Indirect Sensitivities to the Scale of Supersymmetry

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Based on collaboration with J. Ellis, S. Heinemeyer, K. Olive, hep-ph/0411216

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

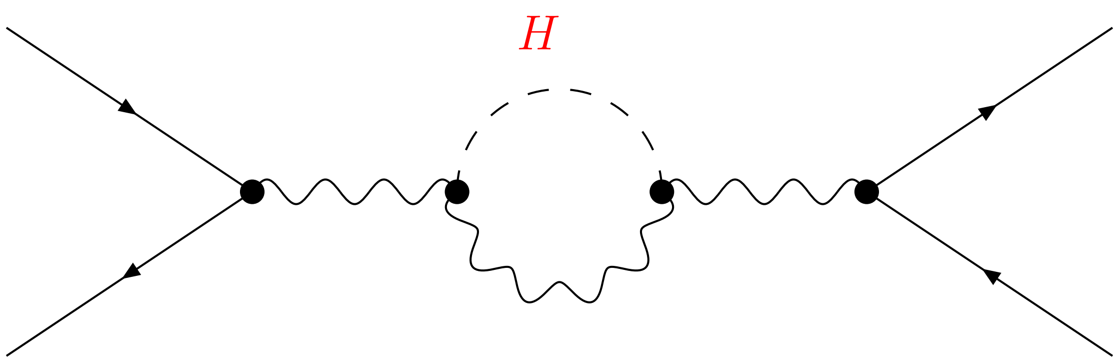
1. Introduction

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"?

Sensitivity to quantum effects (loop corrections) of SUSY:

- Precision measurements resolve %-level loop effects: $M_{\mathrm{W}}, \sin^2\theta_{\mathrm{eff}}, \Gamma_{\mathrm{Z}}, \ldots$

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- Future precision measurements, possibly very large loop effects: M_h, other Higgs-sector observables

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

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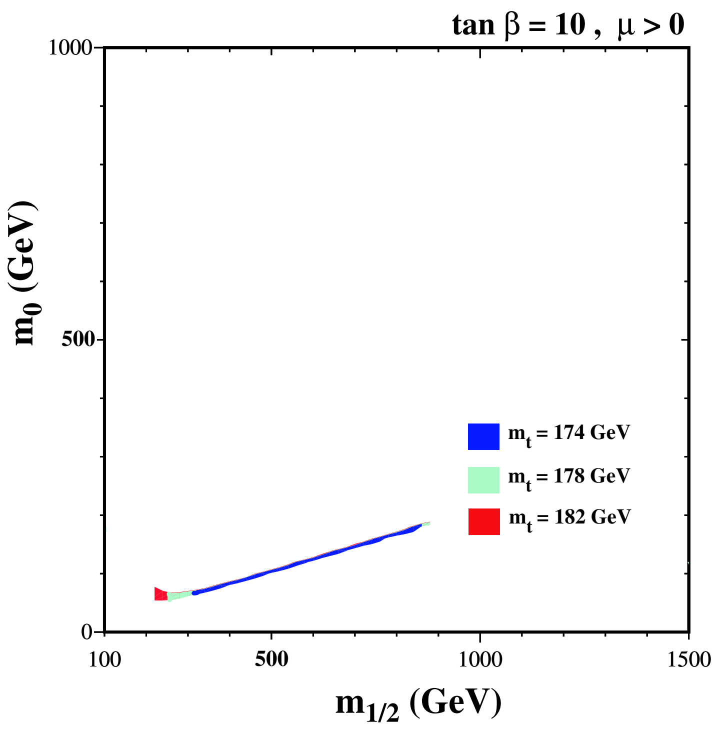
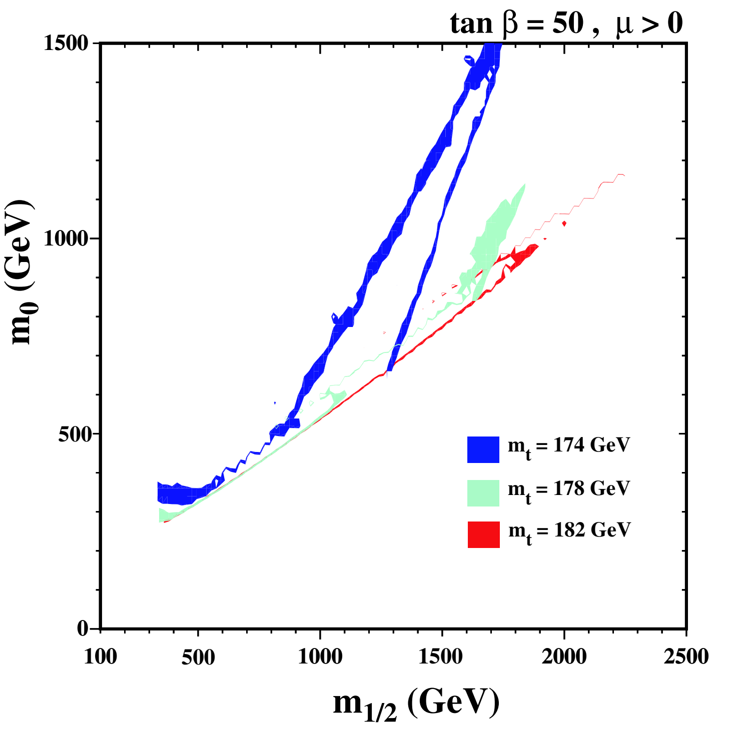
Allowed region in $(m_{1/2}, m_0)$ plane (fixed A_0, different m_t):





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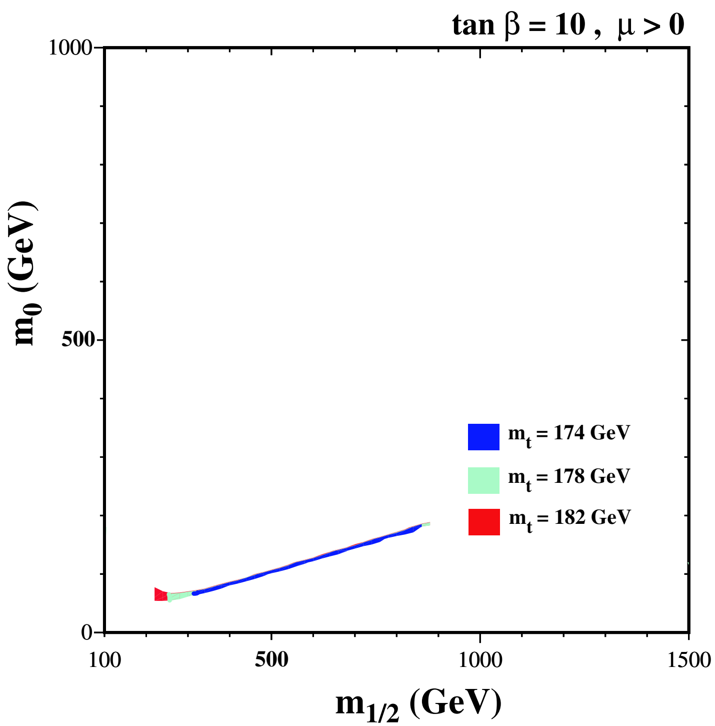

