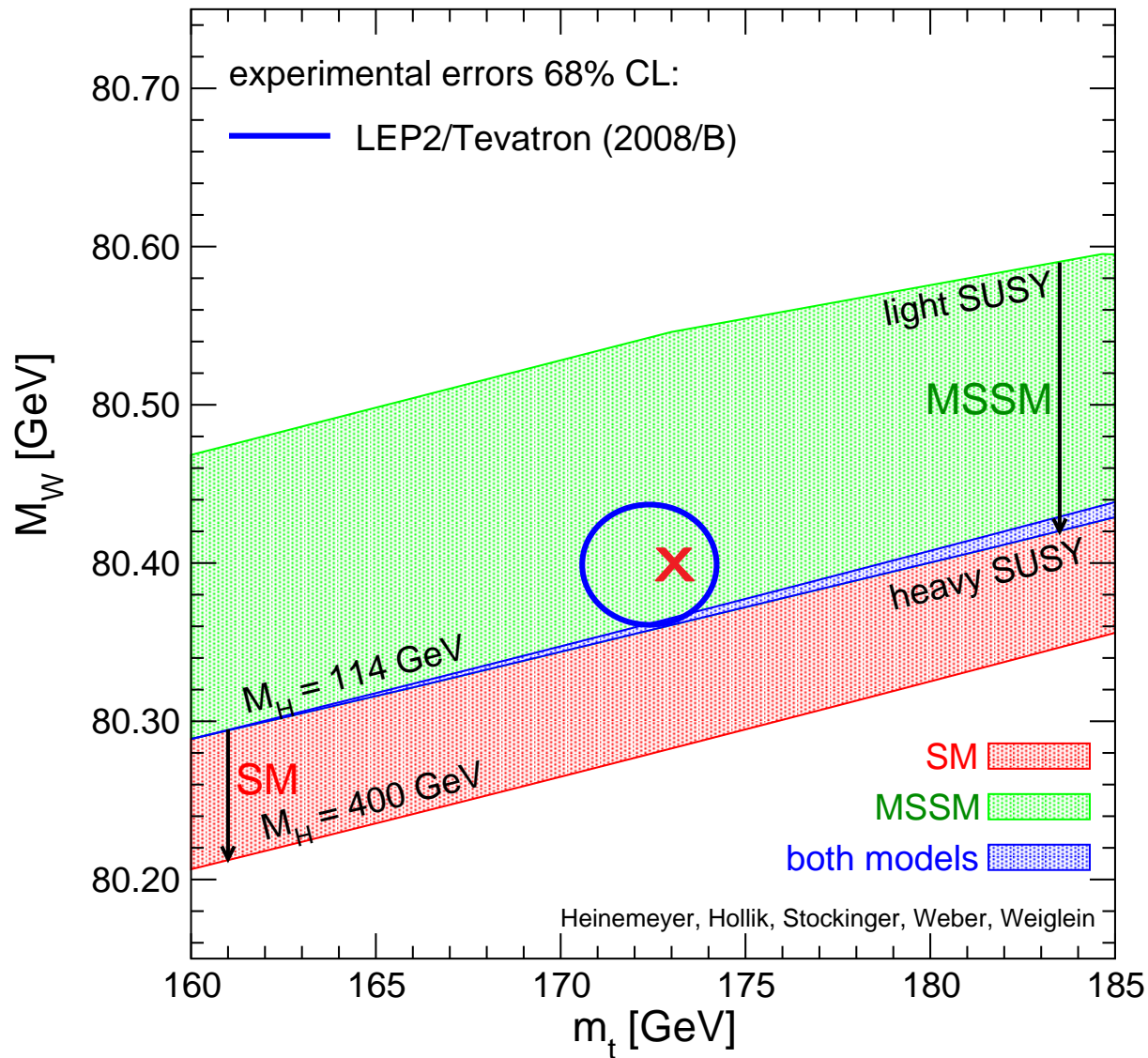
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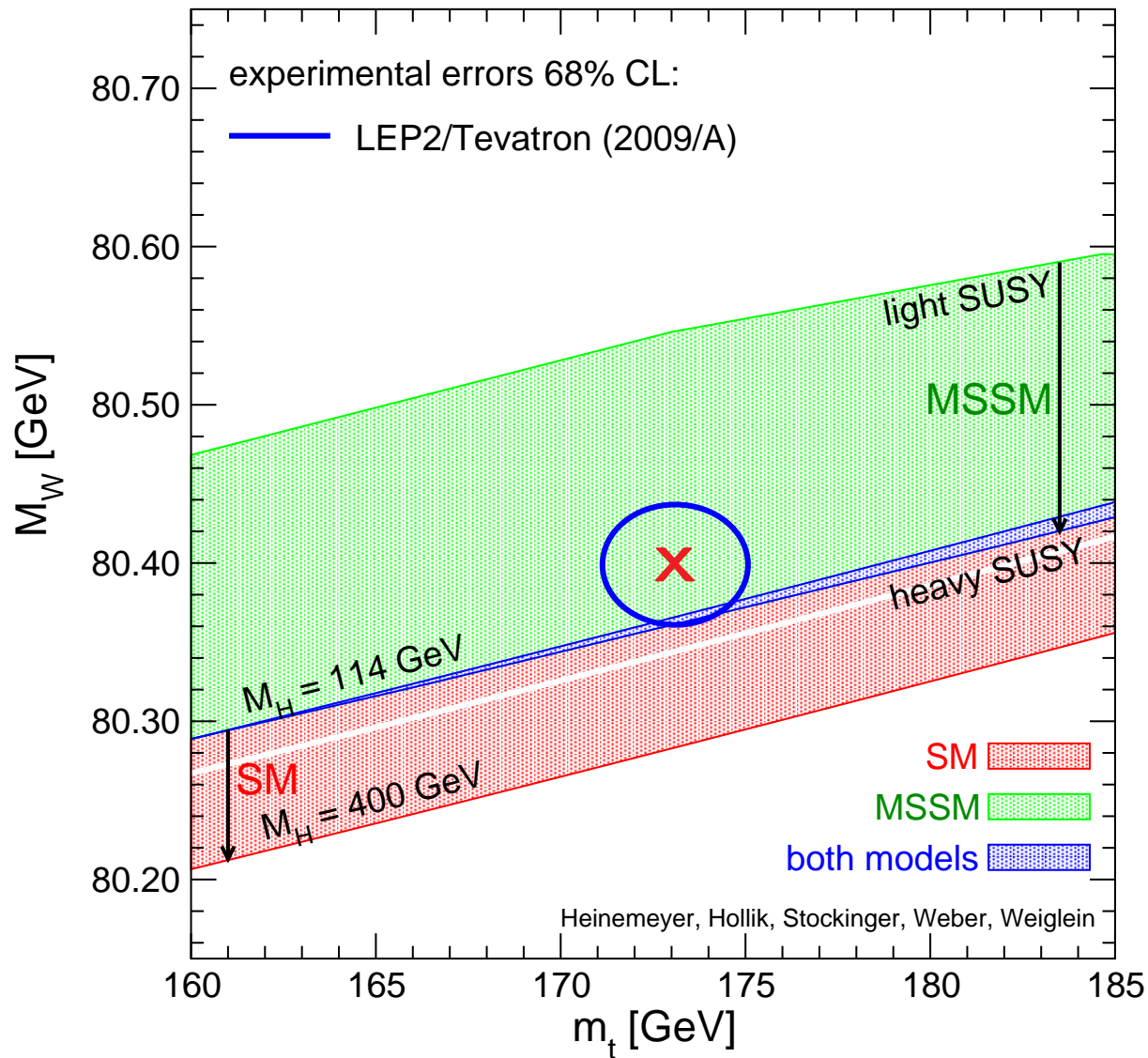
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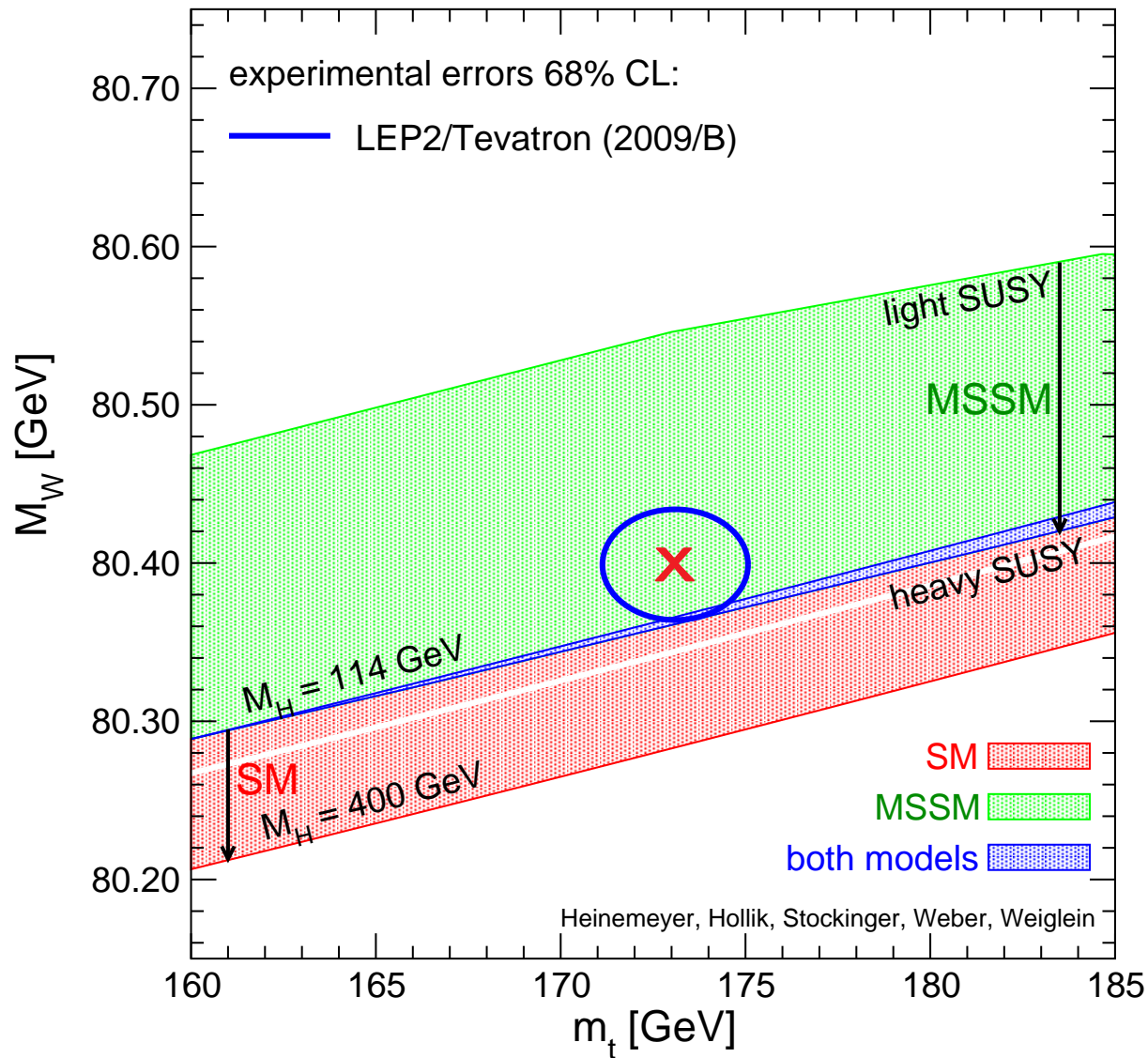
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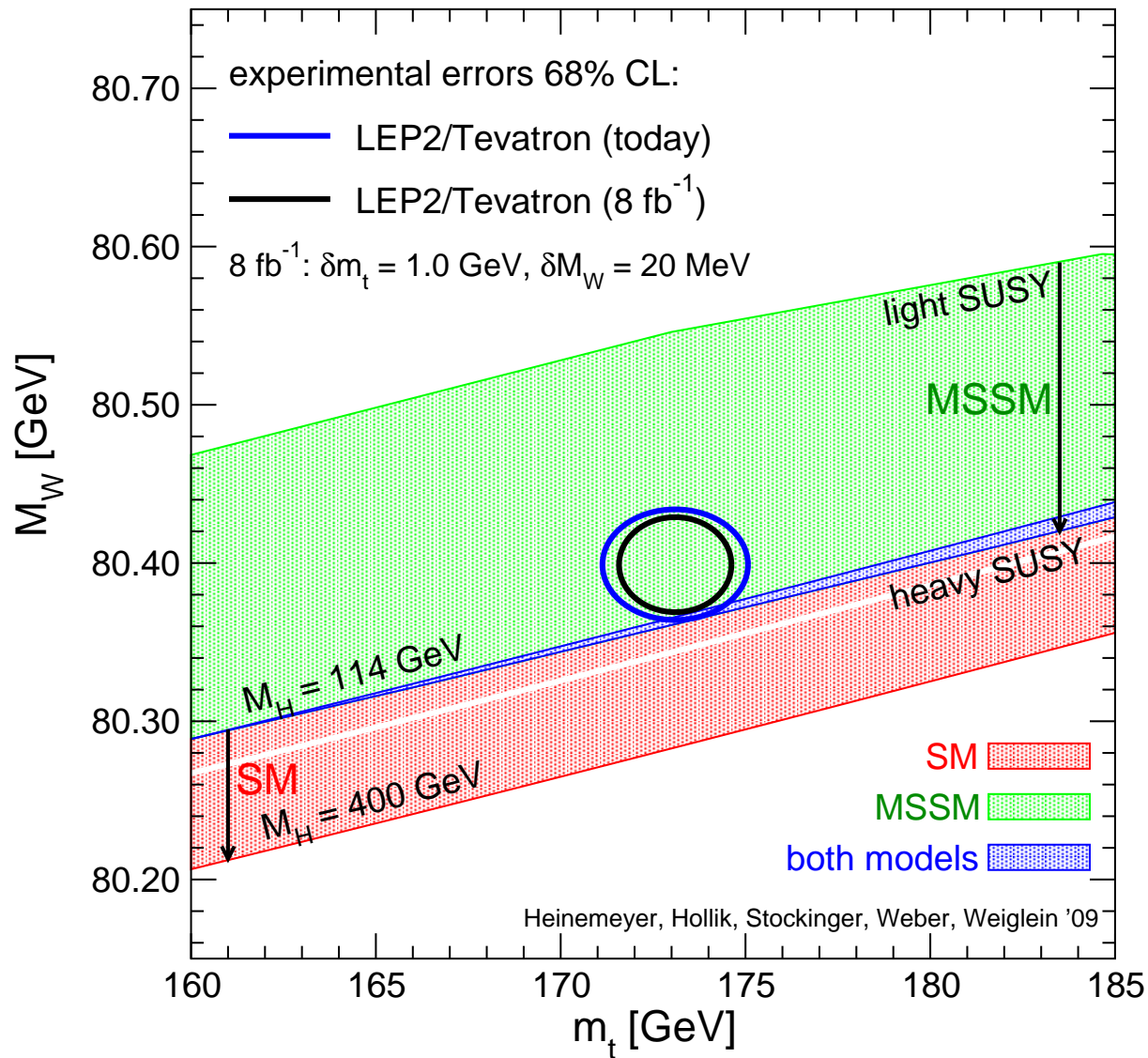
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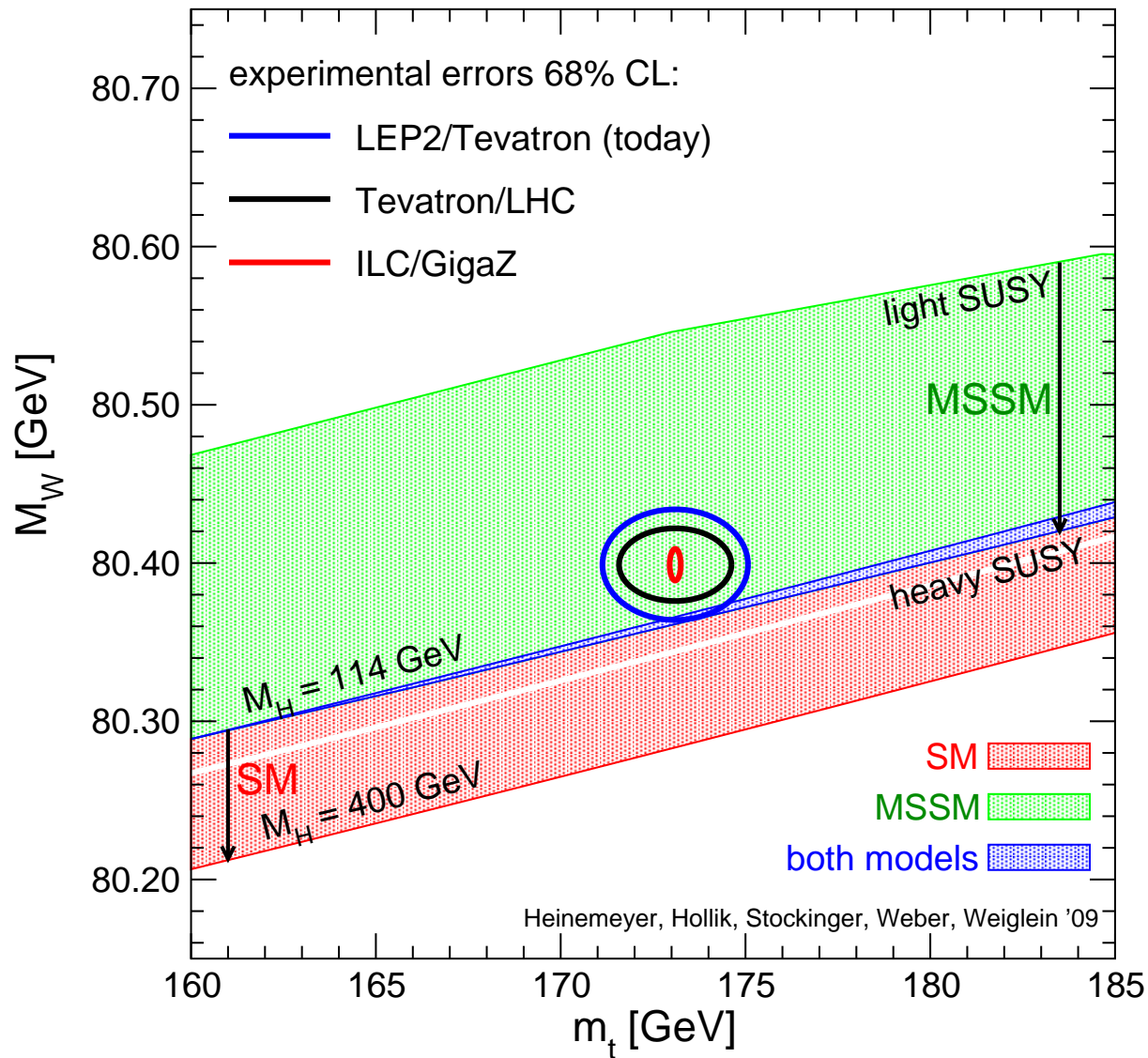
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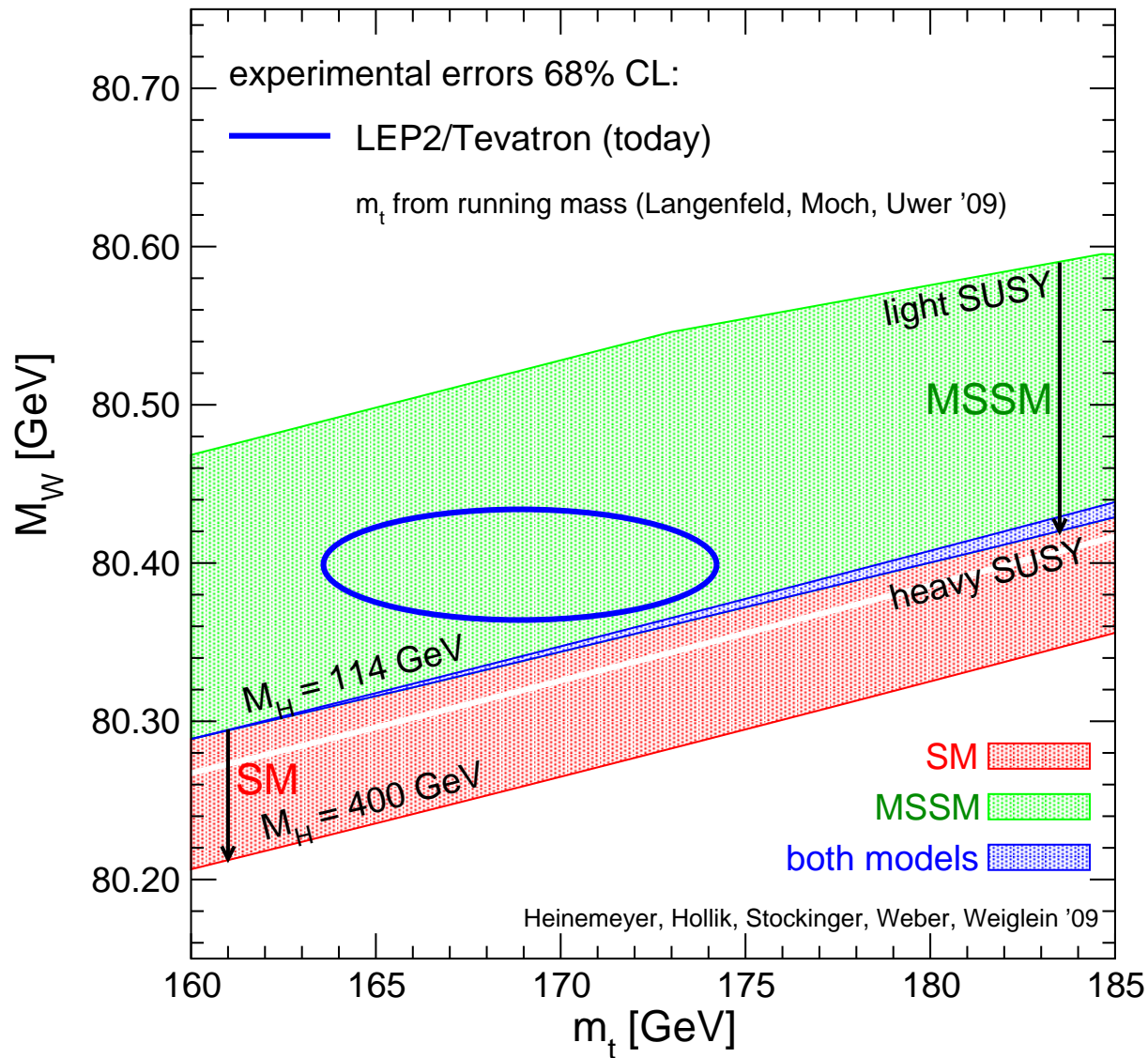
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Global fit to all SM data:

