SIGNATURES OF ELECTROWEAK SUPERSYMMETRIC SECTOR WITH NEUTRALINO DARK MATTER UNDERABUNDANCE

Badziak, Delgado, Olechowski, SP,
Sakurai (work in progress)

Useful references:

Arkani-Hamed, Delgado, Giudice, hep-ph/0601041

Cheung, Hall, Piner, Ruderman, hep-ph/1211.4873

Low, Lian-Tao Wang, hep-ph/1404.0682

Bramante et al., hep-ph/14124789

MOTIVATION

- SUPERSYMMETRIC COLORED PARTICLES (EVEN SFERMIONS IN GENERAL) MAY BE SIGNIFICANTLY HEAVIER THAN THE PRESENT BOUNDS
- IN MODELS WITH STABLE NEUTRALINO (R-parity), AND ACCEPTING THE THERMAL HISTORY OF THE UNIVERSE, ITS MASS IS BOUNDED FROM ABOVE $(\Omega h^2 \approx A \frac{m^2_{\chi^0}}{1TeV})$
- NEUTRALINO COMPONENT IN THE OBSERVED DARK MATTER CAN BE SMALL (ONLY SMALL PARAMETER RANGE GIVES 0.12)

THE FRAMEWORK

- THERMAL HISTORY OF THE UNIVERSE
- R-PARITY CONSERVATION
- DECOUPLED SFERMIONS

PARAMETERS $M_1, \quad M_2, \quad \mu, \quad \tan\beta$

SIGNATURES OF THE ELECTROWEAK SECTOR FOR

$$\Omega h^2 \leq 0.12$$

It is covenient to organize the discussion according to the LSP composition

BINO-HIGGSINO MIXING $(M_2 = m_{sf} = m_A = 6TeV)$

HIGGSINO-WINO MIXING $(M_1 = m_{sf} = m_A = 6TeV)$

PURE BINO- EXCLUDED BY $\Omega h^2 < 0.12$

BINO-HIGGSINO-WINO MiXING

PURE HIGGSINO

$$\Omega_h h^2 = 0.10(\frac{\mu}{1\ TeV})^2$$

$\Omega h^2 < 0.12$ for

$$\mu < 1TeV$$

PURE WINO

$$\Omega_w h^2 = 0.13(\frac{M_2}{2.5\ TeV})^2$$

$\Omega h^2 < 0.12$ for

$$M_2 < 2.2(2.8)TeV$$

Blino-higgsino- wino mixing effects determine the relic abundance for a given neutralino mass

Considered signatures

- SPIN INDEPENDENT NEUTRALINO-NUCLEUS SCATTERING
- COLIIDER SIGNATURES (DEPEND ON VARIOUS MASS DIFFERENCES AND PRODUCTION CROSS SECTIONS)

$$\sigma_{SI} = 8 \times 10^{-45} cm^2 (\frac{c_{h\chi\chi}}{0.1})^2$$

where

$$L = \frac{c_{h\chi\chi}}{2} h(\chi\chi + \chi^\dagger\chi^\dagger)$$

and (approximately)

$$c_{h\chi\chi} \sim \theta$$ (MIXING)

Gaugino/higgsino $\theta = \frac{(\sin\beta \pm \cos\beta)}{\sqrt{2}} (\frac{M_Z}{(\mu \mp M_i)}$

Bino/wino $\theta = \frac{(\sin 2\beta \sin 2\theta_W)}{2} (\frac{M_Z^2}{(M_2 - M_1)\mu})$

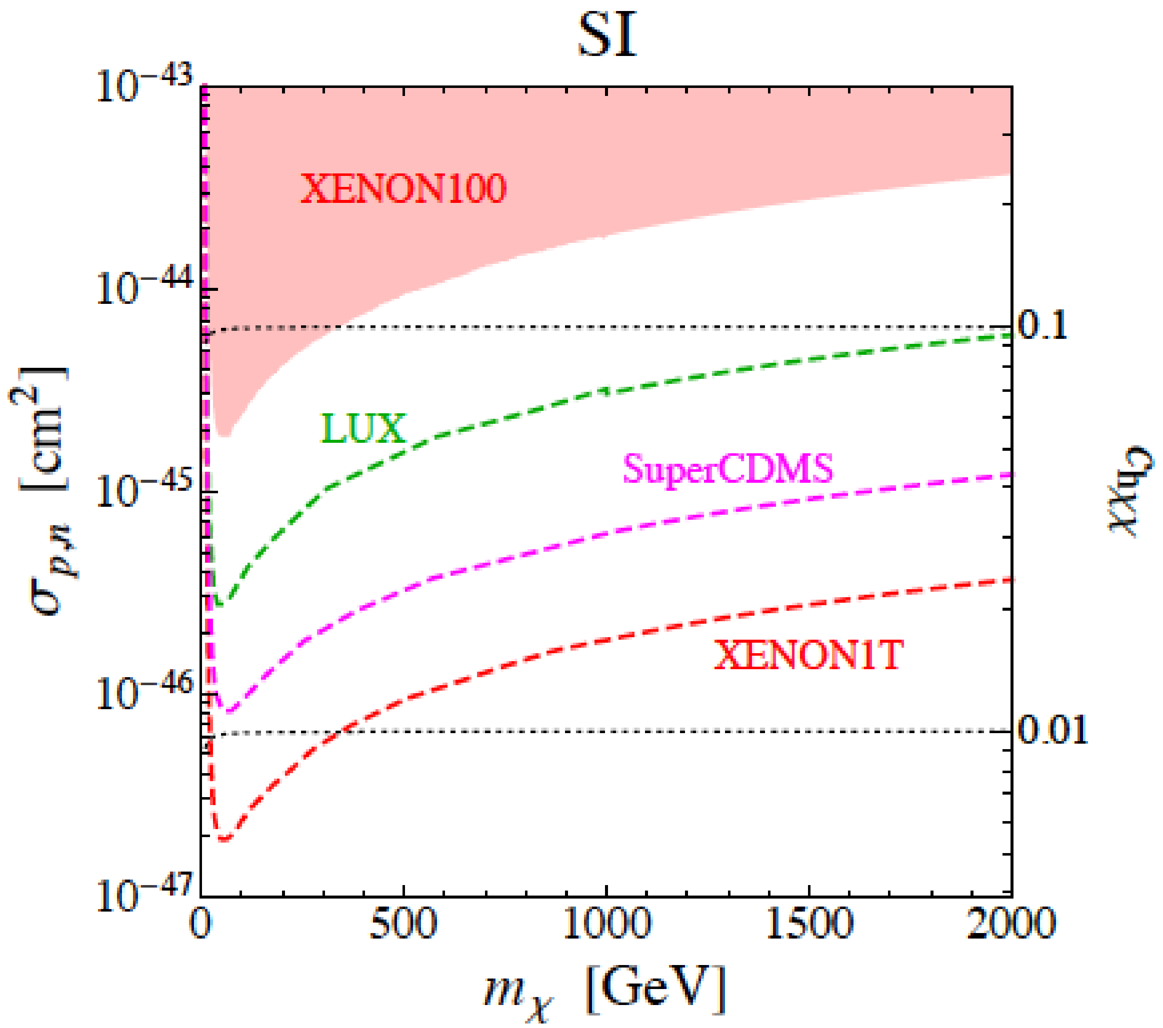
SPIN INDEPENDENT SCATTERING CROSS SECTION

EXCLUSION LIMITS (LUX) AND FUTURE PROSPECTS

REMEMBER: FOR NEUTRALINOS WITH Ω_χ

AND CROSS SECTION σ_{SI}

THE EXCLUSION LIMIT IS $$\frac{\sigma_{SI}^{\chi}}{\sigma_{SI}^{LUX}}\frac{\Omega_\chi}{\Omega_{DM}} > 1$$

SI
10^-43
10^-44
10^-45
10^-46
10^-47
σ_{p,n} [cm^2]
0
500
1000
1500
2000
m_χ [GeV]
0.1
0.01
c_{hχχ}
XENON100
LUX
SuperCDMS
XENON1T

MASS DIFFERENCES (E.G.)

