Searching for Dark Matter in Unifications Models: A Hint from Indirect Sensitivites towards Future Signals in Direct Detection and B-decays.

Comparison between accelerator and direct detection constraints in unification models:

- mSugra
- CMSSM
- NUHM

with: Ellis, Falk, Heinemeyer, Santoso, Spanos Weiglein

Unification Conditions

- Gaugino masses: $M_i = m_{1/2}$
- Scalar masses: $m_i = m_0$
- Trilinear terms: $A_i = A_0$

mSugra Conditions

- Gaugino masses: $m_{3/2} = m_0$
- Bilinear term: $B_0 = A_0 - m_0$

Boundary Conditions

- Input parameters: μ, m_0, $m_{1/2}$, A_0, B. predict M_Z, $\tan\beta$, m_A

CMSSM conditions

- Instead CMSSM:
  Input parameters: M_Z, m_0, $m_{1/2}$, A_0, $\tan\beta$

predict μ, B, m_A

mSUGRA conditions

- Then:
  Input parameters: M_Z, m_0, $m_{1/2}$, A_0, B predict μ, m_A, $\tan\beta$

Constraints

- Chargino mass limit

$M_{\chi^\pm} \geq 104$ GeV

Constrains (M_2 and μ)/ $m_{1/2}$

- Higgs mass limit

$M_H \geq 114$ GeV

Constrains (m_A, M_2, A)/ $m_{1/2}$

particularly at low tan β

- b to s γ

Constrains (m_A)/ $m_{1/2}$ at high tan β and $\mu < 0$

- Also sfermion mass limits from LEP and CDF

$m_f \geq$ 99 GeV (roughly)

χ is the LSP

- Chargino mass limit

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- Also sfermion mass limits from LEP and CDF

$m_f \geq 99$ GeV (roughly)

χ is the LSP

- $(g-2)_\mu$

$a^{exp} - a^{theo} = (25.2 \pm 9.2) \times 10^{-10}$

- $B_s \rightarrow \mu^+ \mu^-$

BR < 2.0×10^{-7} from CDF and DØ

Important at large tan β and small m_A

Indirect Sensitivities

$$\chi^2 \equiv \sum_{n=1}^{4} \left(\frac{R_n^{\rm exp} - R_n^{\rm theo}}{\sigma_n} \right)^2 + \chi^2_{M_h}$$

- M_W
- $\sin^2 \theta$
- $(g-2)_\mu$
- BR($b \to s \gamma$)
- M_h

$$\chi^2(M_h) = -2 \log \left(\int_{-\infty}^{\infty} e^{-\tilde{\chi}^2(x)/2} \, \tilde{\Phi}(M_h - x) \, {\rm d}x \right)$$

$\chi^2(M_h)$ determined from LEP CLs

Ellis, Heinemeyer, Olive, Weiglein

How Much Dark Matter

WMAP 1 Spergel etal

Precise bounds on matter content

How Much Dark Matter

WMAP 1 Spergel etal

Precise bounds on matter content

$$\Omega_m h^2 = 0.135^{+0.008}_{-0.009} \qquad \Omega_b h^2 = 0.0224 \pm 0.0009$$

$$\Omega_{cdm} h^2 = 0.1126^{+0.0080}_{-0.0090}$$

or

$$\Omega_{cdm}\, h^2 = 0.094 - 0.129 \quad (2\,\sigma)$$

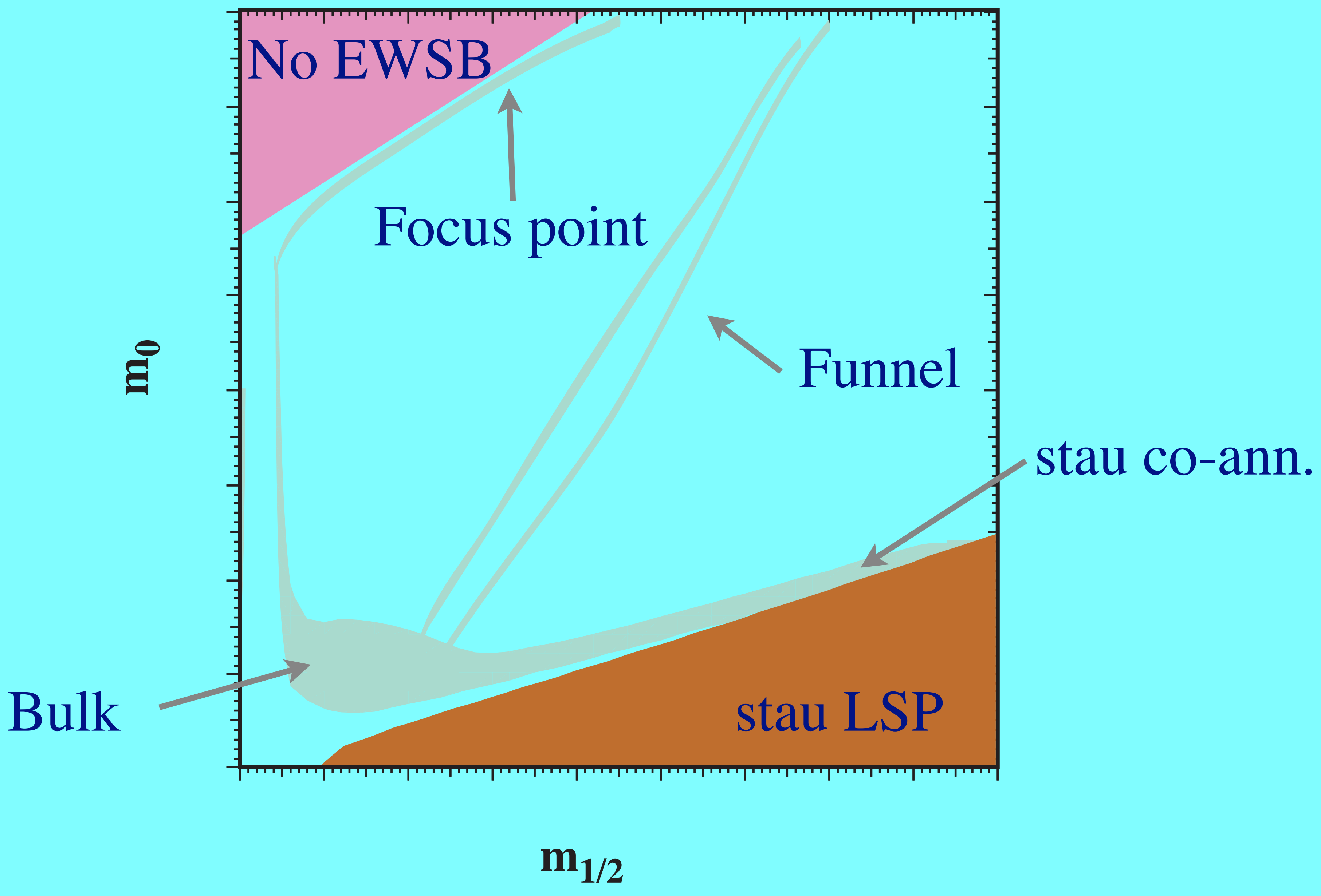
WMAP 3 Spergel etal

$$\Omega_{cdm} h^2 = 0.1045^{+0.0072}_{-0.0095}$$

or

$$\Omega_{cdm}\, h^2 = 0.085 - 0.119 \quad (2\,\sigma)$$

Typical Regions



Direct Detection

- Eastic scattering cross sections
  for χ p

- Use only parameters which satisfy accelerator bounds
  and
  relic density

- Dominant contribution to spin-independent scattering

$$\mathcal{L} = \alpha_{3i}\bar{\chi}\chi\bar{q}_i q_i,$$

Through light squark exchange

– Dominant for binos

Through Higgs exchange

– Requires some Higgsino component

Uncertainties from hadronic matrix elements

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

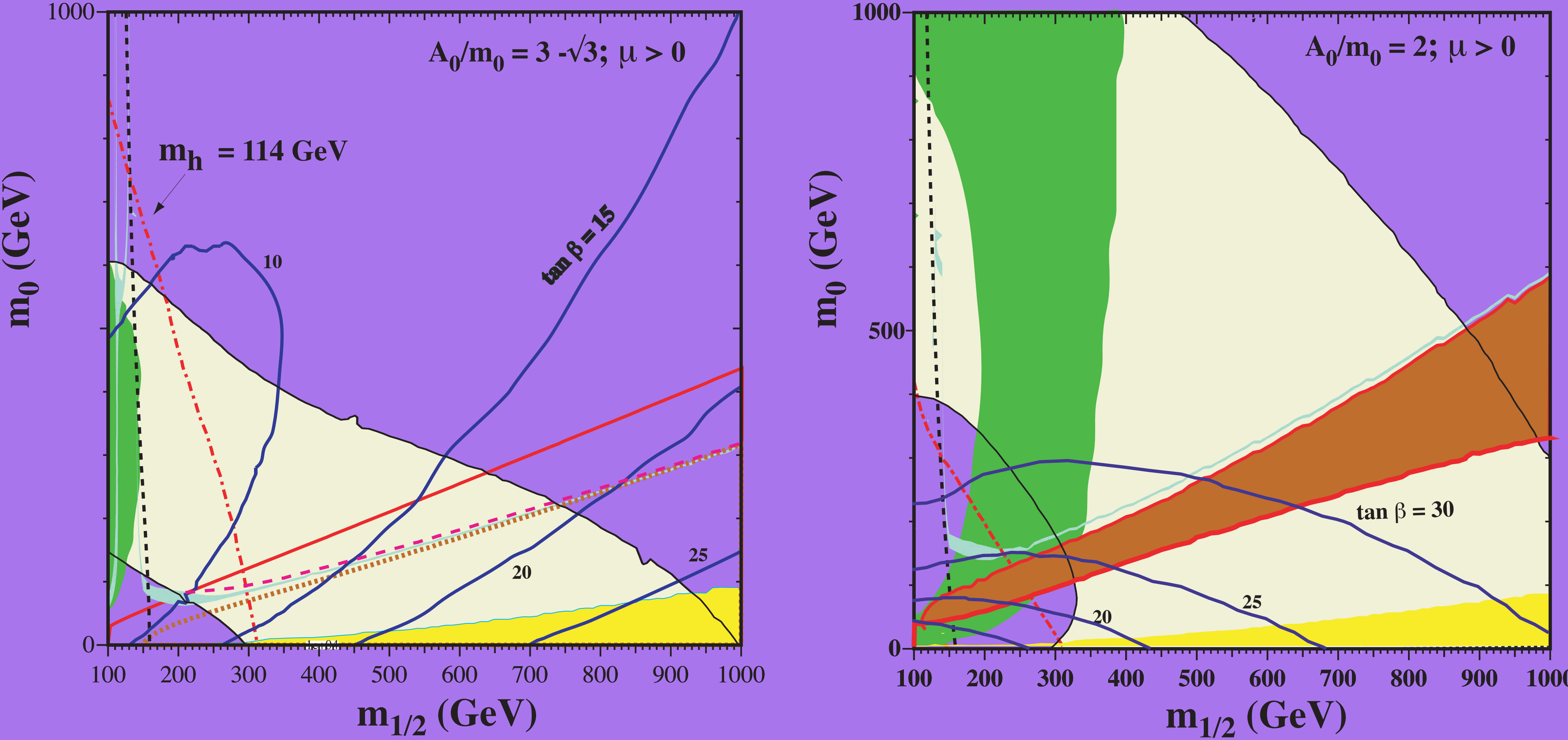
$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

$\Sigma = 45$ GeV or 64 GeV

mSugra models

- tan β fixed by boundary conditions ($B_0 = A_0 - m_0$)
- ``planes” determined by A_0/m_0
- Gravitino often the LSP ($m_{3/2} = m_0$)



The Very CMSSM (mSUGRA):

Ellis, Olive, Santoso, Spanos

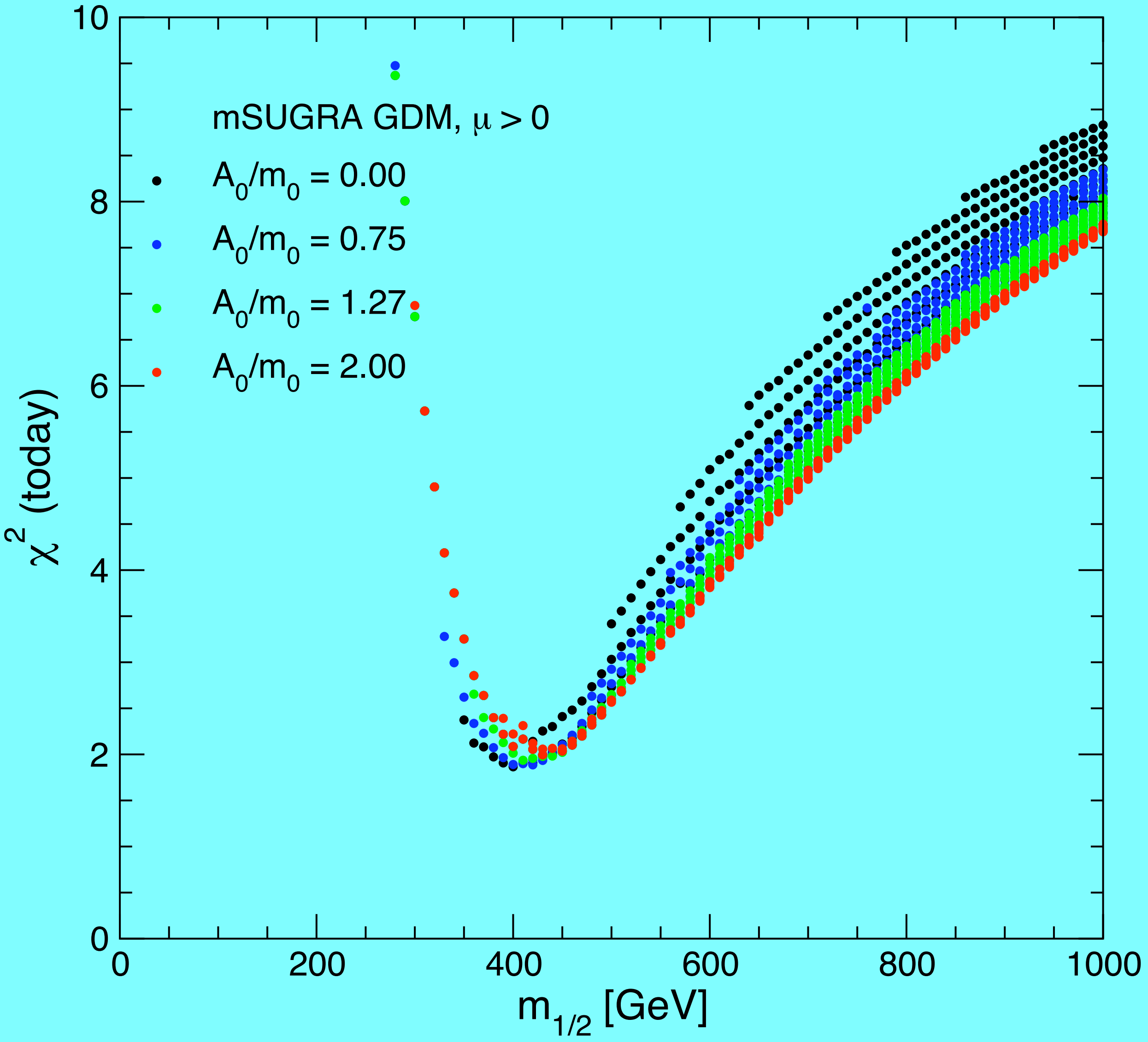
mSugra models

- tan β fixed by boundary conditions ($B_0 = A_0 - m_0$)
- ``planes'' determined by A_0/m_0
- Gravitino often the LSP ($m_{3/2} = m_0$)
- No Funnels
- No Focus Point

mSugra models

- $\tan\beta$ fixed by boundary conditions ($B_0 = A_0 - m_0$)
- ``planes'' determined by A_0/m_0
- Gravitino often the LSP ($m_{3/2} = m_0$)
- No Funnels
- No Focus Point
- Weak signal from $B_s \to \mu^+\mu^-$

Indirect Sensitivities to Gravitino Dark Matter Models



$\chi 2$ deteremined predominantly by $(g\text{-}2)_\mu$ on the right and m_h on the left

