Sensitivities to the Scale of Supersymmetry from Precision Observables

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Snowmass, 08/2005

Based on collaboration with J. Ellis, S. Heinemeyer, K. Olive

hep-ph/0411216 + updates for $m_{\rm t} = 172.7 \pm 2.9\ \mathrm{GeV}$

1. Introduction
2. Electroweak precision observables
3. Combined sensitivity: present situation and ILC precision
4. Conclusions

1. Introduction

EW precision data:

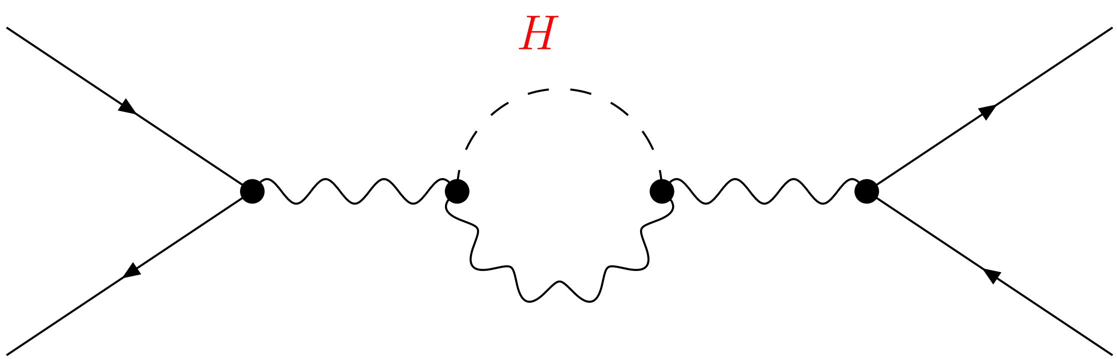
$M_Z, M_W, \sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}, \ldots$

Theory:

SM, MSSM, ...

$\Downarrow$

Test of theory at quantum level: sensitivity to loop corrections



$\Downarrow$

Indirect constraints on unknown parameters: M_H, $m_{\tilde{t}}$, ...

Effects of "new physics"?

Constrained MSSM (CMSSM) with restrictions from dark matter relic density

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: $\tilde{\chi}_1^0$

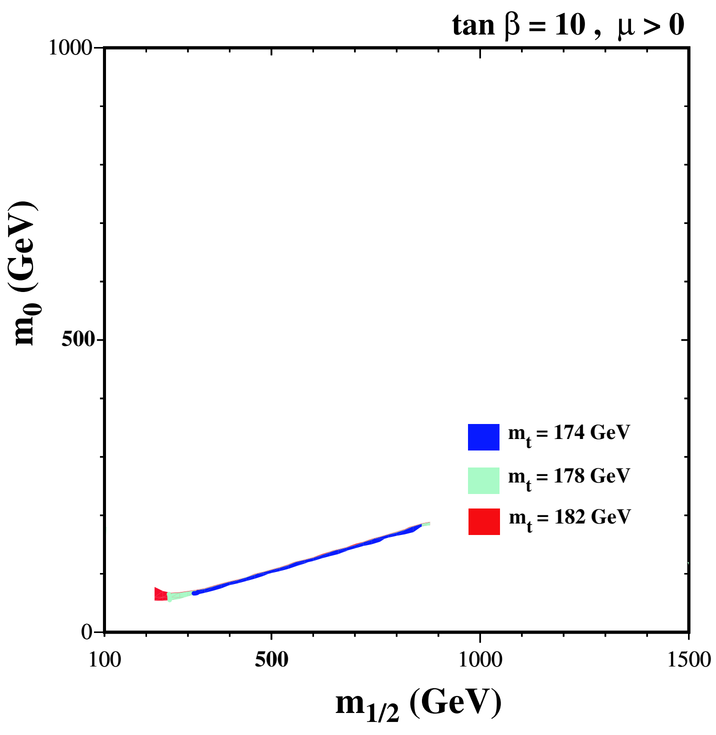
Cold dark matter (CDM) density (WMAP, . . .):

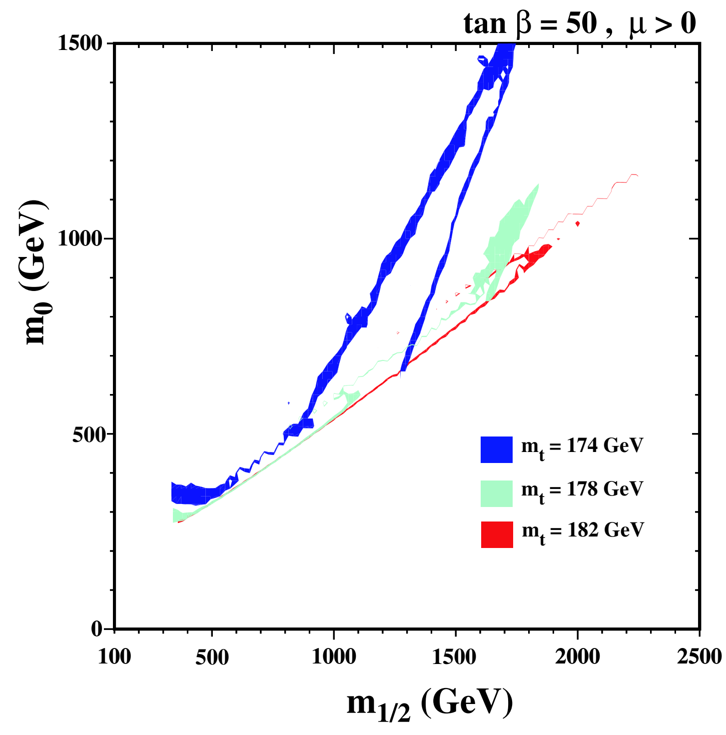
$$0.094 < \Omega_{\rm CDM}\, h^2 < 0.129$$

$\Rightarrow$ Constraints on SUSY parameter space

Constrained MSSM (CMSSM) with restrictions from dark matter relic density

Allowed region in $(m_{1/2}, m_0)$ plane (fixed A_0, different m_t):





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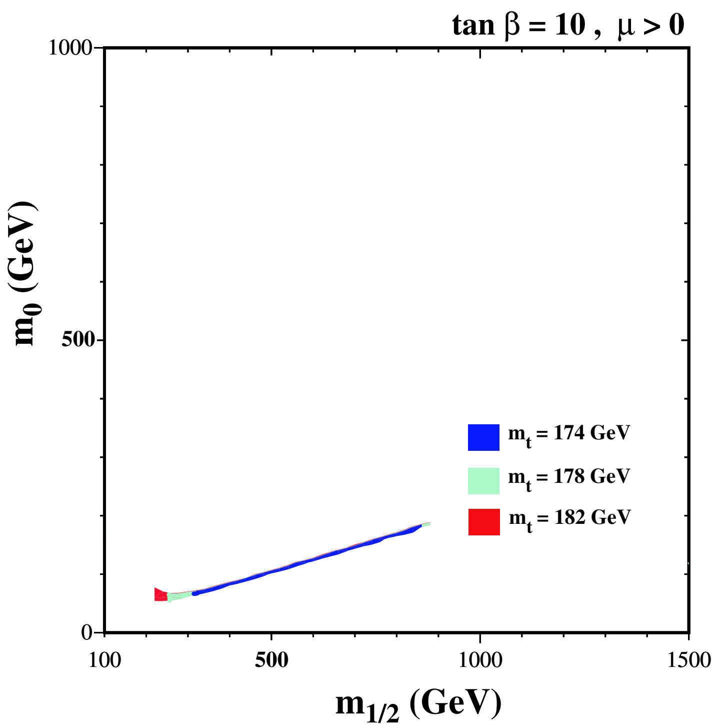

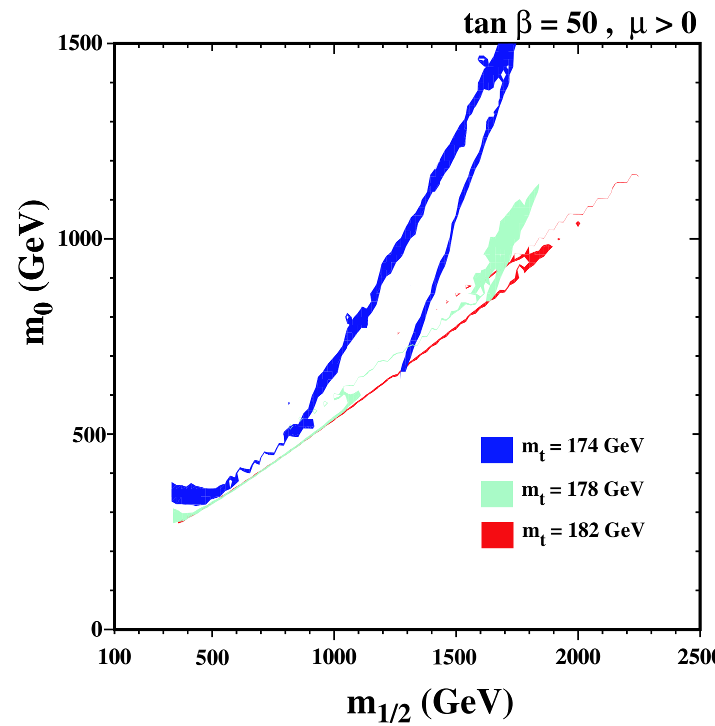

$\Rightarrow$ narrow “WMAP strips”

