Gravitino Dark Matter and Related Issues

The CMSSM after WMAP

Detectability

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

The VCMSSM (mSUGRA)

Gravitino Dark Matter

BBN limits - Li problem

with: Ellis, Santoso, Spanos

Boundary conditions

- Input parameters: μ, m_1, m_2, B. predict M_Z, $\tan\beta$, m_A

  (in addition to m_0, $m_{1/2}$, and A_0)

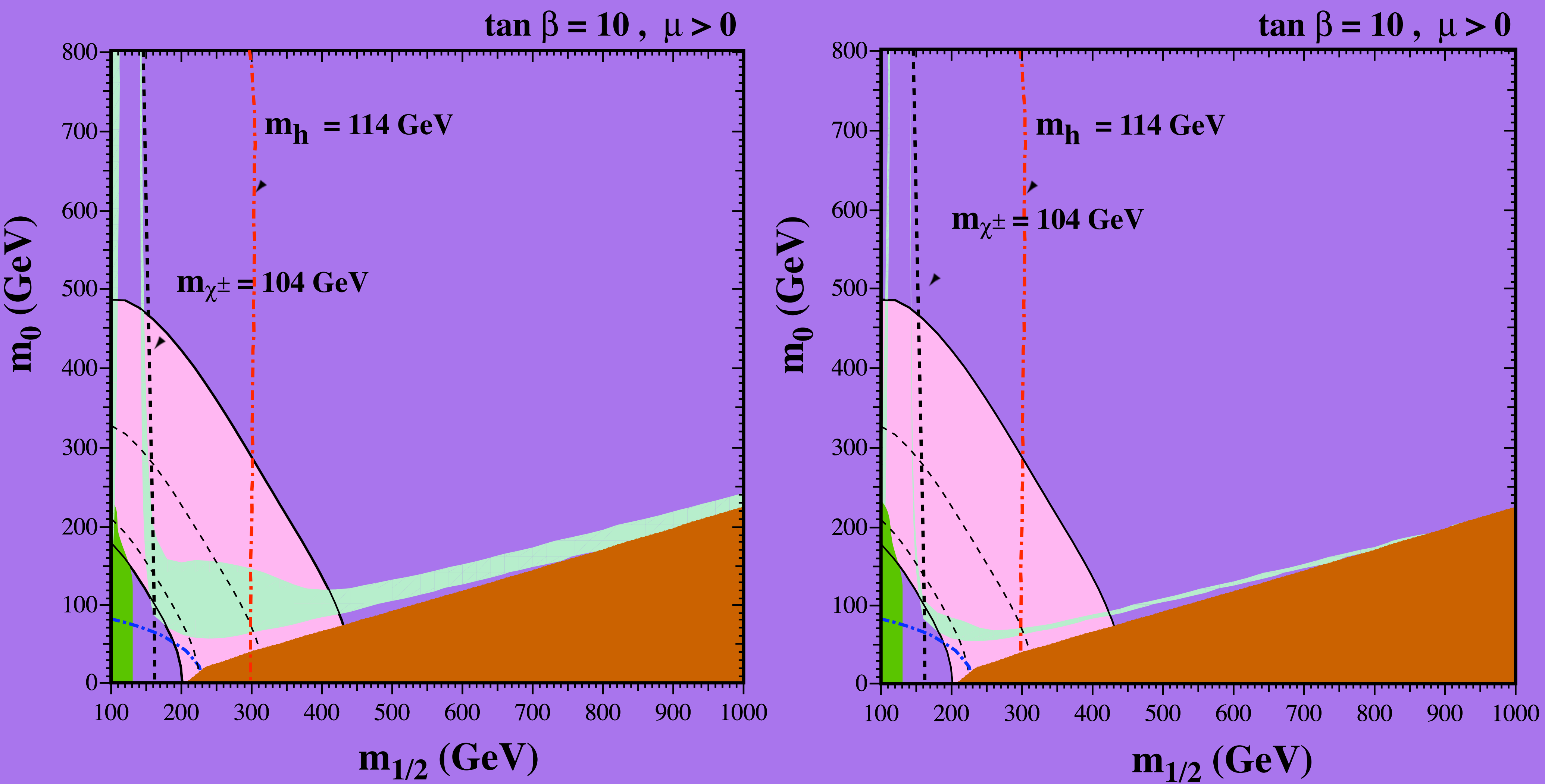
CMSSM conditions

- Instead CMSSM:

  Input parameters: M_Z, m_1, m_2, $\tan\beta$ ($m_1 = m_2 = m_0$)