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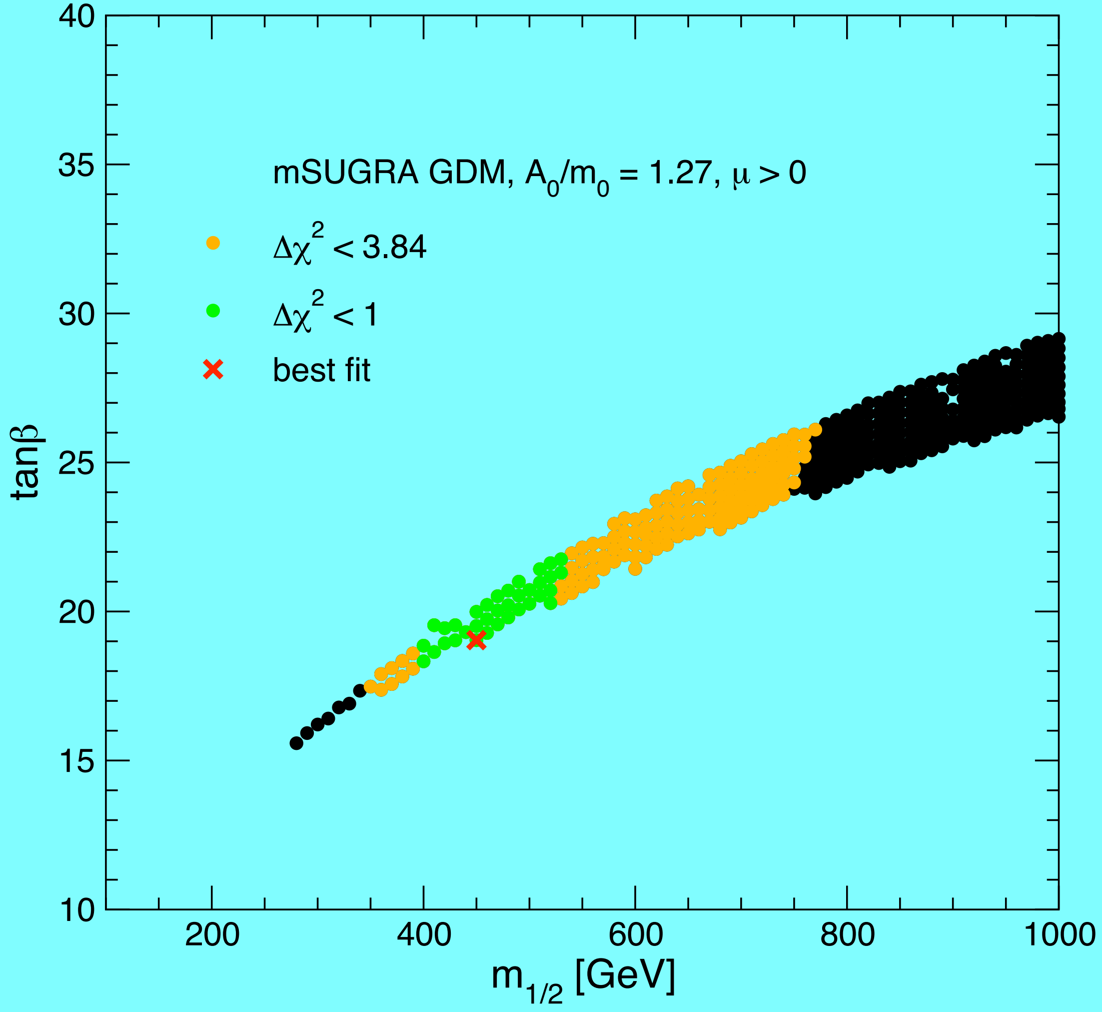
Sensitivity to GDM models



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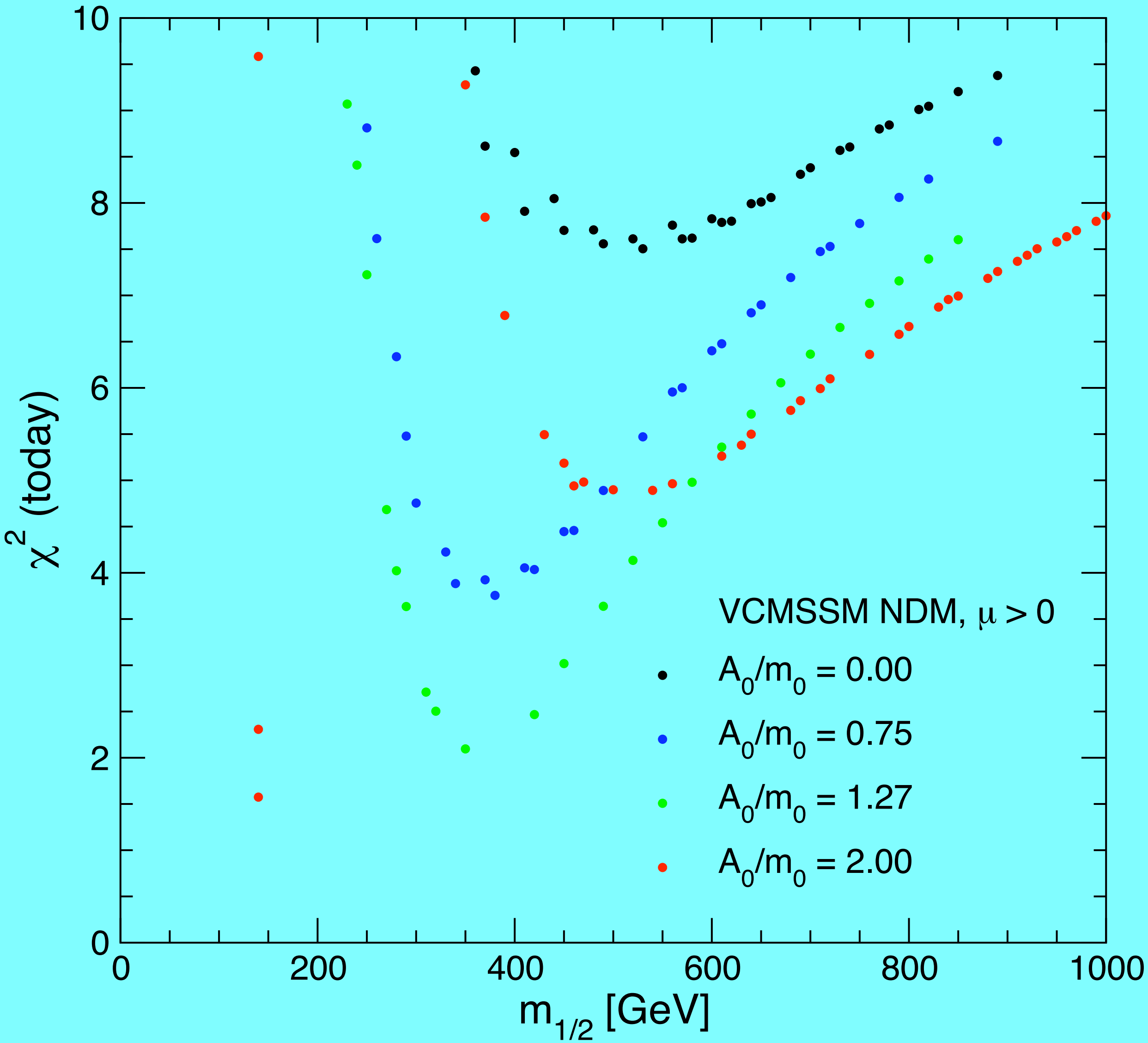
Drop $m_{3/2} = m_0$: Indirect Sensitivities to Neutralino Dark Matter



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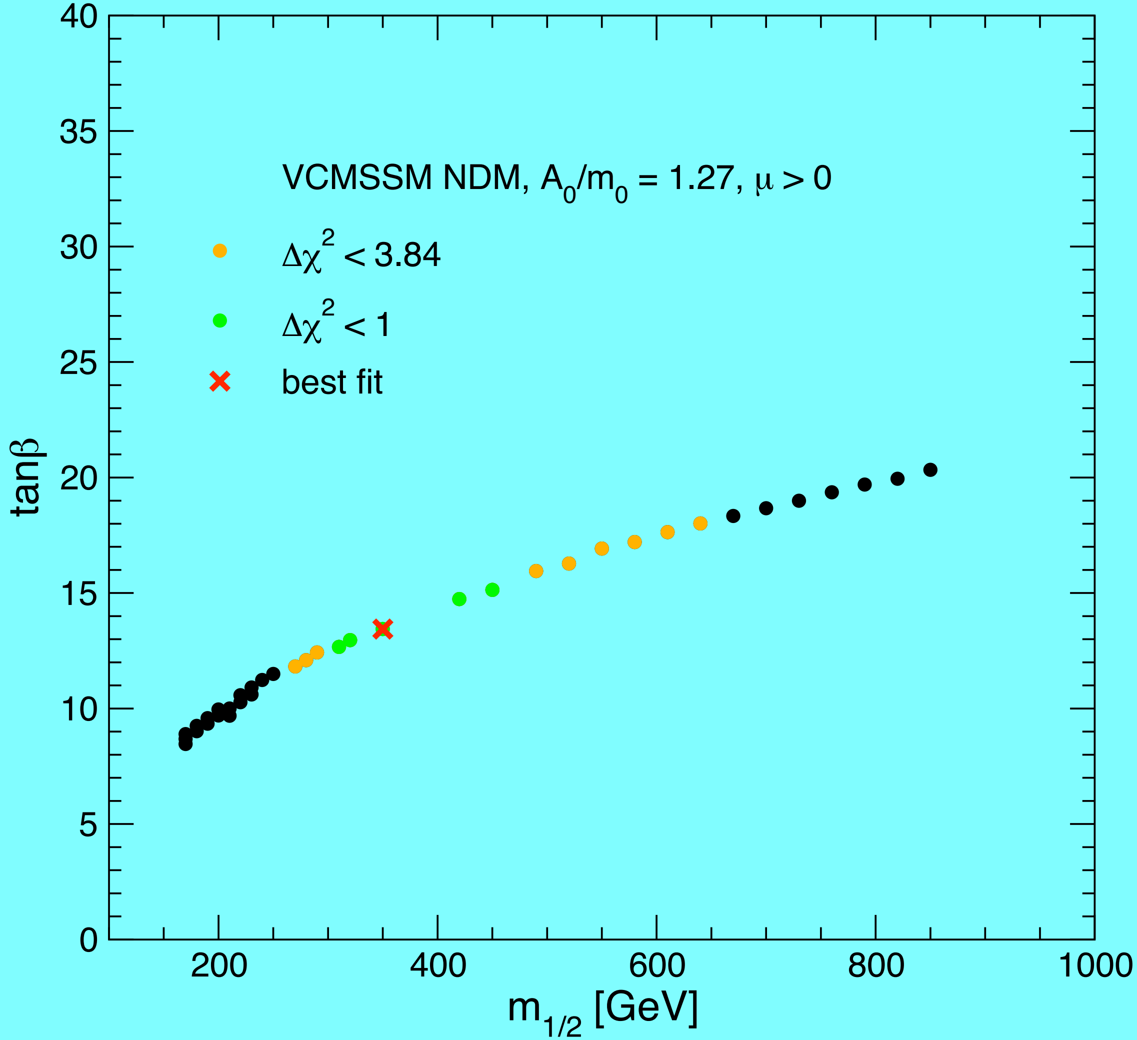
Sensitivity to NDM models



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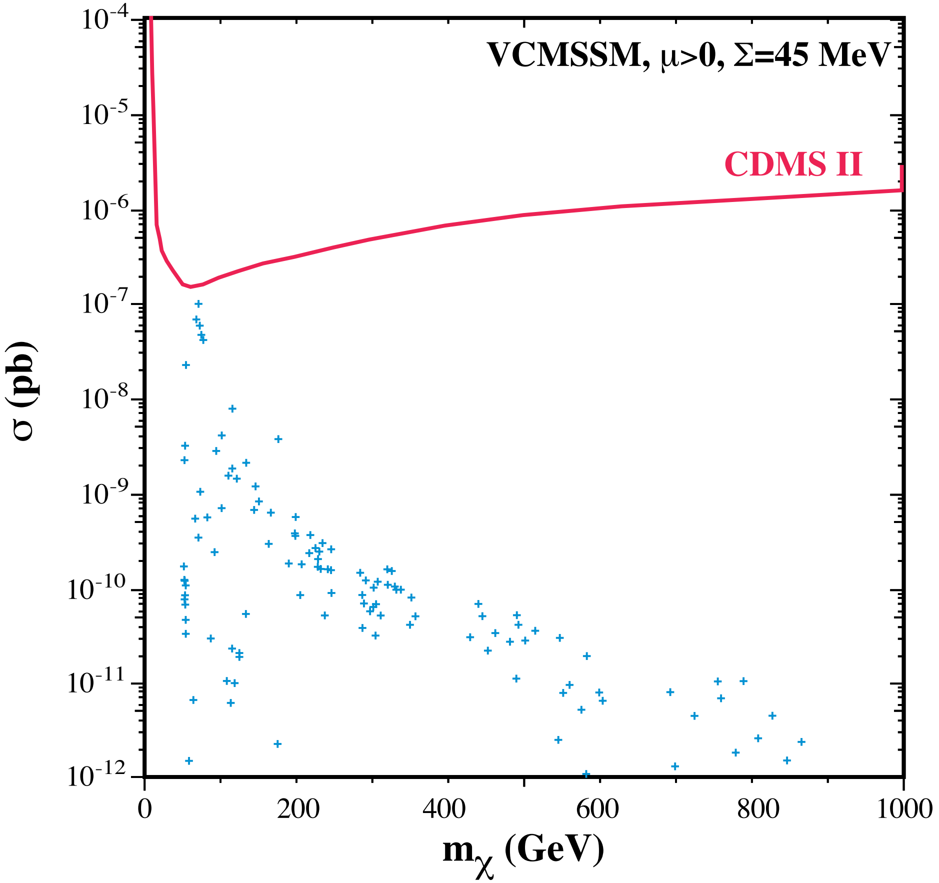
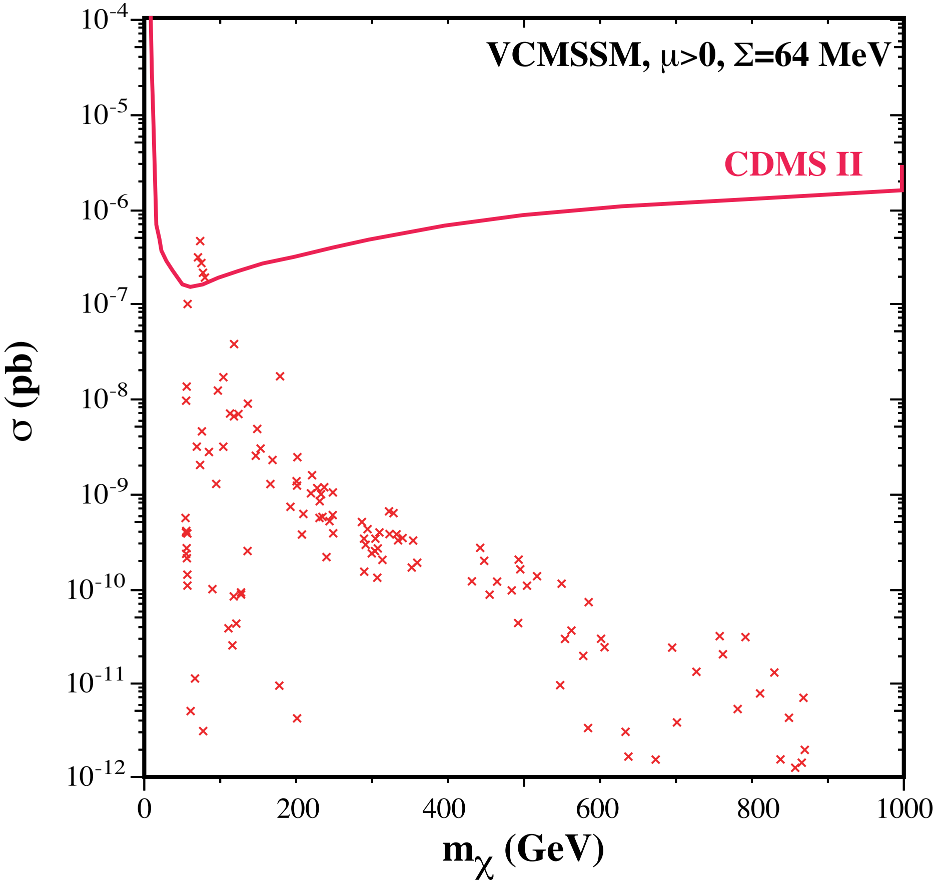
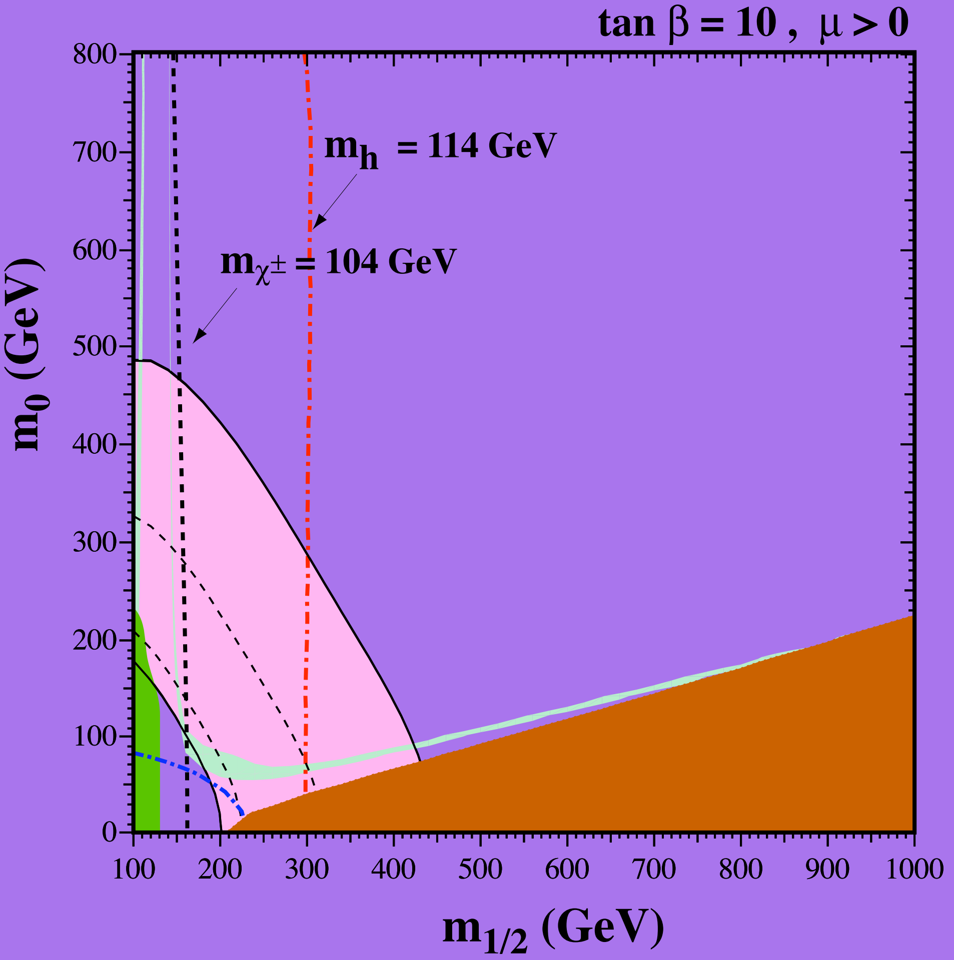
Direct Detection of NDM in the mSugra models