[LEPEWWG '09]

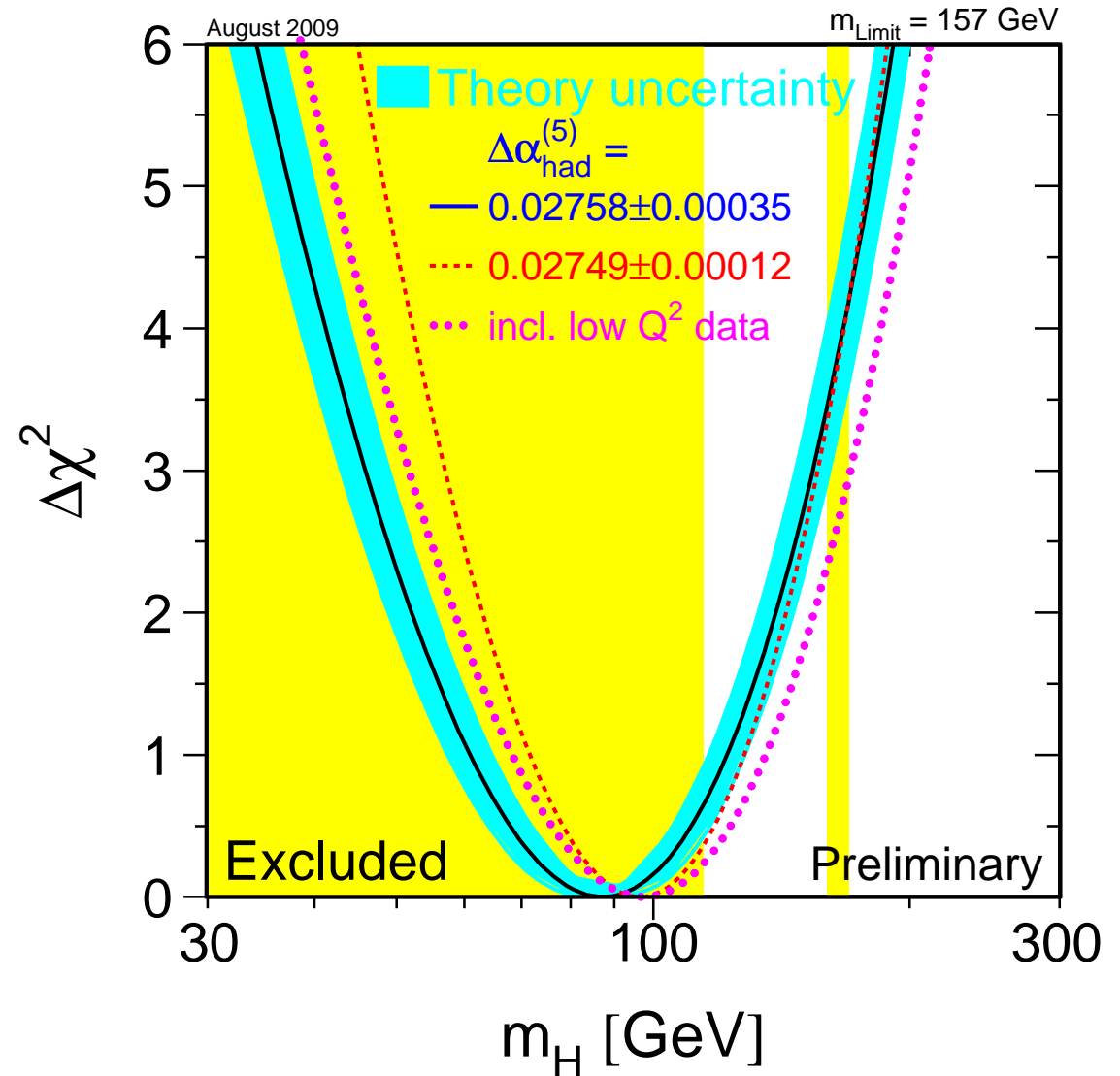
$$\Rightarrow M_H = 87^{+35}_{-26} \text{ GeV}$$

$$M_H < 157 \text{ GeV, 95\% C.L.}$$

Assumption for the fit:

SM incl. Higgs boson

\Rightarrow no confirmation of Higgs mechanism



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

Global fit to all SM data incl. direct searches:

[GFitter '09]

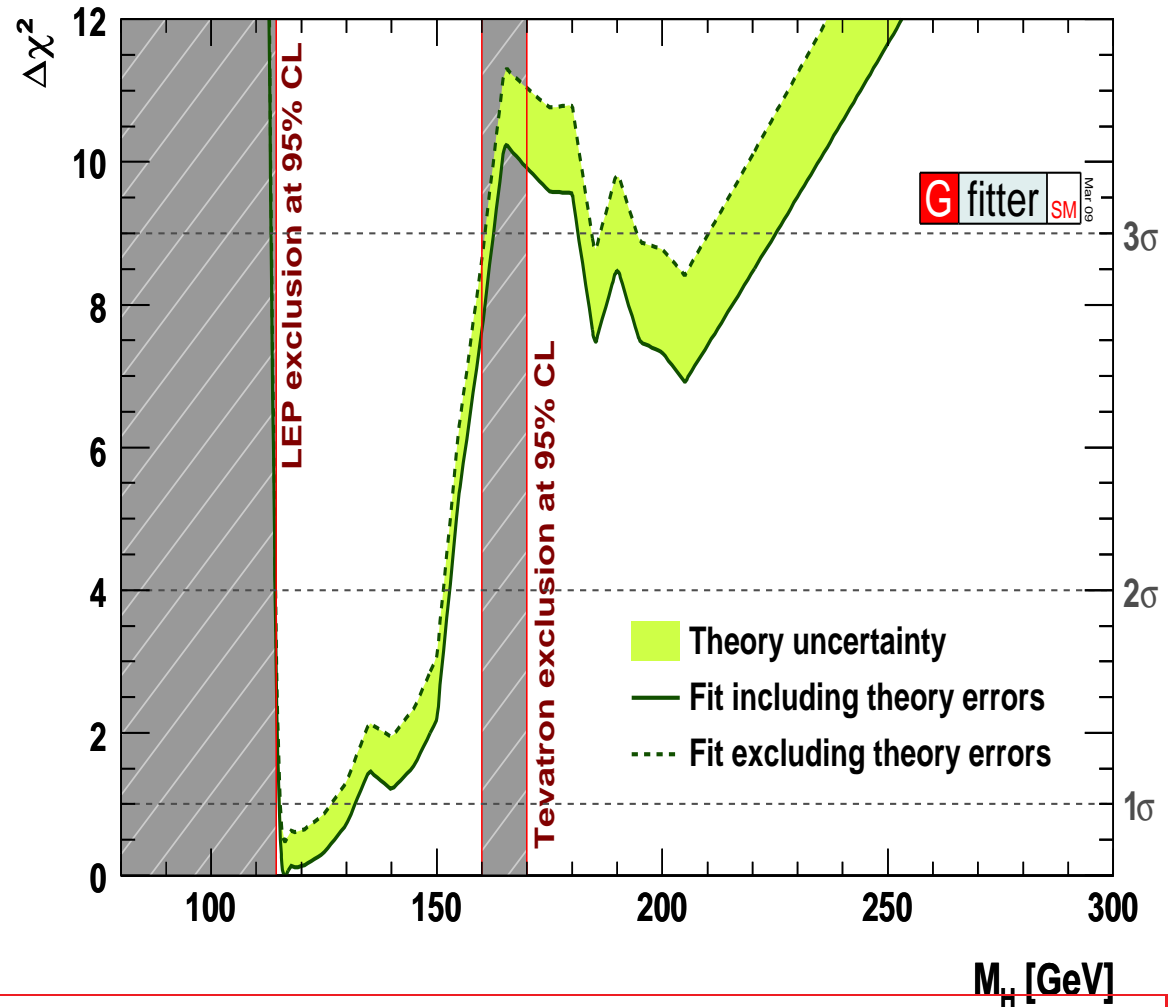
$$\Rightarrow M_H = 116.4^{+18.3}_{-1.4} \text{ GeV}$$

$$M_H < 152 \text{ GeV, 95\% C.L.}$$

Assumption for the fit:

SM incl. Higgs boson

\Rightarrow no confirmation of Higgs mechanism



\Rightarrow Higgs boson seems to be light, $M_H \lesssim 150$ GeV

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) ?

⇒ 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 $\text{BR}(b \rightarrow s\gamma)$: 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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⇒ combination makes only sense if all parameters are connected!

⇒ 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

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

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

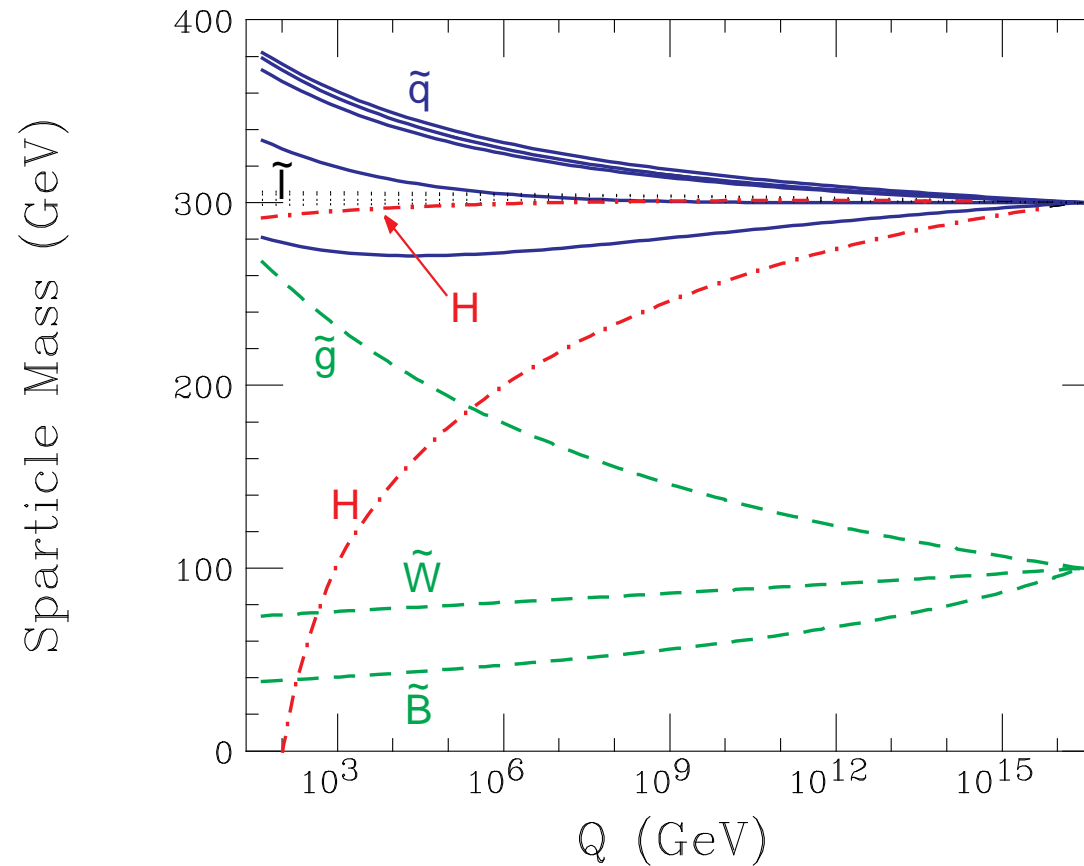
} at the GUT scale

⇒ 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

$$M_0 = 300 \text{ GeV}, M_{1/2} = 100 \text{ GeV}, A_0 = 0$$

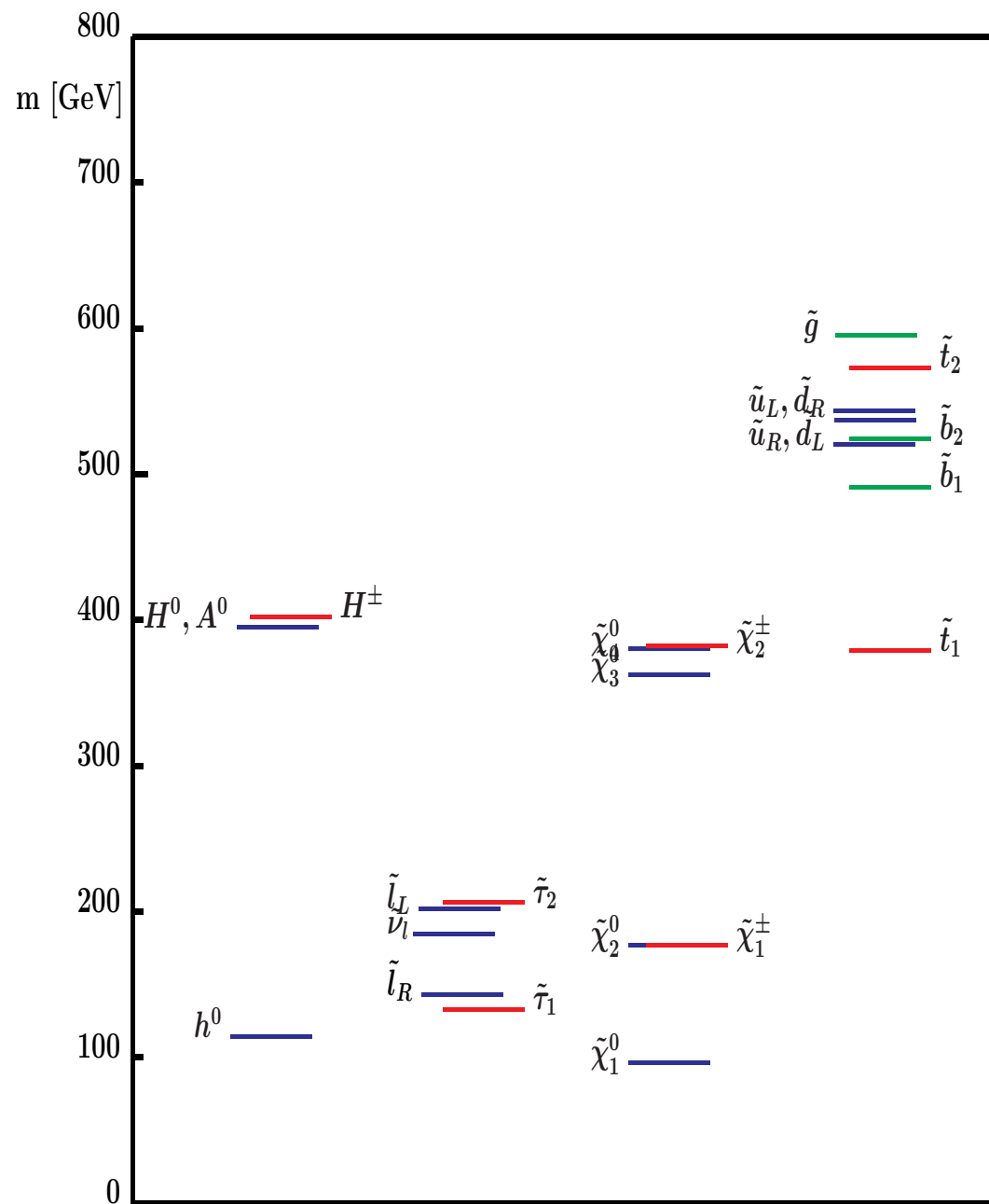


⇒ one parameter turns negative ⇒ Higgs mechanism for free

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

\Rightarrow 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?