  predict μ, B, m_A

Effect of WMAP Densities

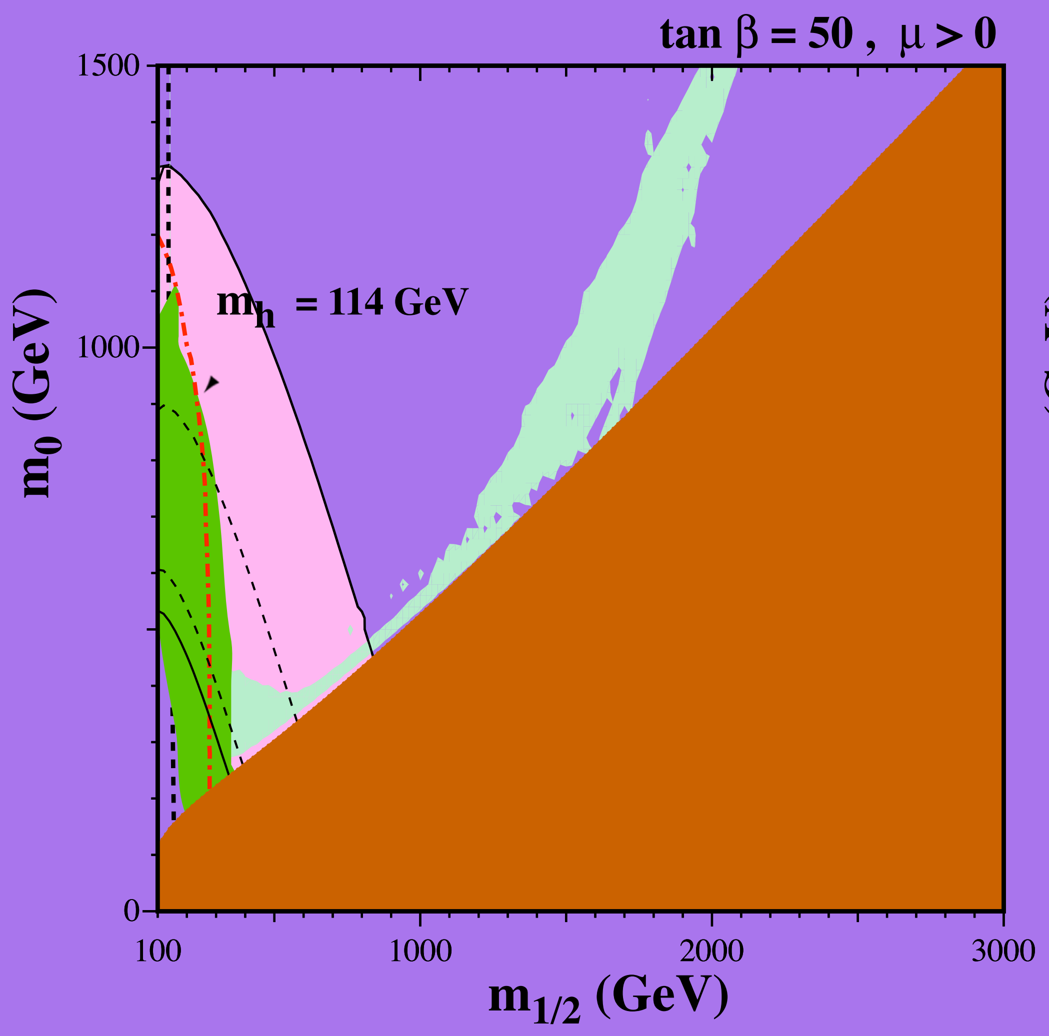


$\Omega h^2 = 0.1 - 0.3$ $\Omega h^2 = 0.09 - 0.13$

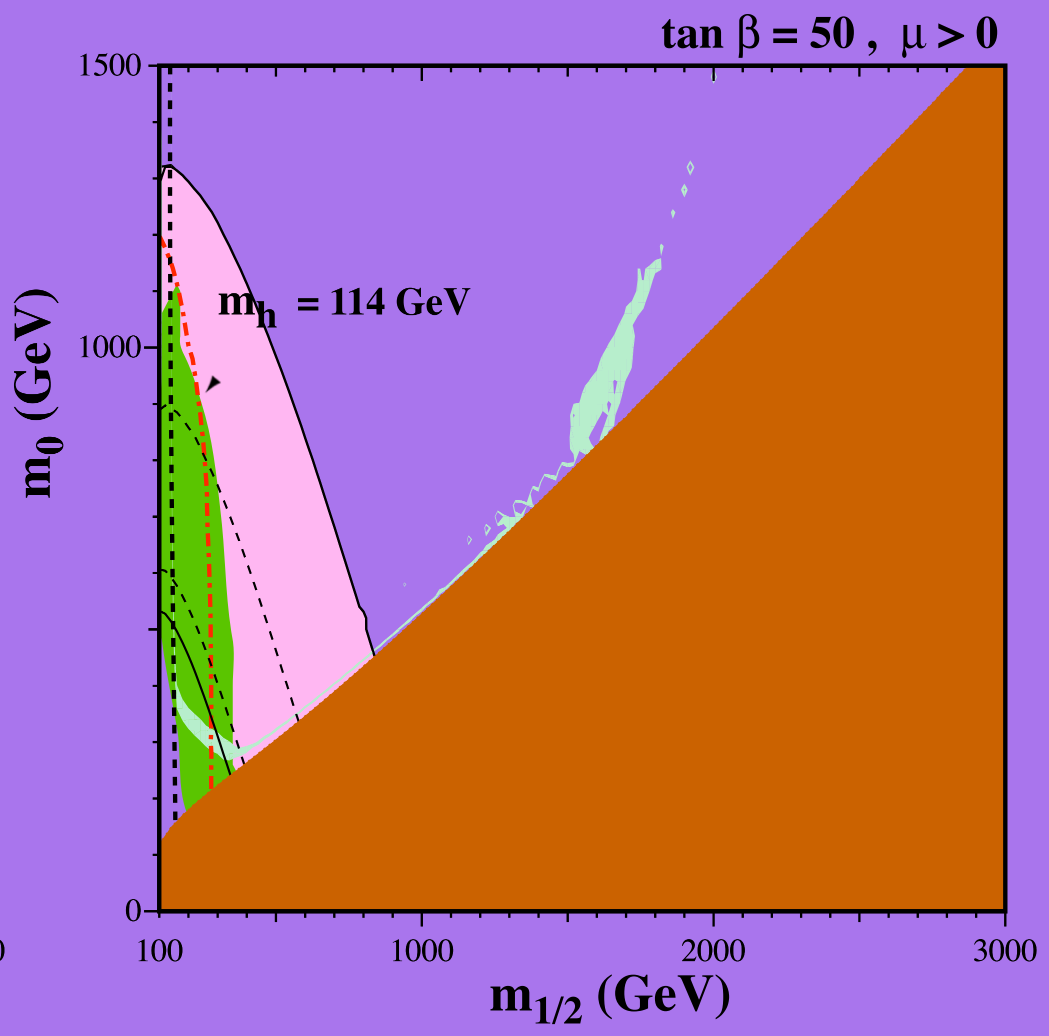
$m_\chi \approx 0.4\, m_{1/2}$

Ellis, Olive, Santoso, Spanos

Effect of WMAP Densities



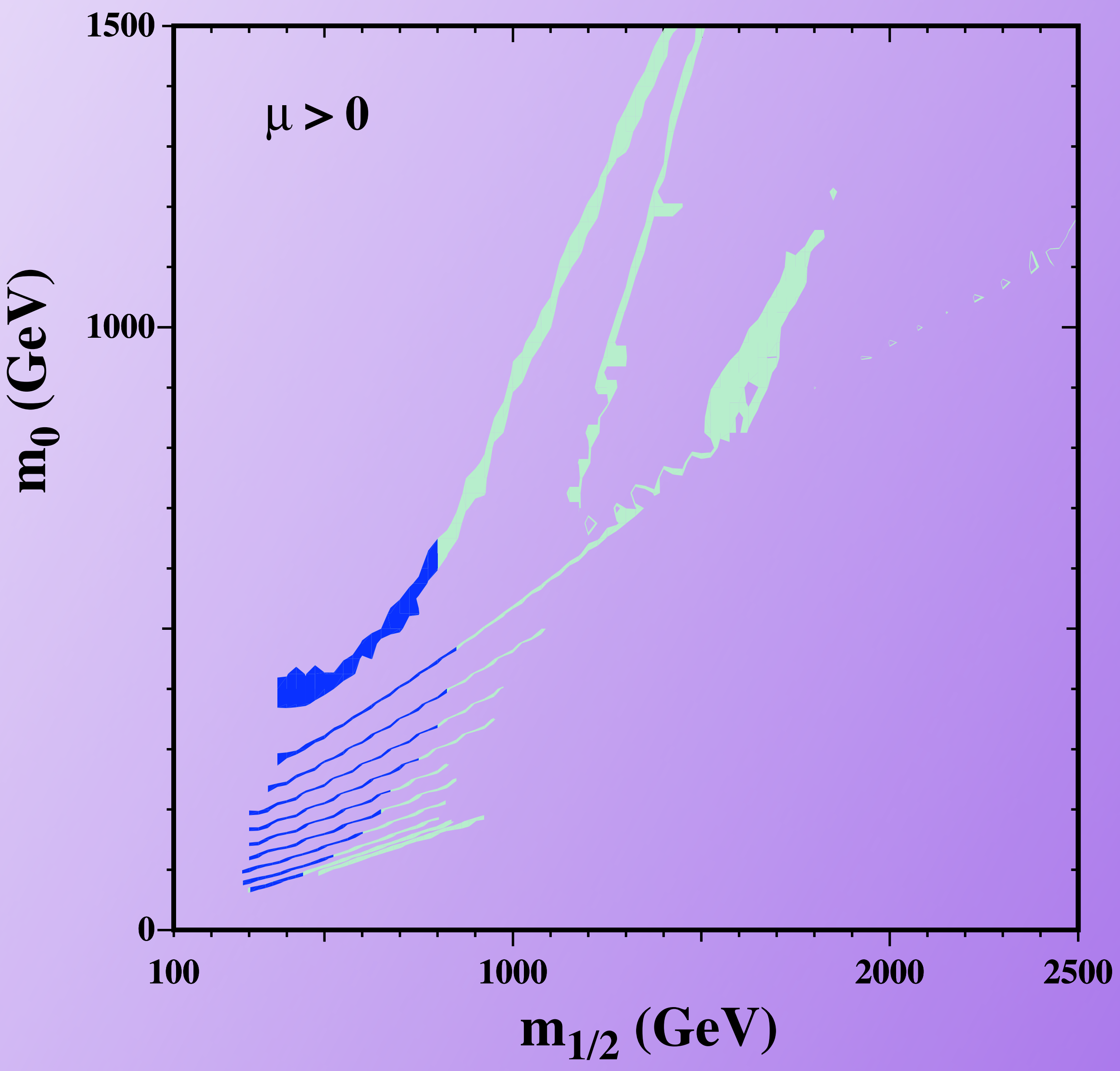
$\Omega\, h^2 = 0.1 - 0.3$



$\Omega\, h^2 = 0.09 - 0.13$

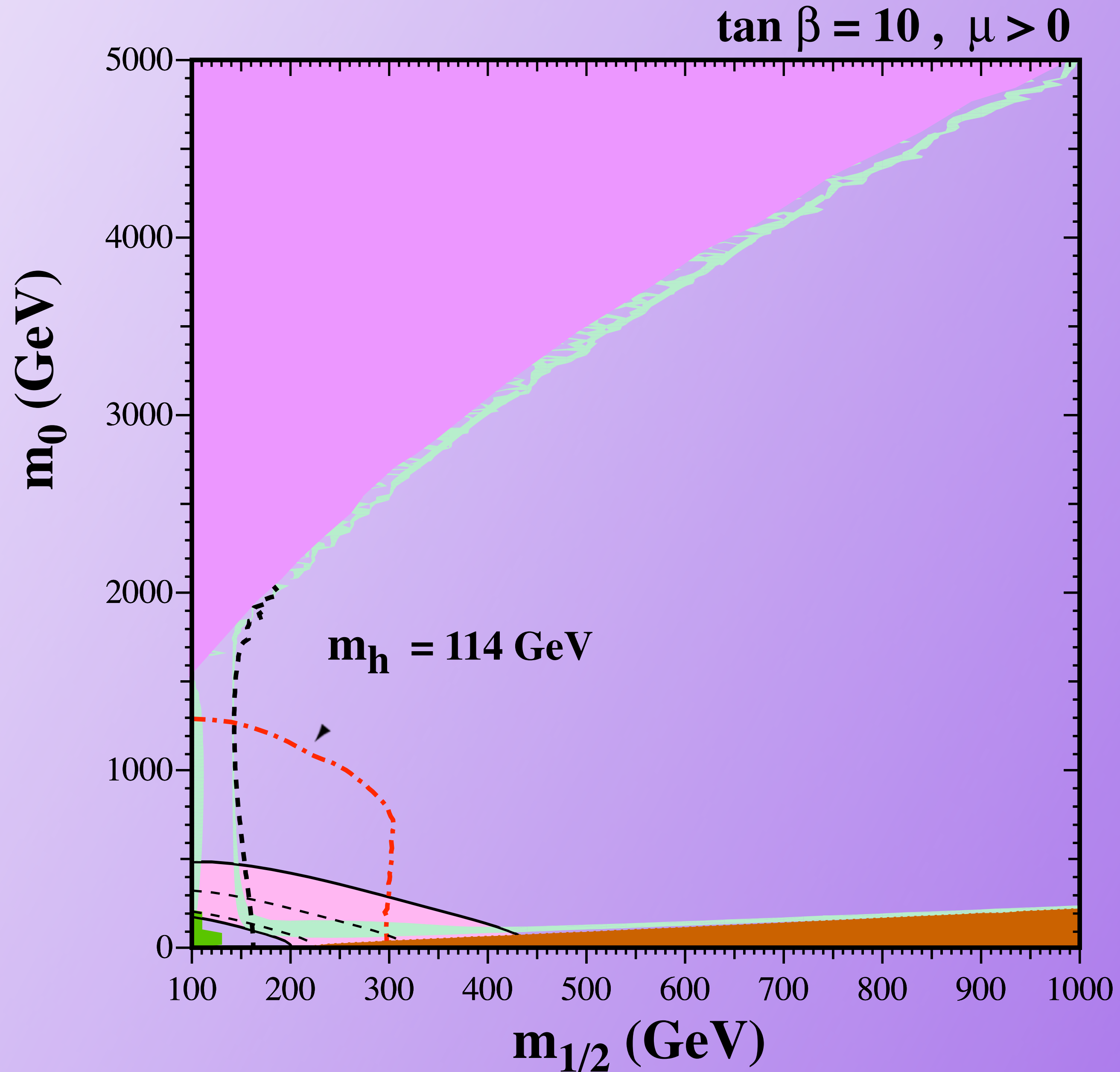
Ellis, Olive, Santoso, Spanos

Foliation in tan β



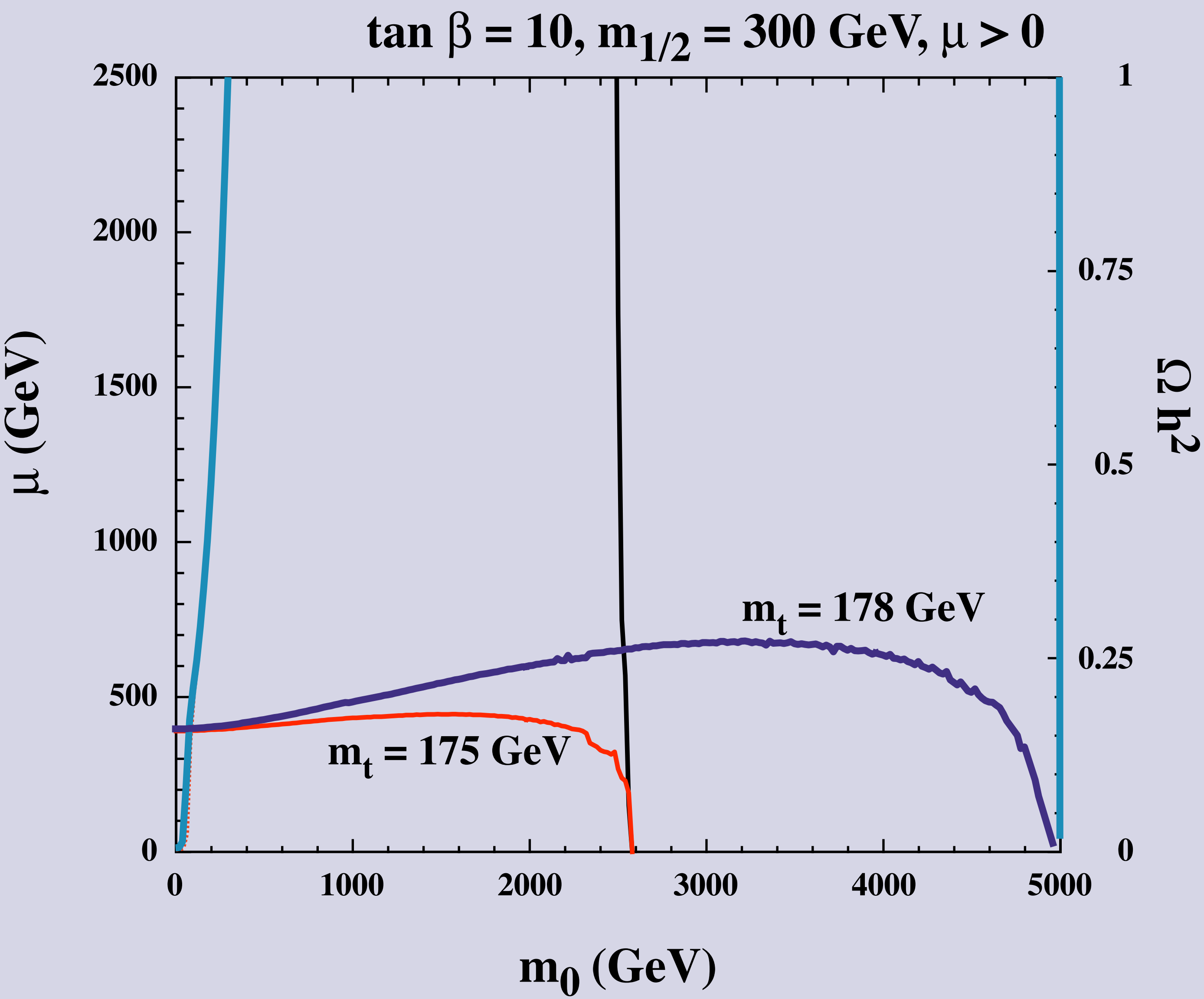
Focus Point Region

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

Large shift in focus point when $m_t = 178$ GeV



Likelihood Analysis of the CMSSM parameter space

Ellis, KAO, Santoso, Spanos

Includes

- Likelihood for the direct LEP Higgs Search

  hep-ex/0306033

  - + Global fit to precision electroweak data

- Likelihood for b to s γ

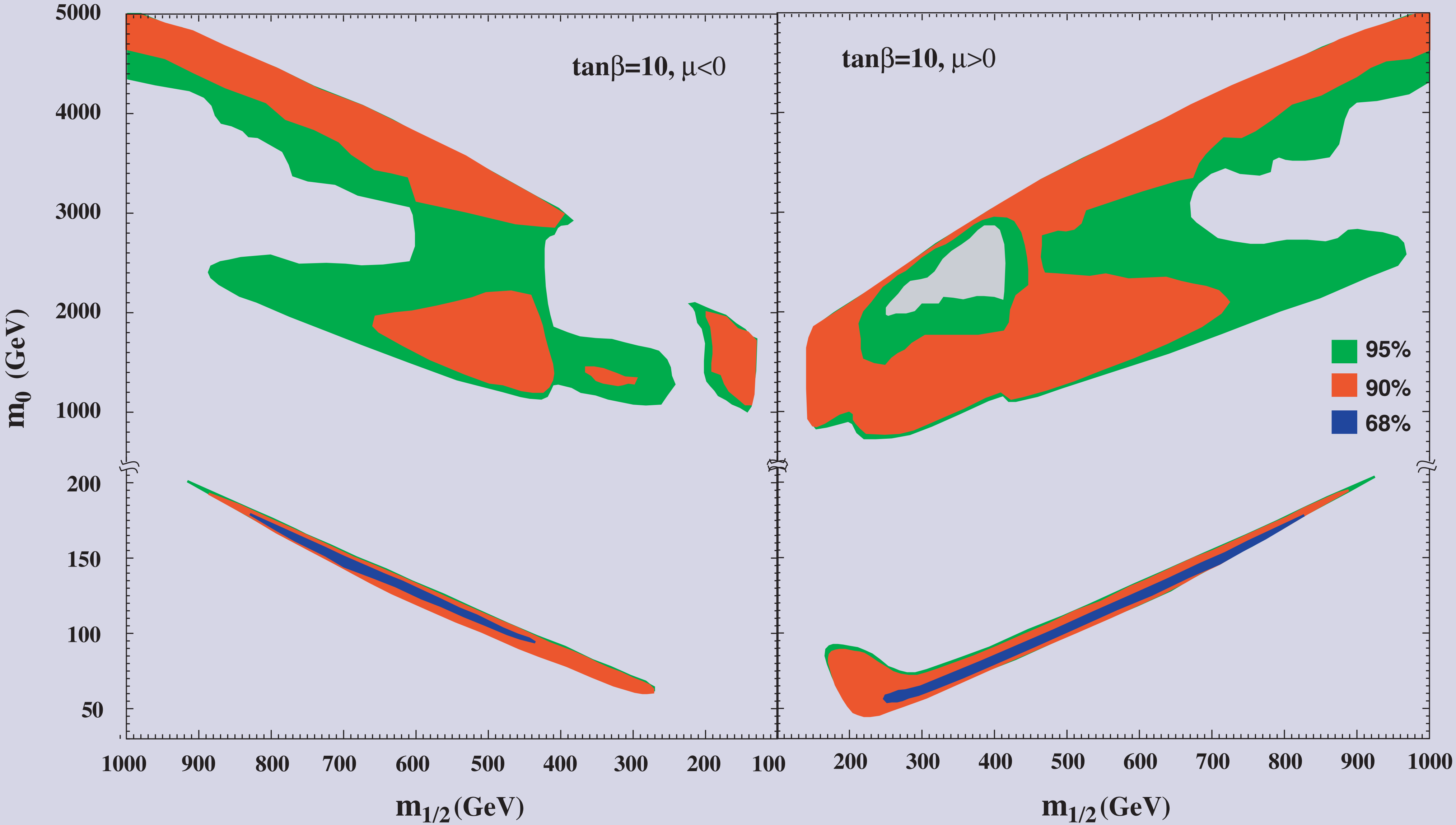
  Gambino and Ganis

- g-2 data (optional)