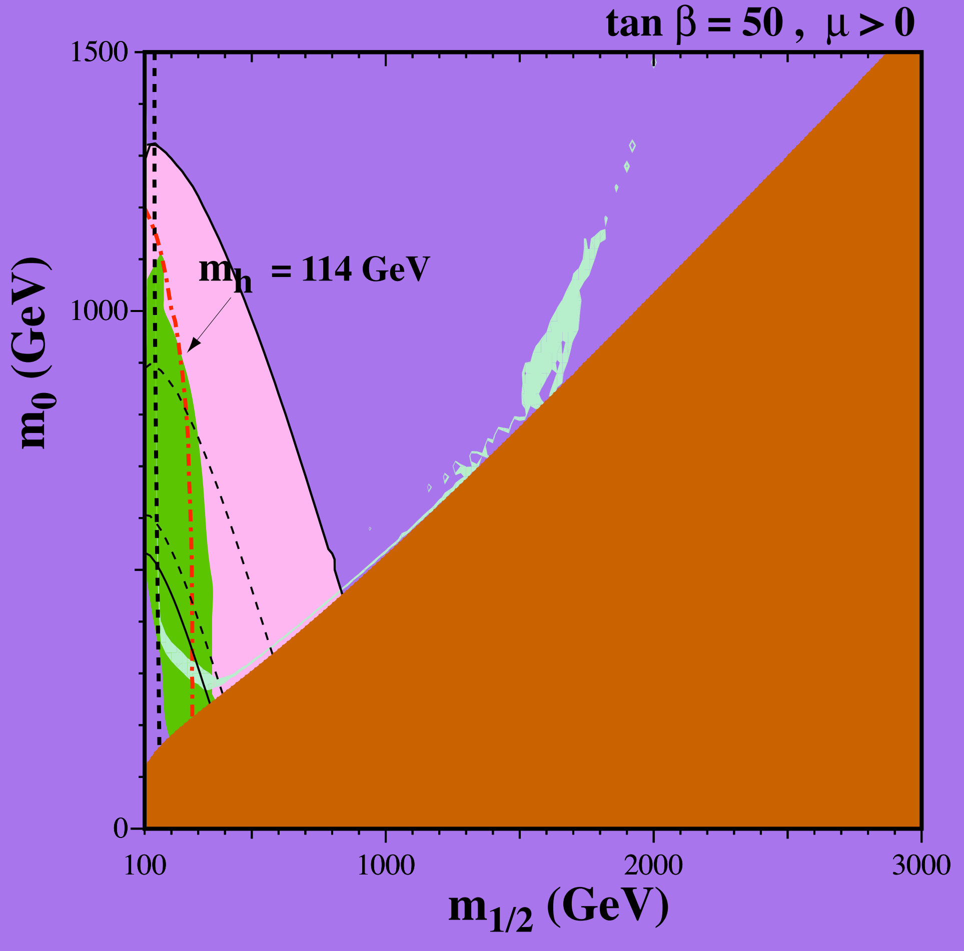




CMSSM

- Drop $B_0 = A_0 - m_0$: Select $\tan\beta$





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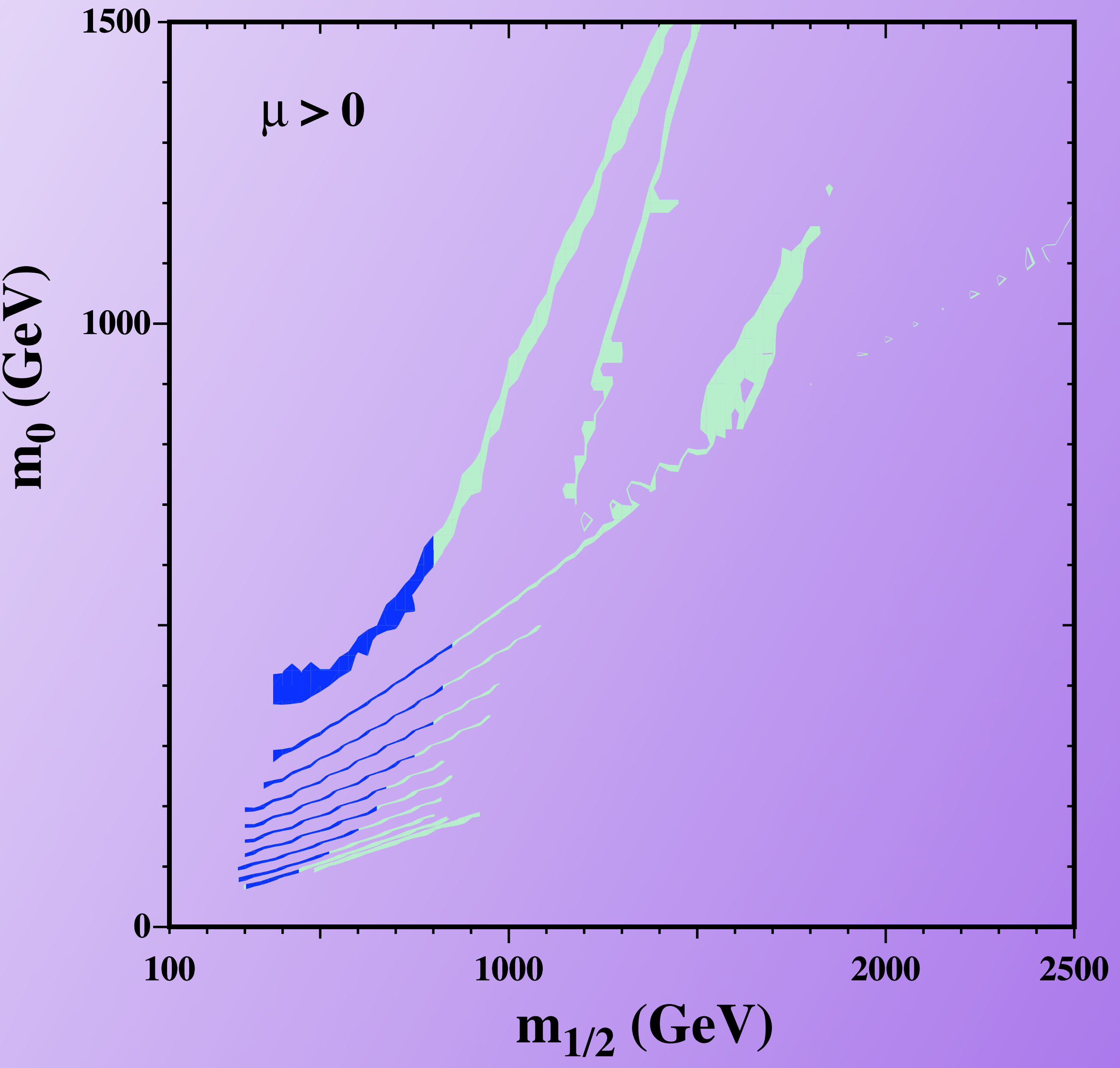
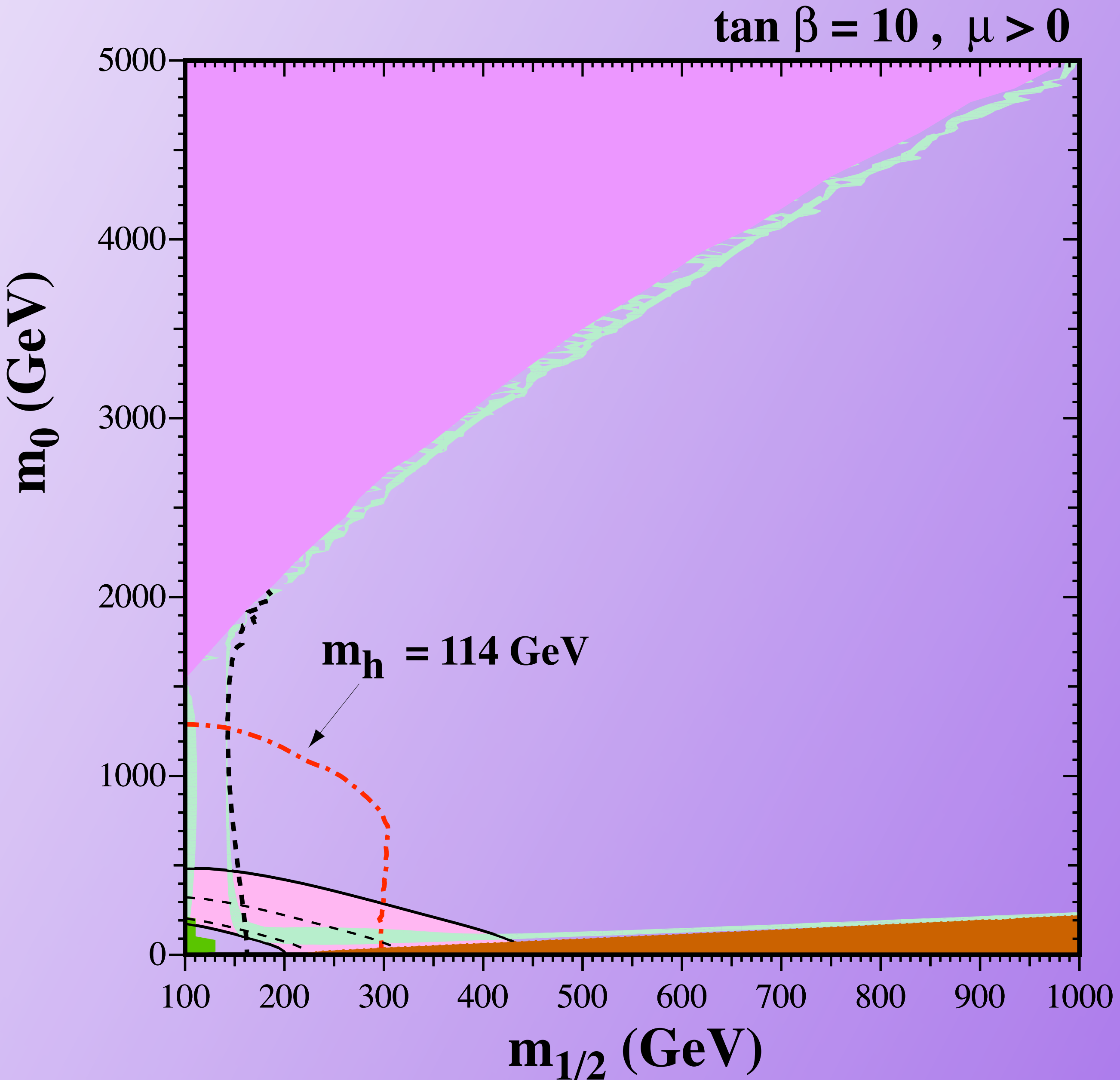
Foliation in tan β



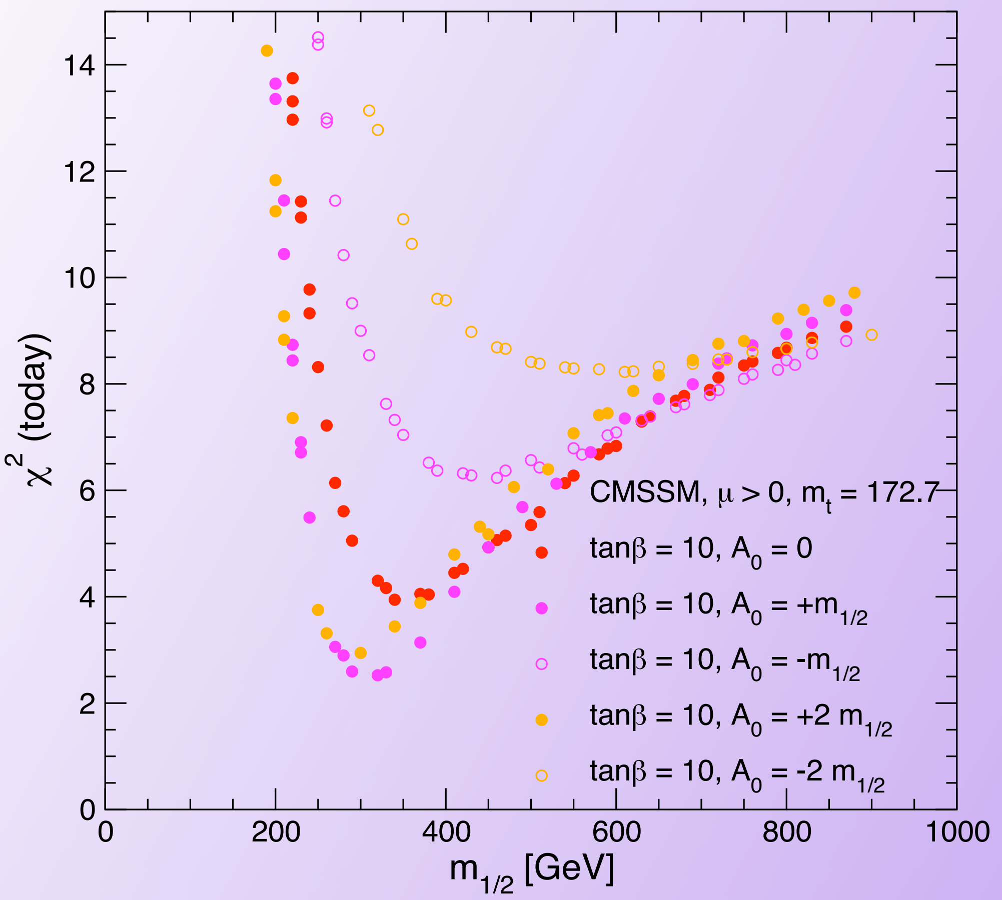
Focus Point Region

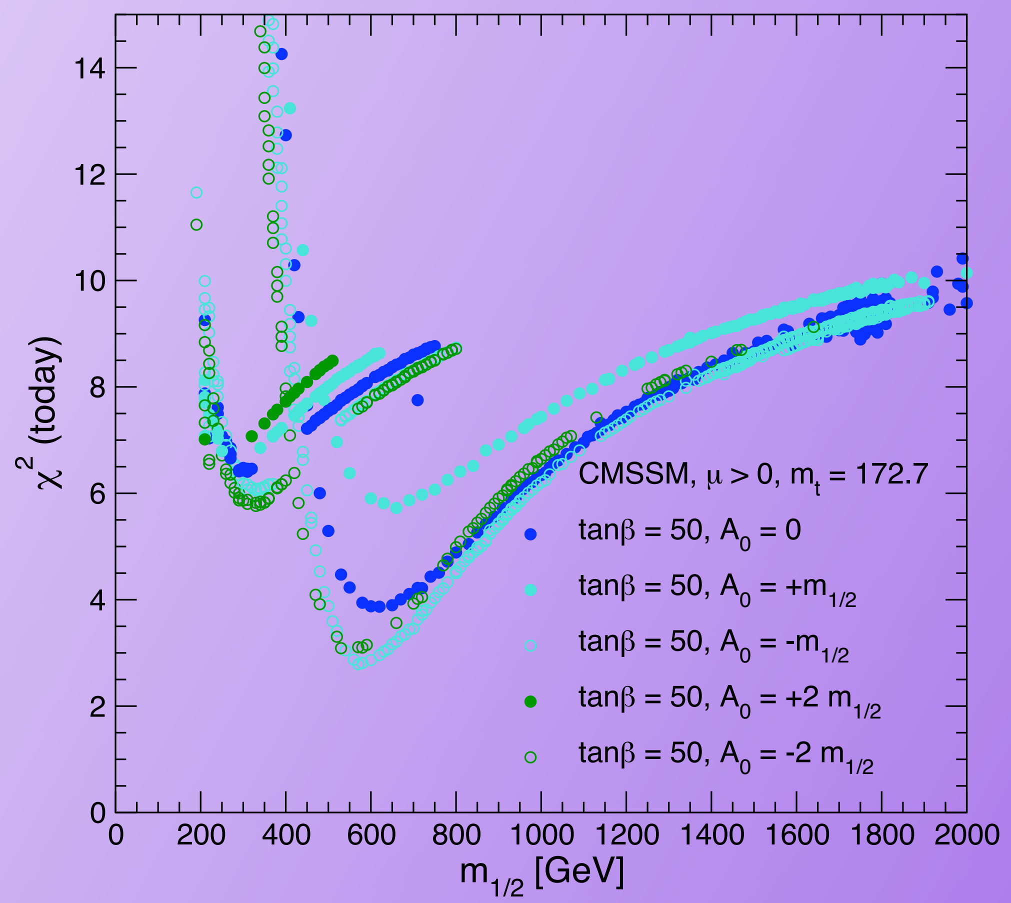
As m_0 gets very large, RGE's force μ to 0, allowing neutralino to become Higgsino like with an acceptable relic density.