$\Rightarrow$ effectively reduces dimensionality of parameter space

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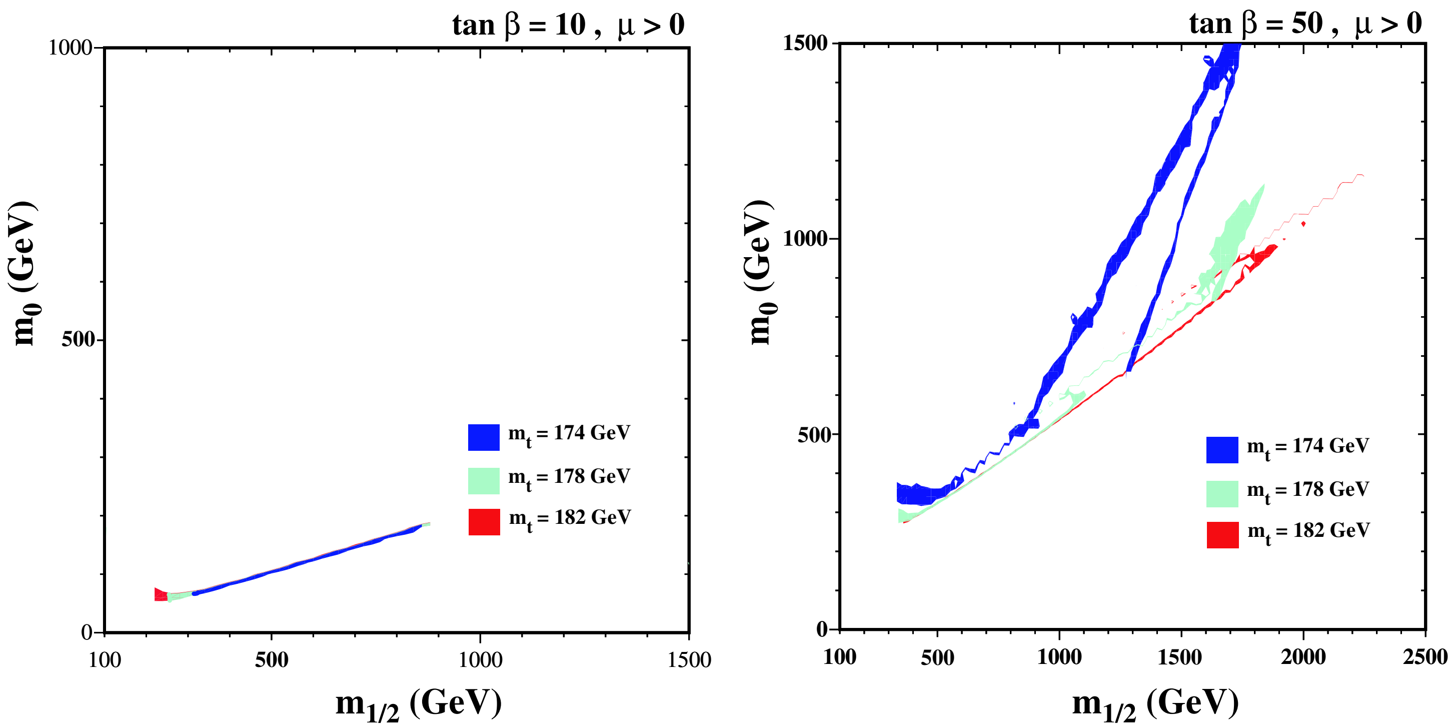

⇒ narrow “WMAP strips”

⇒ effectively reduces dimensionality of parameter space

⇒ analyse CMSSM along WMAP strips

2. Electroweak precision observables

Observables taken into account:

Present:

$M_{\mathrm{W}}, \sin^2\theta_{\mathrm{eff}}, (g-2)_\mu, b \to s\gamma, B_{\mathrm{s}} \to \mu^+\mu^-$

Current experimental errors $+$ estimate of current theoretical uncertainties (from unknown higher-orders $+$ experimental errors of input parameters)

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Future (ILC):

$M_{\mathrm{W}}, \sin^2\theta_{\mathrm{eff}}, (g-2)_\mu, b \to s\gamma, B_{\mathrm{s}} \to \mu^+\mu^-,$
M_{h}, BR($h \to b\bar{b}$)/BR($h \to WW^*$)

Experimental precision at the ILC + estimate of future theoretical uncertainties

Theoretical predictions for $M_{\rm W}$*,* $\sin^2\theta_{\rm eff}$*:*

Comparison of prediction for muon decay with experiment (Fermi constant G_μ)

$$\Rightarrow \quad M_{\rm W}^2\left(1-\frac{M_{\rm W}^2}{M_{\rm Z}^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}\left(1+\Delta r\right),$$

$\Updownarrow$

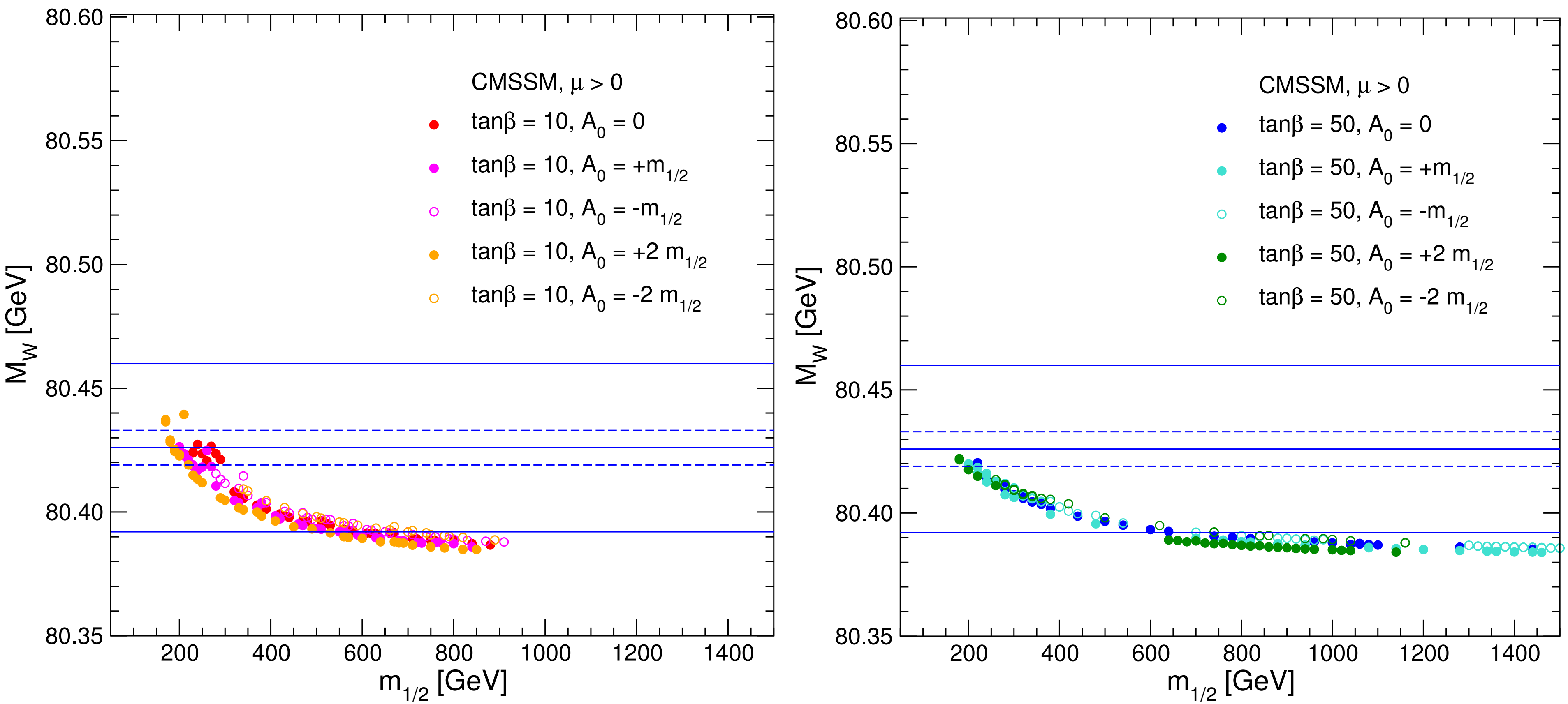
loop corrections

$\Rightarrow$ Theo. prediction for $M_{\rm W}$ in terms of $M_{\rm Z}$, α, G_μ, $\Delta r(m_{\rm t}, m_{\tilde{\rm t}}, \ldots)$

Effective couplings at the Z resonance:

$$\Rightarrow \quad \sin^2\theta_{\rm eff}=\frac{1}{4}\left(1-{\rm Re}\,\frac{g_V}{g_A}\right)=\left(1-\frac{M_{\rm W}^2}{M_{\rm Z}^2}\right){\rm Re}\,\kappa_l(s=M_{\rm Z}^2)$$

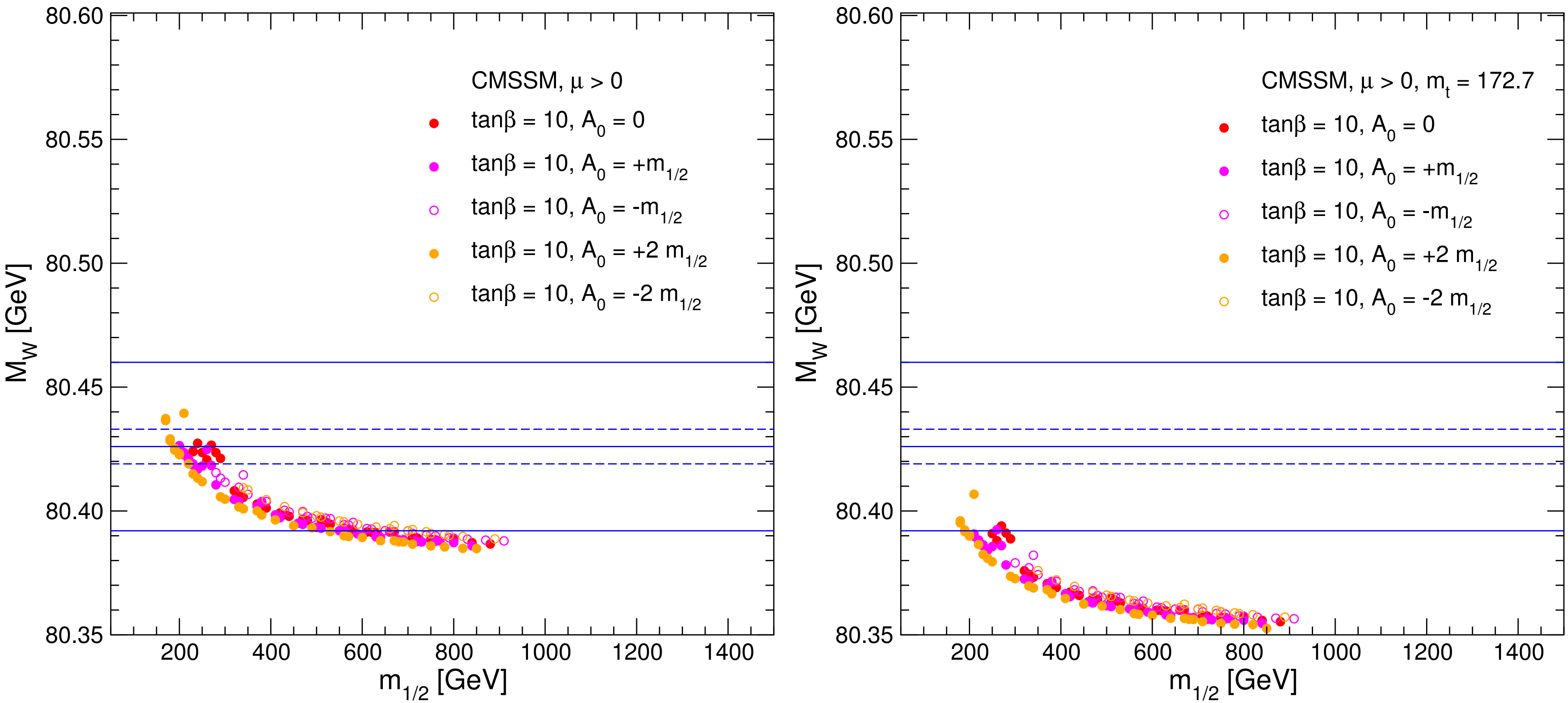
CMSSM prediction for M_W vs. current precision and ILC (MegaW) for $m_t = 178.0$ GeV