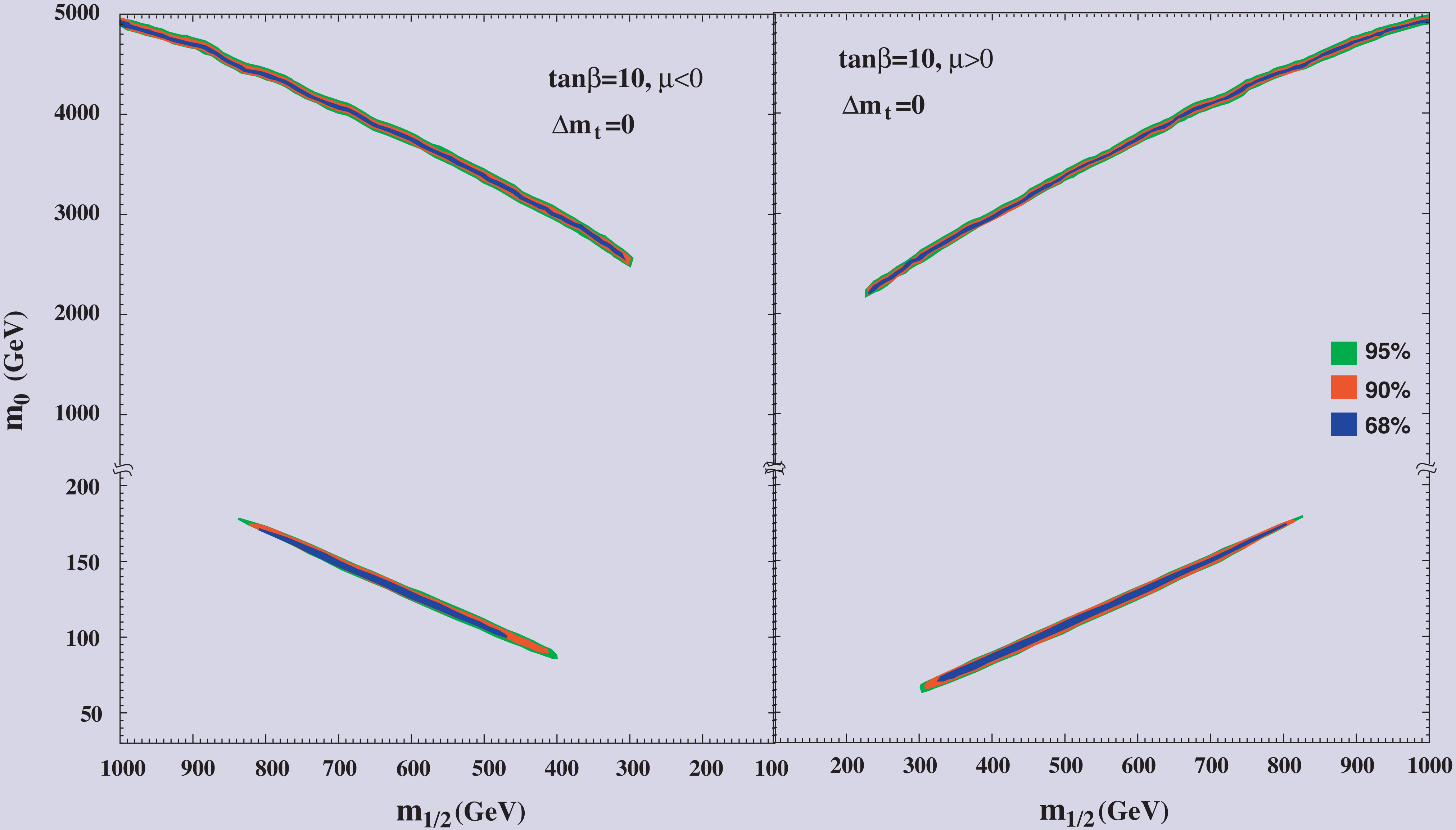
  Davier et al

- Relic Density

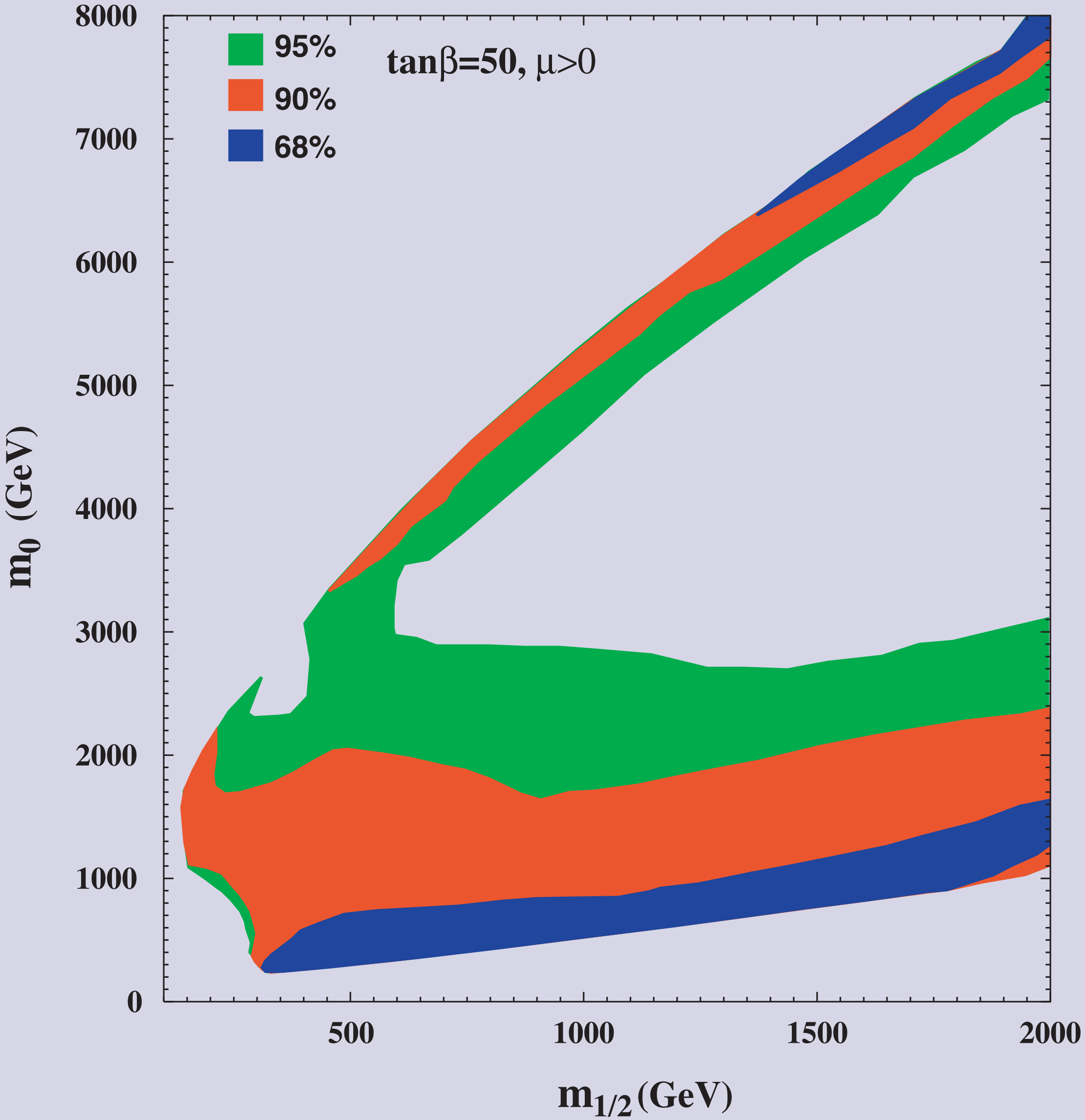
Likelihood Projections



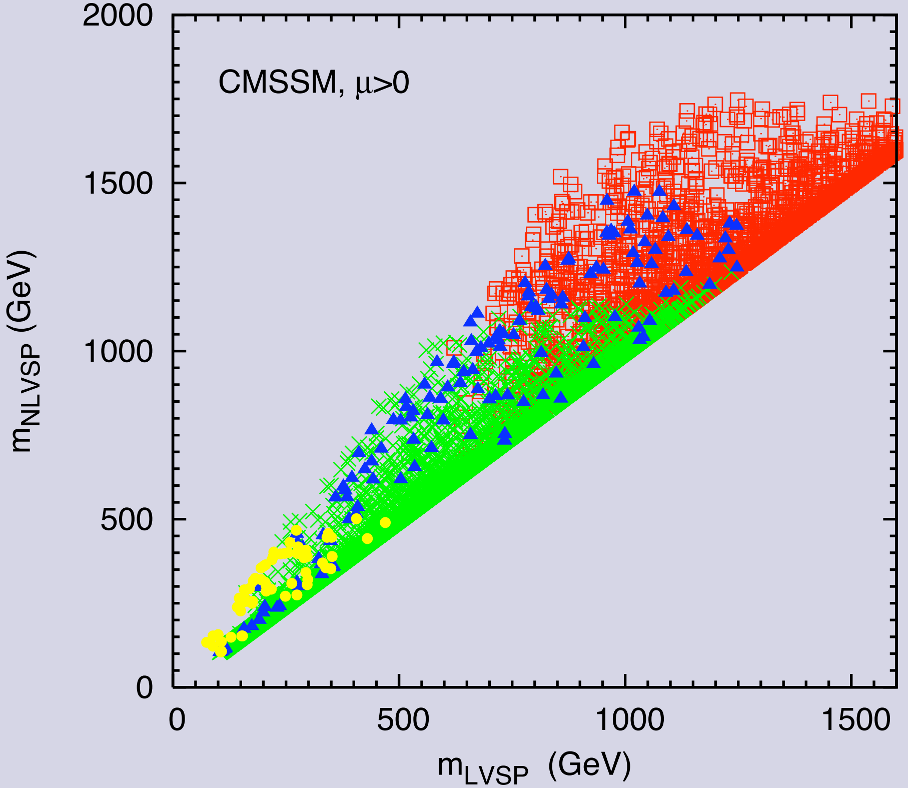
Likelihood Projections



Likelihood Projections



Visible Particle Masses



□ Phenomenologically acceptable points

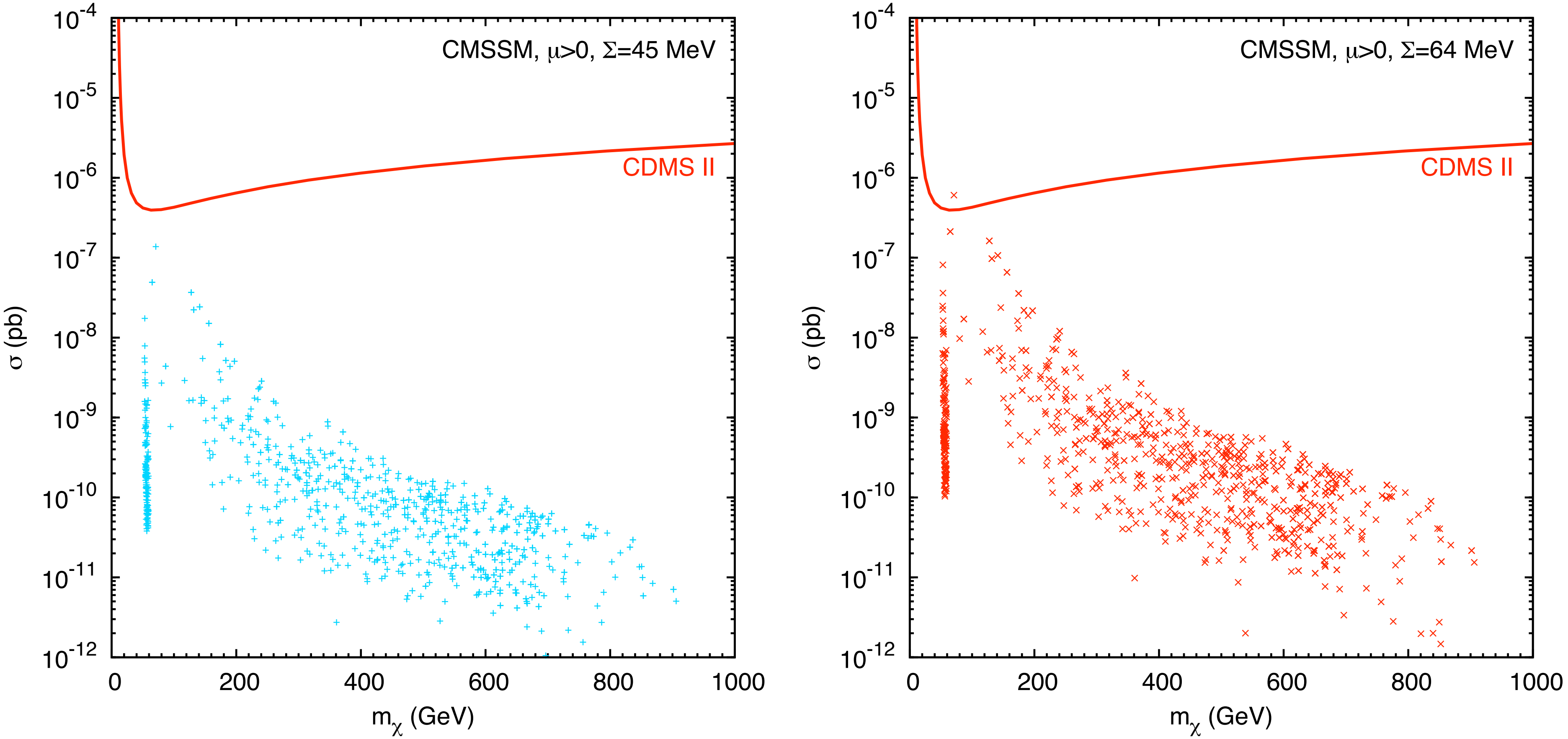
X LHC visible points
cf Baer etal

▲ Cosmologically acceptable points

● $\sigma_p > 10^{-8}$ pb

Ellis, KAO, Santoso, Spanos

Direct Detection in the CMSSM



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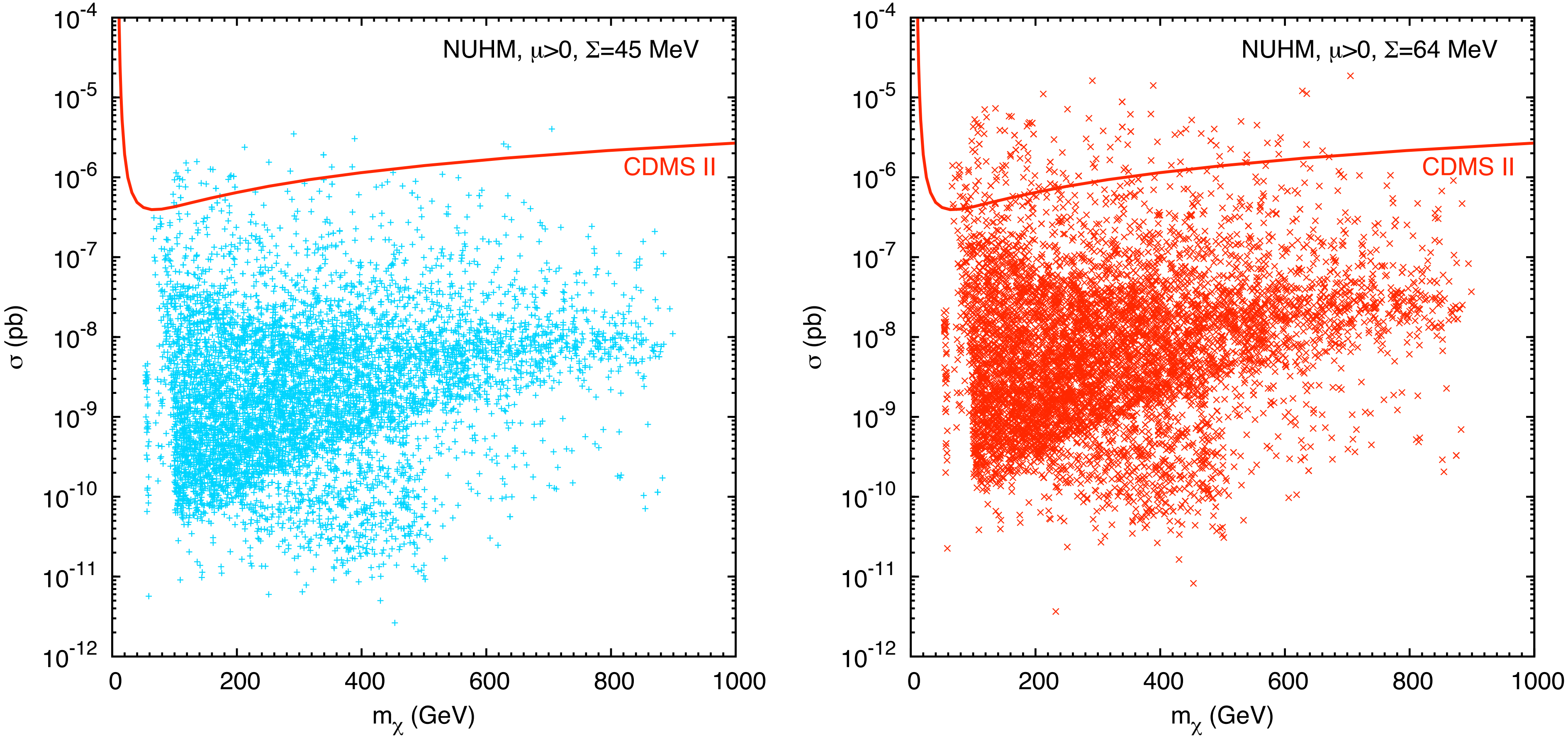
Direct Detection in the NUHM



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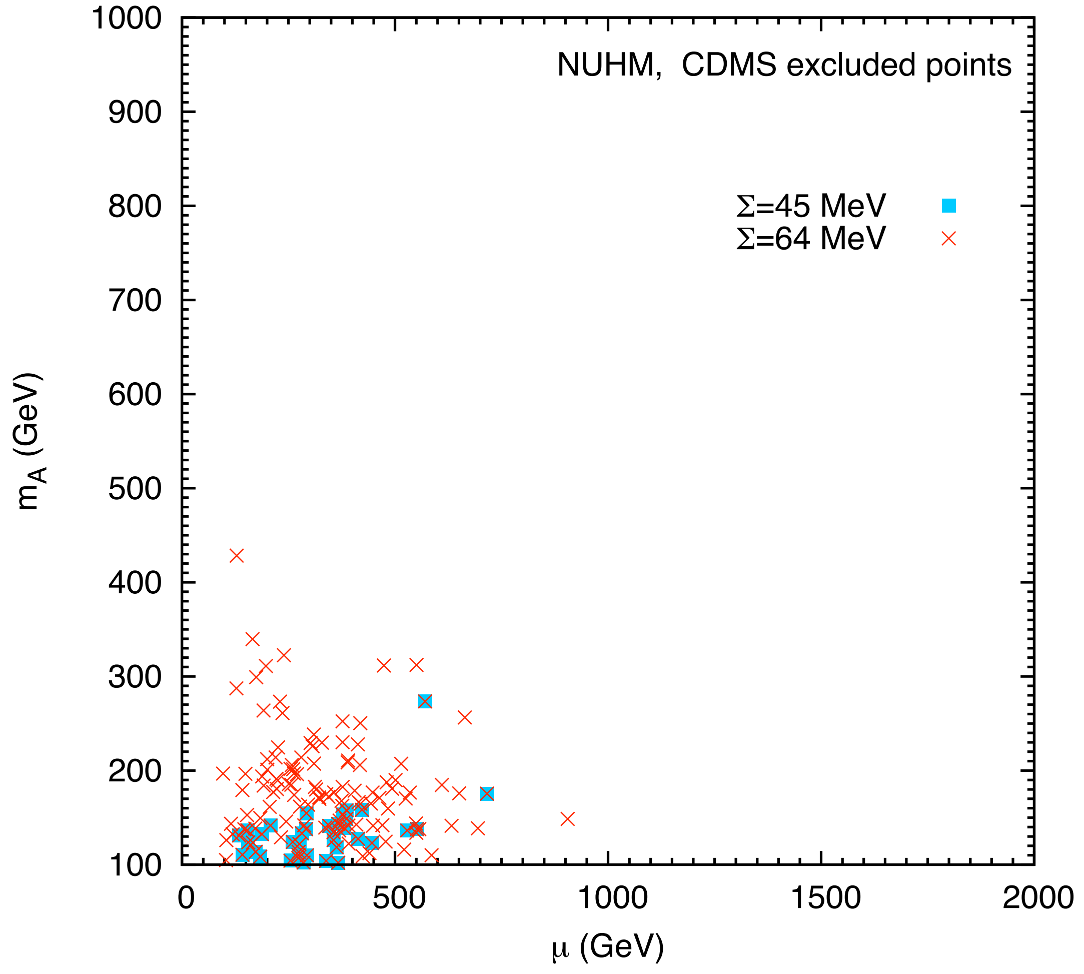
CDMS Excluded models

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

cf. Kim, Cerdeno, Scopel



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Uncertainties in $\boldsymbol{B_s \to \mu^+ \mu^-}$

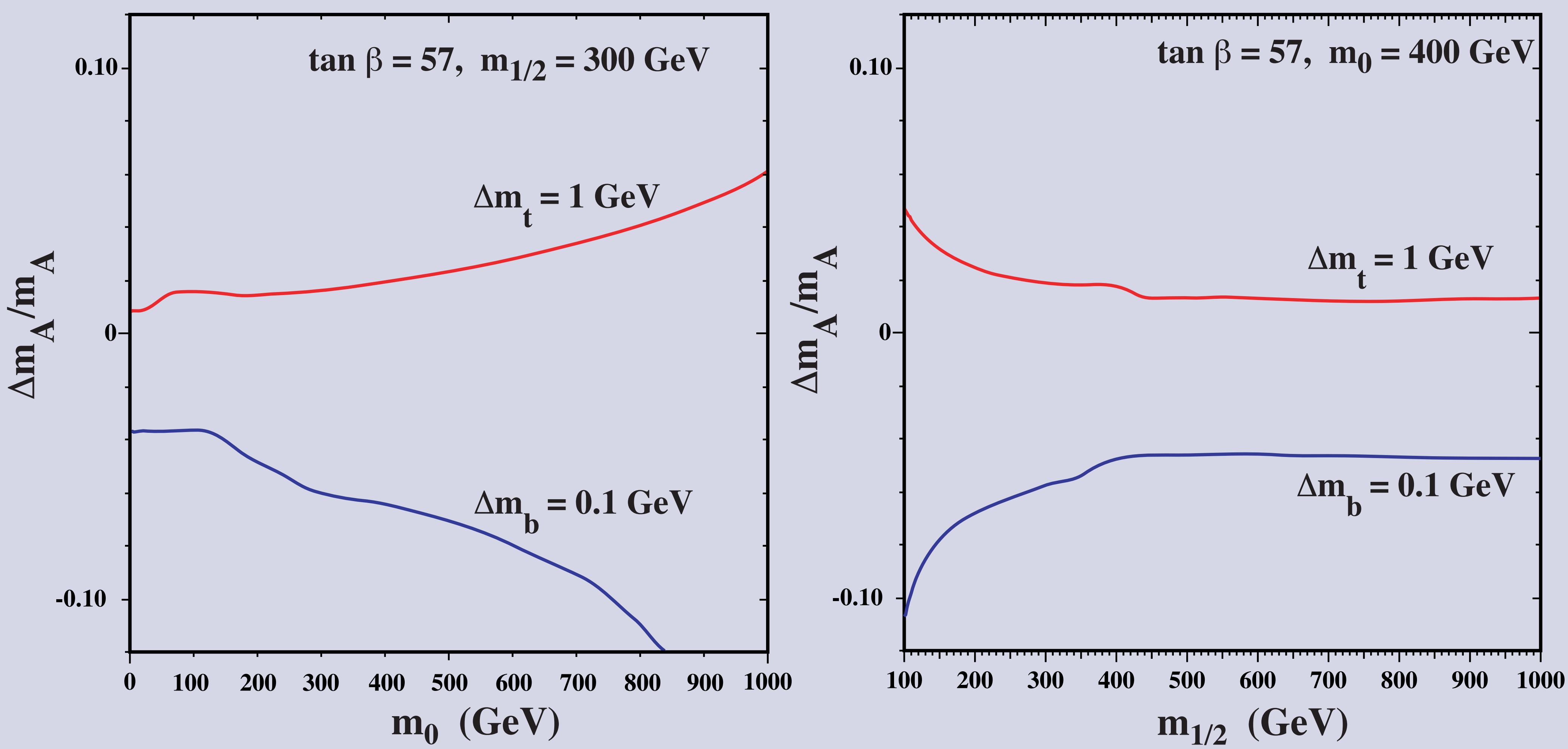
$$\mathcal{B}(B_s \to \mu^+ \mu^-) = \frac{G_F^2 \alpha^2}{16\pi^3} \frac{M_{B_s}^5 f_{B_s}^2 \tau_B}{4} |V_{tb} V_{ts}^*|^2 \sqrt{1 - \frac{4m_\mu^2}{M_{B_s}^2}} \times \left\{ \left(1 - \frac{4m_\mu^2}{M_{B_s}^2}\right) |C_S|^2 + \left| C_P - 2\, C_A \frac{m_\mu}{M_{B_s}^2} \right|^2 \right\} ,$$

$$C_{S,P}^{\rm CT} = \mp \frac{m_\mu \tan^3 \beta}{\sqrt{2} M_W^2 m_A^2} \sum_{i=1}^{2} \sum_{a=1}^{6} \sum_{m,n=1}^{3} [m_{\tilde{\chi}_i^\pm} D_3(y_{ai}) U_{i2} (\Gamma^{U_L})_{am} \Gamma^a_{imn}],$$

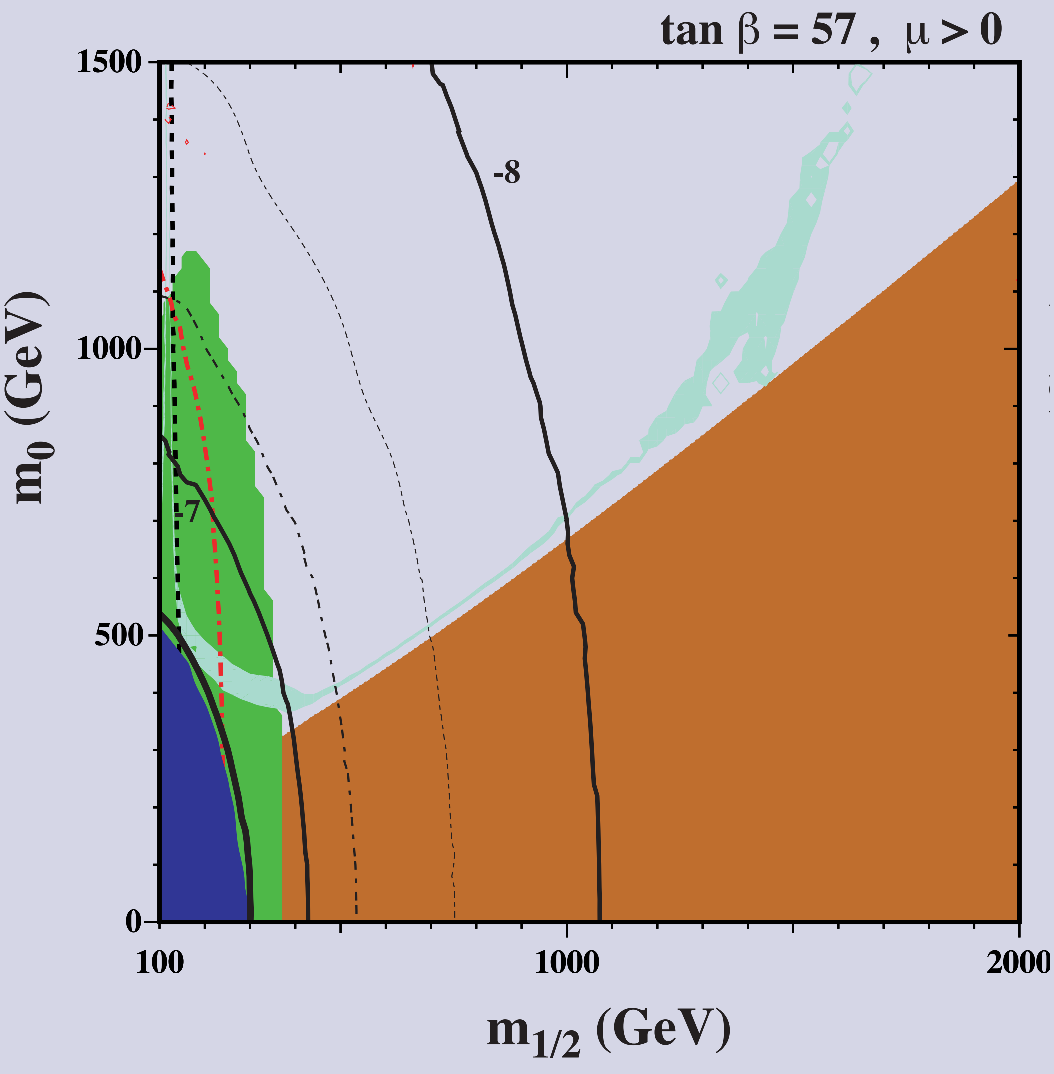
- B_s meson parameters - f_B, m_B, τ_B
- $m_t = 178 \pm 4$ GeV
- $m_b = 4.25 \pm 0.11$ GeV