Feng Matchev Moroi Wilczek

Indirect Sensitivities to CMSSM models





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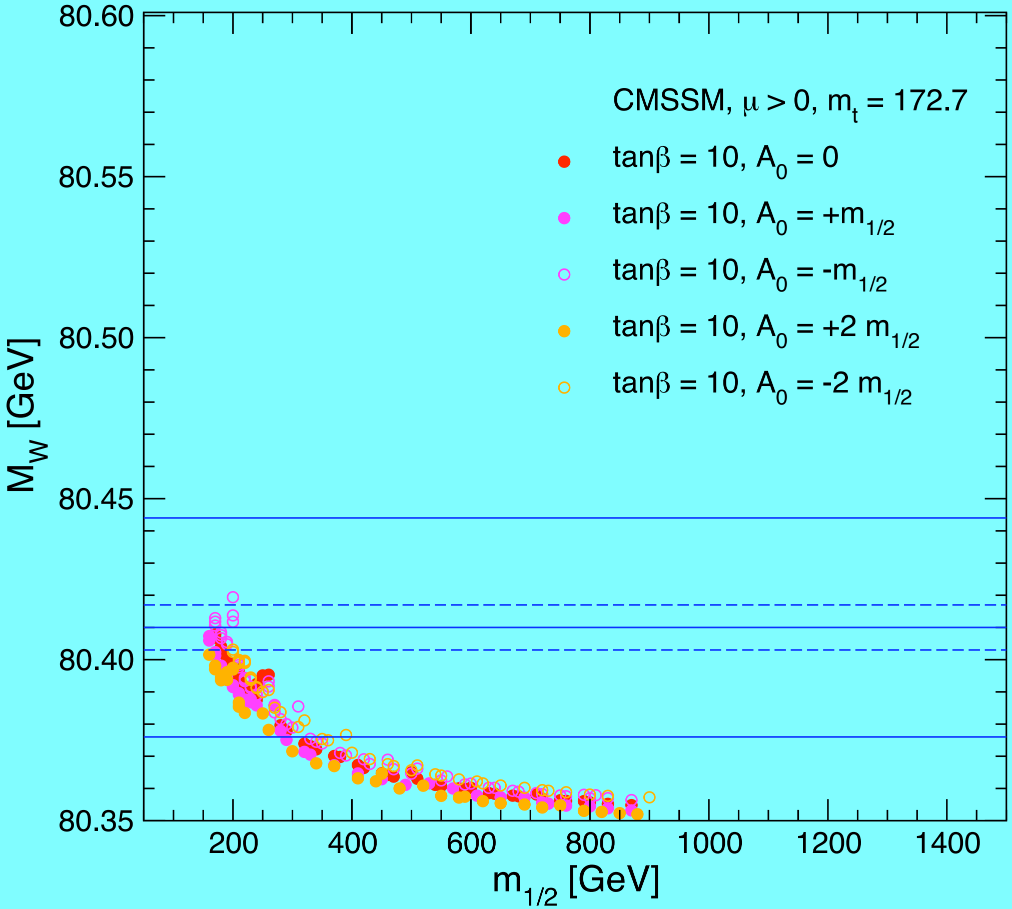
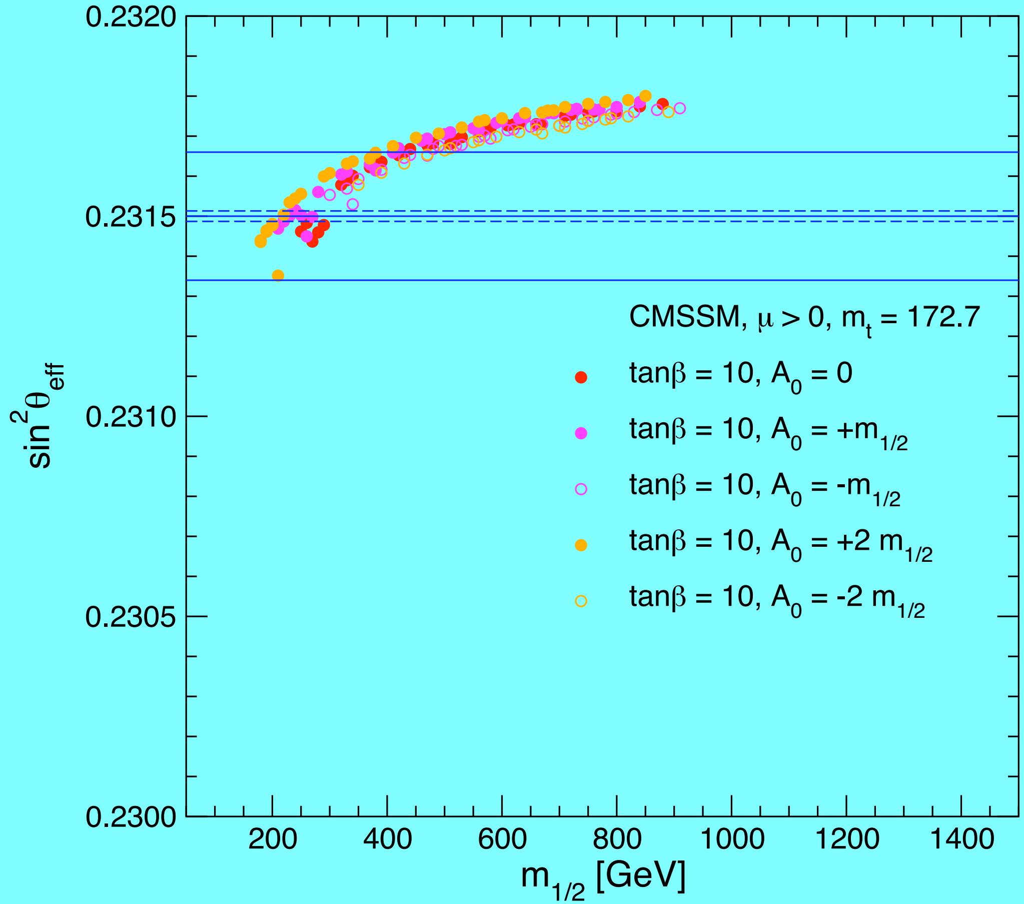
Sensitivity to M_W and $\sin^2 \theta_W$





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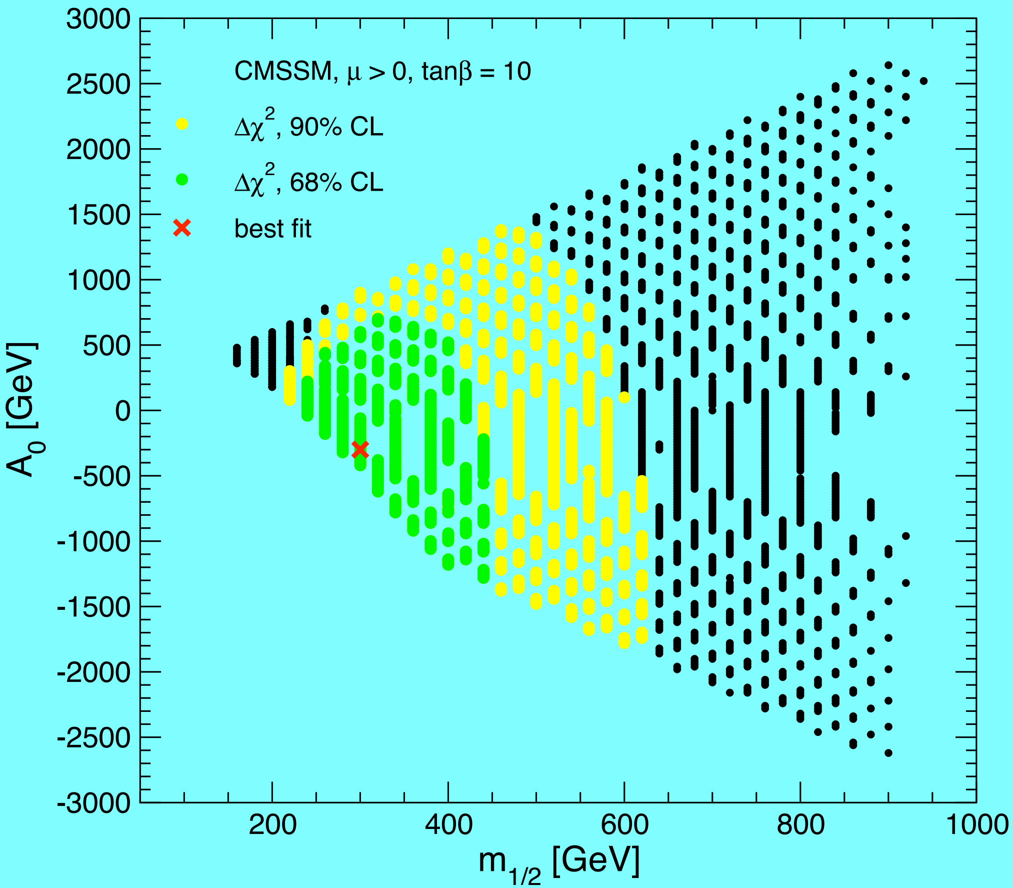
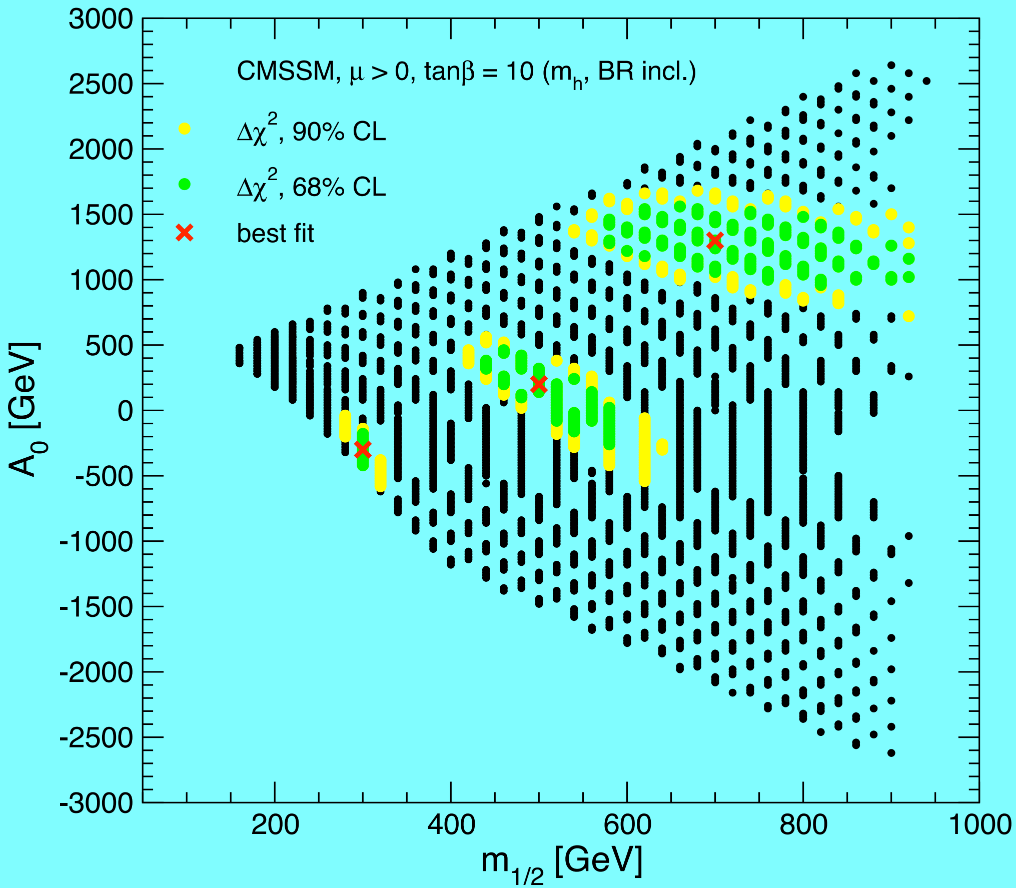
Current and future sensitivities





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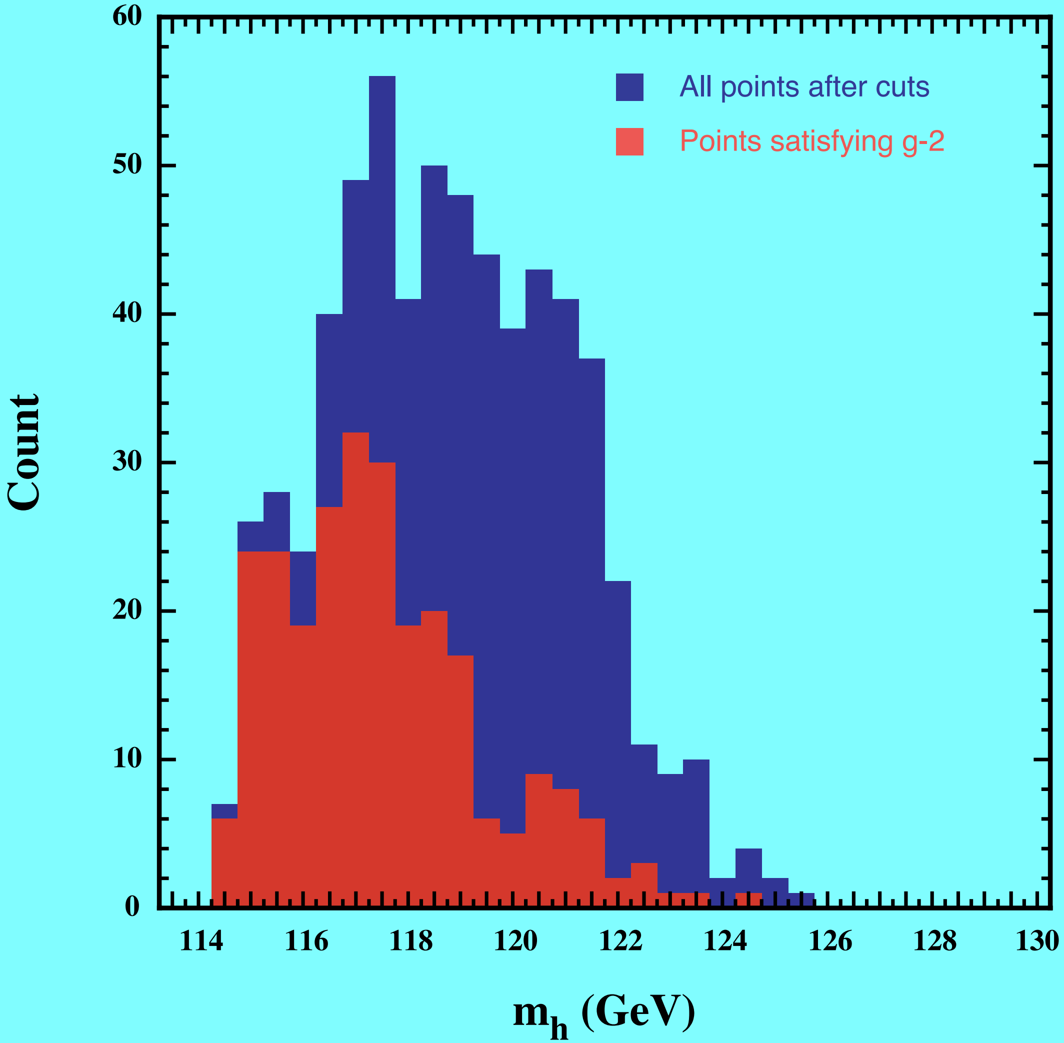
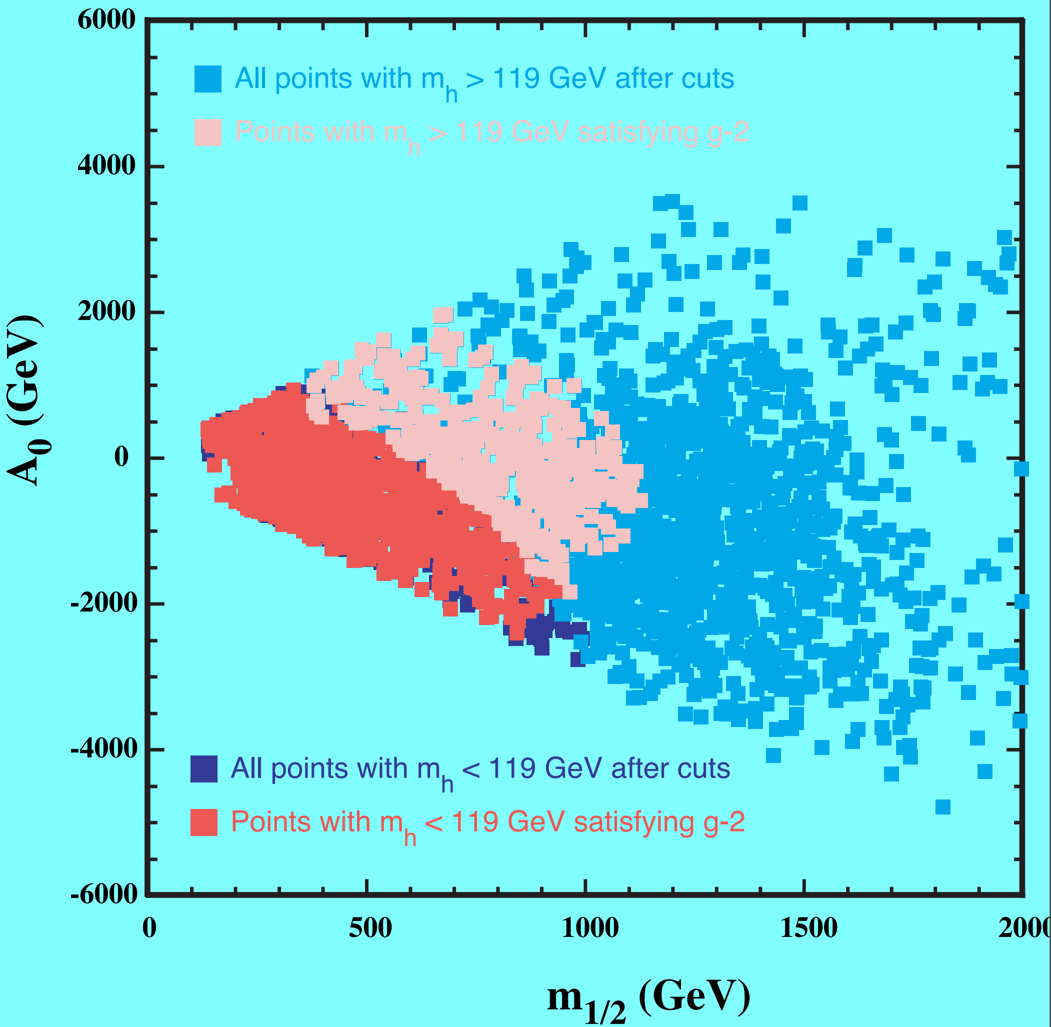
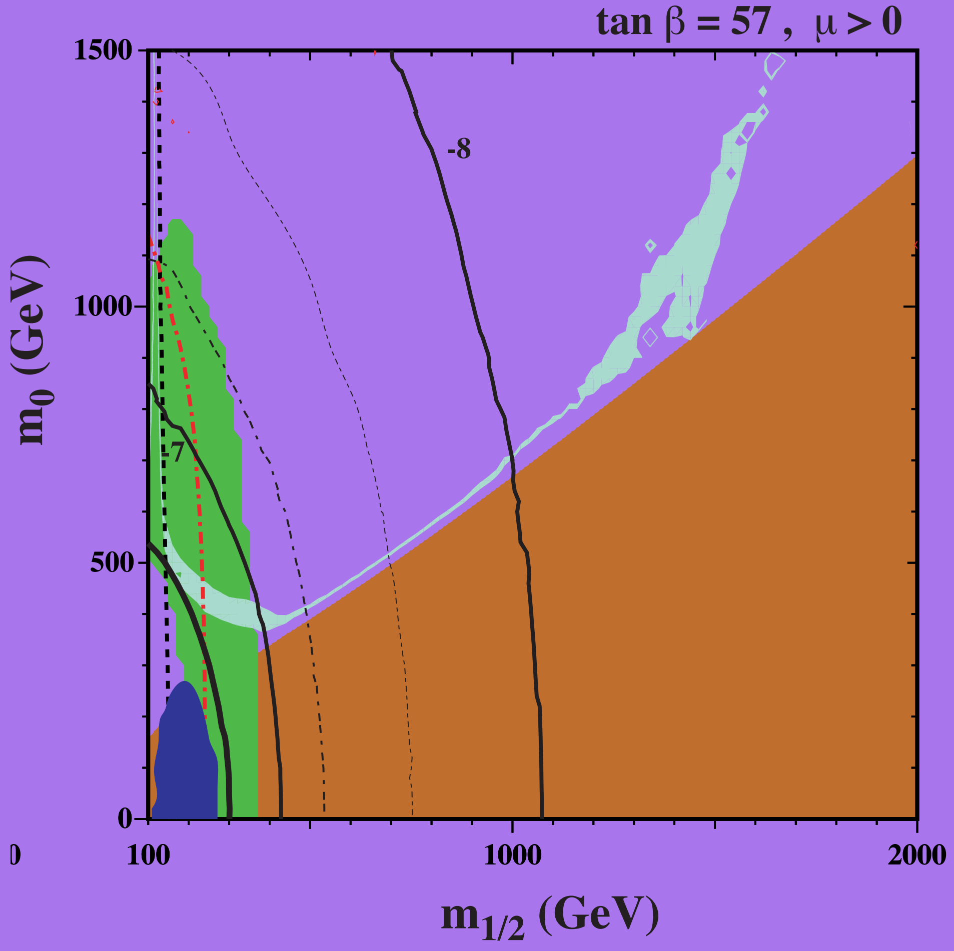
Using the Higgs mass to determine CMSSM parameters