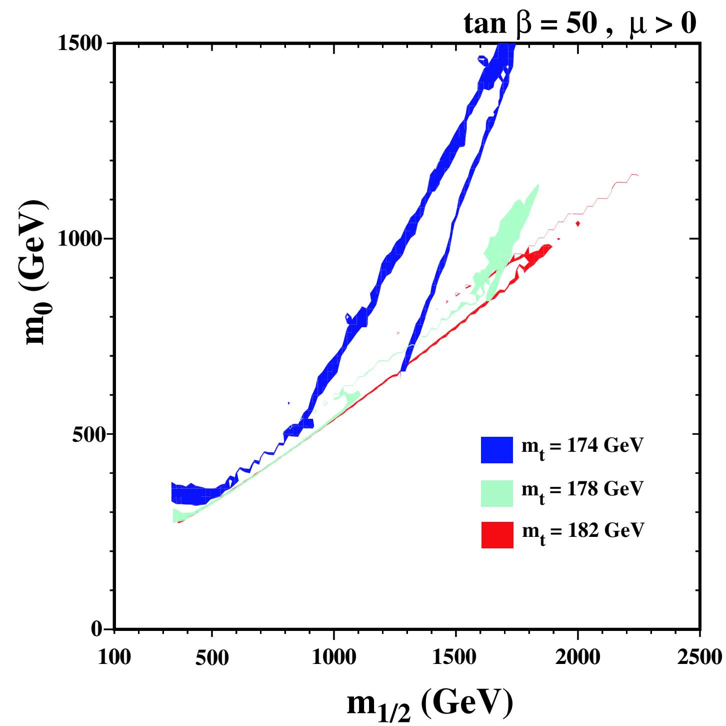

⇒ narrow "WMAP strips"

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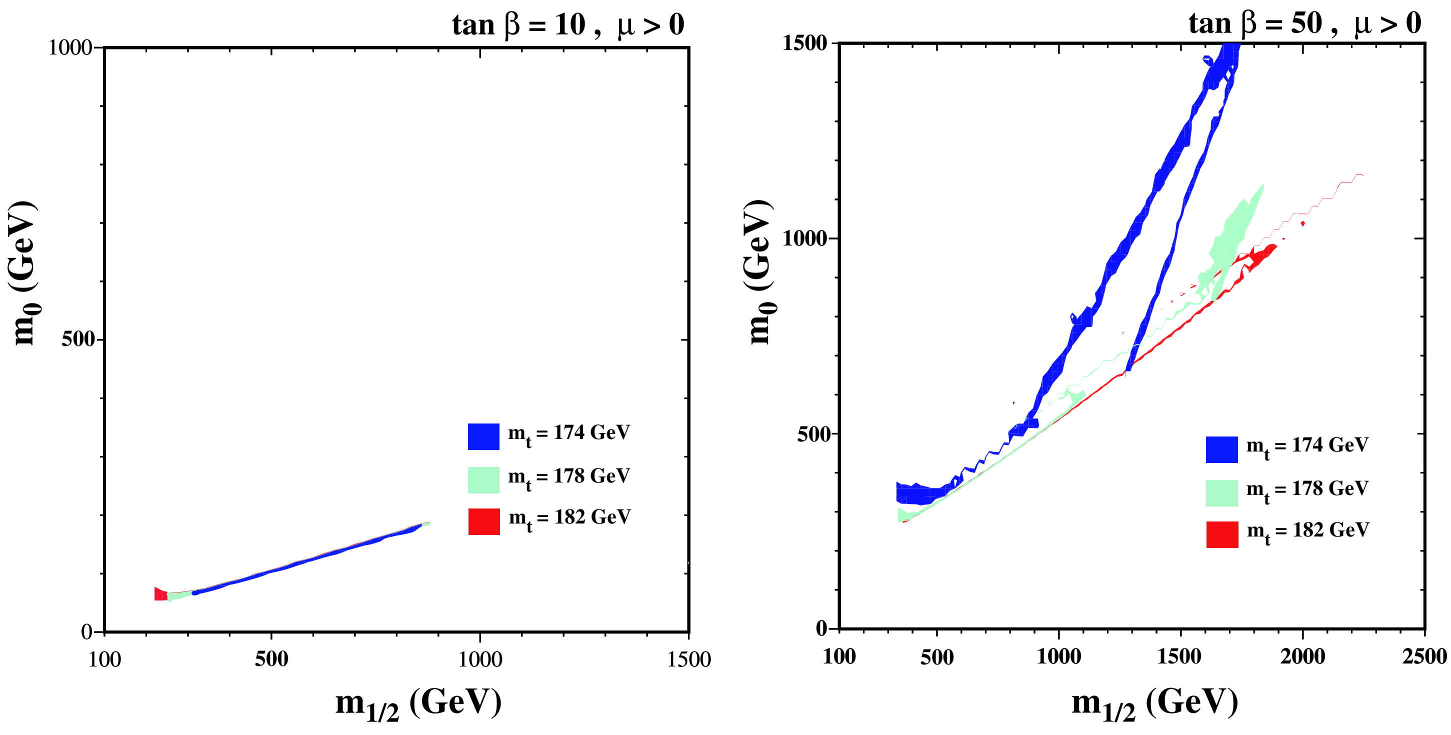

$\Rightarrow$ narrow "WMAP strips"

$\Rightarrow$ effectively reduces dimensionality of parameter space

$\Rightarrow$ analyse CMSSM along WMAP strips

2. Electroweak precision observables

Observables taken into account:

Present:

M_{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_{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_{W}*,* $\sin^2\theta_{\mathrm{eff}}$*:*

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

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

$$\Updownarrow$$

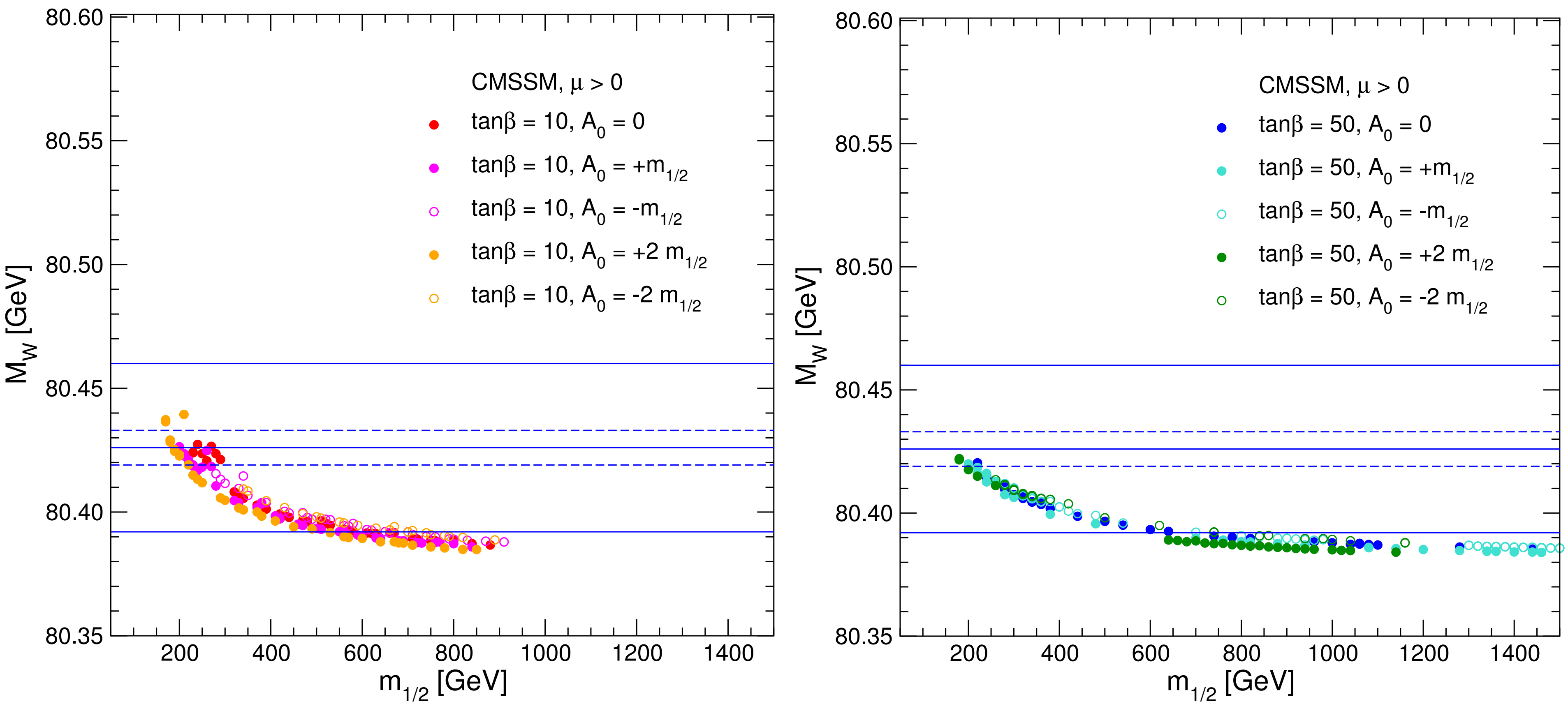
loop corrections

$\Rightarrow$ Theo. prediction for M_{W} in terms of $M_{\mathrm{Z}}, \alpha, G_\mu, \Delta r(m_{\mathrm{t}}, m_{\tilde{\mathrm{t}}}, \ldots)$