⇒ Relatively small values of $m_{1/2}$ favoured

great improvement at the ILC

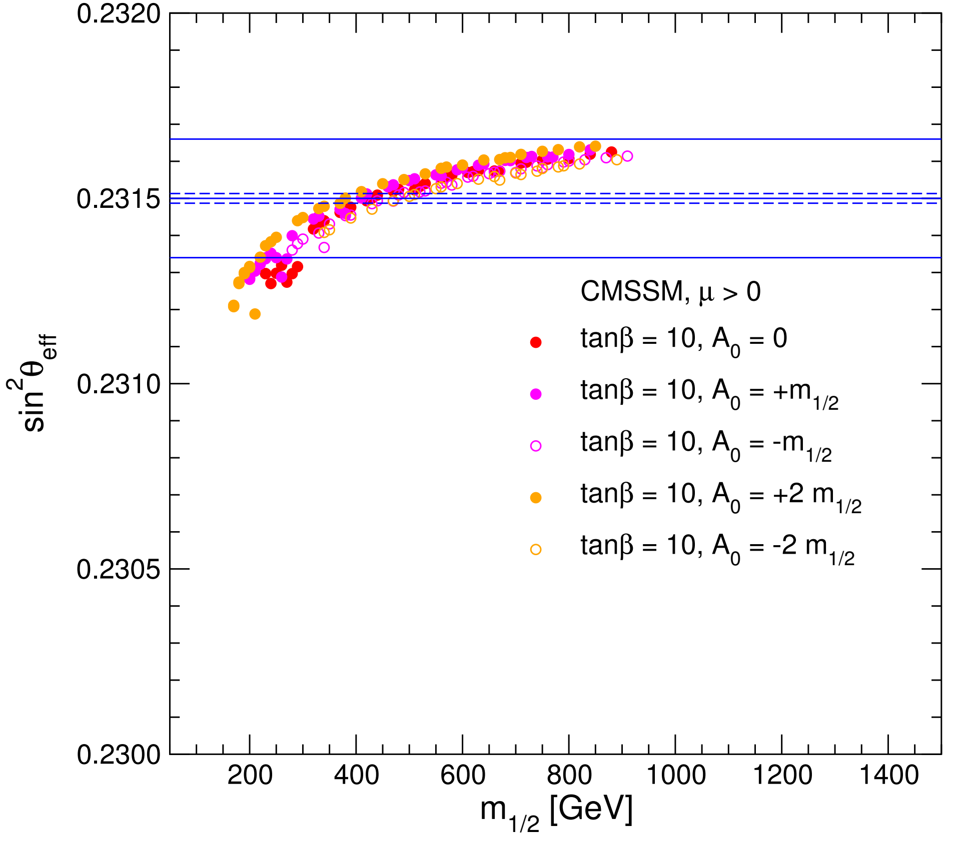
Comparison: $m_t = 178.0$ GeV ***(left) vs.*** $m_t = 172.7$ GeV ***(right)***

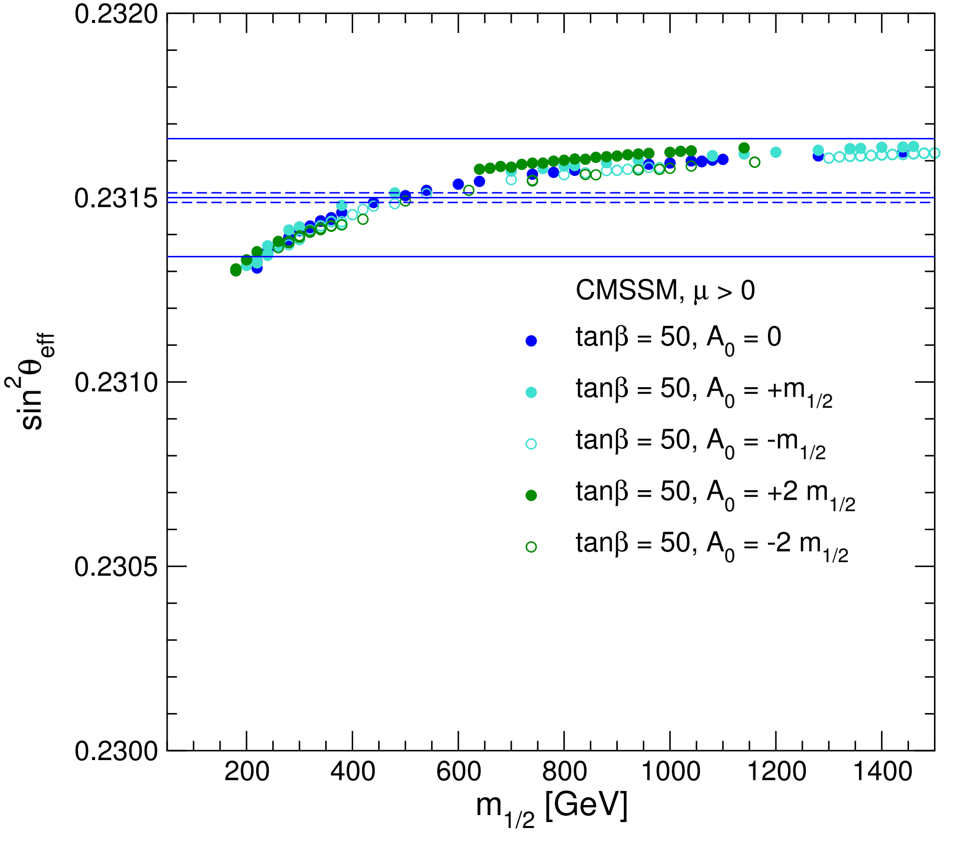


$\Rightarrow$ Lower m_t yields lower M_W

preference for small values of $m_{1/2}$ becomes more pronounced

CMSSM prediction for $\sin^2\theta_{\rm eff}$ vs. current precision and ILC (GigaZ)





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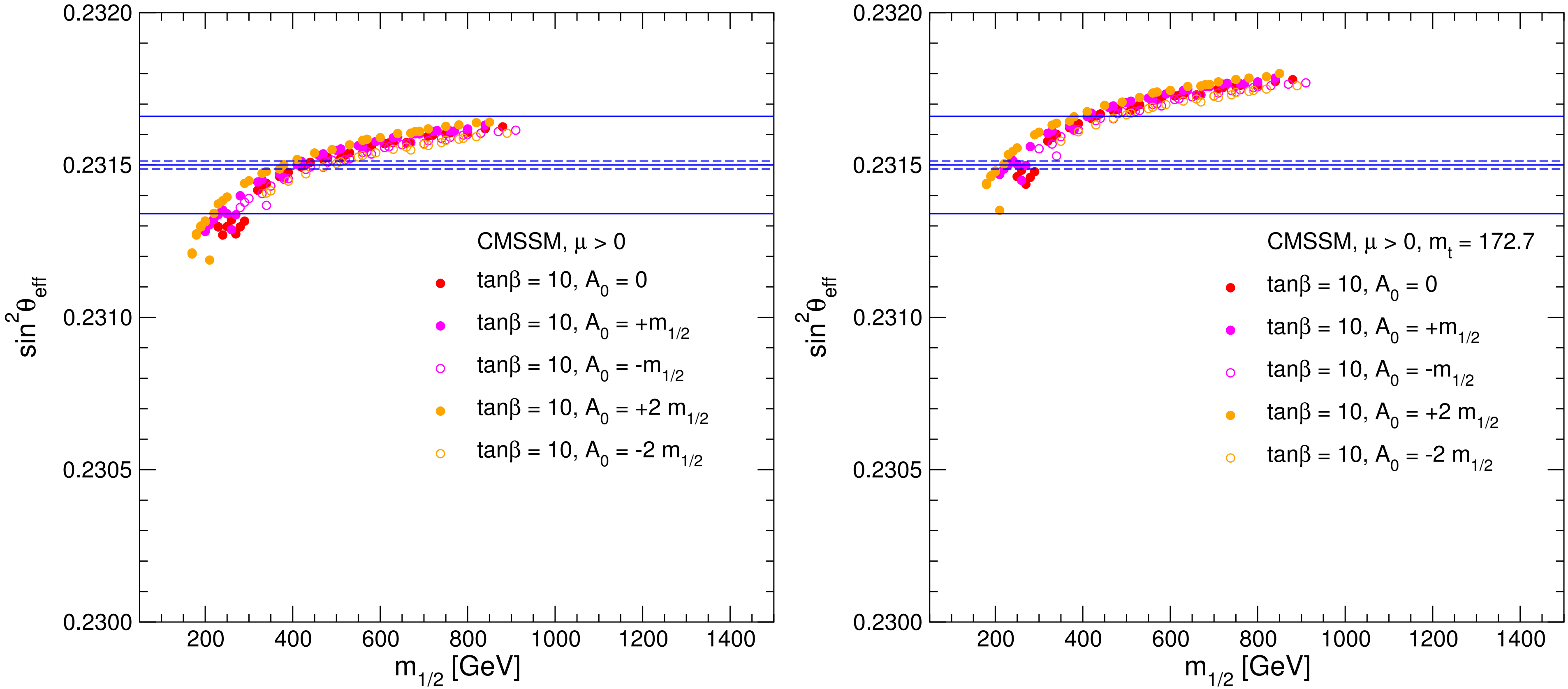