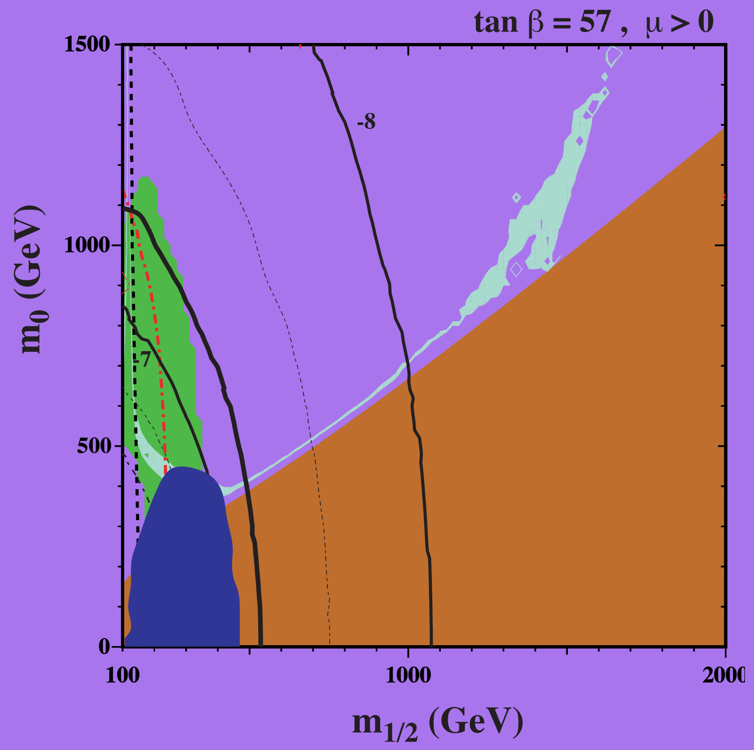


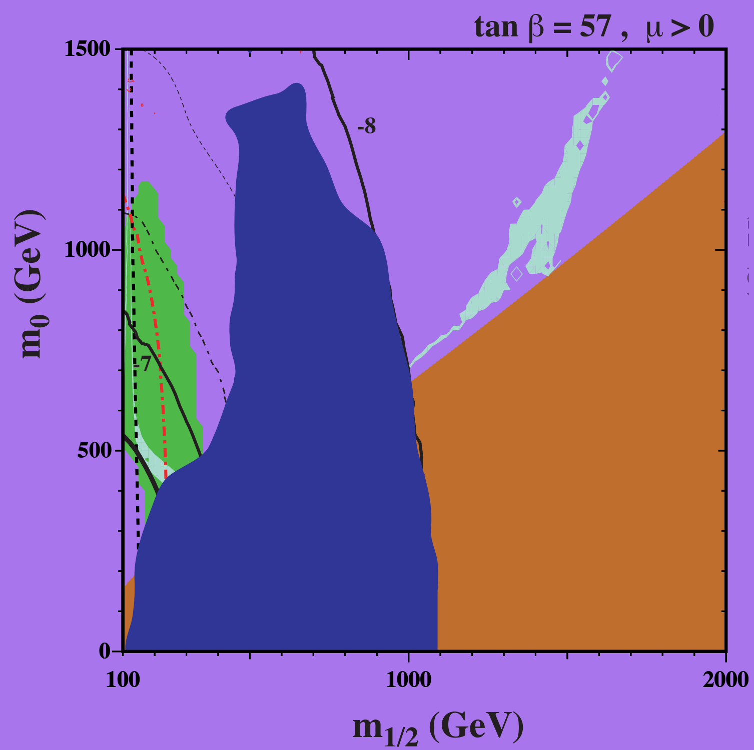


Ellis, Nanopoulos, Olive, Santoso

$$B_s \to \mu^+\mu^-$$

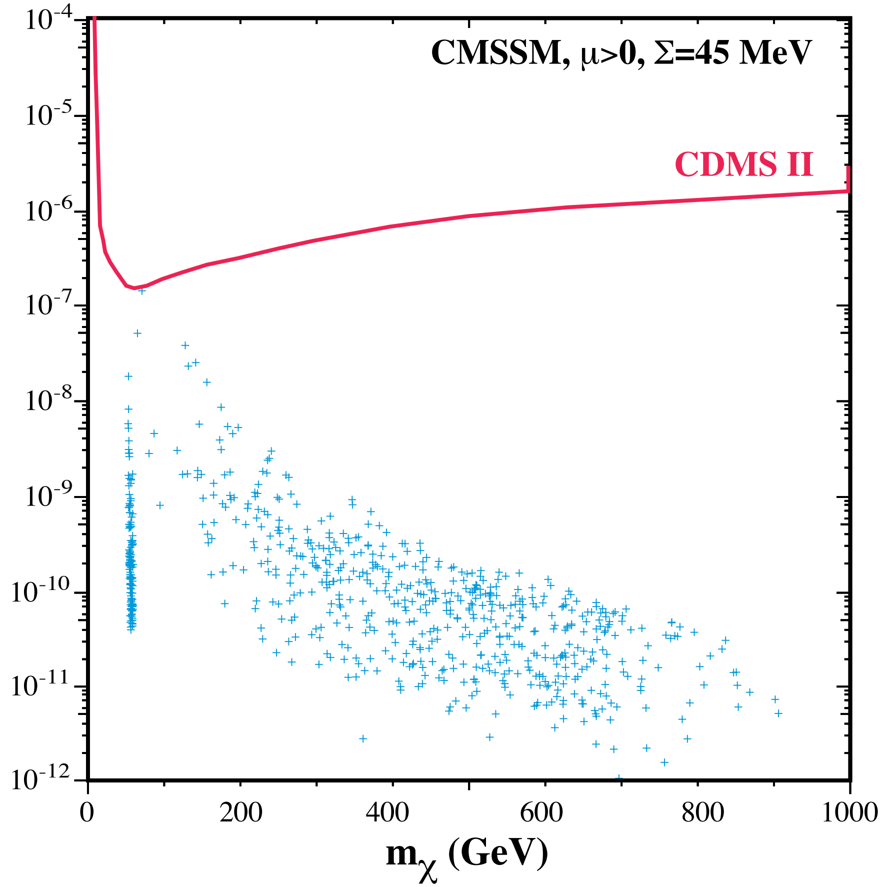


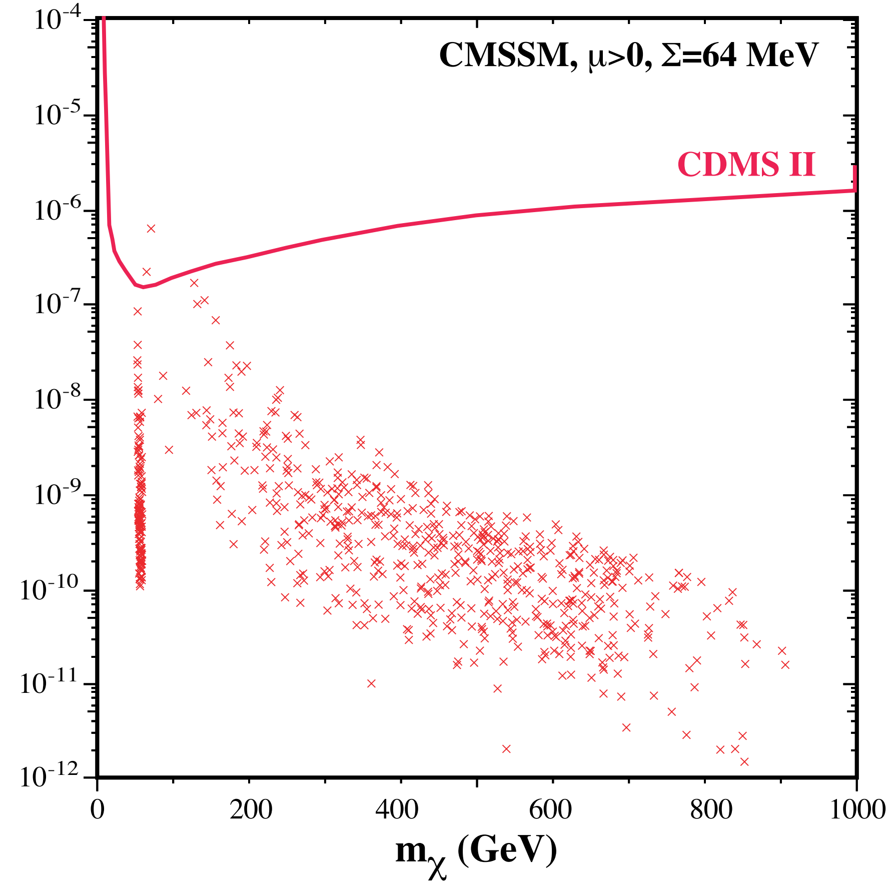




Ellis, Olive, Spanos

Direct Detection in the CMSSM





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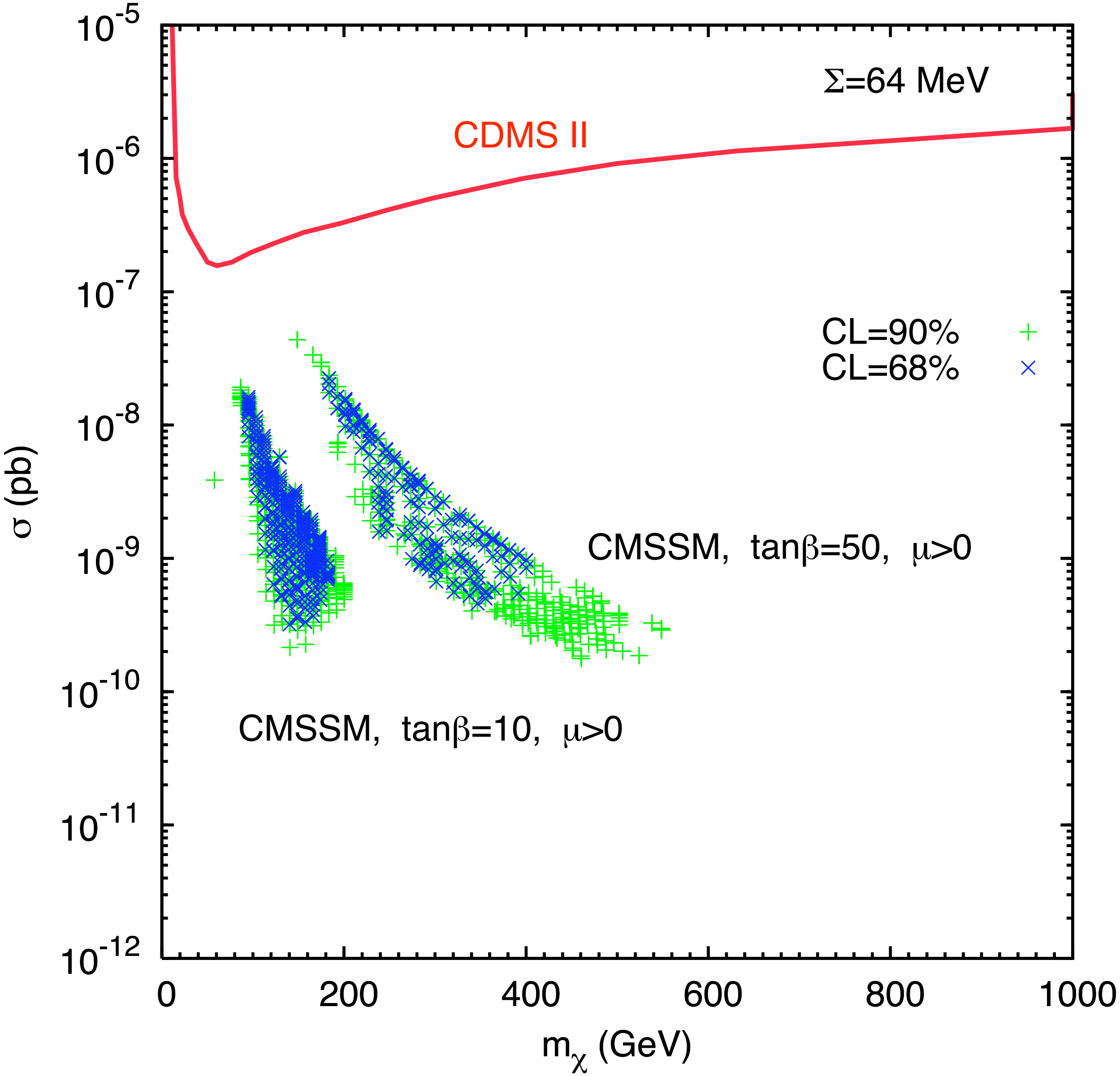
Direct Detection in regions of lowest χ^2



