Testing the MSSM at the Tevatron

Sven Heinemeyer, IFCA (CSIC)/Zaragoza

Elba, 06/2006

1. Introduction & Motivation
2. Direct searches: Higgs
3. Direct searches: SUSY (short)
4. Indirect searches: EWPO – and back to direct searches
5. Conclusions $\oplus$ theorist's wish list

1. Introduction & Motivation

Q: Which Lagrangian describes the world?

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

1. Introduction & 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?)

$\rightarrow$ more than 9 reasons as a motivation:
(incl. 3 1/2 exp. verified SUSY predictions!)

1.) (Original motivation:) Stability of Higgs mass against higher order corrections in the MSSM

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

2.) Haag-Lopuszanski-Sohnius theorem:
maximal gauge symmetry for a QFT:
inner gauge symmetry $\otimes$ (local) SUSY

3.) Lorentz algebra $\subset$ SUSY algebra (local)
$\rightarrow$ connection to general relativity
Superstring theories contain N $=$ 1 SUSY as low energy limit.

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

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

5.) Lifetime of the proton: for SU(5) GUTs:

$\tau_{p,\text{SM}} < \tau_{p,\text{exp}} < \tau_{p,\text{SUSY}}$

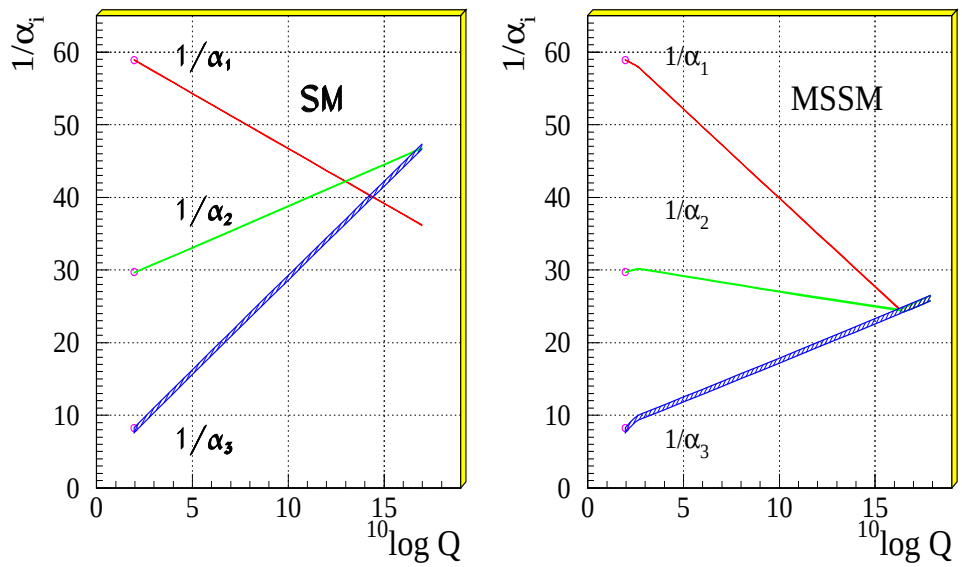
6.) Spontaneous symmetry breaking via Higgs mechanism is automatically achieved in SUSY GUTs

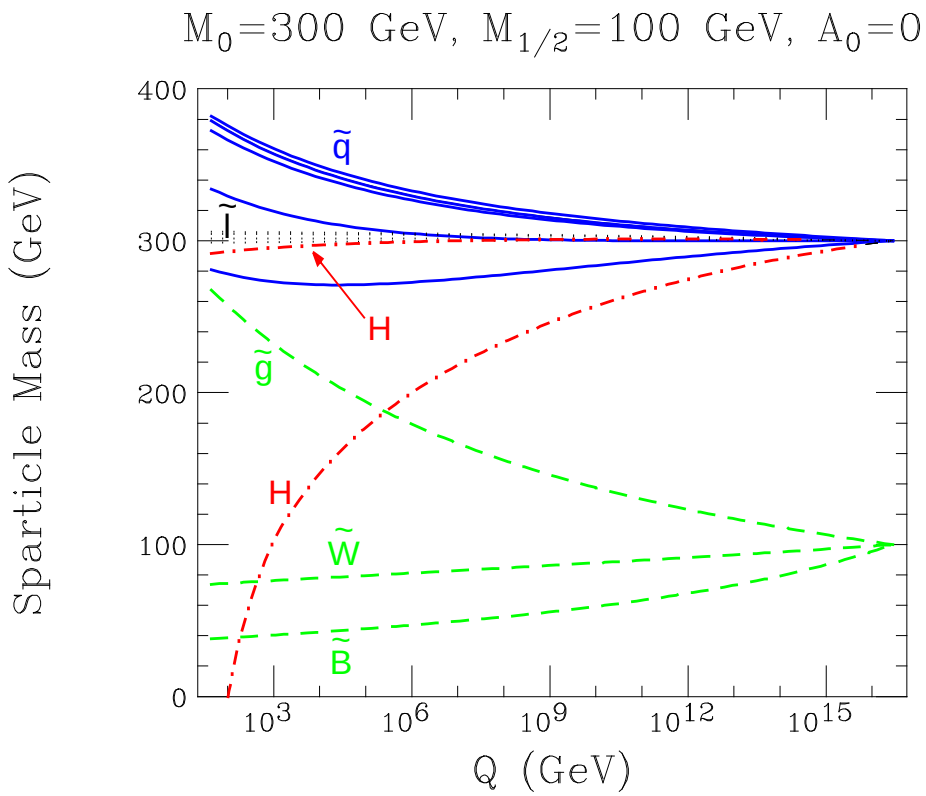
$\rightarrow$ T

SUSY prediction #1 experimentally verified:

$m_t = 150 - 200$ GeV

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




M_0=300 GeV, $M_{1/2}$=100 GeV, A_0=0
Sparticle Mass (GeV)
Q (GeV)
$\tilde{q}$
$\tilde{l}$
H
$\tilde{g}$
H
$\tilde{W}$
$\tilde{B}$

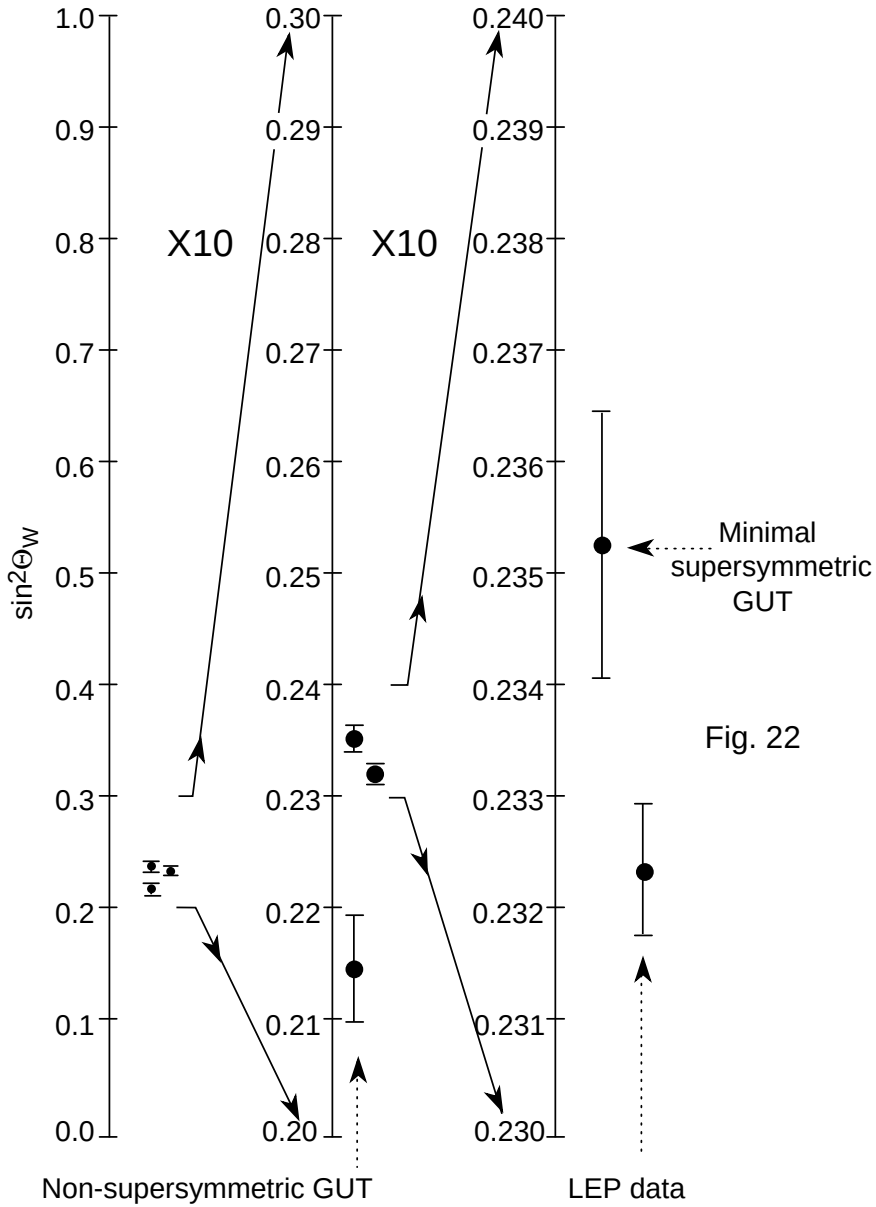

$\sin^2\Theta_W$
X10
X10
Minimal supersymmetric GUT
Non-supersymmetric GUT
LEP data

Fig. 22

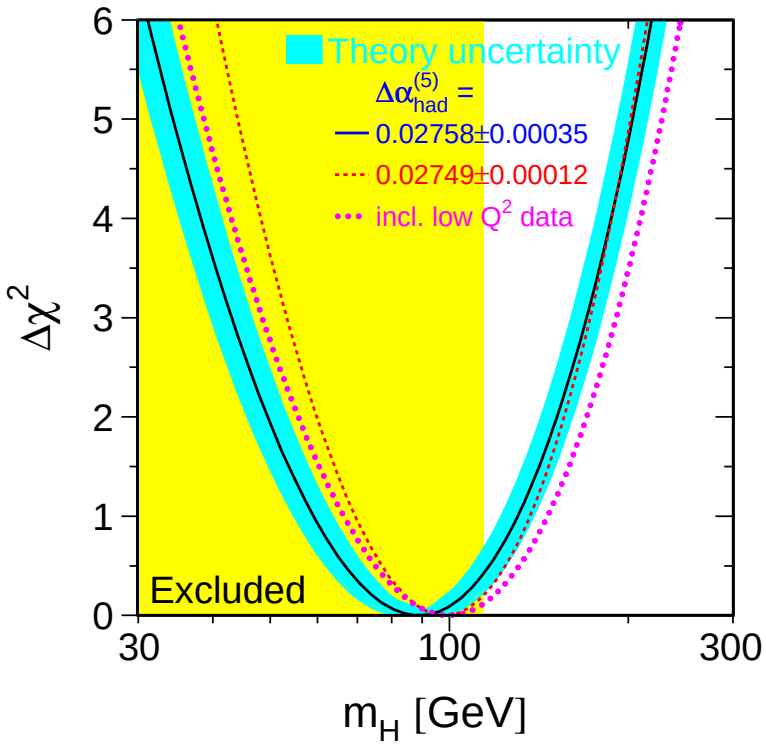
7.) Prediction for $\sin\theta_{W|M_{GUT}} = \frac{3}{8}$
low energy prediction via RGE $\rightarrow$ T

SUSY prediction #2 exp. verified:
$\sin^2\theta_{\text{eff}} \approx 0.232$

8.) LSP (lightest SUSY particle) is stable
SUSY prediction #3 exp. verified:
cold dark matter
(with correct properties)

9.) Prediction of a light Higgs boson in the MSSM (see below): $m_h \lesssim 135$ GeV
Indirect search: Global fit to SM data:
[*LEPEWWG '04*]

SUSY prediction #3 1/2 exp. verified:
$m_h \lesssim 135$ GeV



...) Solution for Flavor problem? Solution for Baryogenesis?

Q: Which Lagrangian describes the world?

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A: Let's try again . . .

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A: Let's try again . . .

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

- Search for indirect effects of SUSY via Precision Observables

- Combination of both?

$\Rightarrow$ Tevatron can contribute to both possibilities

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

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

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

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

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

Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

$\tilde{t}/\tilde{b}$ 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 $\Rightarrow m_h \leq M_Z$

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

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

Input parameters: (to be determined experimentally)

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

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:

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

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

$$\begin{aligned} \text{Tevatron} &: \Delta m_h = ? \\ \text{LHC} &: \Delta m_h \approx 0.2 \text{ GeV} \\ \text{ILC} &: \Delta m_h \approx 0.05 \text{ GeV} \end{aligned}$$

Upper bound on m_h in the MSSM:

"Unconstrained MSSM":

M_A, $\tan\beta$, 5 parameters in $\tilde{t}$–$\tilde{b}$ sector, μ, $m_{\tilde{g}}$, M_2

$$m_h \lesssim 135 \text{ GeV}$$

for $m_t = 172.5\,\text{GeV}$

(including theoretical uncertainties from unknown higher orders)

$\Rightarrow$ interesting prospects for the Tevatron

Obtained with:

FeynHiggs

[*T. Hahn, S.H., W. Hollik, G. Weiglein '98 – '06*]

`www.feynhiggs.de`

$\rightarrow$ all Higgs masses, couplings, BRs (easy to link, easy to use :-)

(recently included into *Pythia*, *Herwig*, *Sherpa* . . .)

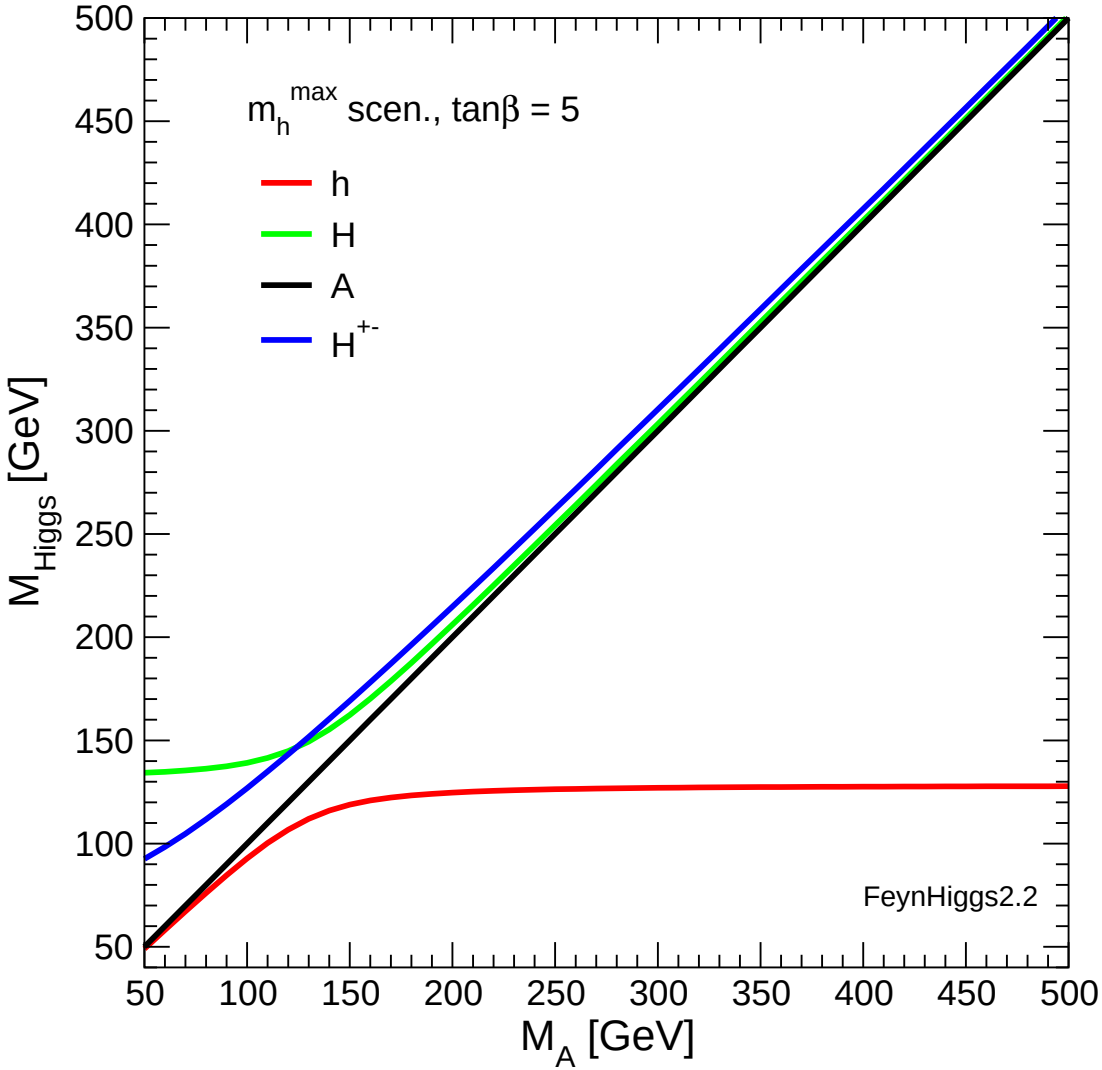
The decoupling limit:

For $M_A \gtrsim 150$ GeV:

The lightest MSSM Higgs is SM-like

The heavy MSSM Higgses: $M_A \approx M_H \approx M_{H^\pm}$

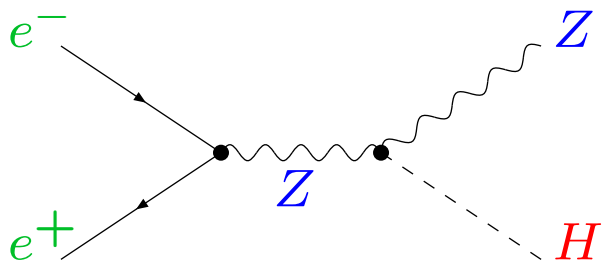
of course there are exceptions . . .



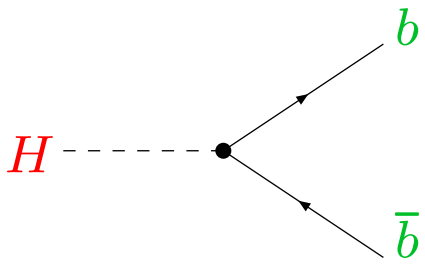
2. Direct searches: Higgs

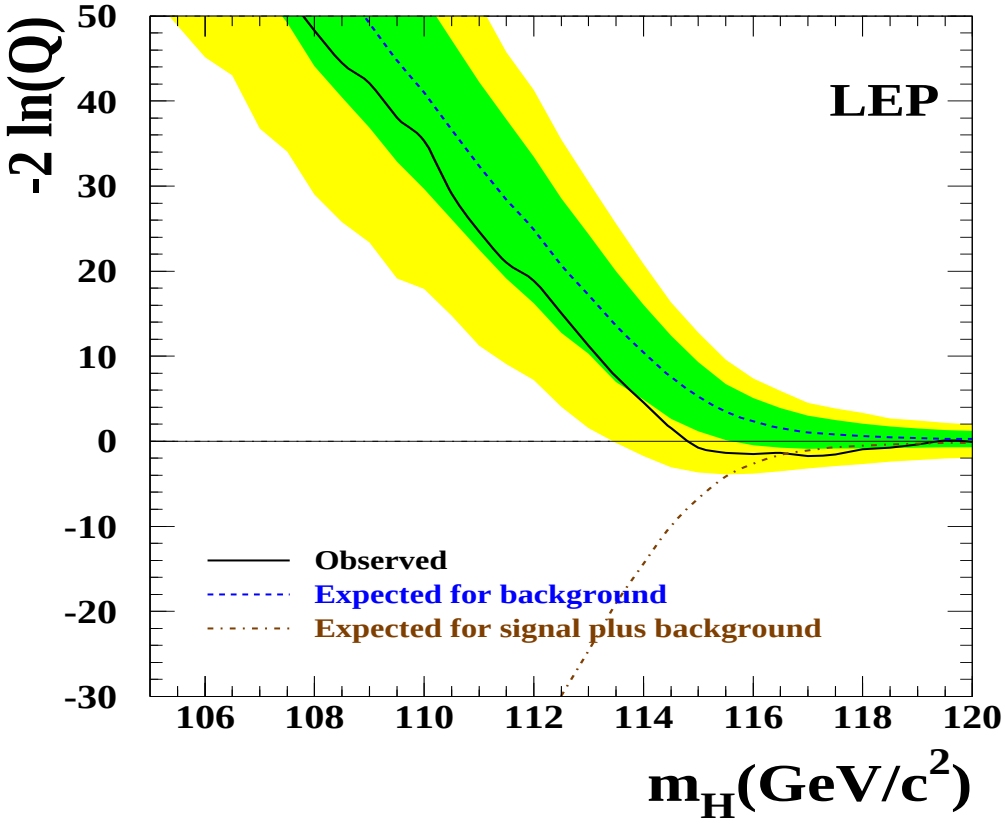
Search for the Standard Model Higgs at LEP: [*LEP Higgs WG '03*]

Dominant production process:
$e^+e^- \to ZH$:



Dominant decay process: $H \to b\bar{b}$

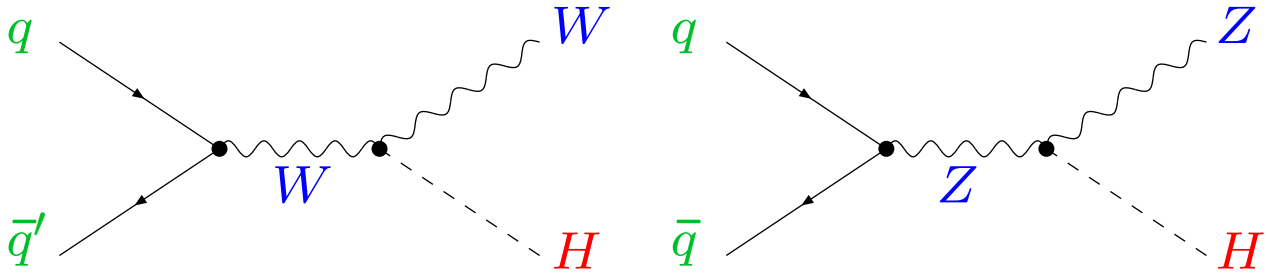




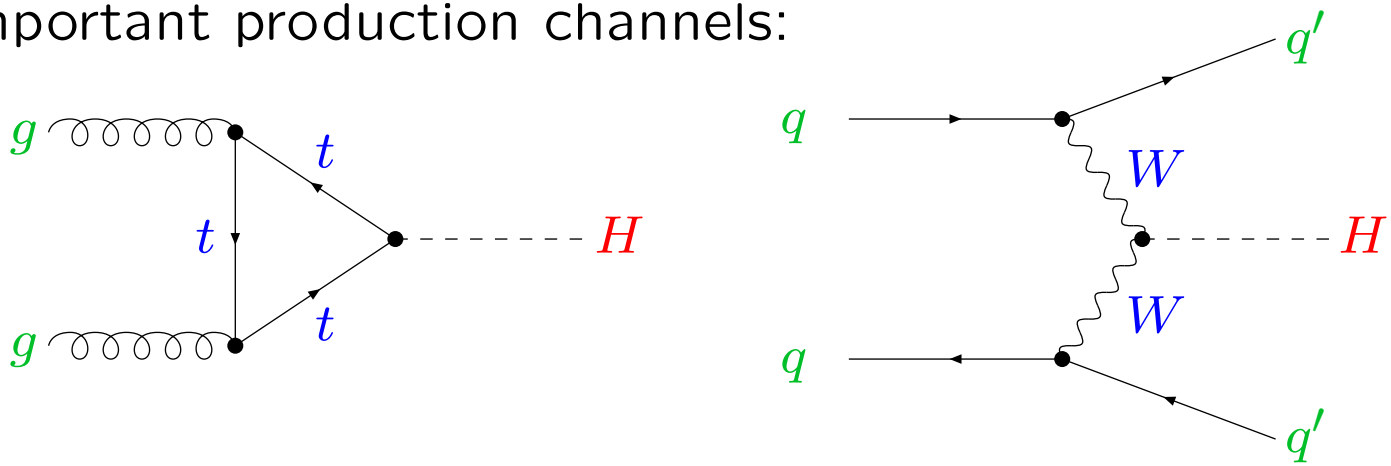
Exclusion limit, 95% C.L.: $M_H > 114.4$ GeV (expected: 115.3 GeV)

Search for the SM Higgs at the Tevatron:

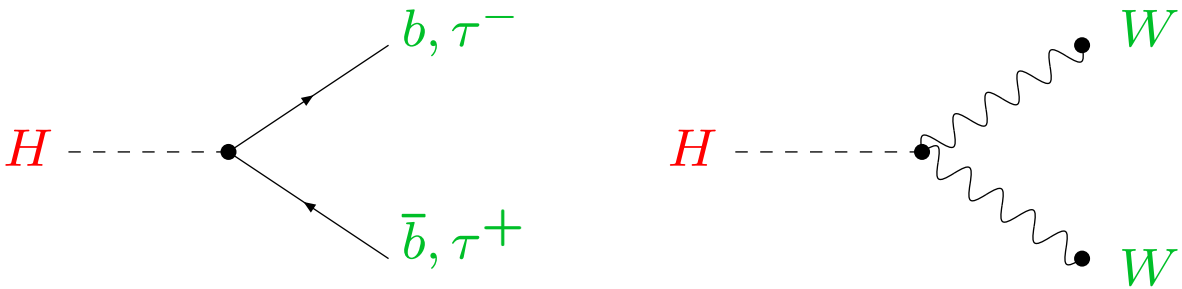
Production processes as at LEP:



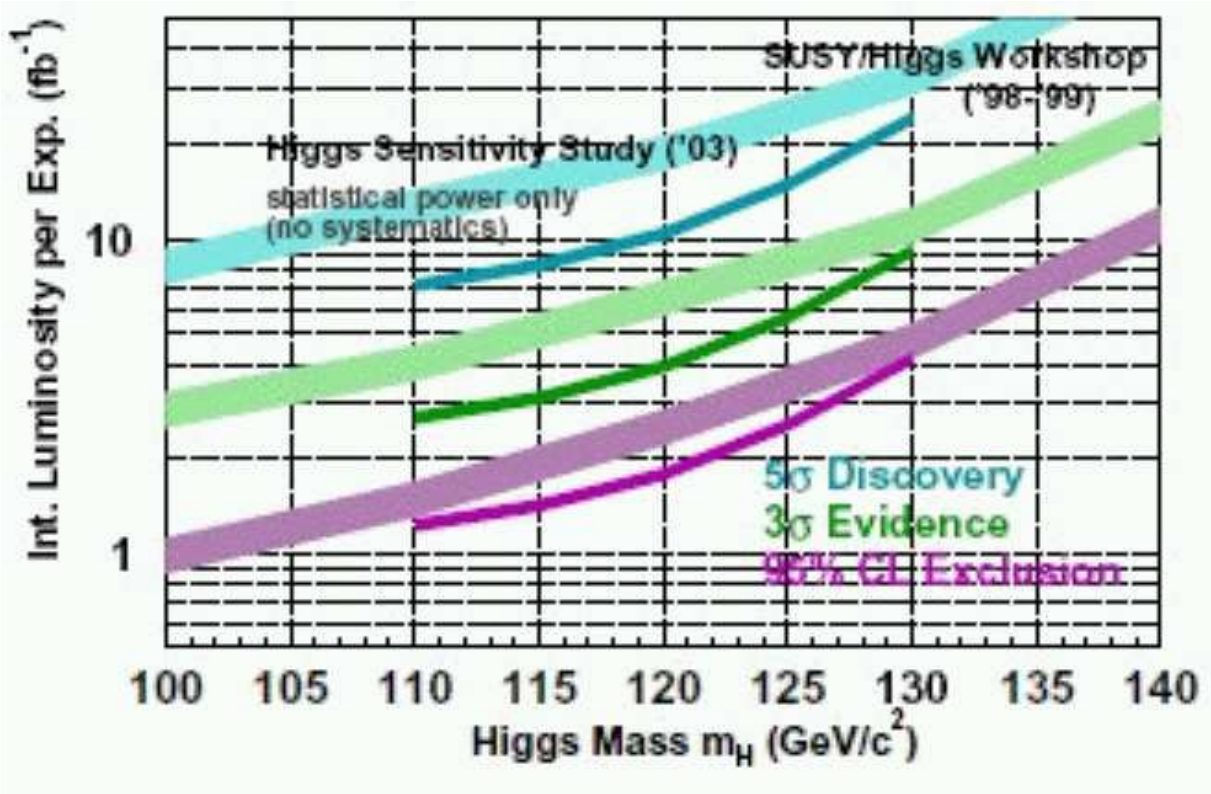
Other important production channels:



Dominant decays:



Expectations for Higgs discovery at the Tevatron:



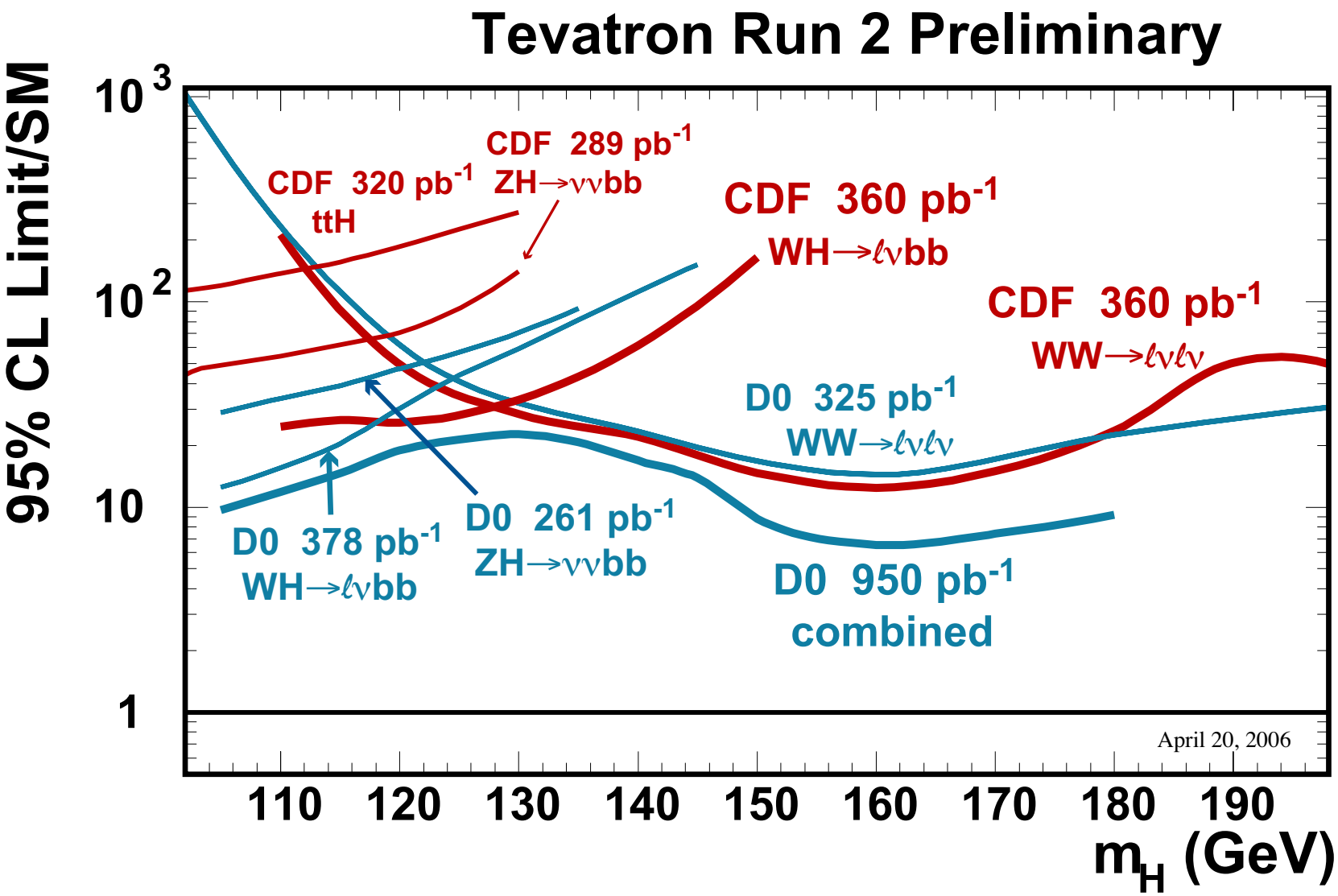
Integrated luminosity: 4–8 fb^{-1}:

sensitivity for 3σ evidence for $M_H \approx 120$ GeV

SM Higgs up to $M_H \approx 130$ GeV can be excluded at 95% C.L.

Current status of SM Higgs search:

[CDF, D0 '06] *[special thanks go to T. Junk and J. Conway]*



Can YOU close the gap?

Search for the MSSM Higgs bosons:

Situation is more involved due to many SUSY parameters

→ investigate benchmark scenarios:

→ Vary only M_A and $\tan\beta$
→ Keep all other SUSY parameters fixed

1. m_h^{max} scenario:
   → obtain conservative $\tan\beta$ exclusion bounds ($X_t = 2\,M_{\text{SUSY}}$)
2. no-mixing scenario
   → no mixing in the scalar top sector ($X_t = 0$)
3. small α_{eff} scenario
   → $hb\bar{b}$ coupling $\sim \sin\alpha_{\text{eff}}/\cos\beta$ can be zero: $\alpha_{\text{eff}} \to 0$:
   main decay mode vanishes, important search channel vanishes
4. gluophobic Higgs scenario
   → hgg coupling is small: main LHC production mode vanishes

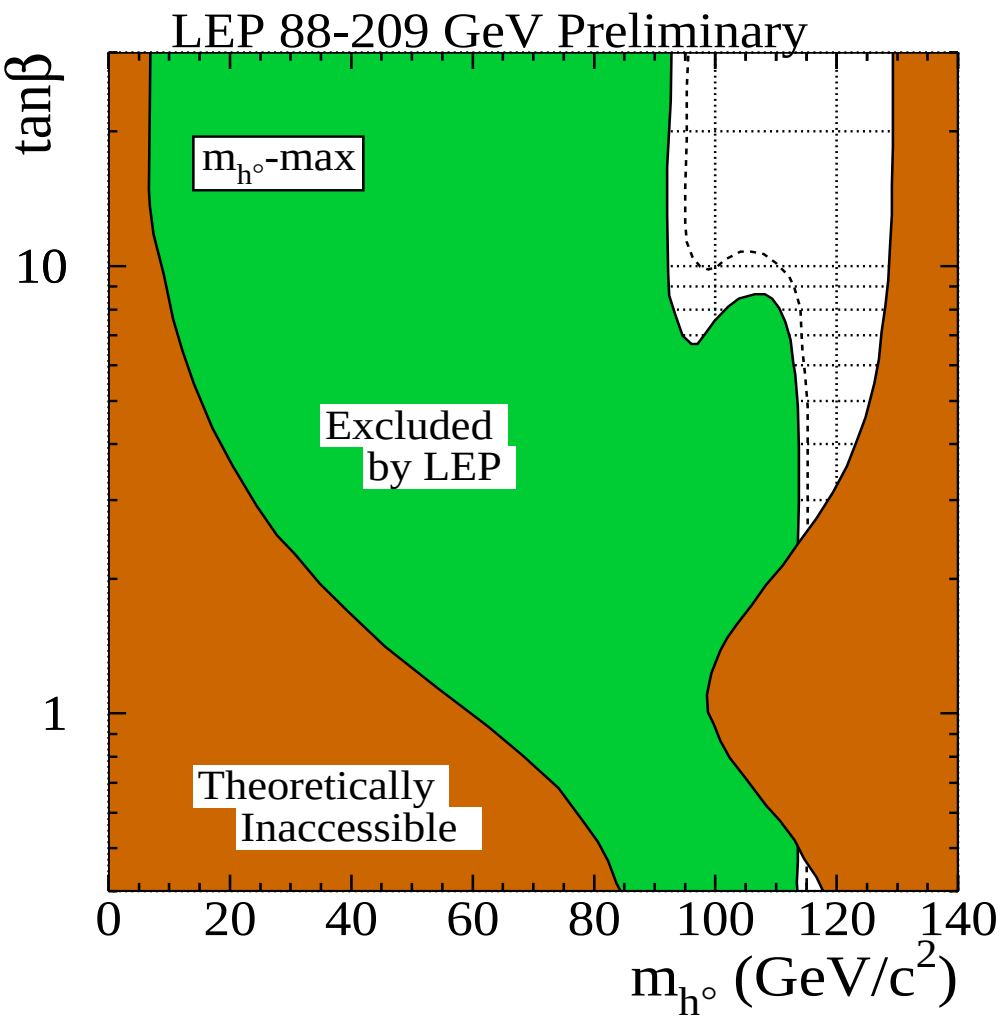
[*M. Carena, S.H., C. Wagner, G. Weiglein '02*]

Final LEP results [*LEP Higgs Working Group '06*]

Results in the $m_h^{\max}$ scenario:

Experimental search vs. upper m_h-bound (`FeynHiggs2.0`)

$m_t = 174.3$ GeV, $M_{\text{SUSY}} = 1$ TeV:



$m_h > 92.7$ GeV
(expected: 94.8 GeV), 95% C.L.

$M_A > 93.1$ GeV
(expected: 95.1 GeV)

Parameter region where experimental lower bound on m_h is significantly lower than SM bound, $M_H > 114.4$ GeV, corresponds to $\sin^2(\beta - \alpha_{\text{eff}}) \ll 1$

"Excluded" $\tan\beta$ region:

$$0.7 < \tan\beta < 2.2$$

Note: this exclusion bound assumes

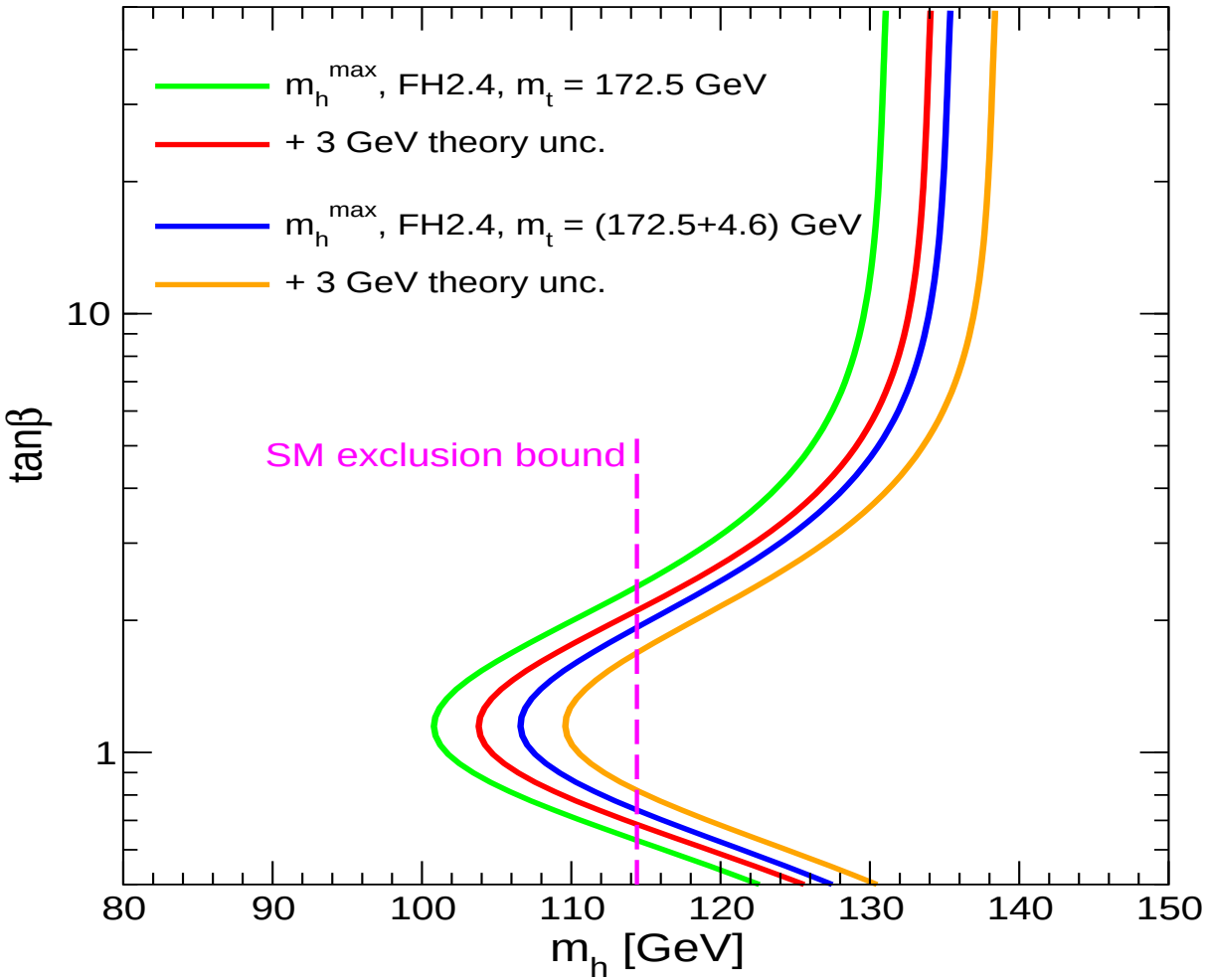
m_t, M_{SUSY} fixed, $m_t = 174.3$ GeV, $M_{\text{SUSY}} = 1$ TeV

no theoretical uncertainties included

Note: new m_t value: $m_t = 172.5 \pm 2.3$ GeV

parametric uncertainty: $\delta m_h^{\text{para}} \approx \delta m_t$

Effect on $\tan\beta$ exclusion bounds



$m_h^{\max}$ scenario, *FeynHiggs*2.4, $m_t = 172.5$ GeV

$m_h^{\max}$ scenario, *FeynHiggs*2.4, + 3 GeV theory unc.

$\Rightarrow$ $\tan\beta$ bound considerably weakened by theory unc.

Exp. error in m_t:

$m_h^{\max}$ scenario, $m_t = 177.1$

$m_h^{\max}$ scenario $m_t = 177.1$ + 3 GeV theory unc.

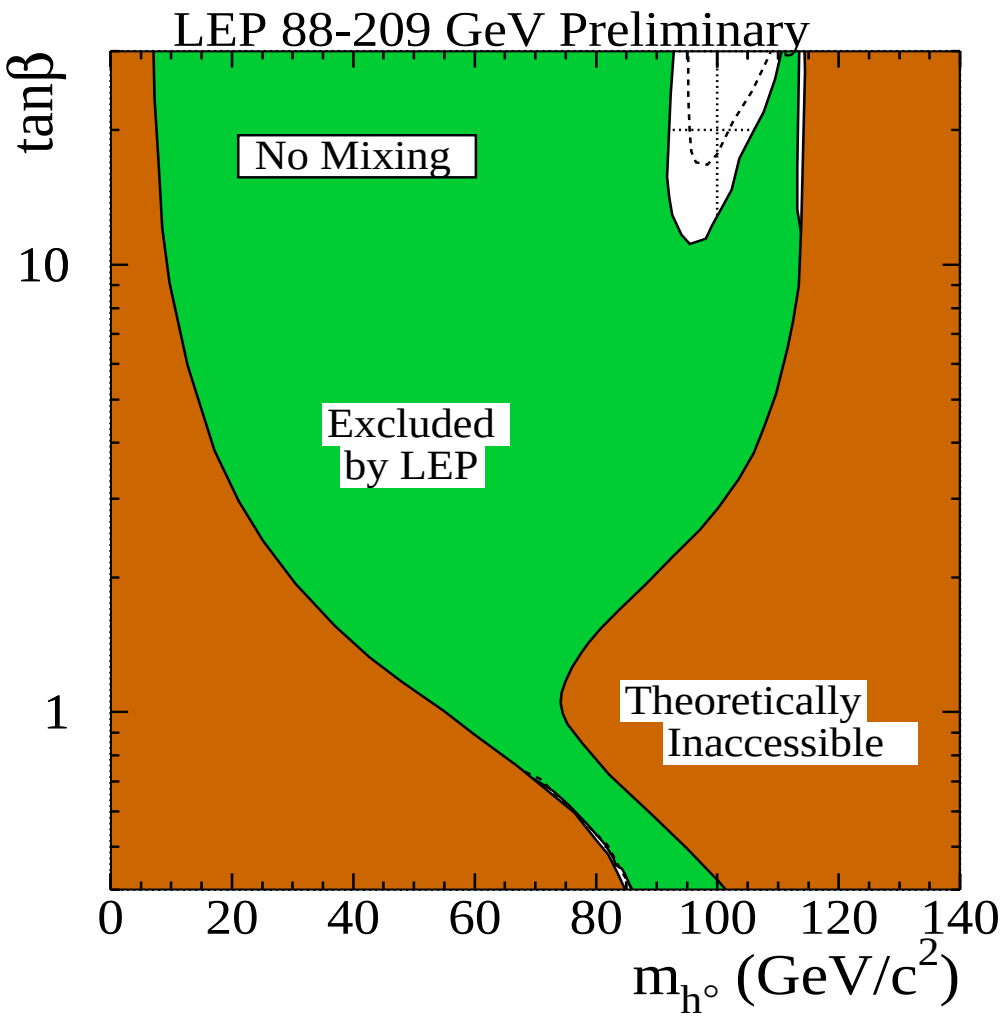
$\Rightarrow$ hardly any $\tan\beta$ exclusion

$\Rightarrow$ considerable improvement needed in both: δm_t^{exp} and δm_h^{theo}

Results in the no-mixing scenario [*LEP Higgs Working Group '06*]

Experimental search vs. upper m_h-bound (`FeynHiggs2.0`)

$m_t = 174.3$ GeV, $M_{\mathrm{SUSY}} = 1$ TeV:



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

$M_A > 93.1$ GeV
(expected: 95.1 GeV)

$0.7 \leq \tan\beta \leq 4.6$ excluded

Tevatron MSSM Higgs searches (I): Search for a "SM-like" light Higgs:

Prediction in "simplified" versions of the MSSM:
($m_t^{\rm exp} = 172.5$ GeV, $\delta m_t^{\rm exp} = 2.3$ GeV, $M_{\rm SUSY} \lesssim$ few TeV)
[*A. Dedes, S.H., S. Su, G. Weiglein '03*] [*S.H., W. Hollik, G. Weiglein '04,'05*]

	max. m_h [GeV]	$\delta m_h/\delta m_t$	for $m_t^{\rm exp} + 2\delta m_t$
mSUGRA/CMSSM	125.5	0.65	128.5
mGMSB	119.9	0.70	123.1
mAMSB	121.4	0.58	124.1

Exclusion potential of the Tevatron: $M_H^{\rm SM} \lesssim 130$ GeV

mSUGRA/CMSSM, mGMSB, mAMSB: no suppression of hVV coupling
$\Rightarrow$ SM bound applies

$\Rightarrow$ Tevatron can exclude mSUGRA/CMSSM, mGMSB, mAMSB, ...

$\Rightarrow$ potentially huge impact on search strategies at LHC

Possible problem in SUSY:

$$h \to b\bar{b}$$

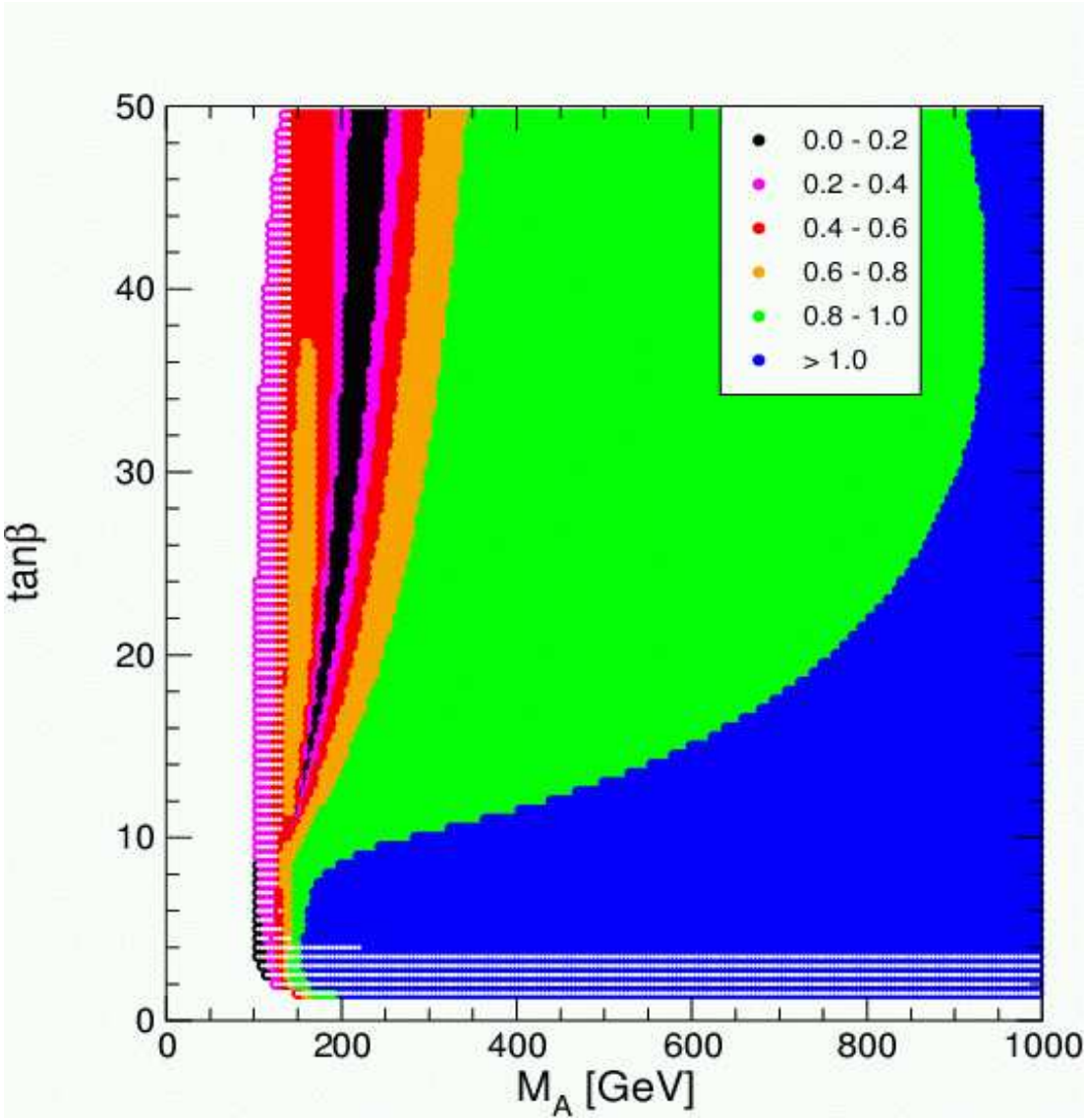
can be strongly suppressed

$\to$ "Small α_{eff} scenario"

[*M. Carena, S.H., C. Wagner, G. Weiglein '02*]

$\Rightarrow$ Strong suppression of $h \to b\bar{b}$ possible, up to $M_A \lesssim 350$ GeV

(not realized in mSUGRA/CMSSM, GMSB, AMSB, . . .)