How does this work 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
- $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$ can be used as a constraint
- M_h can be predicted from other parameters
⇒ stronger constraints possible

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⇒ stronger constraints possible

Disadvantages of fits in the MSSM vs. SM

- many independent mass scales
- M_h can be predicted from other parameters
⇒ more difficult to disentangle effects

Prediction of M_h in the CMSSM/NUHM1

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

General idea:

Take the most simple MSSM version: CMSSM/NUHM1

→ 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, \dots
- scan over the full CMSSM/NUHM1 parameter space

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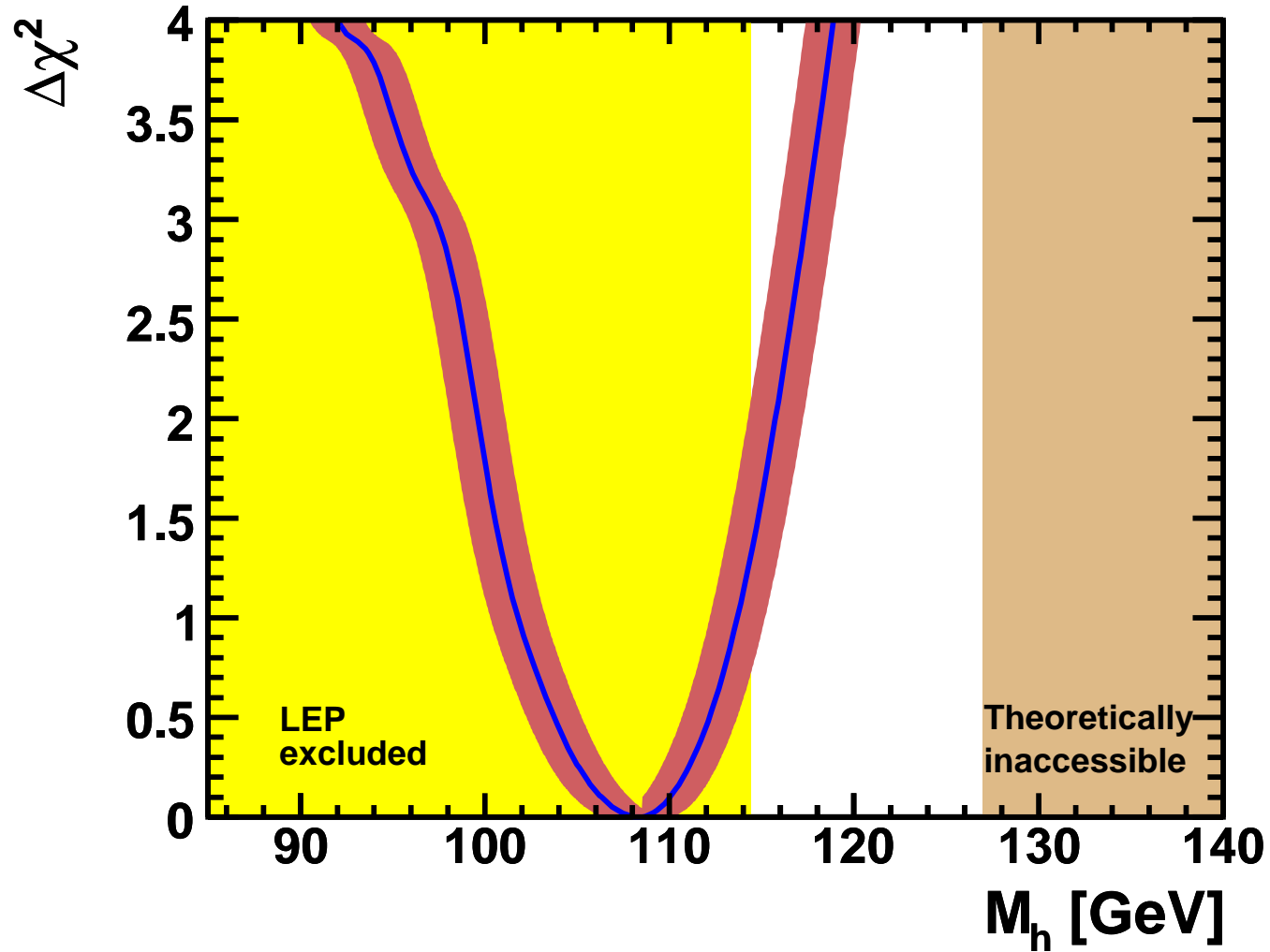
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⇒ preferred M_h values

CMSSM: red band plot:

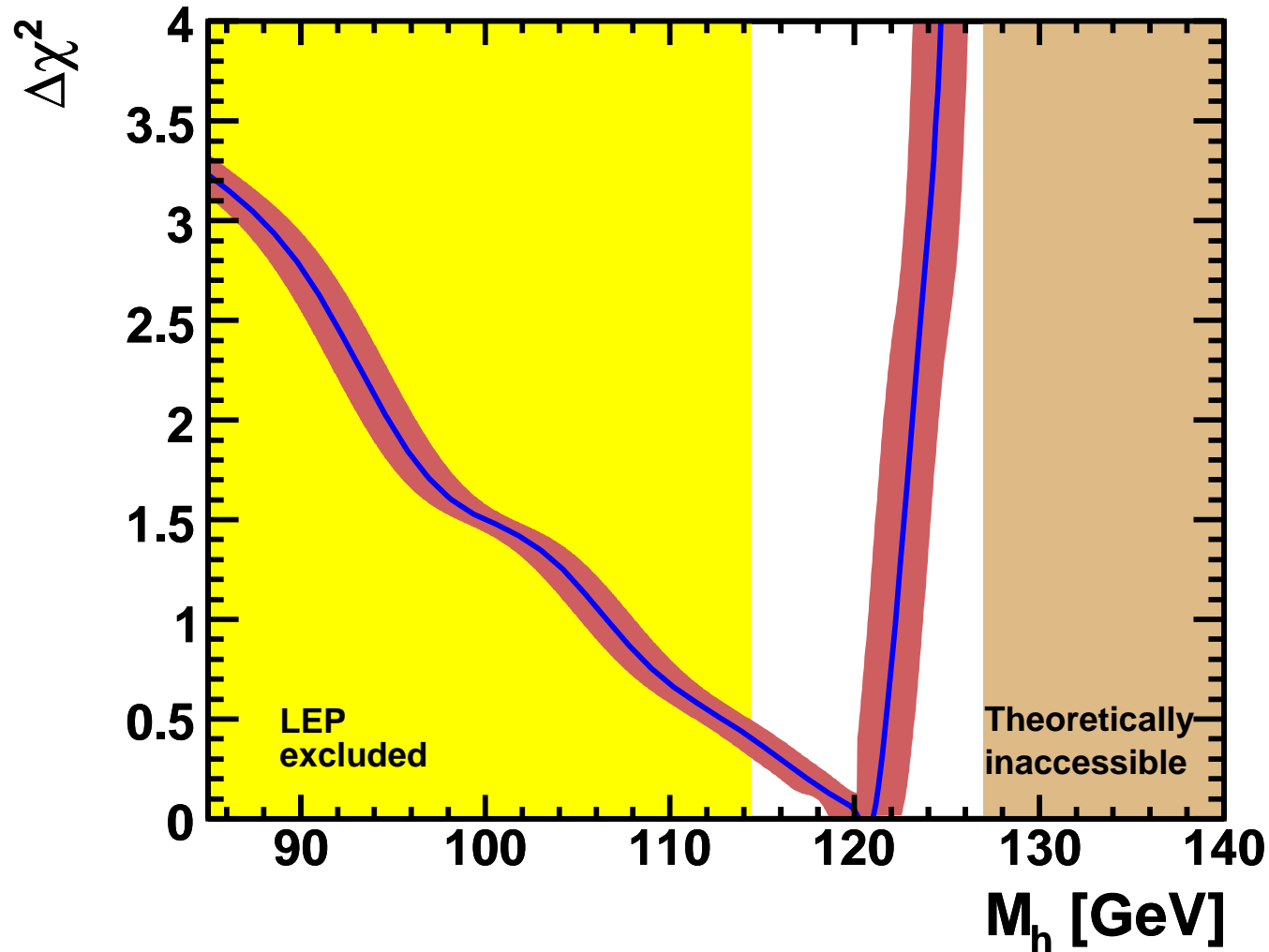
[MasterCode '09]



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

NUHM1: red band plot:

[MasterCode '09]



$$M_h = 121_{-14}^{+1} (\text{exp}) \pm 1.5 (\text{theo}) \text{ GeV}$$

⇒ 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 , $\Delta\alpha_{\text{had}}$

⇒ χ^2 function

→ scan over the full CMSSM/NUHM1 parameter space

~ $2.5 \cdot 10^7$ points samples with MCMC

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

→ final minimum: Minuit

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

⇒ preferred CMSSM/NUHM1 parameters

⇒ LHC/ILC reach

Best-fit points:

CMSSM:

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

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

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

⇒ very similar to SPS 1a :-)

NUHM1:

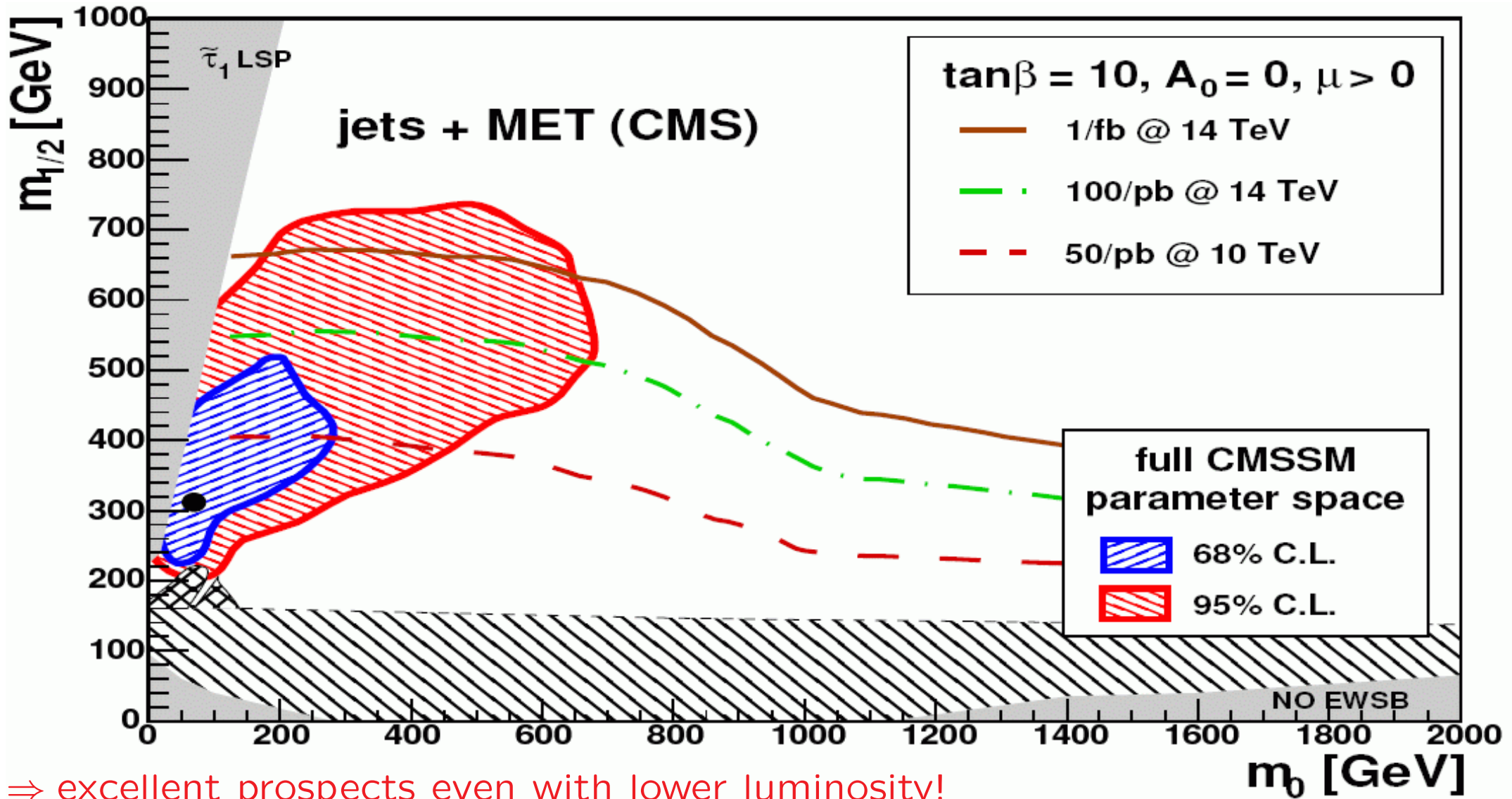
$$m_{1/2} = 270 \text{ GeV}, m_0 = 150 \text{ GeV}, A_0 = -1300 \text{ GeV},$$

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

(similar probability)

LHC (CMS):