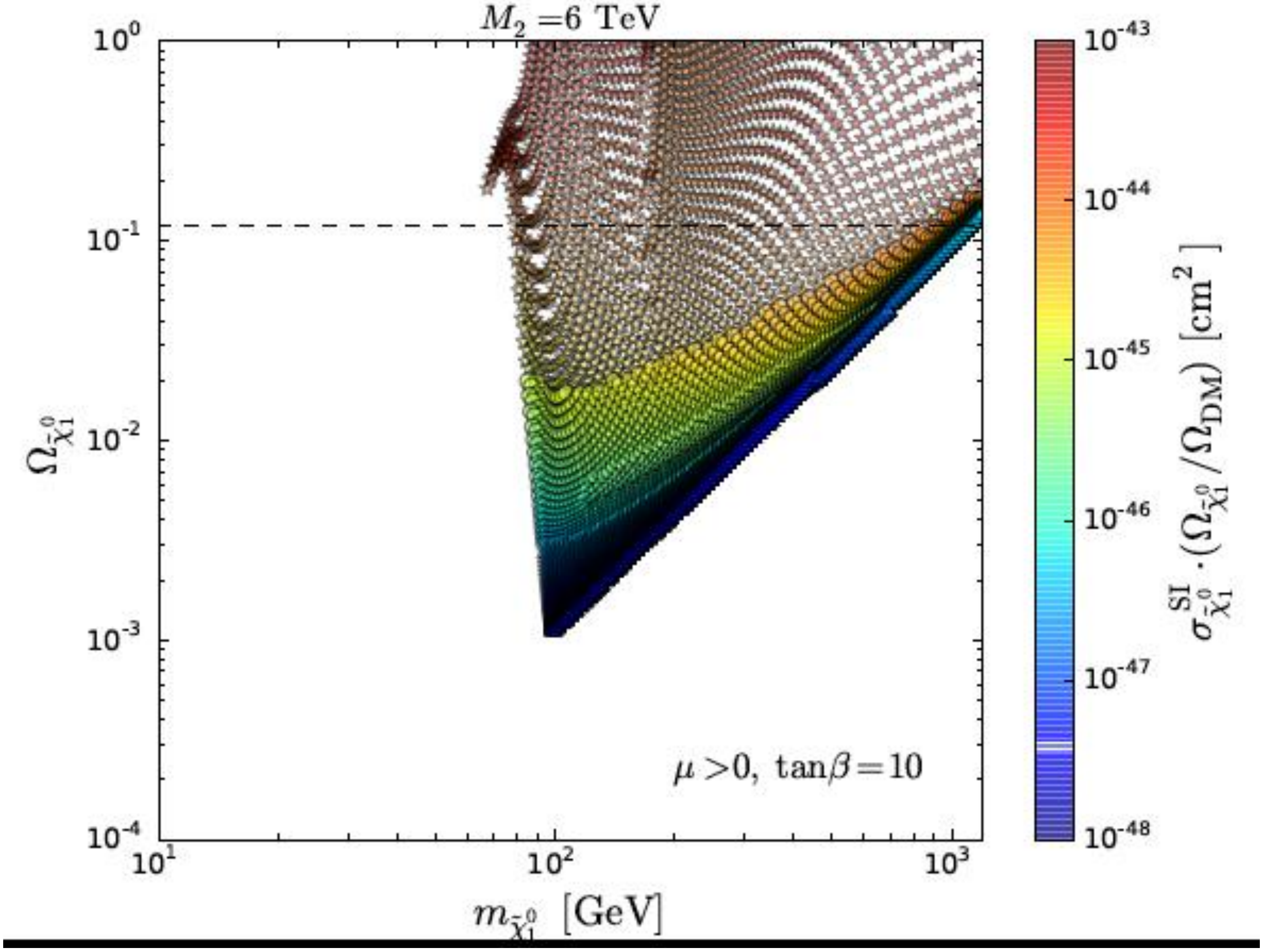
$$|\mu| < |M_1| << |M_2|$$ HIGGSINO-BINO

$$m_{\chi_2^0} - m_{\chi_1^0} \approx 2(m_{\chi_1^+} - m_{\chi_1^0}) \approx \frac{1}{2} M_Z^2 (\frac{cos^2\theta_W}{M_2} + \frac{sin^2\theta_W}{M_1})$$

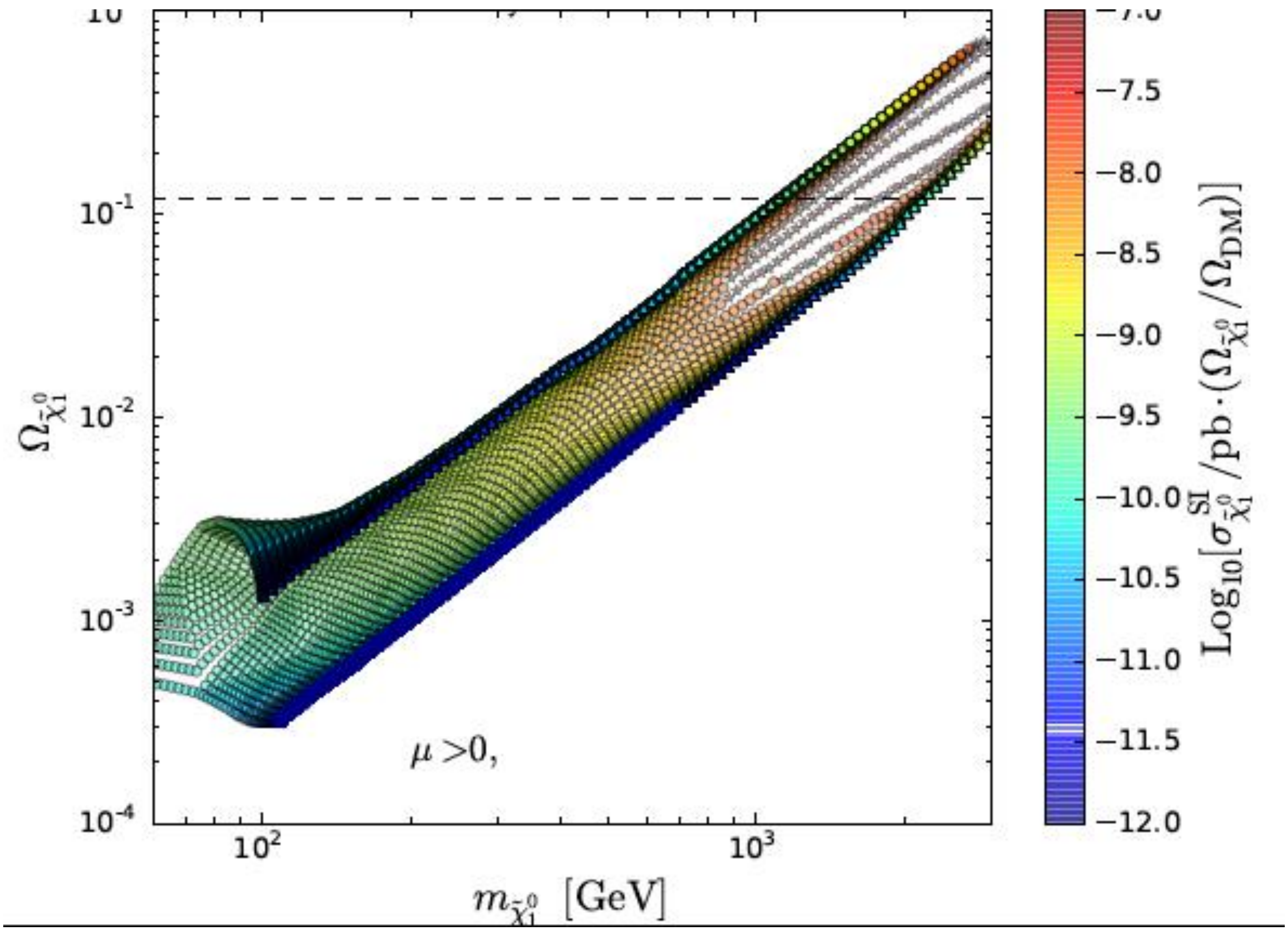
$$|M_2| < |\mu| << M_1$$ HIGGSINO-WINO

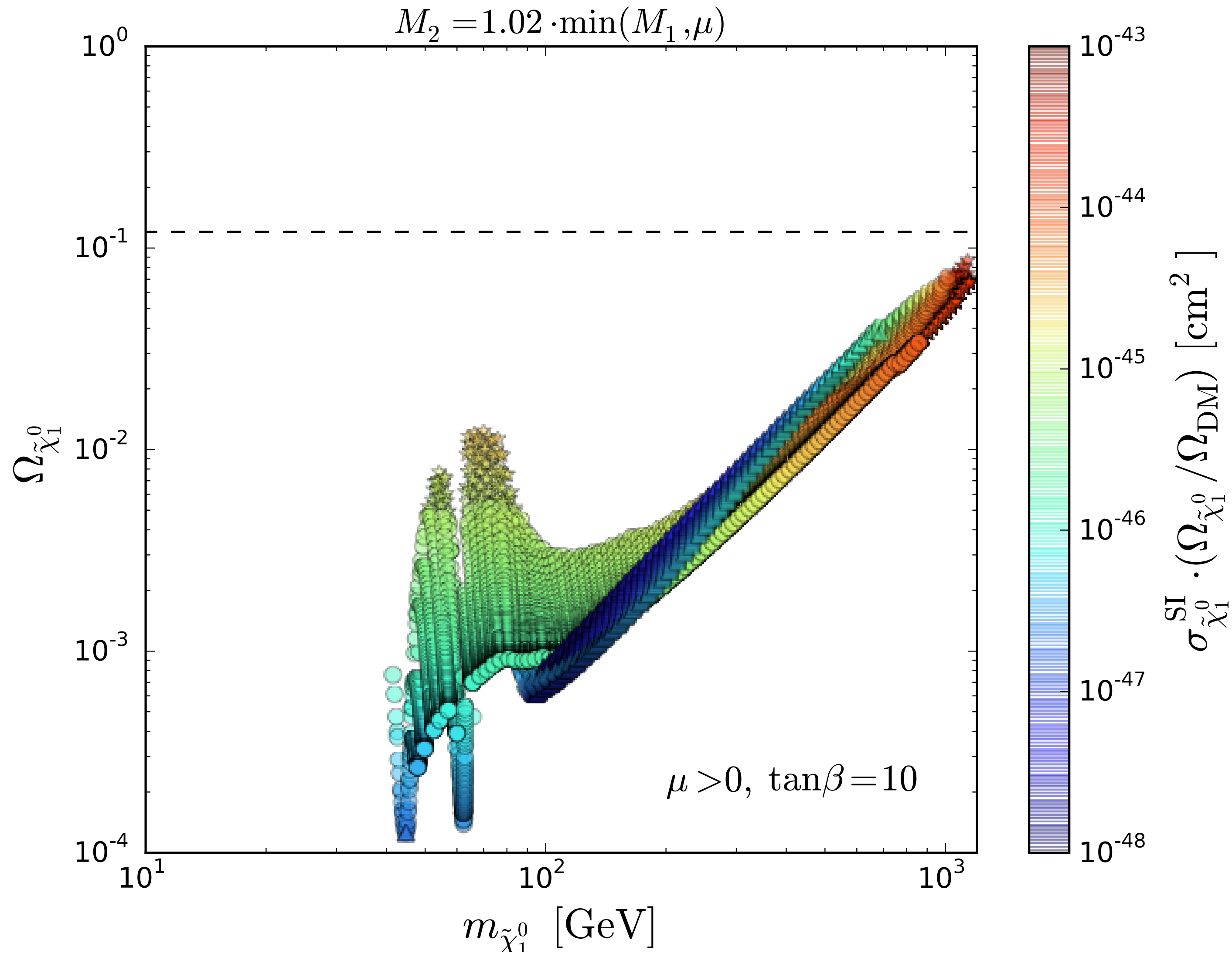
$$m_{\chi_1^+} - m_{\chi_1^0} = \frac{1}{2} \frac{|M_2| M_Z^2}{\mu^4} \cos^4\theta_W cos^2(2\beta)$$