Possible problem in SUSY:

$$gg \to h \to \gamma\gamma$$

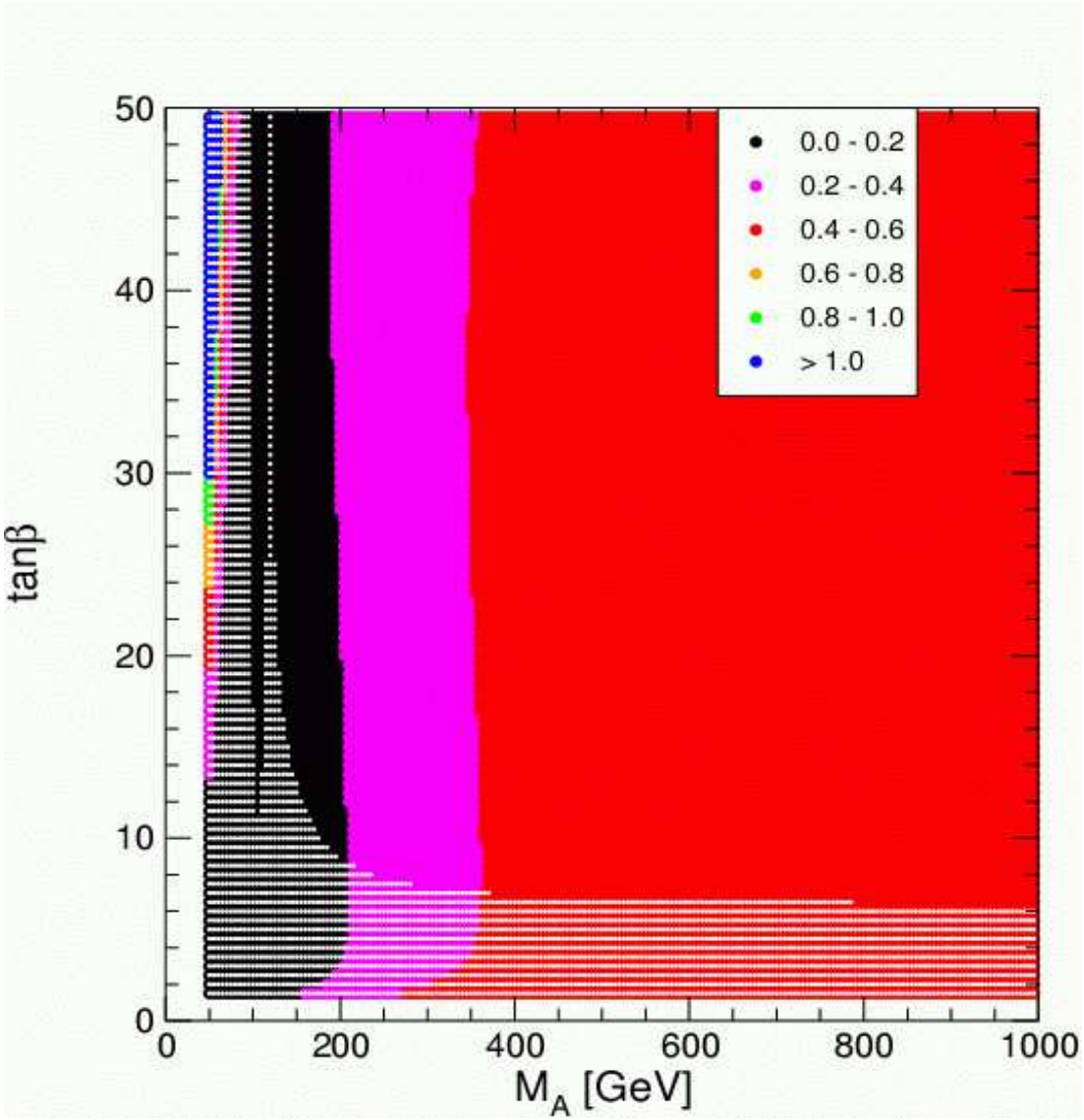
can be strongly suppressed

→ "gluophobic Higgs scenario"

[*M. Carena, S.H., C. Wagner, G. Weiglein '02*]

⇒ Strong suppression of $gg \to h \to \gamma\gamma$ possible over the whole parameter space

(not realized in mSUGRA/CMSSM, GMSB, AMSB, . . .)



Tevatron MSSM Higgs searches (II): "Heavy" MSSM Higgs bosons

Search modes:

$$b\,\bar{b} \to \phi\, b\,\bar{b}\ , \quad \phi = h, H, A$$
$$p\,\bar{p} \to \phi \to \tau^+\,\tau^-\ , \quad \phi = h, H, A$$

Strong enhancement compared to the SM:

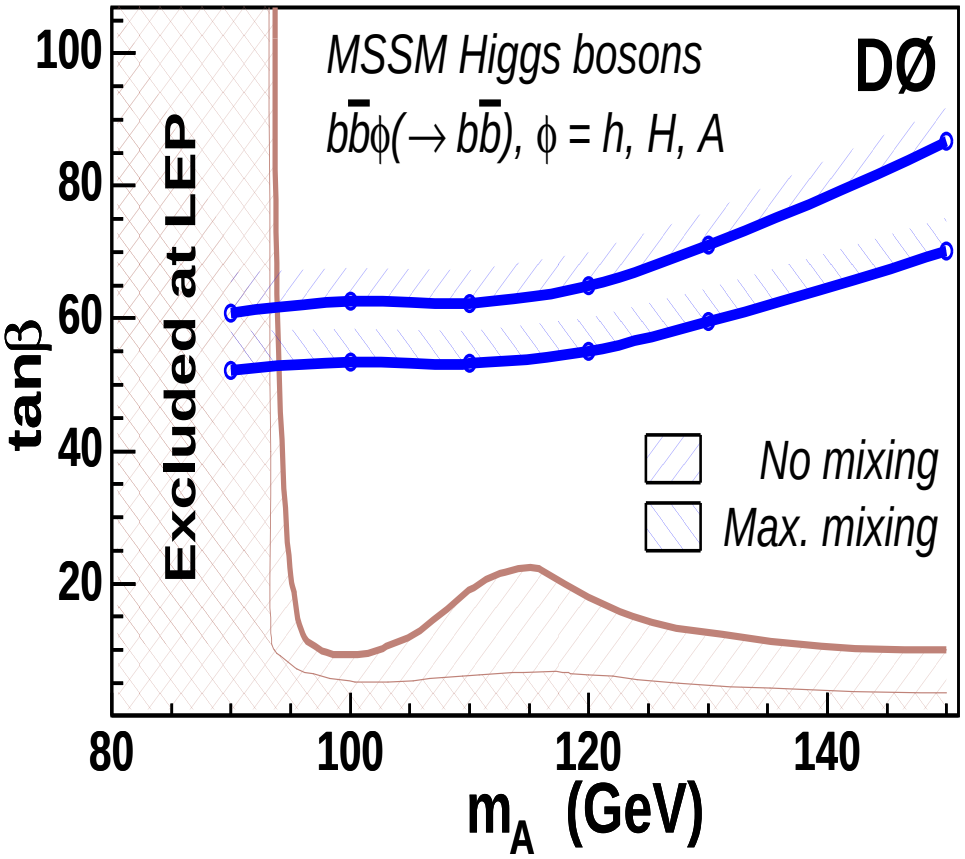
$$\sigma(b\bar{b}A) \times \mathrm{BR}(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

$$\sigma(gg, b\bar{b} \to A) \times \mathrm{BR}(A \to \tau^+\tau^-) \simeq \sigma(gg, b\bar{b} \to A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2+9}$$

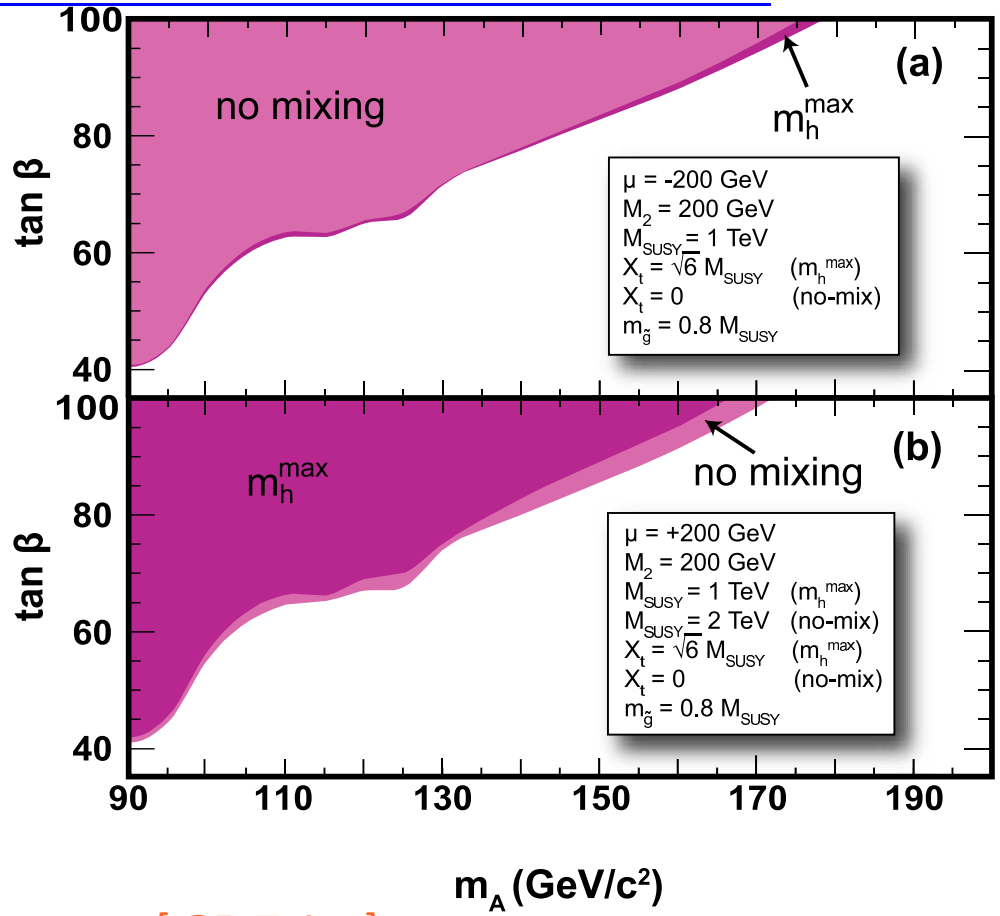
$$\Delta_b = \frac{2\alpha_s}{3\pi} m_{\tilde{g}}\,\mu\,\tan\beta \times I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}) + \frac{\alpha_t}{4\pi} A_t\,\mu\,\tan\beta \times I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu)$$

Either $H \approx A$ or $h \approx A \Rightarrow$ another factor of 2

Existing Tevatron data allows bounds on SUSY parameter space:



[D0 '05]



[CDF '05]

⇒ Bounds on the MSSM parameter space for low M_A, high $\tan\beta$:

$\tan\beta \approx 50$ excluded for $M_A \approx 100$ GeV

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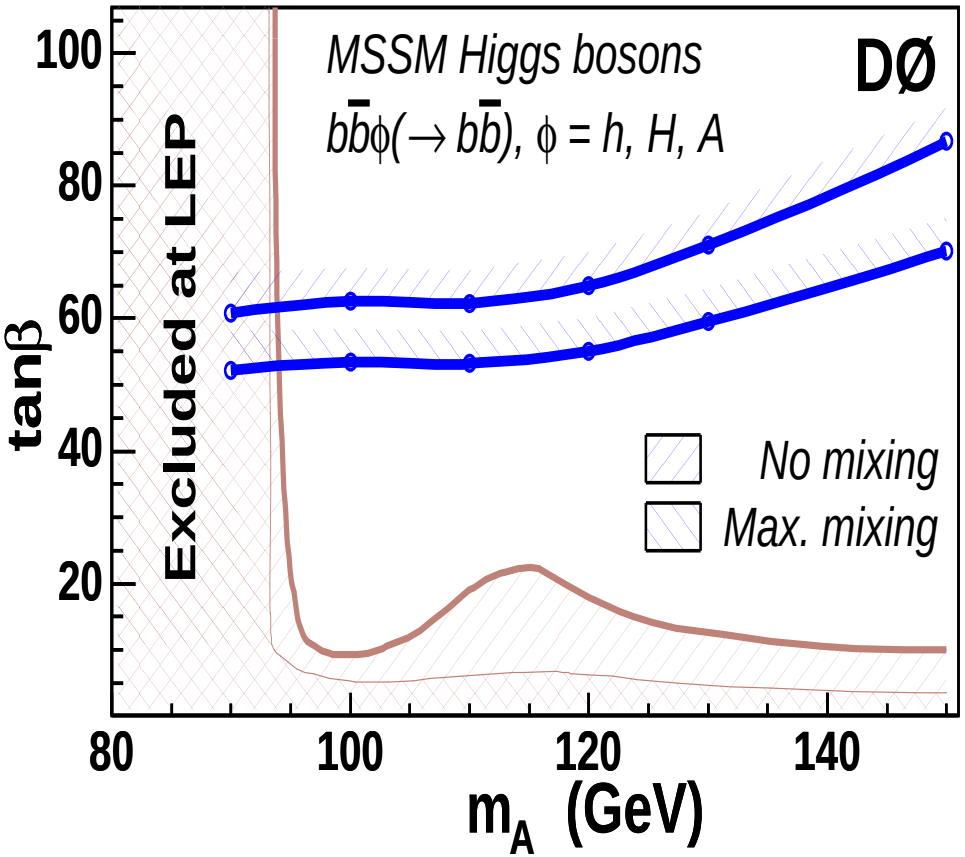
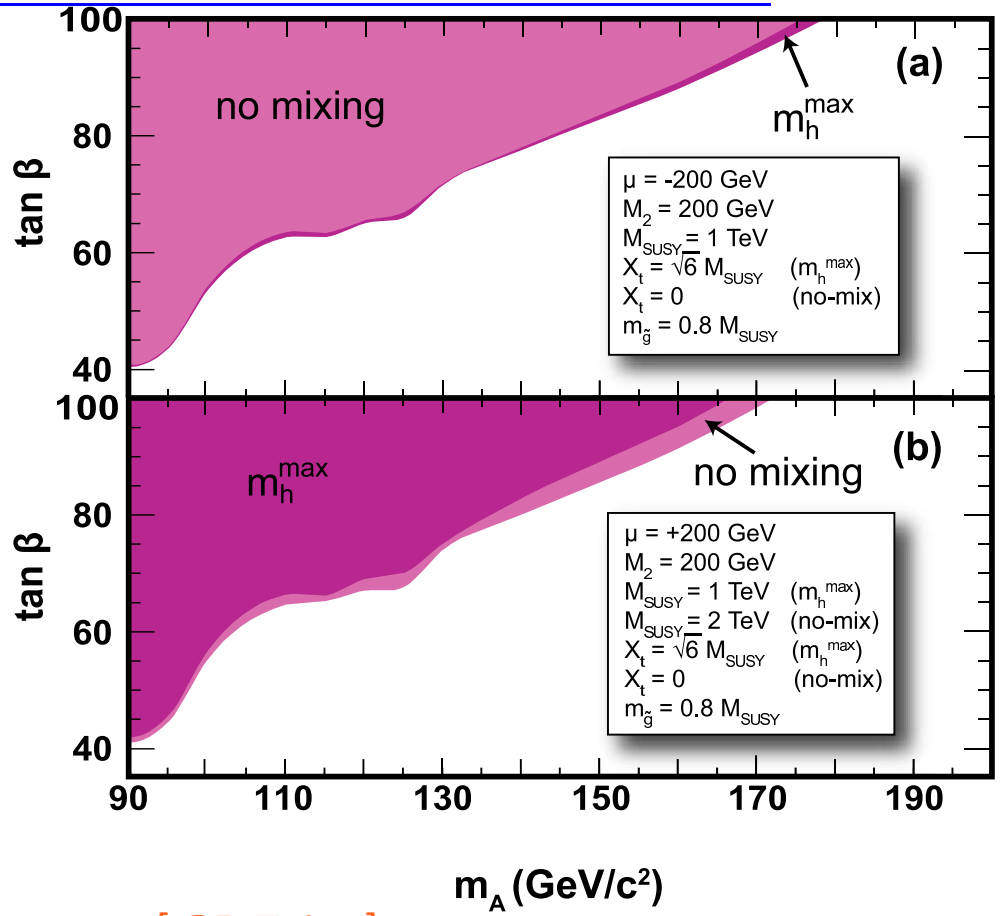


[D0 '05]



[CDF '05]

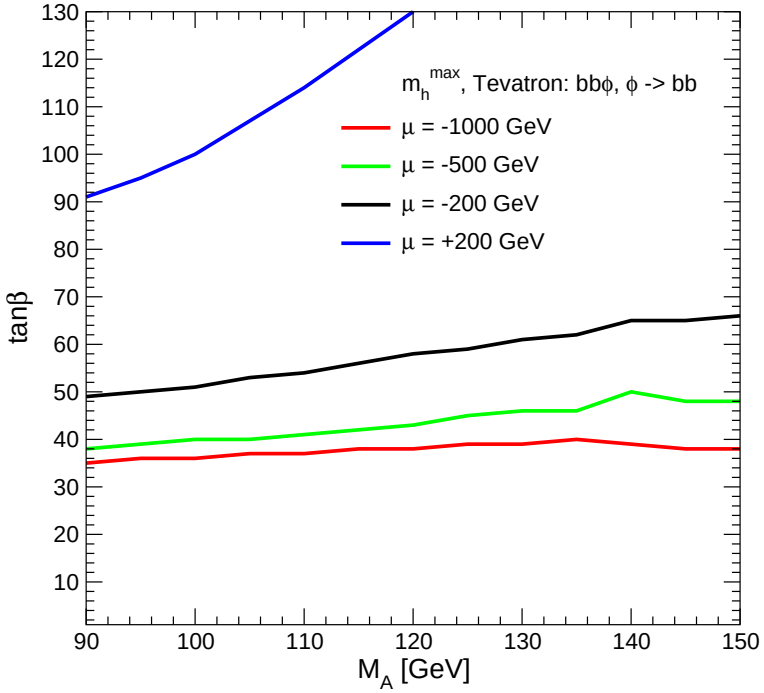
⇒ Bounds on the MSSM parameter space for low M_A, high $\tan\beta$:

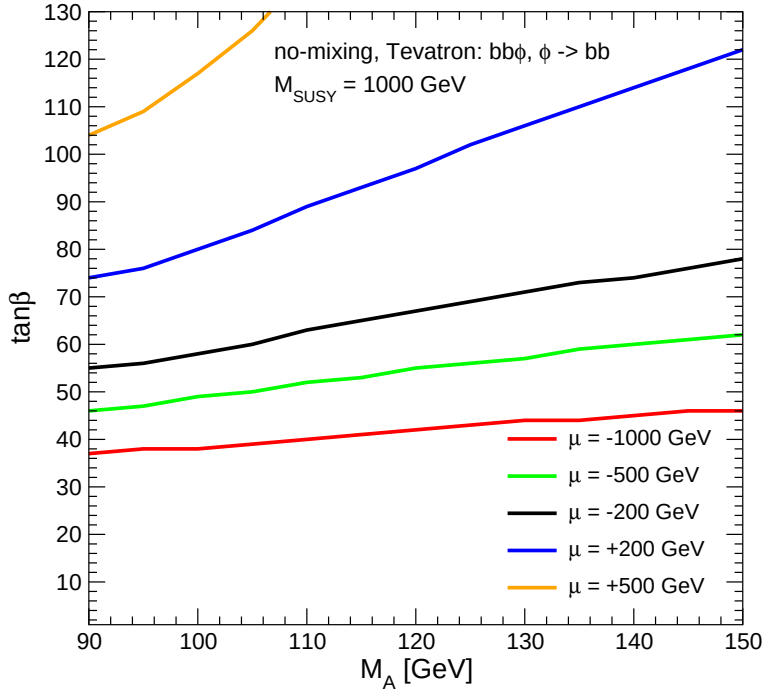
$\tan\beta \approx 50$ excluded for $M_A \approx 100$ GeV

in certain benchmark scenarios!

Dependence of Tevatron bounds from $b\bar{b}\phi, \phi \to b\bar{b}$ on μ:

[*M. Carena, S.H., C. Wagner, G. Weiglein '05*]





$\Rightarrow$ strong variation with the sign and absolute value of μ

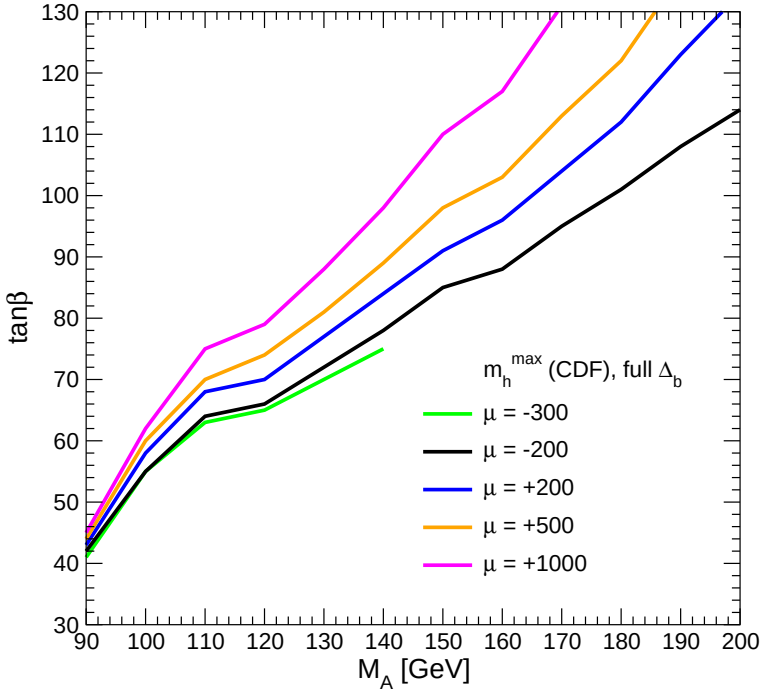
$\Rightarrow$ much stronger or weaker bounds possible

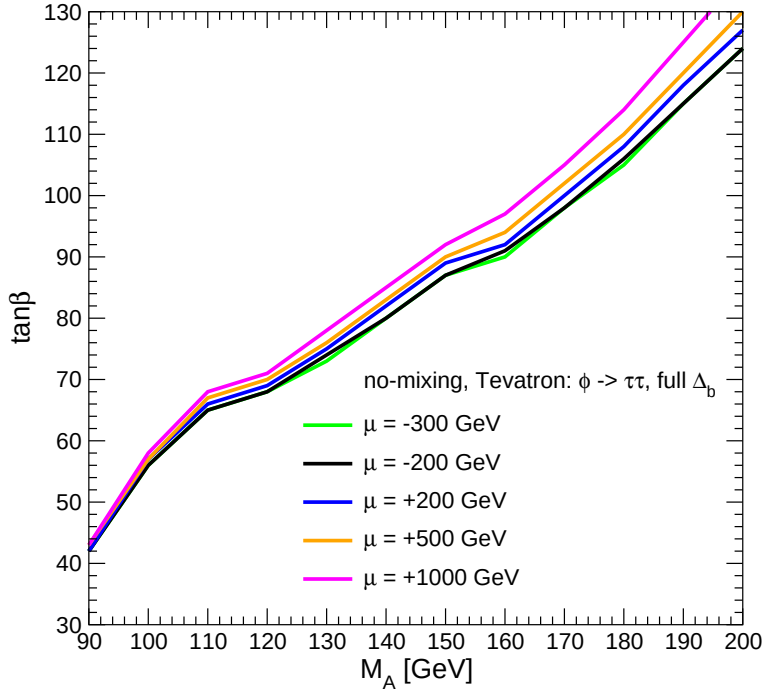
no bounds for $\mu \gtrsim 200$ GeV

(positive μ preferred by $(g-2)_\mu$)

Dependence of Tevatron bounds from $p\bar{p} \to \phi, \phi \to \tau^+\tau^-$ on μ:

[*M. Carena, S.H., C. Wagner, G. Weiglein '05*]





⇒ less strong variation with the sign and absolute value of μ

(→ numerical compensations in production and decay)

⇒ still much stronger or weaker bounds possible

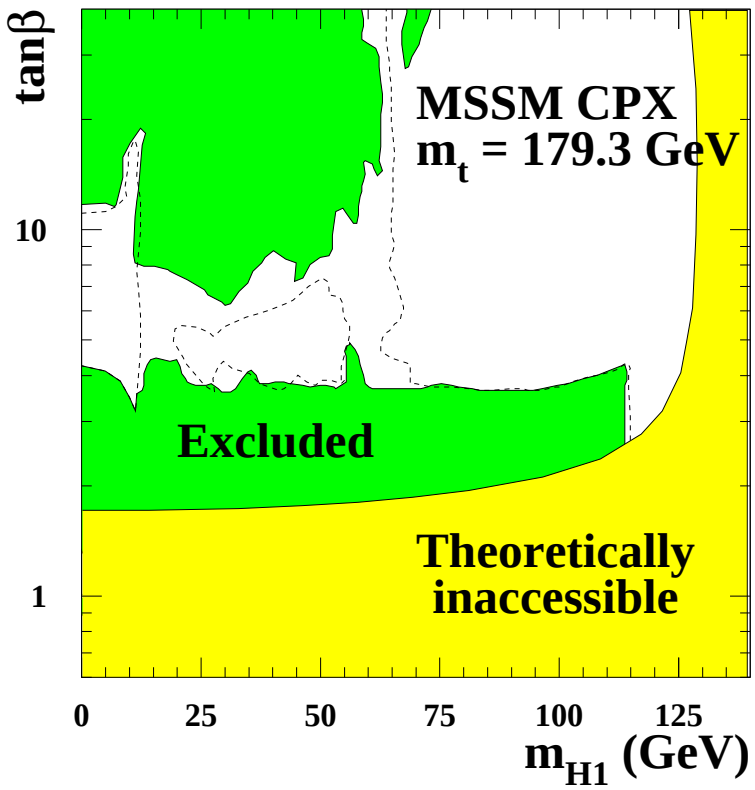
strong dependence on benchmark scenario

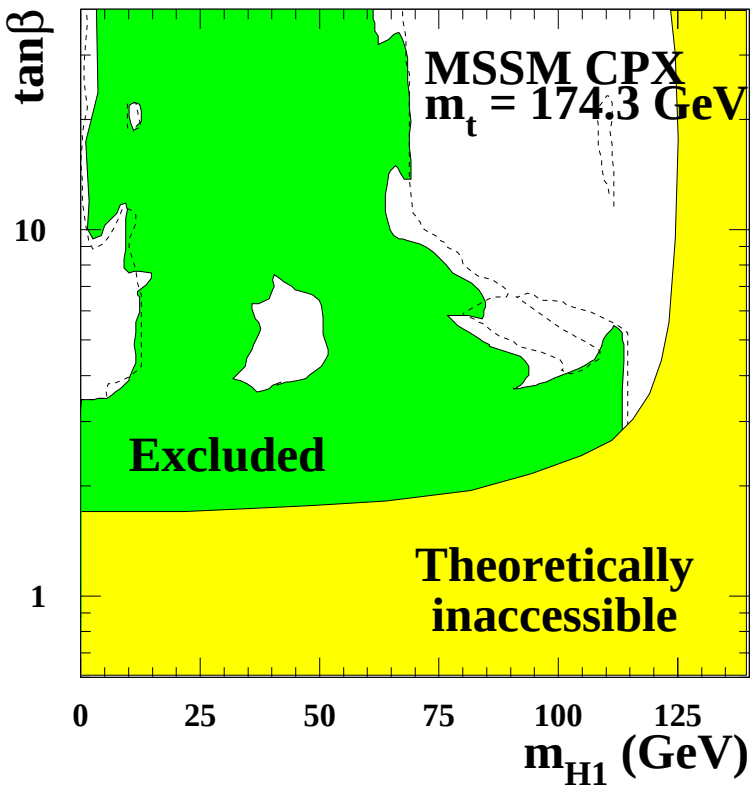
Higgs search in the MSSM with complex parameters: (CPX scenario)

[*LEP Higgs Working Group '06*]

⇒ large uncovered holes, even for very low Higgs masses

⇒ observe m_t dependence:



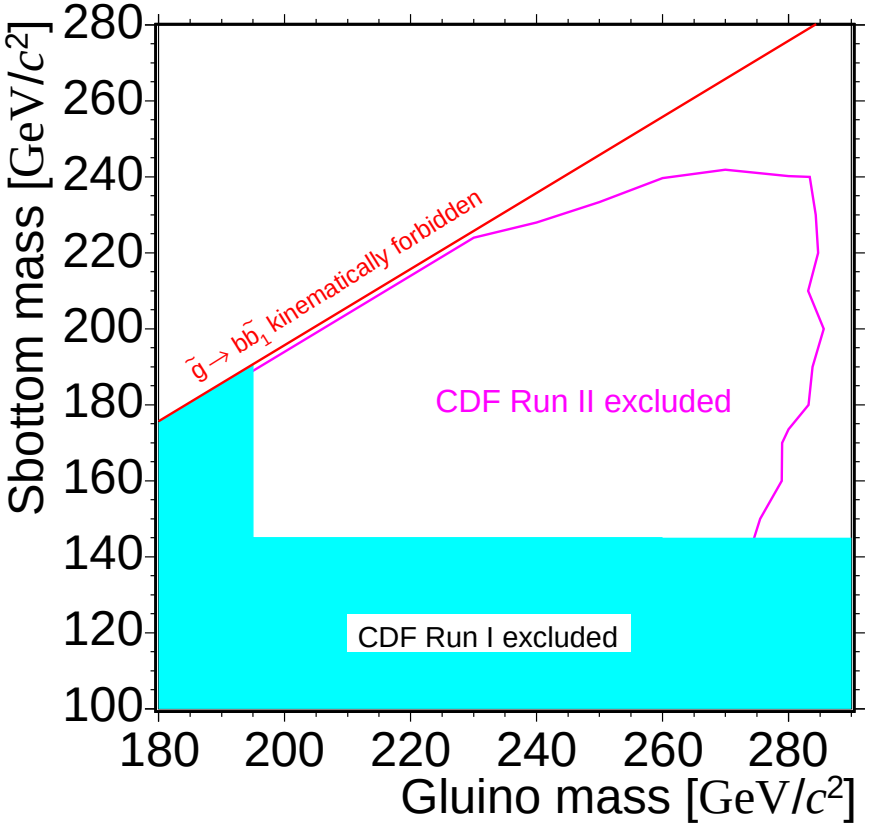


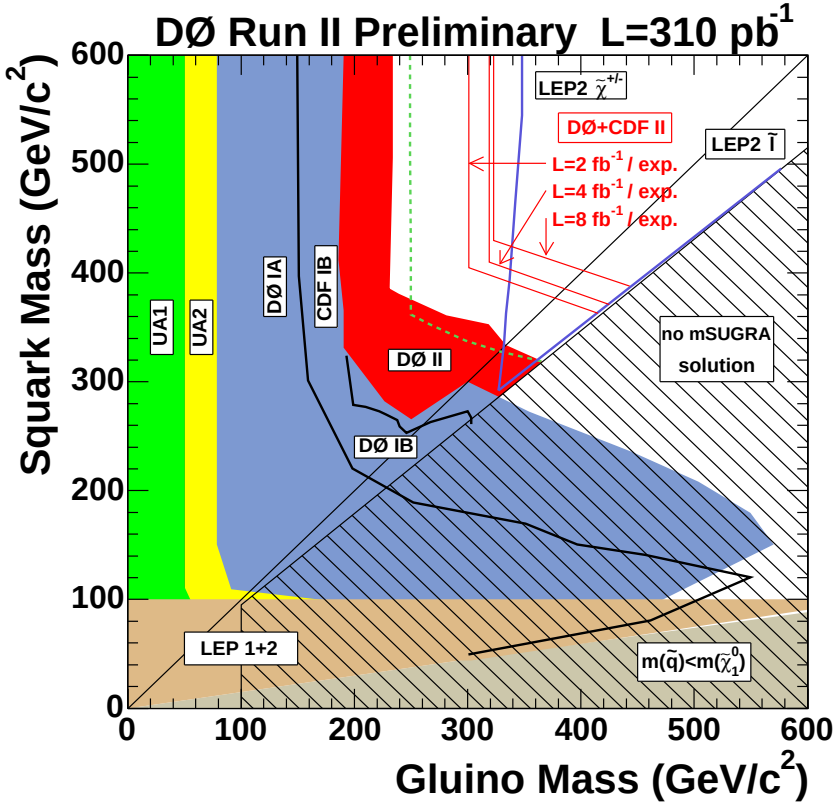
What the Tevatron can do to cover the holes:

⇒ measure a **small** and **accurate** m_t value

3. Direct searches: SUSY (short)

The Tevatron is actively searching for squarks/gluinos:

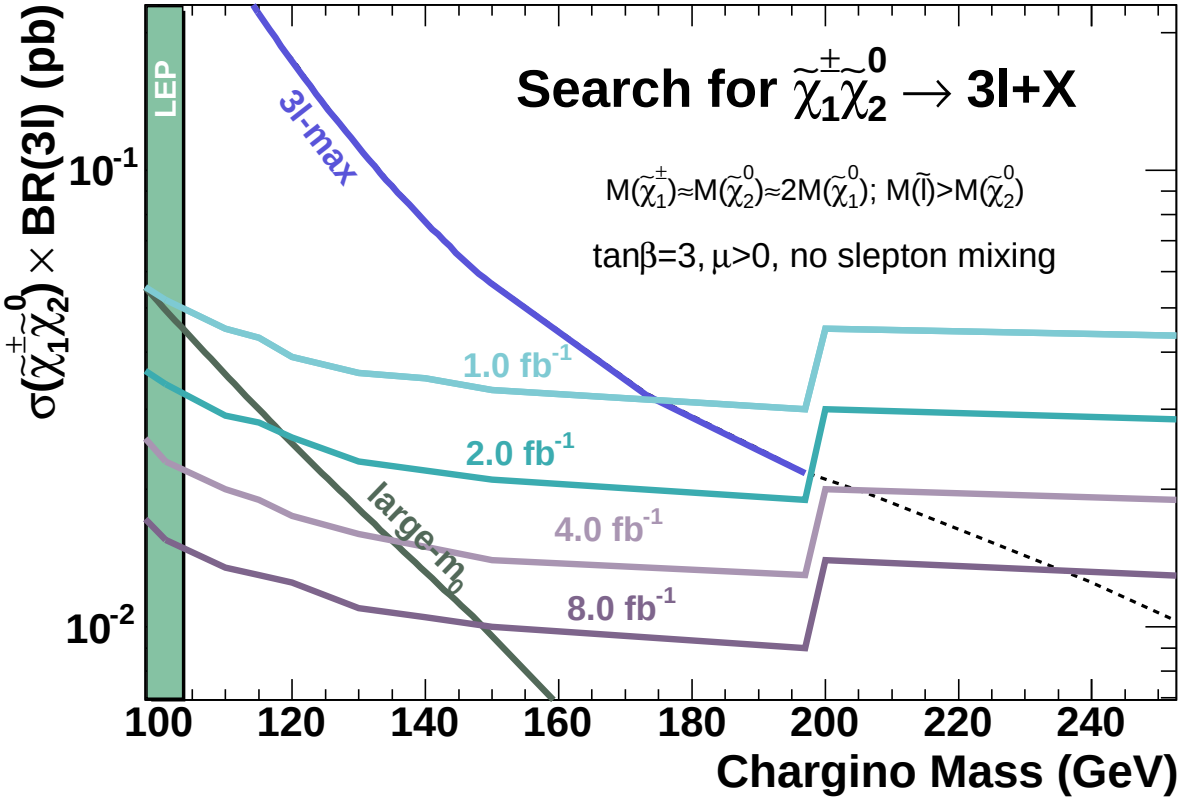




$\Rightarrow$ often certain assumptions are made

Another example: search for charginos/neutralinos:

[*D0 '06*]



⇒ note the "restrictive assumptions"

The Tevatron has a very good potential to test large parts of the MSSM parameter space!

From a theorist's perspective:

- Results are easily usable only if few (or no!) assumption are made

- if searches are performed in certain models
  $\Rightarrow$ as many models as possible should be covered
  i.e. not only mSUGRA/CMSSM

- if searches are performed in a certain model
  $\Rightarrow$ cover wide ranges of underlying parameters
  $\tan\beta$: decay chains change at large $\tan\beta$
  A_0: off-diagonal terms for stops and sbottoms can be important

- competition is healthy :-)
  $\Rightarrow$ eventually combination of CDF and D0 data
  (competition with the LHC . . .)

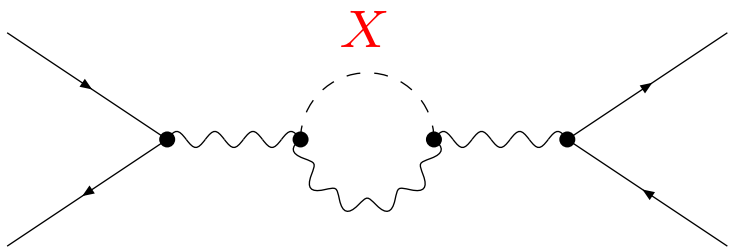
4. Indirect searches: Electroweak Precision Observables

Comparison of electro-weak precision observables with theory:

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

The most prominent example: m_t vs. M_W

Several steps:

1. Evaluate theory prediction in the SM:
   - take an m_t value
   - vary last free parameter, M_H^{SM}, in a reasonable range: 114 . . . 400 GeV
   - evaluate M_W prediction

   $\Rightarrow$ Red band in the m_t–M_W plane

2. Evaluate theory prediction in the MSSM:
   - Scan over all MSSM parameters independently
   - take an m_t value
   - evaluate the Higgs boson mass (not a free parameter)
   - evaluate M_W prediction [*hep-ph/0604147*]

   $\Rightarrow$ Green band in the m_t–M_W plane

   $\Rightarrow$ small blue overlap area of both models in m_t–M_W plane

   $\rightarrow$ MSSM behaves SM-like: all SUSY masses heavy

   $\rightarrow$ SM behaves MSSM-like: $M_H^{\mathrm{SM}} \lesssim 135$ GeV

3. Compare with experimental values

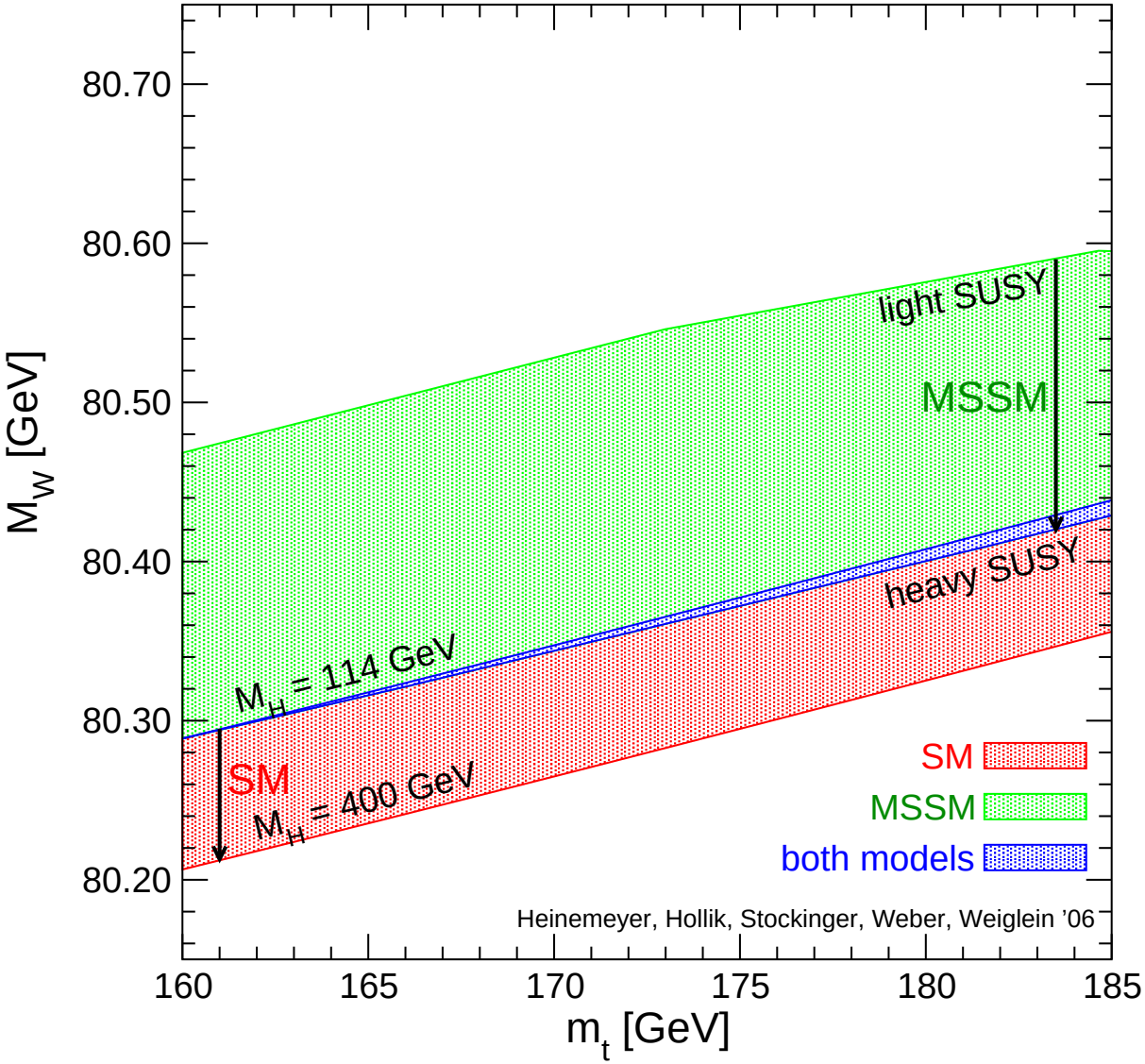
4. Read off preferred parameter space

   SM: preferred Higgs boson mass

   MSSM: preferred SUSY masses

Prediction for M_W in the SM and the MSSM :

[*S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '06*]



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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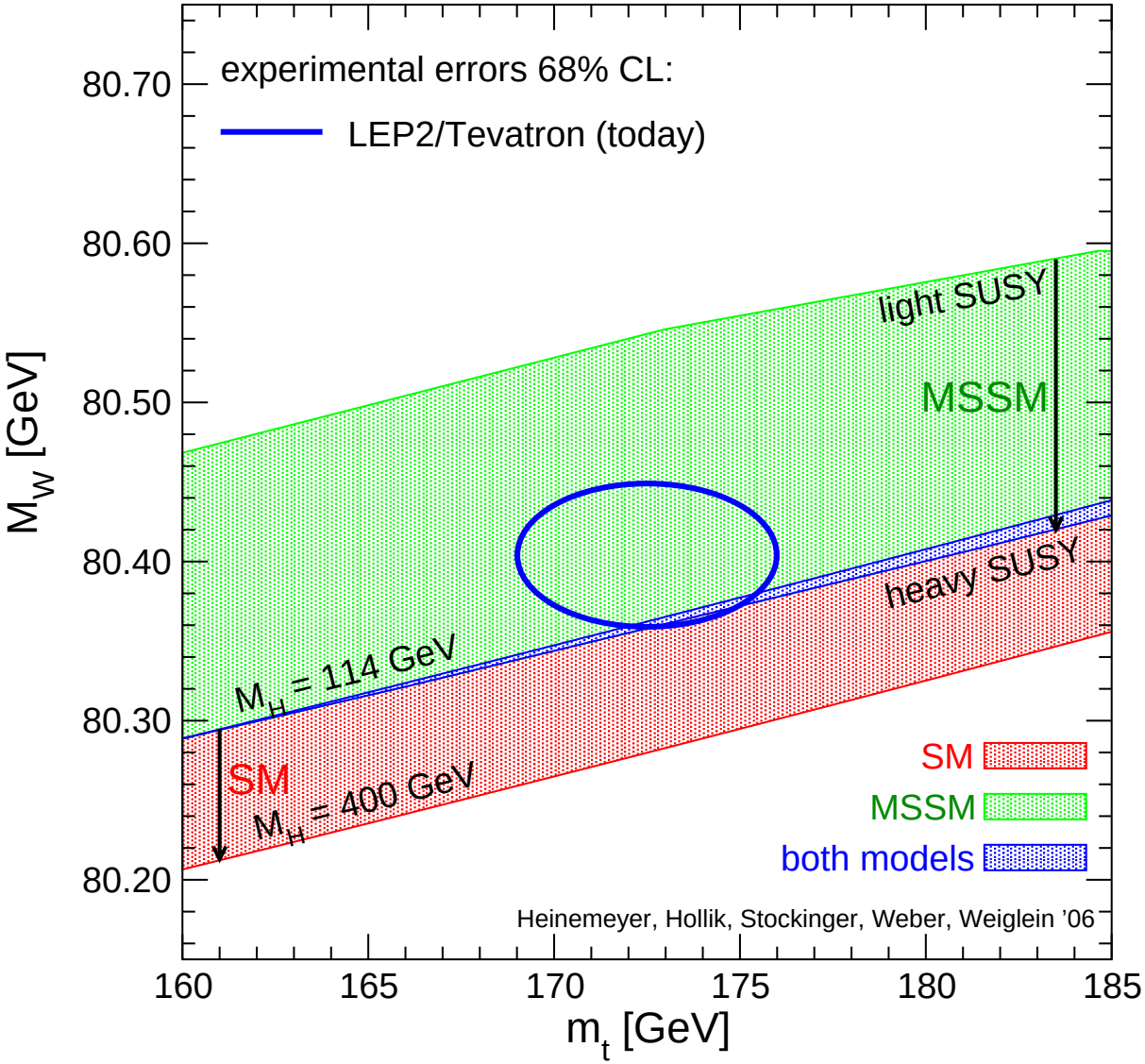

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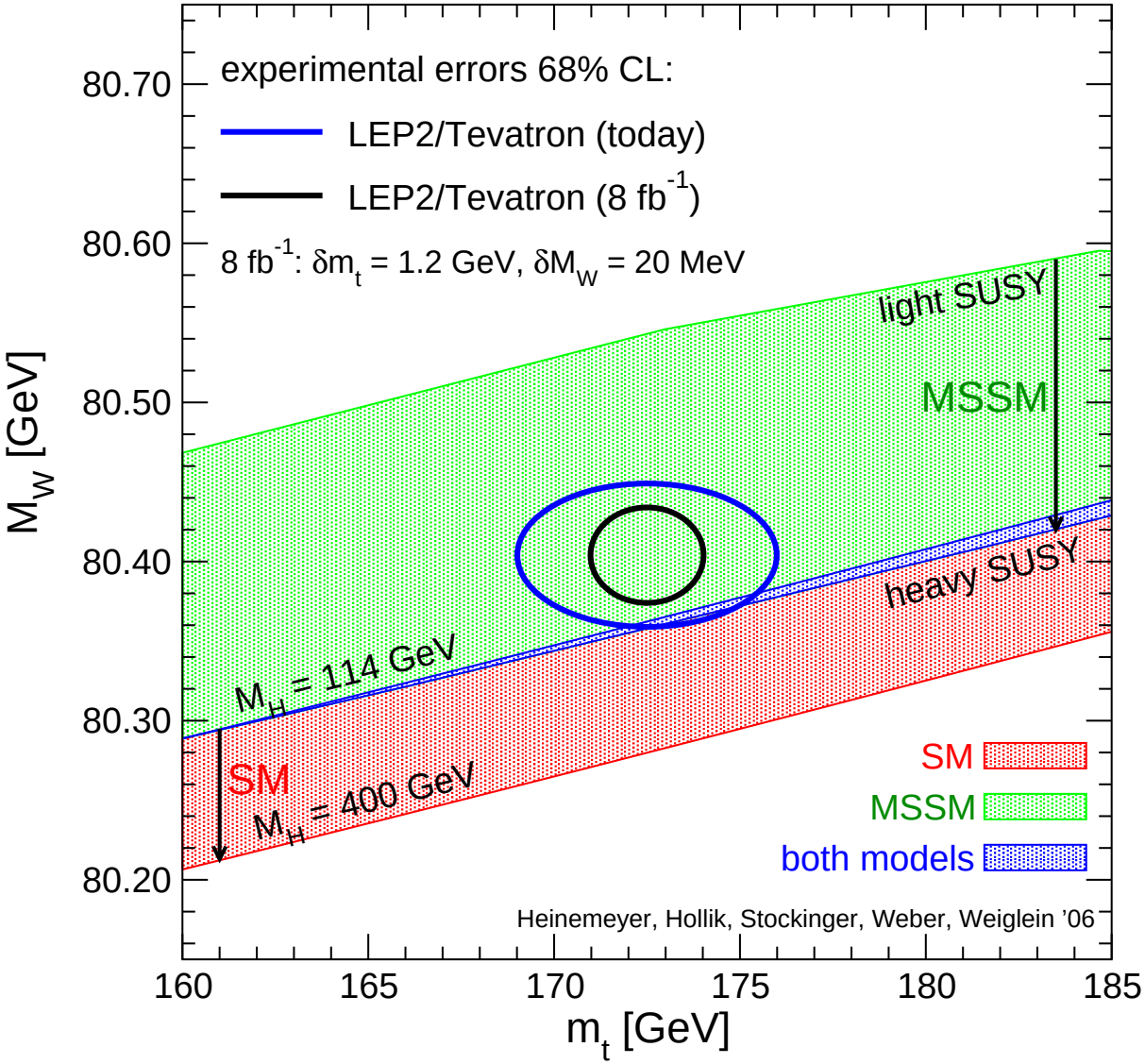

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Experimental errors: today vs. (Tevatron-)future

	today	Tevatron	LHC	ILC	GigaZ
δM_W [MeV]	34	20	15	10	7
$\delta \sin^2\theta_{\text{eff}} (\times 10^5)$	17	17	17	–	1.3

Relevant SM parametric errors: $\delta(\Delta\alpha_{\text{had}}) = 5 \times 10^{-5}$, $\delta M_Z = 2.1$ MeV

	$\delta m_t = 2$	$\delta m_t = 1$	$\delta m_t = 0.1$	$\delta(\Delta\alpha_{\text{had}})$	δM_Z
ΔM_W [MeV]	12	6	1	1	2.5
$\delta \sin^2\theta_{\text{eff}}$ [10^{-5}]	6	3	0.3	1.8	1.4

To keep the parametric error induced by m_t at/below the level of other uncertainties:

$\Rightarrow$ $\delta m_t \lesssim 0.2$ GeV for M_W, $\delta m_t \lesssim 0.5$ GeV for $\sin^2\theta_{\text{eff}}$

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$\Rightarrow$ Tevatron can improve current knowledge a lot!

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$\Rightarrow$ Tevatron can contribute substantially here

Determination of preferred SUSY masses:

→ focus on mSUGRA/CMSSM → T

Procedure:

1. use as many as possible precision observables:
   M_W, $\sin^2\theta_{\text{eff}}$, $(g-2)_\mu$, BR$(b \to s\gamma)$, M_h, CDM
   (CDM allows only thin strips in the CMSSM parameter space)
   → interested in results including B-physics? Ask me for my back-up!
2. Scan over (remaining) parameter space:
   – fixed $\tan\beta = 10, 50$
   – fixed $A_0/m_0 = 0, \pm 1, \pm 2$
3. Perform χ^2 fit
   m_t plays an important role (see talk by S.H. in top session :-)
4. Find preferred values for masses
   ⇒ Tevatron reach

→ focus on mSUGRA/CMSSM

mSUGRA/CMSSM:

⇒ 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

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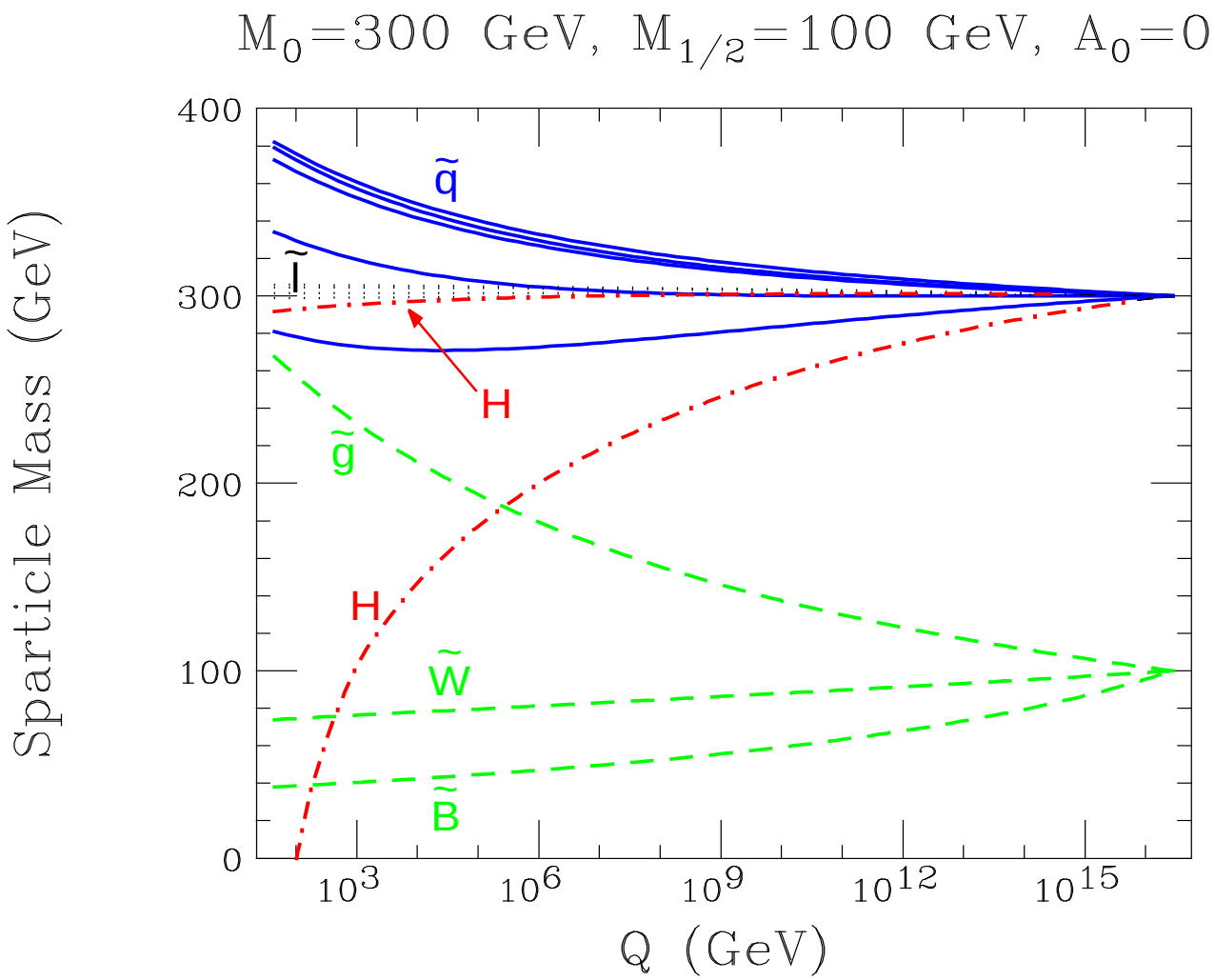
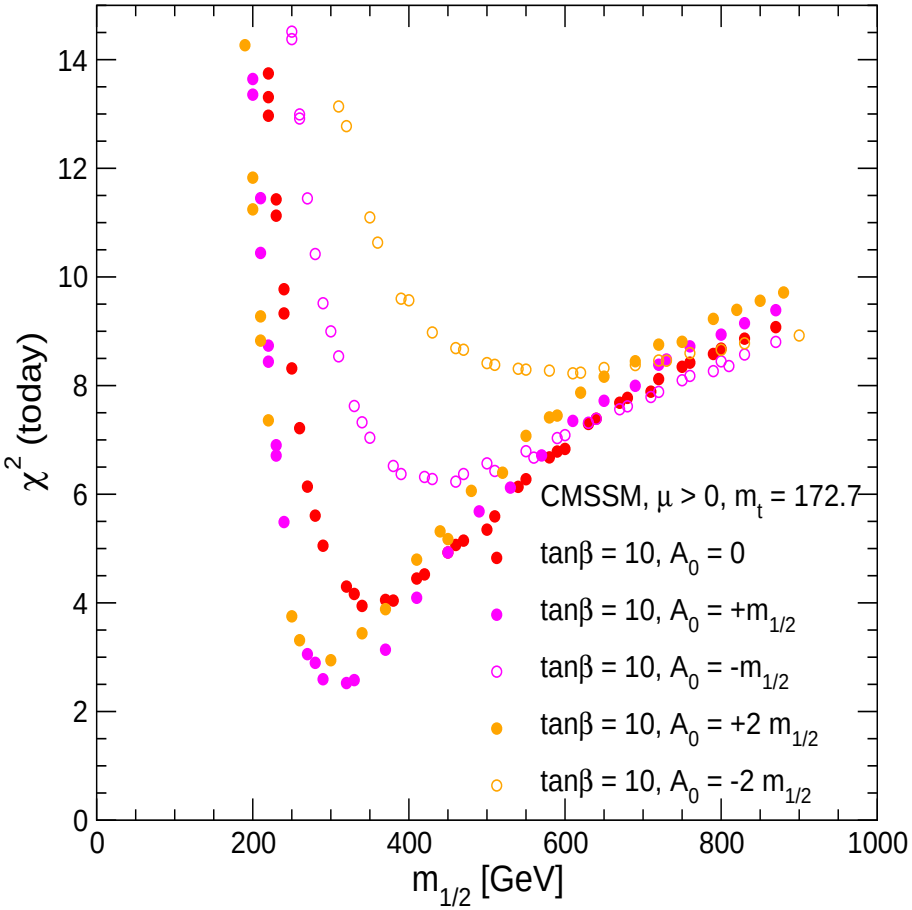