Effective couplings at the Z resonance:

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

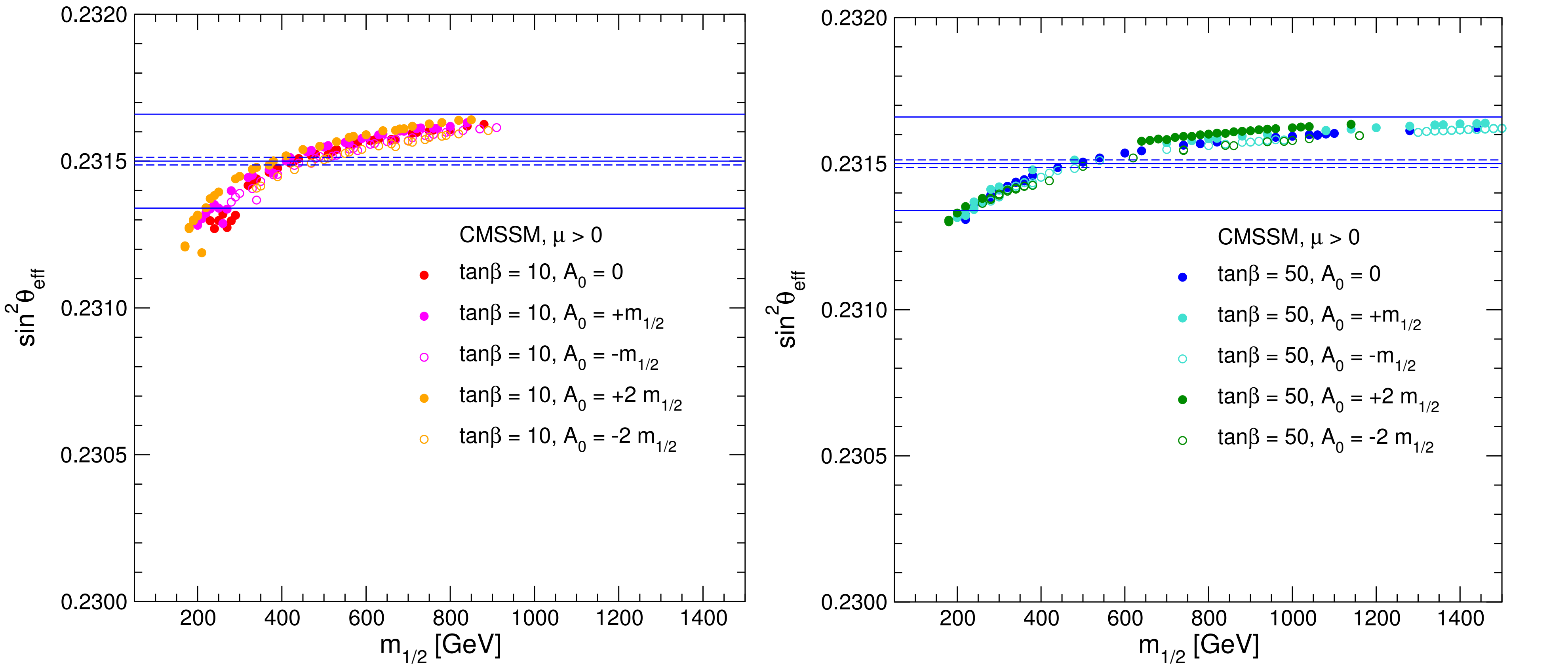
CMSSM prediction for M_W vs. current precision and ILC (MegaW)



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

great improvement at the ILC

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



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The anomalous magnetic moment of the muon:

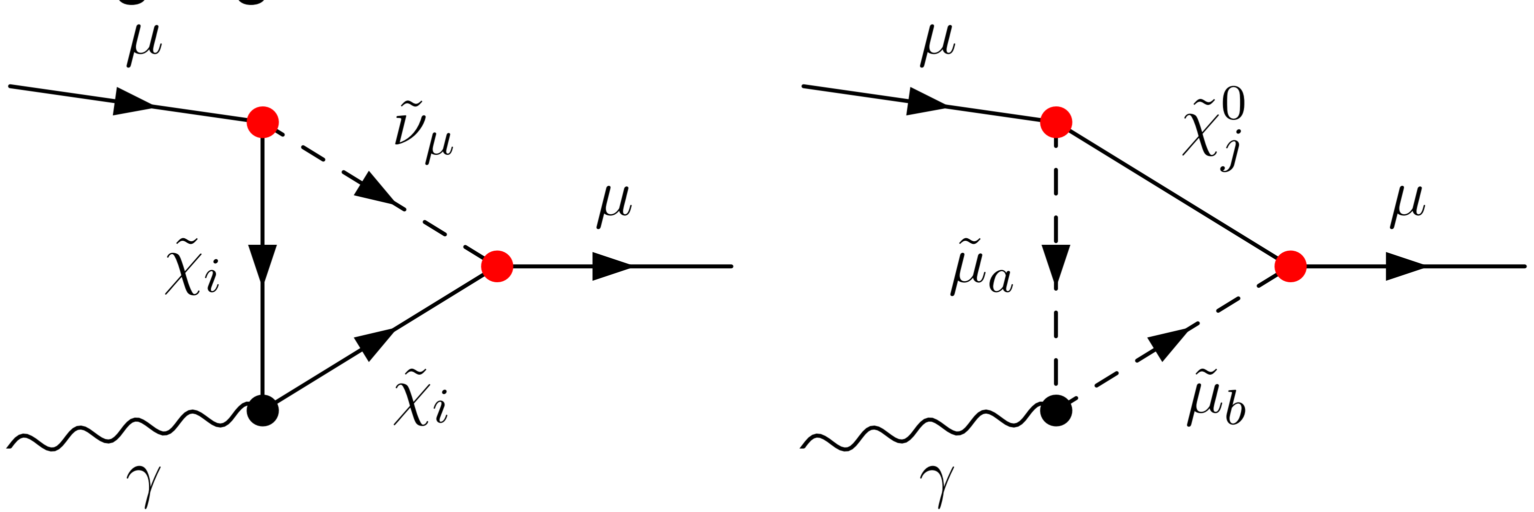
$$(g-2)_\mu \equiv 2a_\mu$$

Experimental result for a_μ vs. SM prediction:

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

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



SUSY contributions to a_μ

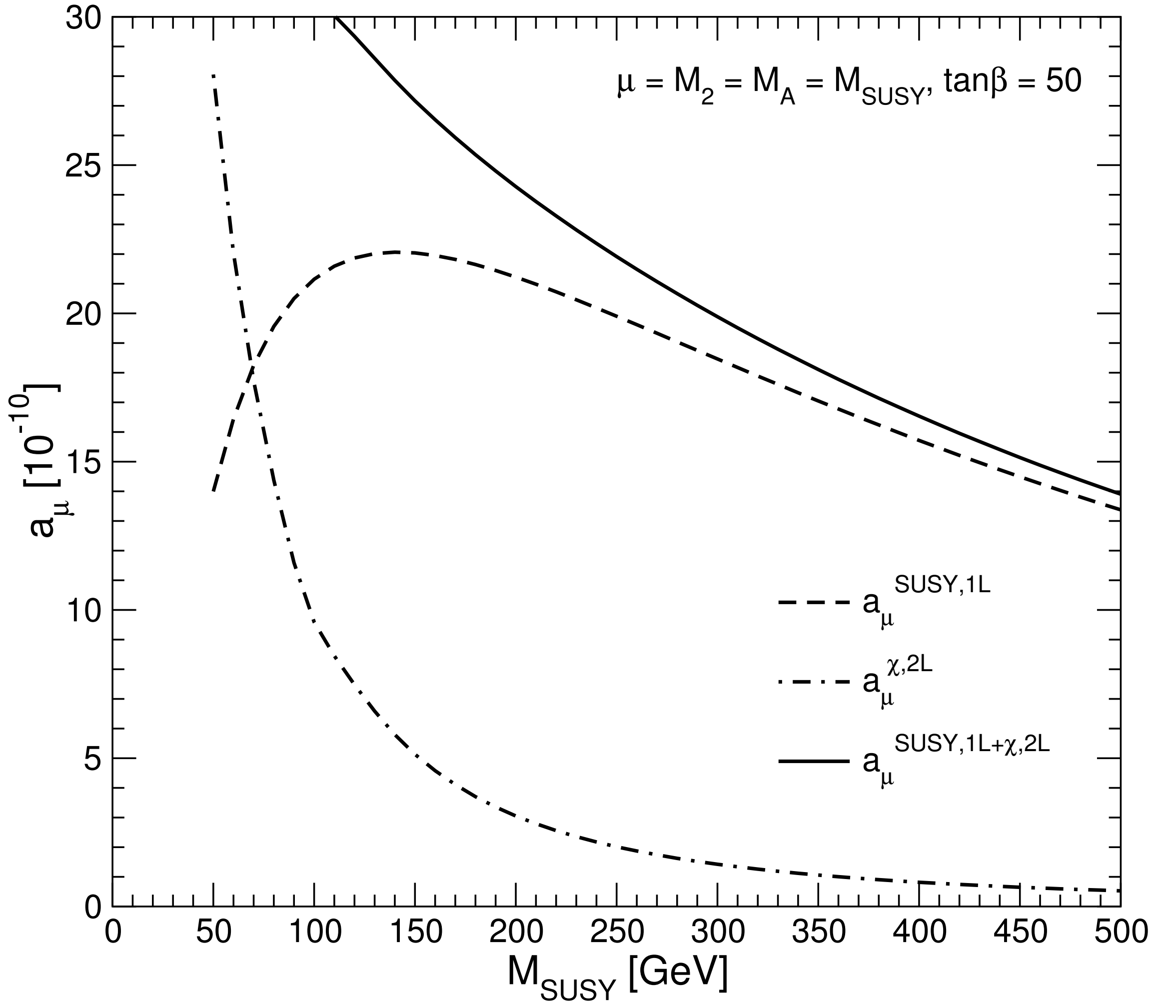
[*S. Heinemeyer, D. Stöckinger, G. W. '04*]

One-loop SUSY contribution (dashed),

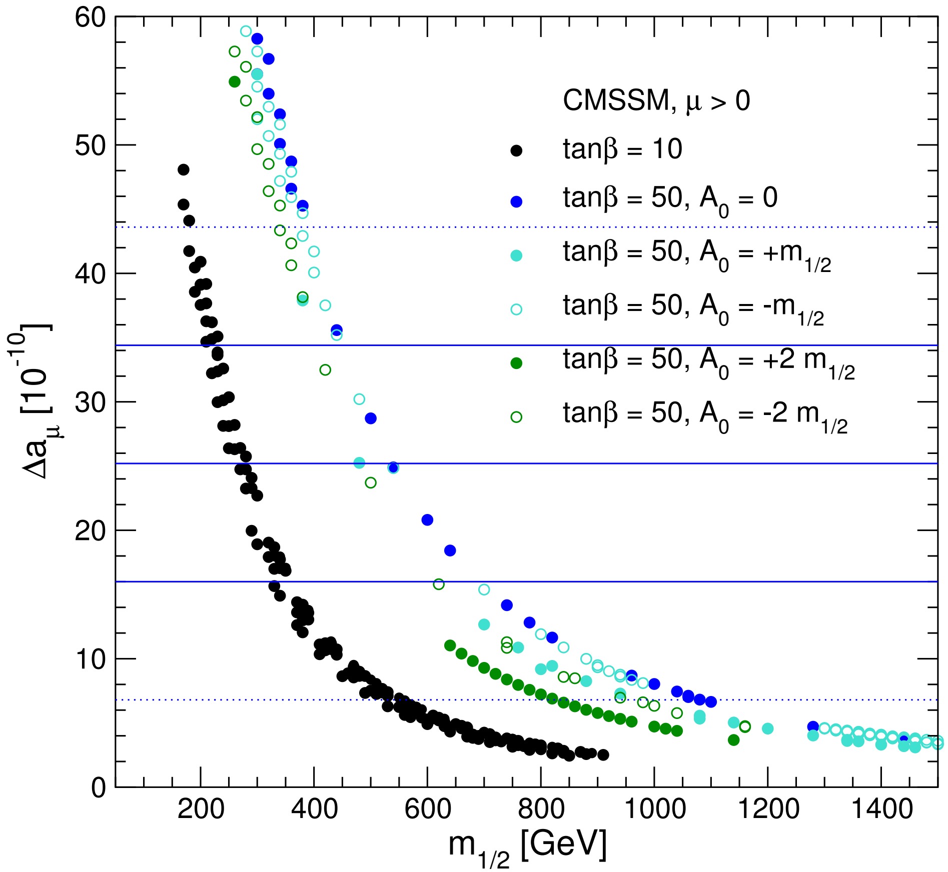
two-loop chargino/neutralino contributions (dash-dotted)

and the sum (full line)

for
$\mu = M_2 = M_A \equiv M_{\rm SUSY}$,
$m_{\tilde f} = 1$ TeV, $\tan\beta = 50$:



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

Higgs mass prediction in the MSSM:

Prediction for M_{h}, M_{H}, ...

Tree-level result for M_{h}, M_{H}:

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

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

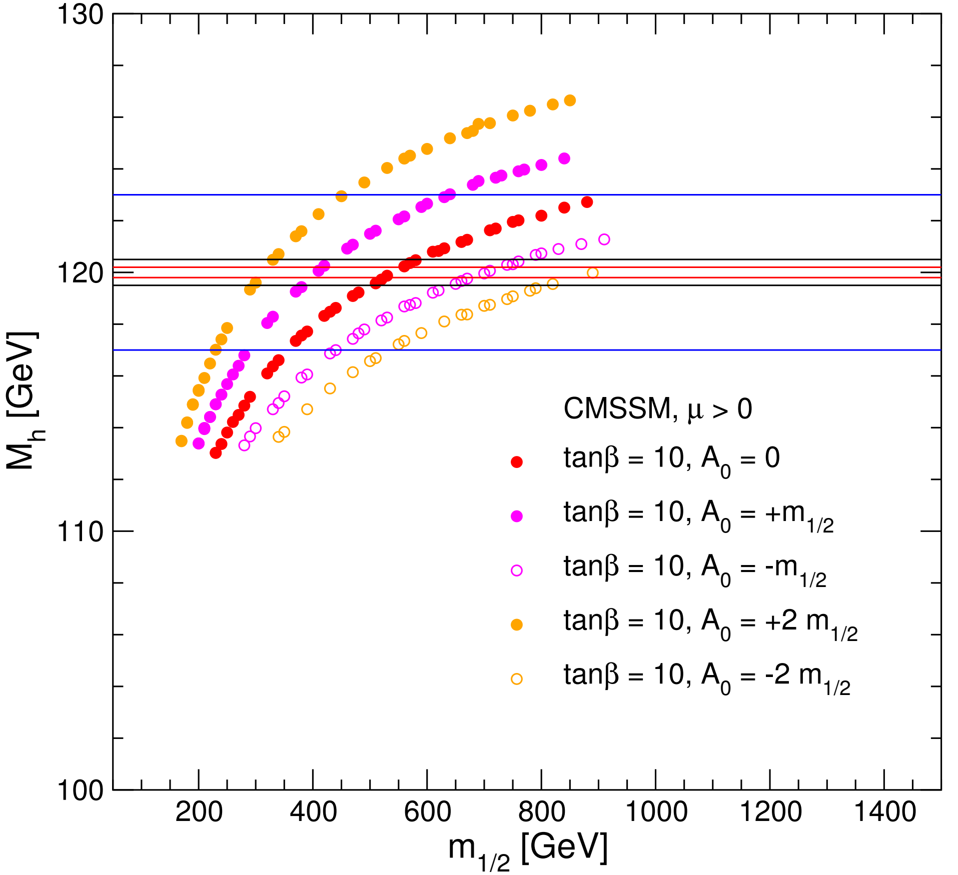
MSSM tree-level bound (gauge sector): excluded by LEP!