Bino-Higgsino (M2 decoupled)

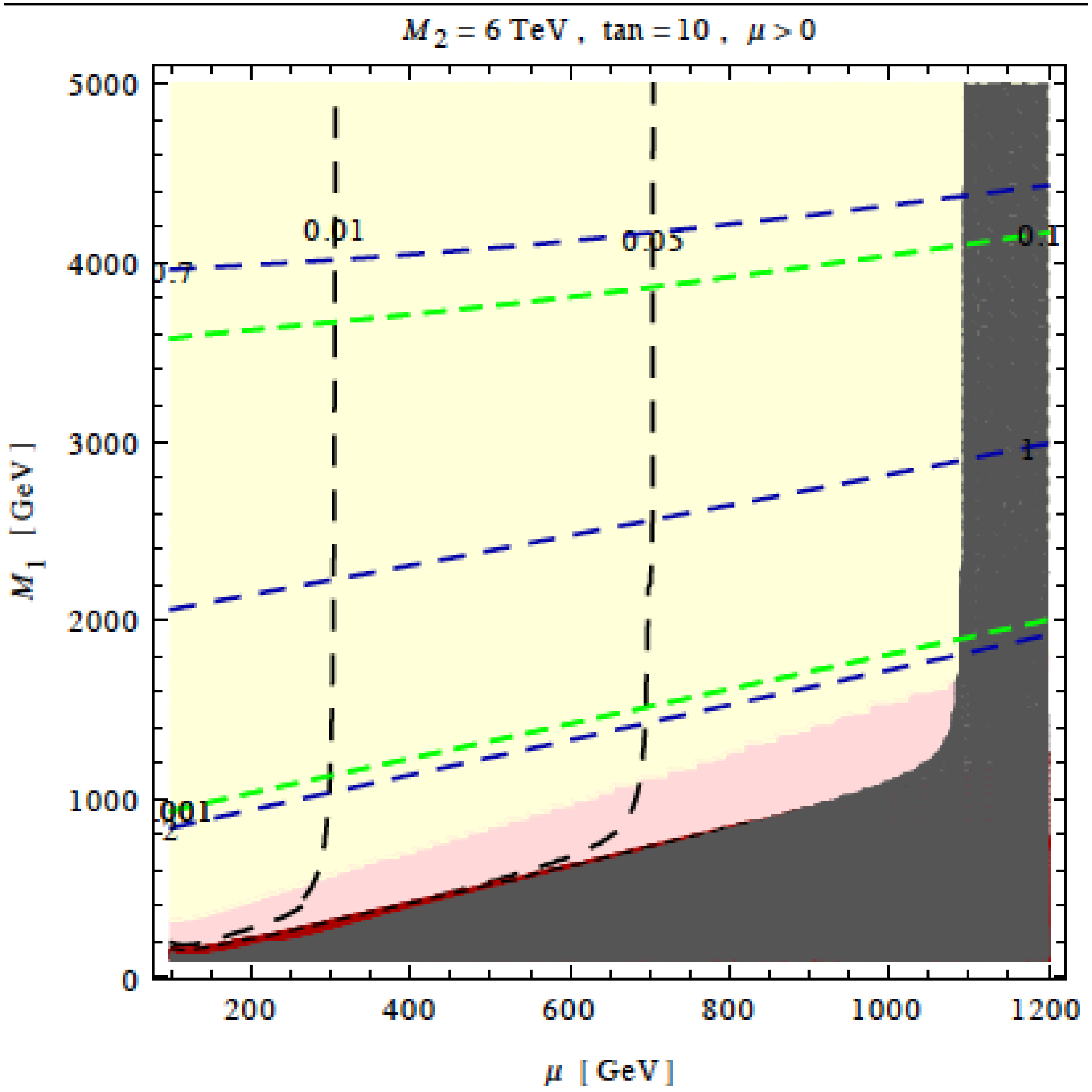


HIGGSINO-WINO (M1 decoupled)

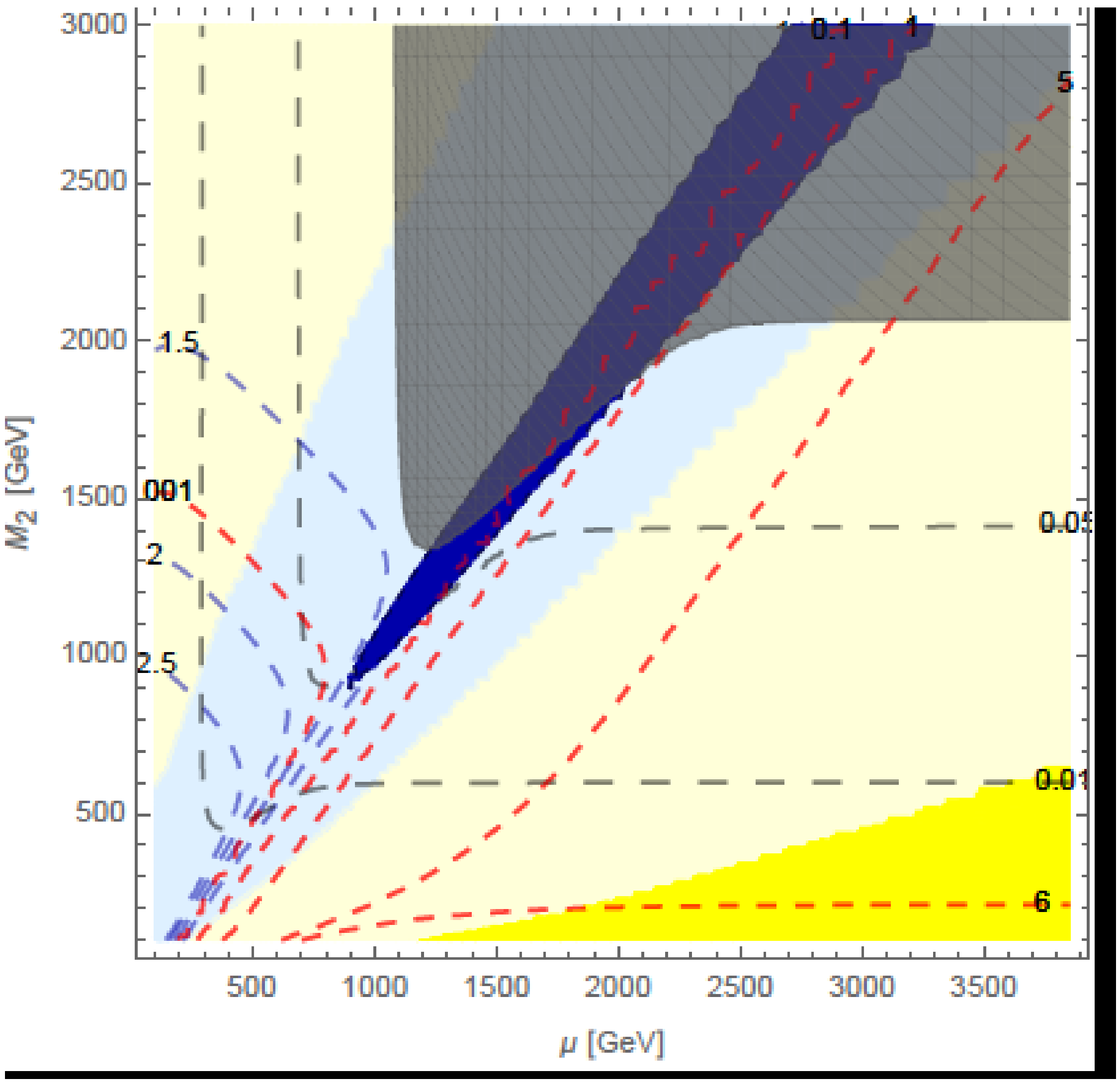



$M_2 = 1.02 \cdot \min(M_1, \mu)$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\Omega_{\tilde{\chi}_1^0}$
10^1
10^2
10^3
$m_{\tilde{\chi}_1^0}$ [GeV]
$\mu > 0,\ \tan\beta = 10$
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
$\sigma^{\rm SI}_{\tilde{\chi}_1^0} \cdot (\Omega_{\tilde{\chi}_1^0}/\Omega_{\rm DM})$ [cm^2]

Bino-higgsino



Higgsino-wino



VAST PARAMETER REGION CORRESPONDS TO $\Omega h^2 < 0.12$

ONLY VERY SPECIAL CONFIGURATIONS GIVE $\Omega h^2 = 0.12$

Reaching pure wino or higgsino states is very slow; non-decoupling effects are clearly visible, at least up to O(10 TeV) of the „decoupled” parameter; the limits are reached for large splitings of the parameters

POSITIVE: spin independent scattering remains sizeable, usually above the neutrino background

NEGATIVE: mass differences often in the most difficult range O(1 TeV) for collider searchers

Nevertheless, general correlation: the smaller the spin independent cross section the smaller the mass differences and longer life times of the NLPS

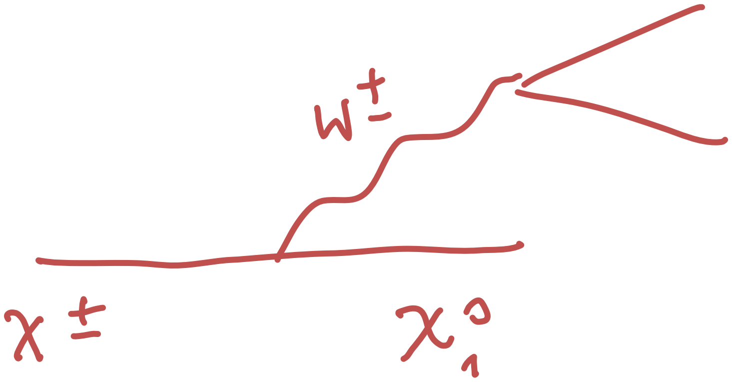
Collider

Drell-Yan production of a pair of gauginos + a hard jet

$\chi_1^+ \chi_1^-$, $\chi_2^0 \chi_1^0$, $\chi_1^+ \chi_1^0$, $\chi_2^0 \chi_1^+$ etc

