SUSY in the Light of B Physics and Electroweak Precision Observables

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In collaboration with *J. Ellis, S. Heinemeyer, K. Olive, A. Weber*, arXiv:0706.0652

- Introduction
- Observables: EWPO and BPO
- Results in the CMSSM
- Results in the NUHM
- Conclusions

Introduction

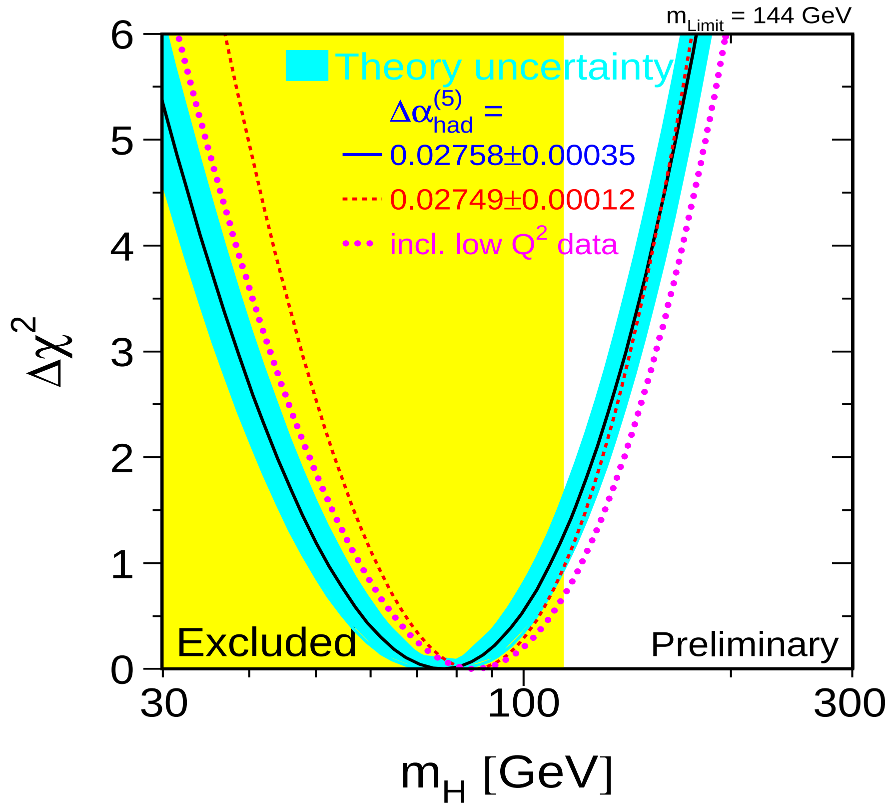
Electroweak precision physics $\Leftrightarrow$ sensitivity to loop effects

Introduction

Electroweak precision physics ⇔ sensitivity to loop effects

Example: indirect constraints on M_{H} in the SM

[*LEPEWWG '07*]



⇒ Tension between indirect bounds on M_{H} in the SM and direct search limit has increased

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles:

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

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

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

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

Enlarged Higgs sector: two Higgs doublets, physical states:
$h^0, H^0, A^0, H^{\pm}$

General parametrisation of possible SUSY-breaking terms
$\Rightarrow$ free parameters, no prediction for SUSY mass scale

The Constrained MSSM (CMSSM)

Universality assumptions at the GUT scale:

- Common scalar mass m_0
- Common gaugino mass $m_{1/2}$
- Common trilinear coupling A_0

Further parameters (weak scale): $\tan\beta$, $\mathrm{sgn}(\mu)$

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Electroweak precision observables (EWPO) $+$ dark matter constraint $\Rightarrow$ Preference for relatively light SUSY scale

[*J. Ellis, S. Heinemeyer, K. Olive, G. W. '05, '06*]

[*J. Ellis, K. Olive, Y. Santoso, V. Spanos '04*] [*B. Allanach, C. Lester '06*]

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

[*R. de Austri, R. Trotta, L. Roszkowski '06*] [*G. Isidori, F. Mescia, P. Paradisi, D. Temes '07*] [*M. Carena, A. Menon, C. Wagner '07*]

The Non-Universal Higgs Model (NUHM)

Universality of soft SUSY-breaking contributions to the Higgs scalar masses is less motivated than universality between squarks and sleptons

$\Rightarrow$ NUHM:

two additional parameters, can be traded for $M_{\rm A}$ and μ after imposing the electroweak vacuum conditions

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two additional parameters, can be traded for M_A and μ after imposing the electroweak vacuum conditions

- Can vary $m_{1/2}$ or μ such that (essentially) the whole M_A–$\tan\beta$ plane is compatible with the WMAP constraint on the dark matter relic density
  [*J. Ellis, S. Heinemeyer, K. Olive, G. W. '07*]

The Non-Universal Higgs Model (NUHM)

- The recent excess observed at CDF, compatible with a Higgs mass of $M_{\mathrm{H}} \approx 160~\mathrm{GeV}$ and large $\tan\beta$, can be accomodated within the NUHM but not the CMSSM

  Compatible with constraints from direct searches, electroweak precision observables, B physics observables and dark matter

  Signatures should soon be detectable in $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $\mathrm{BR}(b \to s\gamma)$ and direct searches for dark matter
  [*J. Ellis, S. Heinemeyer, K. Olive, G. W. '07*]

Observables: EWPO and BPO

Detailed investigation of indirect sensitivity to SUSY effects from electroweak precision observables (EWPO) and B-physics observables (BPO)

Studied in the CMSSM and the NUHM, taking into account dark matter constraints

- EWPO:

  $M_{\rm W}$, $\sin^2\theta_{\rm eff}$, $\Gamma_{\rm Z}$, $(g-2)_\mu$

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  M_h: Higgs bound from LEP, full likelihood information and theory uncertainty included in the fit

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- BPO:

  ${\rm BR}(b \to s\gamma)$, ${\rm BR}(B_{\rm s} \to \mu^+\mu^-)$, ${\rm BR}(B_{\rm u} \to \tau\nu_\tau)$, $\Delta M_{B_{\rm s}}$

Theoretical predictions for EWPO and BPO

Theoretical predictions:

M_W, $\sin^2\theta_{\rm eff}$, Γ_Z: complete 1-loop result $+$ all available higher-order corrections in SM and MSSM [*see A. Weber's talk*]

$(g-2)_\mu^{\rm SUSY}$, M_h: complete 1-loop result $+$ dominant 2-loop corrections

$\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $\mathrm{BR}(B_u \to \tau\nu_\tau)$, ΔM_{B_s}: latest SM result $+$ dominant SUSY contributions

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Sources of theoretical uncertainties:

- Unknown higher-order corrections
- Parametric uncertainty induced by the experimental errors of the input parameters: $m_{\rm t}$, $m_{\rm b}$, $\Delta\alpha_{\rm had}$, $\alpha_{\rm s}$, ...

Results in the CMSSM

CMSSM characterised by five parameters:

$m_{1/2}$, m_0, A_0 (GUT scale), $\tan\beta$, sgn(μ) (weak scale)

$\Rightarrow$ Low-energy spectrum from renormalisation group running

lightest SUSY particle: $\tilde{\chi}_1^0$

Cold dark matter (CDM) density (WMAP, . . .):

$$0.094 < \Omega_{\rm CDM}\, h^2 < 0.129$$

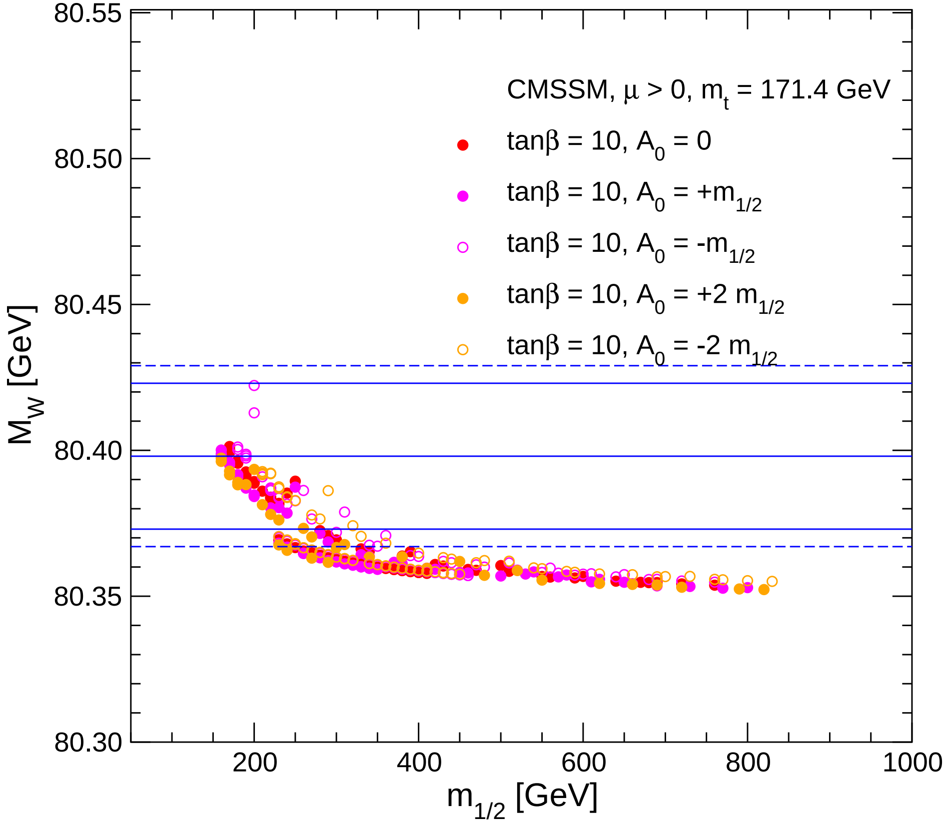
$\Rightarrow$ Restricts CMSSM parameter space to 'WMAP hypersurface'

$\Rightarrow$ Use WMAP constraint to reduce dimensionality of parameter space by 1