$\Rightarrow$ Lower m_t yields higher $\sin^2\theta_{eff}$
preference for small values of $m_{1/2}$ becomes more pronounced

The anomalous magnetic moment of the muon:

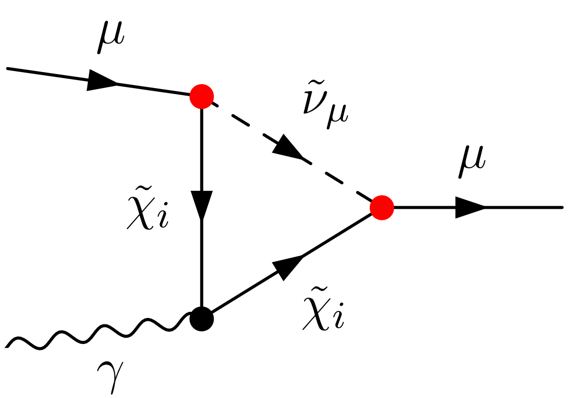
$$(g-2)_\mu \equiv 2a_\mu$$

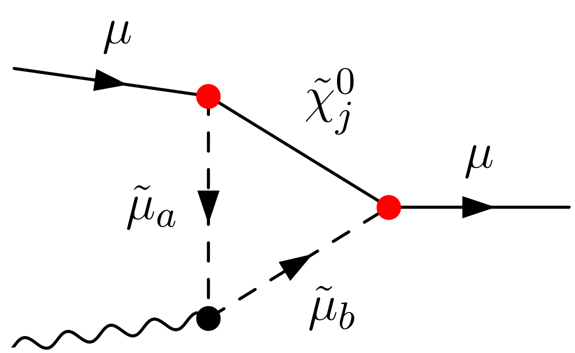
Experimental result for a_μ vs. SM prediction (using e^+e^- data for hadronic vacuum polarization contributions):

$$a_\mu^{\rm exp} - a_\mu^{\rm theo} = (25.2 \pm 9.2) \times 10^{-10} \ : \ 2.7\,\sigma \ .$$

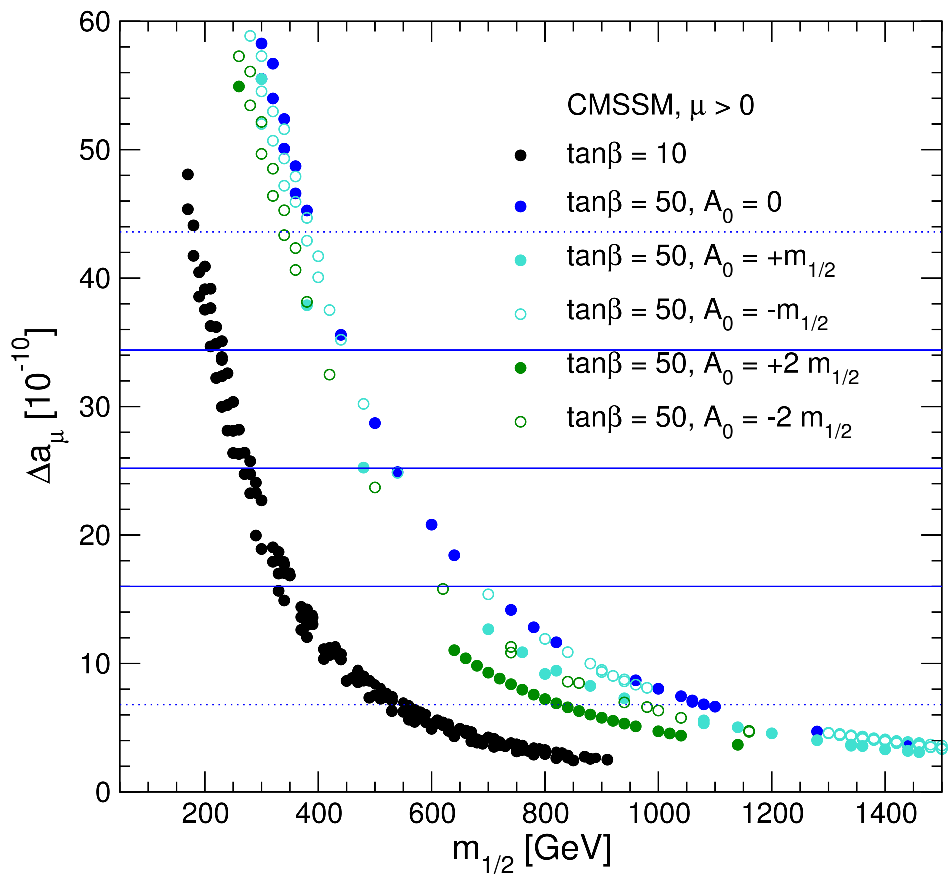
Better agreement between theory and experiment possible in models of physics beyond the SM

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



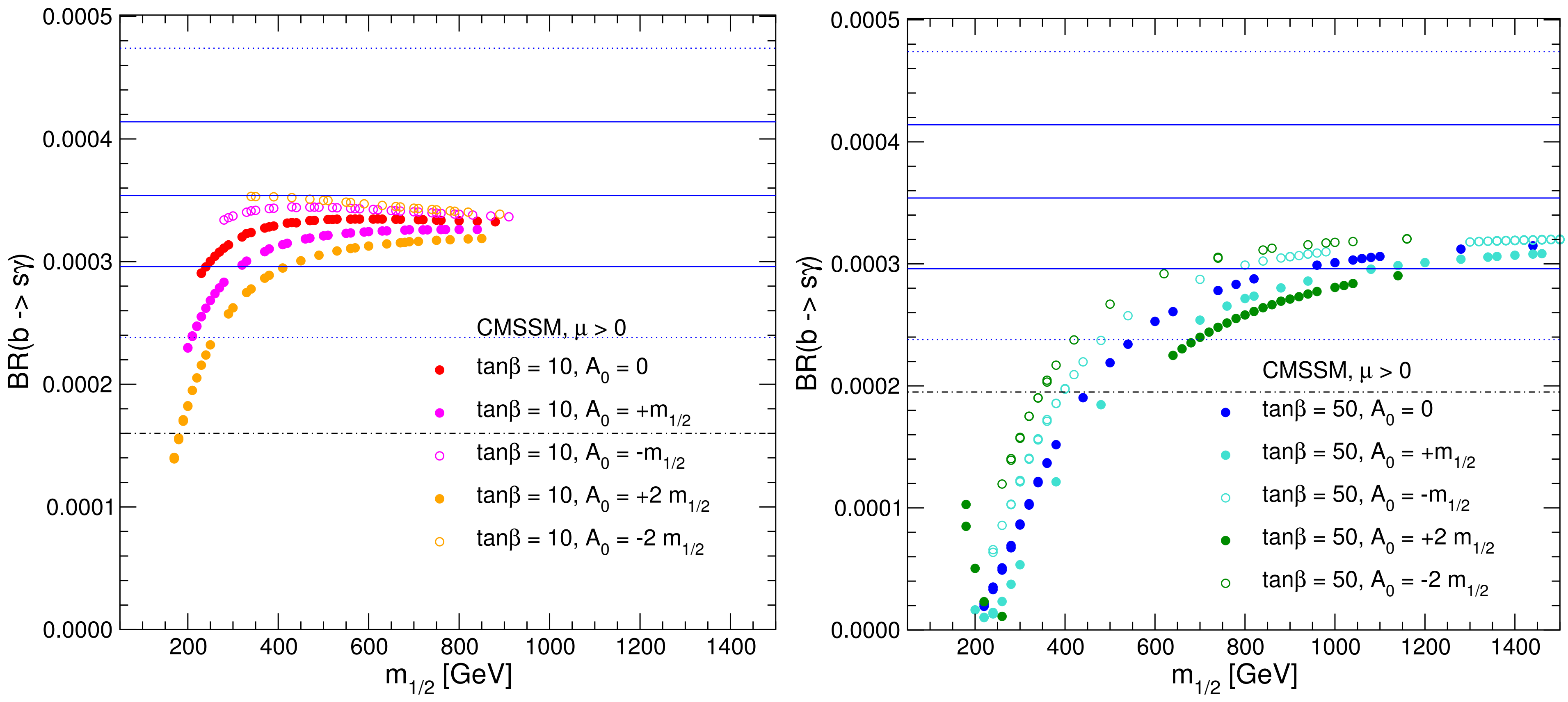


CMSSM prediction for Δa_μ vs. current precision (1 σ and 2 σ bands)



$\Rightarrow$ For $\tan\beta = 10$: relatively small values of $m_{1/2}$ favoured

CMSSM prediction for $\mathrm{BR}(b \to s\gamma)$ *vs. current precision (1* σ *and 2* σ *bands)*



$\Rightarrow$ For $\tan\beta = 10$: relatively small values of $m_{1/2}$ allowed

Higgs mass prediction in the MSSM:

Prediction for M_h, M_H, ...