Ellis, Olive, Spanos

Sensitivity of m_A to m_t and m_b



Effect of B parameters



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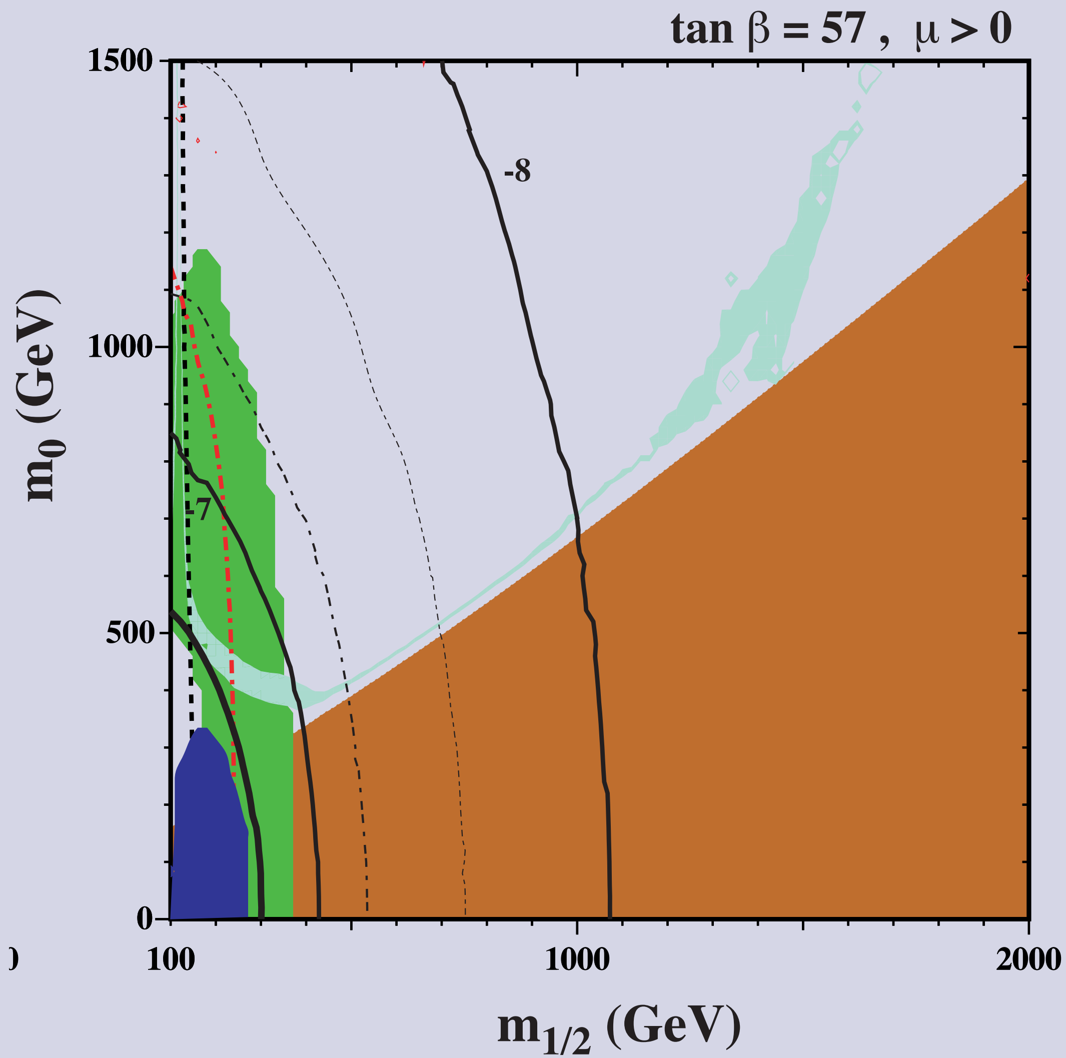
Effect of uncertainty in m_t



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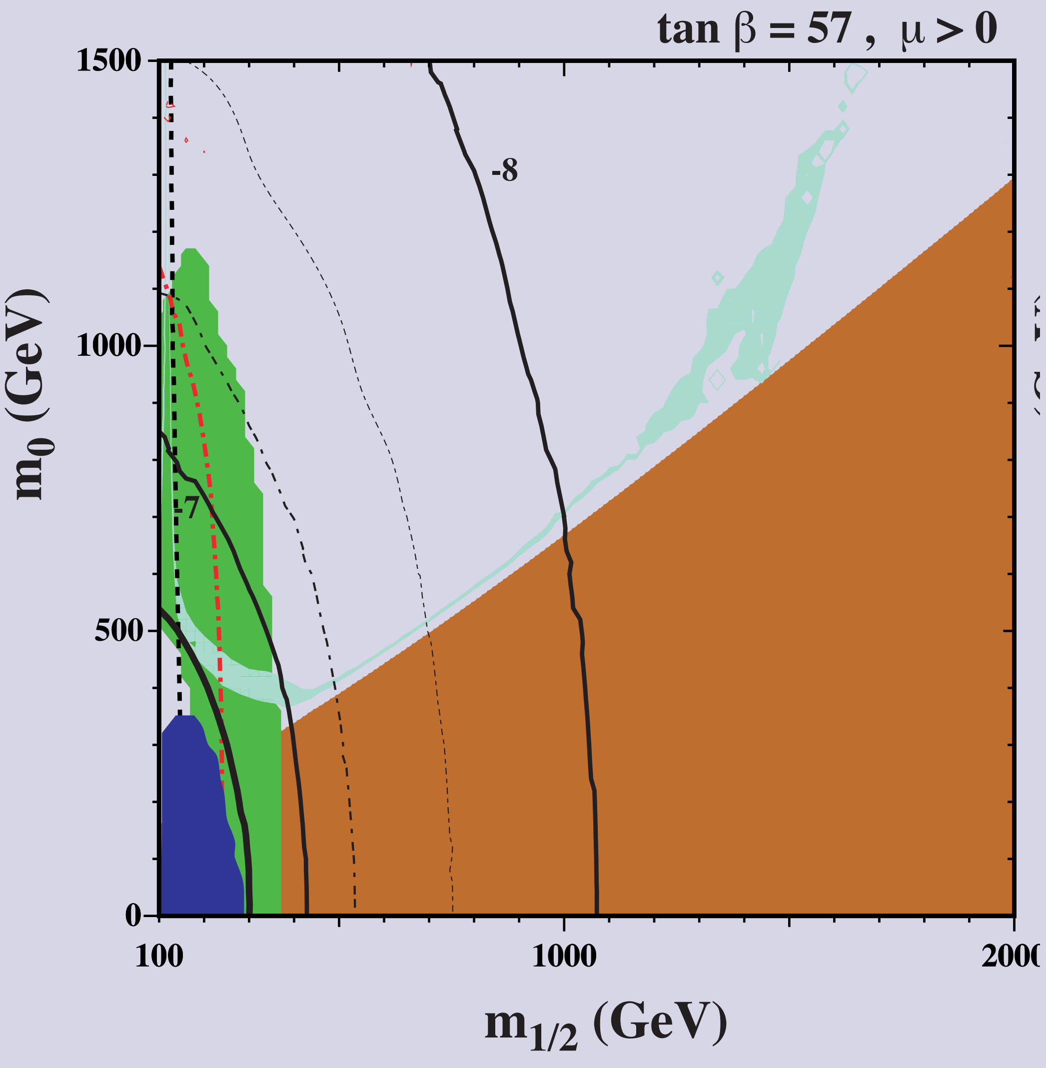
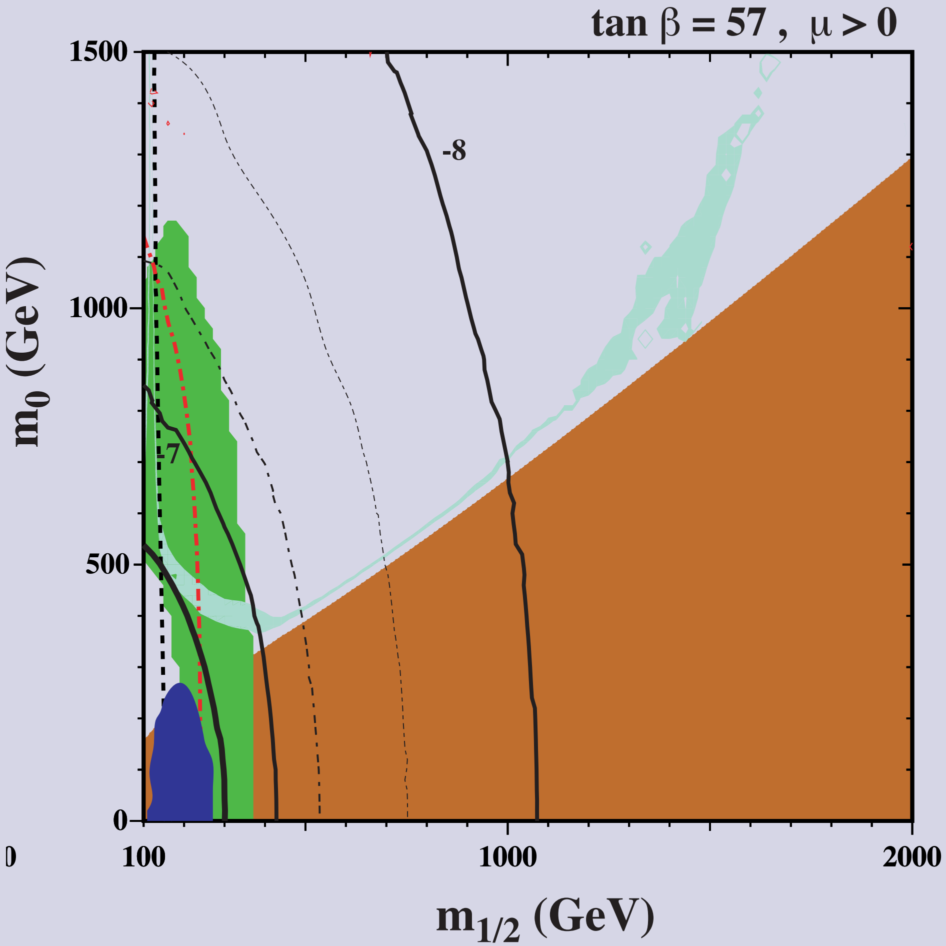
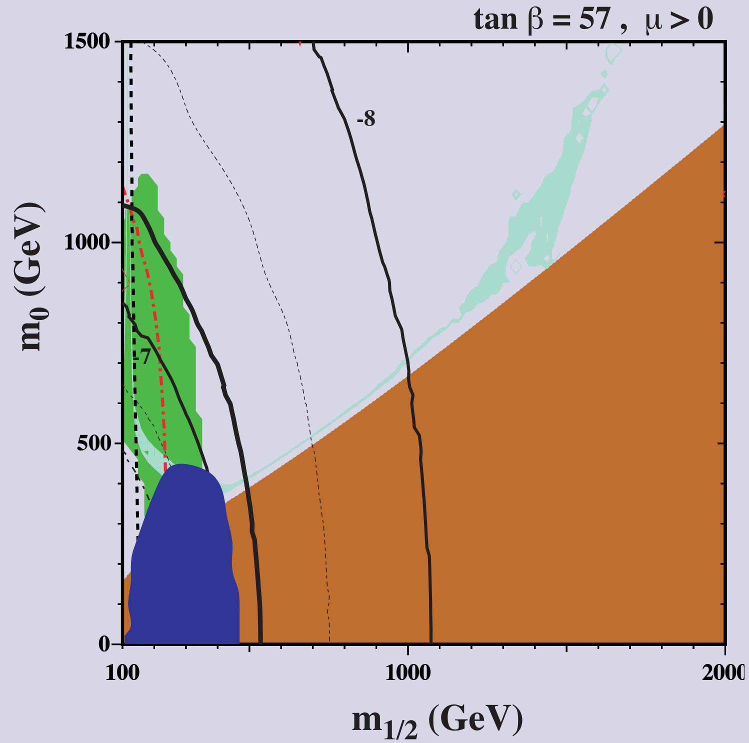
Effect of uncertainty in m_b

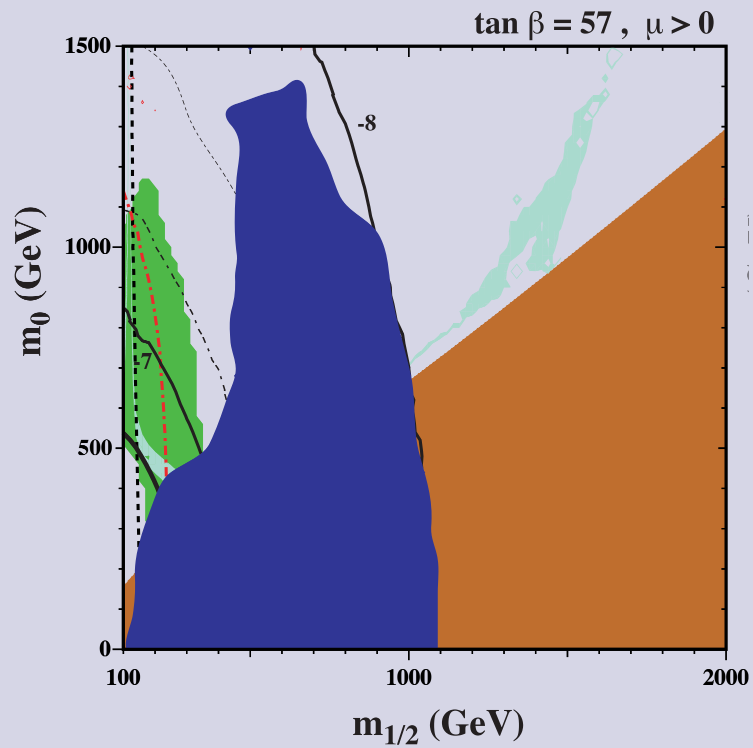


Ellis, Olive, Spanos

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







Ellis, Olive, Spanos

Minimal Supergravity Models

e.g. Barbieri, Ferrara, Savoy

Nilles, Srednicki, Wyler

$$G = \varphi\, \varphi^* + z\, z^* + \ln |W|^2; \quad W = f(z) + g(\varphi)$$

$$V = \left|\frac{\partial g}{\partial \varphi}\right|^2 + m_{3/2}\left(\varphi \frac{\partial g}{\partial \varphi} + \left(\sqrt{3}\langle z\rangle - 3\right) g + h.c.\right) + m_{3/2}{}^2 \varphi\varphi^*$$

3g for trilinear terms
2g for bilinear terms

For Polonyi models $<z> = \sqrt{3} - 1$, and

→ $m_0 = m_{3/2}$; $A_0 = (3 - \sqrt{3})\, m_0$; $B_0 = (A_0 - 1)\, m_0$

Boundary conditions

- Input parameters: μ, m_1, m_2, B. predict M_Z, $\tan\beta$, m_A

(in addition to m_0, $m_{1/2}$, and A_0)

CMSSM conditions

- Instead CMSSM:

Input parameters: M_Z, m_1, m_2, $\tan\beta$ ($m_1 = m_2 = m_0$)

predict μ, B, m_A

Very CMSSM conditions

- Then:

Input parameters: M_Z, m_1, m_2, B predict μ, m_A, $\tan\beta$

Electroweak Symmetry Breaking conditions:

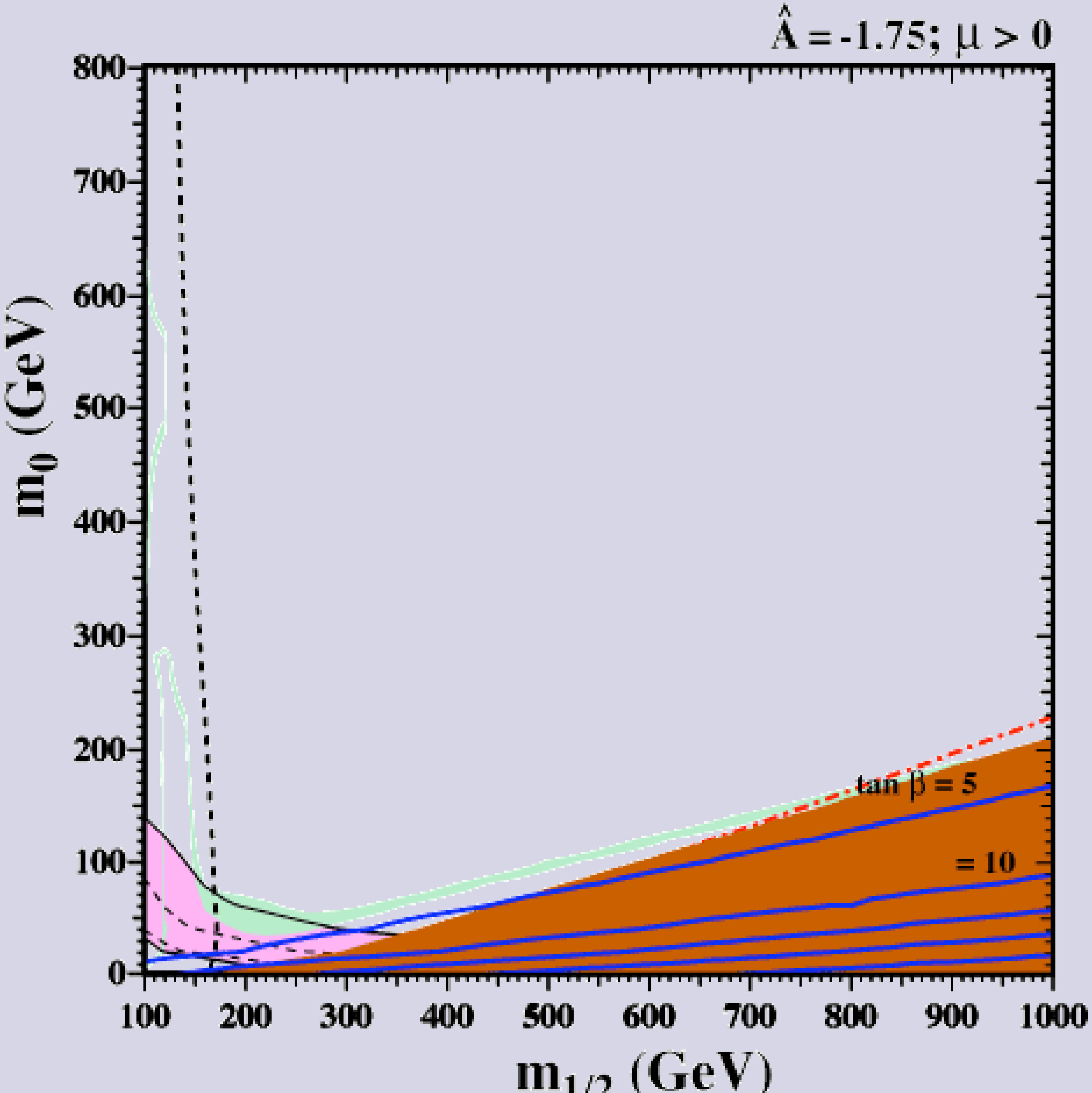
$$\mu^2 = \frac{m_1^2 - m_2^2 \tan^2\beta + \frac{1}{2} m_Z^2 (1 - \tan^2\beta) + \Delta_\mu^{(1)}}{\tan^2\beta - 1 + \Delta_\mu^{(2)}}$$

$$B\mu = -\tfrac{1}{2}(m_1^2 + m_2^2 + 2\mu^2)\sin 2\beta + \Delta_B$$

But Δ_μ depends on tanβ and Δ_B depends on μ and tanβ so one can not write down and expression for