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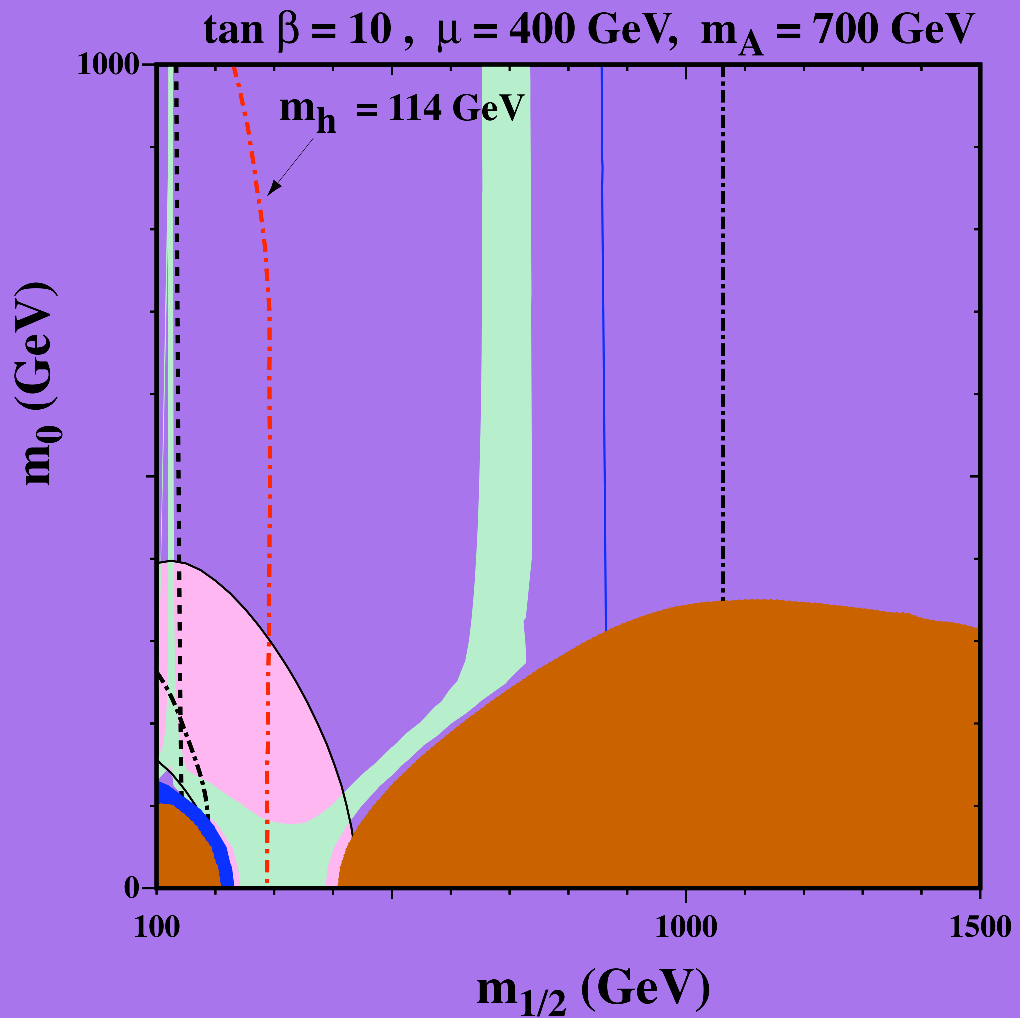
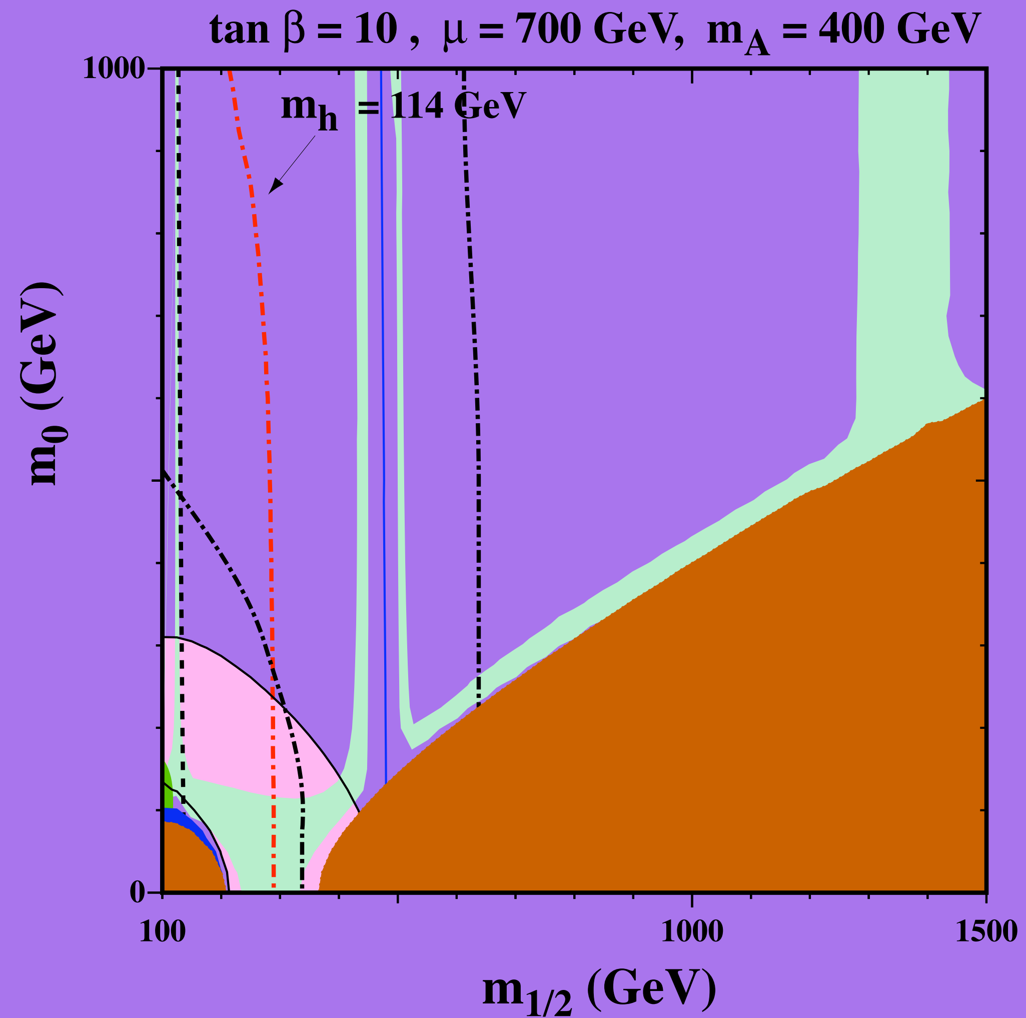
NUHM

- Drop unification of scalar masses
- All Higgs soft masses, m_1 and m_2, to be chosen independently of m_0
- Allows μ and m_A to be free parameters



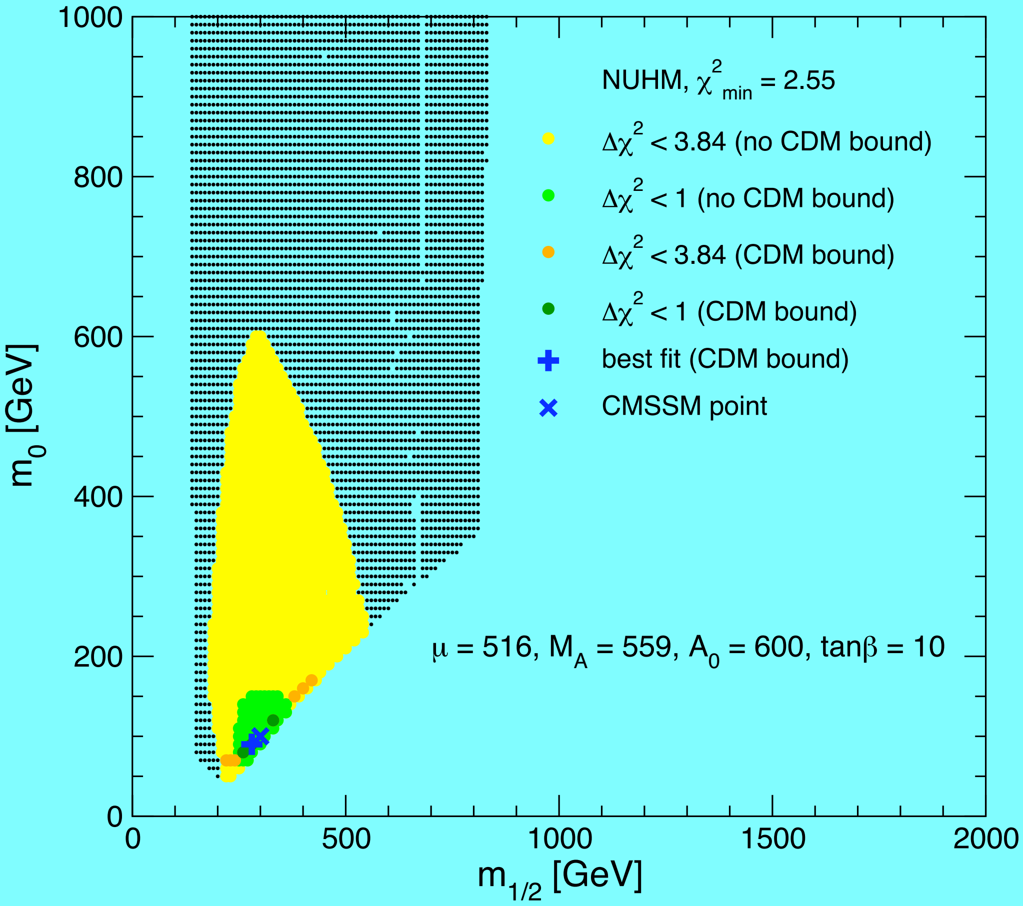


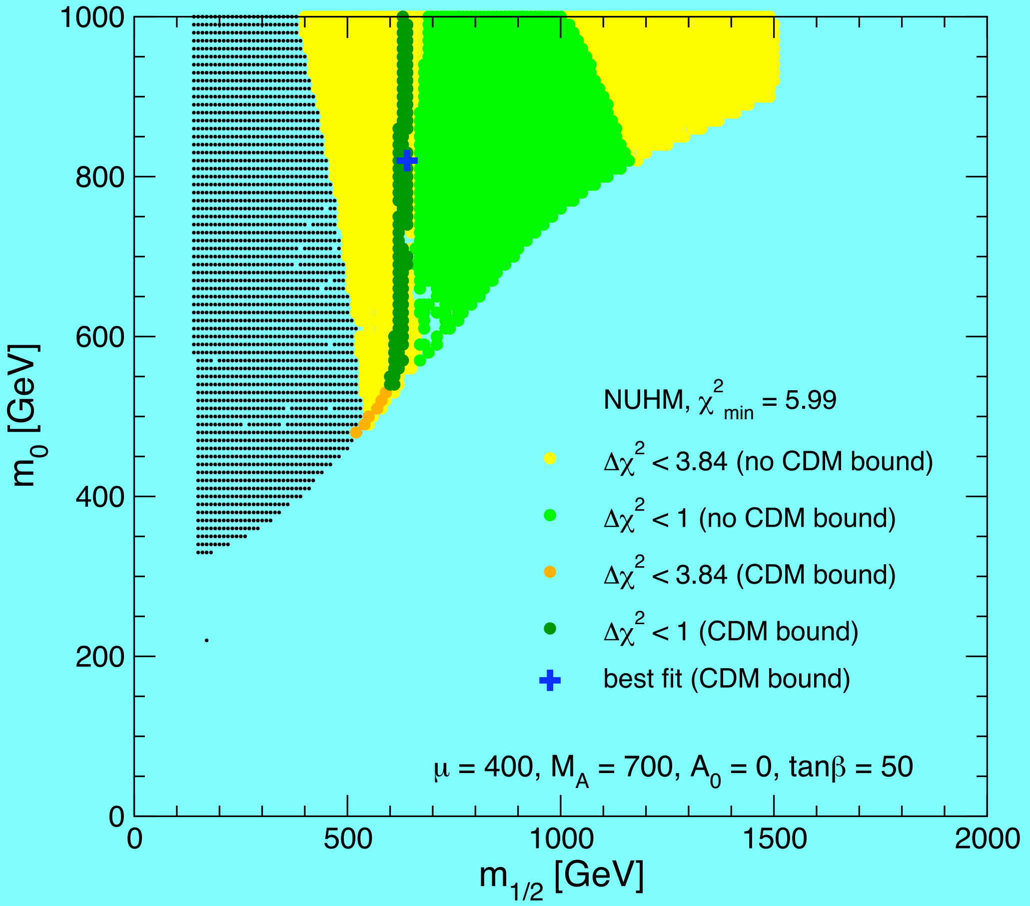
The $m_0 - m_{1/2}$ plane

+ CMSSM value

Ellis, Olive, Santoso

Indirect Sensitivities to NUHM Models





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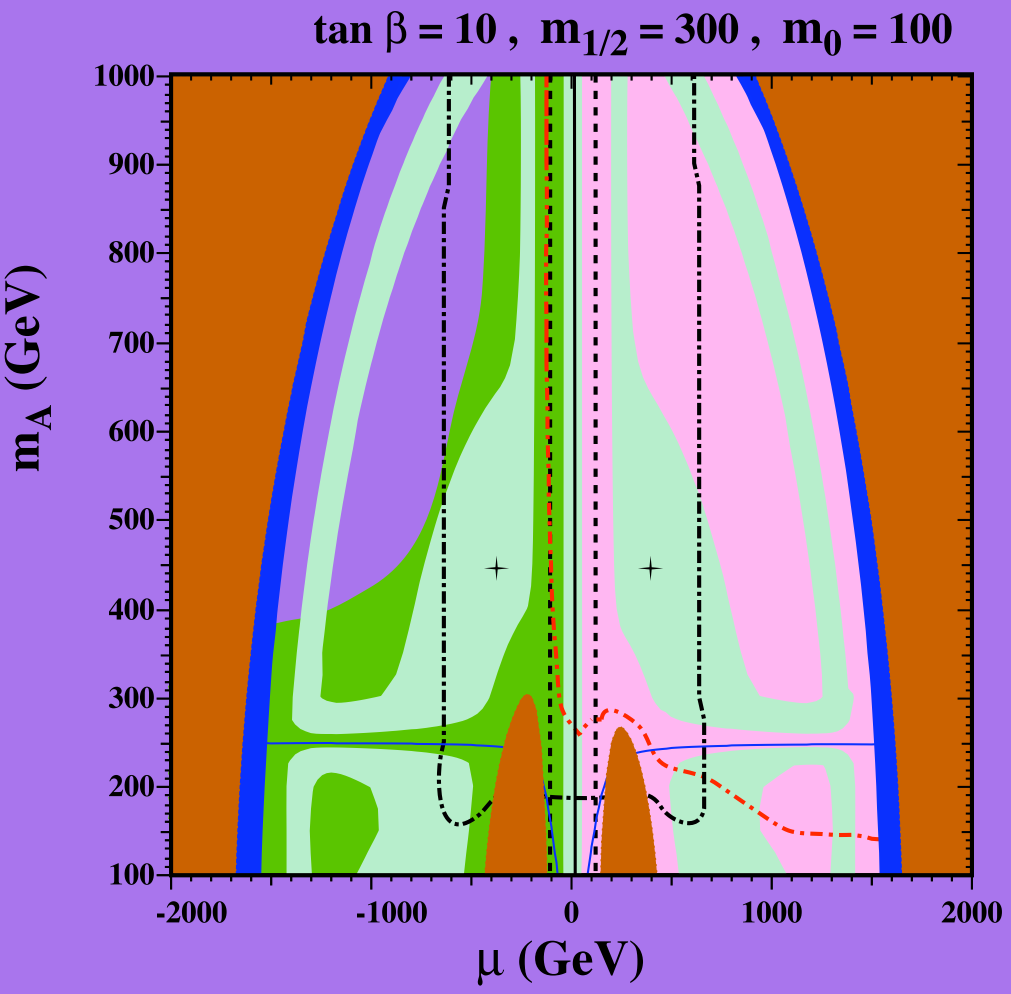