Tree-level result for M_h, M_H:

$$m^2_{\mathrm{H,h}} = \frac{1}{2}\left[M_\mathrm{A}^2 + M_\mathrm{Z}^2 \pm \sqrt{(M_\mathrm{A}^2 + M_\mathrm{Z}^2)^2 - 4M_\mathrm{Z}^2 M_\mathrm{A}^2 \cos^2 2\beta}\right]$$

$\Rightarrow$ $M_\mathrm{h} \leq M_\mathrm{Z}$ at tree level

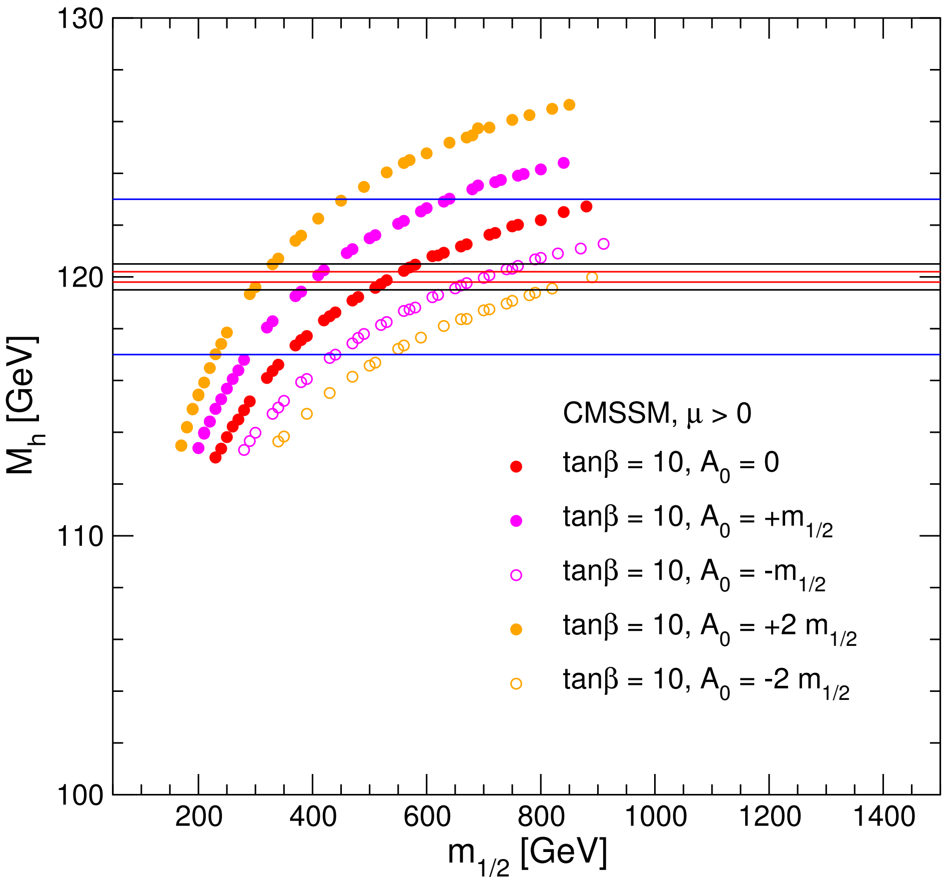
MSSM tree-level bound (gauge sector): excluded by LEP!

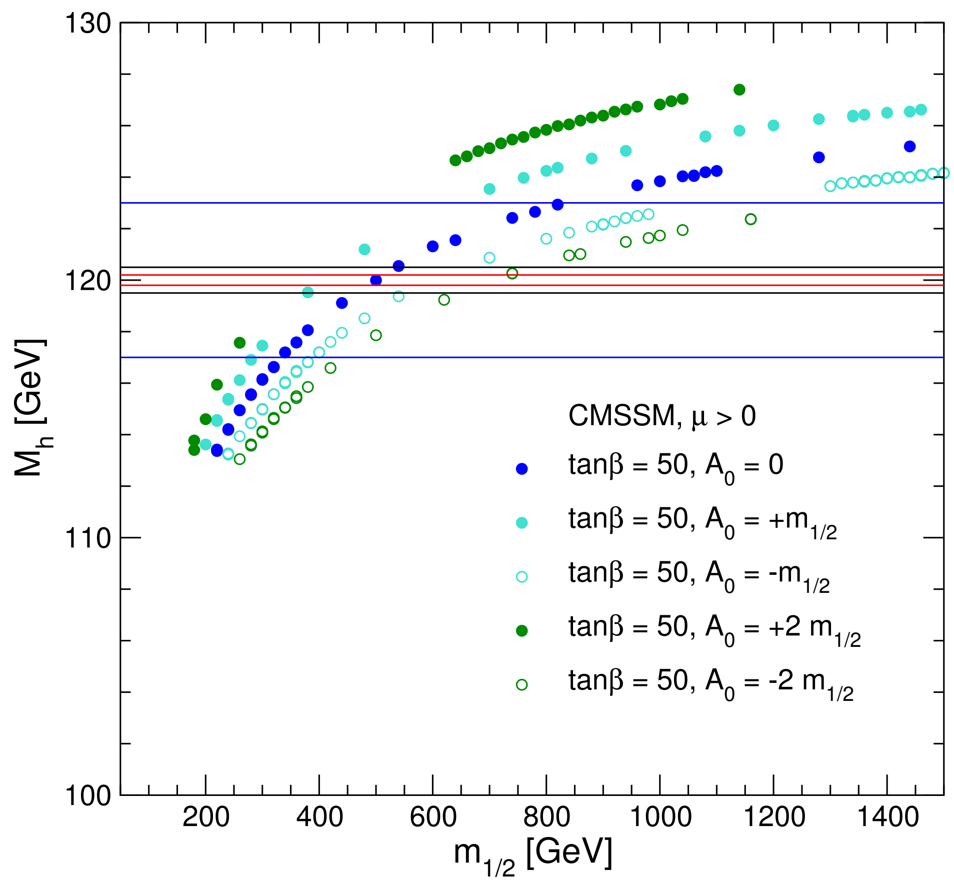
Large radiative corrections (Yukawa sector, ...):

Yukawa couplings: $\frac{\mathrm{e}\, m_\mathrm{t}}{2M_\mathrm{W}s_\mathrm{W}}$, $\frac{\mathrm{e}\, m_\mathrm{t}^2}{M_\mathrm{W}s_\mathrm{W}}$, ...

$\Rightarrow$ Dominant one-loop corrections: $G_\mu m_\mathrm{t}^4 \ln\left(\frac{m_{\tilde{\mathrm{t}}_1} m_{\tilde{\mathrm{t}}_2}}{m_\mathrm{t}^2}\right)$, $\quad \mathcal{O}(100\%)$!

CMSSM prediction for M_h vs. assumed experimental value for current and different future theoretical uncertainties





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

⇒ constraints on SUSY parameter space

3. Combined sensitivity: present situation and ILC precision

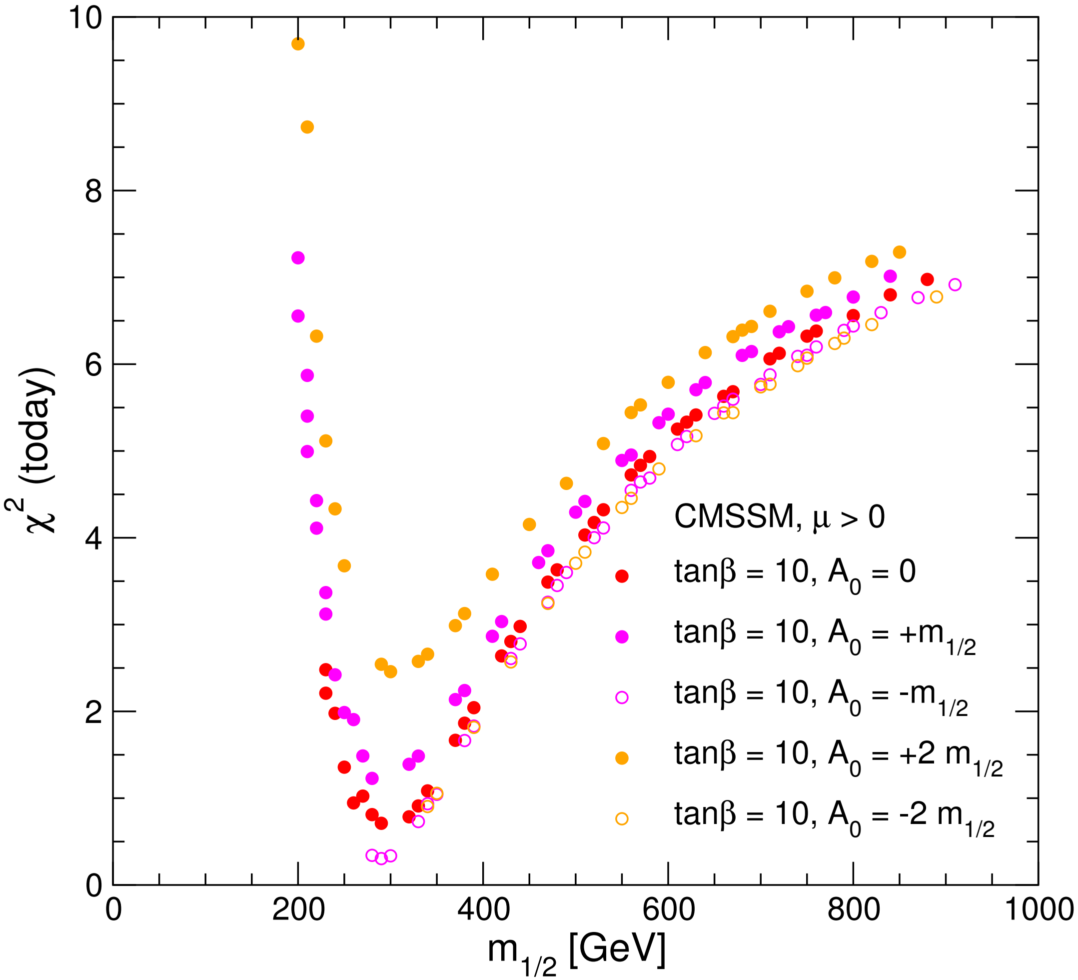
Combined sensitivity investigated for
present situation + ILC precision

Two kinds of fits:

- χ^2 fit for fixed A_0
- χ^2 fit in $(m_{1/2}, A_0)$ plane
  (scan of CMSSM parameter space)

χ^2 *fit in CMSSM with dark matter constraints:* M_W, $\sin^2\theta_{\mathrm{eff}}$, $(g-2)_\mu$, $\mathrm{BR}(b \to s\gamma)$, *present situation*

$\tan\beta = 10$:

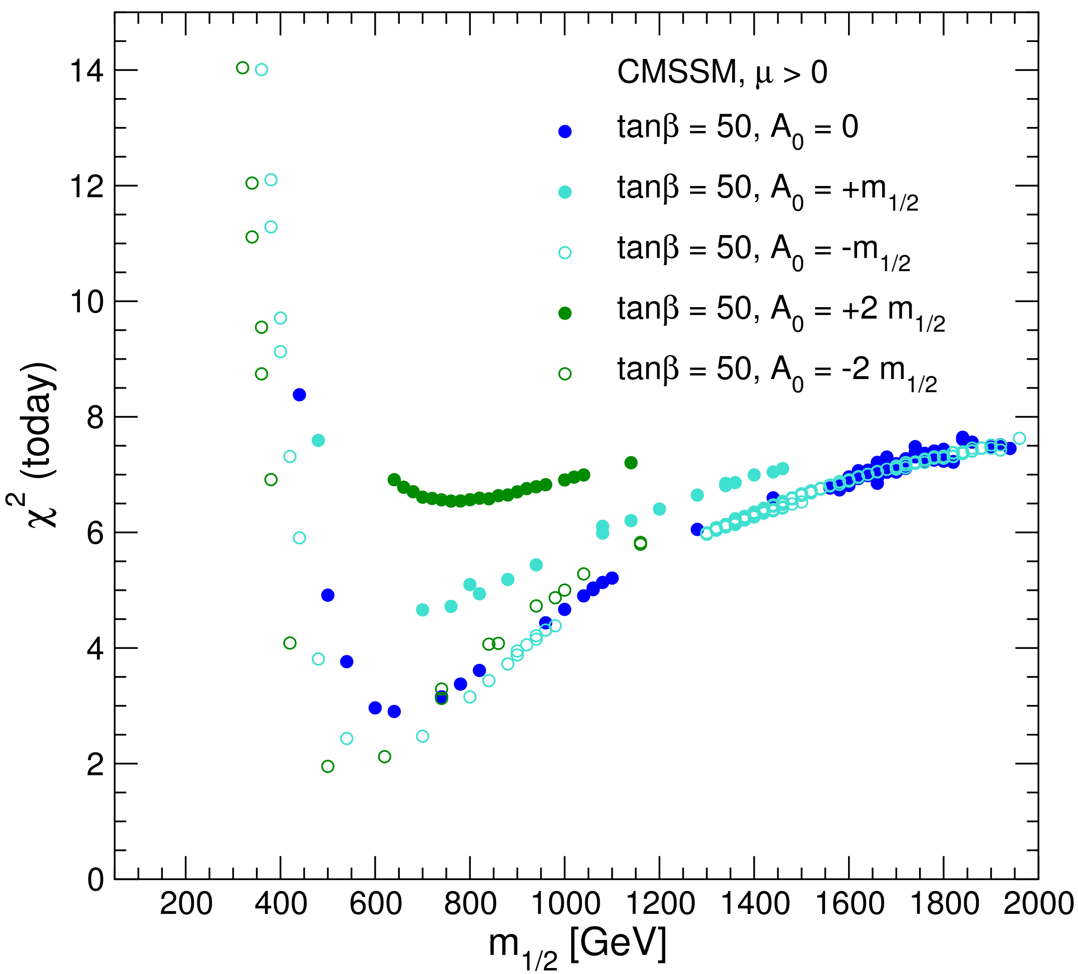


⇒ very good description of the data

preference for relatively small mass values

χ^2 ***fit in CMSSM with dark matter constraints:*** M_W**,** $\sin^2\theta_{\rm eff}$**,** $(g-2)_\mu$**,** $\mathrm{BR}(b \to s\gamma)$**, *present situation***

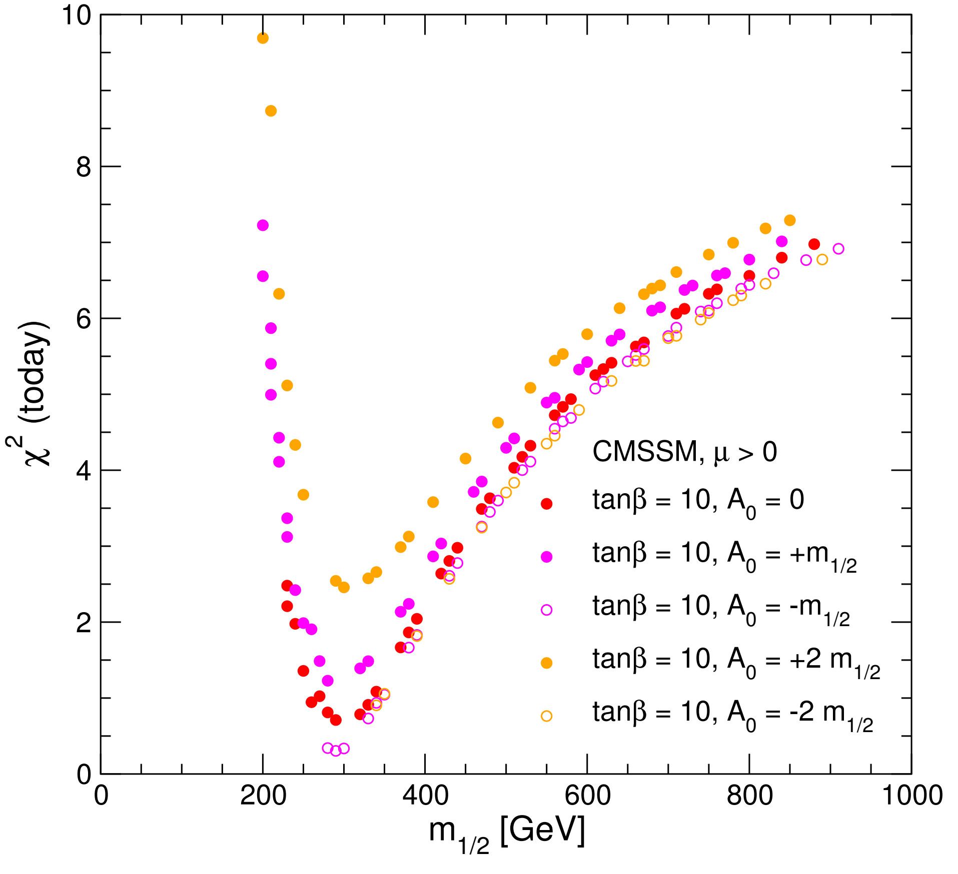
$\tan\beta = 50$:

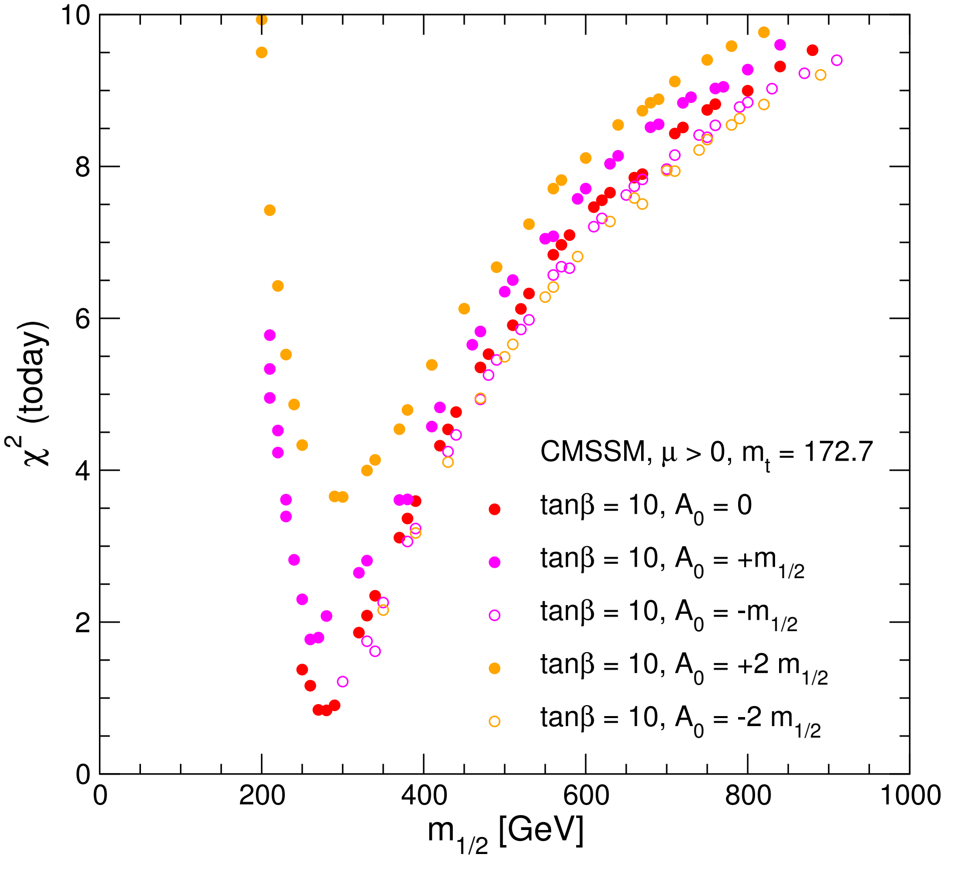


$\Rightarrow$ worse fit quality

preferred $m_{1/2}$ values larger by 200–300 GeV compared to $\tan\beta = 10$ case

Comparison: $m_t = 178.0 \pm 4.3$ GeV ***(left)*** ***vs.*** $m_t = 172.7 \pm 2.9$ GeV ***(right)***