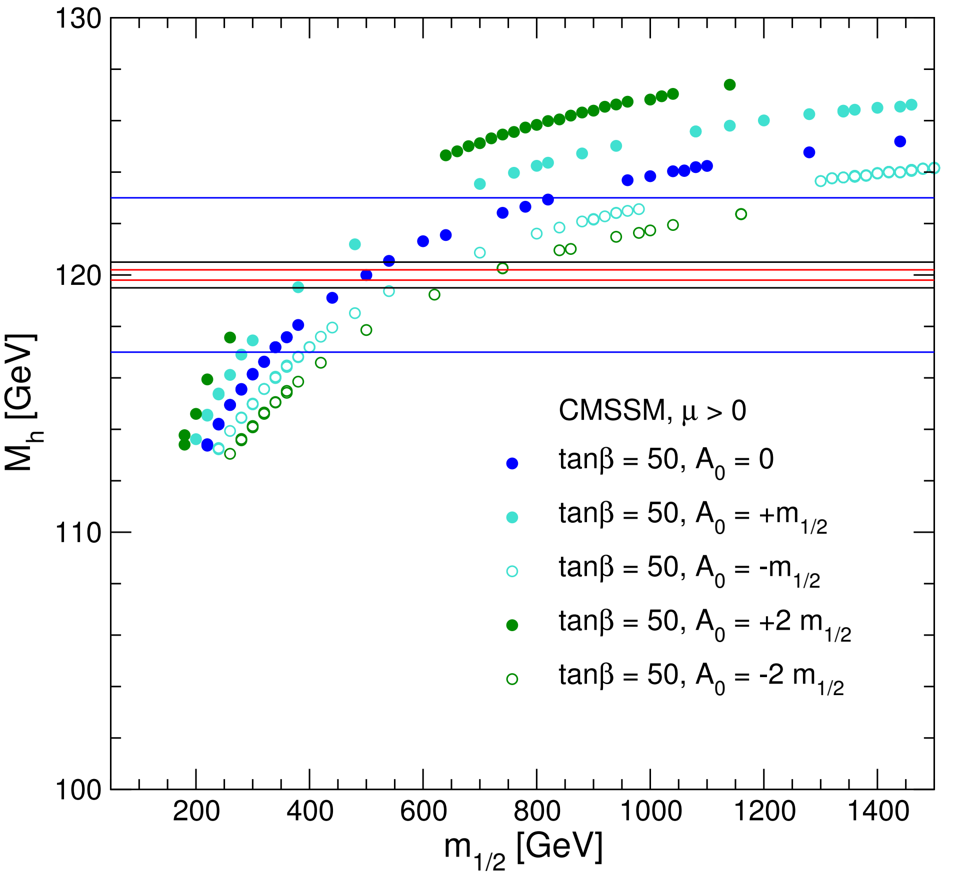
Large radiative corrections (Yukawa sector, ...):

Yukawa couplings: $\frac{e\, m_t}{2M_W s_W}$, $\frac{e\, m_t^2}{M_W s_W}$, ...

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

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





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

$\Rightarrow$ constraints on SUSY parameter space

3. Combined sensitivity: present situation and ILC precision

Combined sensitivity investigated for
present situation + ILC precision

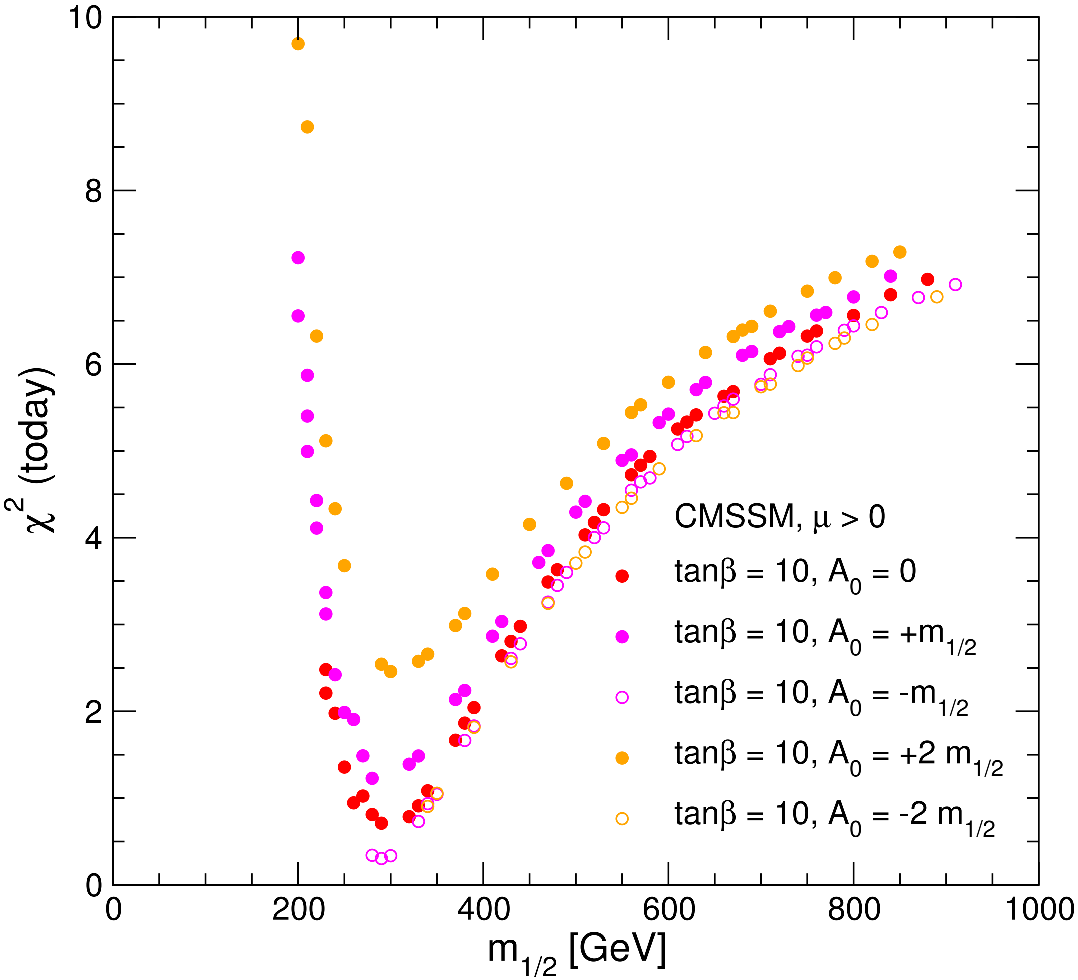
Two kinds of fits:

- 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*

$\tan\beta = 10$:



$\Rightarrow$ very good description of the data

preference for relatively small mass values

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

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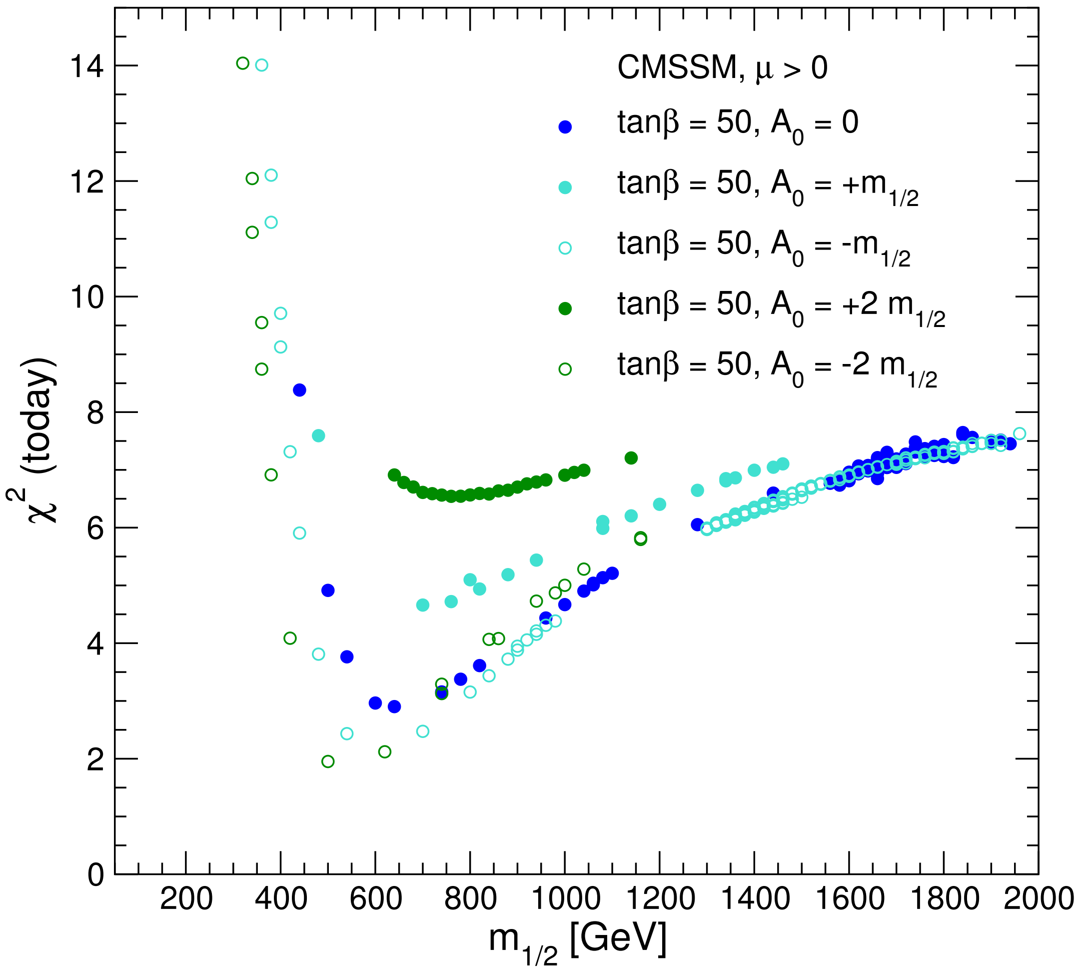


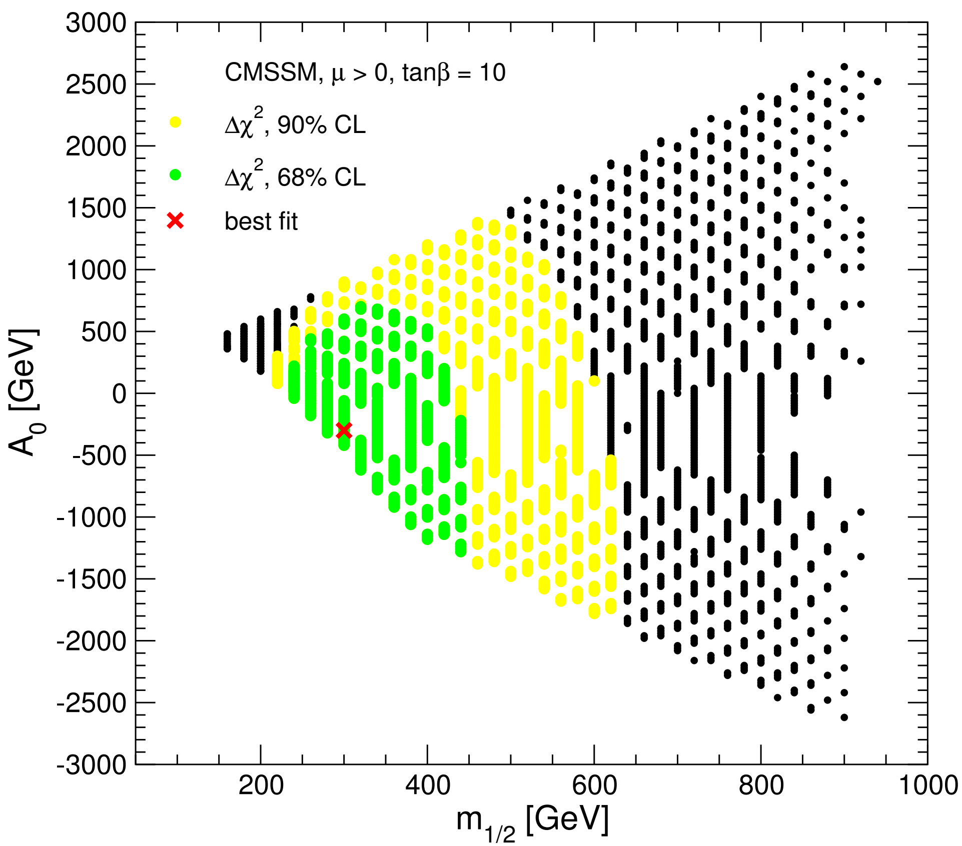
$\Rightarrow$ worse fit quality

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

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*

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

$\tan\beta = 10$:



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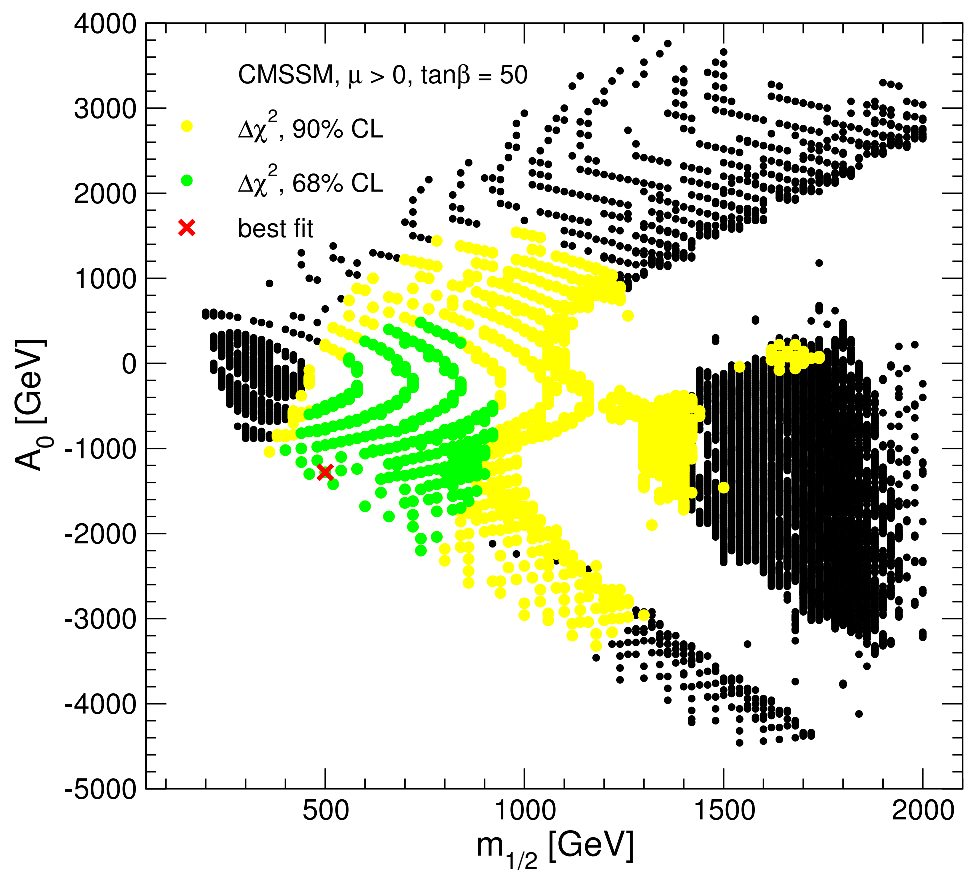
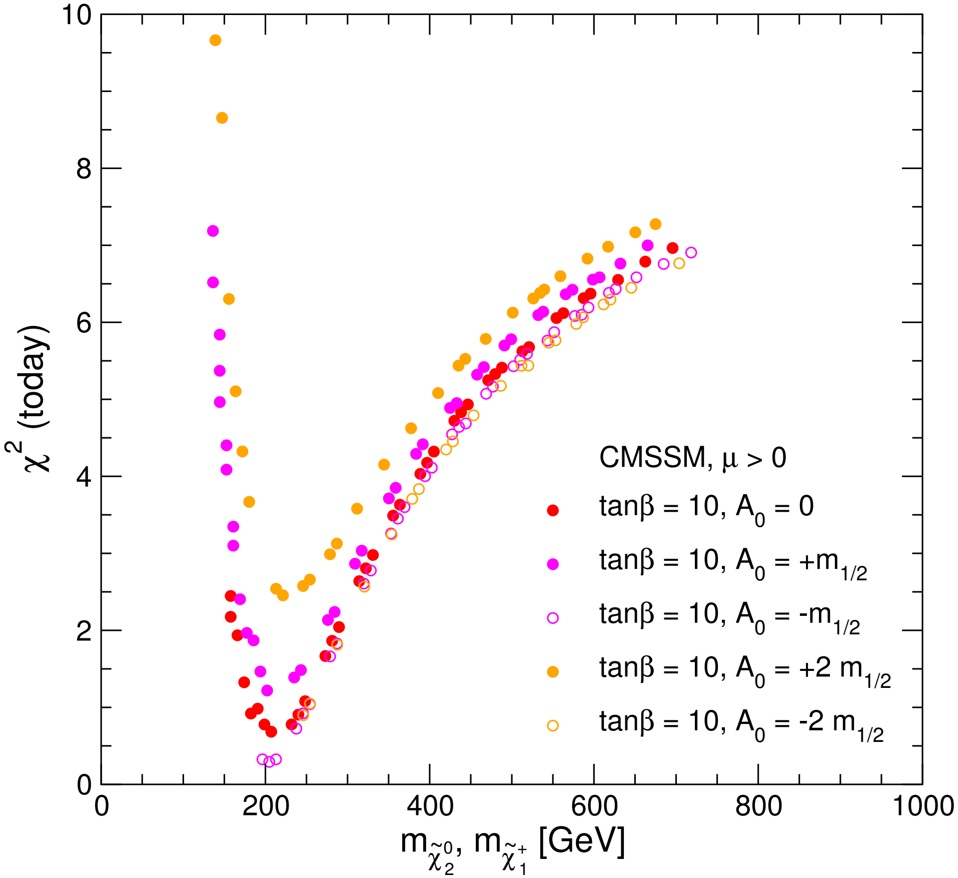
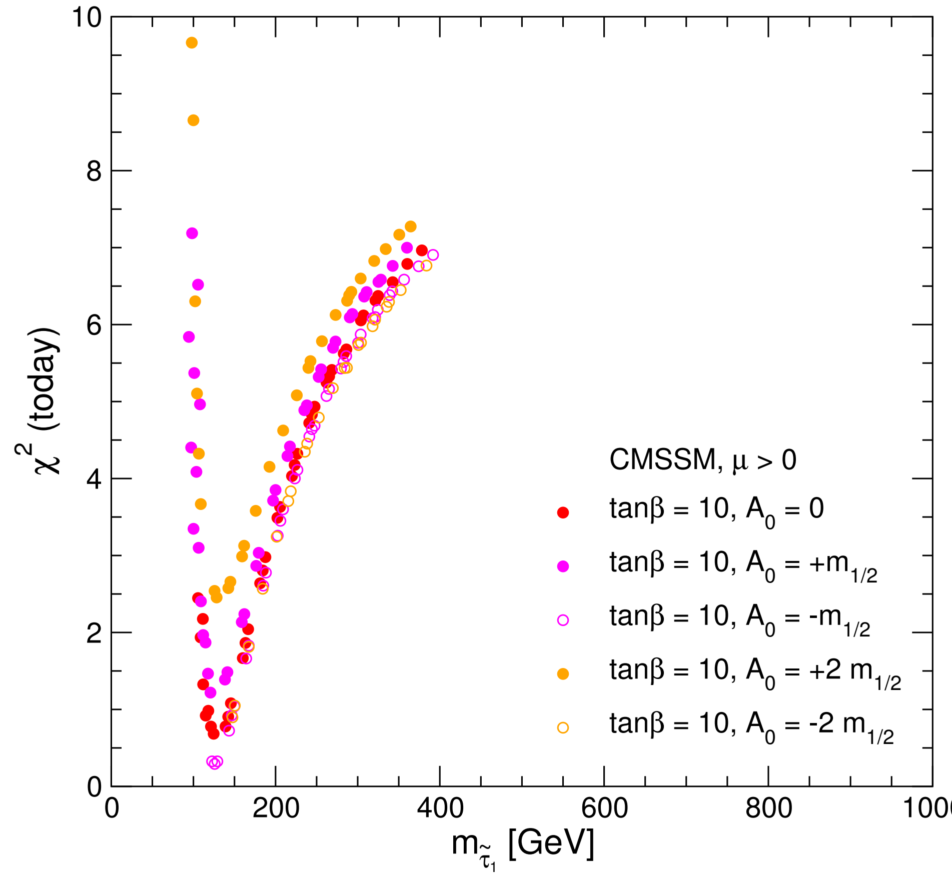