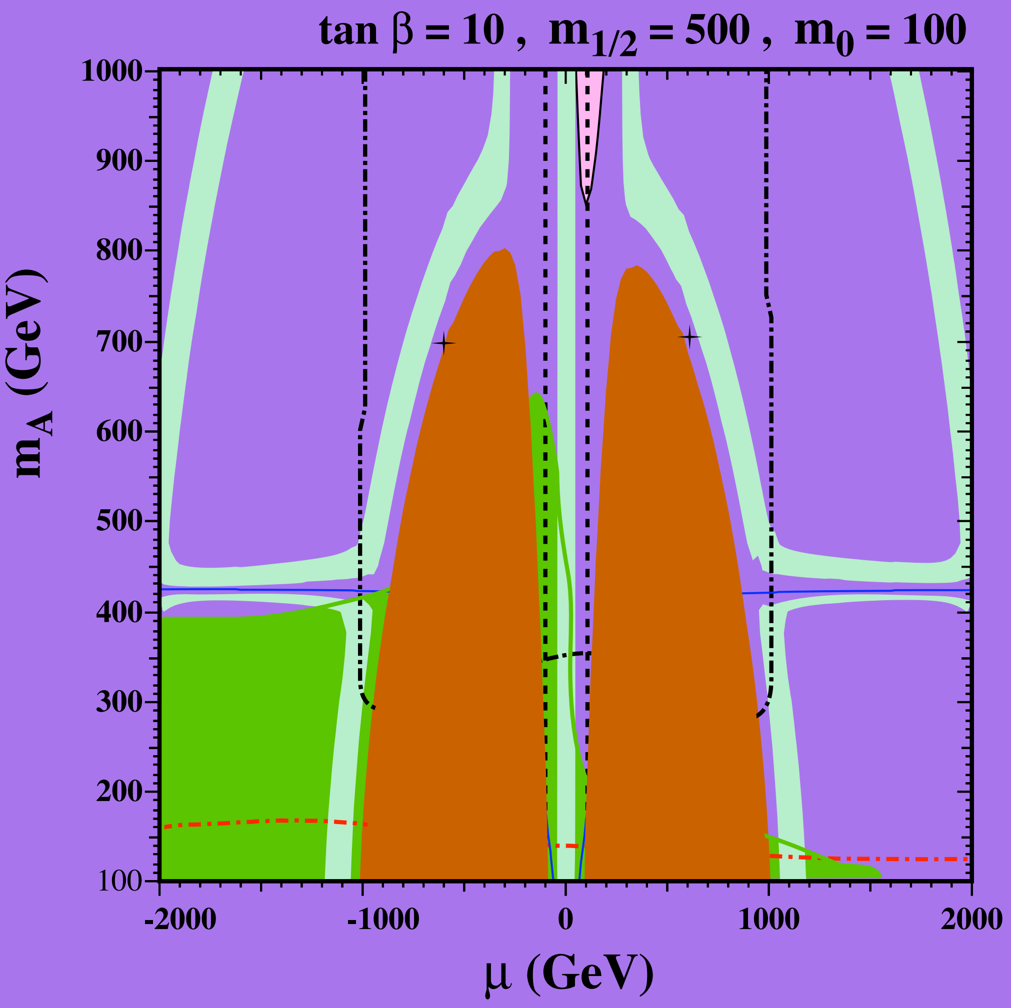

The $m_A - \mu$ plane

+ CMSSM value

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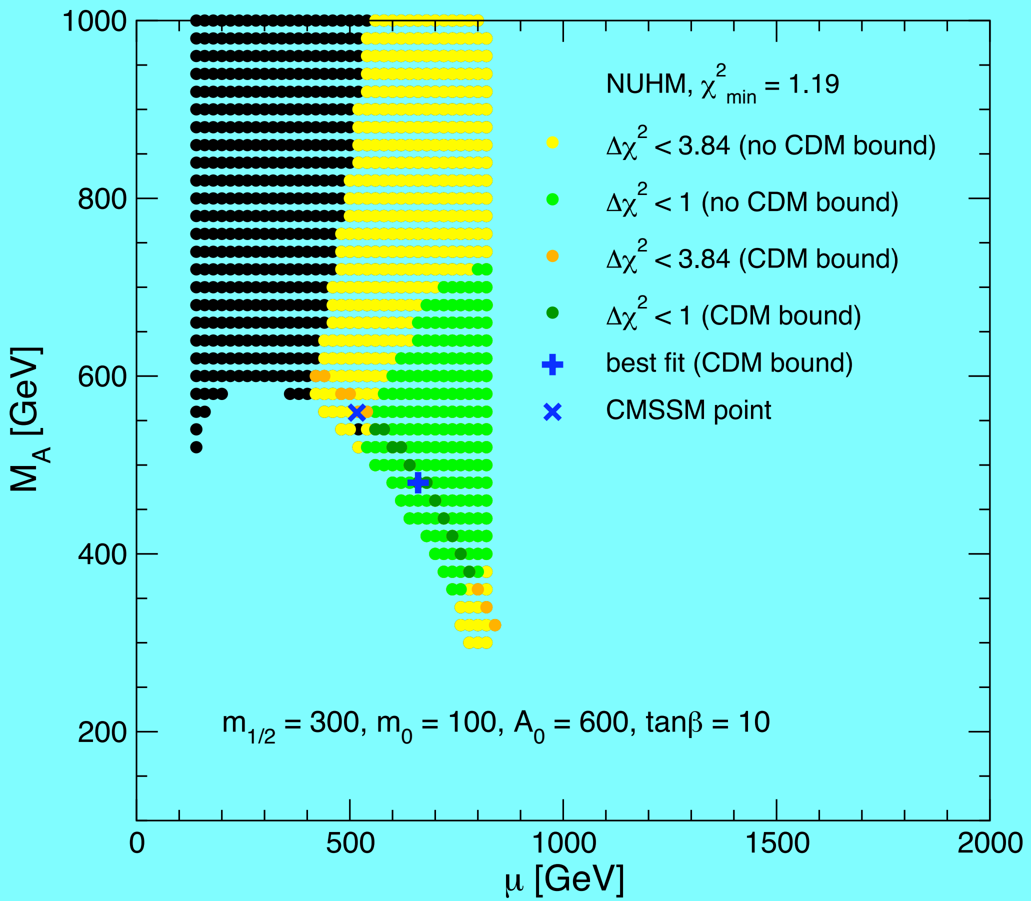
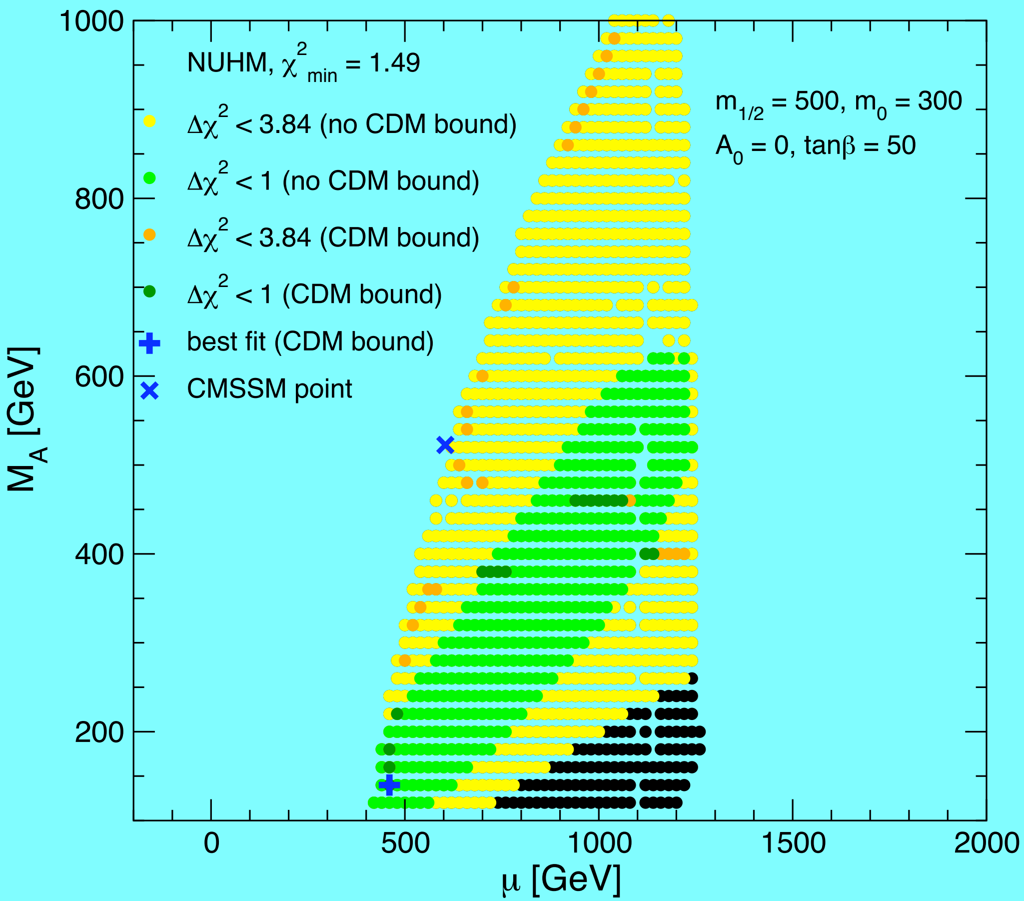


NUHM, χ^2_{min} = 1.19
$\Delta\chi^2$ < 3.84 (no CDM bound)
$\Delta\chi^2$ < 1 (no CDM bound)
$\Delta\chi^2$ < 3.84 (CDM bound)
$\Delta\chi^2$ < 1 (CDM bound)
best fit (CDM bound)
CMSSM point
$m_{1/2}$ = 300, m_0 = 100, A_0 = 600, tanβ = 10
M_A [GeV]
μ [GeV]



NUHM, χ^2_{min} = 1.49
$\Delta\chi^2$ < 3.84 (no CDM bound)
$\Delta\chi^2$ < 1 (no CDM bound)
$\Delta\chi^2$ < 3.84 (CDM bound)
$\Delta\chi^2$ < 1 (CDM bound)
best fit (CDM bound)
CMSSM point
$m_{1/2}$ = 500, m_0 = 300
A_0 = 0, tanβ = 50
M_A [GeV]
μ [GeV]

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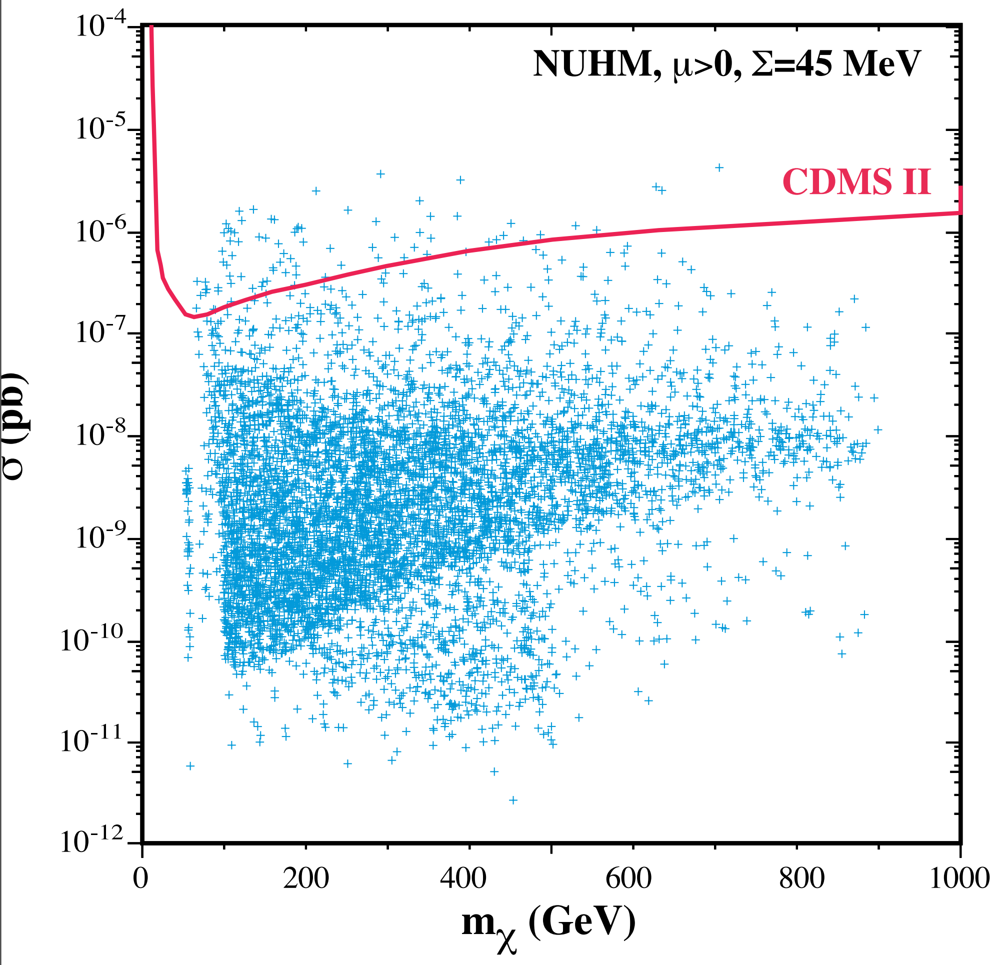
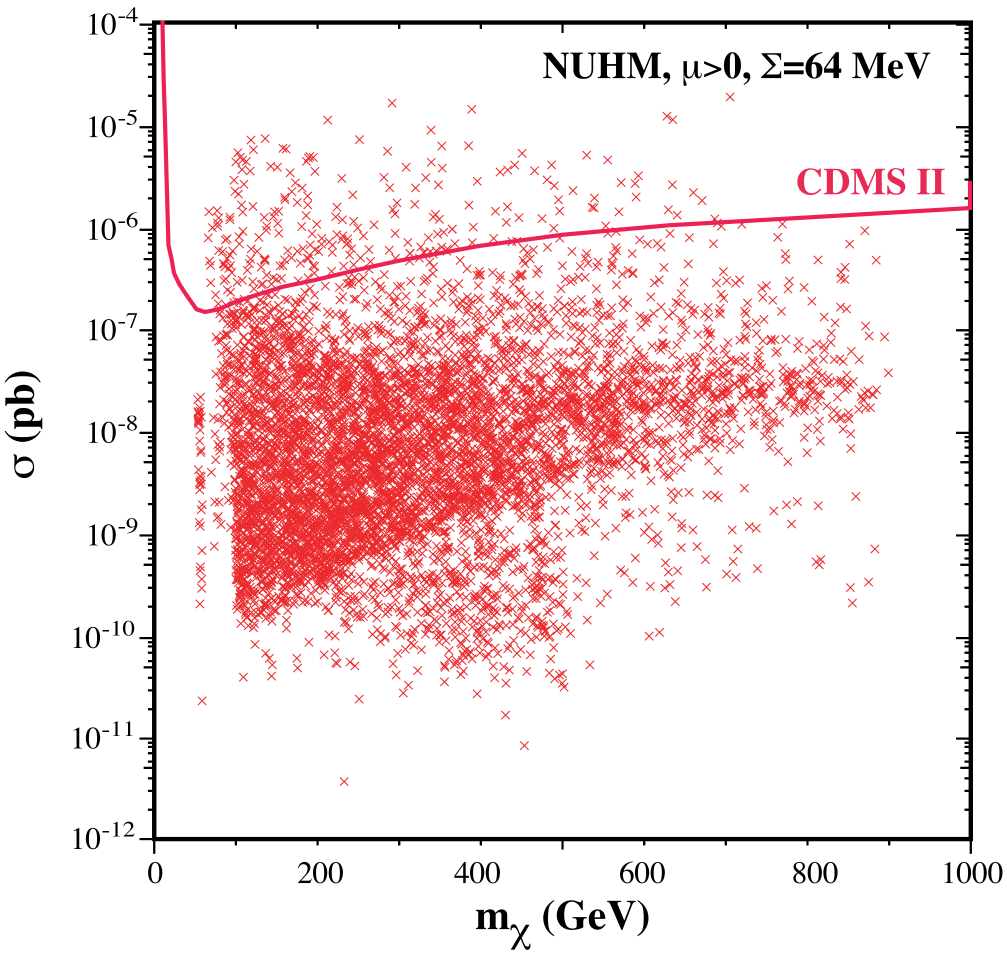
Direct Detection in the NUHM





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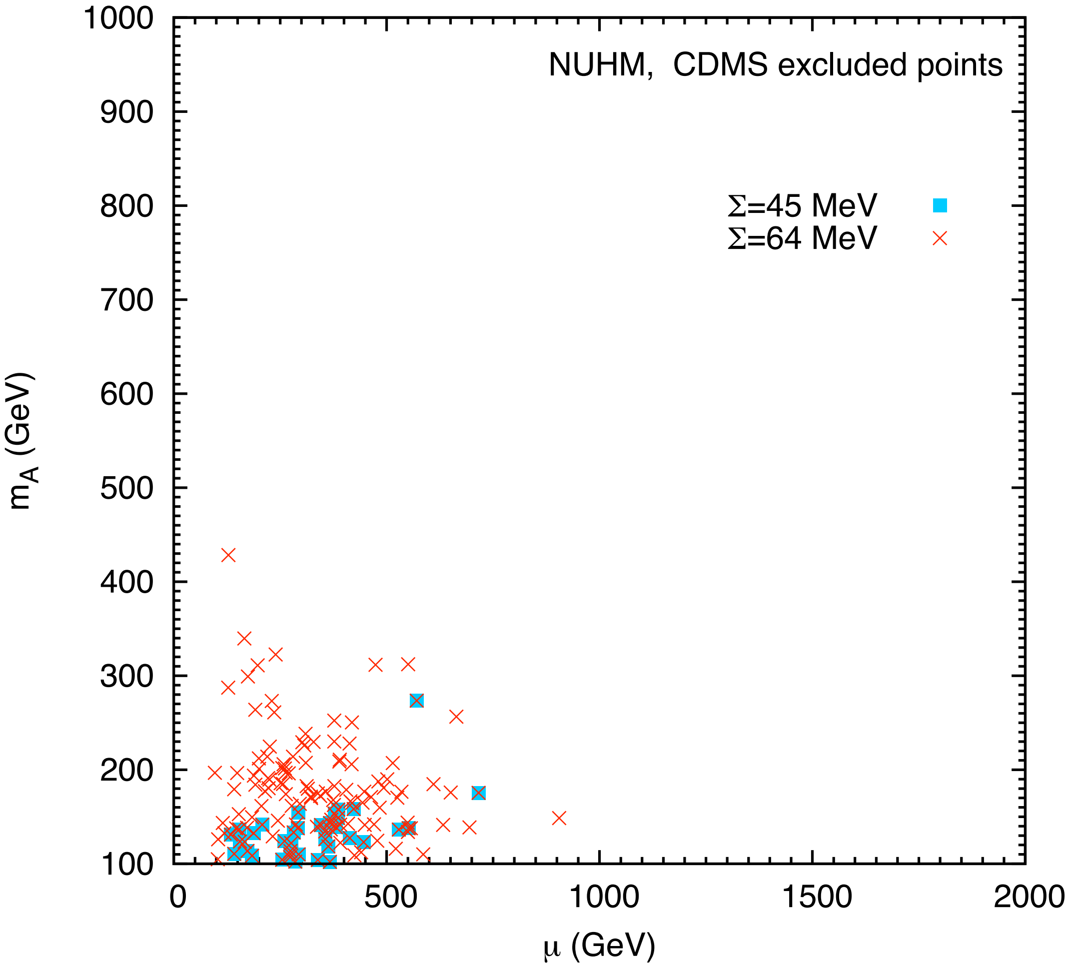
CDMS Excluded models