$\Rightarrow$ best fit value shifted to slightly smaller $m_{1/2}$

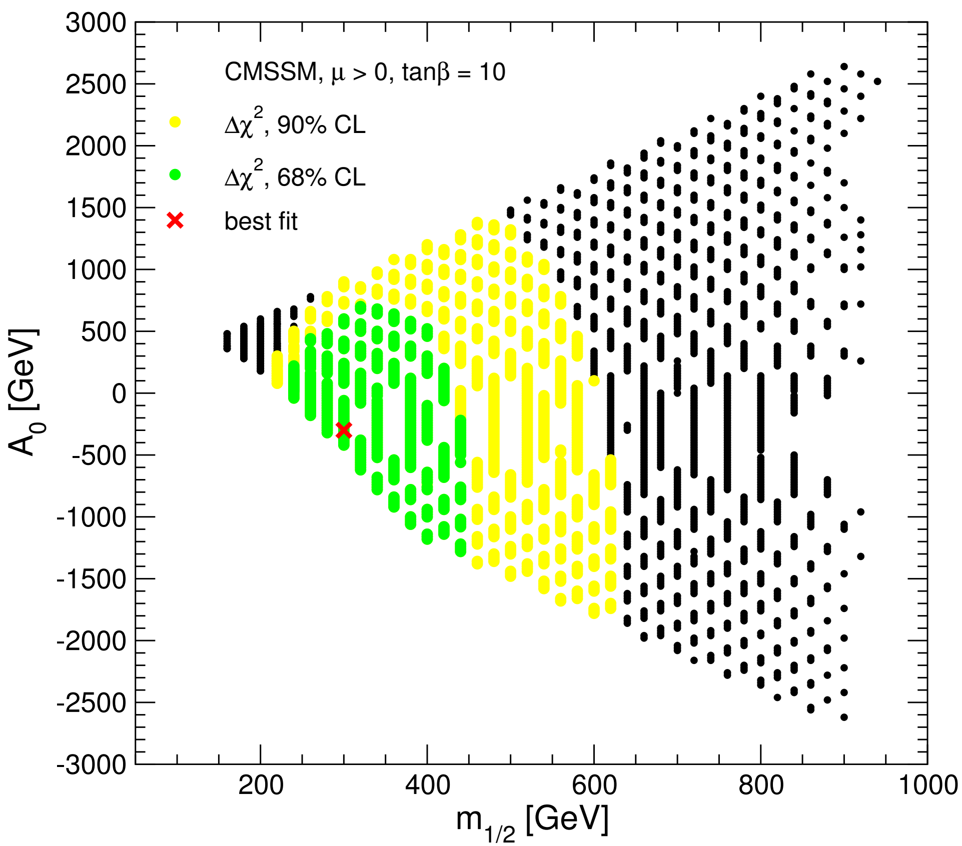
slightly larger minimum χ^2 value

higher precision on m_t yields tighter bounds on $m_{1/2}$

χ^2 *fit in CMSSM with dark matter constraints:* M_W, $\sin^2\theta_{\rm eff}$, $(g-2)_\mu$, $\mathrm{BR}(b \to s\gamma)$, *present situation*

68% and 90% C.L. regions in $m_{1/2}$–A_0 plane:

$\tan\beta = 10$:



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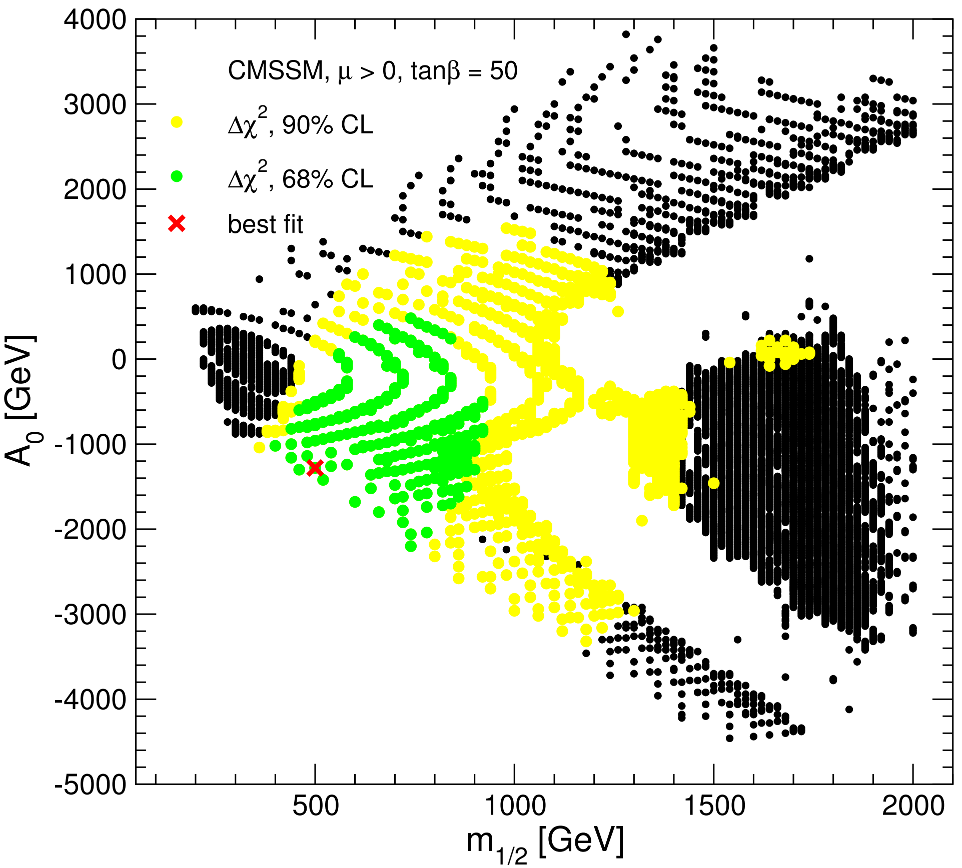
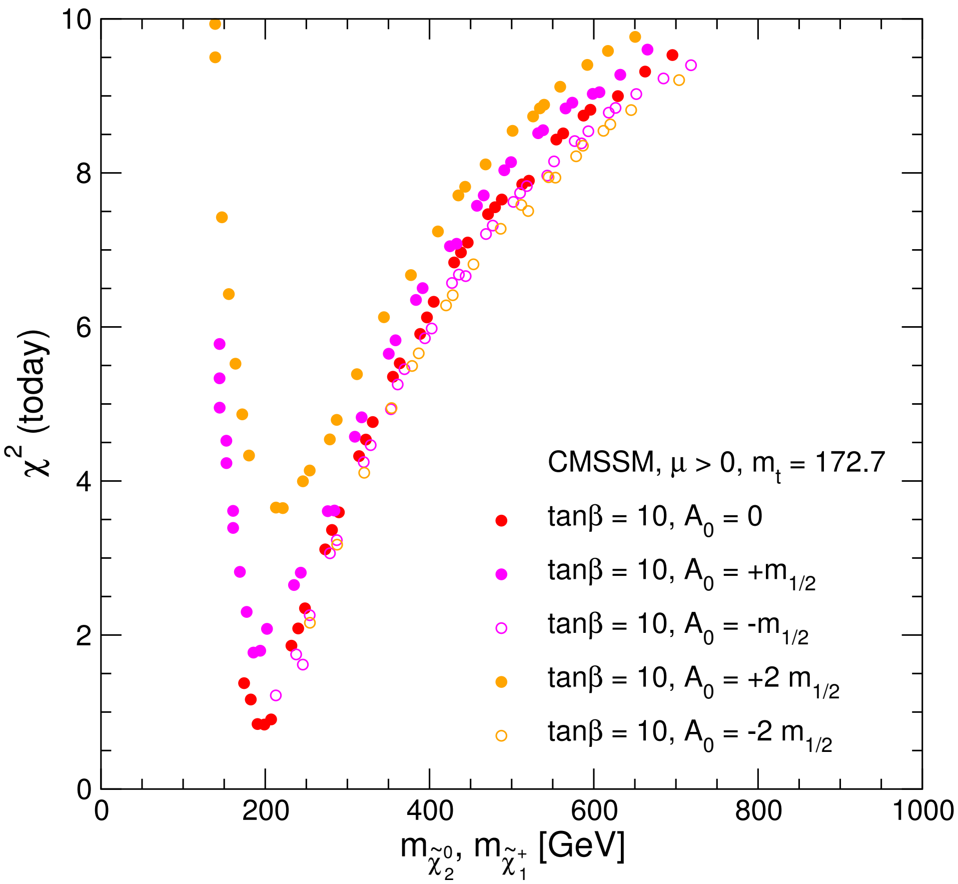
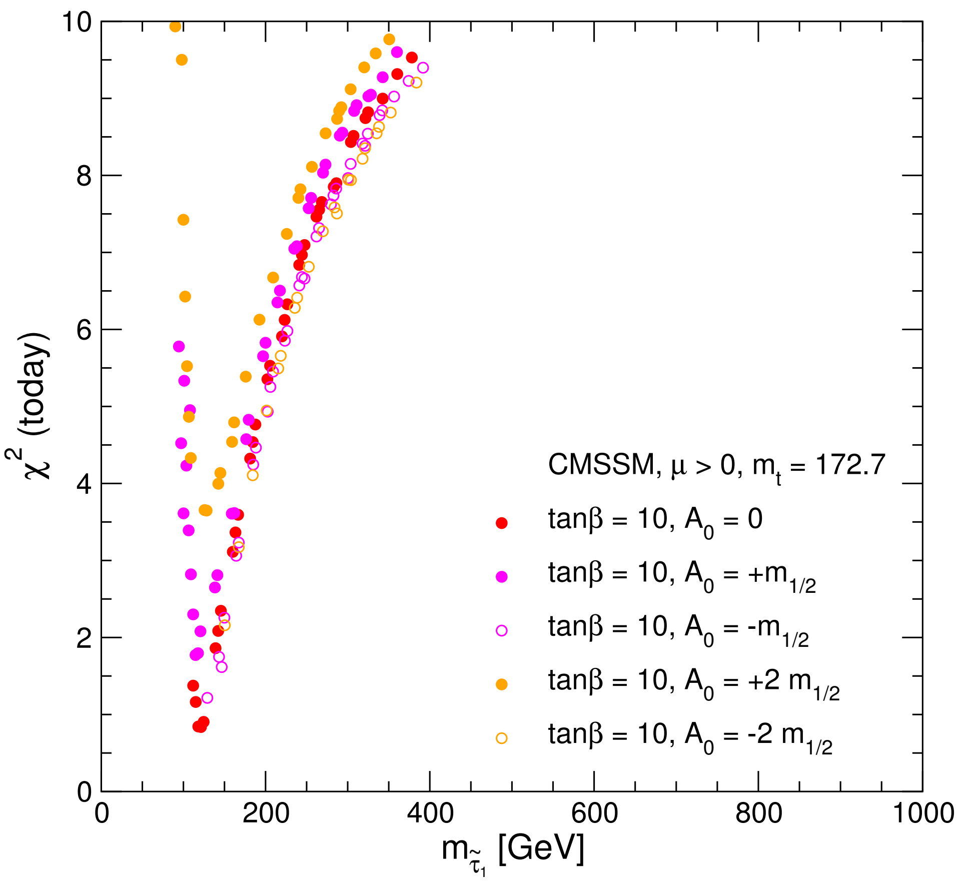