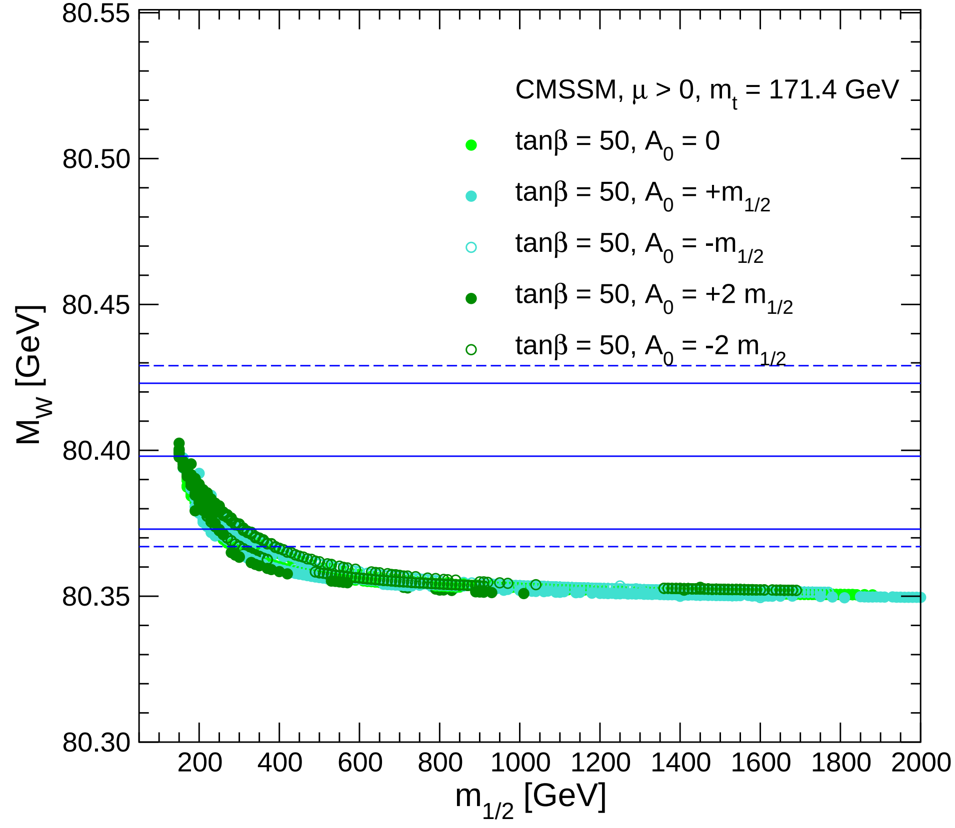
Perform analysis along 'WMAP' strips for fixed $\tan\beta = 10, 50$ and different values of A_0

CMSSM prediction for M_{W} vs. experimental result

$\tan\beta = 10$:



$\tan\beta = 50$:



$\Rightarrow$ Preference for relatively light SUSY scale

The anomalous magnetic moment of the muon:

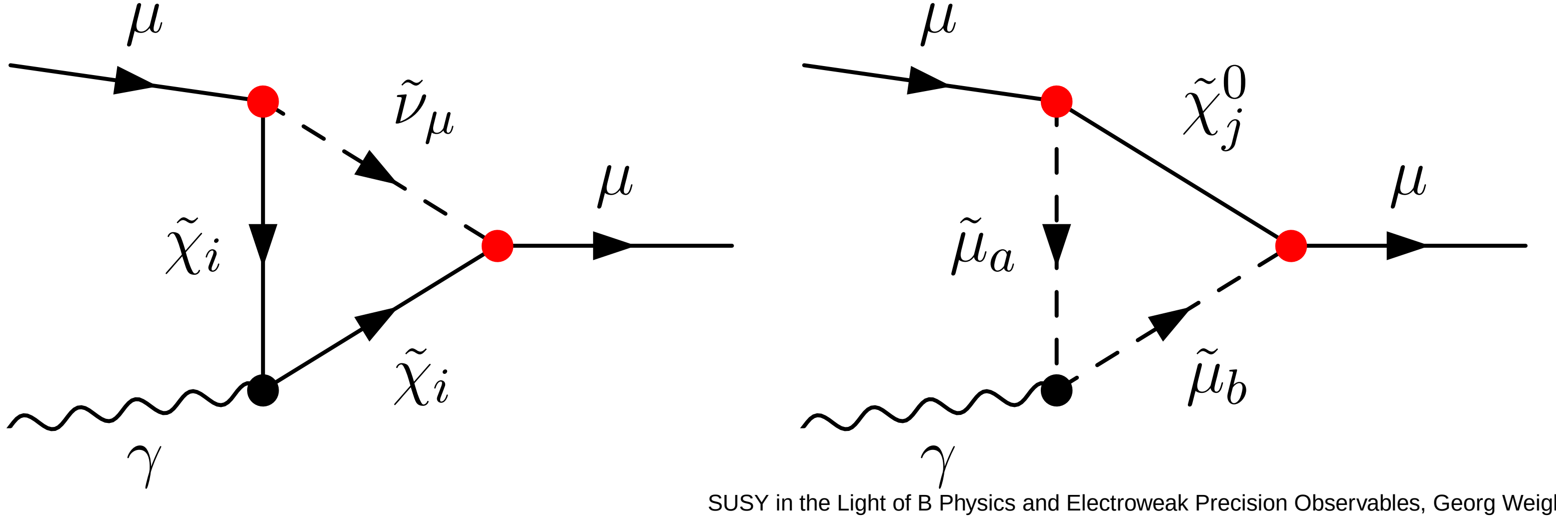
$$(g-2)_\mu \equiv 2a_\mu$$

Experimental result for a_μ vs. SM prediction (using e^+e^- data for hadronic vacuum polarisation):

$$a_\mu^{\rm exp} - a_\mu^{\rm theo} = (27.5 \pm 8.4) \times 10^{-10} \ : \ 3.3\,\sigma \ .$$

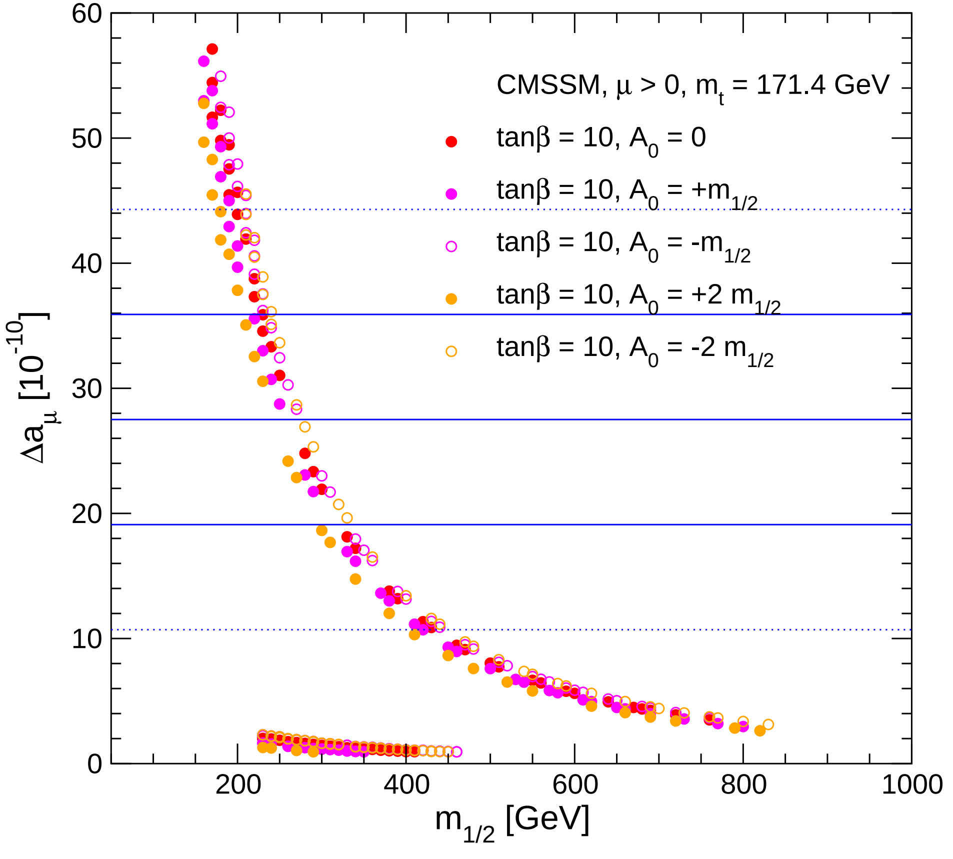
Better agreement between theory and experiment possible in models of physics beyond the SM

Example: one-loop contributions of superpartners of fermions and gauge bosons



CMSSM prediction for Δa_μ vs. experimental result (1σ and 2σ bands)

$\tan\beta = 10$:



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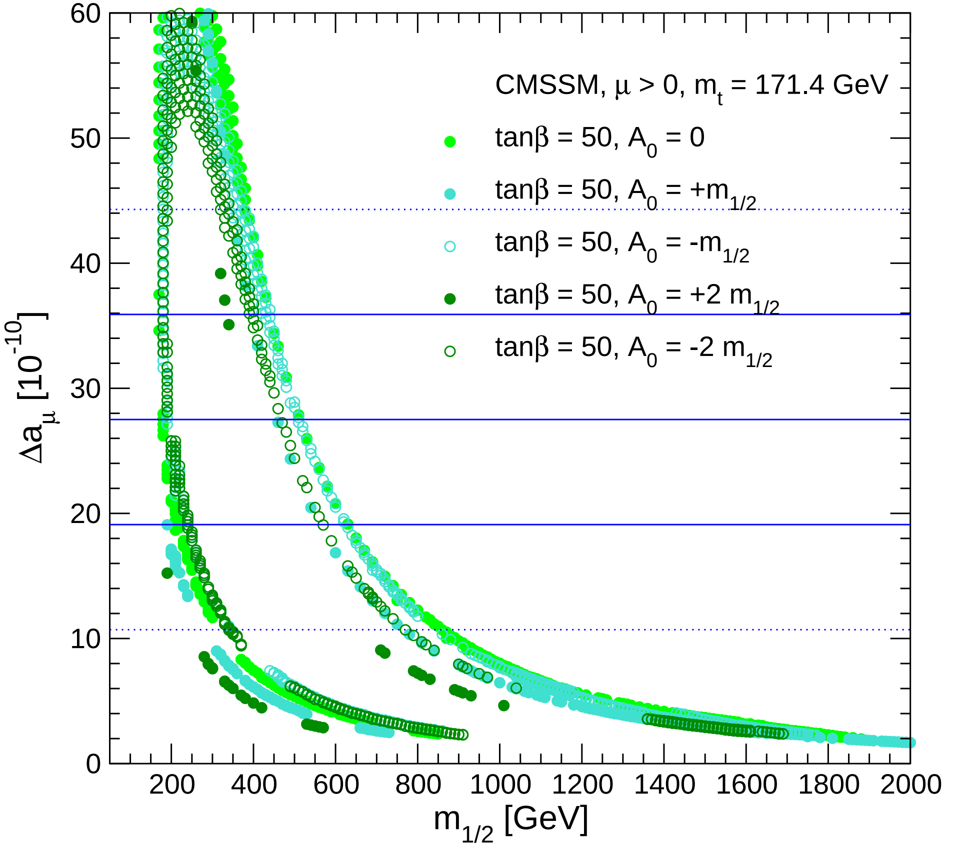
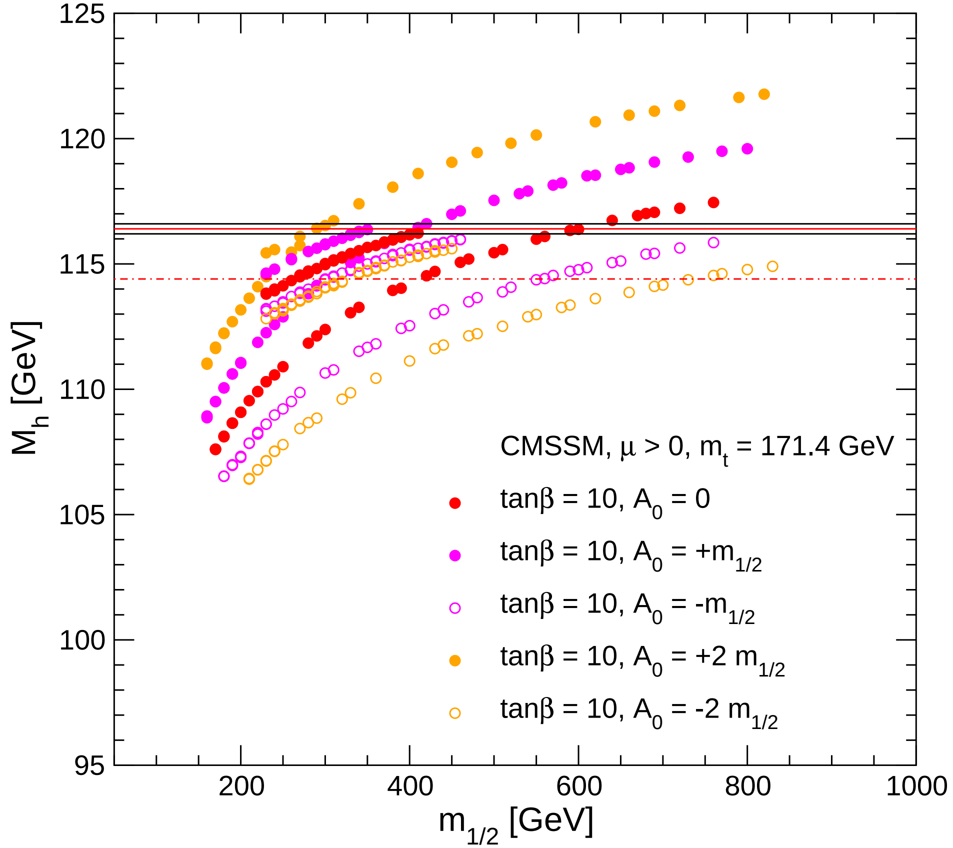


$\Rightarrow$ Preference for relatively light SUSY scale

$\tan\beta = 10$: focus-point region disfavoured

CMSSM prediction for M_h vs. LEP bound and hypothetical experimental result

$\tan\beta = 10$:



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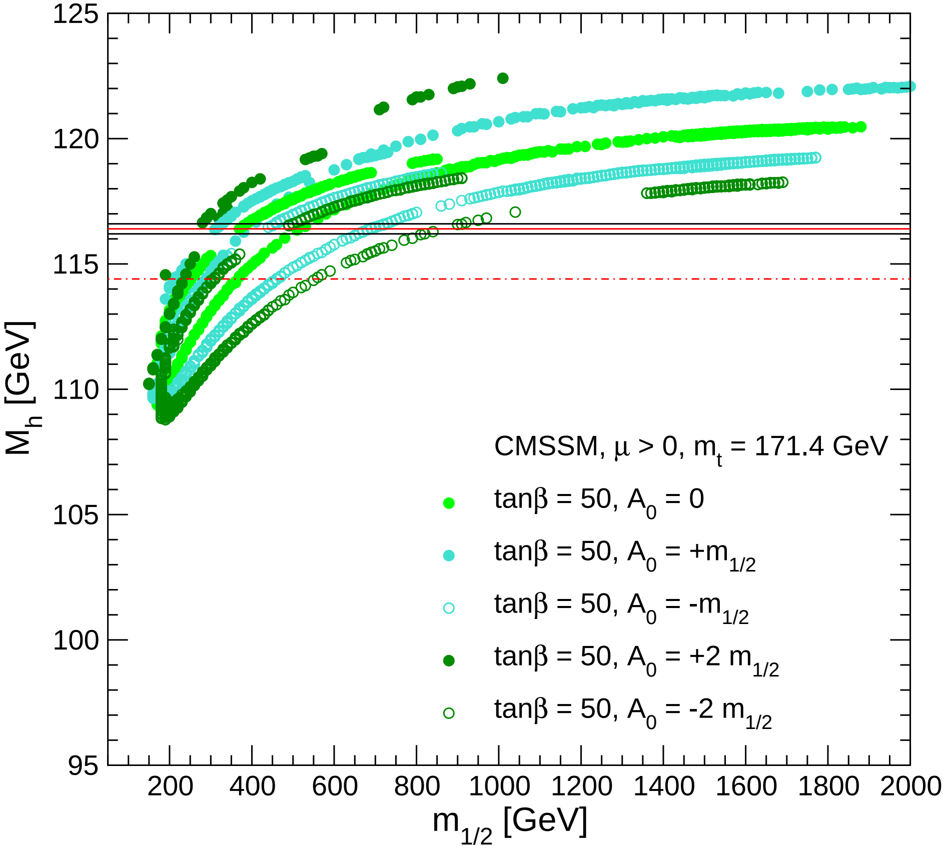
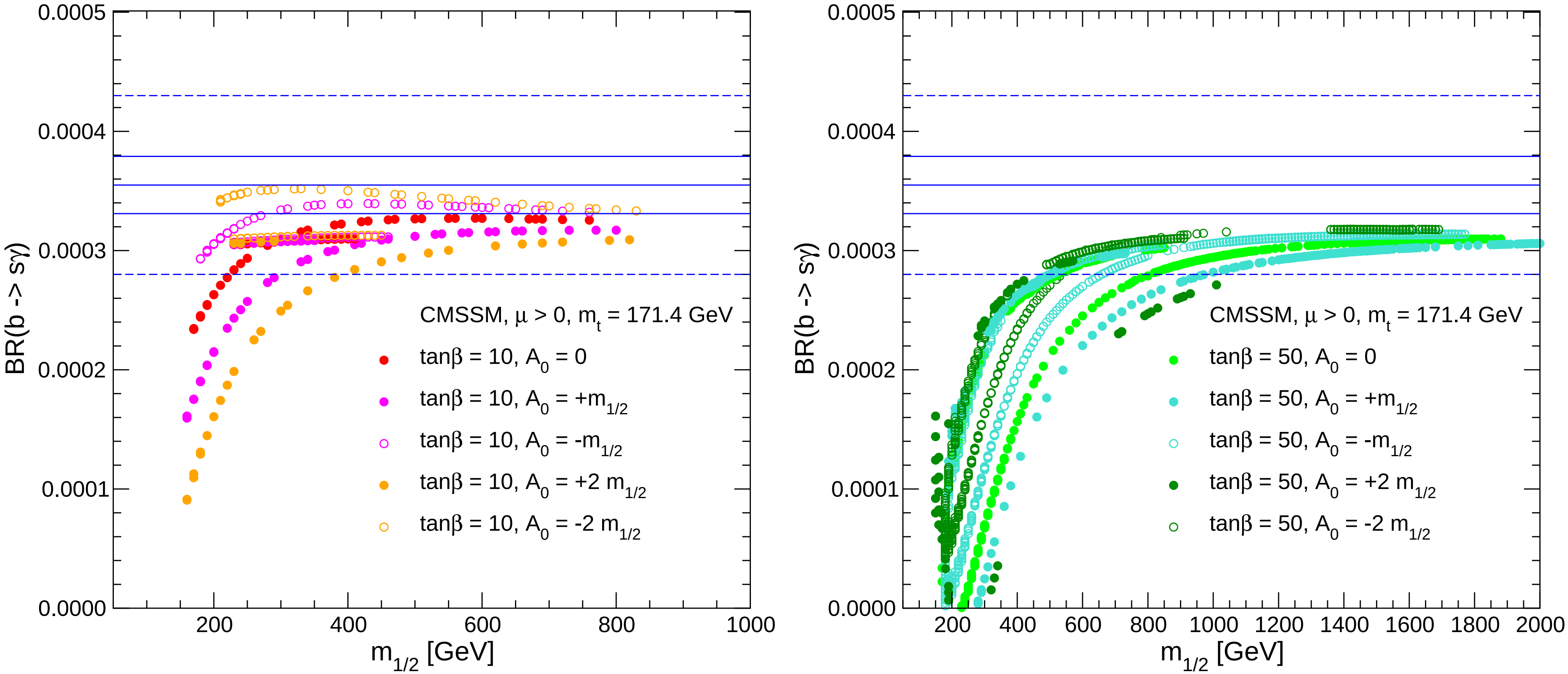


⇒ High sensitivity to variations of $m_{1/2}$, A_0

Relatively small values of $m_{1/2}$ allowed

CMSSM prediction for $\mathrm{BR}(b \to s\gamma)$ *vs. exp. result, exp. error* $+$ *theory uncertainty*