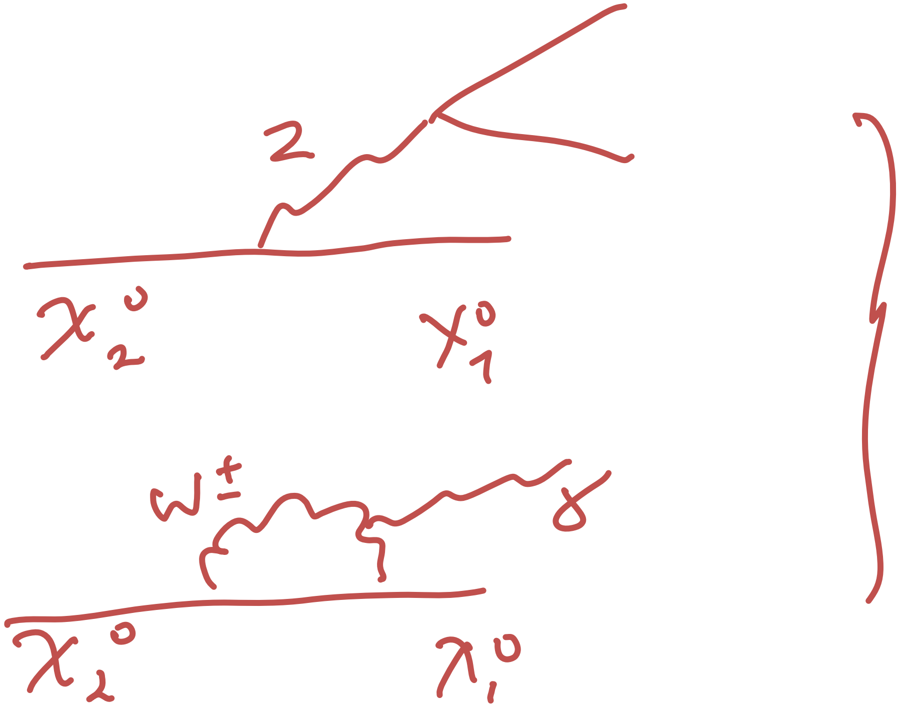
$pp \to \text{jet}\ \cancel{E}_T + X$

depends on mass differences



$$\Delta m = \chi^\pm_1 - \chi^0_1$$

(+ boost)



$$\Delta m = \chi^0_2 - \chi^0_1$$

Final states

$pp \to j \, \not{p}_\perp$ monojets

$pp \to j \, \not{p}_\perp \, \ell \, \nu$

$pp \to j \, \not{p}_\perp \, \ell^+ \ell^-$

$pp \to j \, \not{p}_\perp \, \ell \, \gamma$

$\vdots$

Mass differences for $\Omega h^2 \leq 0.12$

$\Delta m = 20 - 40$ GeV (rare) soft Leptons

$\Delta m \sim O(1$ GeV$)$ (most frequent, most difficult)

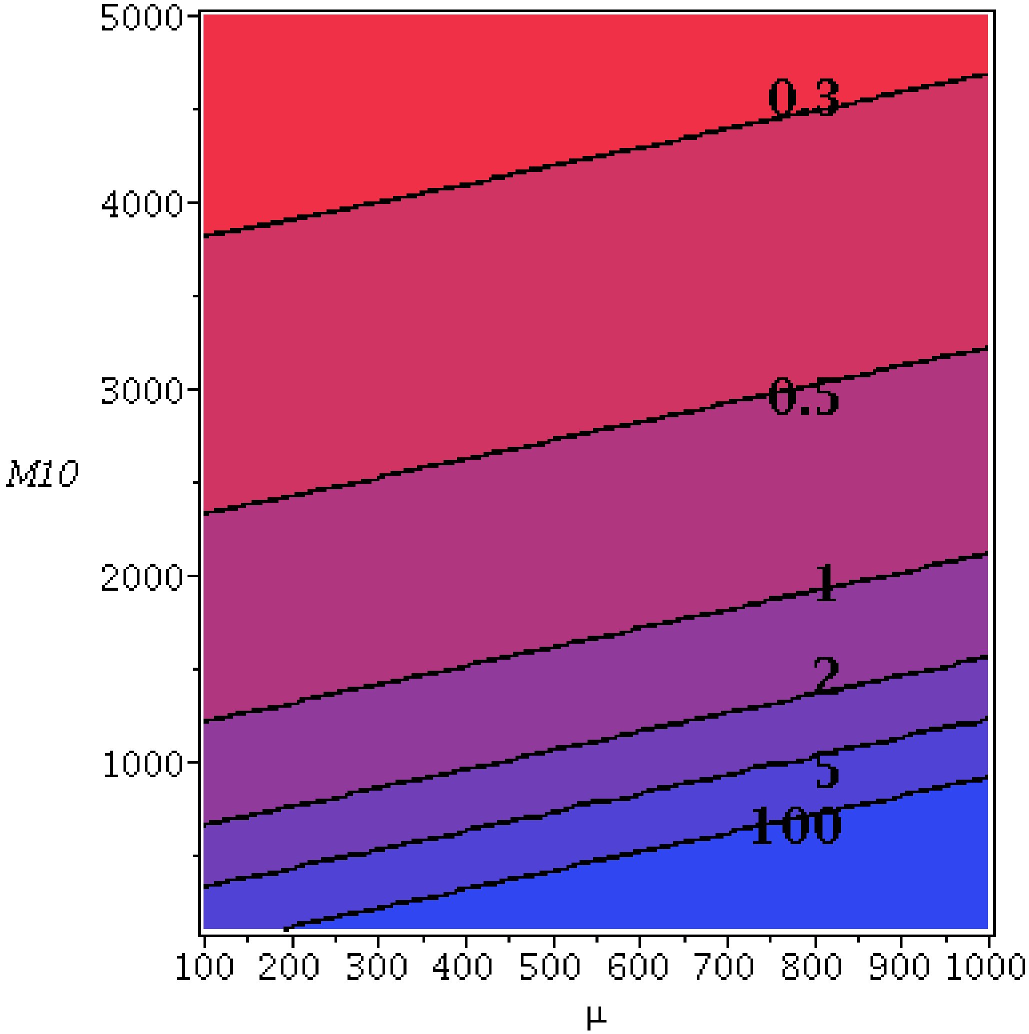
$pp \to j \not{E}_T \, l^\pm \gamma$ promising

$\Delta m \sim O(200 - 300$ MeV$)$ (disappearing tracks)

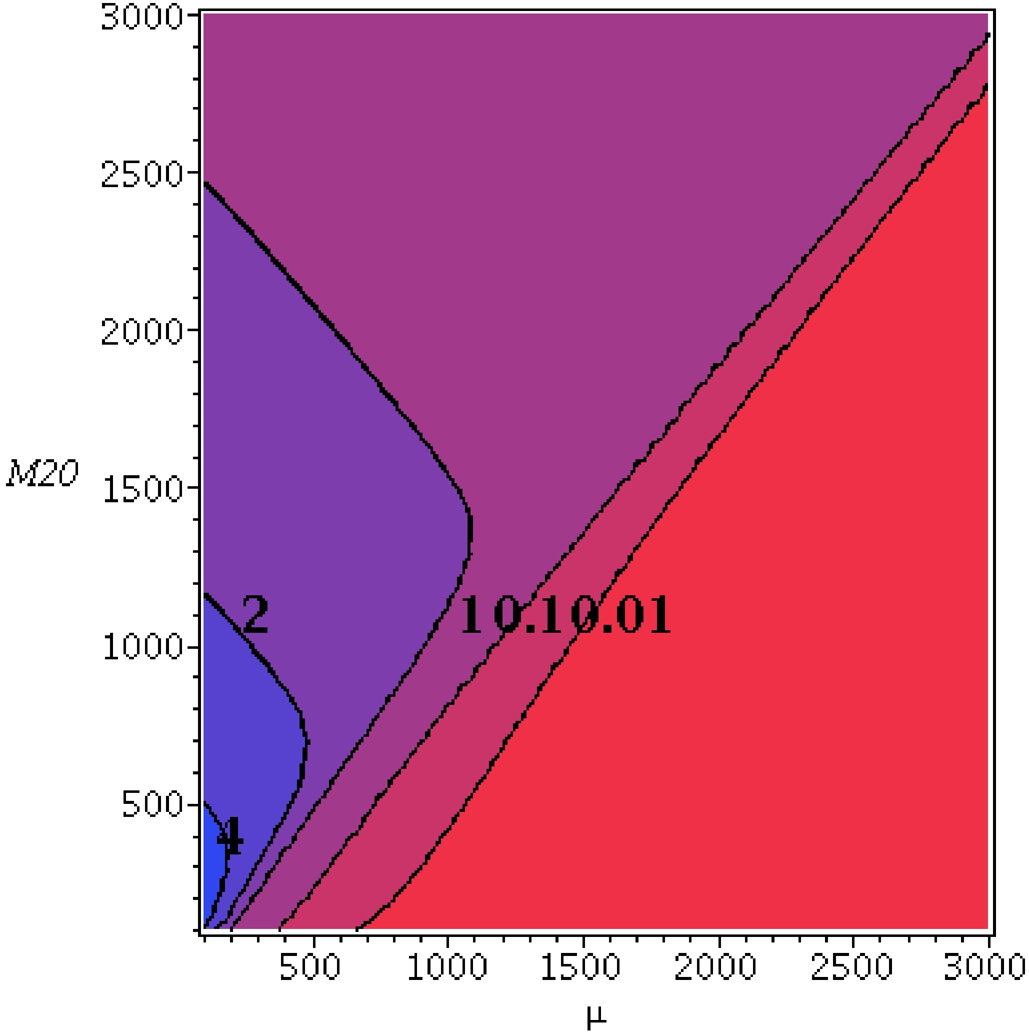
CONCLUSIONS

COMPLEMENTARITY OF DIRECT DETECTION AND COLLIDER EXPERIMENTS WILL EVENTUALLY TEST THE ELECTROWEAKINO SUPERSYMMETRIC SECTOR BUT ONLY A SMALL PART OF IT WILL BE TESTED AT THE LHC