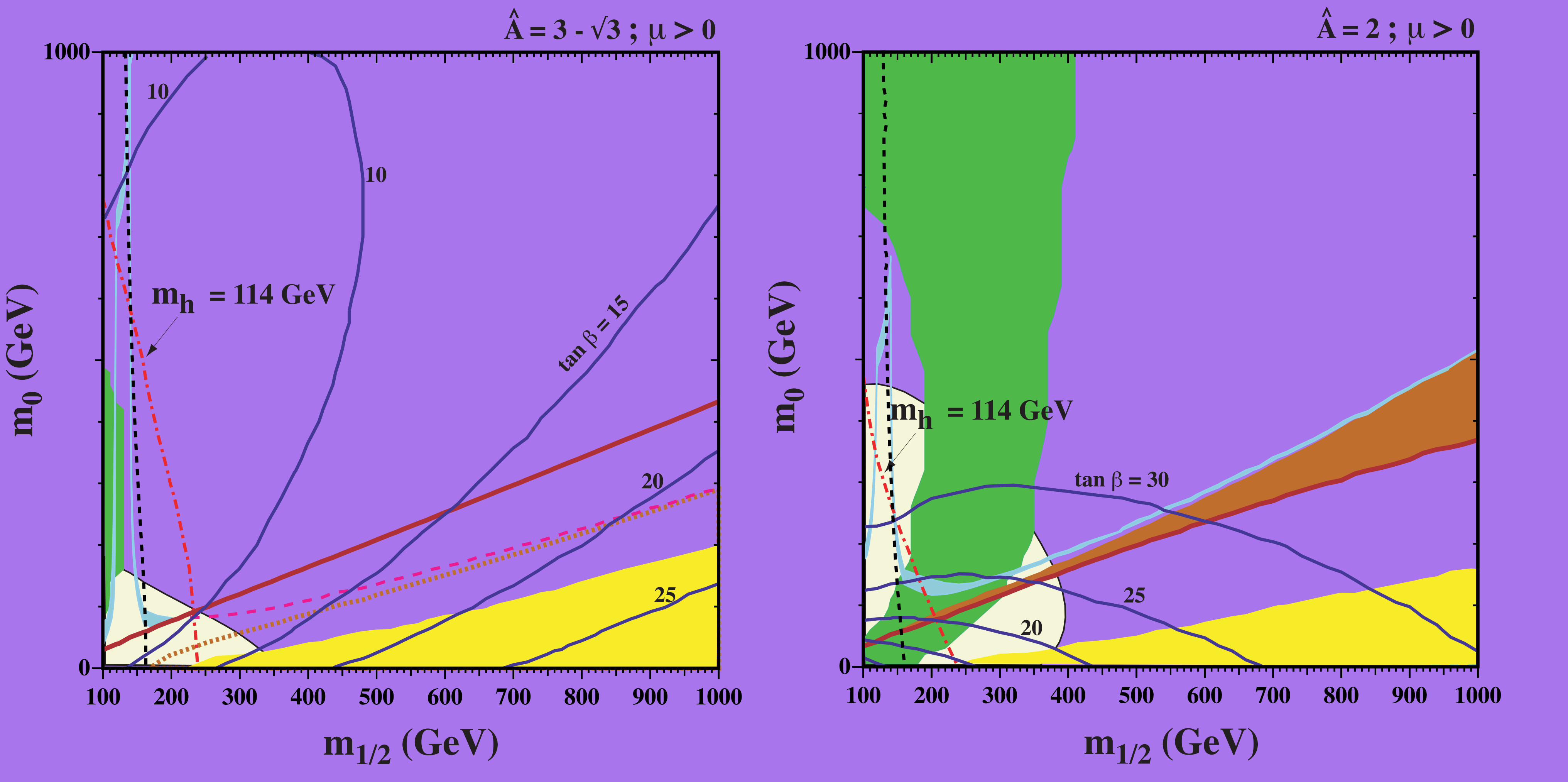
$$\tan\beta = \ldots$$

Of course it can be solved numerically



$\hat{A} = -1.75; \mu > 0$
m_0 (GeV)
$m_{1/2}$ (GeV)
tan β = 5
= 10
0
100
200
300
400
500
600
700
800
100
200
300
400
500
600
700
800
900
1000

VCMSSM



Â = 3 - √3 ; μ > 0
1000
0
10
10
m_h = 114 GeV
tan β = 15
20
25
100 200 300 400 500 600 700 800 900 1000
m_0 (GeV)
m_1/2 (GeV)
Â = 2 ; μ > 0
1000
0
m_h = 114 GeV
tan β = 30
25
20
100 200 300 400 500 600 700 800 900 1000
m_0 (GeV)
m_1/2 (GeV)

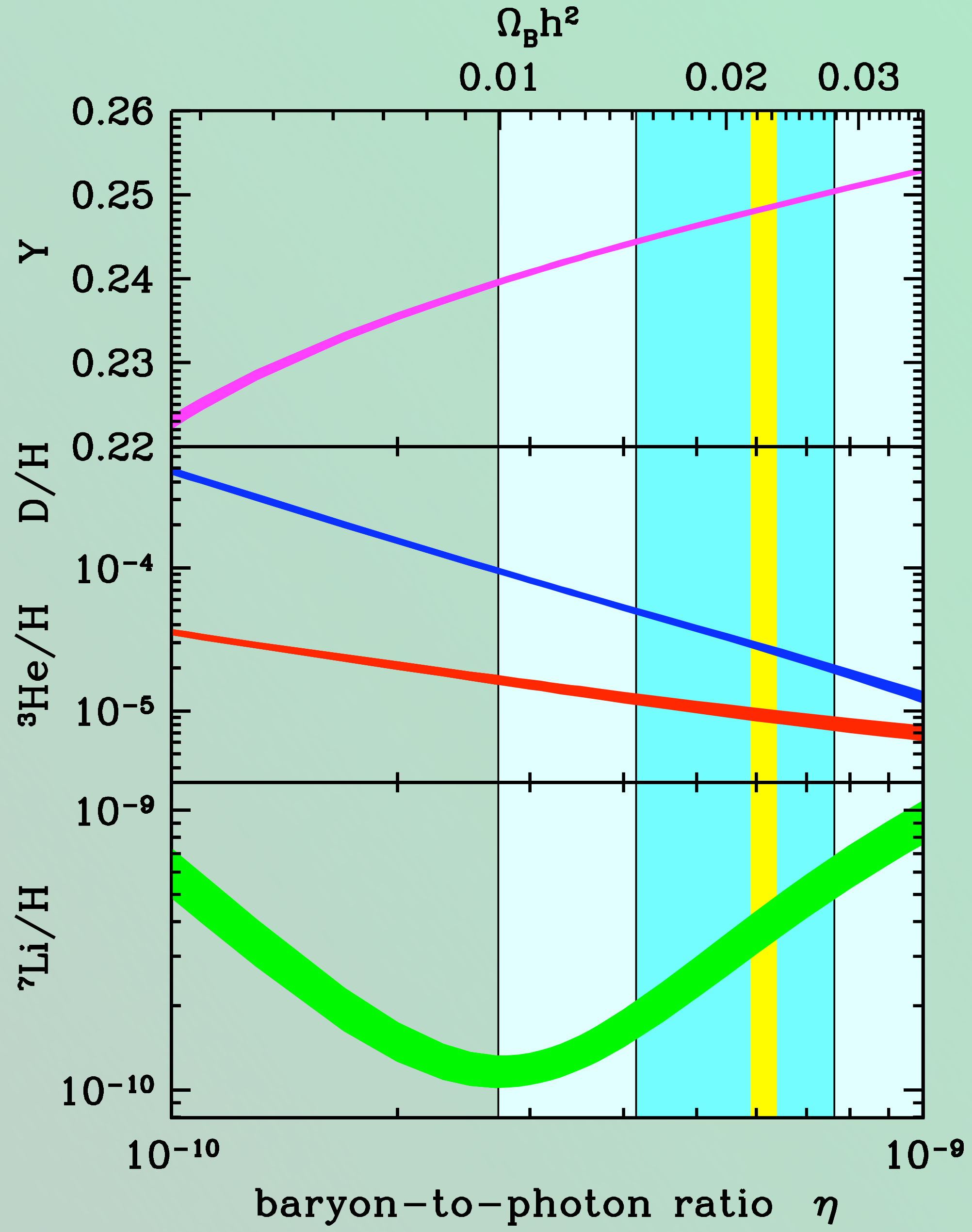
Gravitinos

- Strong cosmological limits on mass
  - $m_{3/2} < 1$ keV (stable)
  - or $m_{3/2} > 10$ TeV (unstable)
- Abundance limits after inflation (unstable)
  - $$\tau \sim 3 \times 10^8 \left(\frac{100GeV}{m_{3/2}}\right)^3$$
  - $$\frac{n_{3/2}}{n_\gamma} \equiv Y_{3/2} < 5 \times 10^{-14} \left(\frac{100GeV}{m_{3/2}}\right) \qquad \tau \sim 10^8 s$$

BBN Concordance

- Concordance rests on balance between interaction rates and expansion rate.

- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, KAO

Limits on Unstable particles due to

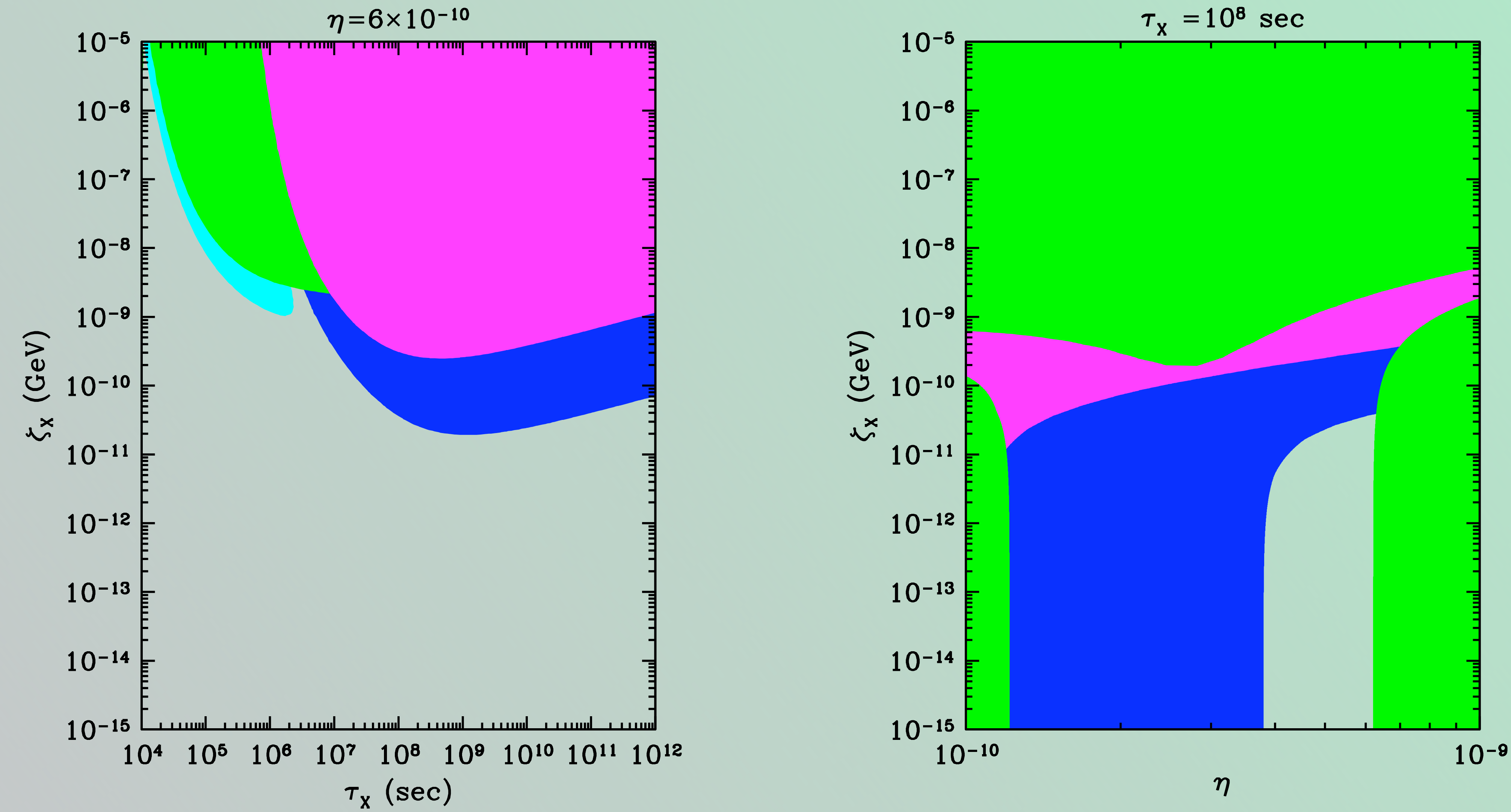
Photo-Destruction and -Production of Nuclei

3 free parameters

$$\zeta_X \equiv \frac{n_X^0}{n_\gamma^0} M_X = r M_X = 2 r E_0,$$

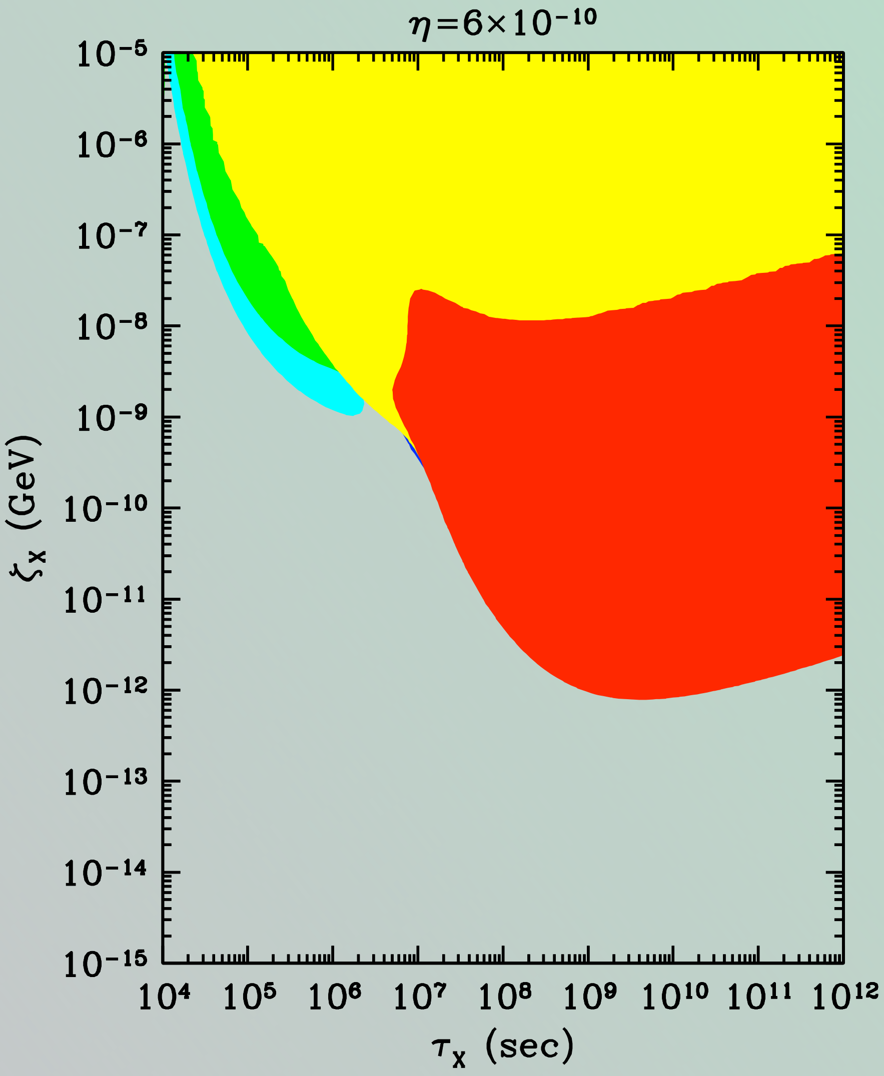
$$\tau_X \text{ and } \eta.$$

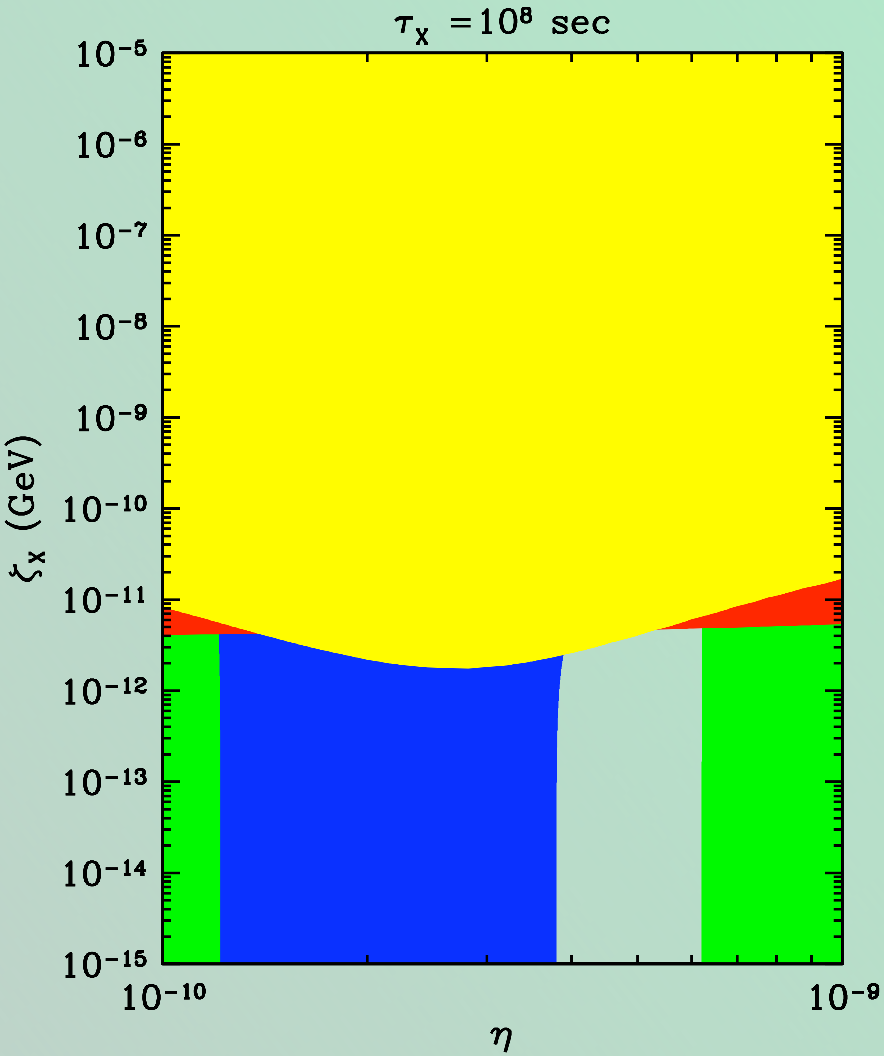
D, He and Li



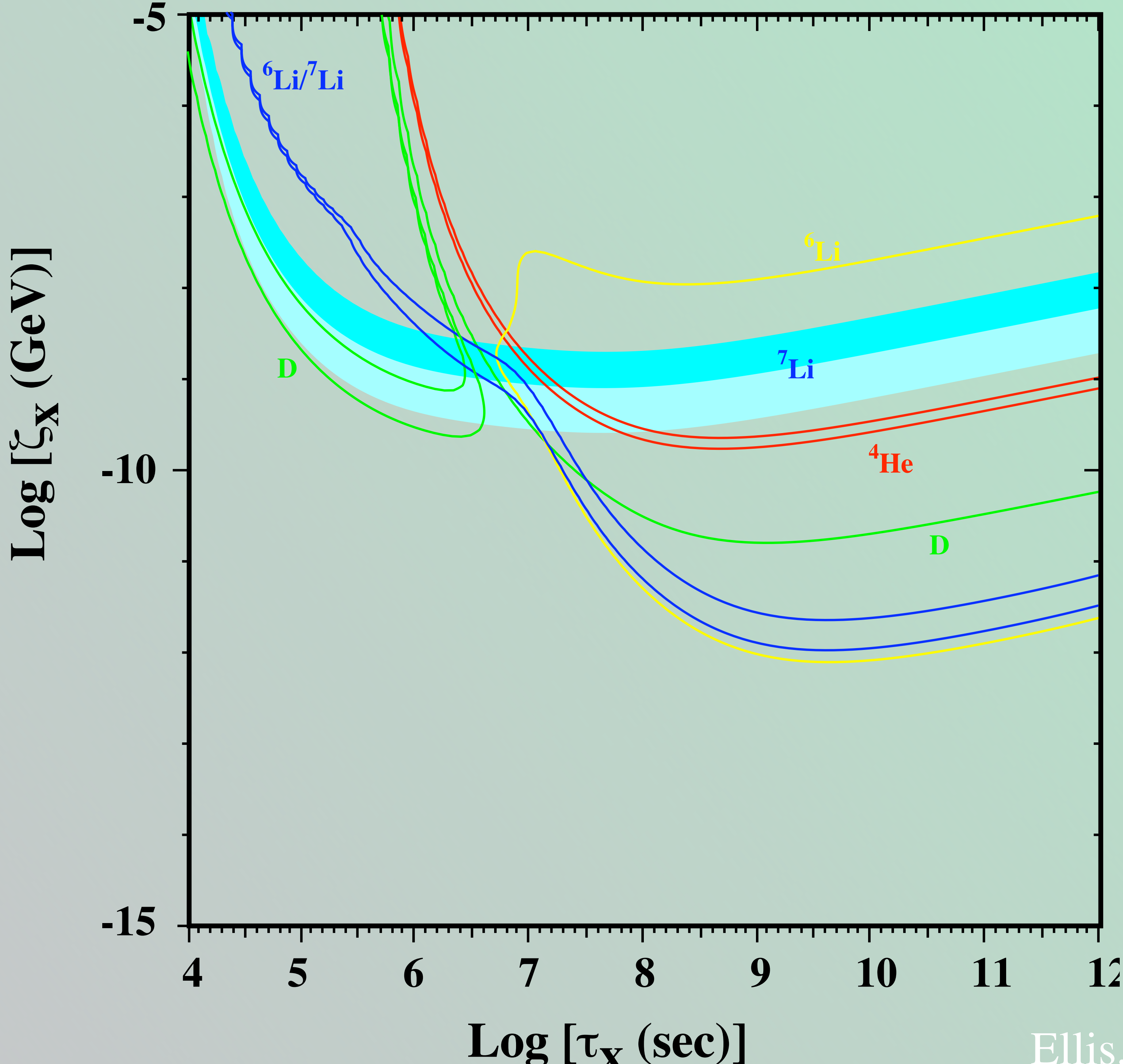
Cyburt, Ellis, Fields, KAO

"All"