Consequences for $B_s \to \mu^+ \mu^-$

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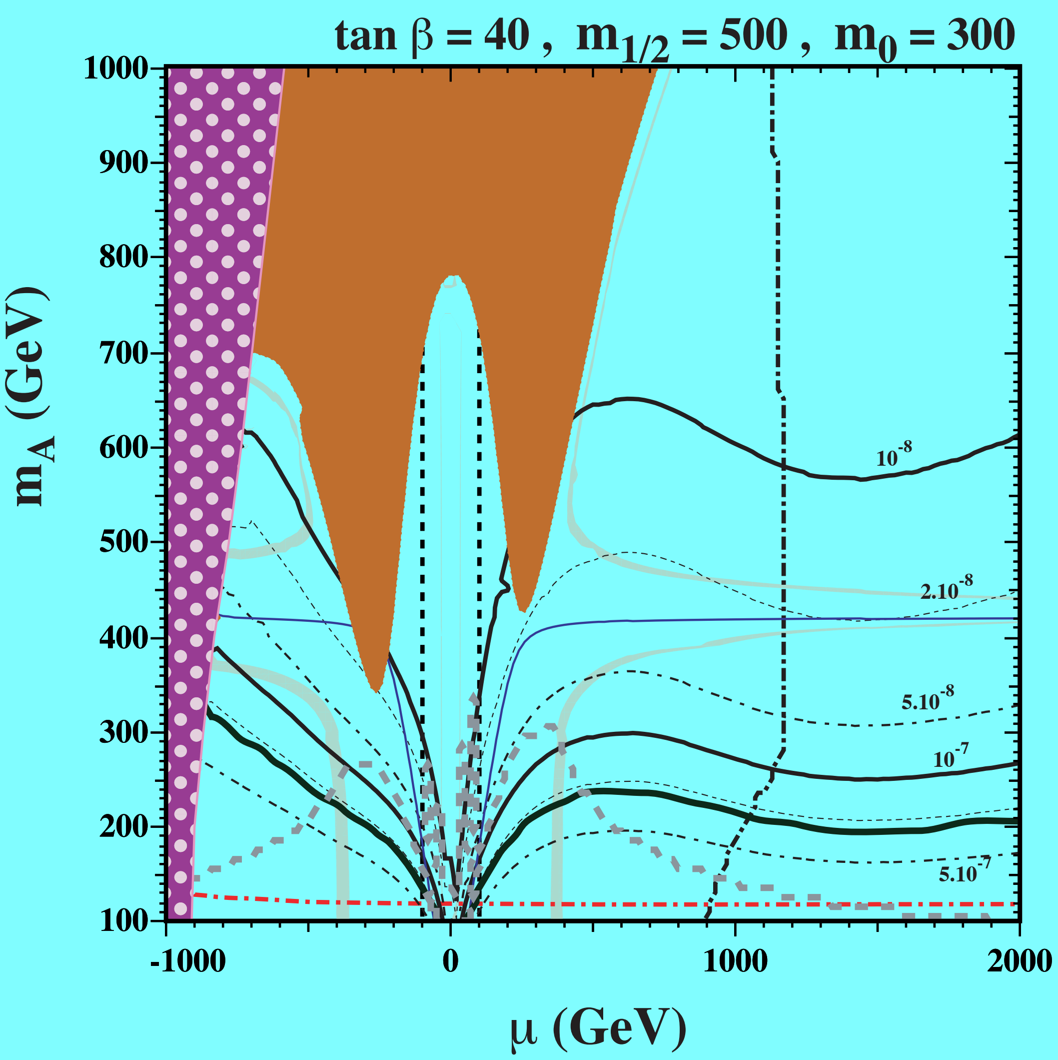
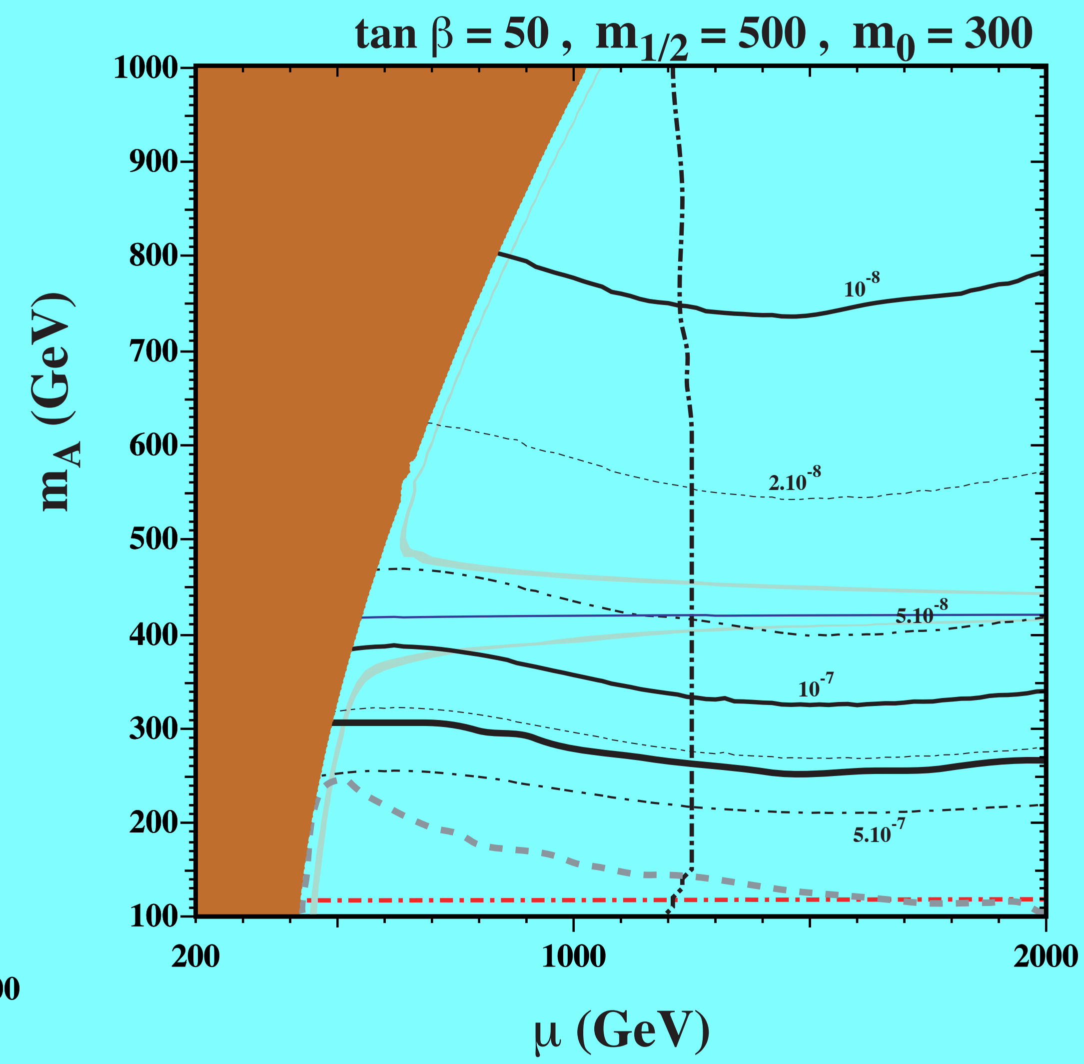
Competition between Direct Detection and B$\rightarrow \mu^+ \mu^-$





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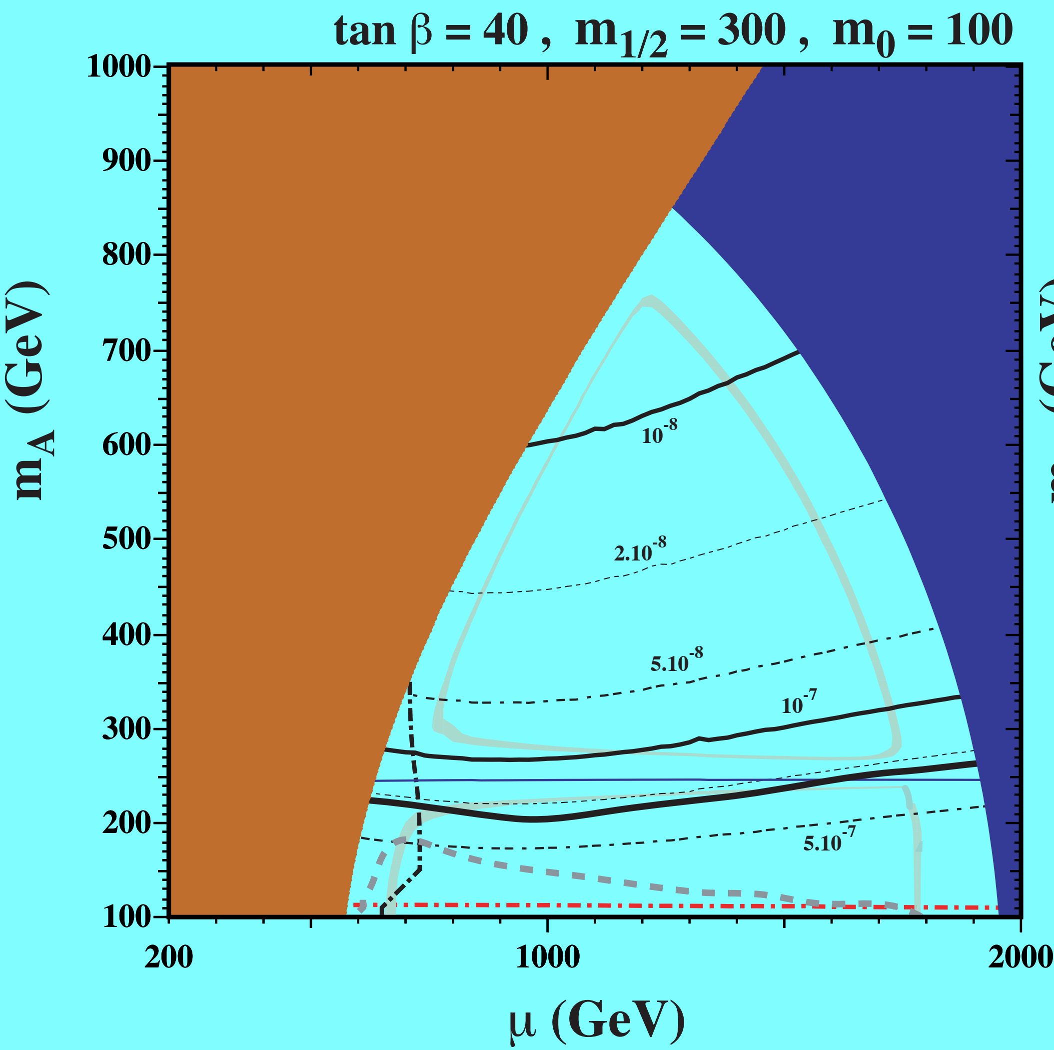
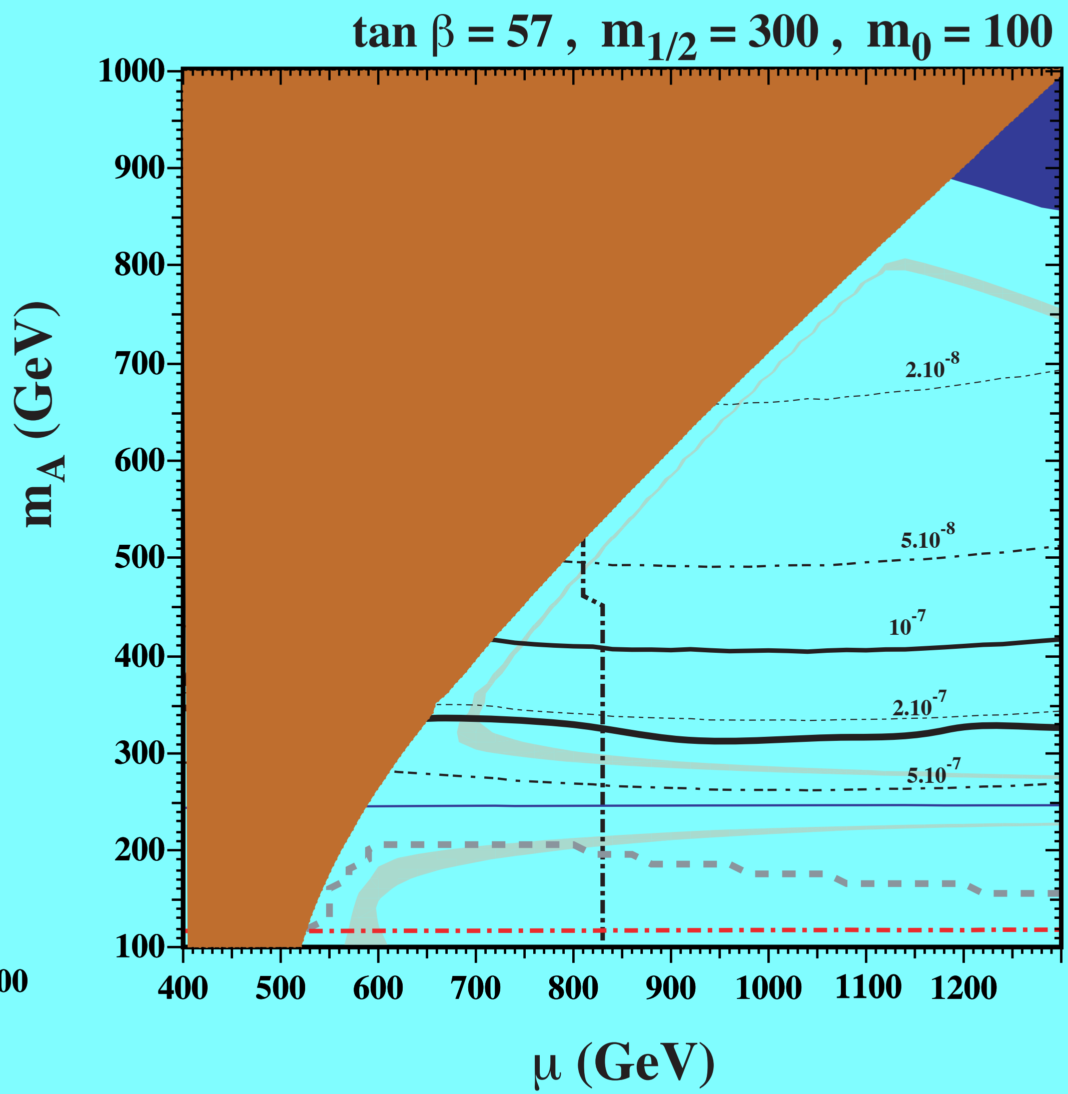

tan β = 40 , m1/2 = 300 , m0 = 100
mA (GeV)
μ (GeV)
10-8
2.10-8
5.10-8
10-7
5.10-7
1000
900
800
700
600
500
400
300
200
100
200
1000
2000


tan β = 57 , m1/2 = 300 , m0 = 100
mA (GeV)
μ (GeV)
2.10-8
5.10-8
10-7
2.10-7
5.10-7
1000
900
800
700
600
500
400
300
200
100
400
500
600
700
800
900
1000
1100
1200

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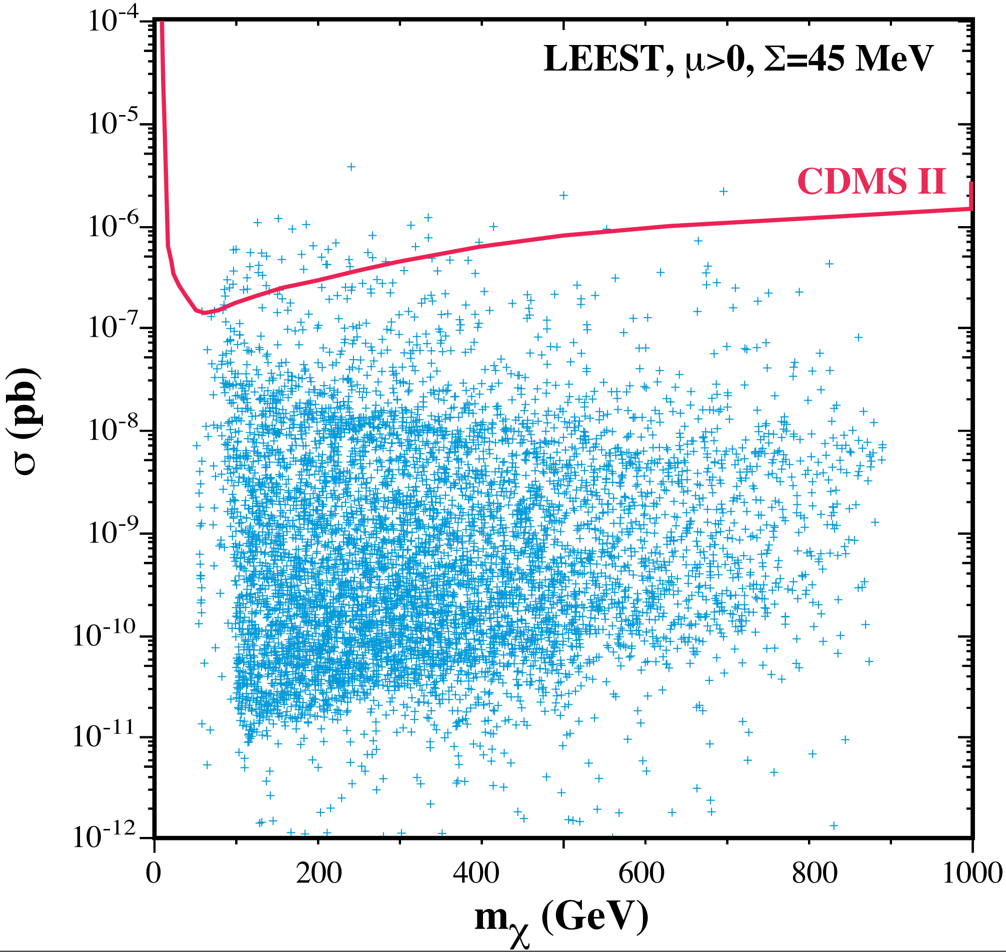
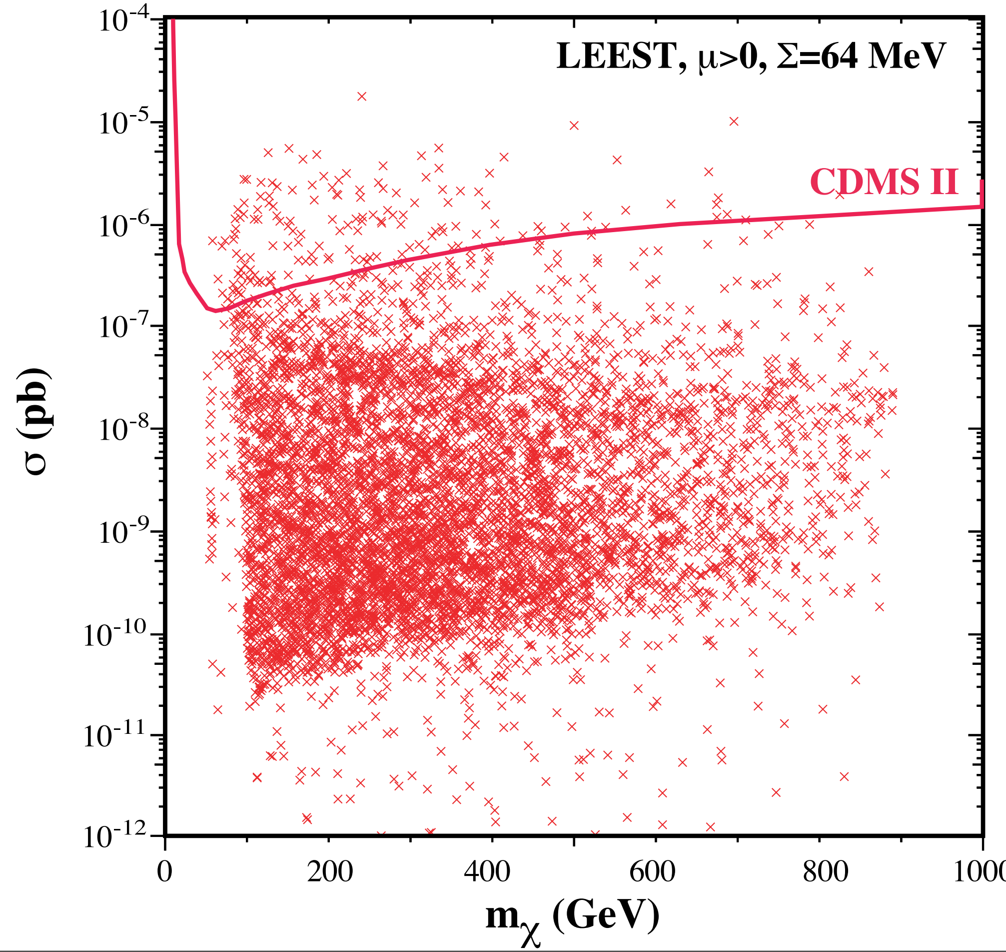
Low Energy Effective Susy Theories

- Drop Squark-Slepton Universality
- Retain GUT constraint





Summary

- mSugra models most difficult to access experimental esp. if GDM
- Good indication from indirect sensitivities for `low' energy signal for SUSY.
- Good prospect for Direct detection and $B \rightarrow \mu^+ \mu^-$ particularly in non CMSSM models (unless GDM)