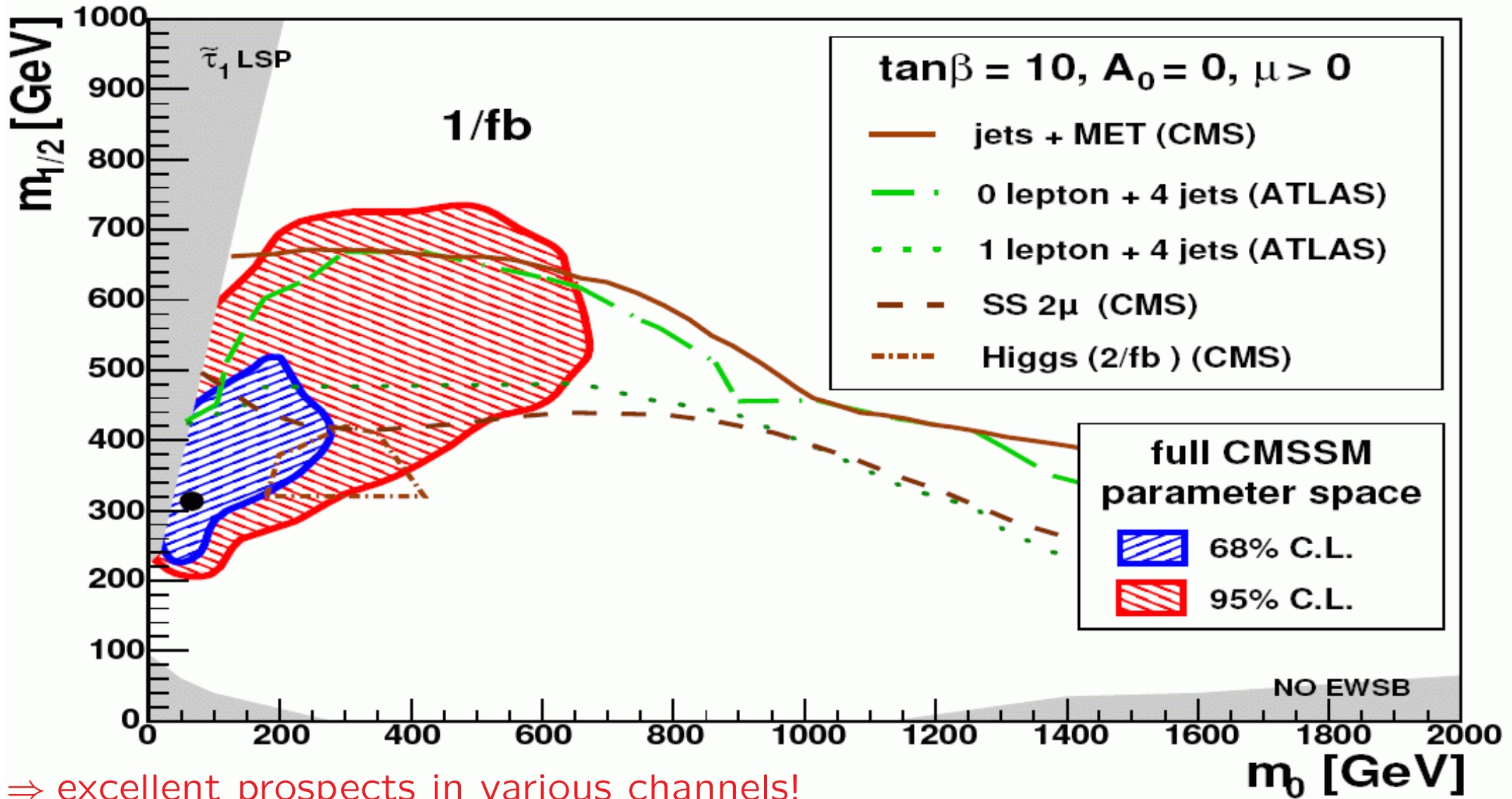
[MasterCode '08] [CMS '07]



⇒ excellent prospects even with lower luminosity!

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

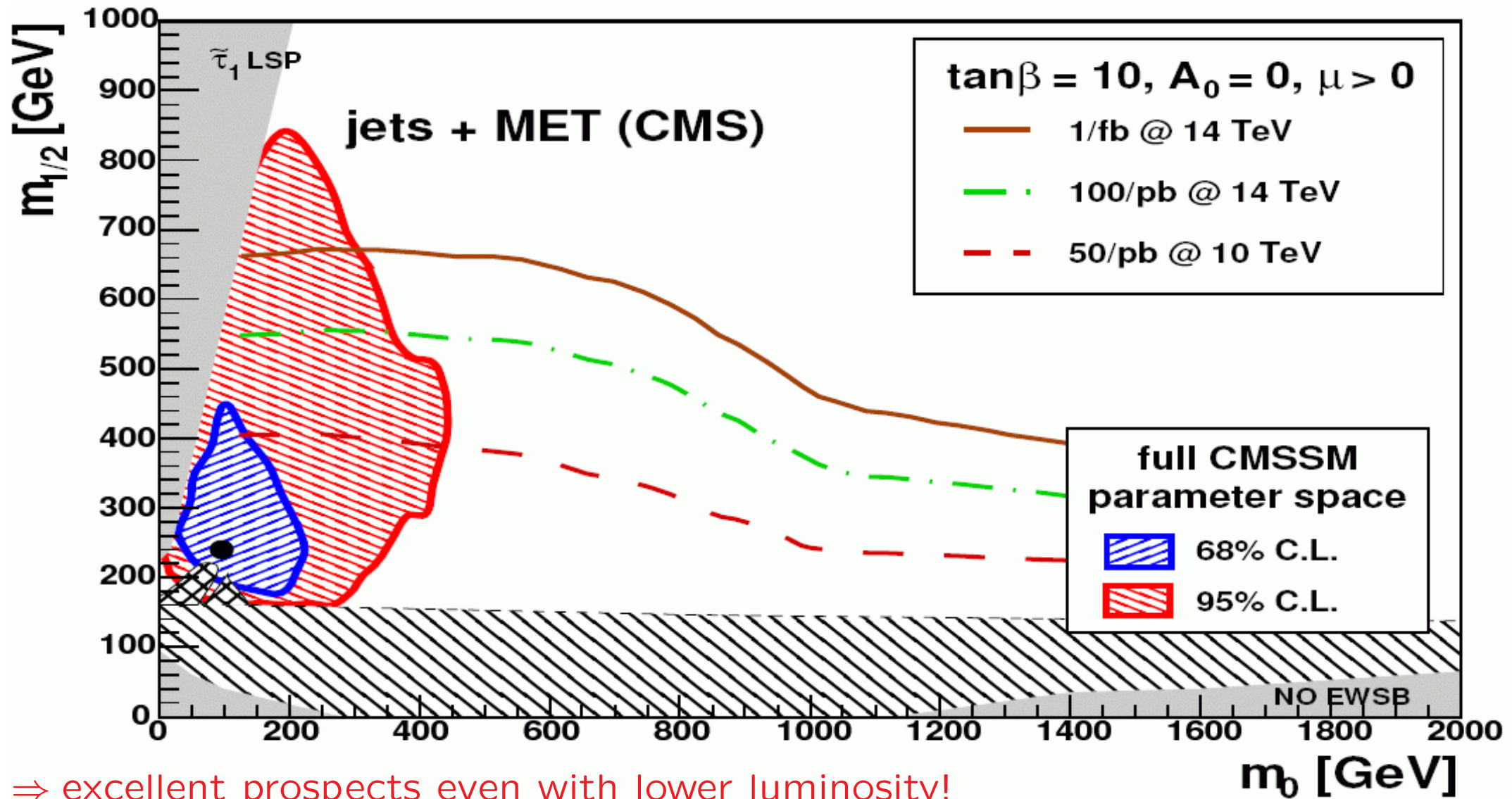
[MasterCode '08] [CMS '07]



⇒ excellent prospects in various channels!

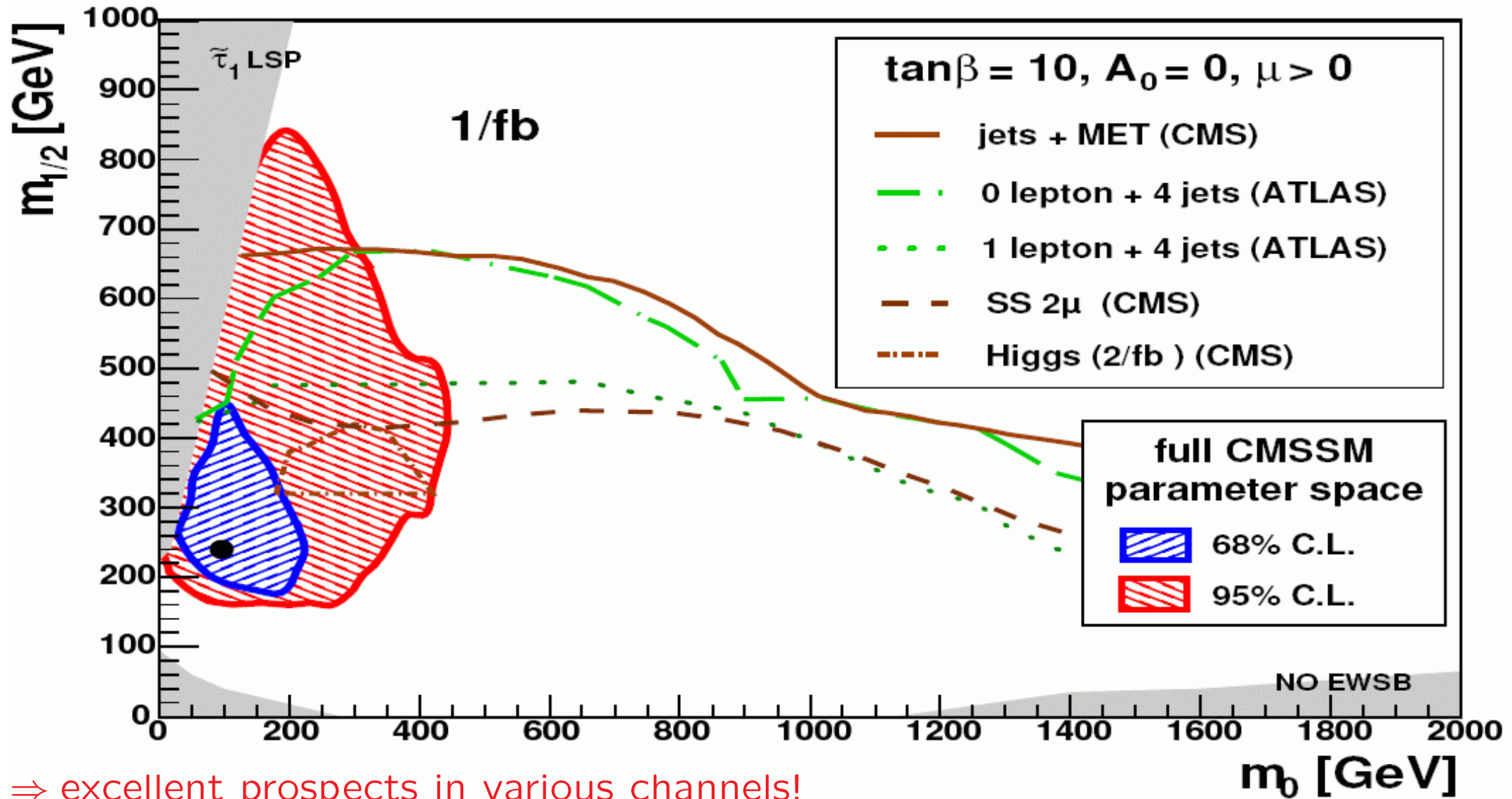
LHC (CMS): NUHM1 analysis

[MasterCode '08] [CMS '07]