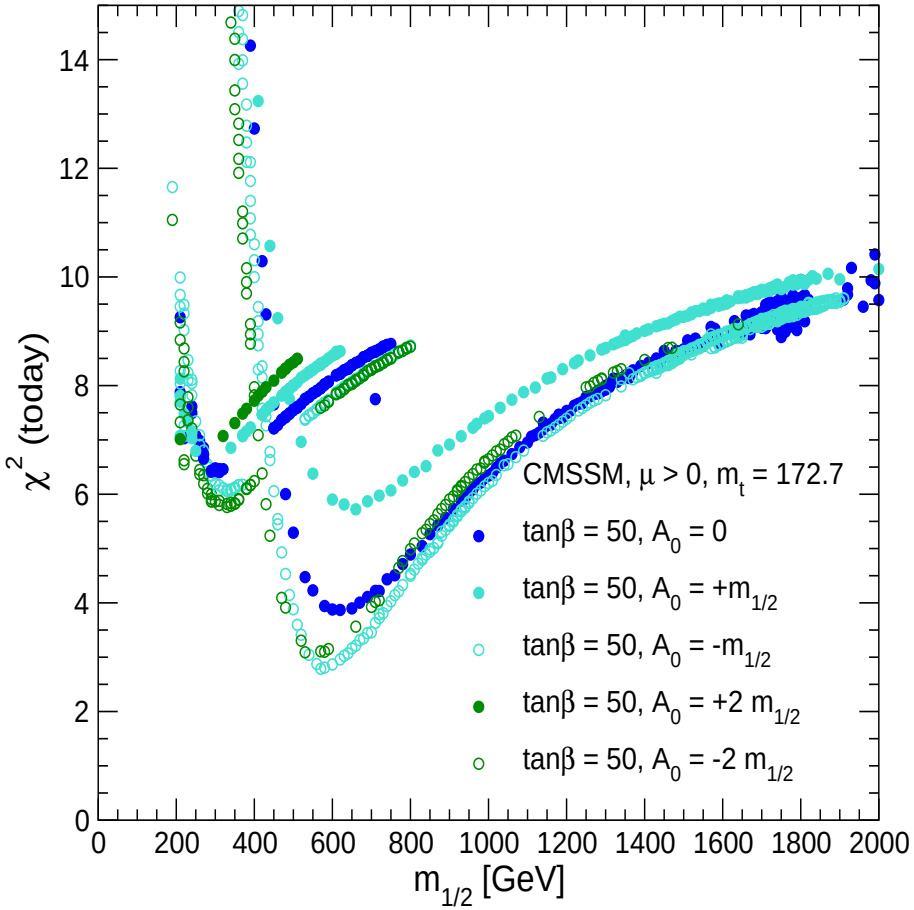
Result for total χ^2:

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

$\tan\beta = 10$



$\tan\beta = 50$



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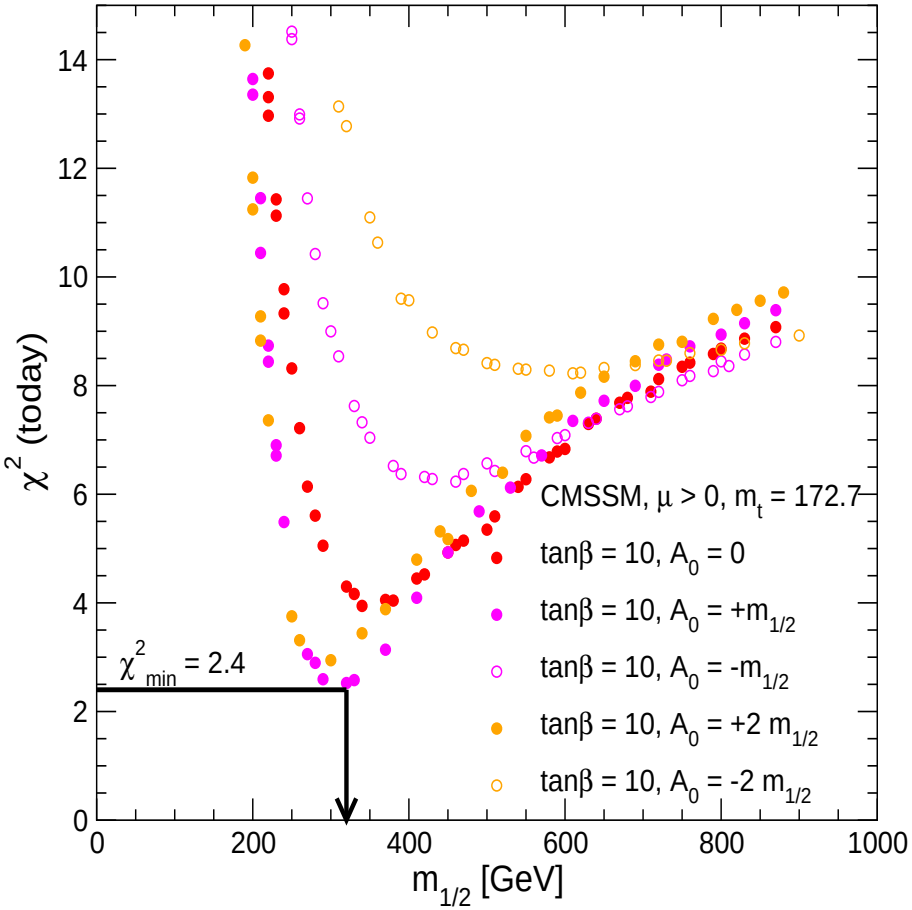

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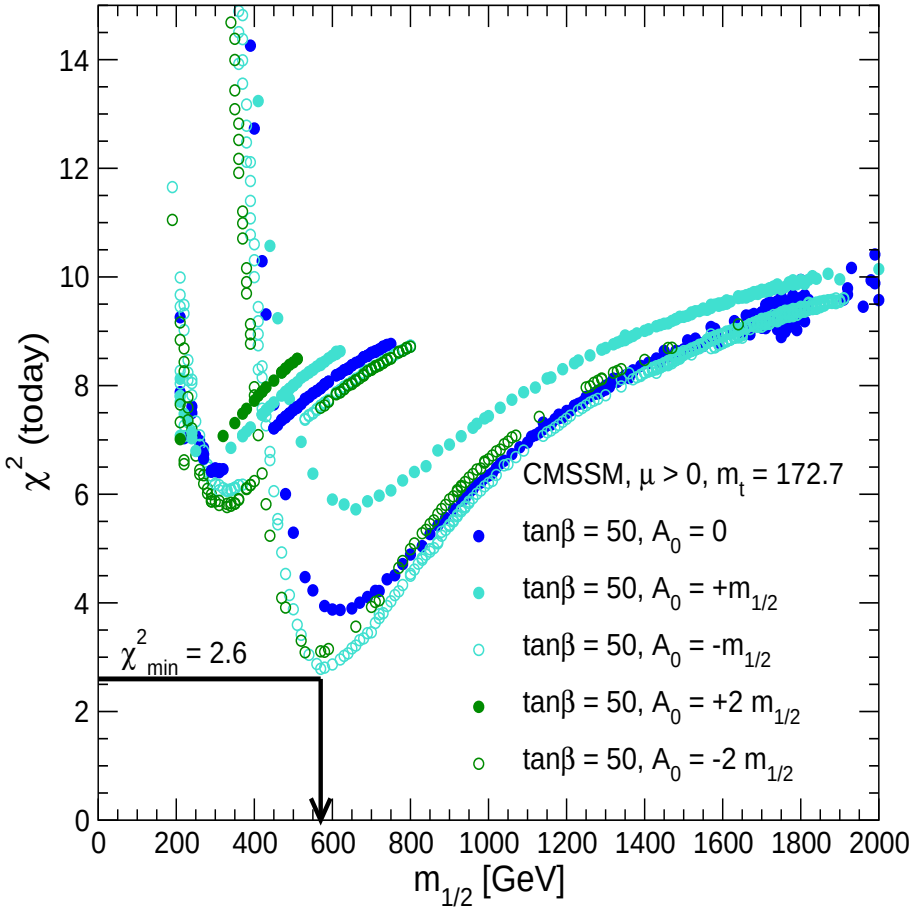

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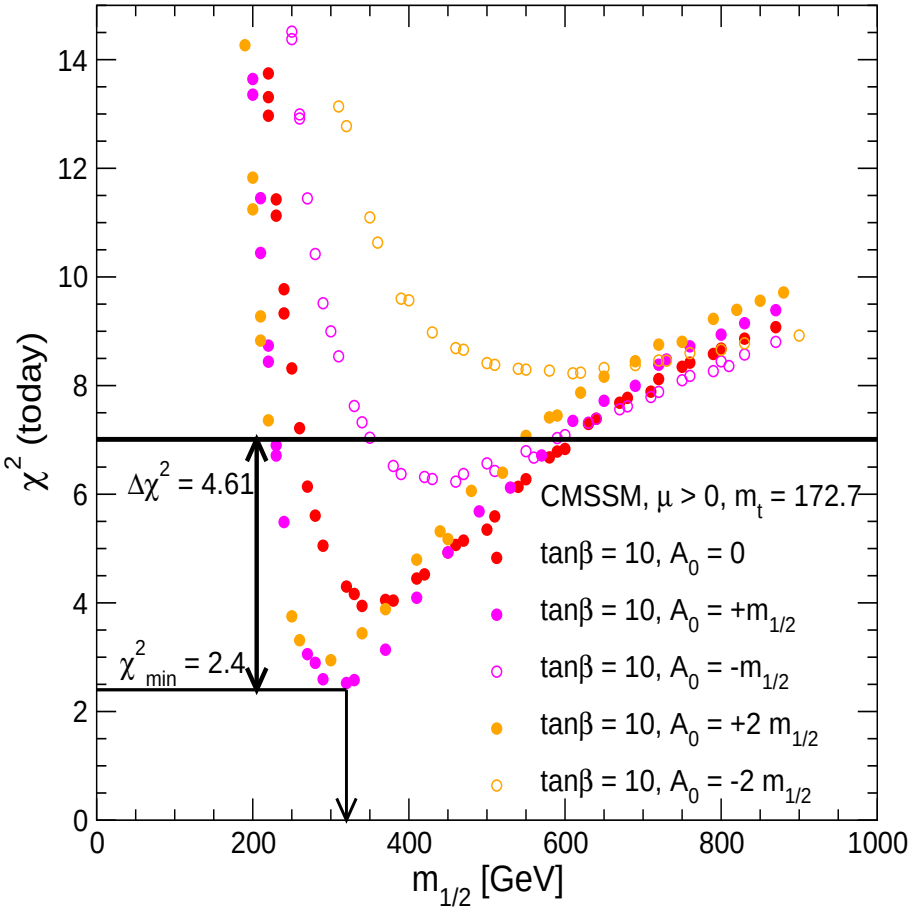

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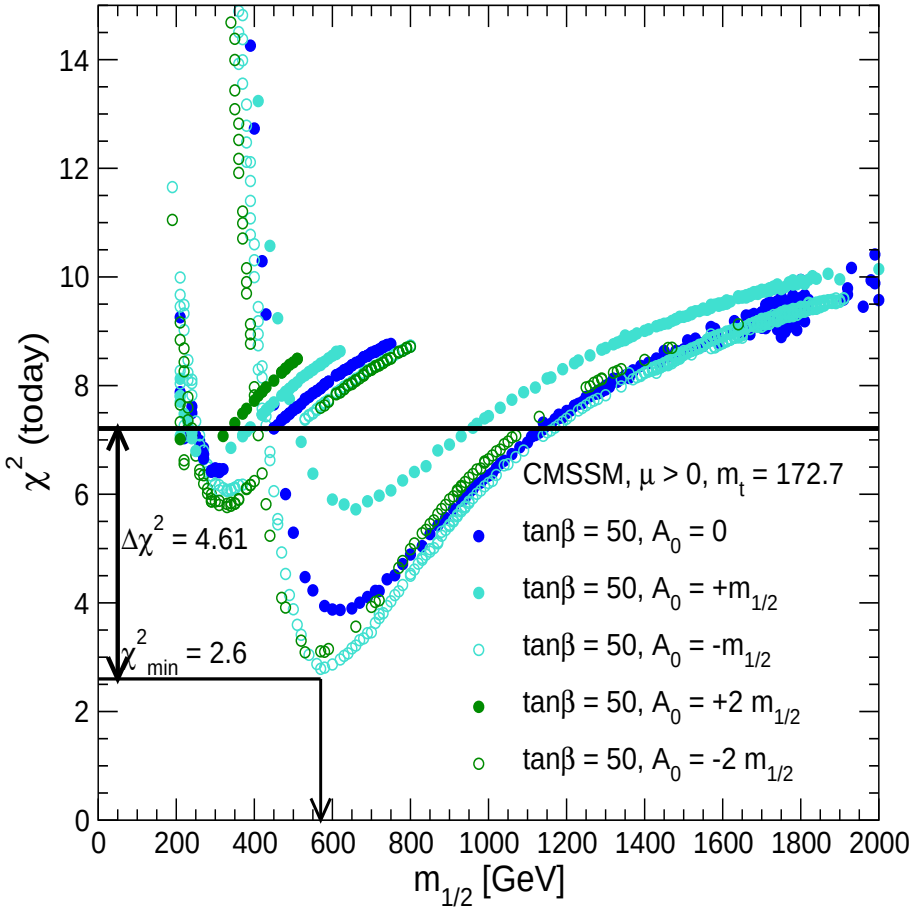
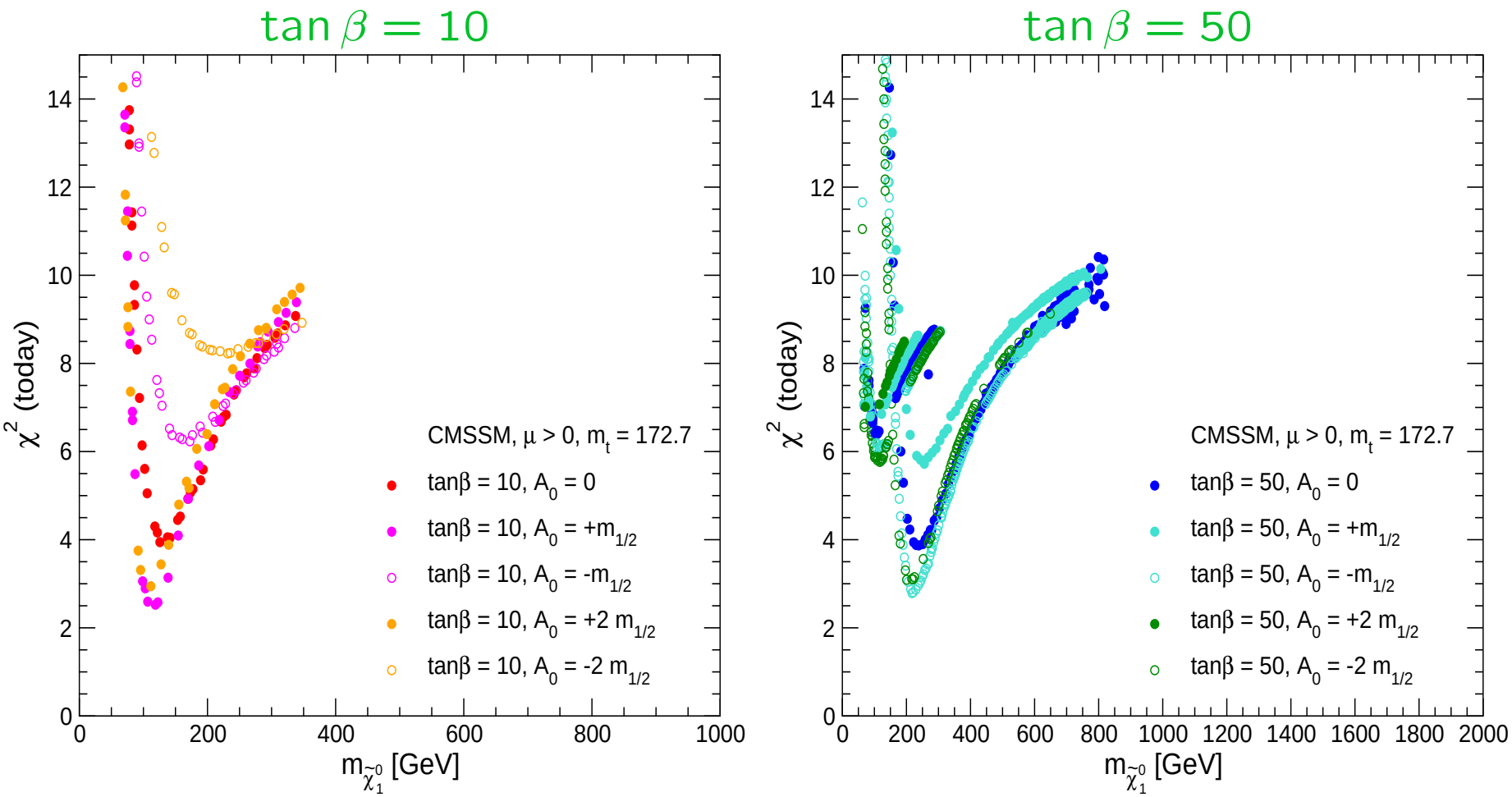


$\Rightarrow$ overall fit very good, $\chi^2_{\text{tot,min}} \approx 2.5$

$\Rightarrow$ upper bound on $m_{1/2}$

CMSSM: LSP mass for $\tan\beta = 10, 50$

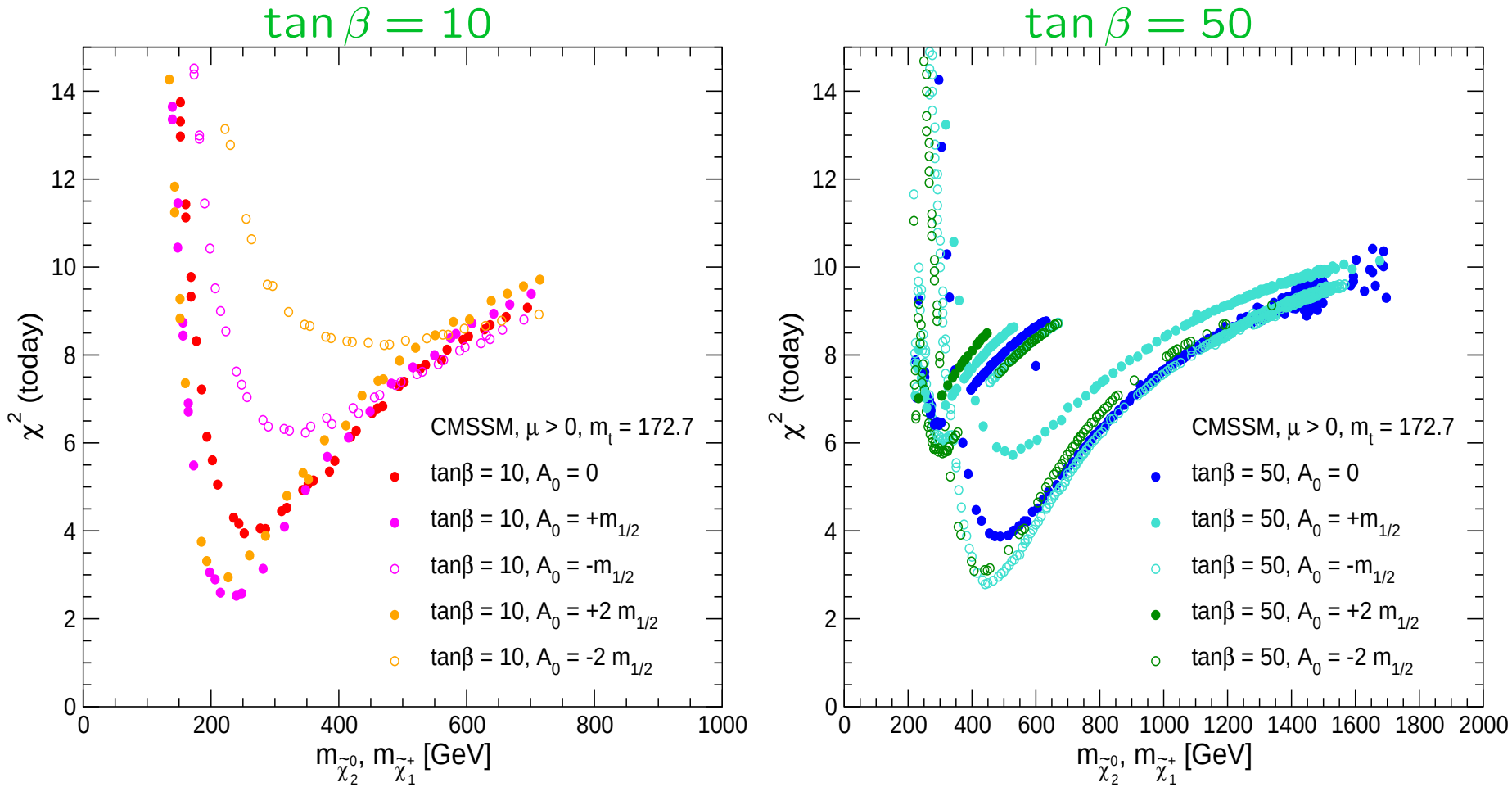
[*J. Ellis, S.H., K. Olive, G. Weiglein '06*]