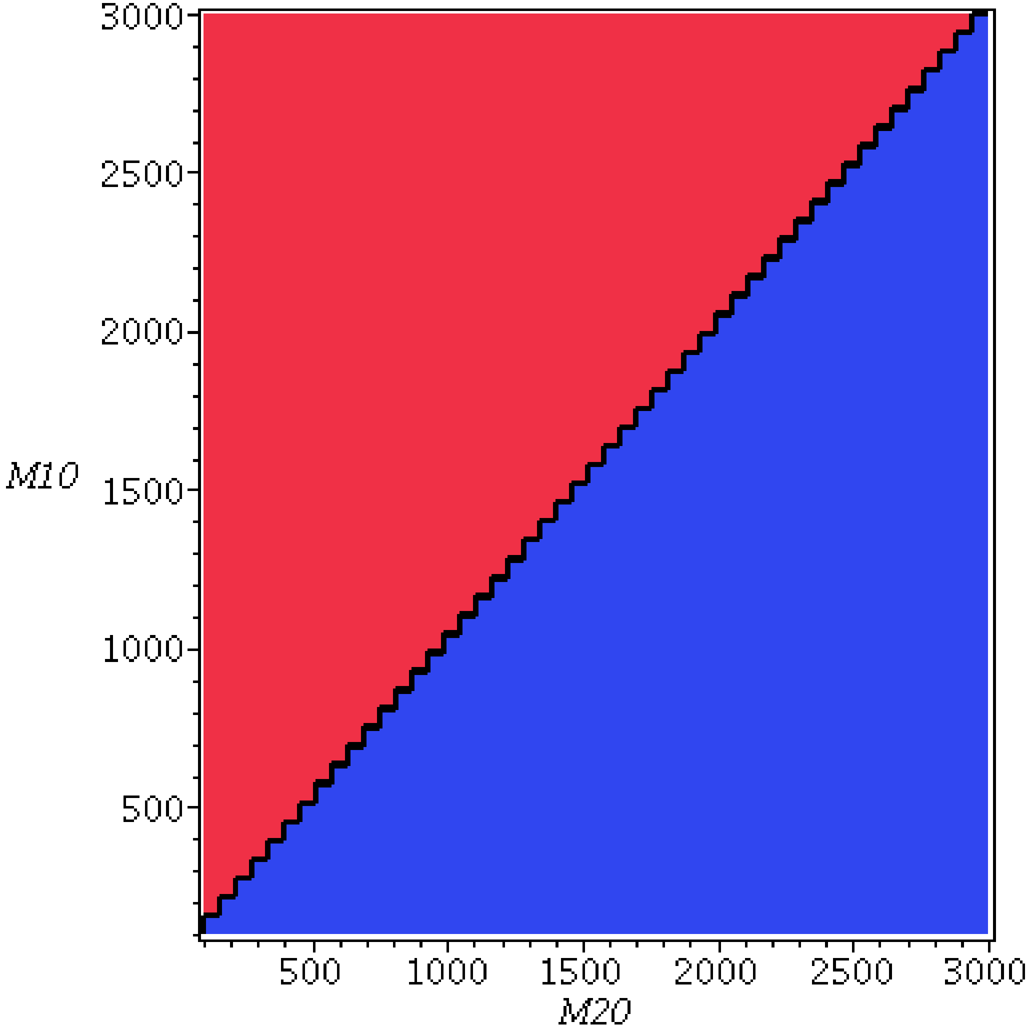
BACKUP



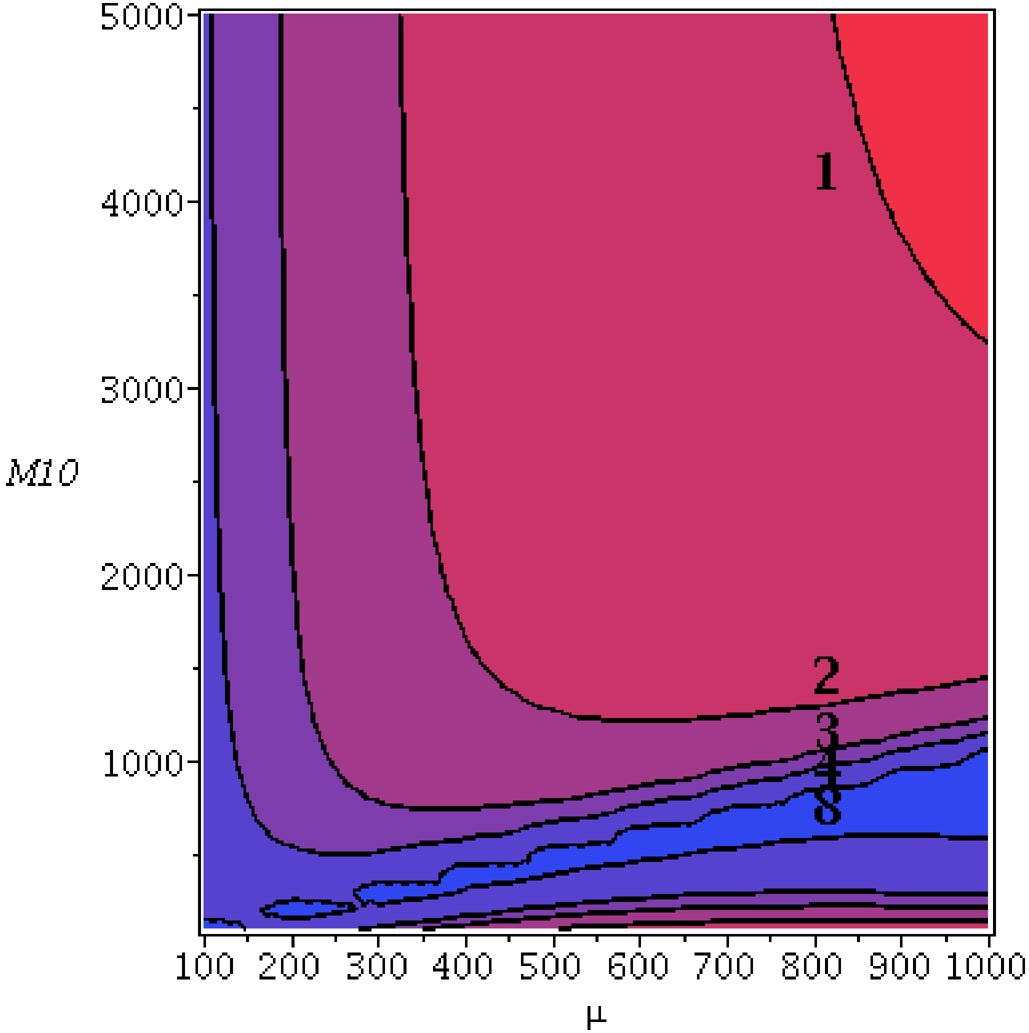
M2 decoupled



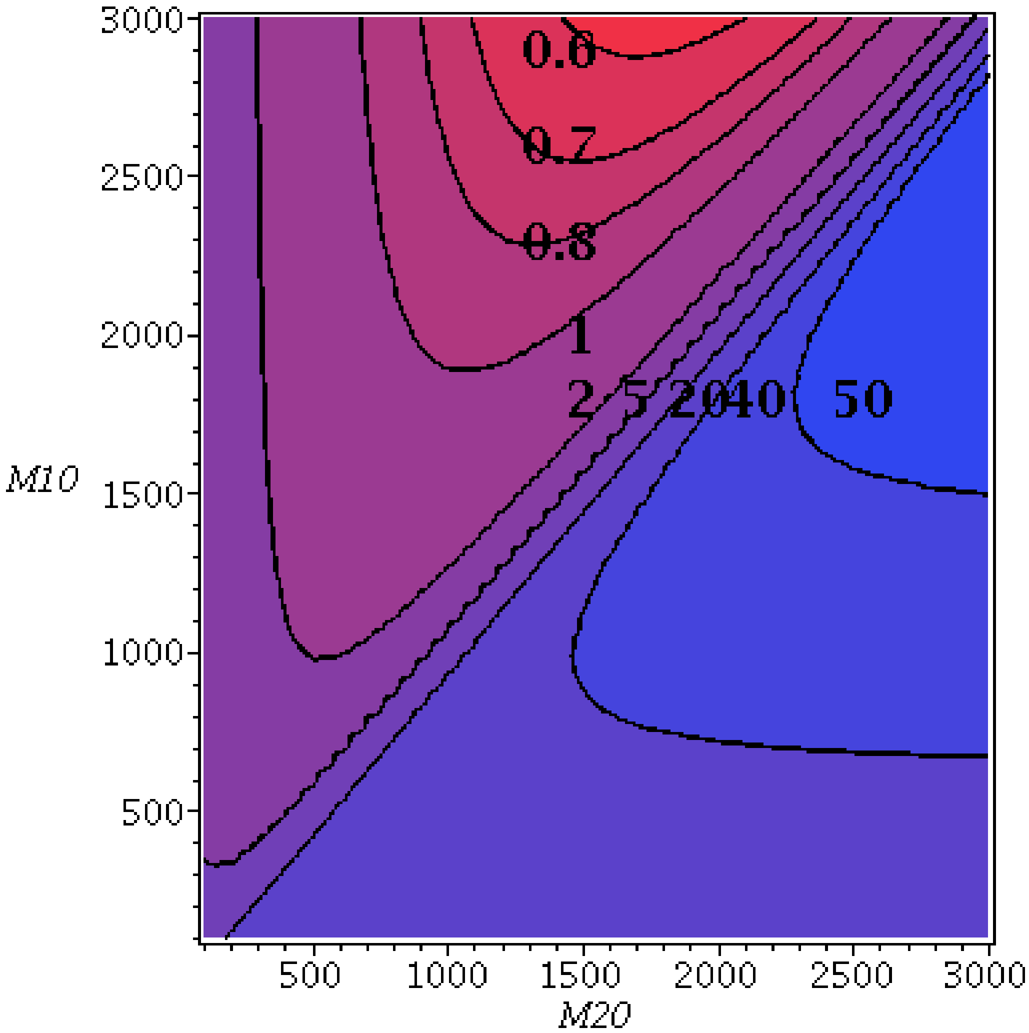
M1 decoupled



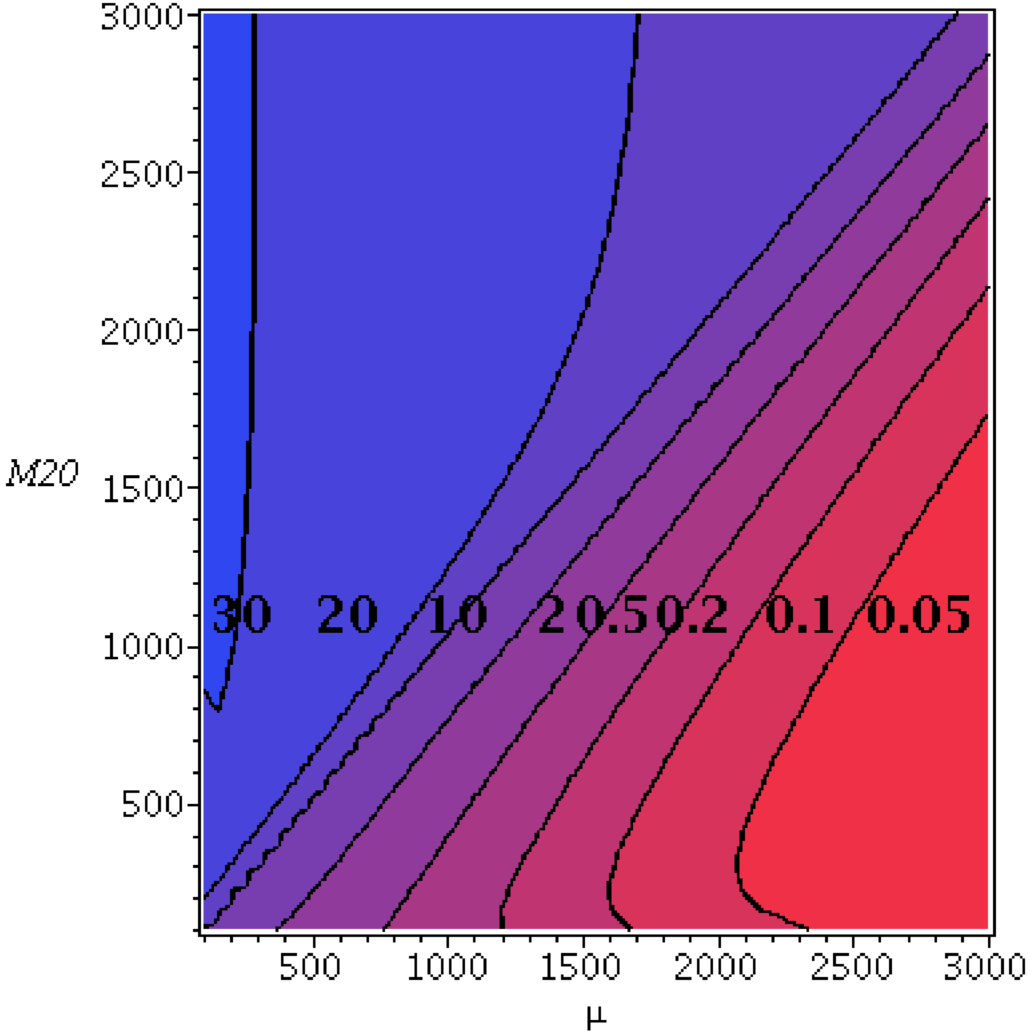
Mu decoupled


5000
4000
3000
2000
1000
M10
100
200
300
400
500
600
700
800
900
1000