Cyburt, Ellis, Fields, KAO



Jedamzik
Feng et al.
Ellis, KAO, Vangioni

Gravitino Dark Matter and NSP decays

Ellis, Olive, Santoso, Spanos

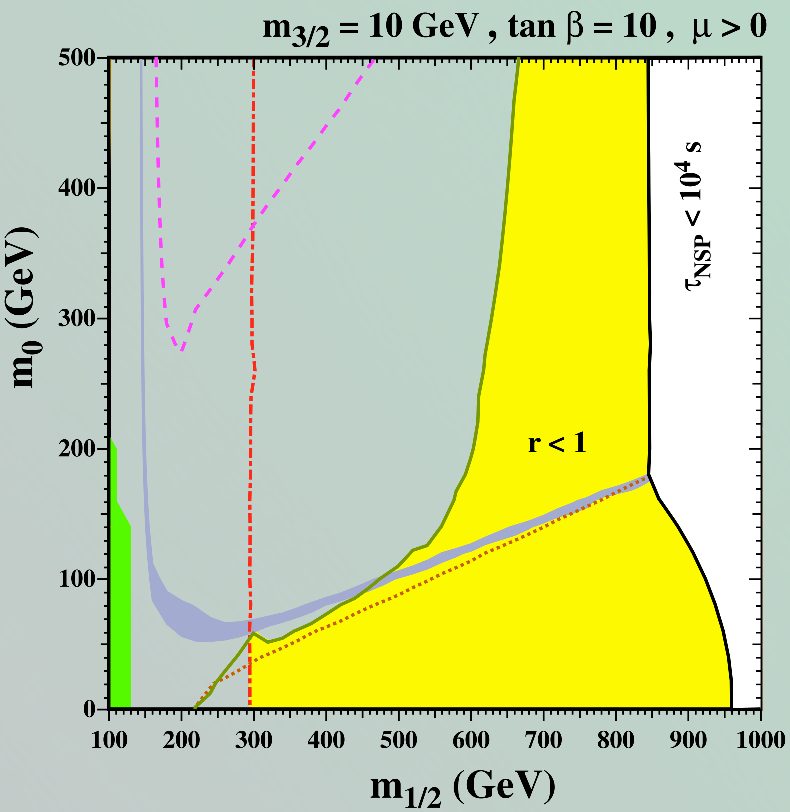
χ is now the NSP and can decay to gravitinos

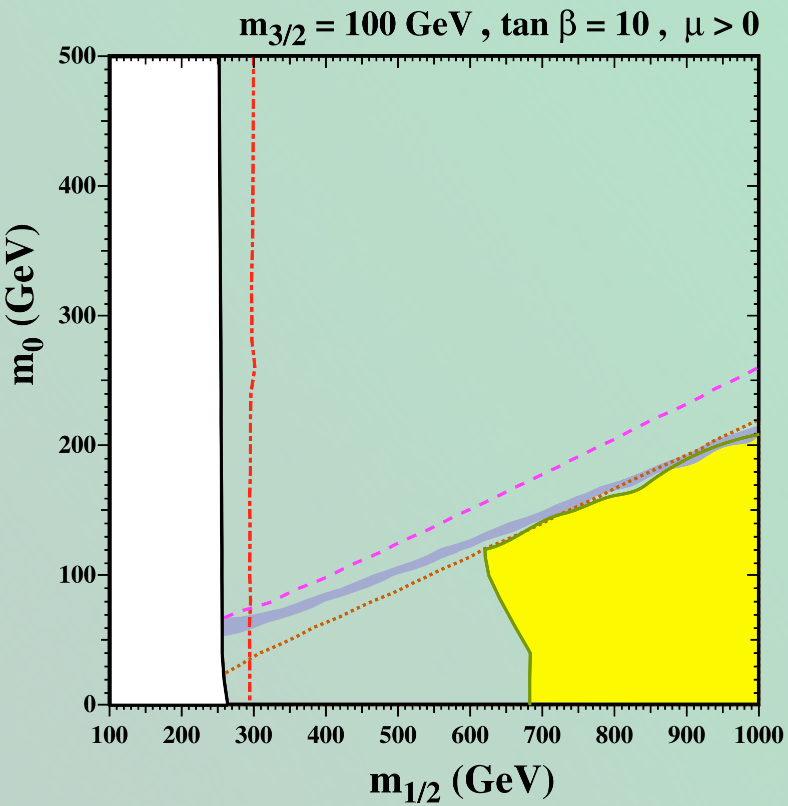
$$\boldsymbol{\Omega_{3/2} = \Omega_\chi (m_{3/2}/m_\chi)}$$

$$\Omega_X^0 h^2 = 3.9 \times 10^7 \ \mathrm{GeV}^{-1} \ \zeta_X$$

There could be additional sources of gravitino dark matter (e.g. inflation)

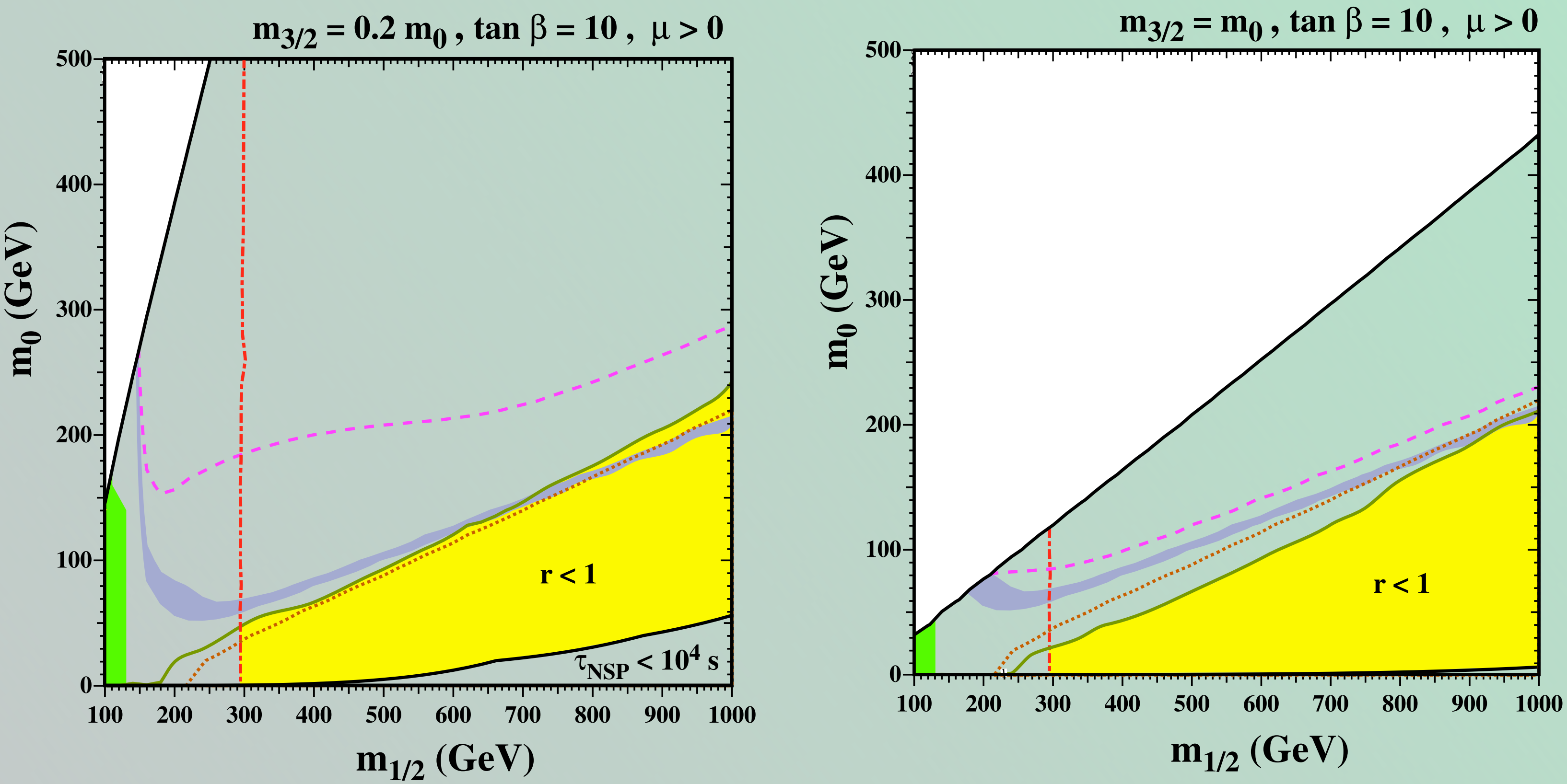
The CMSSM plane with gravitino dark matter





Ellis, KAO, Santoso, Spanos

The CMSSM plane with gravitino dark matter



Ellis, KAO, Santoso, Spanos

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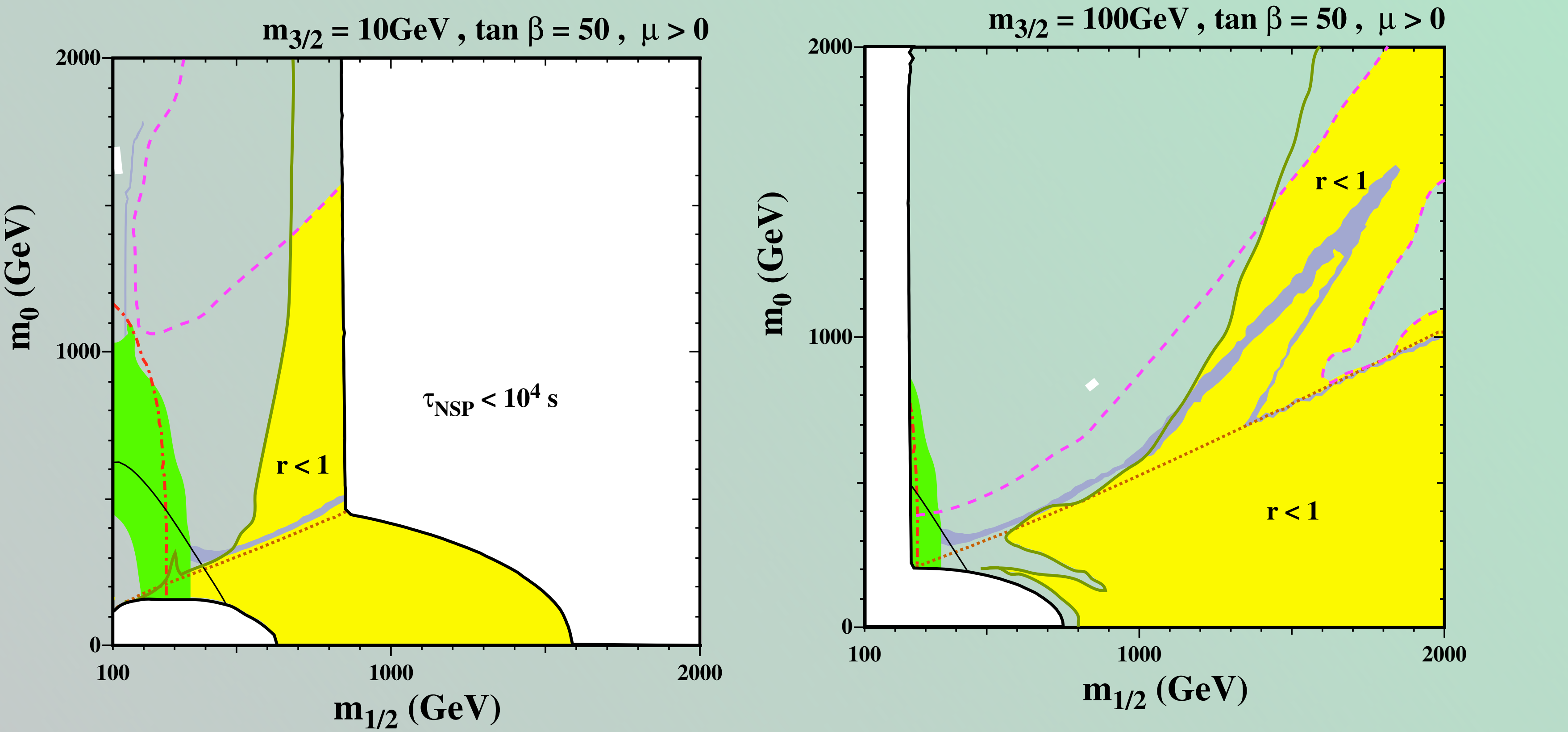

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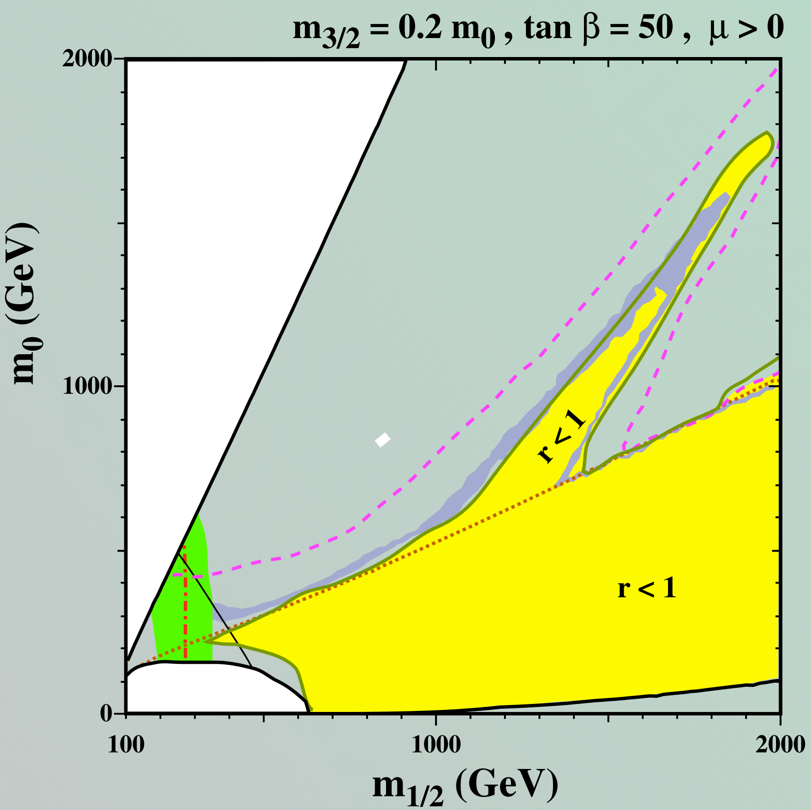
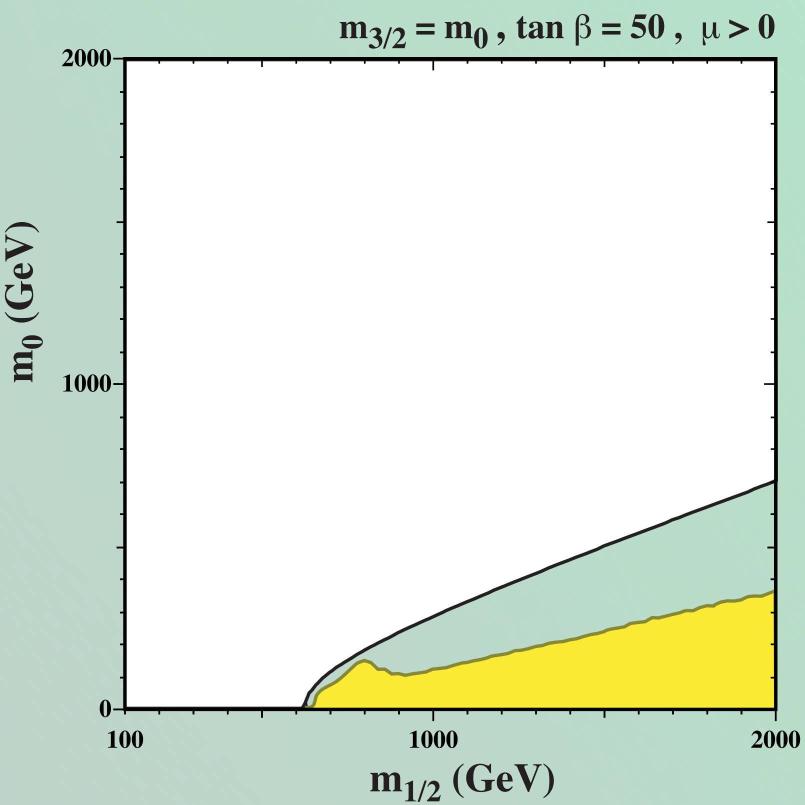
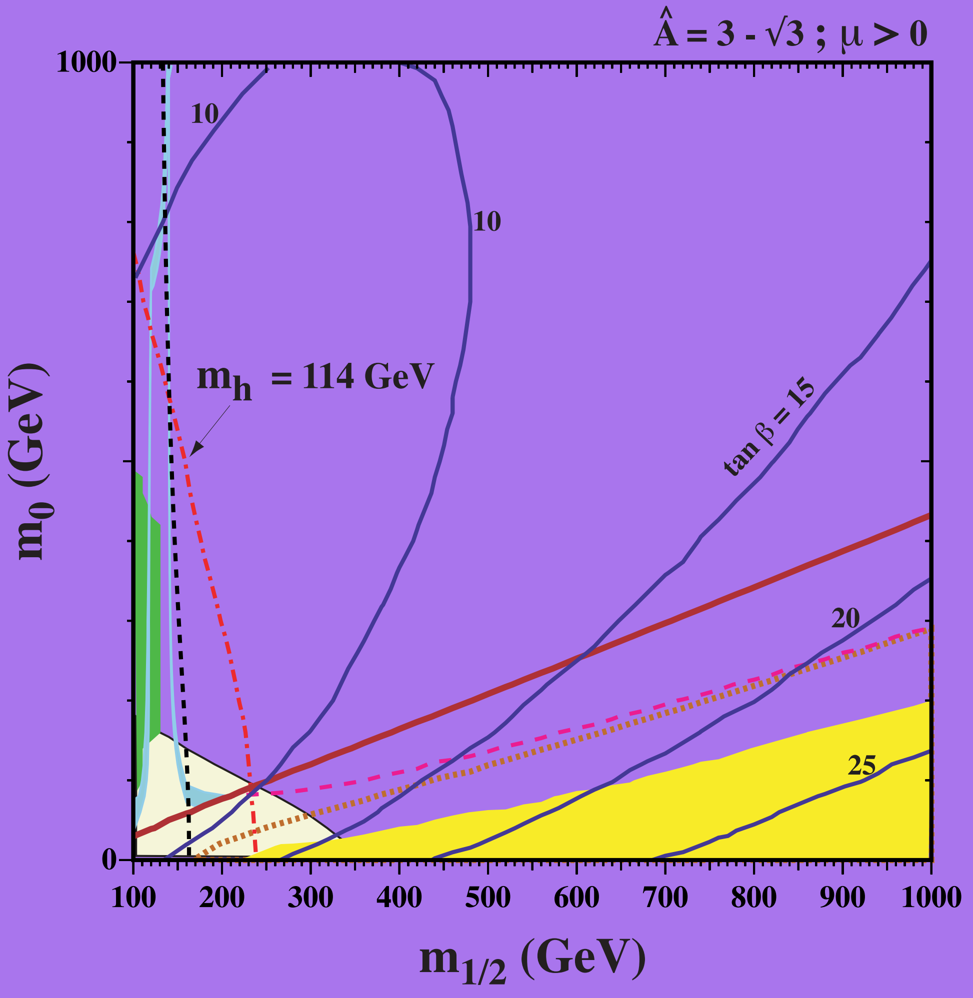
The CMSSM plane with gravitino dark matter