$\tan\beta = 10$: $\tan\beta = 50$:

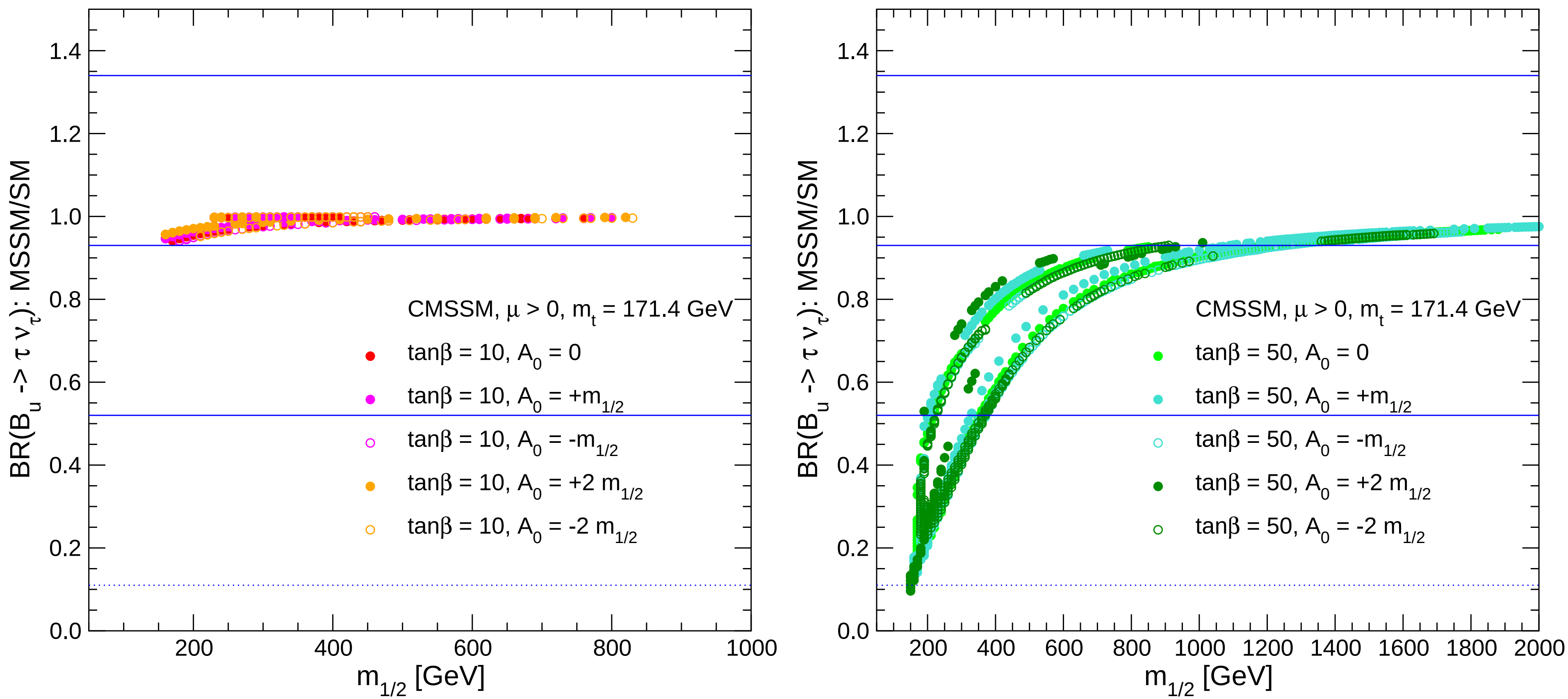


$\Rightarrow$ Preference for relatively heavy SUSY scale

Slight tension with EWPO

$\mathrm{BR}(B_u \to \tau\nu_\tau)$: *prediction for the ratio CMSSM/SM vs. experimental result (1σ and 2σ bands)*

$\tan\beta = 10$: $\tan\beta = 50$:

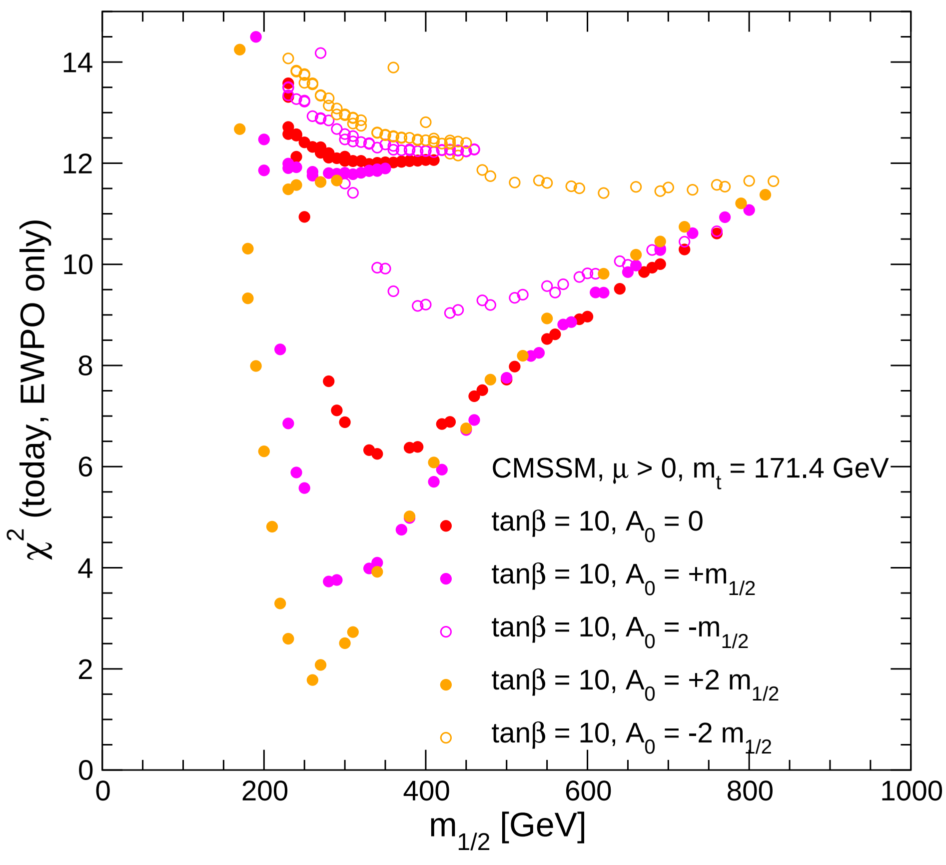


$\Rightarrow \tan\beta = 50$: slight preference for relatively heavy SUSY scale

Combined χ^2 fit in the CMSSM, EWPO only:

M_W, $\sin^2\theta_{\rm eff}$, Γ_Z, $(g-2)_\mu$, M_h

$\tan\beta = 10$:



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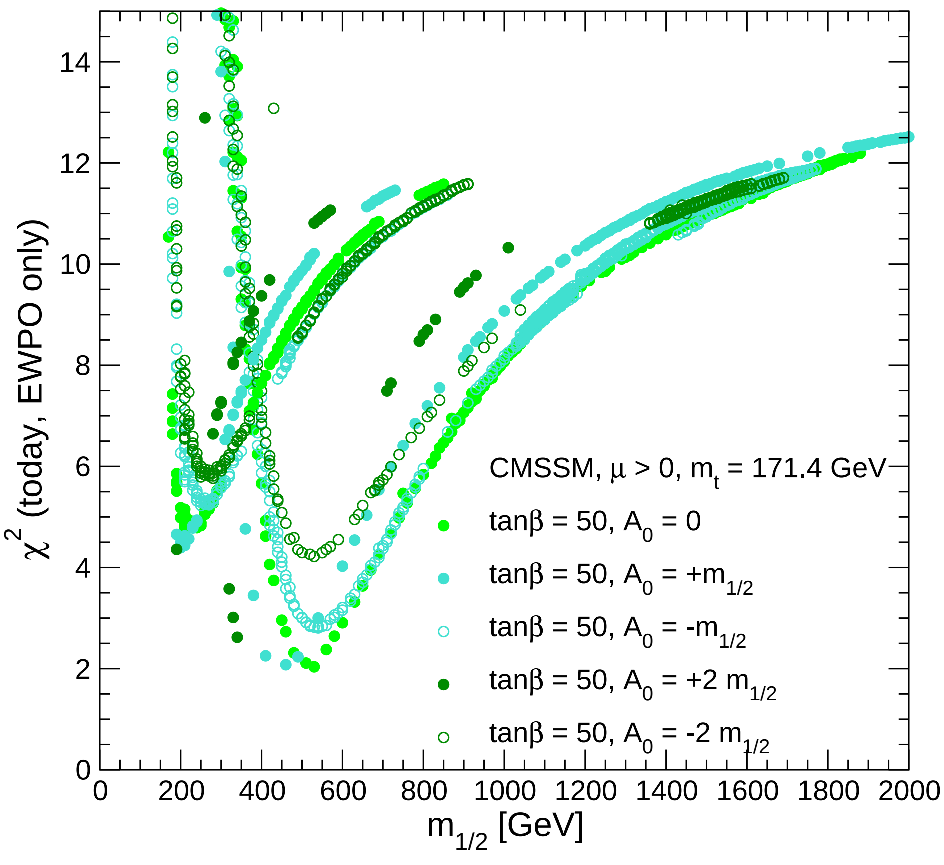