$\longrightarrow$ not observable alone

CMSSM: light neutralino/chargino masses for $\tan\beta = 10, 50$

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

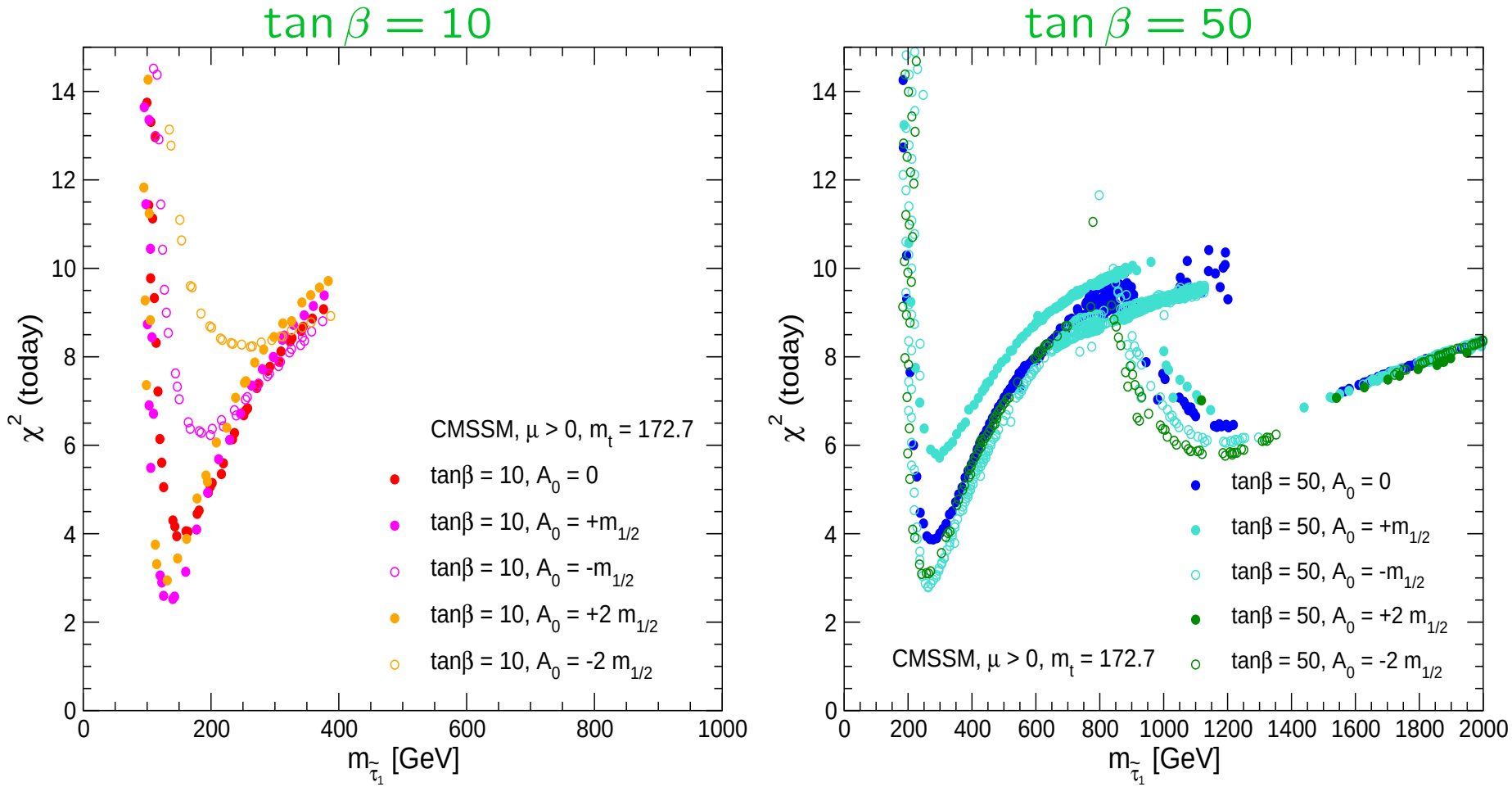


$\tan\beta = 10 \Rightarrow$ good(?) chances for the Tevatron

$\tan\beta = 50 \Rightarrow$ only focus point might be accessible

CMSSM: lightest stau mass for $\tan\beta = 10, 50$

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

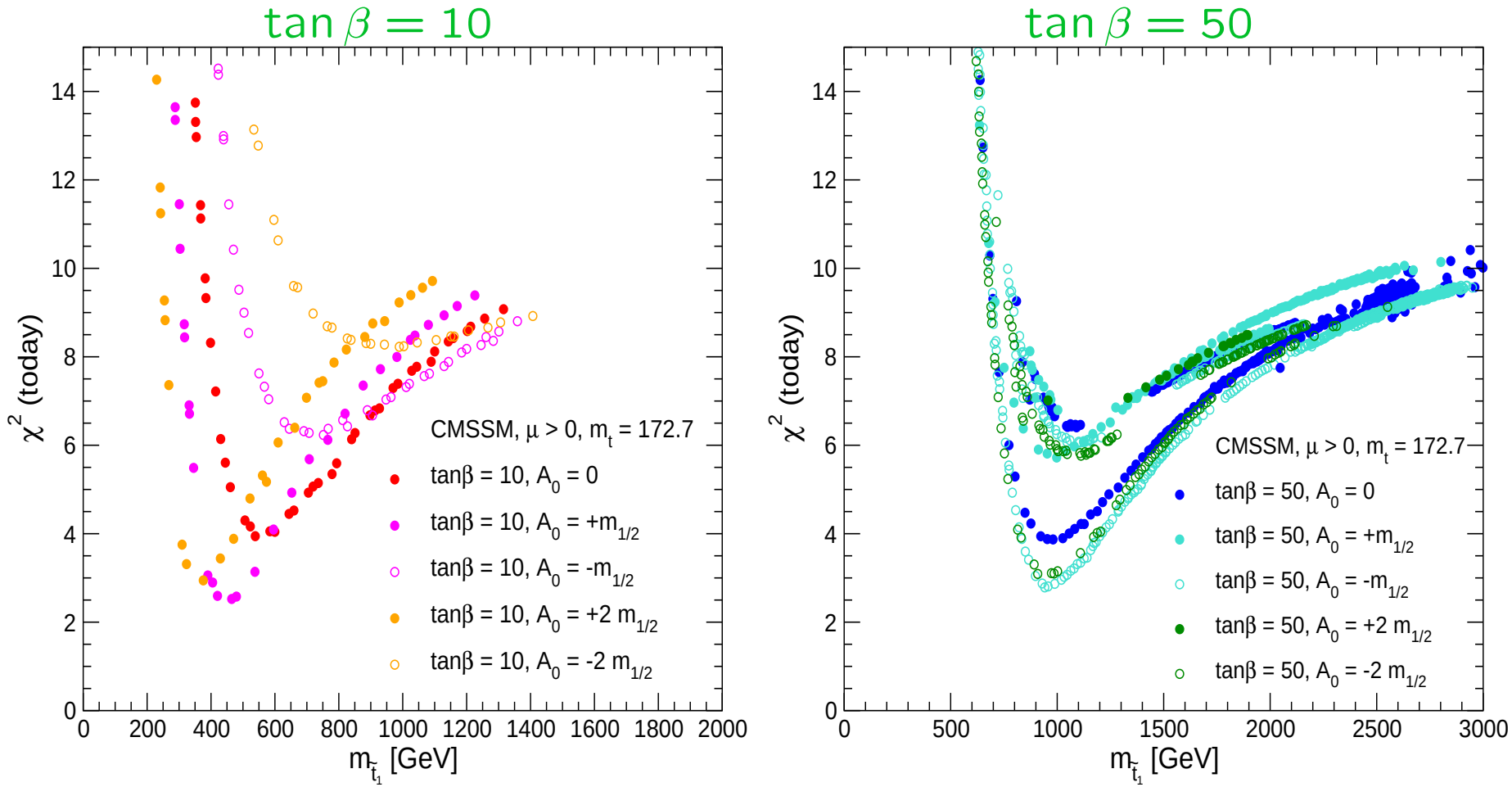


$\tan\beta = 10 \Rightarrow$ again good(?) prospects for the Tevatron

$\tan\beta = 50 \Rightarrow$ partially in reach??

CMSSM: lightest stop mass for $\tan\beta = 10, 50$

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

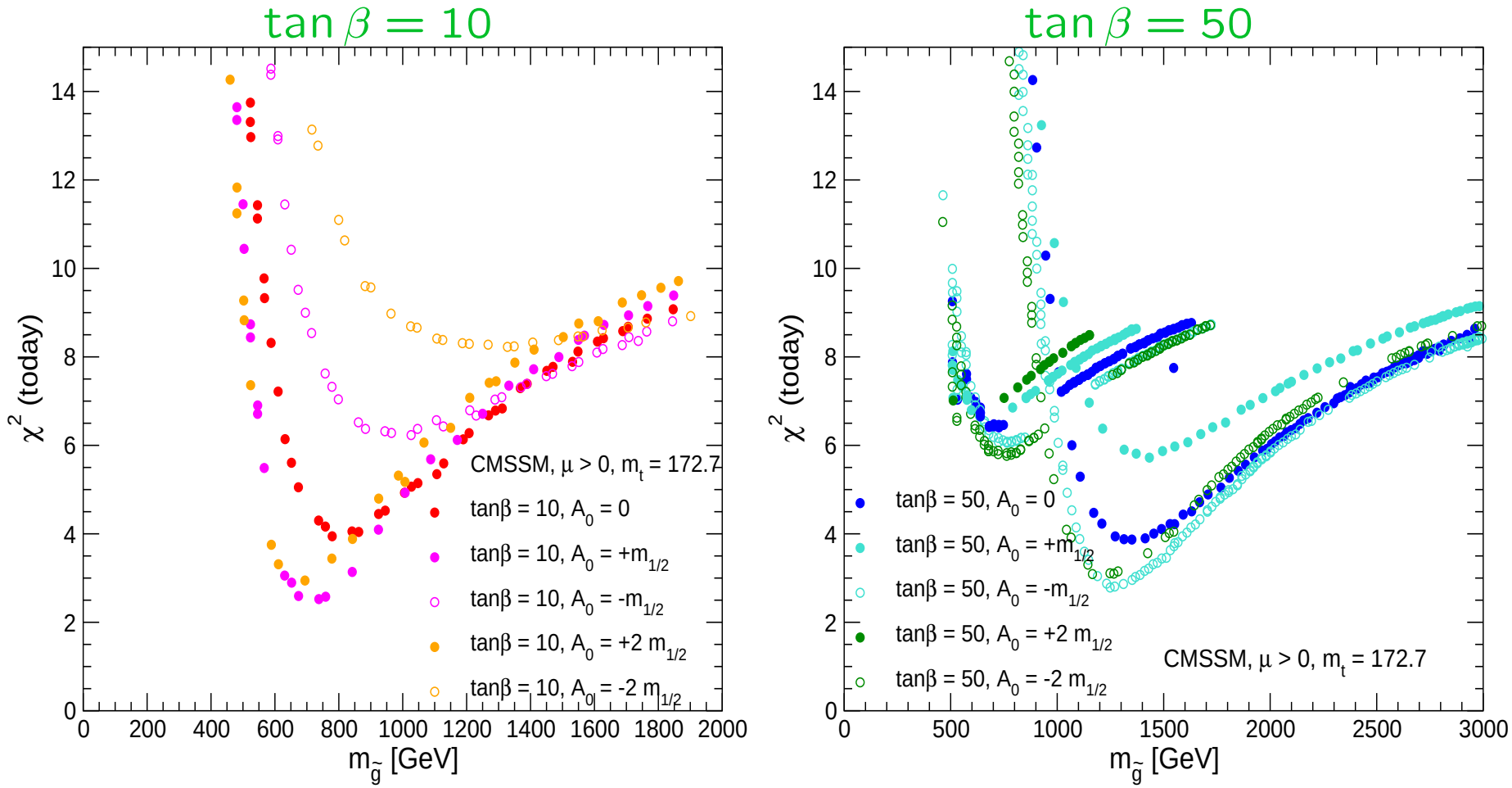


$\tan\beta = 10 \Rightarrow$ mostly too heavy

$\tan\beta = 50 \Rightarrow$ definitely too heavy

CMSSM: gluino mass for $\tan\beta = 10, 50$

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



$\tan\beta = 10 \Rightarrow$ definitely too heavy

$\tan\beta = 50 \Rightarrow$ definitely too heavy

Summary of Tevatron reach in CMSSM/mSUGRA:

(very similar results in many other simplified MSSM versions)

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

- light neutralino/chargino
  $\tan\beta = 10 \Rightarrow$ good(?) chances for the Tevatron
  $\tan\beta = 50 \Rightarrow$ only focus point might be accessible
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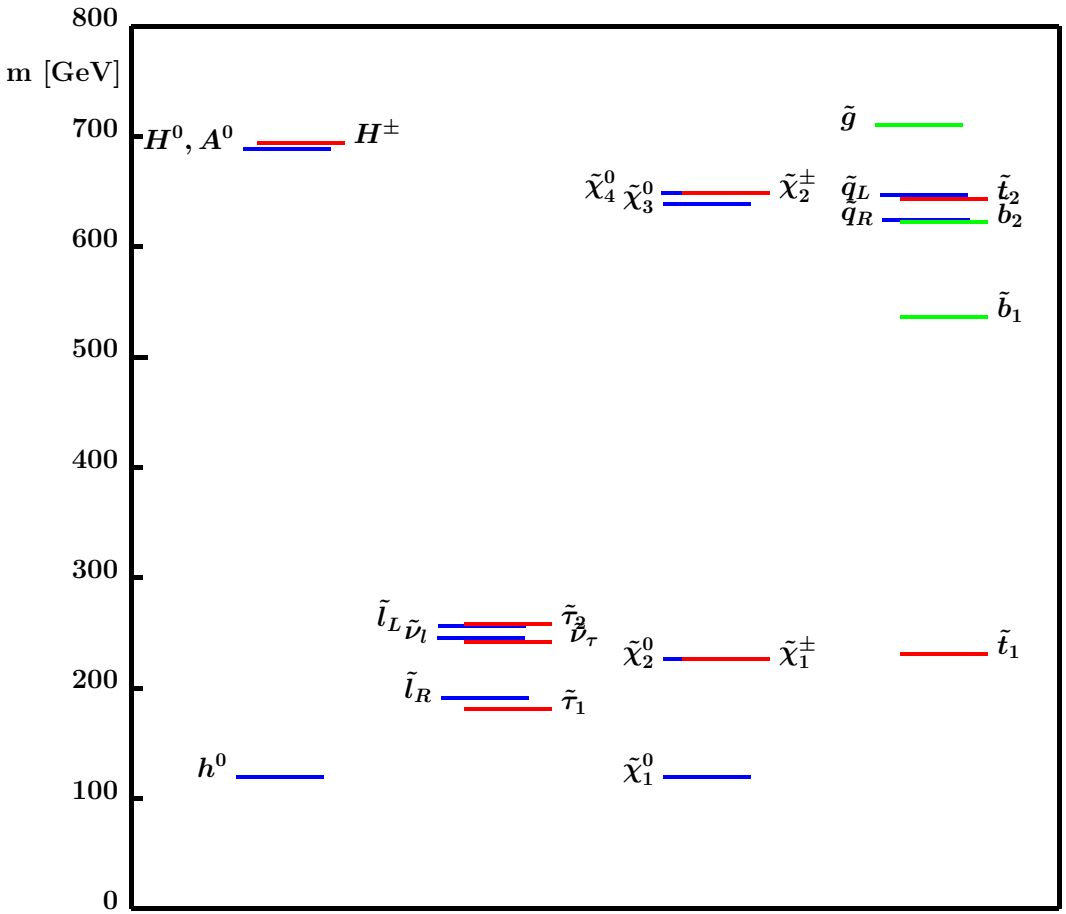
- gluino
  $\tan\beta = 10 \Rightarrow$ definitely too heavy
  $\tan\beta = 50 \Rightarrow$ definitely too heavy

$\Rightarrow$ non-colored particles: good prospects

$\Rightarrow$ colored particles in reach are disfavored by EWPO in simplified models!

Fine and known scenario: SPS 5:



Light stops (and sbottoms and gluinos and . . .) are possible in more general models or with relaxed constraints from other sectors

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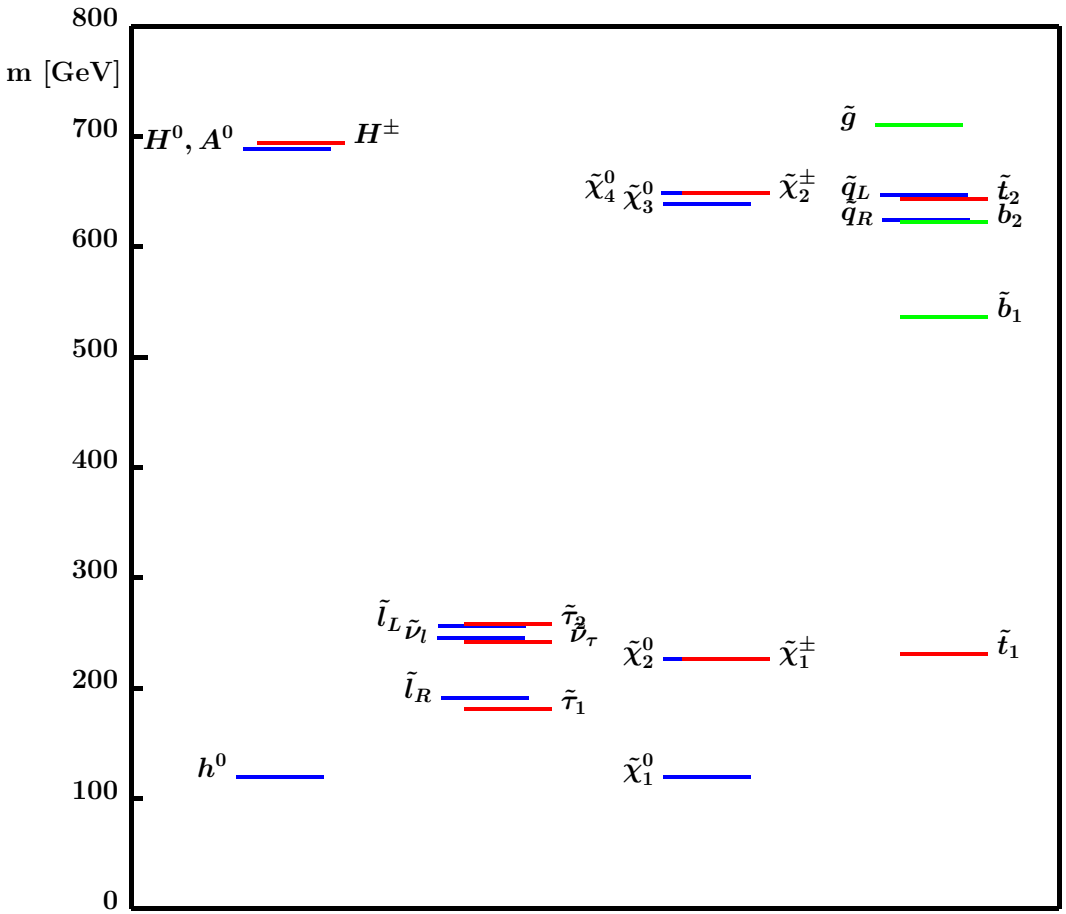

Light stops (and sbottoms and gluinos and . . .) are possible in more general models or with relaxed constraints from other sectors

$\Rightarrow$ go and find them!

5. Conclusinos $\oplus$ theorist's wish list

- There are two ways to search for SUSY at the Tevatron:
  - search for non-SM Higgs, SUSY particles
  - search for indirect effects of SUSY particles via EWPO

- Search for SUSY Higgses: SM-like

  Tevatron can exclude up to $M_H \lesssim 130$ GeV
  $\Rightarrow$ Tevatron can exclude CMSSM/mSUGRA, GMSB, AMSB
  ...or find a light Higgs and confirm their prediction :-)

- Search for SUSY Higgses: the "heavy" Higgses

  search in benchmark scenarios new: μ has large impact
  $\Rightarrow$ Tevatron has good chances for large $\tan\beta$
  MSSM parameters are crucial – interpretation possibly difficult

- Electroweak precision observables (incl. B-physics):

  (in CMSSM/mSUGRA and many other simplified models)
  $\Rightarrow$ favor relatively light SUSY masses
  $\Rightarrow$ non-colored particles: (very?) good prospects

Theorist's wish list:

- Search for SUSY Higgses: SM-like

  → framework to combine channels/CDF and D0

  → cross section bounds

- Search for SUSY Higgses: the "heavy" Higgses

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- SUSY searches:

  → model independent bounds (on masses . . .)

  → framework to combine CDF and D0

- There is something out there . . .

  and the Tevatron could have a good chance to see it!

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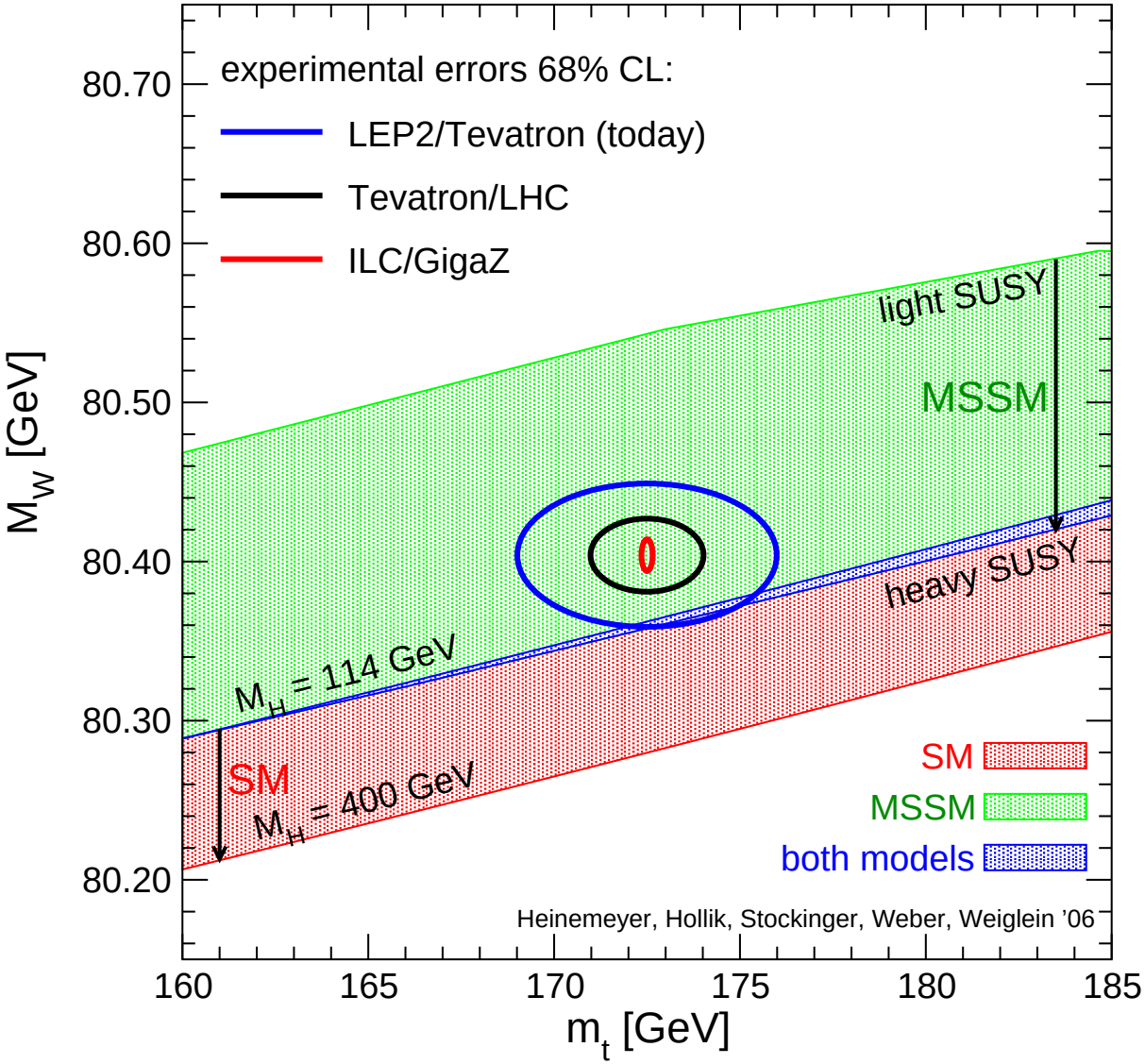
- There is something out there . . .
  and the Tevatron could have a good chance to see it!

- ⇒ Please try as hard as you can, it is definitely worth the effort!

Back-up

Prediction for M_W in the SM and the MSSM :

[*S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '06*]



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scan over
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SM band:
variation of M_H^{SM}

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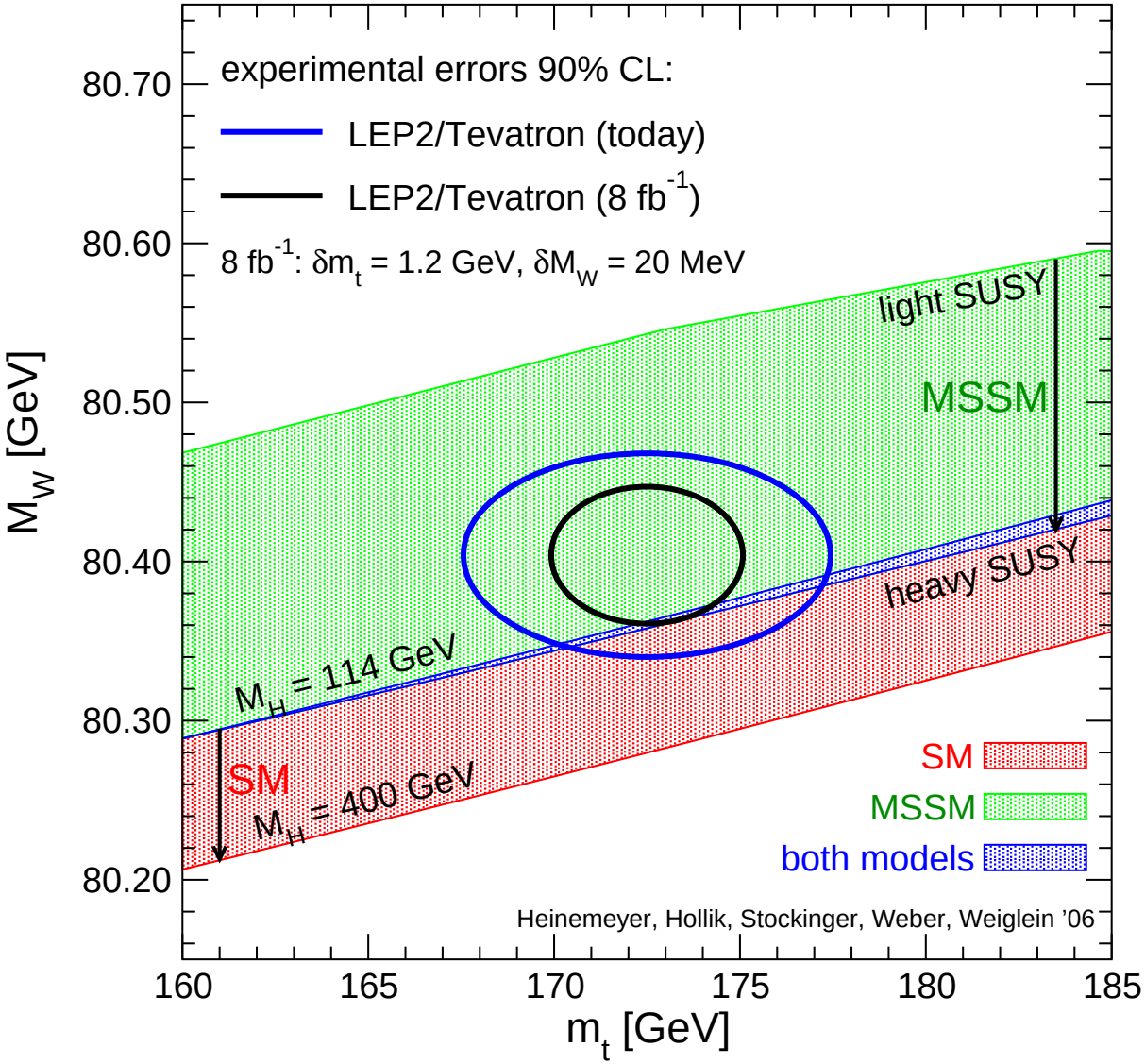