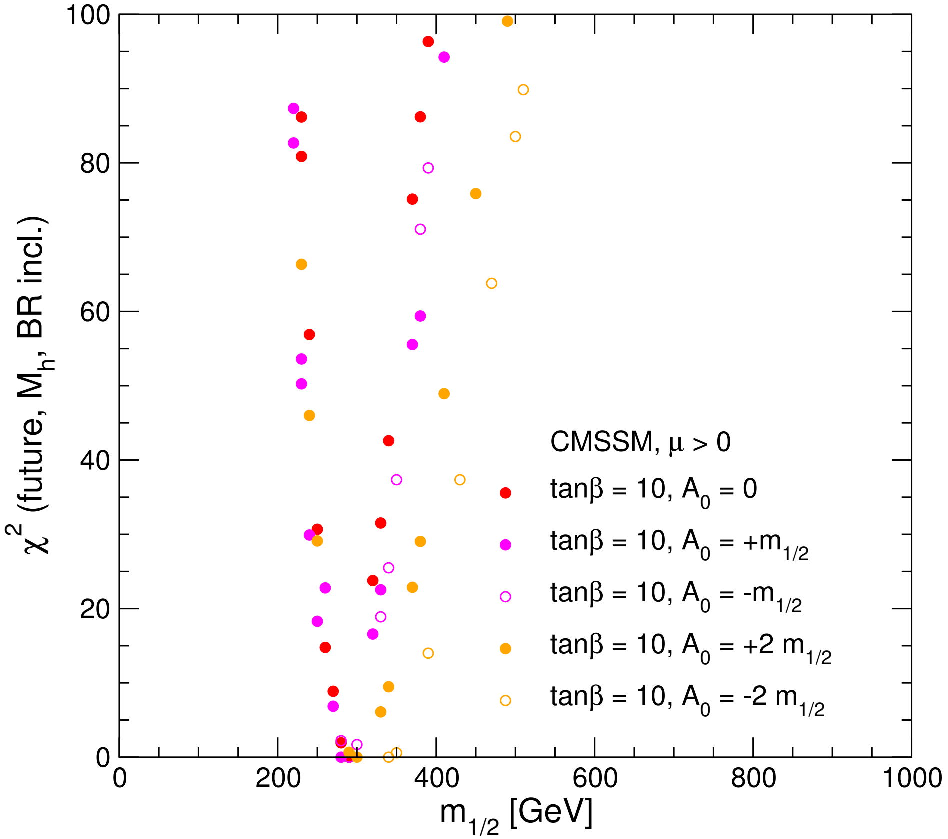
Fit results for particle masses, $\tan\beta = 10$*:*
$m_{\tilde{\chi}_1^+} \approx m_{\tilde{\chi}_2^0}$, $m_{\tilde{\tau}_1}$, *present situation*

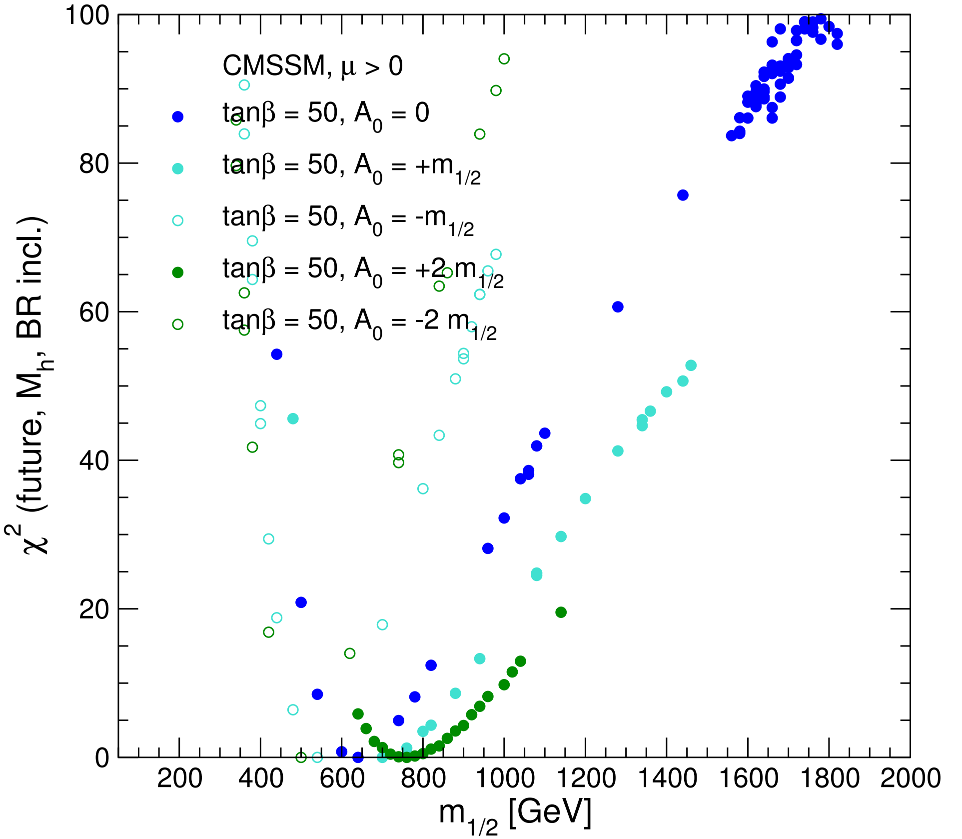




$\Rightarrow$ Good prospects for the LHC and ILC

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*

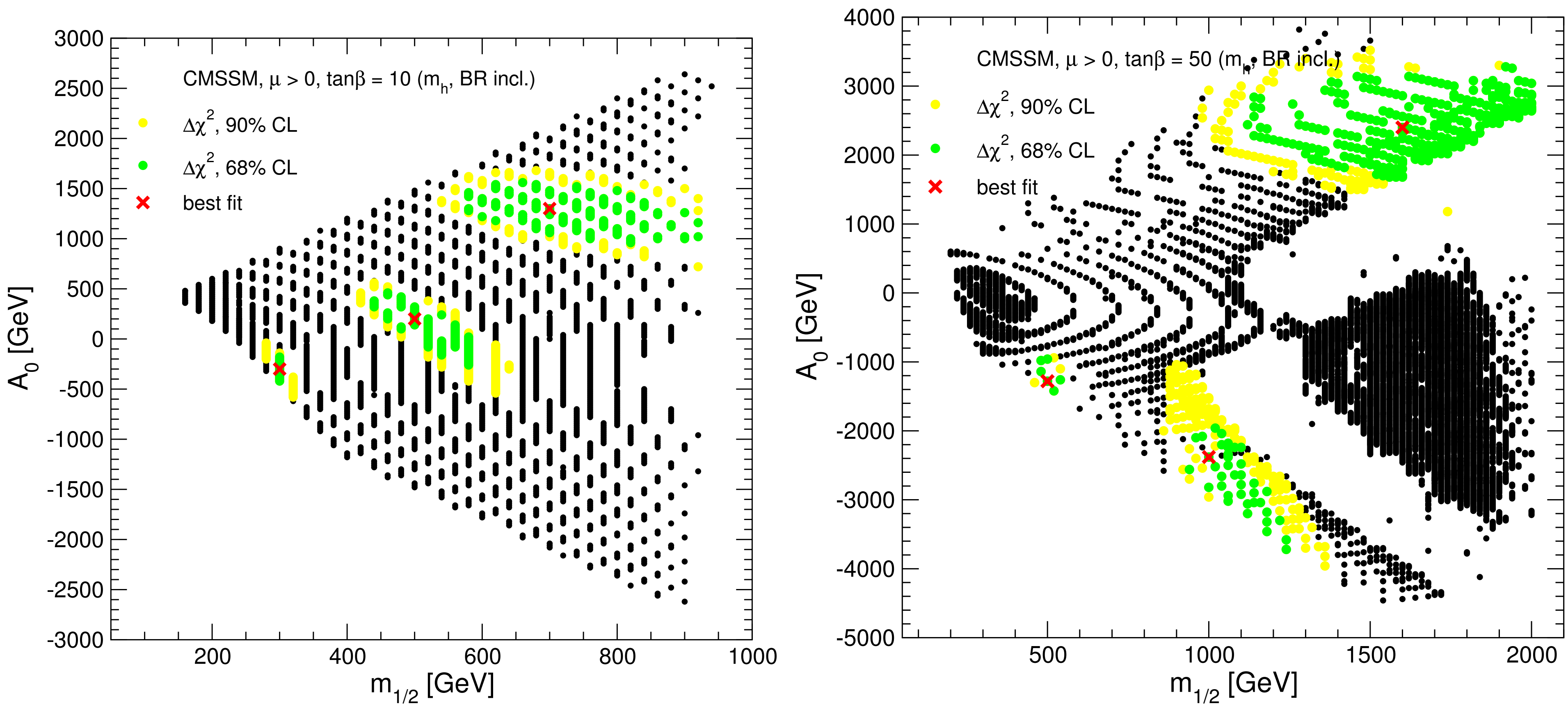




$\Rightarrow$ Great increase in sensitivity

$\Rightarrow$ tight constraints on particle masses

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

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  Comparison with direct experimental information $\Rightarrow$ test of CMSSM at the loop level