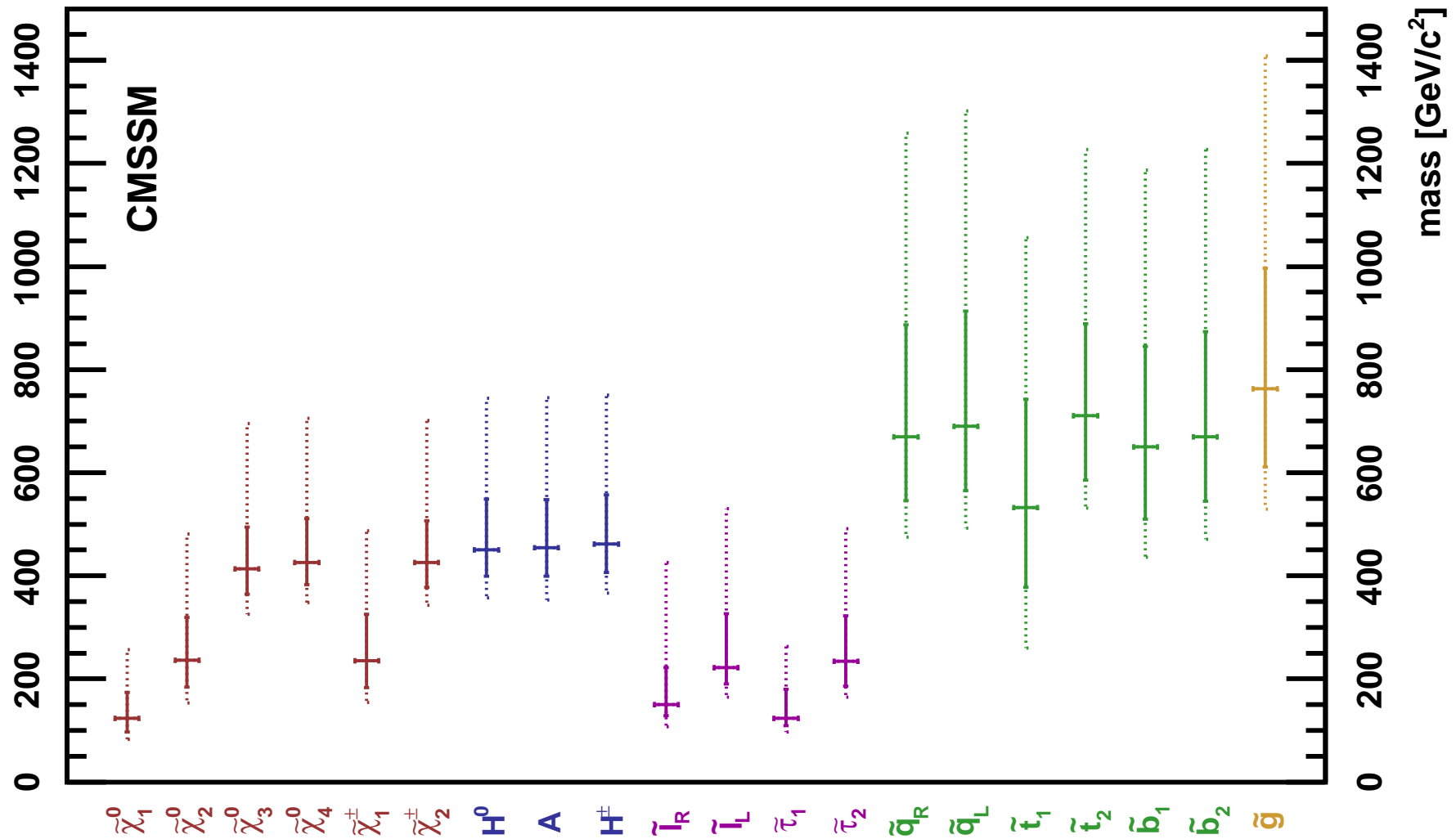


LHC (CMS) reach with 1 fb^{-1} : NUHM1 analysis

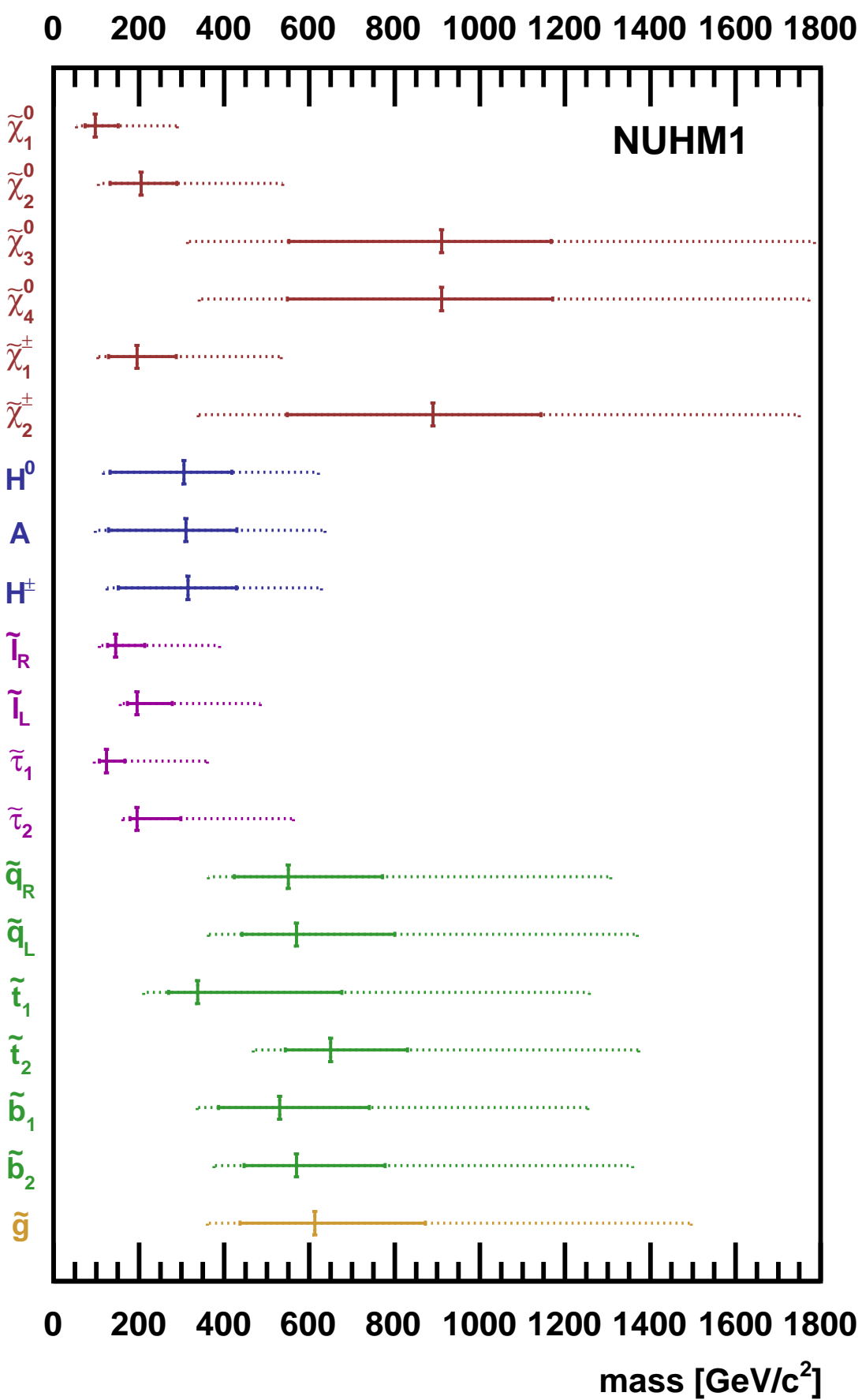
[MasterCode '08] [CMS '07]



⇒ excellent prospects in various channels!