μ
1
2
3
4
8

$$M_2 = min(M_1, \mu)$$

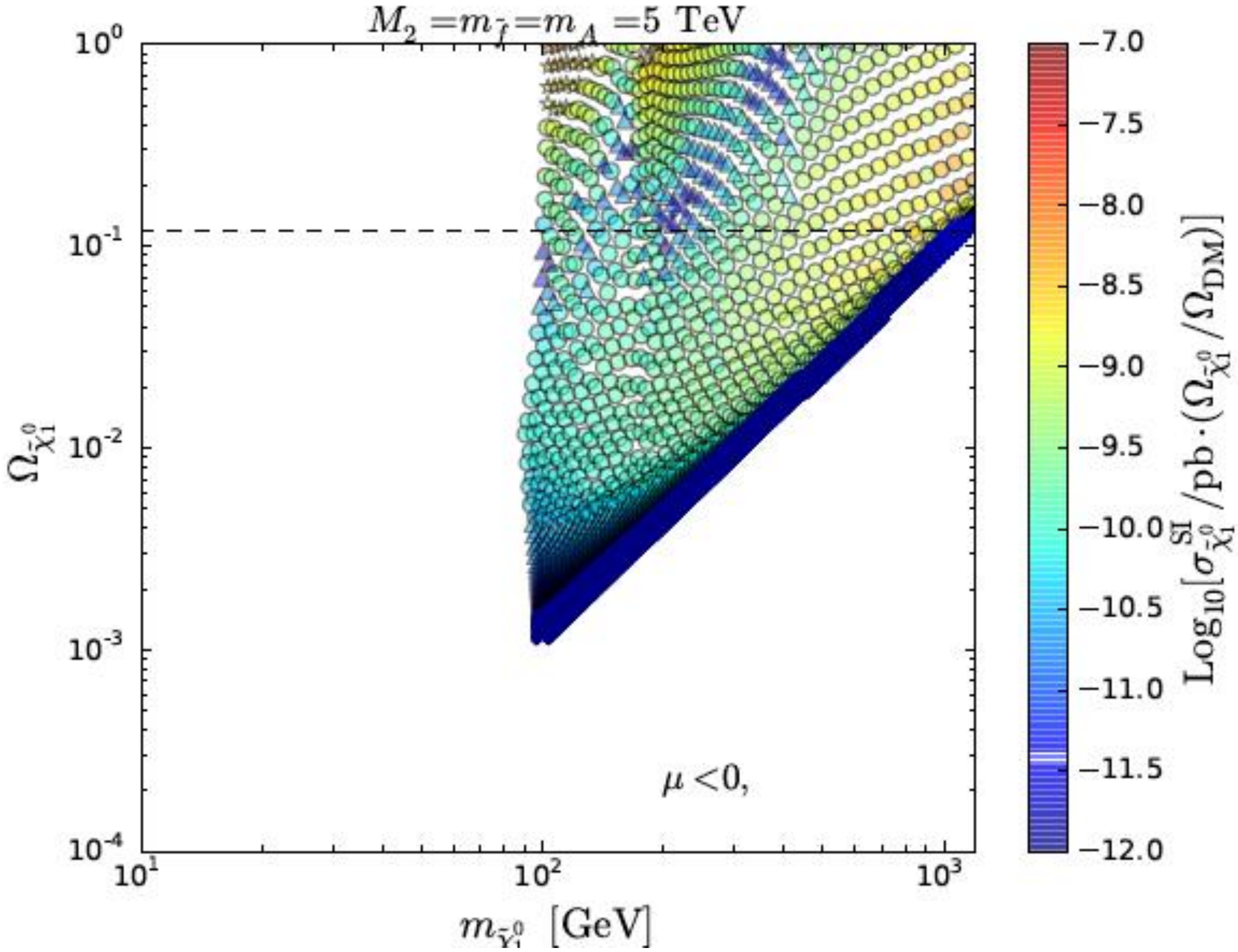

3000
2500
2000
1500
1000
500
M10
500
1000
1500
2000
2500
3000
M20
0.6
0.7
0.8
1
2
5
20
40
50

$$\mu = min(M_1, M_2)$$


M20
3000
2500
2000
1500
1000
500
500
1000
1500
2000
2500
3000
μ
30
20
10
2
0.5
0.2
0.1
0.05