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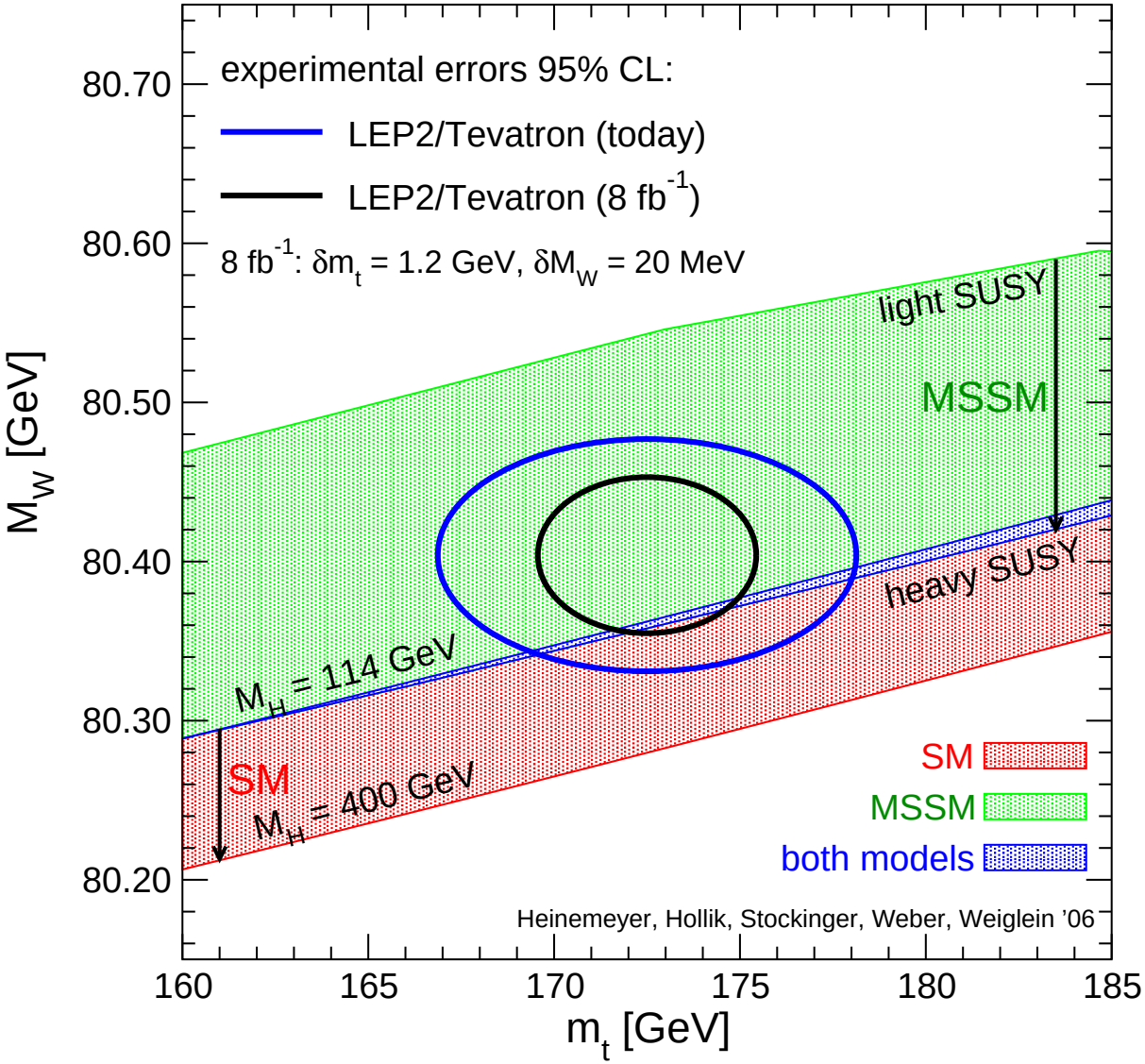

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CMSSM result for total BR($b \to s\gamma$):

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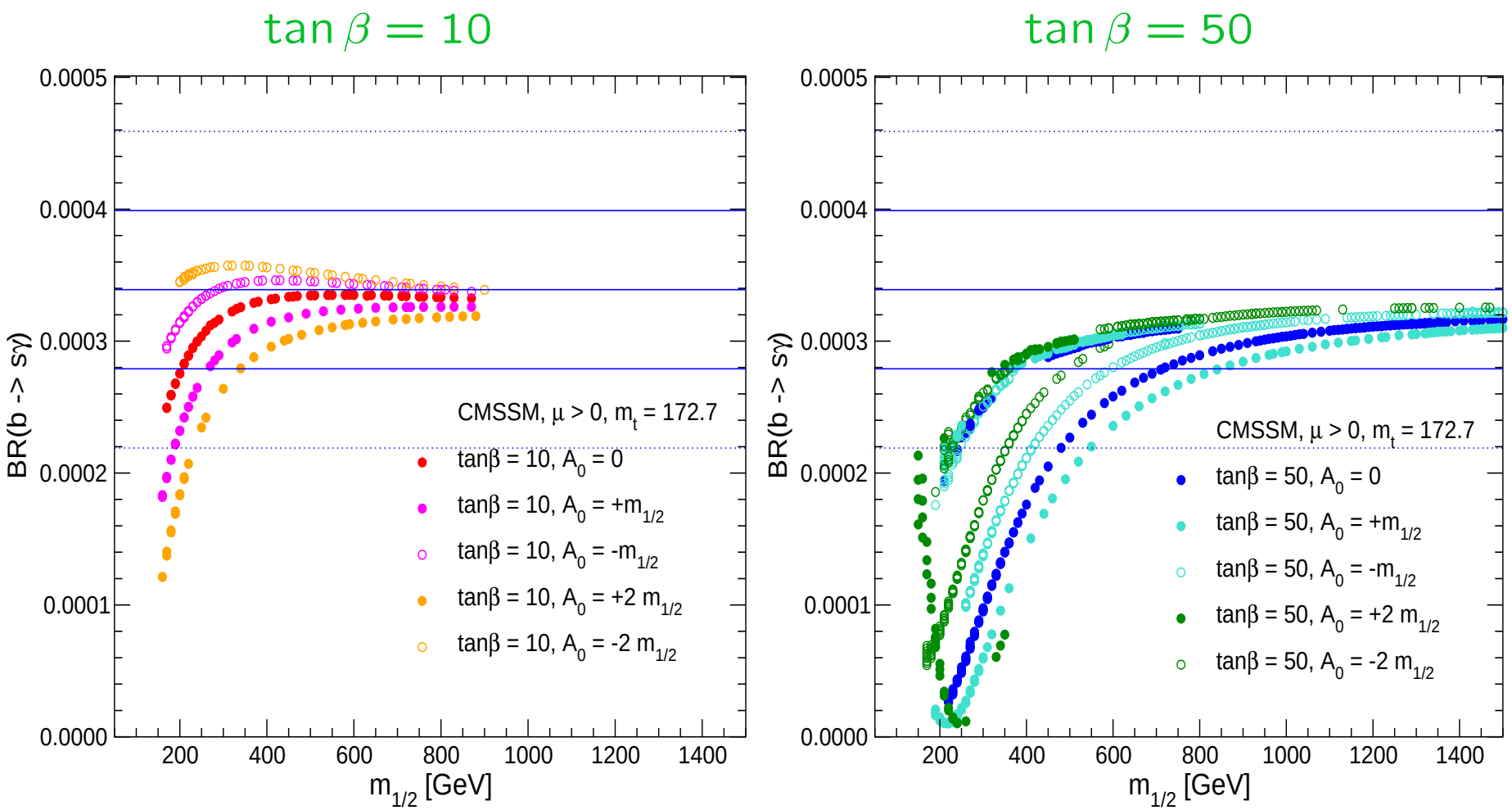
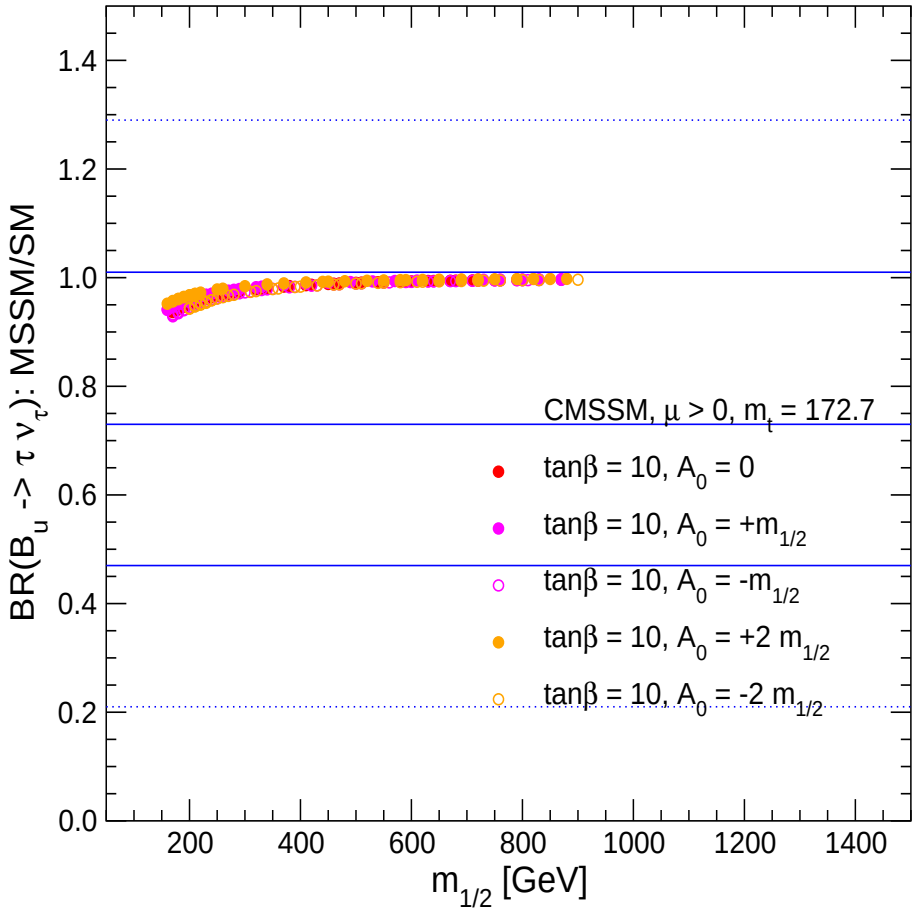


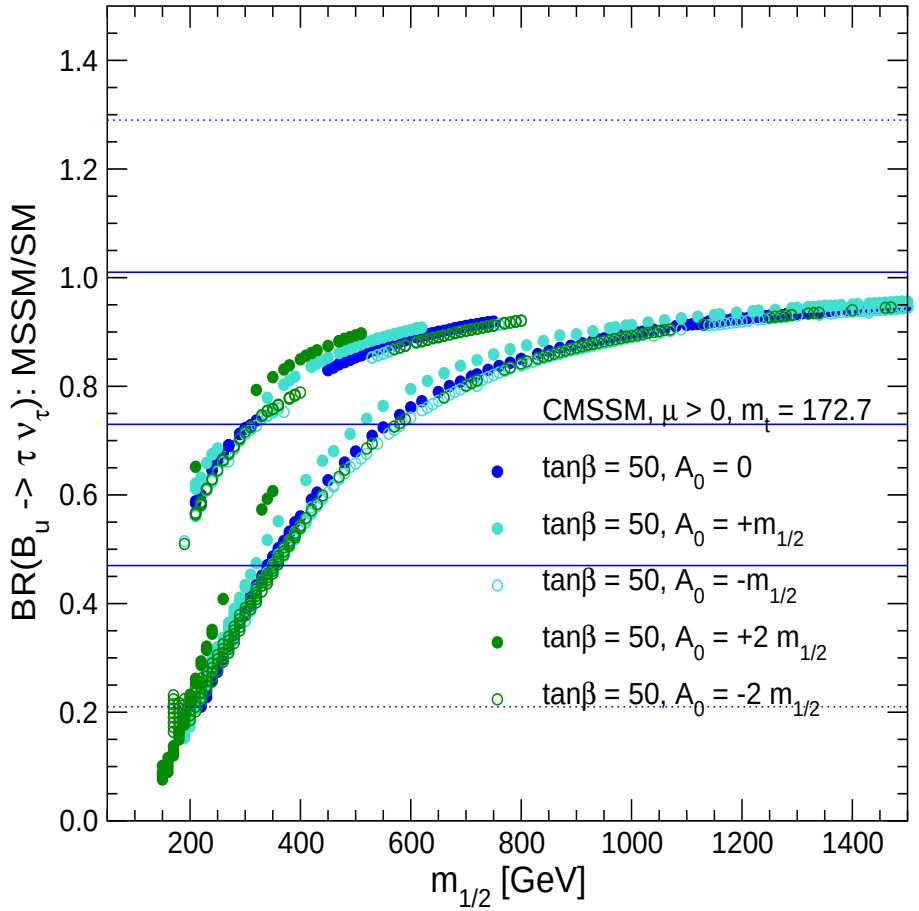
CMSSM result for total BR($B_u \to \tau\nu_\tau$) (MSSM/SM):

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

$\tan\beta = 10$



$\tan\beta = 50$



CMSSM result for total BR($B_s \to \mu^+\mu^-$):

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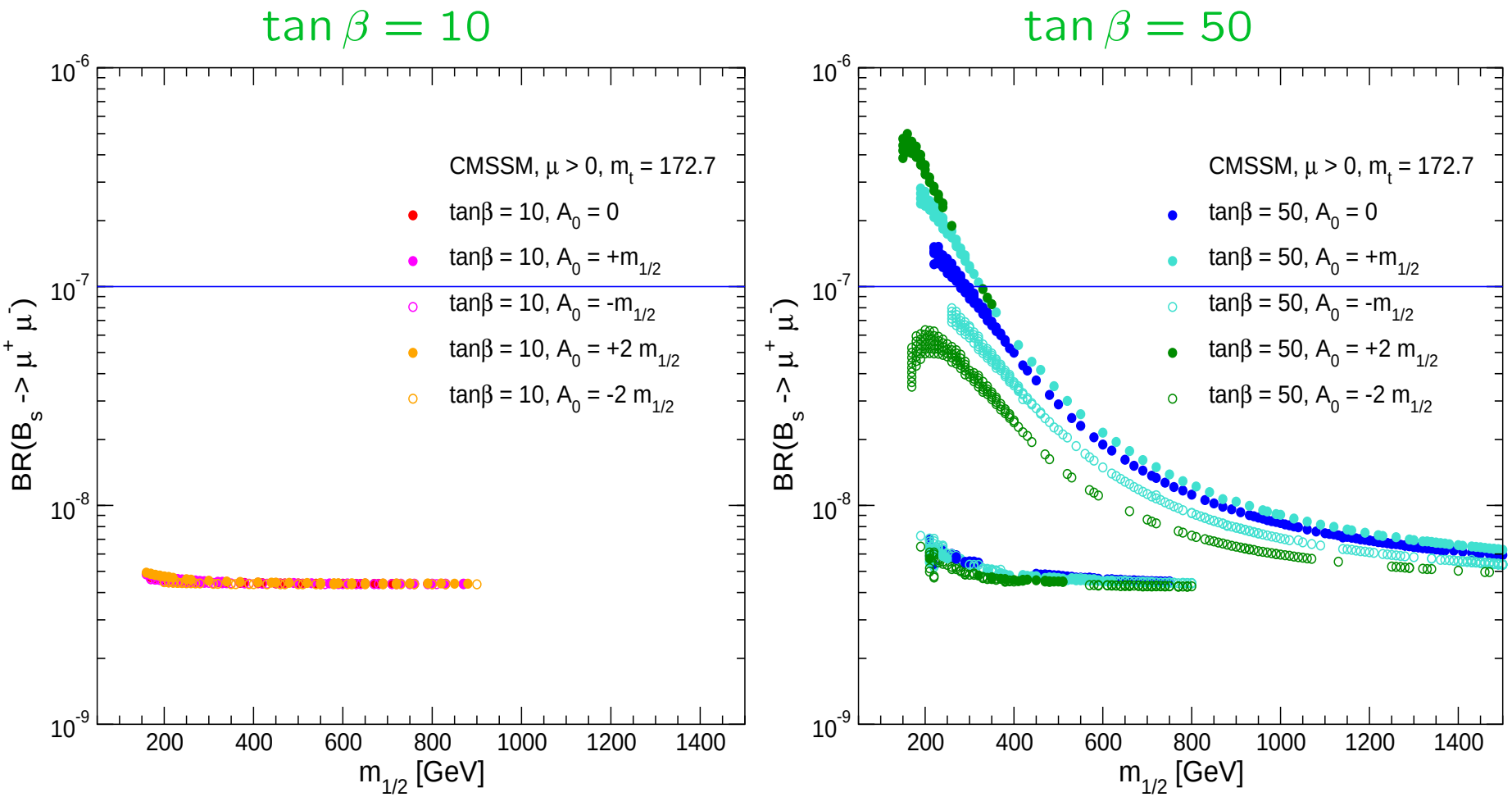

→ thanks to Cheng-Ju Stephen Lin and Matthew Herndon!

CMSSM result for total ΔM_{B_s} (MSSM/SM):

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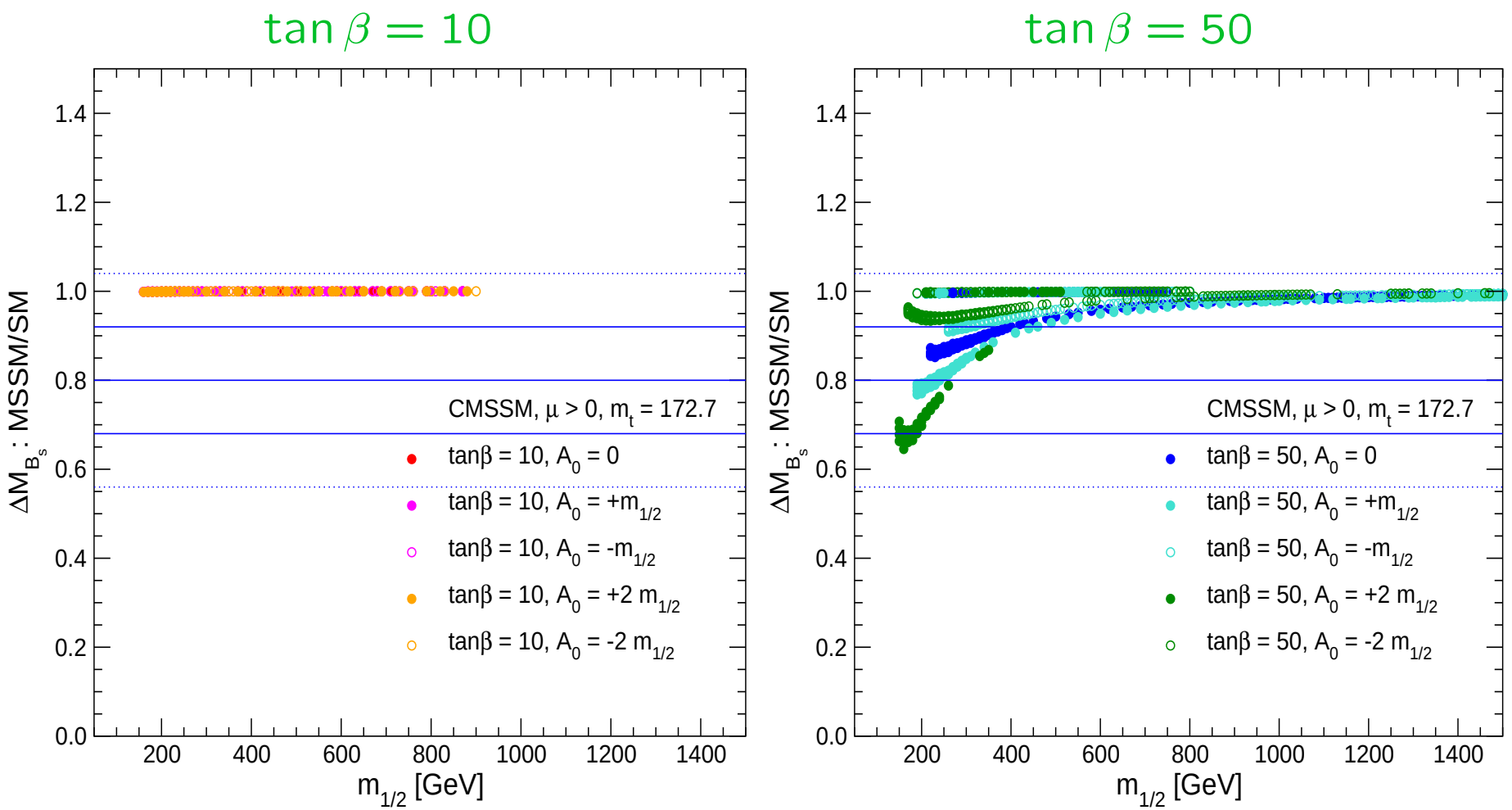

Result for total χ^2 including all B-physics observables:

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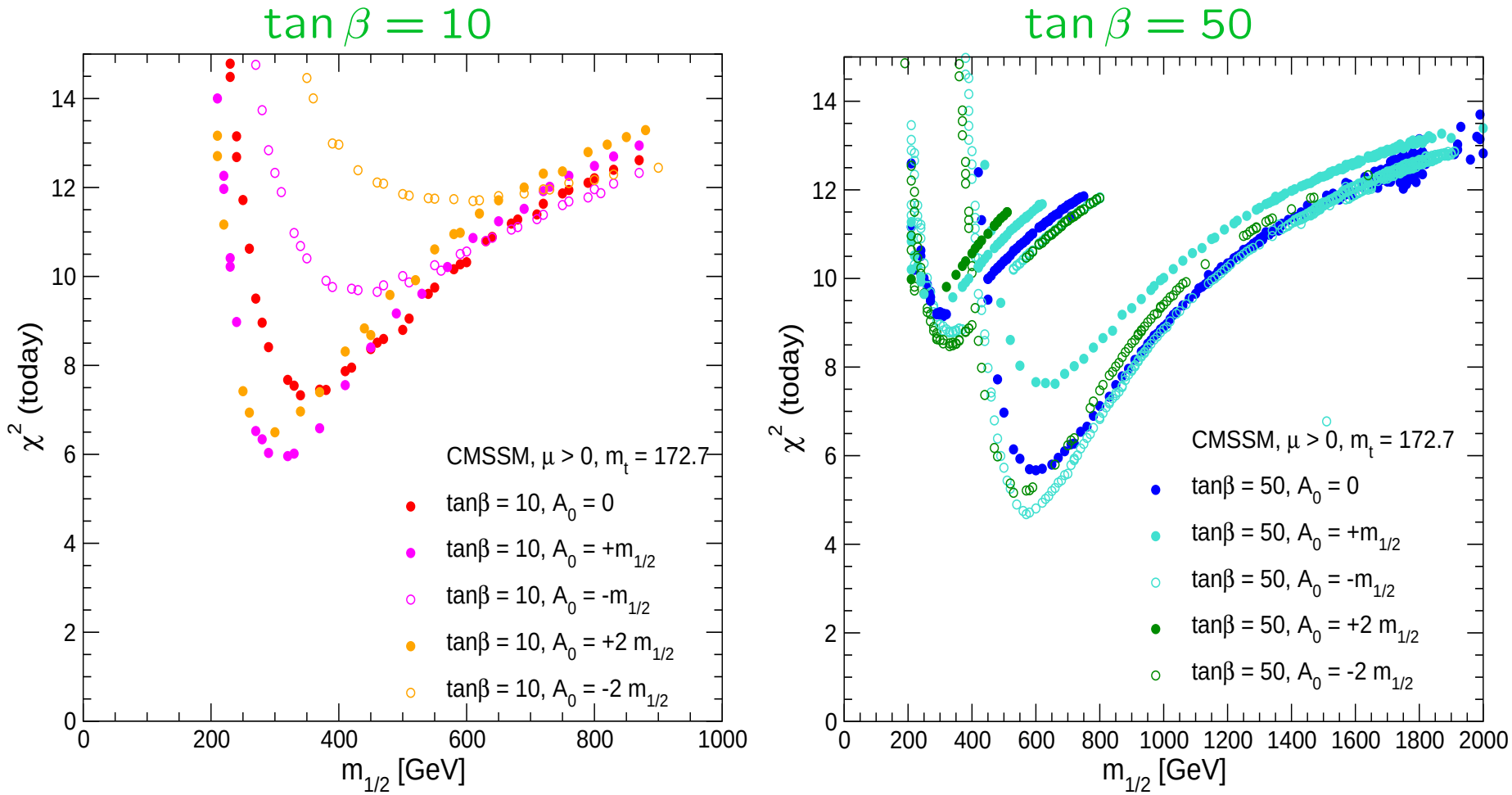
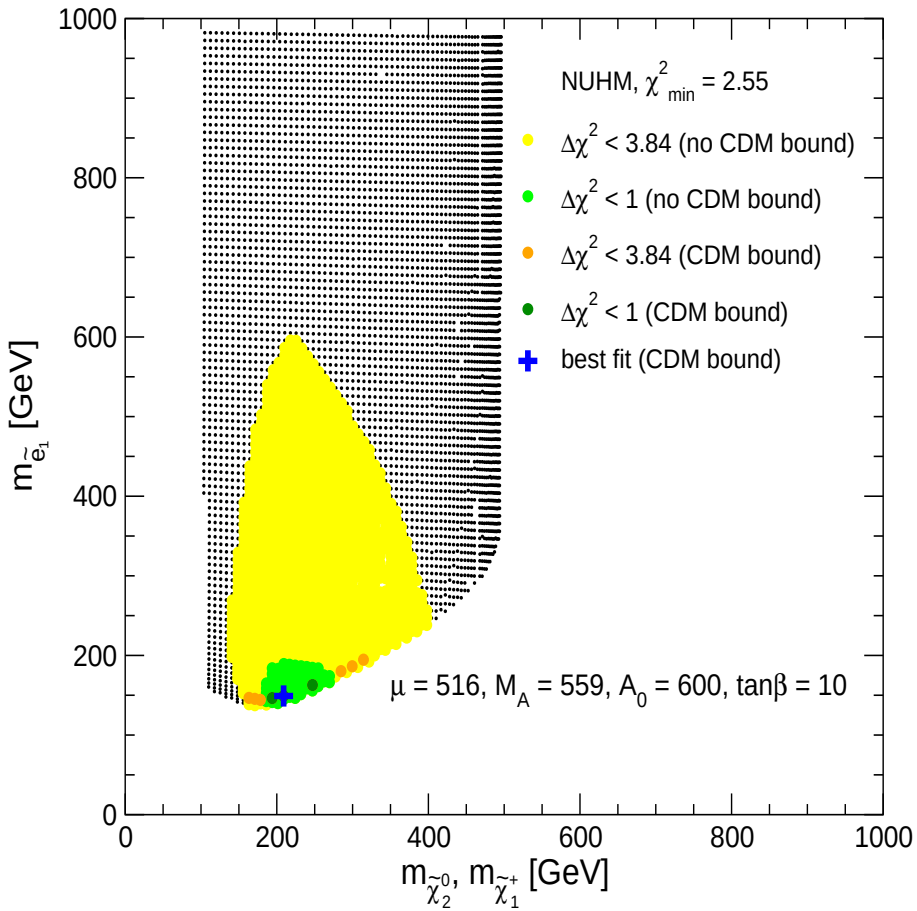
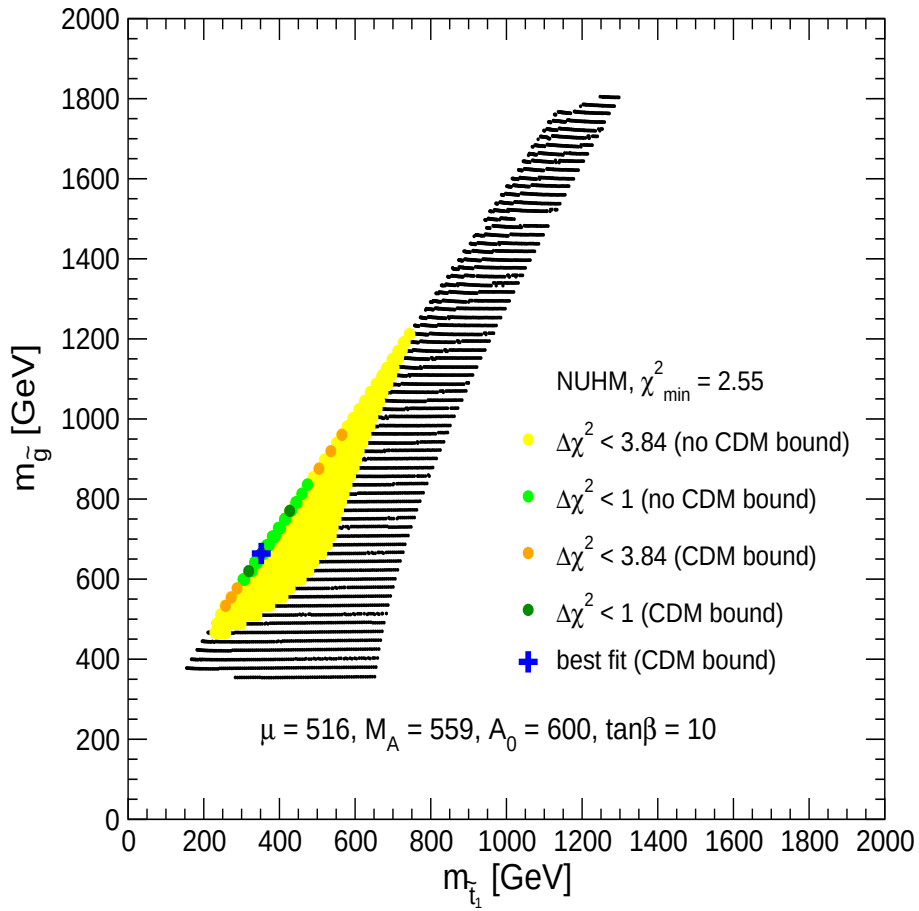