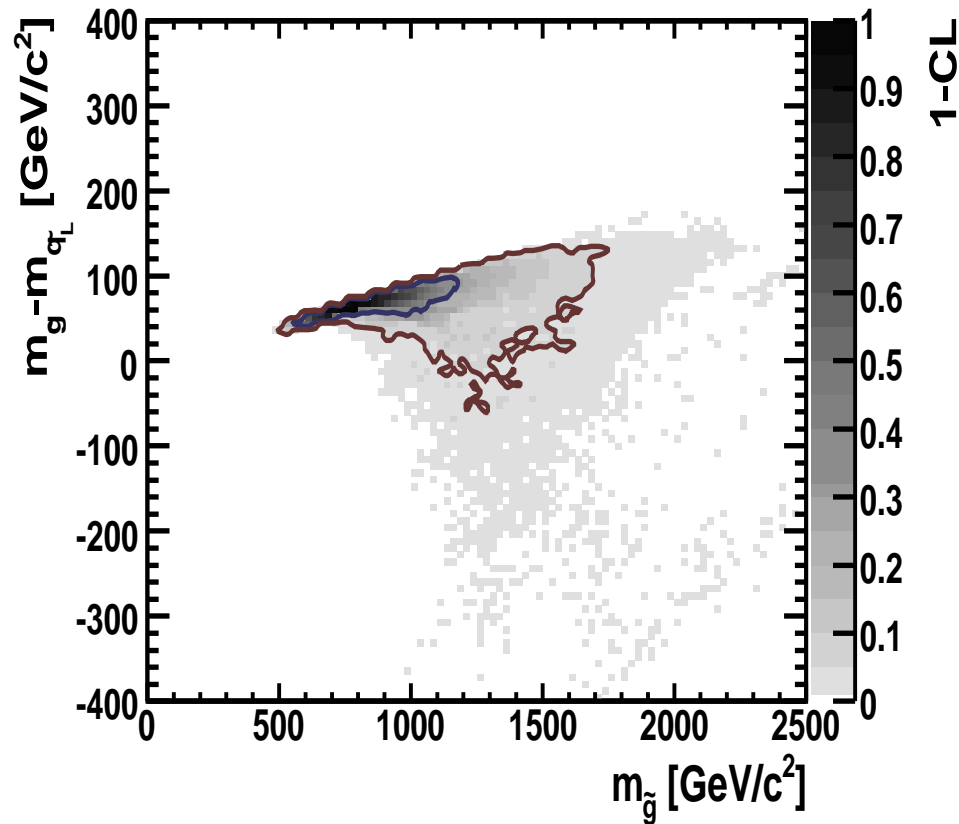


⇒ largely accessible spectrum for LHC and ILC

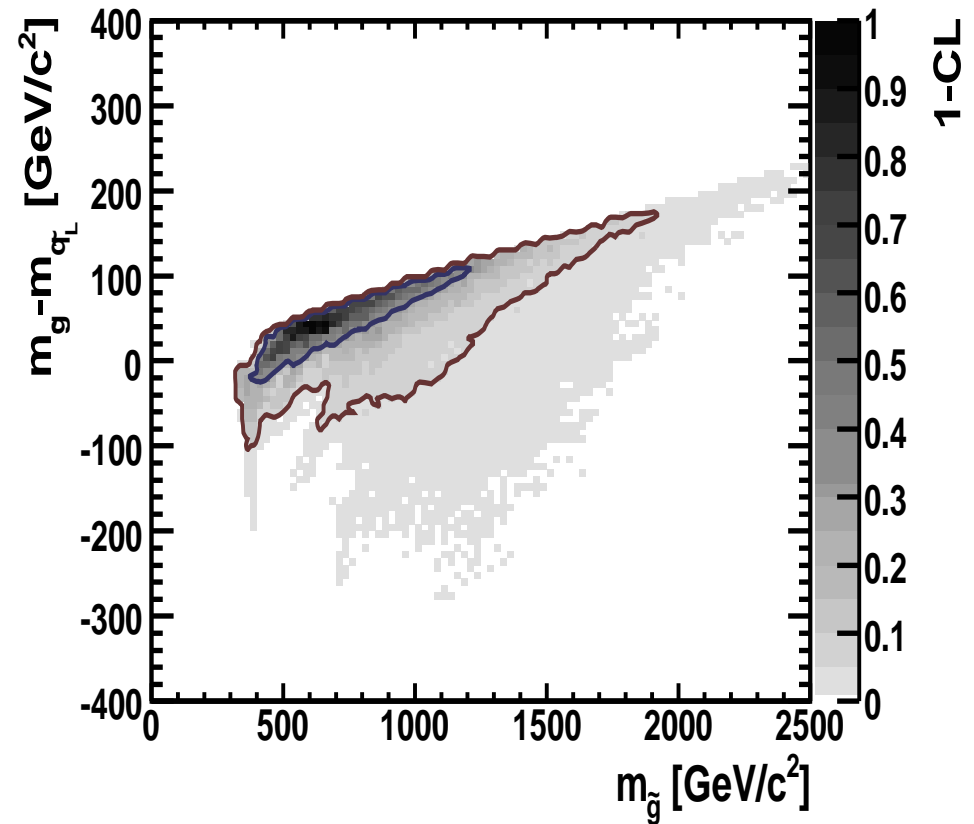


⇒ largely accessible spectrum for LHC and ILC

CMSSM

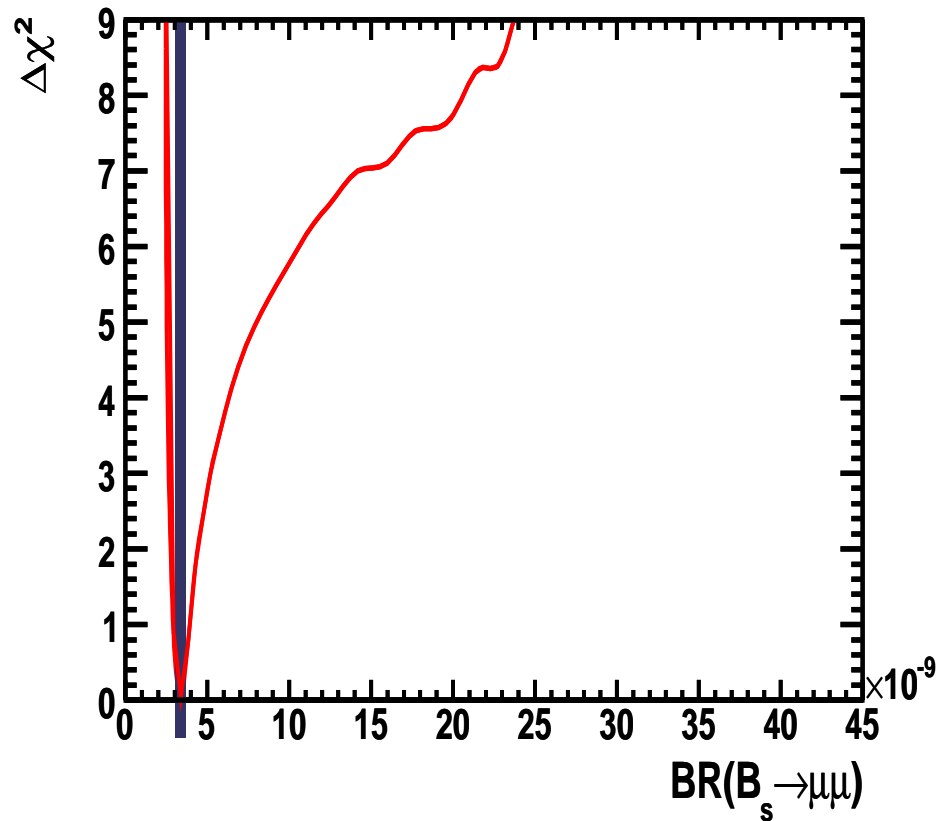


NUHM1

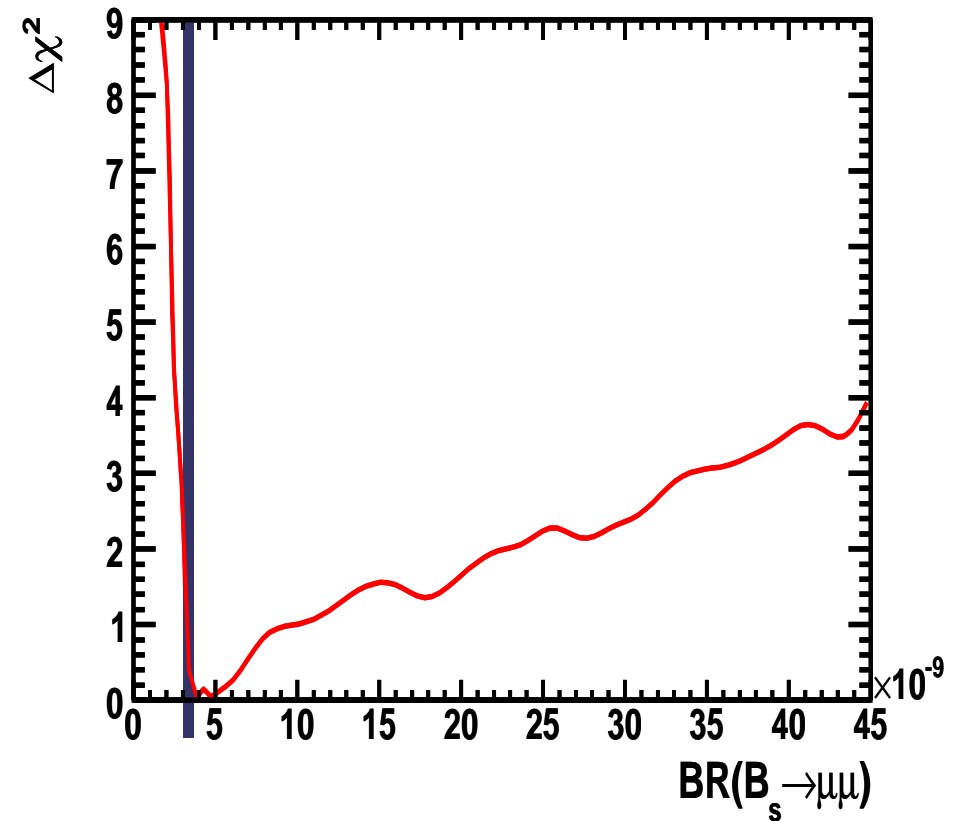


$\Rightarrow m_{\tilde{g}}$ often largest mass, but exceptions are possible

CMSSM



NUHM1

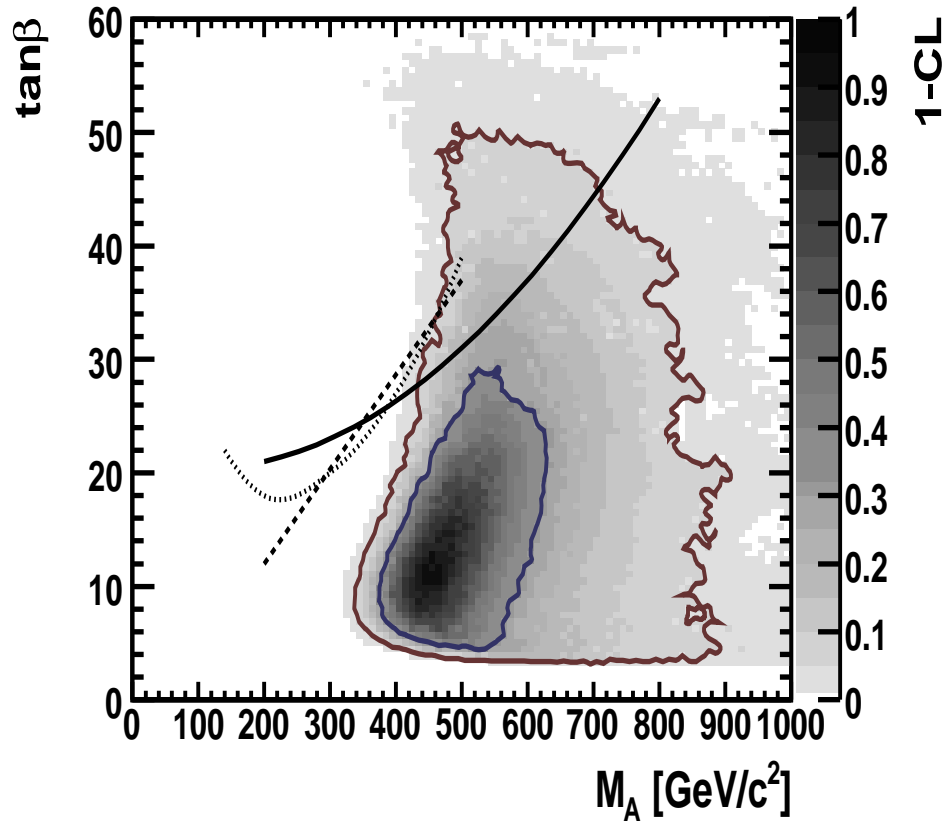


⇒ best-fit similar to SM, larger value would favor NUHM1

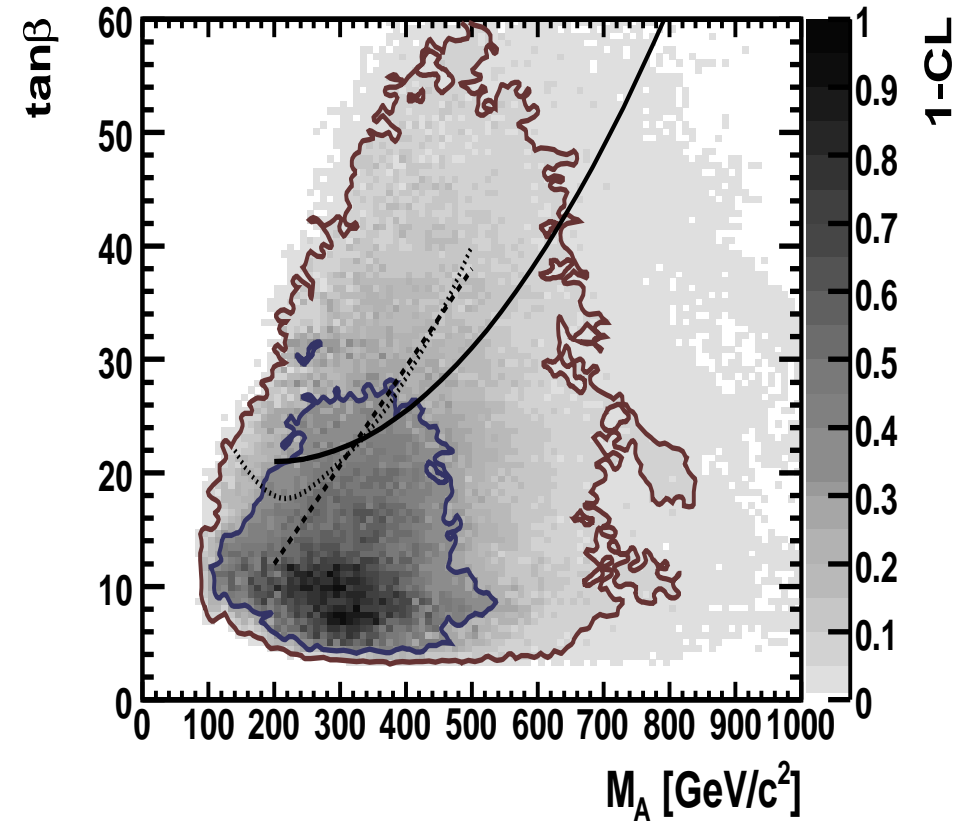
Some more predictions: preferred M_A - $\tan\beta$ parameter space

[MasterCode '09]

CMSSM



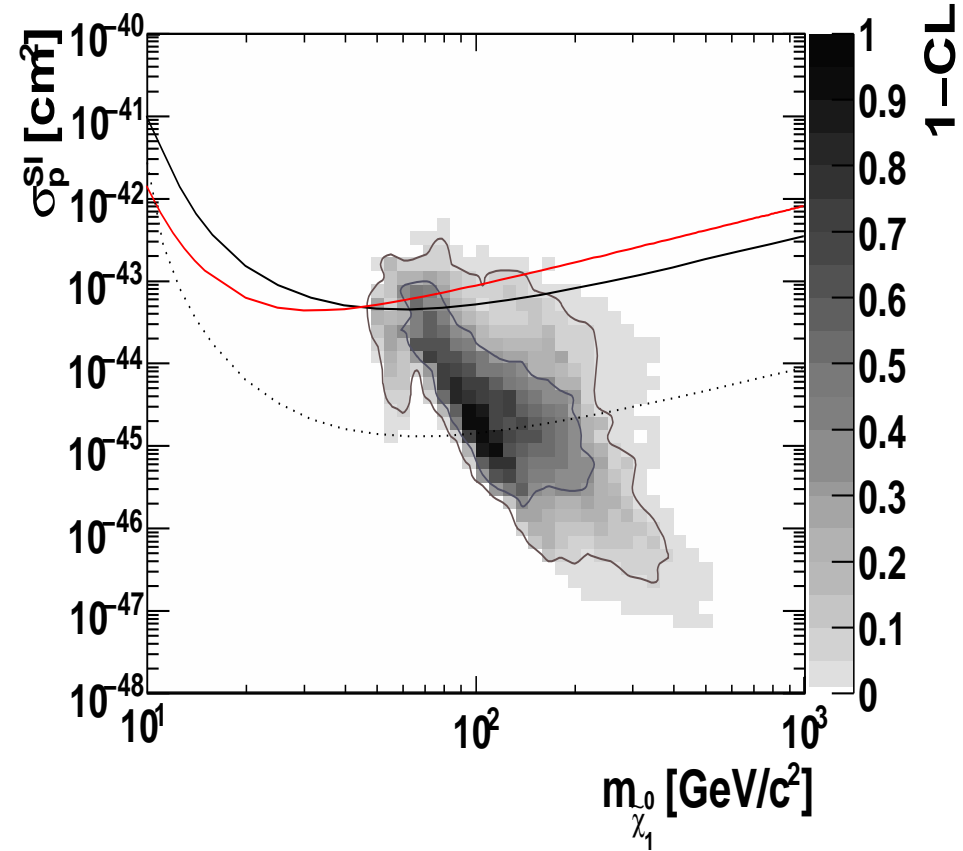
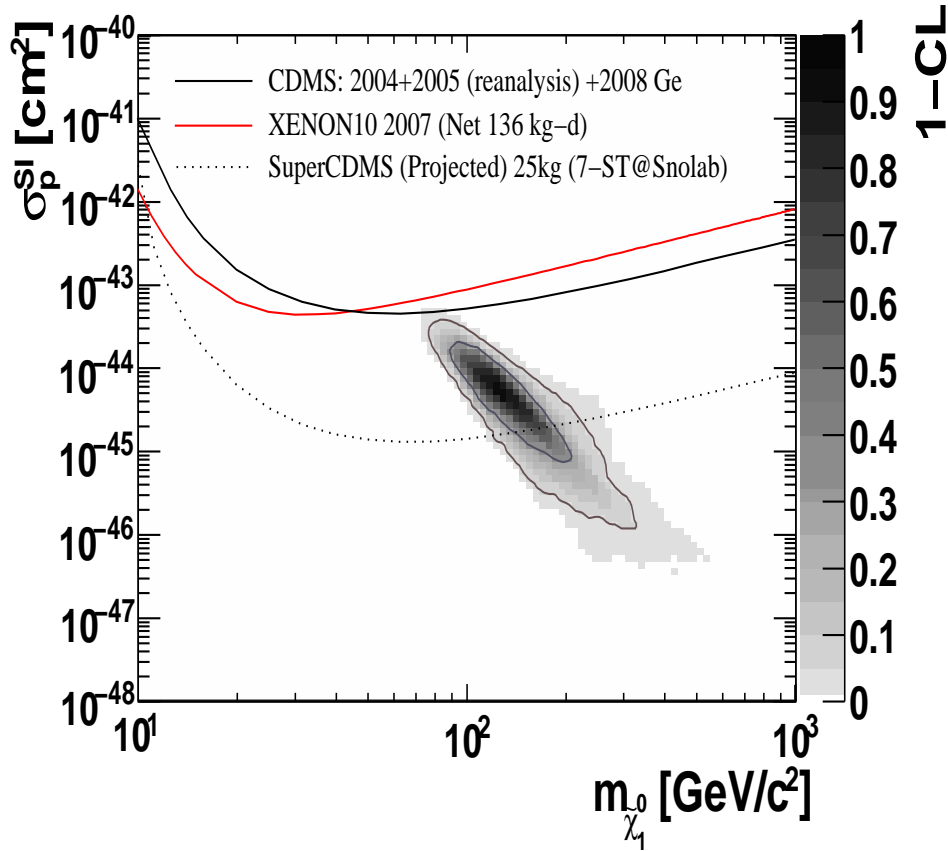
NUHM1