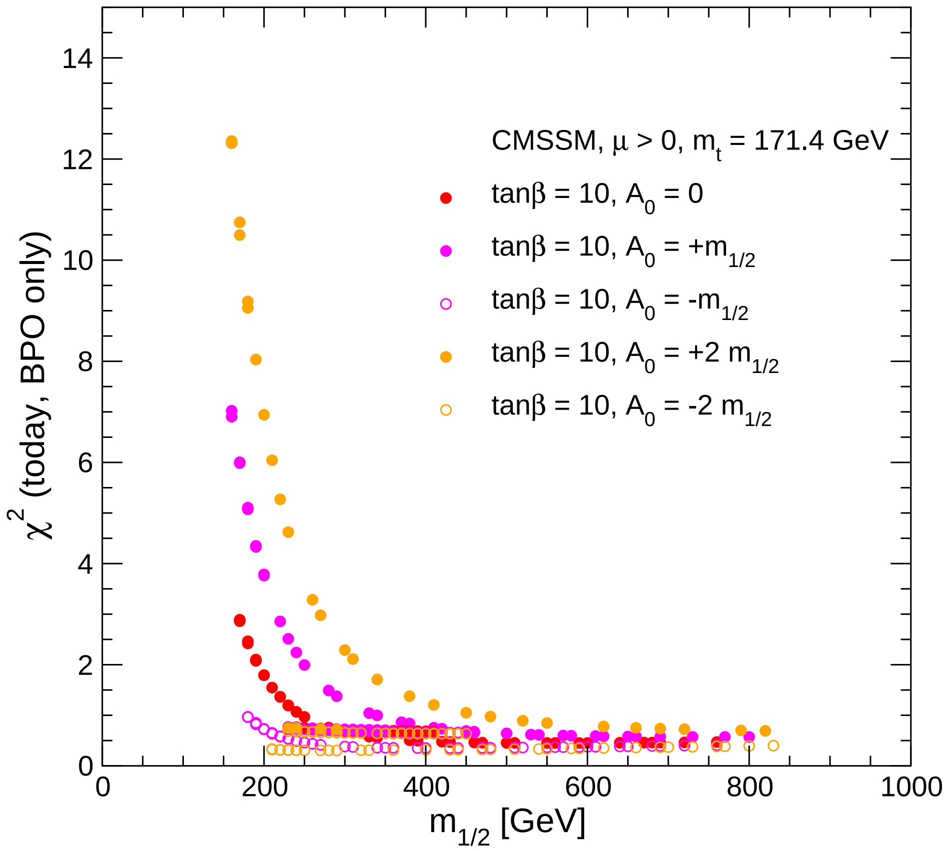
$\Rightarrow$ Very good description of the data

Pronounced minimum, preference for relatively light SUSY

Combined χ^2 fit in the CMSSM, BPO only:

$\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $\mathrm{BR}(B_u \to \tau\nu_\tau)$, ΔM_{B_s}

$\tan\beta = 10$:



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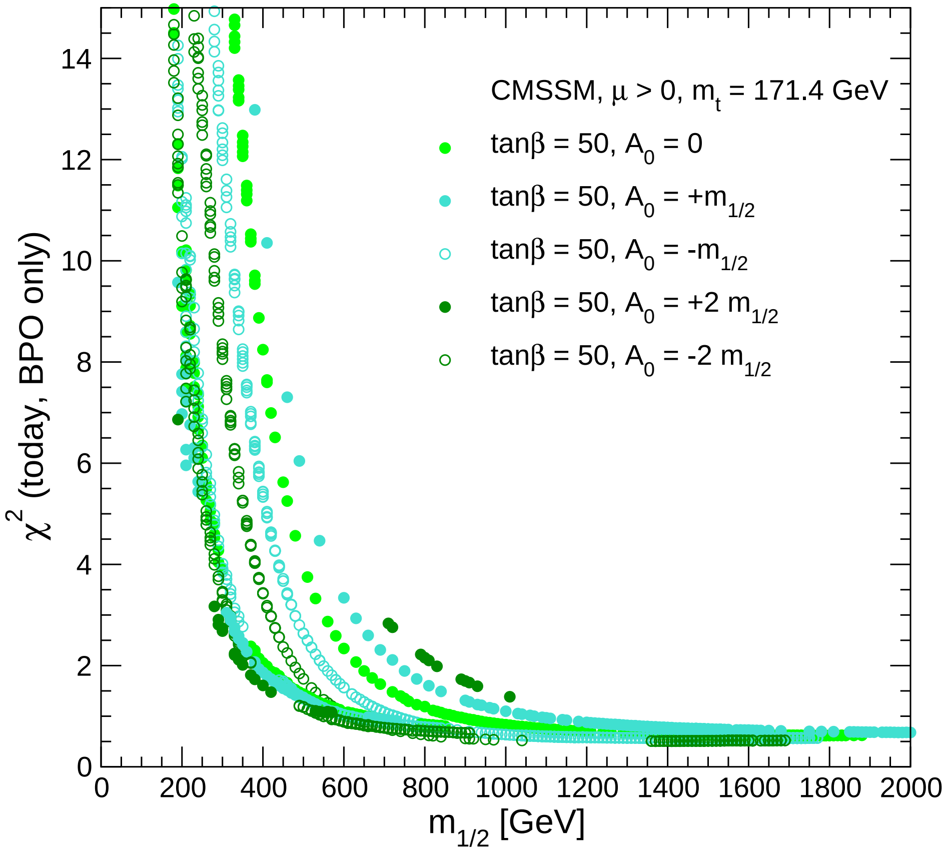

$\Rightarrow$ Preference for relatively heavy SUSY scale

Slight tension with EWPO

Combined χ^2 *fit, EWPO* + *BPO:* M_W, $\sin^2\theta_{\text{eff}}$, Γ_Z, $(g-2)_\mu$, M_h, $\text{BR}(b \to s\gamma)$, $\text{BR}(B_s \to \mu^+\mu^-)$, $\text{BR}(B_u \to \tau\nu_\tau)$, ΔM_{B_s}

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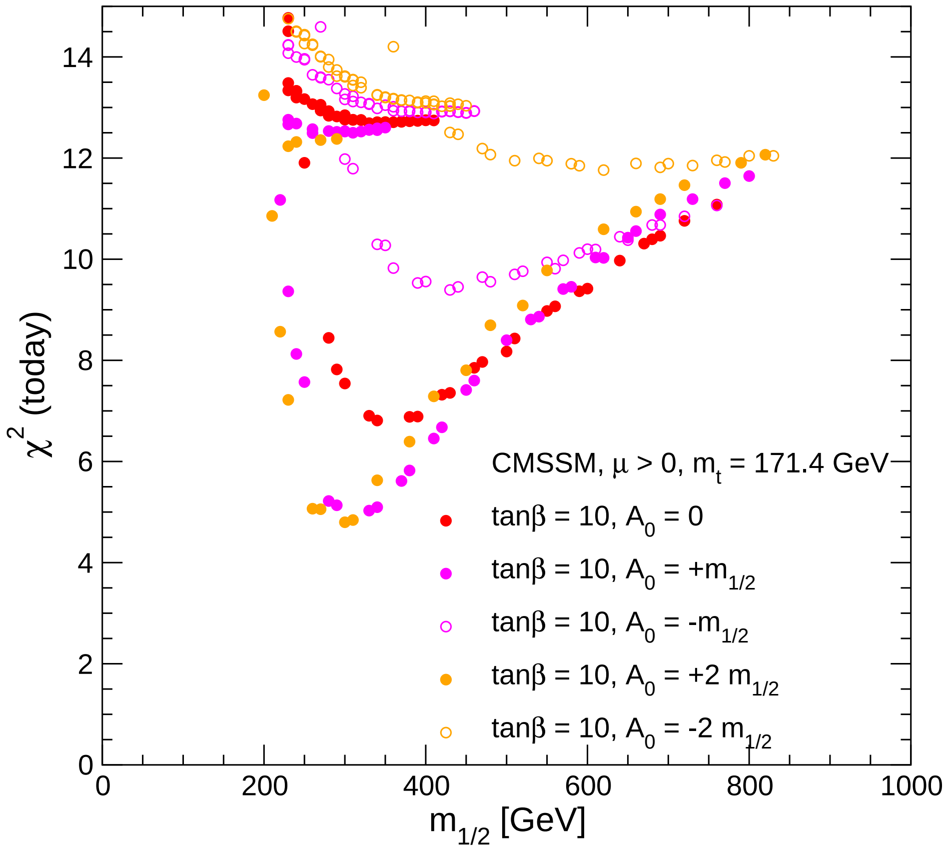