Fit results (present) for particle masses,

$\tan\beta = 10$: $m_{\tilde{\chi}_1^+} \approx m_{\tilde{\chi}_2^0}$, $m_{\tilde{\tau}_1}$, $m_t = 172.7 \pm 2.9$ GeV





$\Rightarrow$ Good prospects for the LHC and ILC

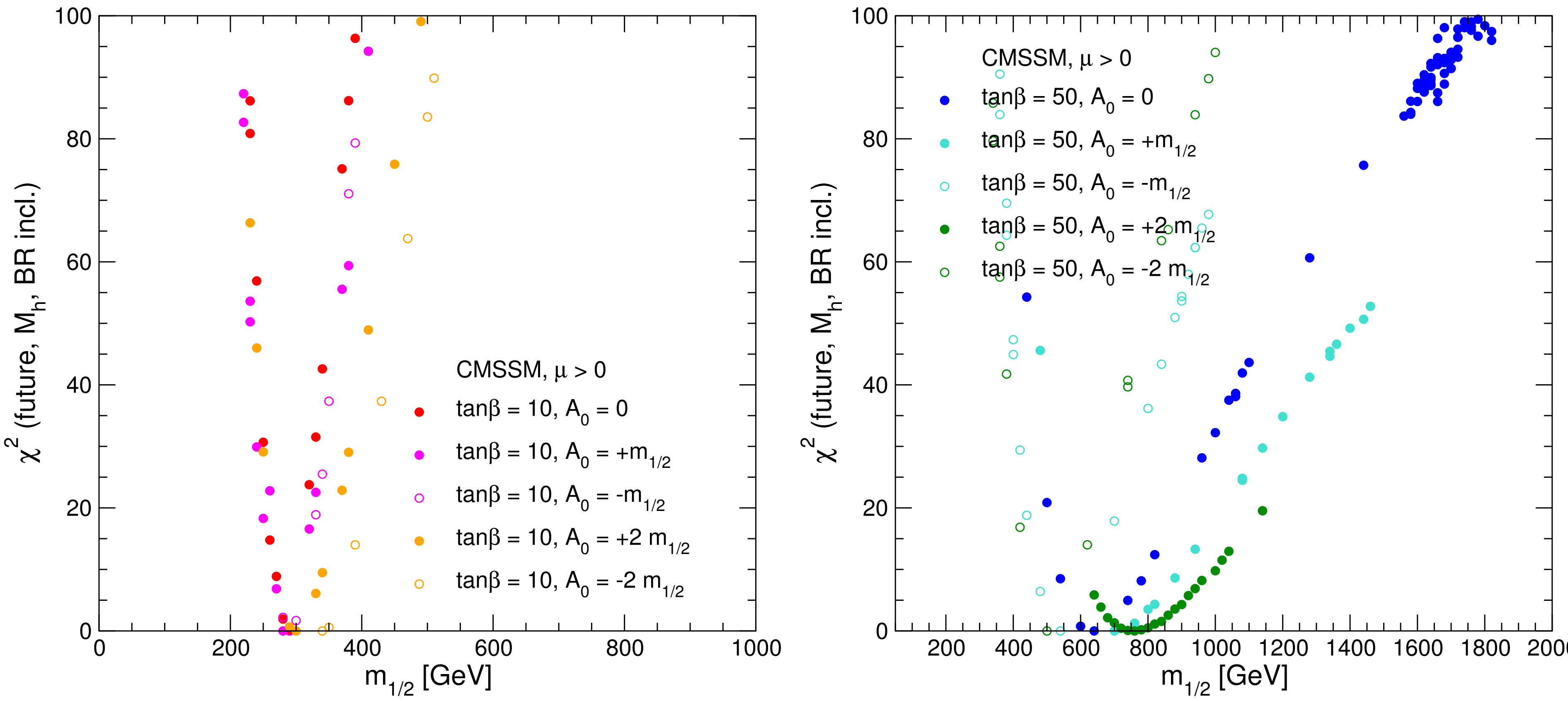
Comparison with other recent analysis

Fit involving all CMSSM parameters, but omitting electroweak precision observables M_W and $\sin^2\theta_\mathrm{eff}$
[*B. Allanach, C. Lester '05*]

$\Rightarrow$ preference for larger values of $\tan\beta$ and somewhat larger $m_{1/2}$

$\Rightarrow$ M_W and $\sin^2\theta_\mathrm{eff}$ are crucial for the fit, give rise to preference for relatively small $m_{1/2}$

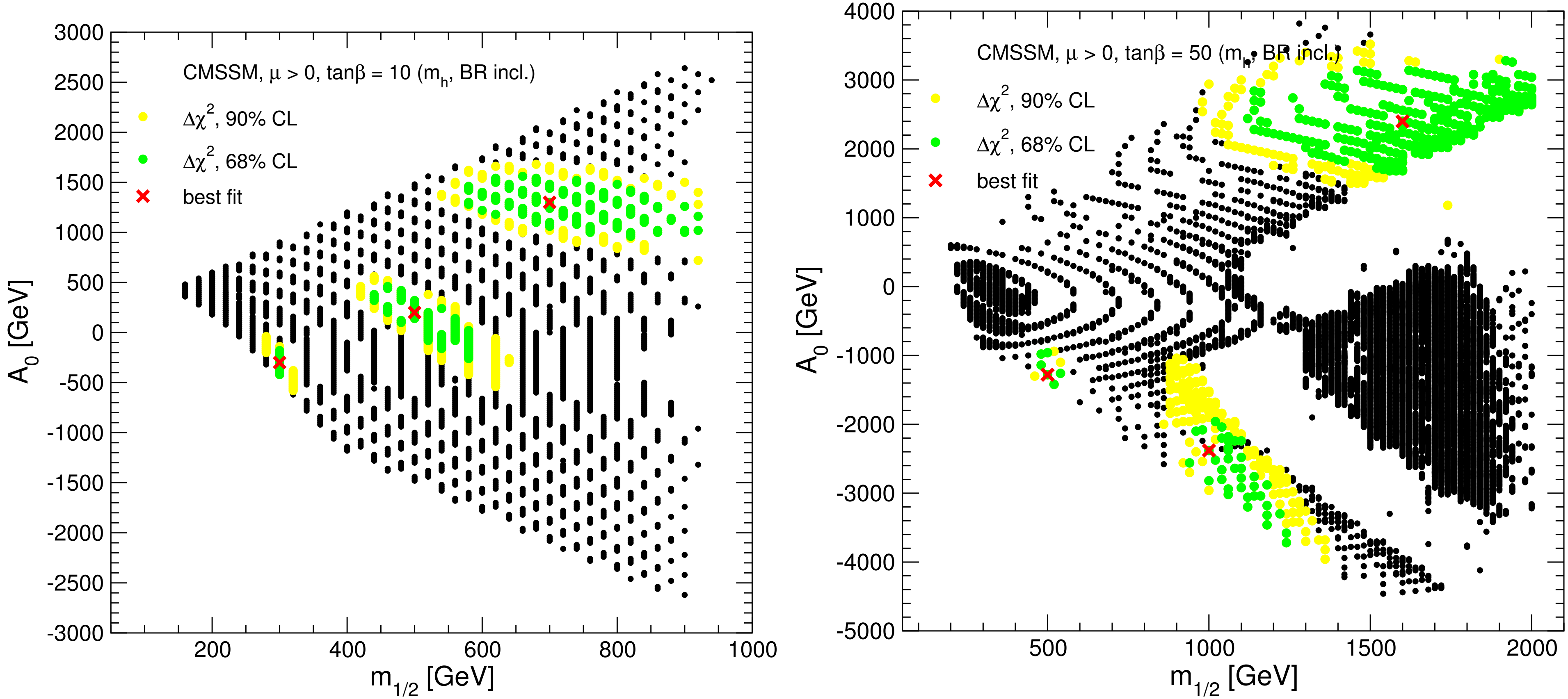
χ^2 *fit in CMSSM with CDM constraints:* M_W, $\sin^2\theta_{\rm eff}$, $(g-2)_\mu$, $BR(b \to s\gamma)$, M_h, $BR(h \to b\bar{b})/BR(h \to WW^*)$, *ILC precison*



⇒ Great increase in sensitivity

⇒ tight constraints on particle masses

χ^2 fit in CMSSM with CDM constraints: $M_{\rm W}$, $\sin^2\theta_{\rm eff}$, $(g-2)_\mu$, $\mathrm{BR}(b\to s\gamma)$, $M_{\rm h}$, $\mathrm{BR}(h\to b\bar{b})/\mathrm{BR}(h\to WW^*)$, ILC precison



$\Rightarrow$ ILC precision greatly improves sensitivity to $m_{1/2}$, A_0

high indirect sensitivity up to $m_{1/2} \lesssim 1$ TeV

4. Conclusions

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  Drastic improvement in sensitivity to $m_{1/2}$, A_0

  high indirect sensitivity up to $m_{1/2} \lesssim 1 \text{ TeV}$

  Comparison with direct experimental information ⇒ test of CMSSM at the loop level