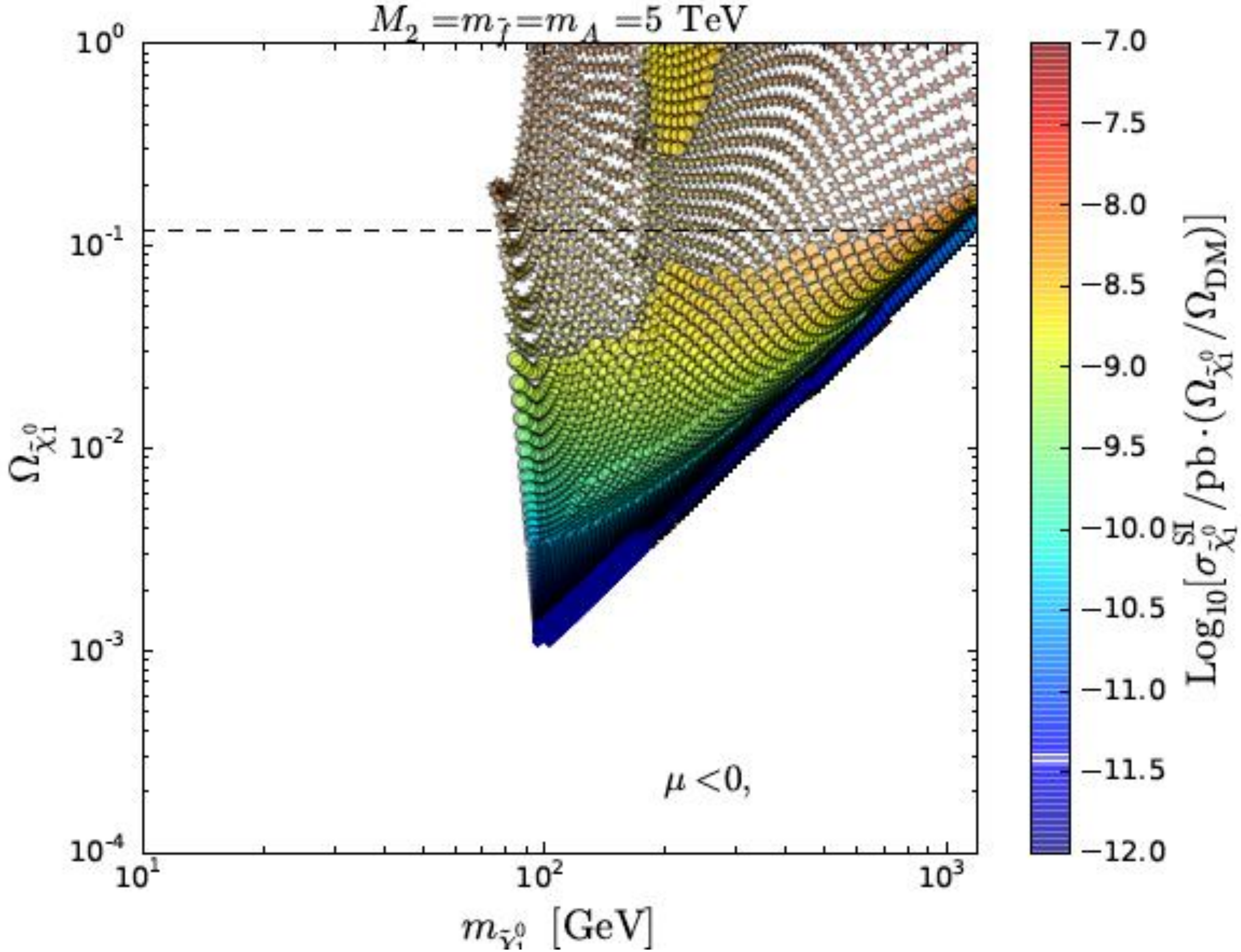
$$M_1 = min(M_2, \mu)$$

$\tan\beta = 2$

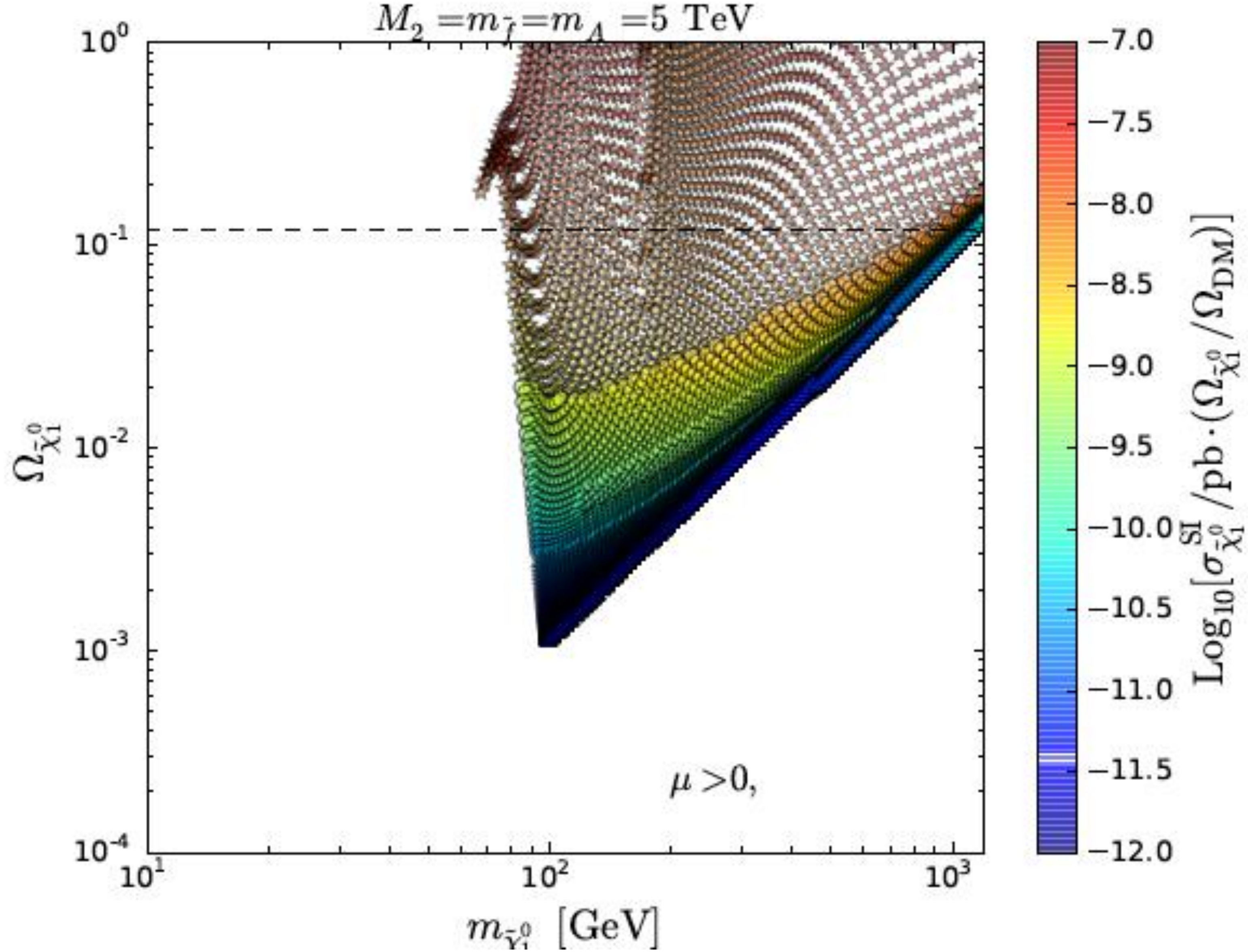


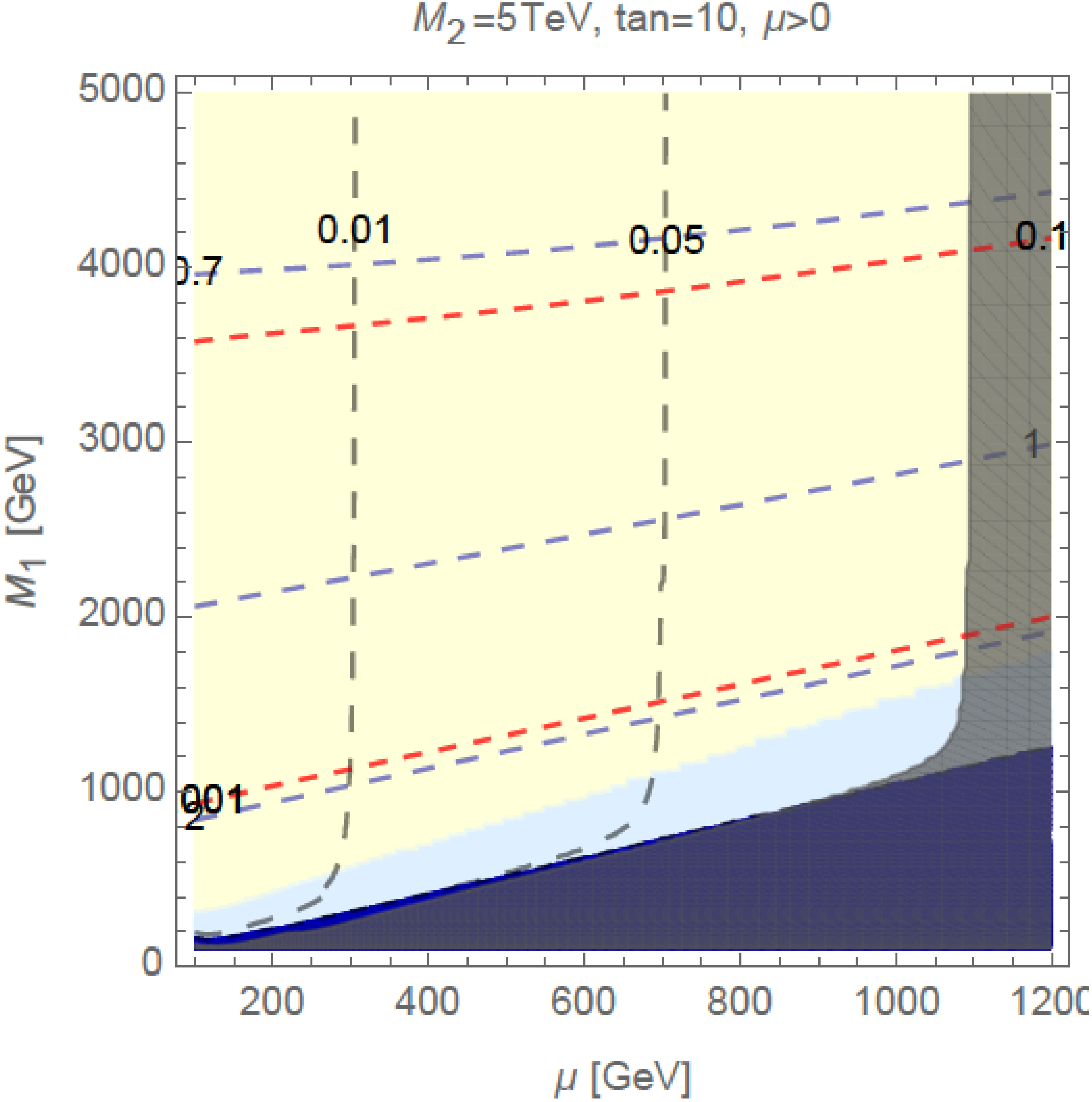
$M_2 = m_{\tilde{f}} = m_A = 5$ TeV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\Omega_{\tilde{\chi}_1^0}$
10^1
10^2
10^3
$m_{\tilde{\chi}_1^0}$ [GeV]
$\mu < 0,$
−7.0
−7.5
−8.0
−8.5
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
$\mathrm{Log}_{10}[\sigma^{\mathrm{SI}}_{\tilde{\chi}_1^0}/\mathrm{pb}\cdot(\Omega_{\tilde{\chi}_1^0}/\Omega_{\mathrm{DM}})]$