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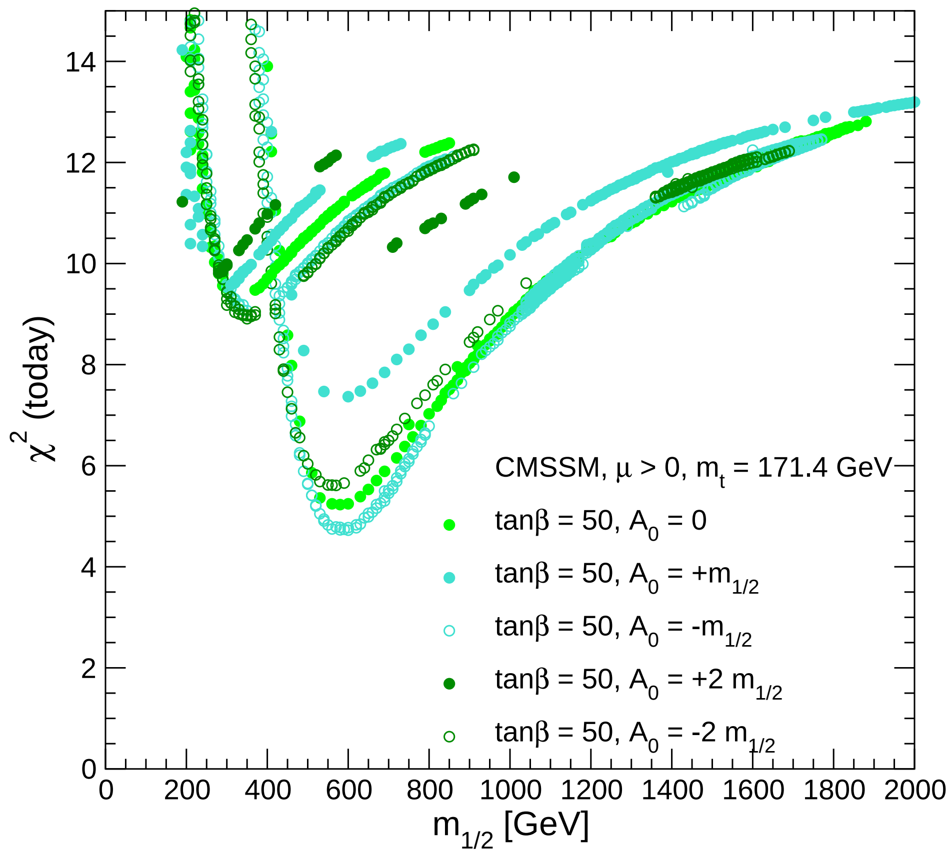
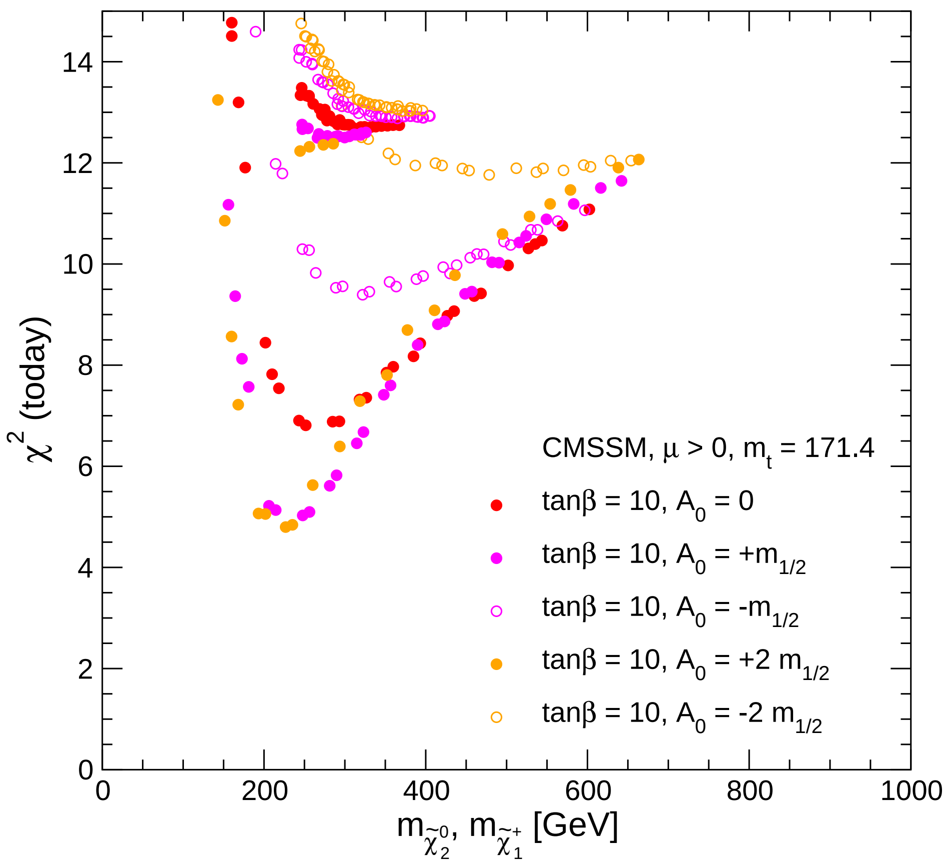


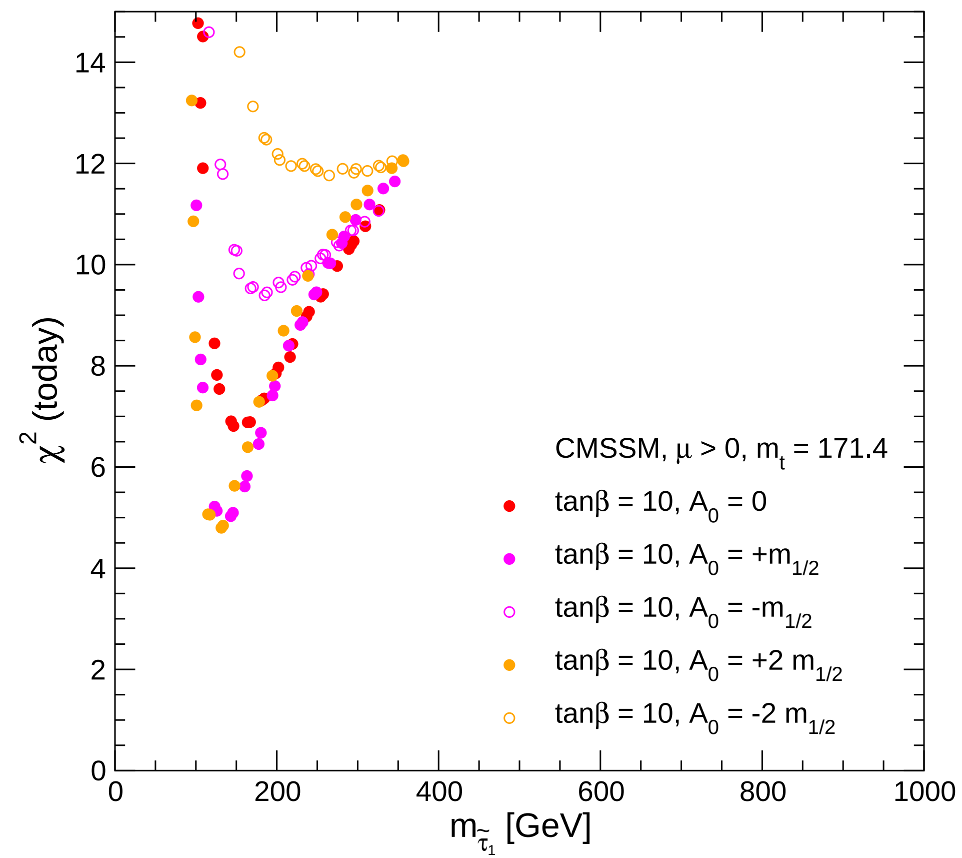
$\Rightarrow$ Good description of the data

Preference for relatively light SUSY scale

Fit results for particle masses, $\tan\beta = 10$*:*

$$m_{\tilde{\chi}_1^+} \approx m_{\tilde{\chi}_2^0},\quad m_{\tilde{\tau}_1}$$





$\Rightarrow$ Good prospects for the LHC and ILC

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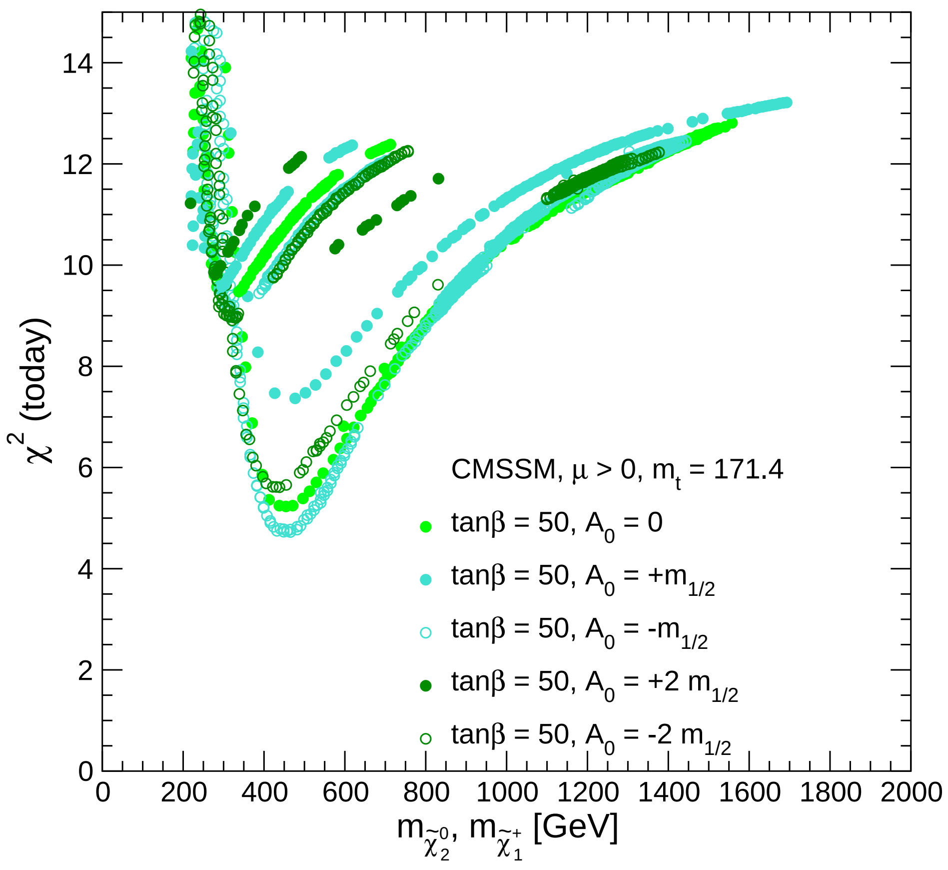
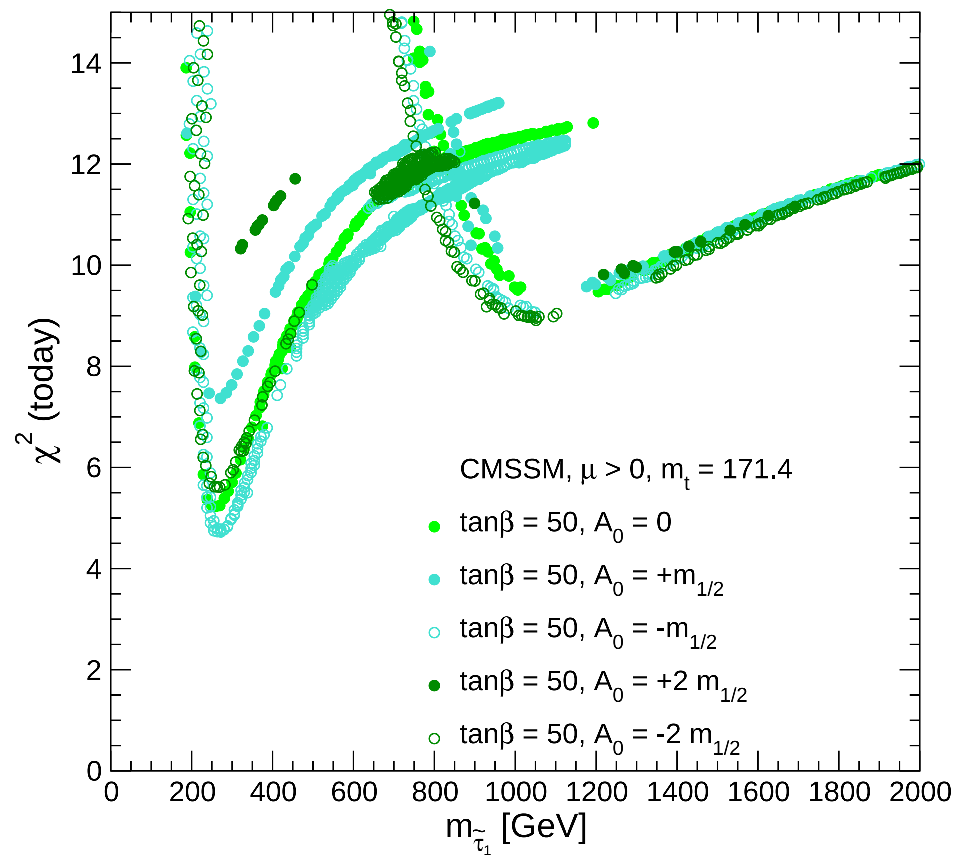