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

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: $\Rightarrow M_H^{\text{SM}} = 87_{-26}^{+35}$ 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
 - $\Rightarrow M_h^{\text{NUHM1}} = 121_{-14}^{+1} \pm 1.5$ 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

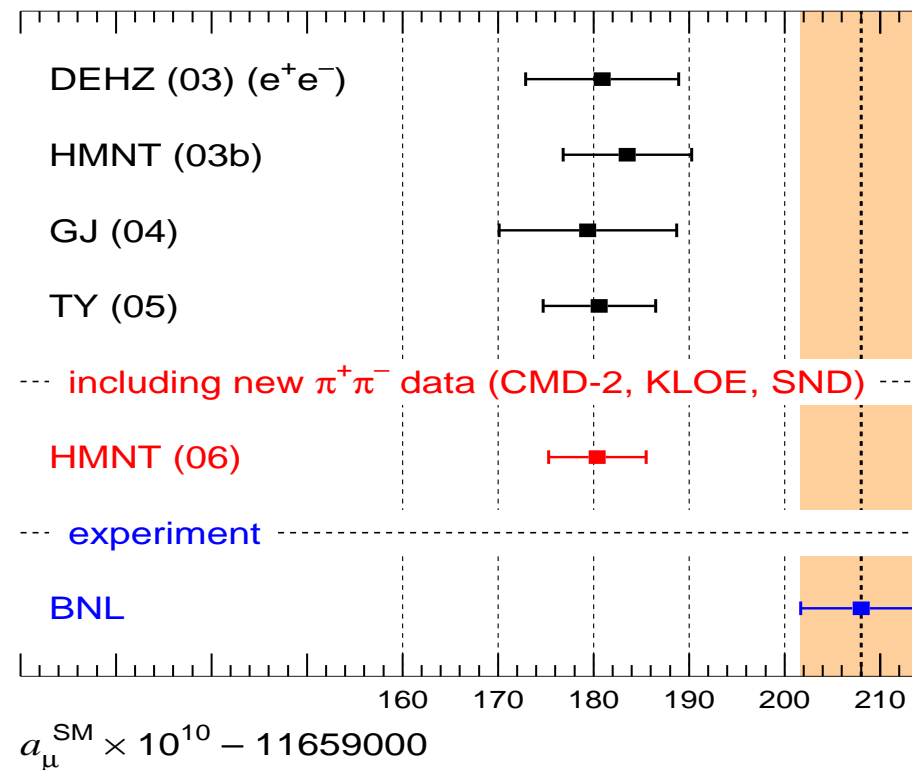
Another EWPO: the anomalous magnetic moment of the muon

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

Overview about the current **experimental** and **SM (theory)** result:

[*g-2 Collaboration, hep-ex/0602035*]

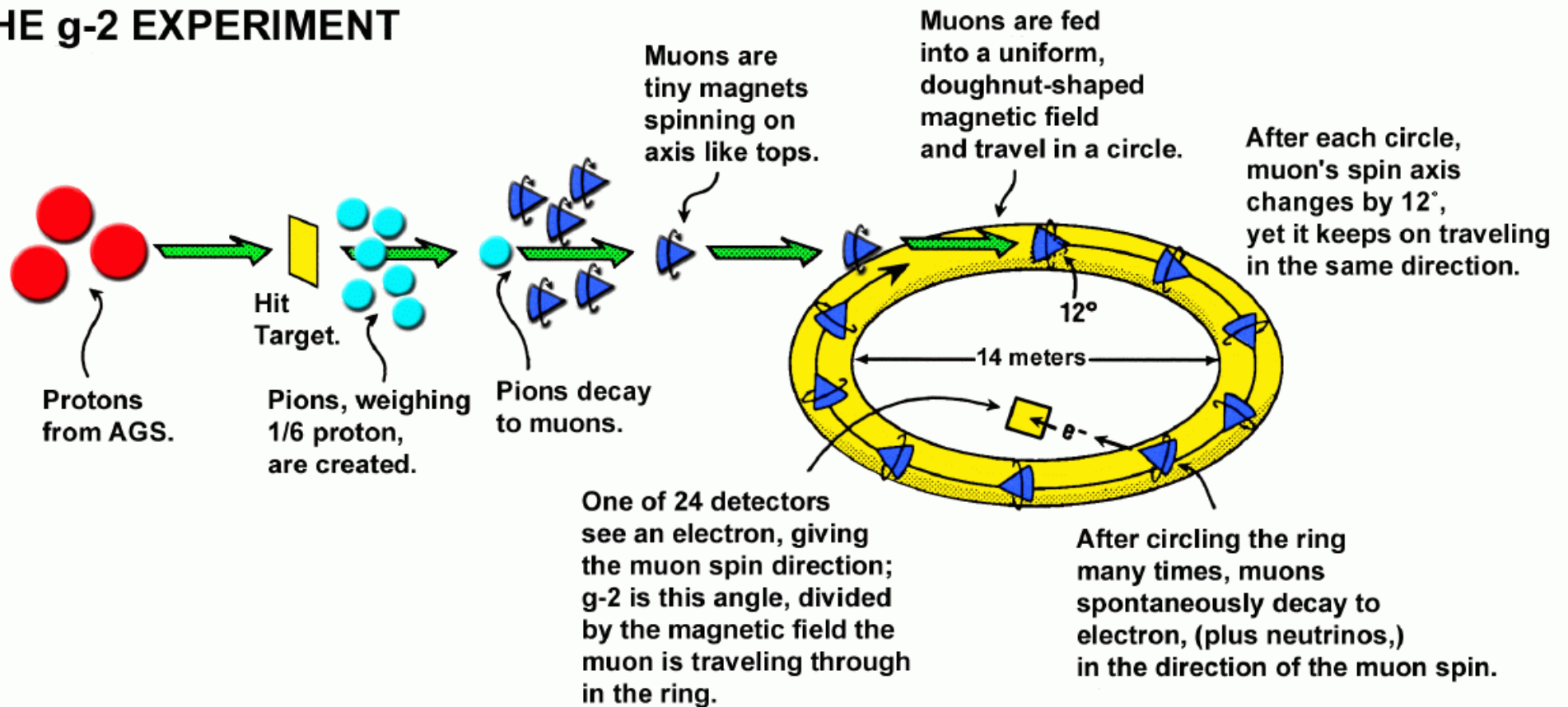
→ T



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

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

LIFE OF A MUON: THE g-2 EXPERIMENT



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

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

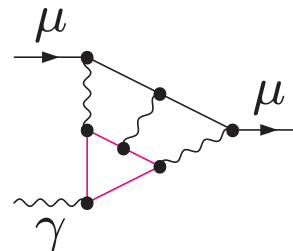
Current status of $(g - 2)_\mu$:

Experiment:

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

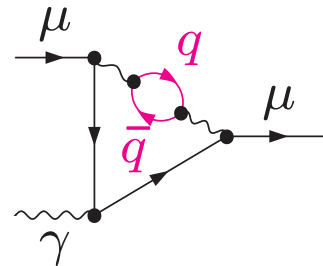
Theory:

- 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



3σ deviation has now been definitely established

(based on e^+e^- data)

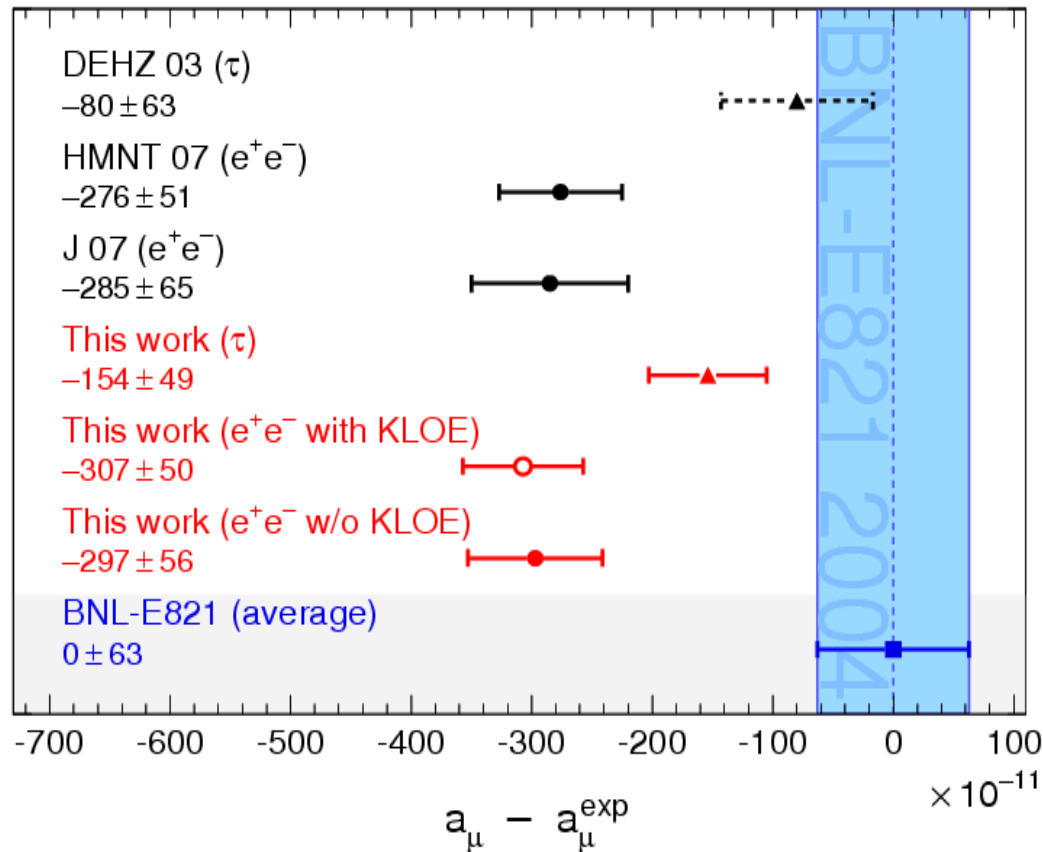
*: including the latest Babar data

New development for τ data:

[M. Davier, A. Höcker et al. '09]

Re-evaluation of τ data: improved evaluation of iso-spin breaking effects

⇒ shift in τ data :

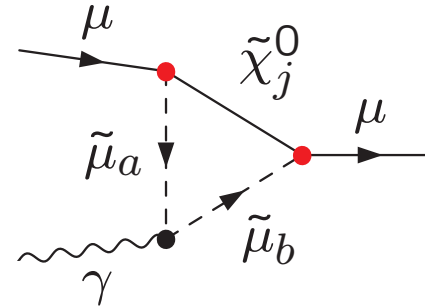
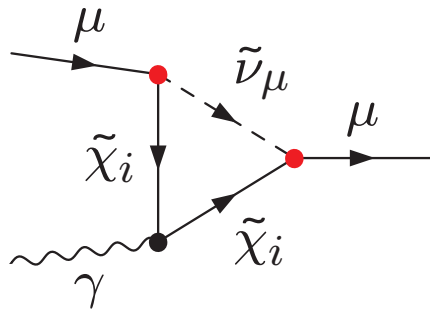


Now: 1.9σ deviation! ⇒ still tbc!

If correct: ⇒ 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:

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

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

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

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

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

$$a_{\mu}^{\text{SUSY,1L}} = (-100 \dots + 100) \times 10^{-10}$$
$$a_{\mu}^{\text{exp}} - a_{\mu}^{\text{theo,SM}} \approx (28 \pm 8) \times 10^{-10}$$

⇒ SUSY could easily explain the “discrepancy”

⇒ a_{μ} can provide bounds on SUSY parameter space
(by requiring agreement at the 95% C.L.)