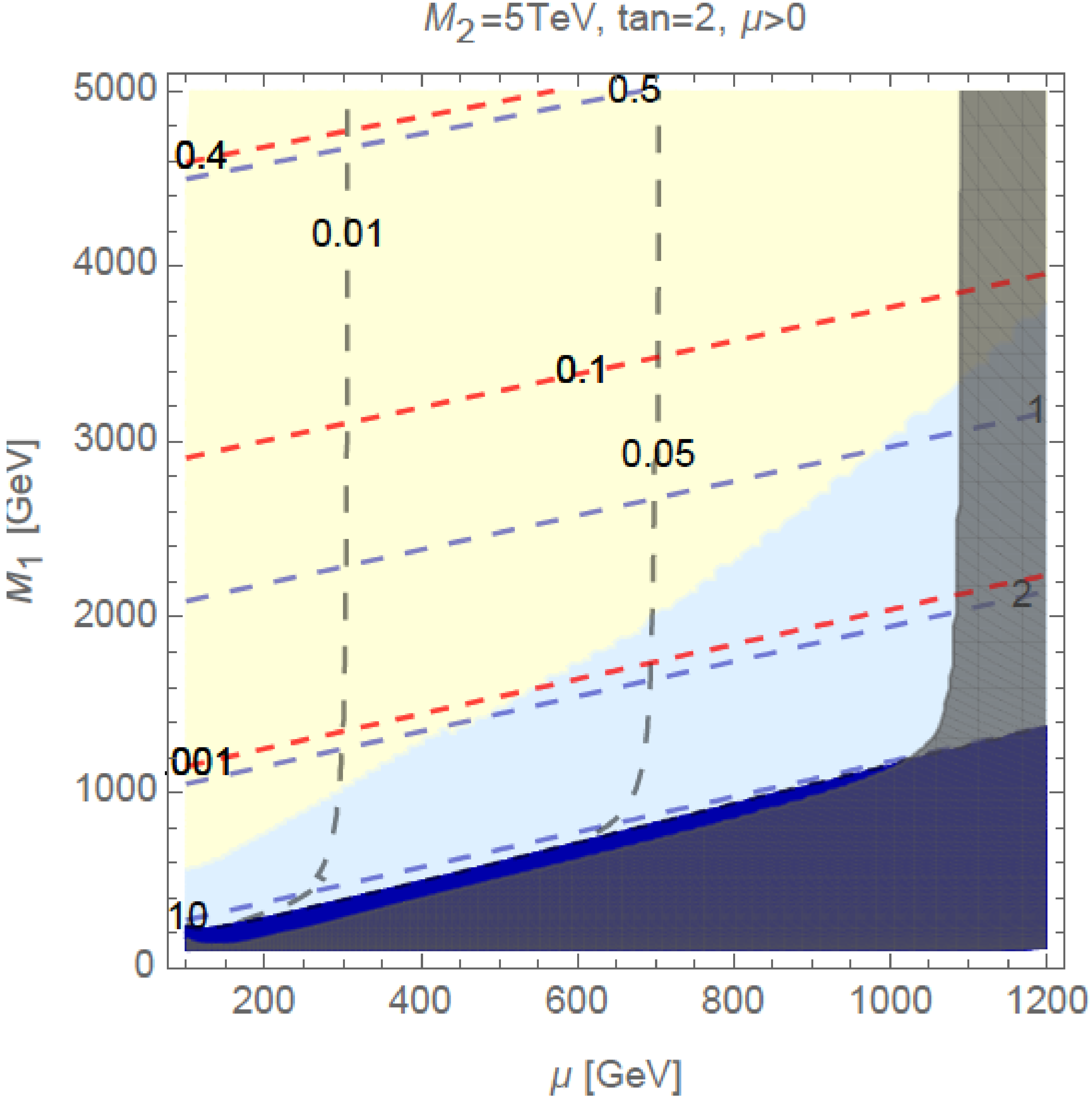
$\tan\beta = 10$


$M_2 = m_{\tilde{l}} = m_A = 5$ TeV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\Omega_{\tilde{\chi}_1^0}$
10^1
10^2
10^3
$m_{\tilde{\chi}_1^0}$ [GeV]
$\mu < 0,$
−7.0
−7.5
−8.0
−8.5
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
$\mathrm{Log}_{10}[\sigma^{\mathrm{SI}}_{\tilde{\chi}_1^0}/\mathrm{pb}\cdot(\Omega_{\tilde{\chi}_1^0}/\Omega_{\mathrm{DM}})]$

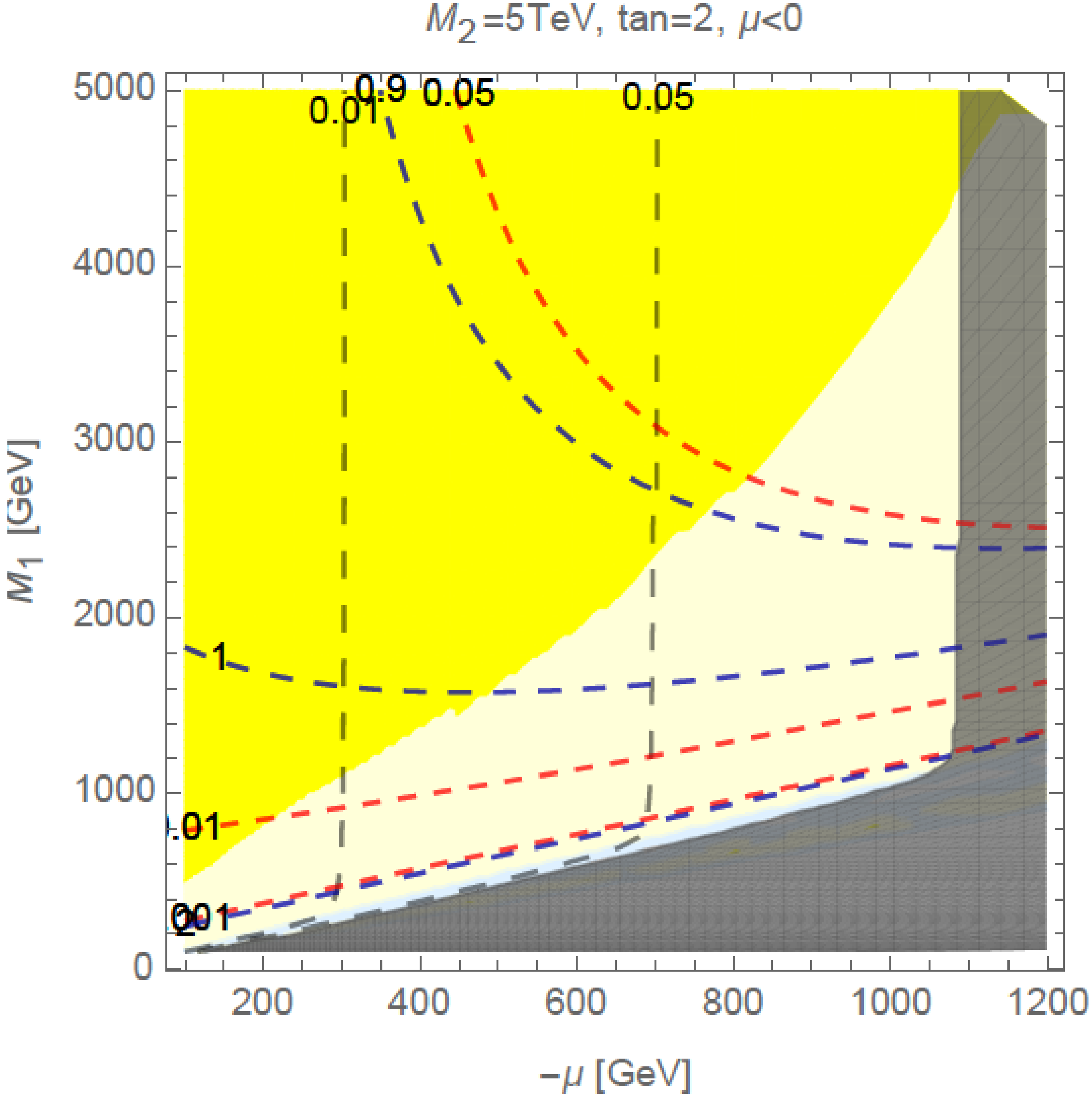
$\tan\beta = 10$


$M_2 = m_{\tilde{f}} = m_A = 5$ TeV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\Omega_{\tilde{\chi}_1^0}$
10^1
10^2
10^3
$m_{\tilde{\chi}_1^0}$ [GeV]
$\mu > 0$,
−7.0
−7.5
−8.0
−8.5
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
$\mathrm{Log}_{10}[\sigma^{\mathrm{SI}}_{\tilde{\chi}_1^0}/\mathrm{pb}\cdot(\Omega_{\tilde{\chi}_1^0}/\Omega_{\mathrm{DM}})]$


M_2=5TeV, tan=10, μ>0
5000
4000
3000
2000
1000
0
M_1 [GeV]
200
400
600
800
1000
1200
μ [GeV]
0.01
0.05
0.1
).7
1
001
2



M_2=5TeV, tan=2, μ>0
0.5
0.4
0.01
0.1
0.05
1
2
.001
10
5000
4000
3000
2000
1000
0
200
400
600
800
1000
1200
M_1 [GeV]
μ [GeV]


M_2=5TeV, tan=2, μ<0
M_1 [GeV]
$-\mu$ [GeV]
0
1000
2000
3000
4000
5000
200
400
600
800
1000
1200
0.01
0.9
0.05
0.05
1
.01
001
20