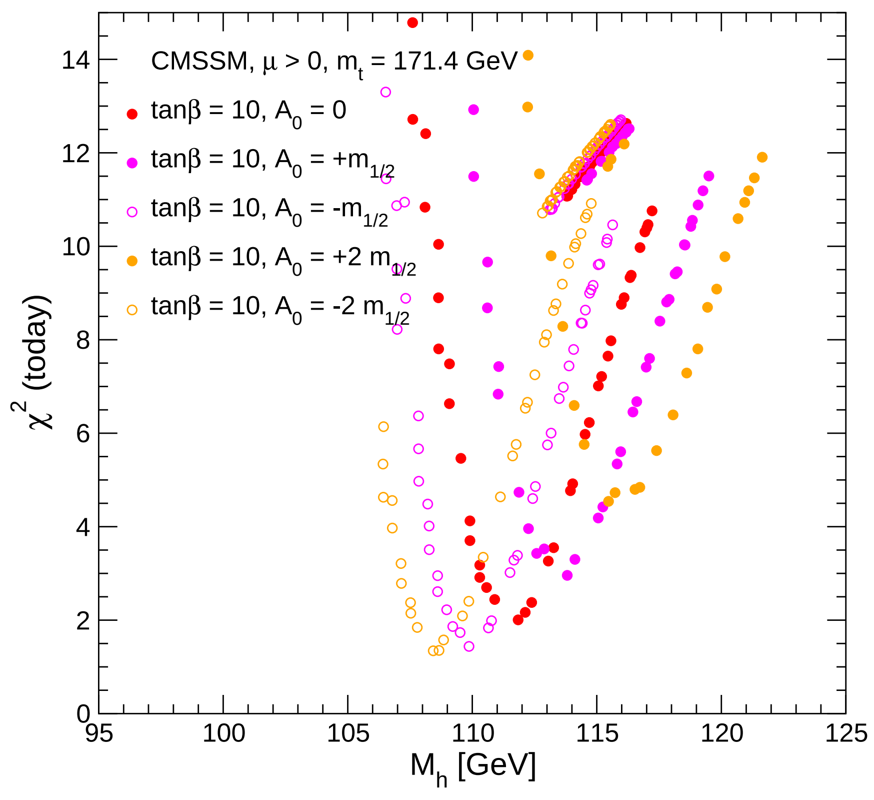


$\Rightarrow$ Good prospects for the LHC and ILC

Bounds on the light Higgs mass in the CMSSM with dark matter constraints from EWPO and BPO

χ^2 fit for M_h, without imposing direct search limit:

$\tan\beta = 10$:



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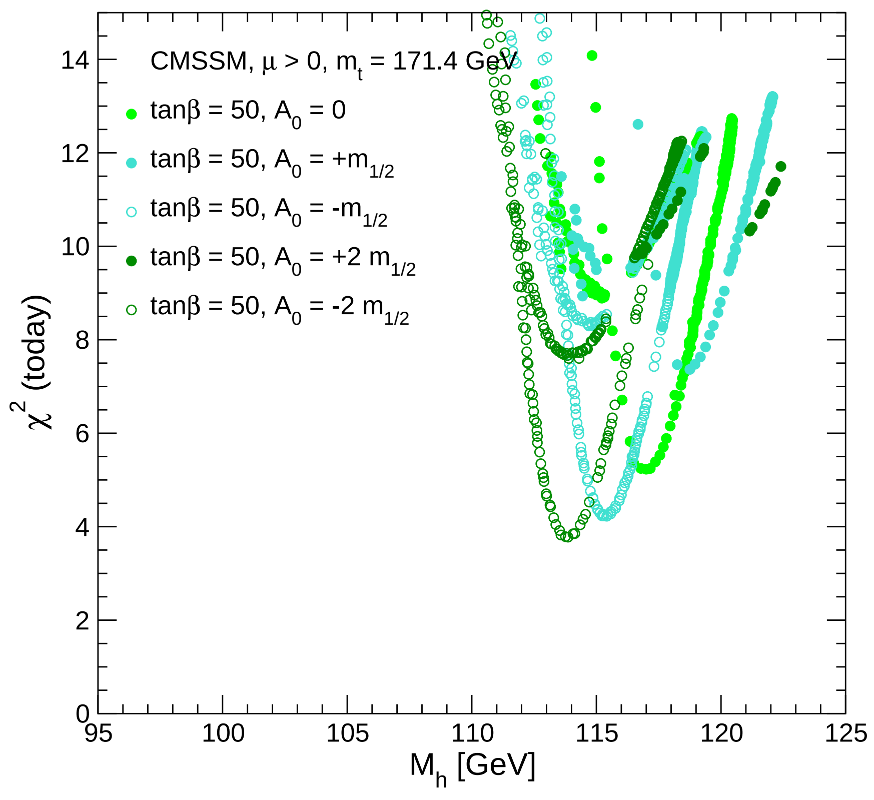
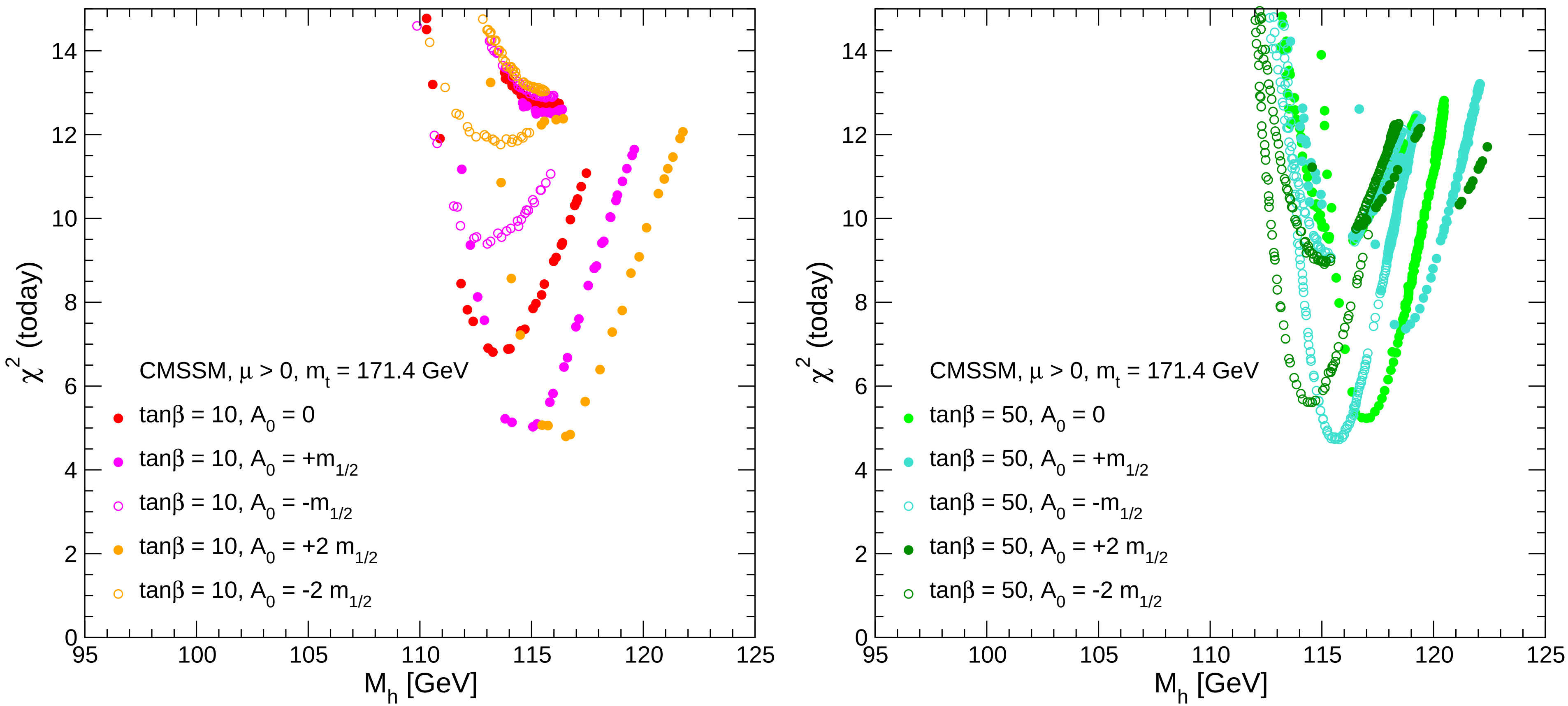


$\Rightarrow$ Pronounced minimum, less tension than in SM, best fit value $\gtrsim 110$ GeV

Bounds on the light Higgs mass in the CMSSM with dark matter constraints from EWPO and BPO

χ^2 fit for M_h, direct search limit included:

$\tan\beta = 10$: $\tan\beta = 50$:



⇒ Pronounced minimum, less tension than in SM

Alternative approach: all CMSSM parameters and dark matter constraint included in the fit

Results have been confirmed by a χ^2 fit where all CMSSM parameters and the constraint from the dark matter relic density are included in the fit

[*O. Buchmueller, R. Cavanaugh, A. De Roeck, S. Heinemeyer, G. Isidori, P. Paradisi, F. Ronga, A. Weber, G. W. '07*]

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- Best fit value for $\tan\beta \approx 10$, other local minimum at $\tan\beta \approx 50$
- Best fit value for $m_{1/2} \approx 300 \text{ GeV}$
- Indirect limit on M_h without imposing direct search limit:

$$M_\text{h}^\text{CMSSM} = 110^{+8}_{-10} \text{ (exp.)} \pm 3 \text{ (theo.) GeV}$$