⇒ overall fit still very good, $\chi^2_{\text{tot,min}} \approx 5$

⇒ preference for relatively light SUSY masses confirmed

NUHM: vary $m_{1/2}$ and m_0 around best CMSSM fit point $\tan\beta = 10$:





Only dark-colored points are allowed

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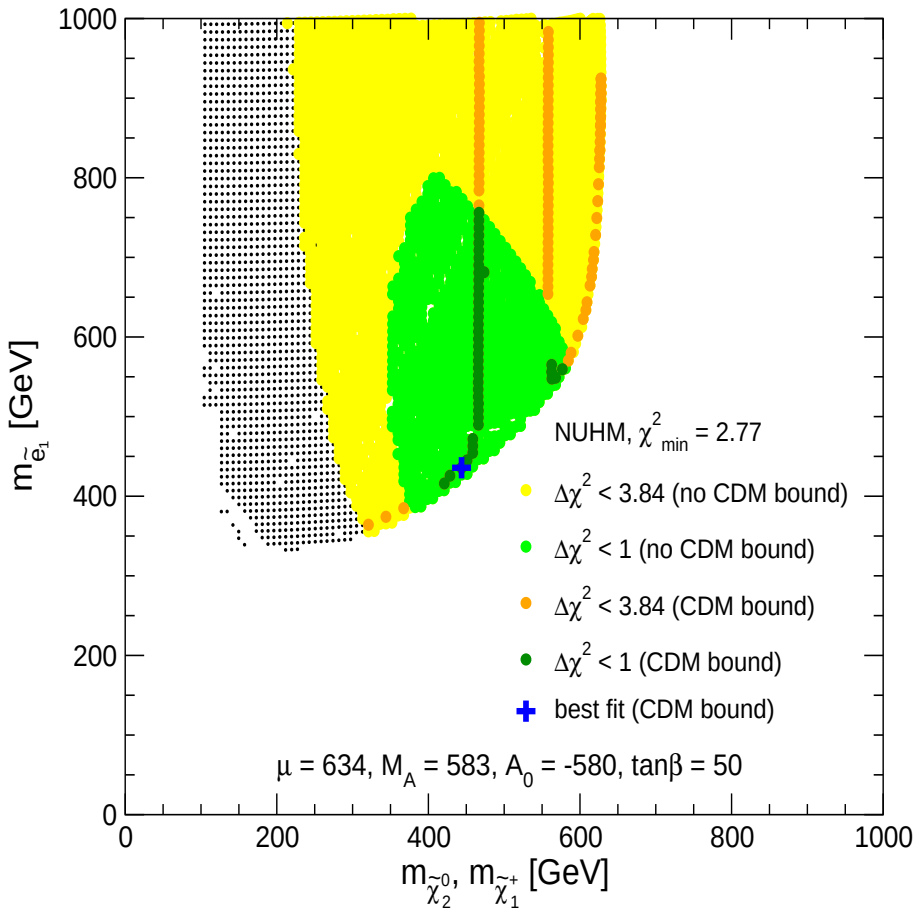
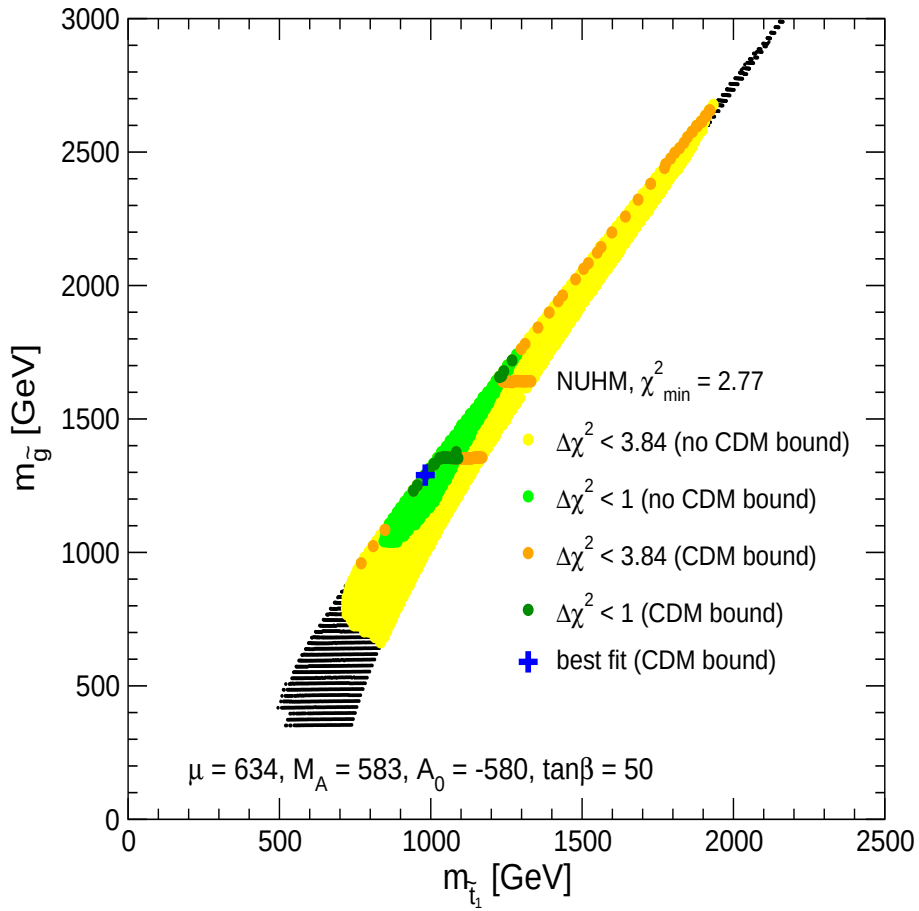
NUHM: vary $m_{1/2}$ and m_0 around best CMSSM fit point $\tan\beta = 50$:

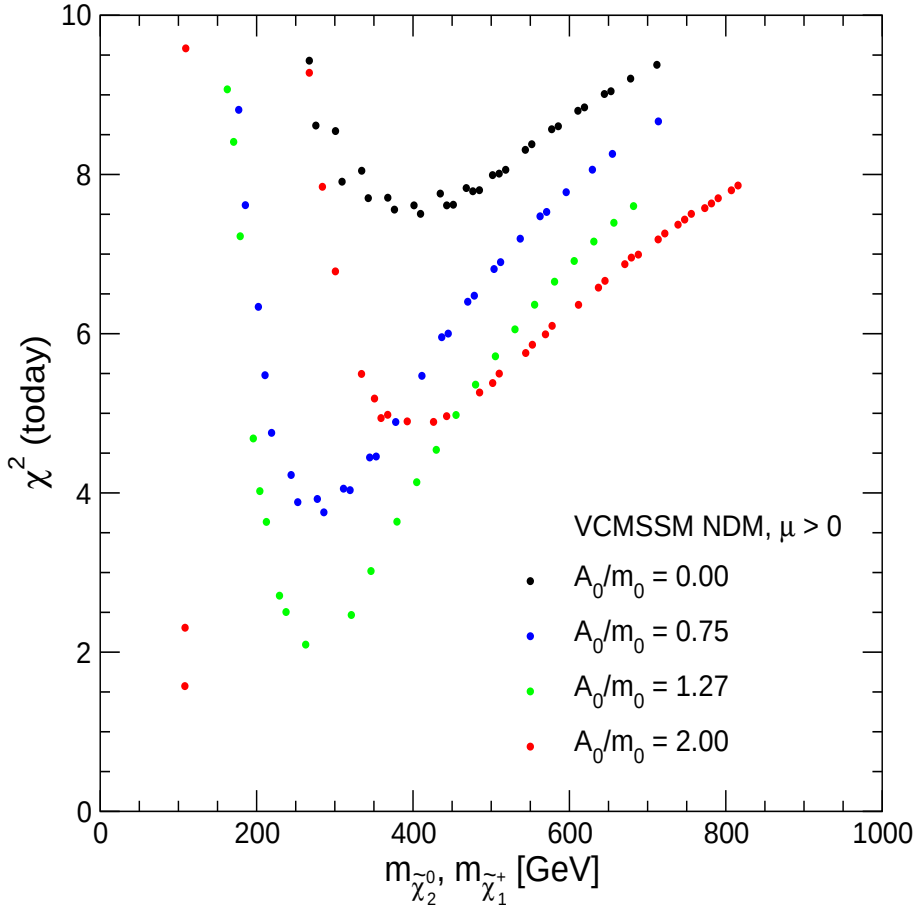


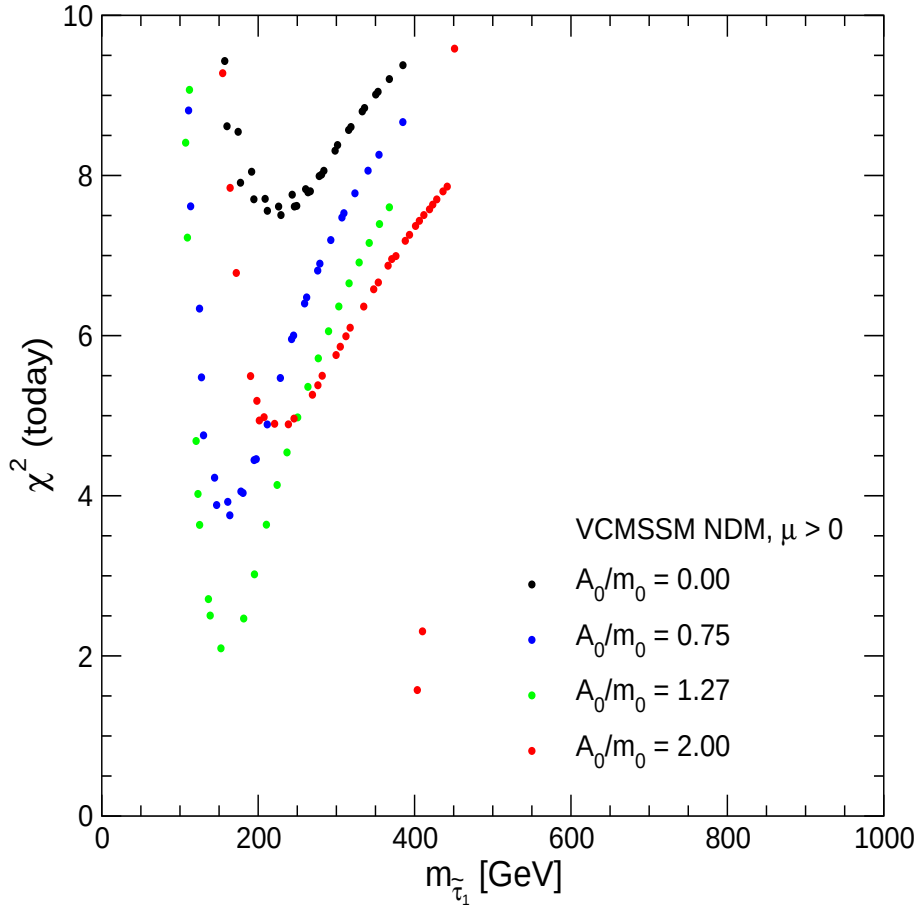


Only dark-colored points are allowed

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

VCMSSM: scan over full parameter space





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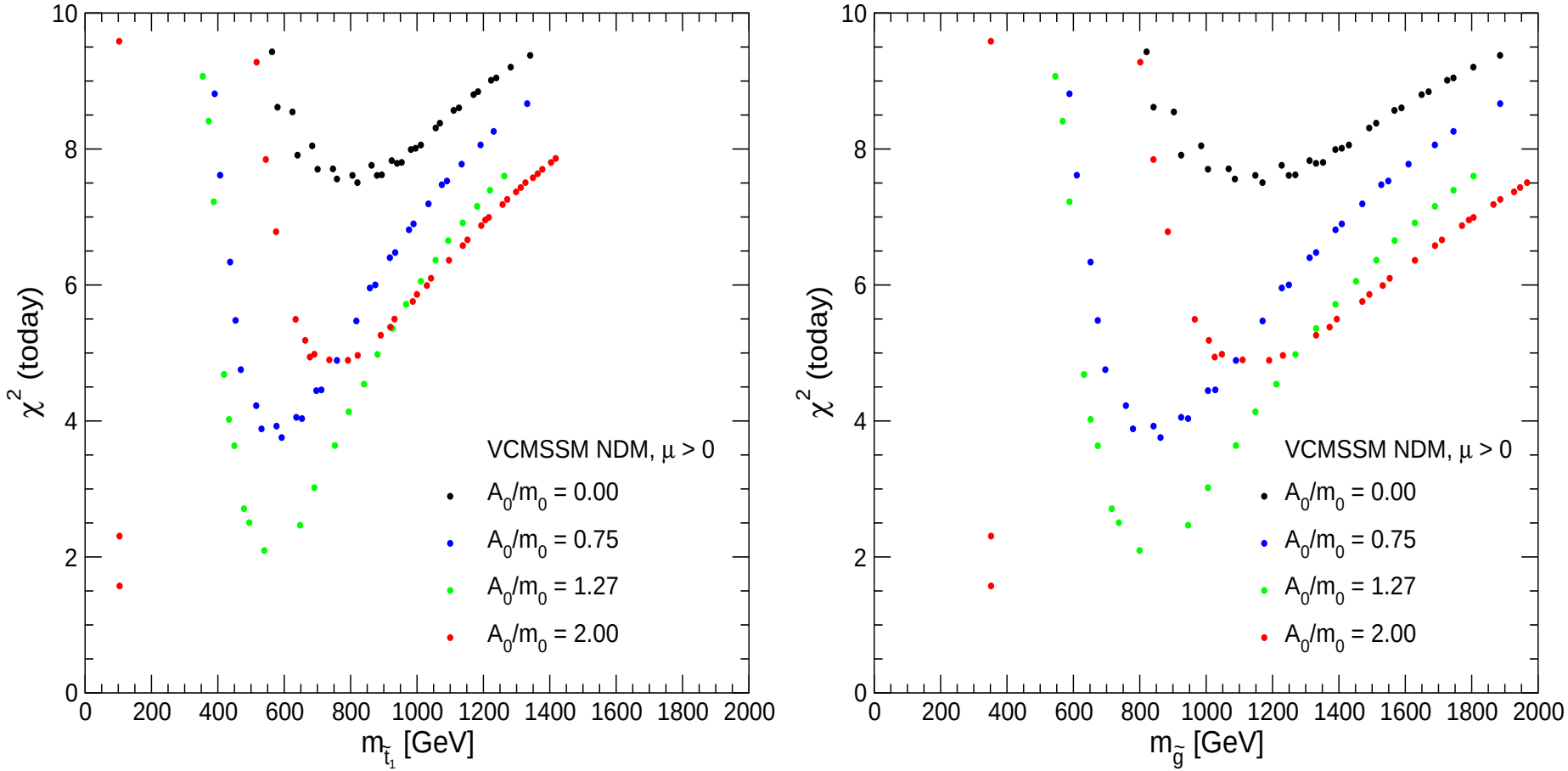
VCMSSM: scan over full parameter space



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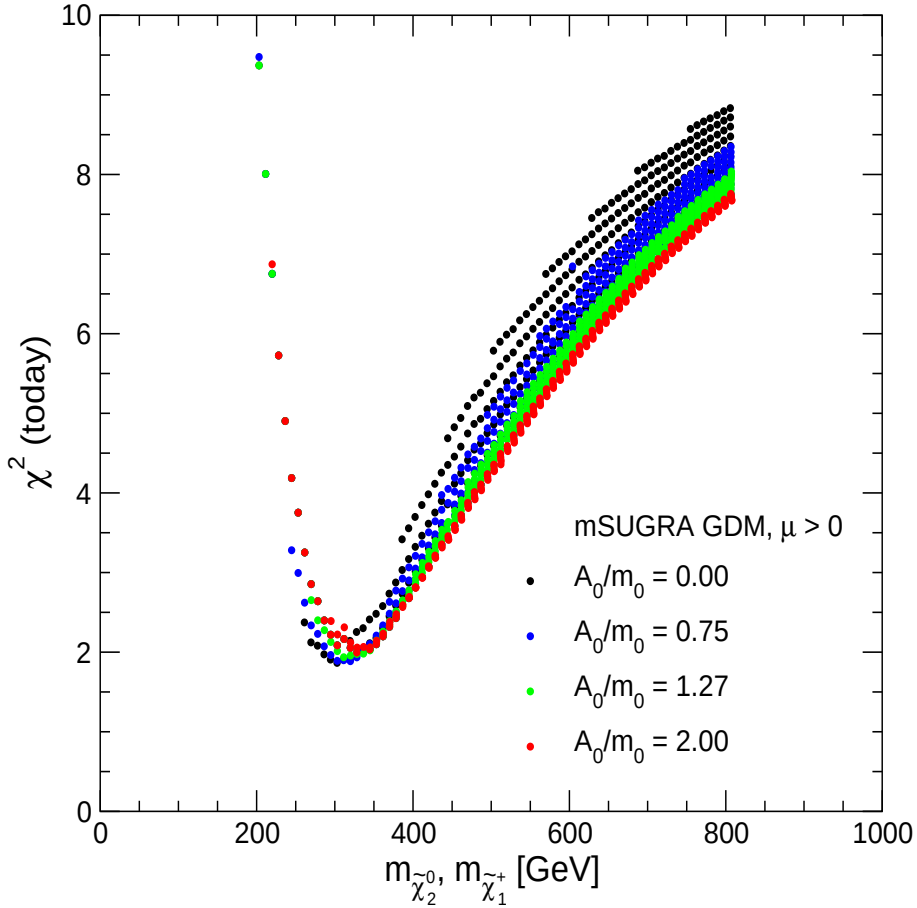
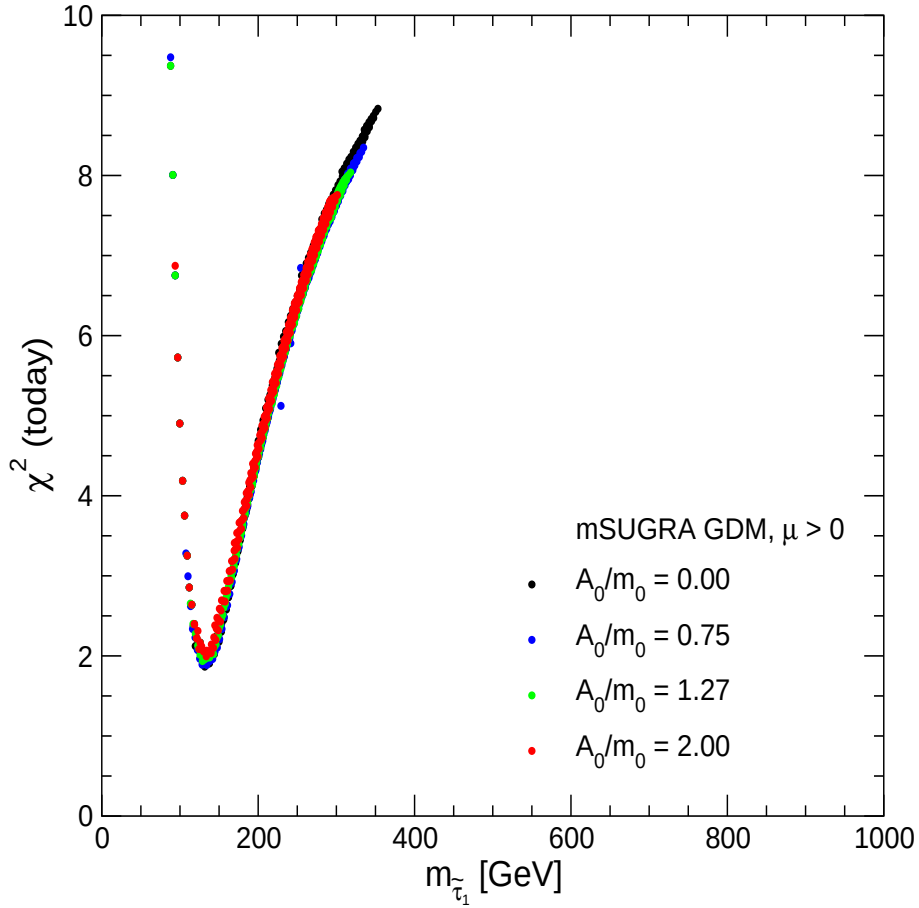
GDM (mSUGRA): scan over full parameter space





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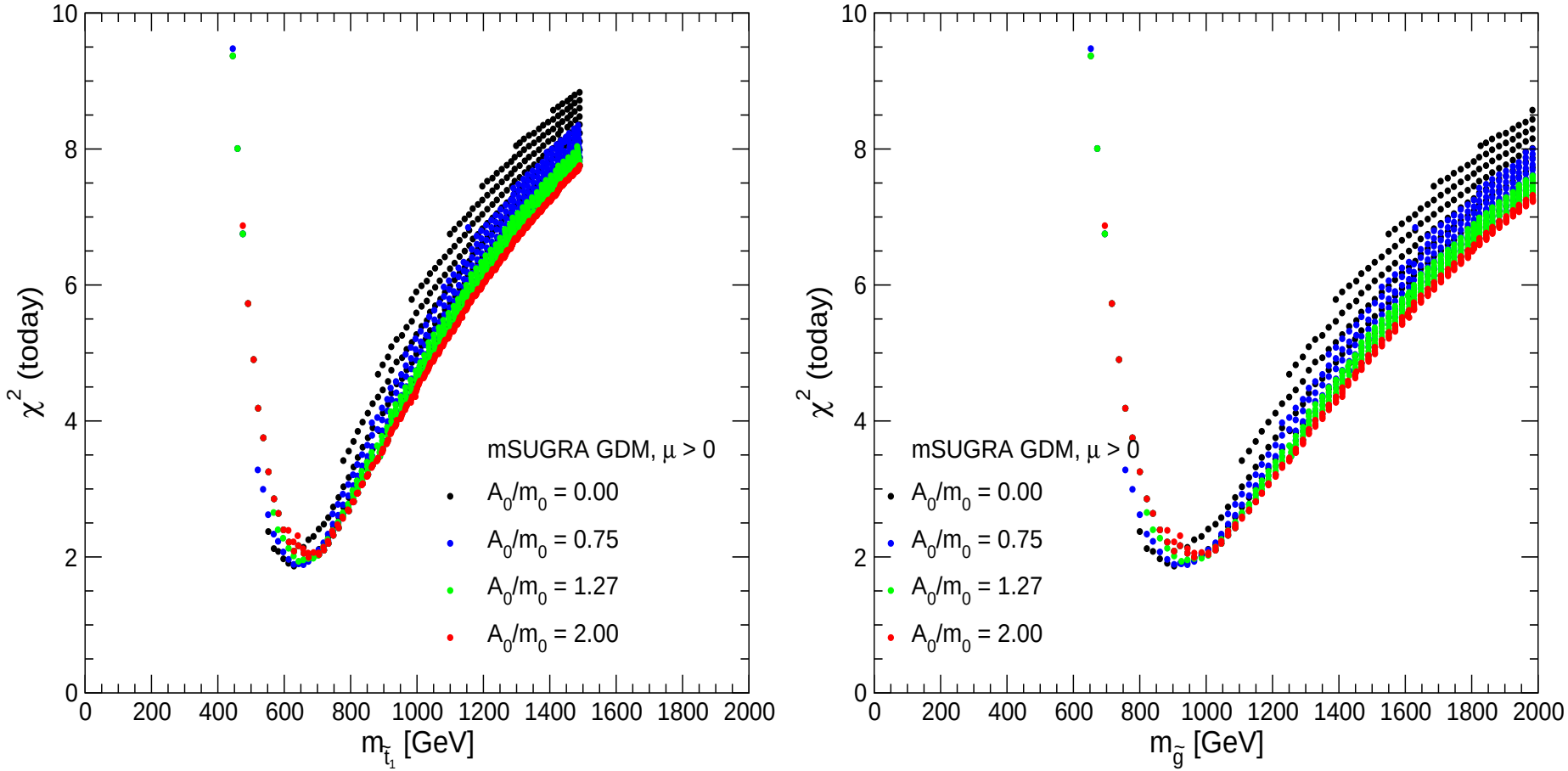
GDM (mSUGRA): scan over full parameter space



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