[*see F. Ronga's talk*]

Results in the NUHM

Combined χ^2 fit, EWPO + BPO:

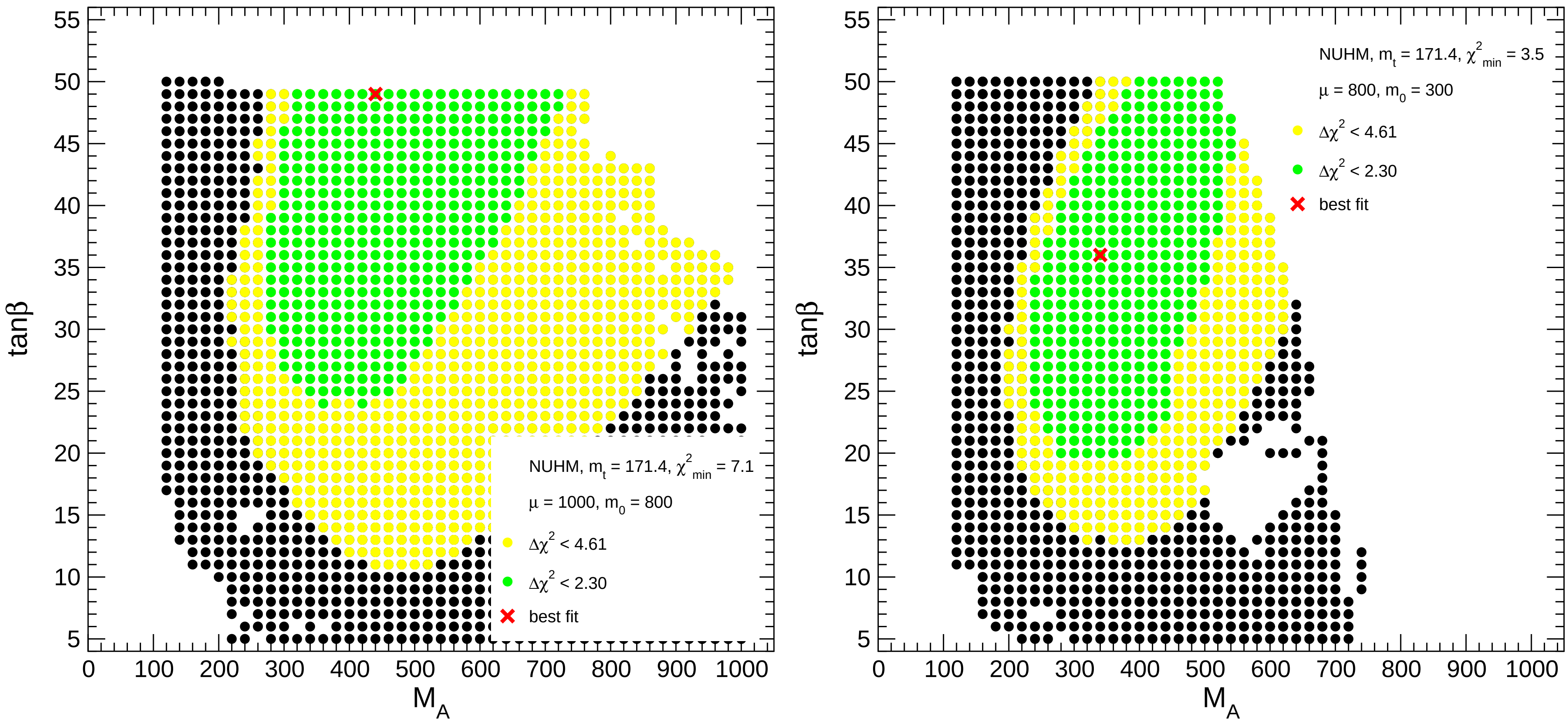
M_W, $\sin^2\theta_\mathrm{eff}$, Γ_Z, $(g-2)_\mu$, M_h, $\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_\mathrm{s} \to \mu^+\mu^-)$, $\mathrm{BR}(B_\mathrm{u} \to \tau\nu_\tau)$, ΔM_{B_s}

Results are analysed in WMAP-compatible M_A–$\tan\beta$ planes

4 examples:

- $m_{1/2}$ varied, $m_0 = 800$ GeV, $A_0 = 0$, $\mu = 1000$ GeV
- $m_{1/2}$ varied, $m_0 = 300$ GeV, $A_0 = 0$, $\mu = 800$ GeV
- μ varied, $m_{1/2} = 500$ GeV, $m_0 = 1000$ GeV, $A_0 = 0$
- μ varied, $m_{1/2} = 300$ GeV, $m_0 = 300$ GeV, $A_0 = 0$

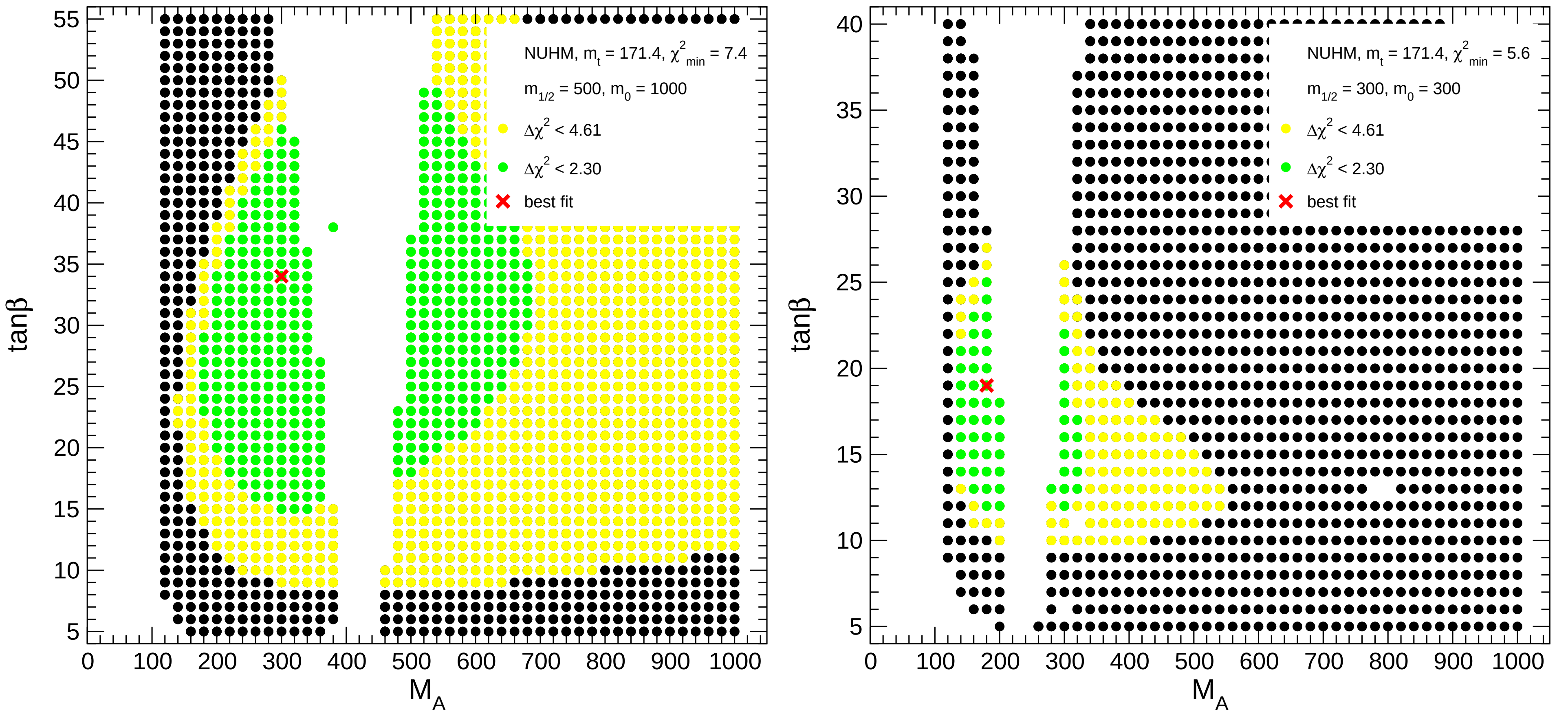
Combined χ^2 fit, EWPO + BPO in WMAP-compatible M_A–$\tan\beta$ planes ($m_{1/2}$ varied)



⇒ Best fit points have $\chi^2_{\rm min} = 7.1$ (left) and $\chi^2_{\rm min} = 3.5$ (right)

Slight improvement of $\chi^2_{\rm min}$ compared to CMSSM possible

Combined χ^2 fit, EWPO + BPO in WMAP-compatible M_A–$\tan\beta$ planes (μ varied)



⇒ Best fit points have $\chi^2_{\rm min} = 7.4$ (left) and $\chi^2_{\rm min} = 5.6$ (right)

High indirect sensitivity to M_A and $\tan\beta$

Preference for relatively small M_A

Conclusions

- Combined χ^2 fits of EWPO + BPO, M_W, $\sin^2\theta_{\rm eff}$, Γ_Z, $(g-2)_\mu$, M_h, $\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $\mathrm{BR}(B_u \to \tau\nu_\tau)$, ΔM_{B_s}, in CMSSM and NUHM with dark matter constraints

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  $\Rightarrow$ Good description of the data

  Preference for relatively light SUSY scale

- CMSSM: slight tension between EWPO and BPO

  EWPO $+$ BPO allow to establish indirect bound on M_h

  Best fit value $\gtrsim 110~\mathrm{GeV}$ (without direct search limit)

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- Combined χ^2 fits of EWPO + BPO, M_W, $\sin^2\theta_\mathrm{eff}$, Γ_Z, $(g-2)_\mu$, M_h, $\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_\mathrm{s} \to \mu^+\mu^-)$, $\mathrm{BR}(B_\mathrm{u} \to \tau\nu_\tau)$, ΔM_{B_s}, in CMSSM and NUHM with dark matter constraints

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- NUHM results in WMAP-compatible M_A–$\tan\beta$ planes:

  Slight improvement of χ^2_min compared to CMSSM possible

  Preference for relatively small M_A