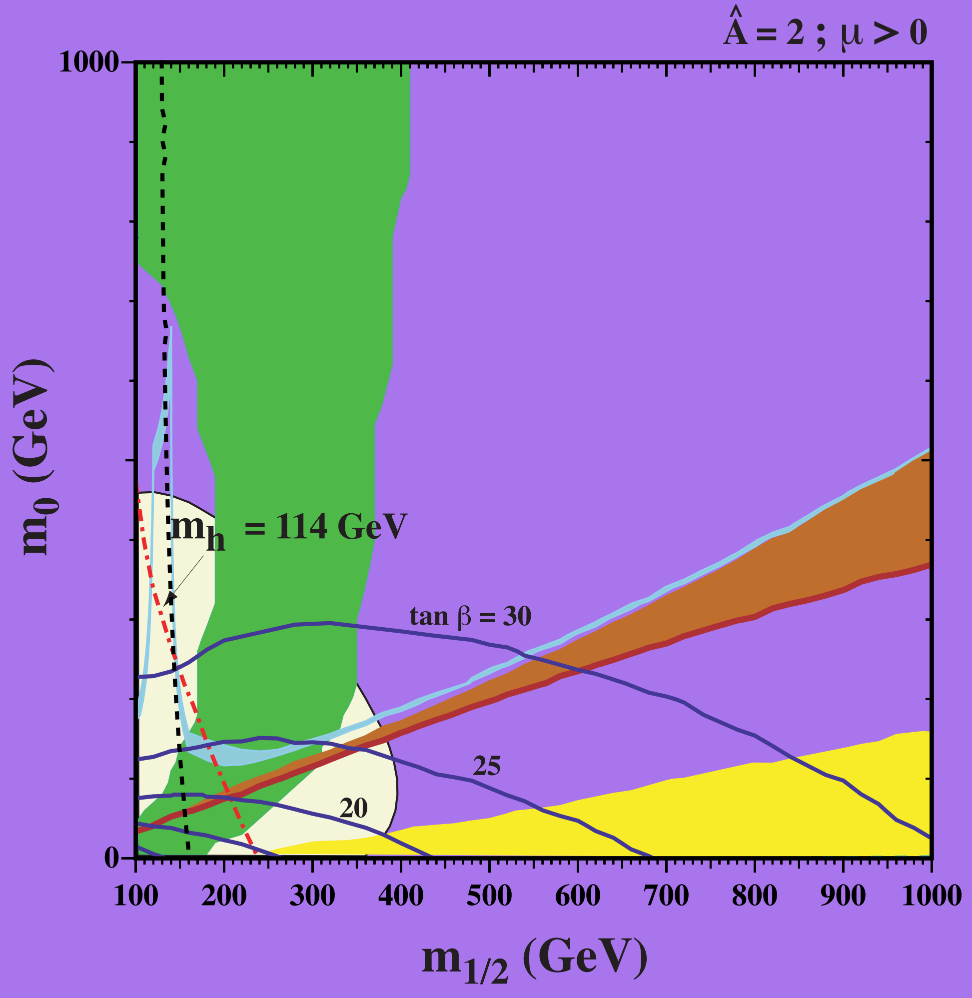


Ellis, KAO, Santoso, Spanos

VCMSSM

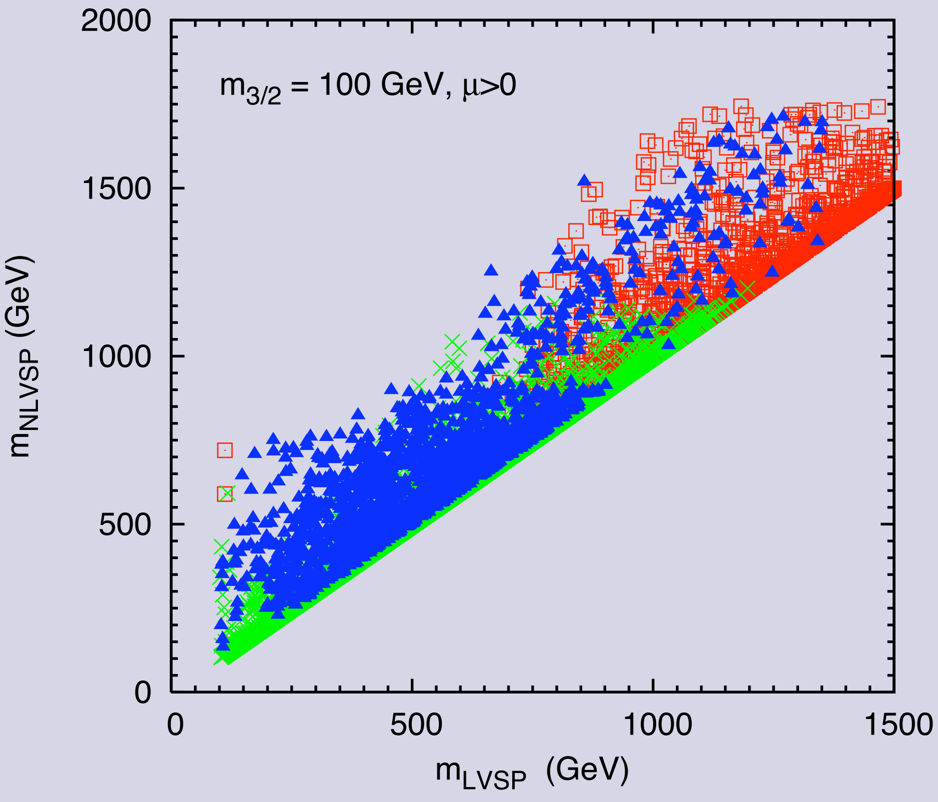


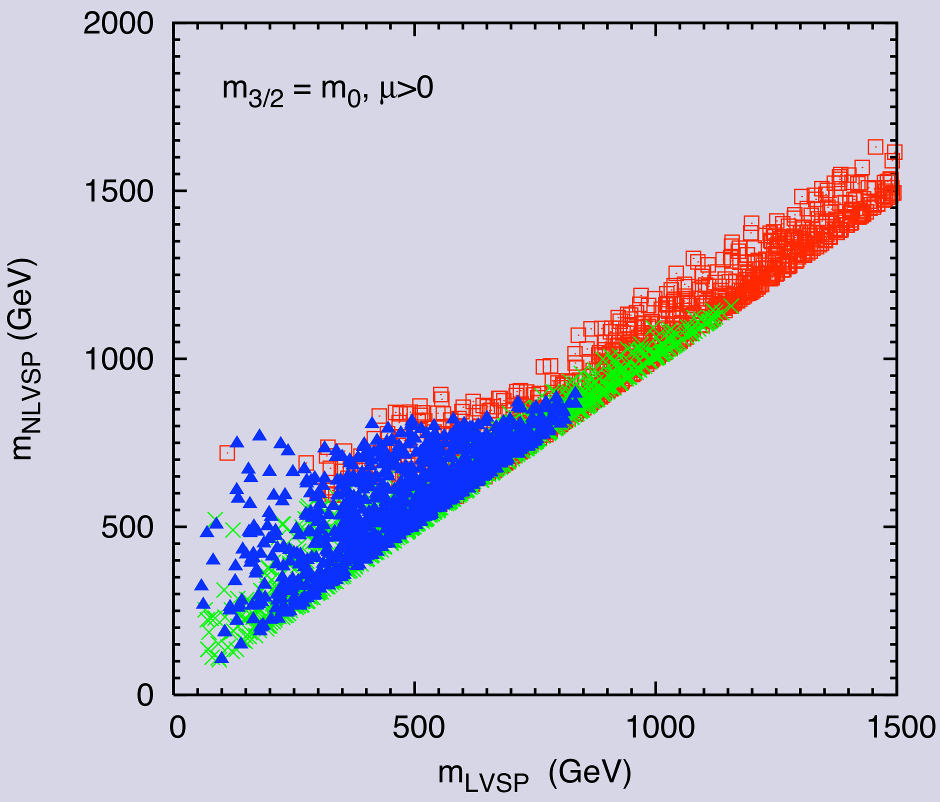
$\hat{A} = 3 - \sqrt{3}$; $\mu > 0$
1000
0
100
200
300
400
500
600
700
800
900
1000
m_0 (GeV)
$m_{1/2}$ (GeV)
10
10
m_h = 114 GeV
tan β = 15
20
25



$\hat{A} = 2$; $\mu > 0$
1000
0
100
200
300
400
500
600
700
800
900
1000
m_0 (GeV)
$m_{1/2}$ (GeV)
m_h = 114 GeV
tan β = 30
25
20

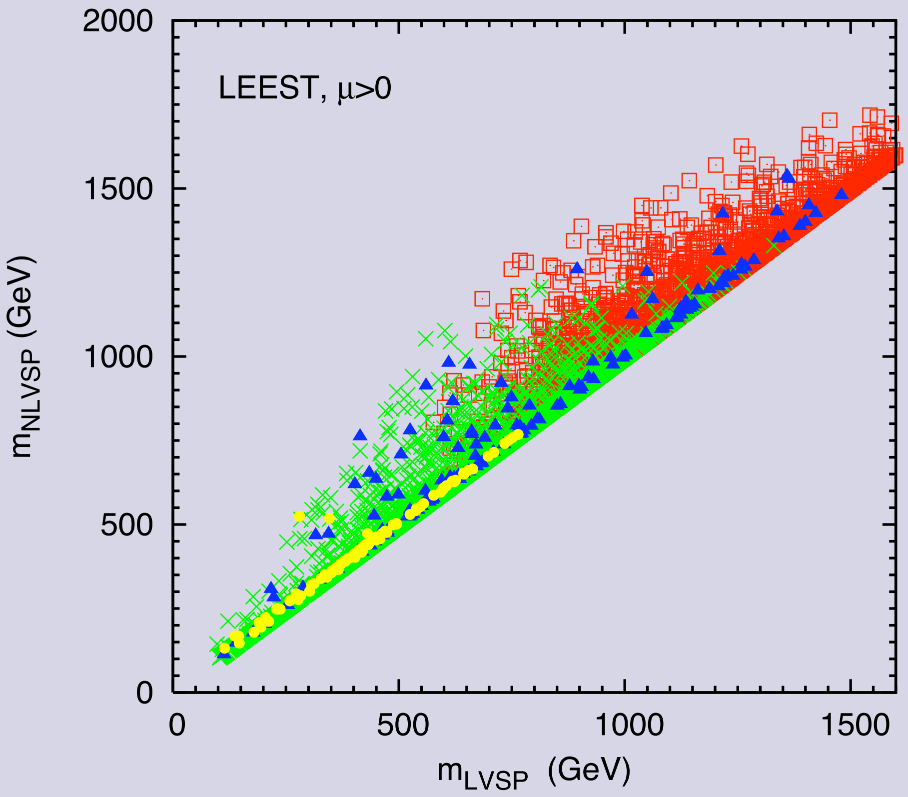
Visible Particle Masses



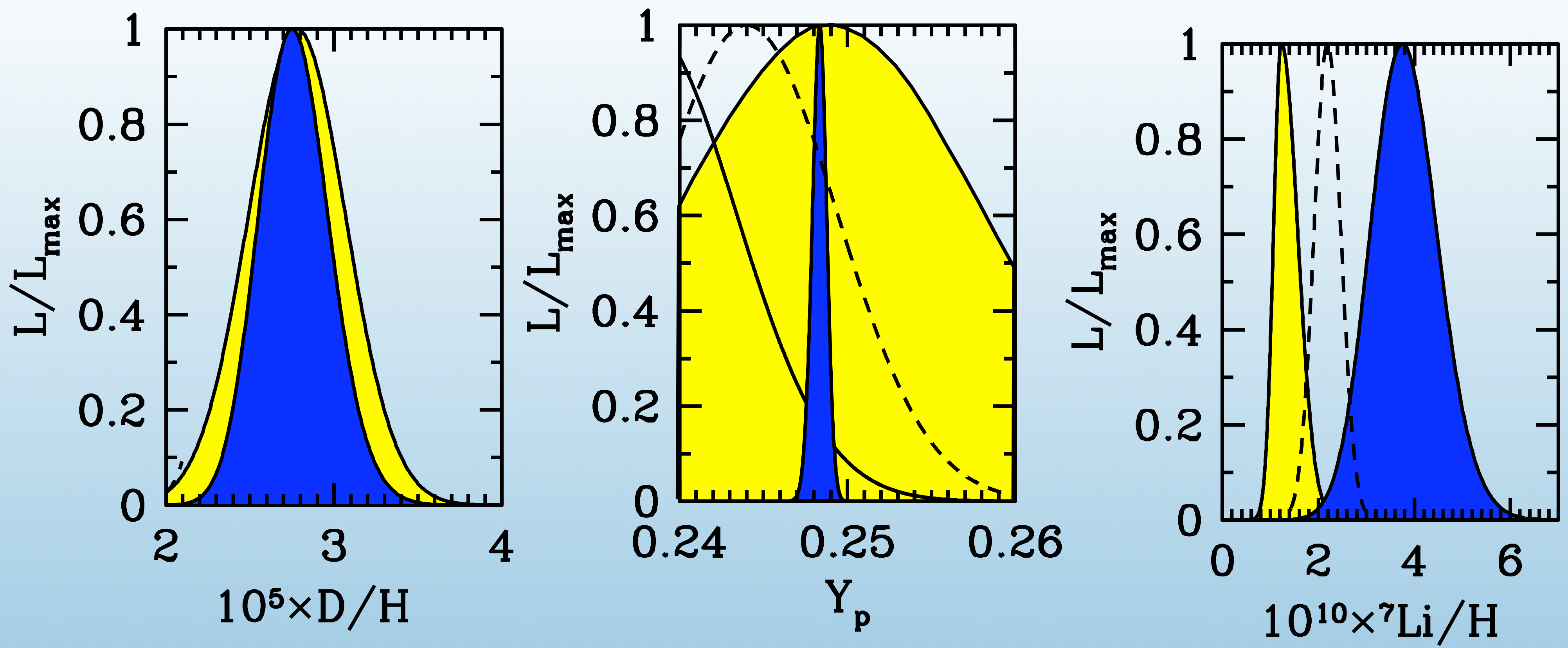


Required Center of Mass Energies

Model	*sgn*(μ)	*one sparticle*	*two sparticles*
CMSSM	$\mu > 0$	2.2	2.6
	$\mu < 0$	2.2	2.5
NUHM	$\mu > 0$	2.4	2.8
	$\mu < 0$	2.6	2.9
LEEST	$\mu > 0$	2.6	3.0
	$\mu < 0$	2.5	3.2
LEEST10	$\mu > 0$	1.2	1.6
	$\mu < 0$	1.1	1.5
GDM $m_{3/2} = 10$ GeV	$\mu > 0$	1.1	1.7
	$\mu < 0$	1.1	1.4
GDM $m_{3/2} = 100$ GeV	$\mu > 0$	2.6	2.9
	$\mu < 0$	2.6	3.5
GDM $m_{3/2} = 0.2m_0$	$\mu > 0$	2.5	2.7
	$\mu < 0$	2.6	3.0
GDM $m_{3/2} = m_0$	$\mu > 0$	1.7	1.8
	$\mu < 0$	1.7	1.9



In most cases the LVSP is the τ but often there is a lower threshold due to the associated production of $\chi\ \chi_2$



Concordance of BBN with WMAP

Cyburt, Fields, KAO

Possible sources for the Li discrepancy

- Stellar Depletion
  - lack of dispersion in the data, ^{6}Li abundance
  - standard models (< .05 dex), models (0.2 - 0.4 dex)

Vauclaire & Charbonnel
Pinsonneault et al.

- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

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- Nuclear Rates
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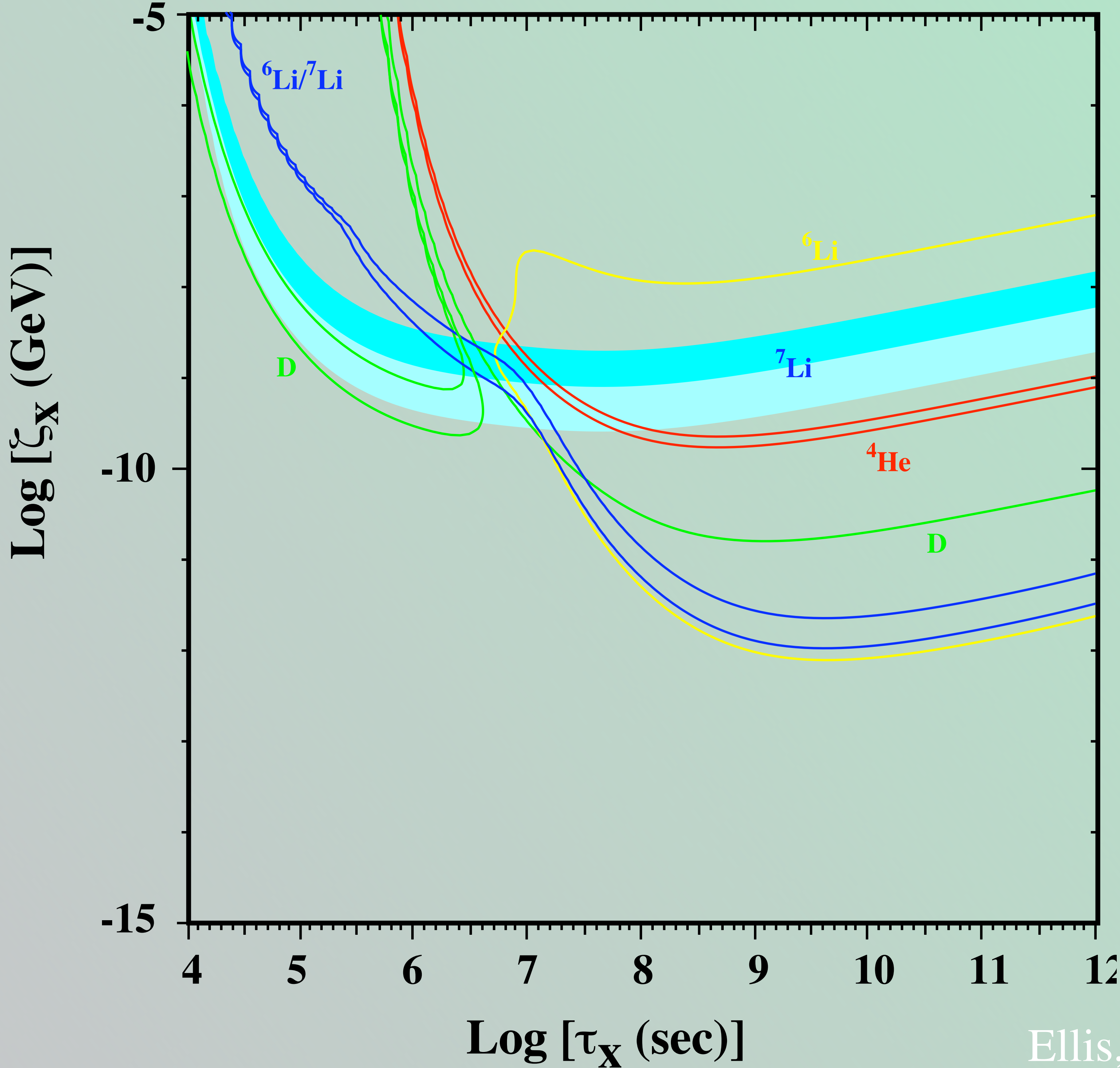
Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

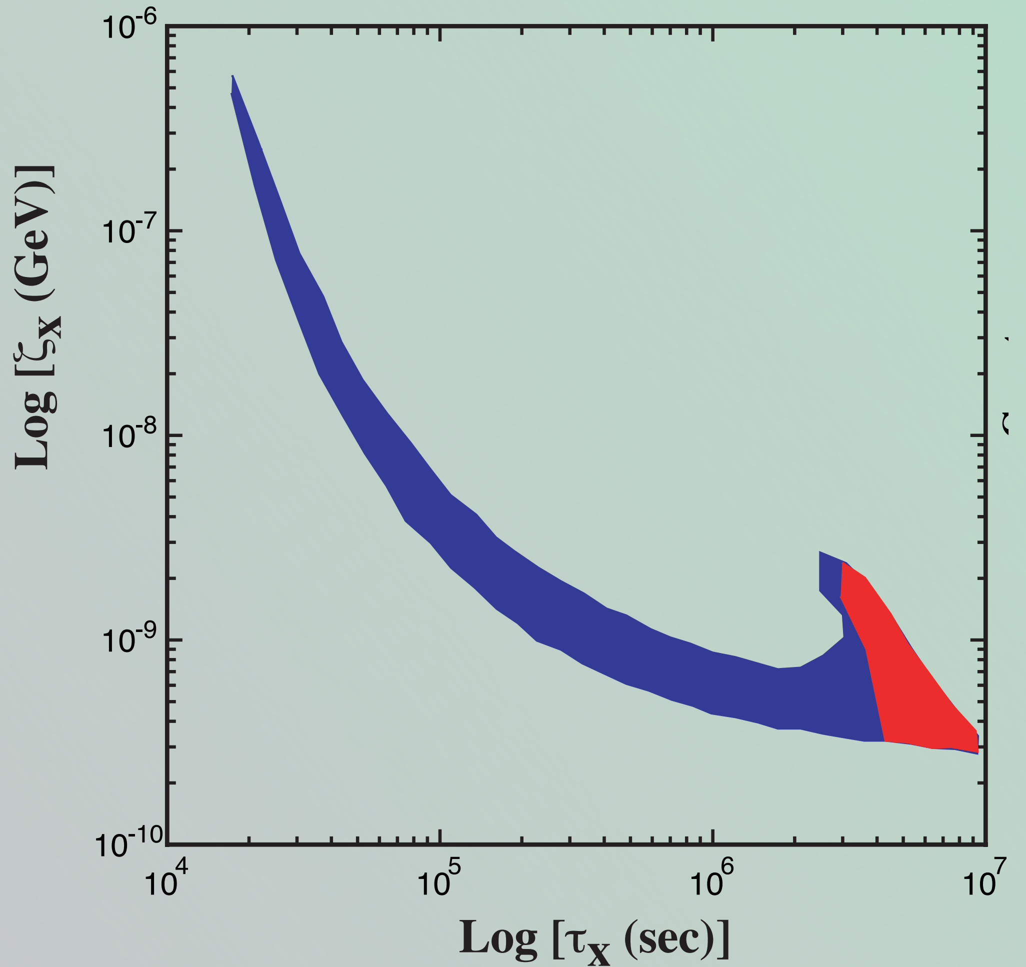
- Particle Decays

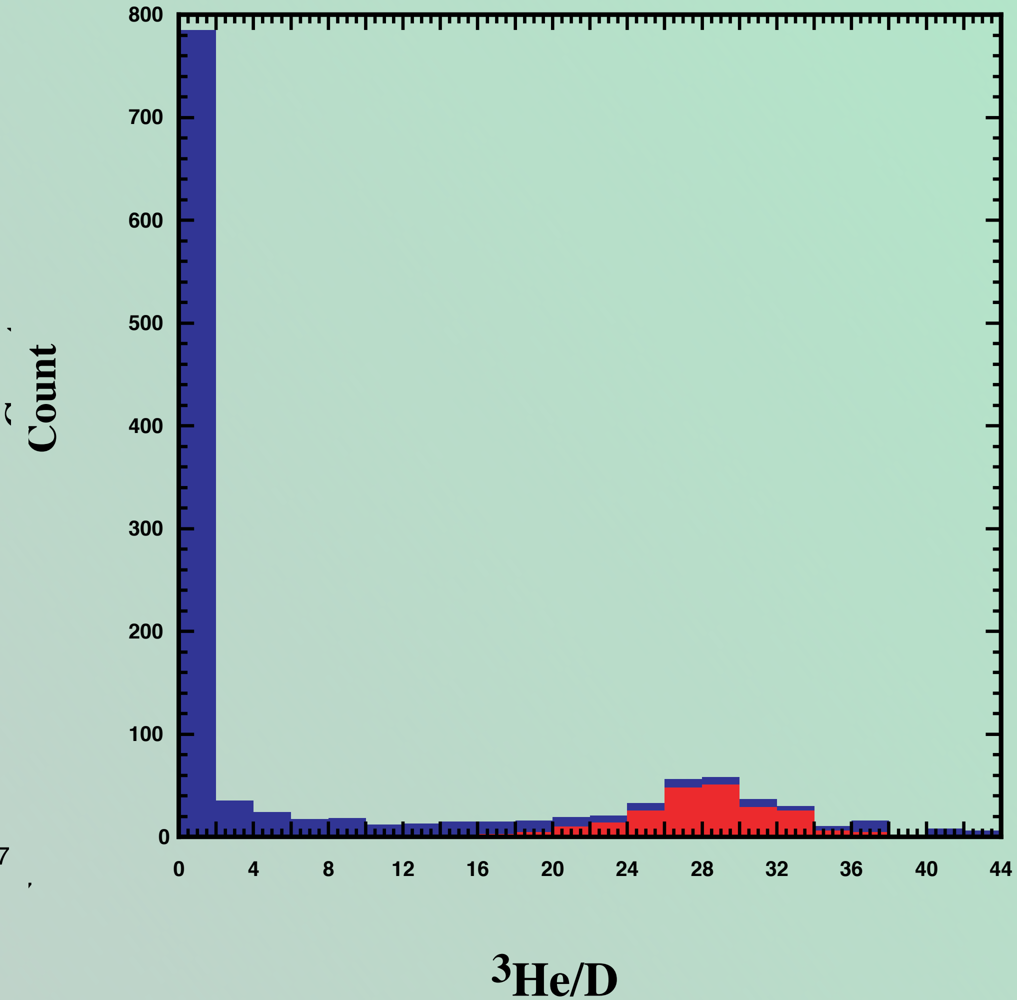


Jedamzik
Feng et al.
Ellis, KAO, Vangioni

Blue: D/H > 1.3 x 10^{-5}

Red: D/H > 2.2 x 10^{-5}





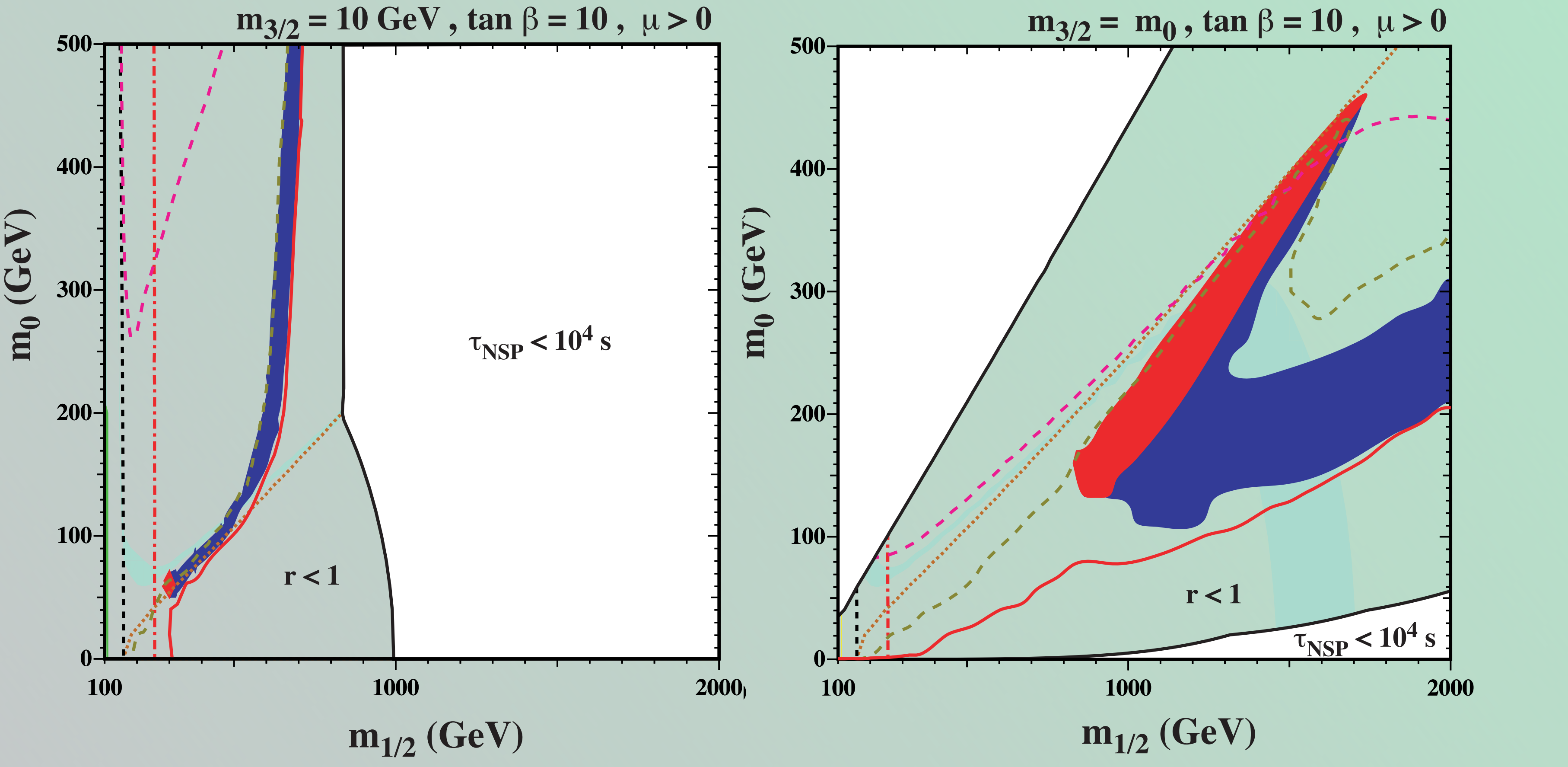
Require ^{3}He/D < 1

Ellis, KAO, Vangioni

Regions in the plane with Li/H < 3 x 10^{-10}

Blue: D/H > 1.3 x 10^{-5}

Red: D/H > 2.2 x 10^{-5}



Ellis, KAO, Vangioni

Regions in the plane with Li/H < 3 x 10^{-10}

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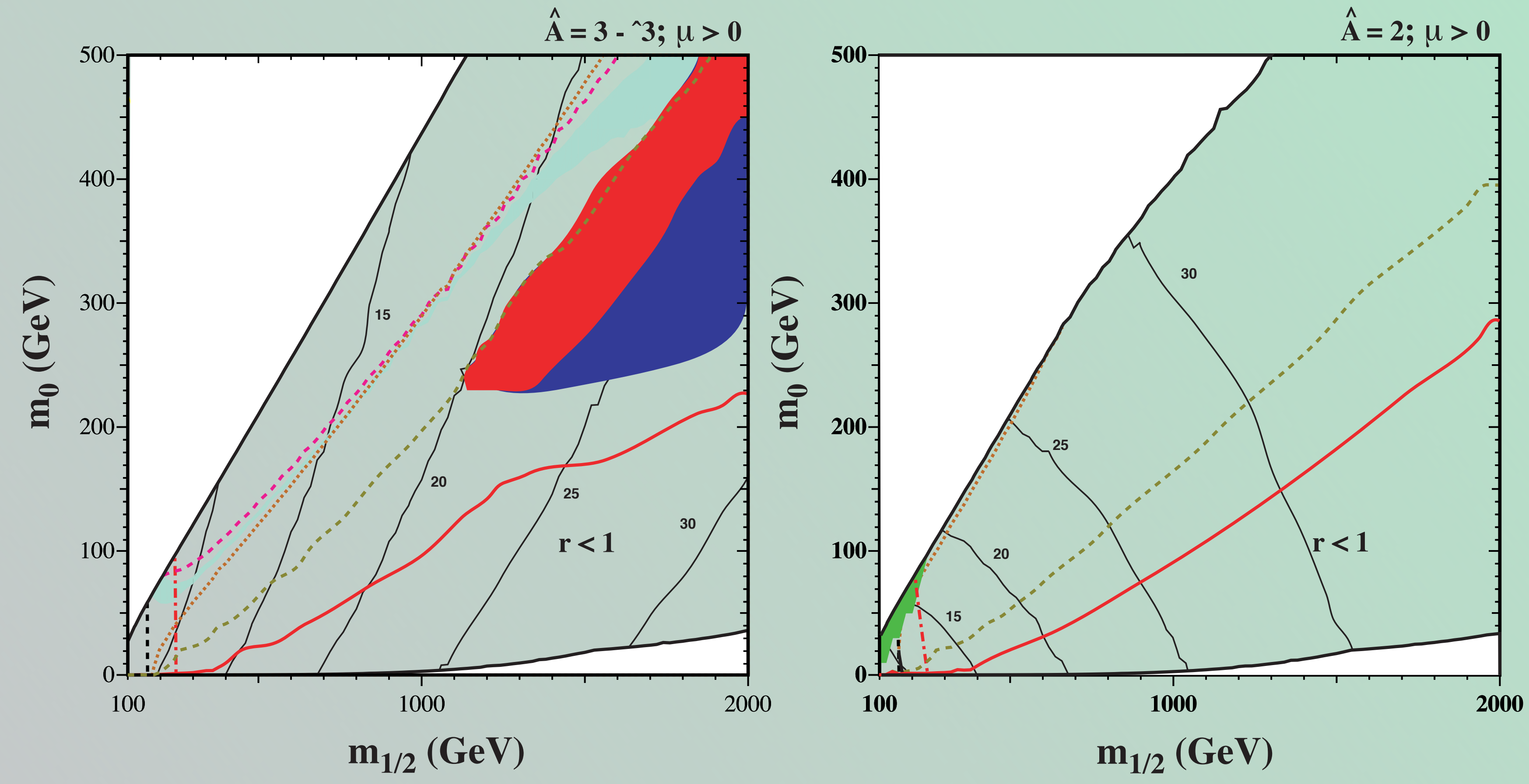
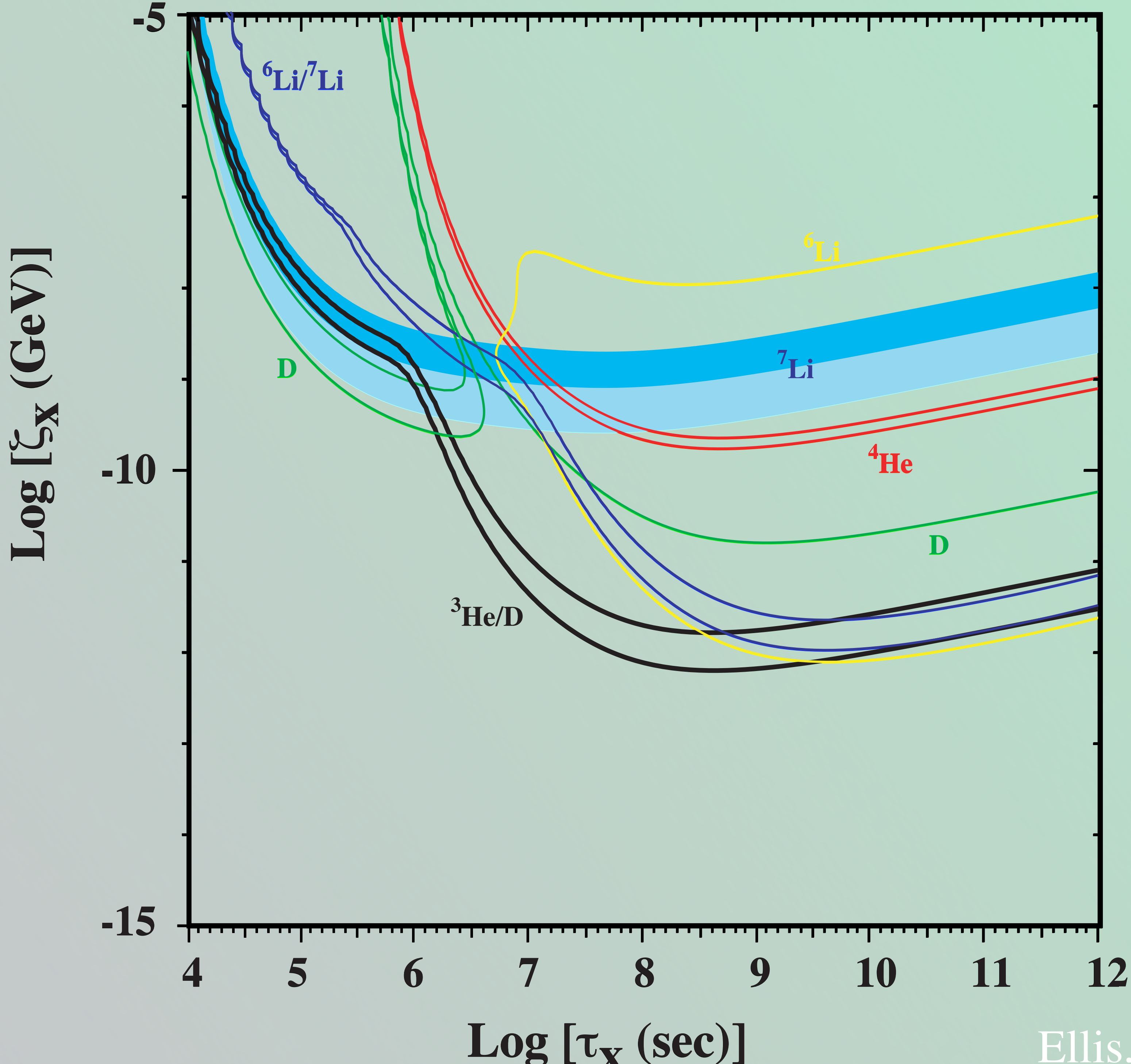


Ellis, KAO, Vangioni



Ellis, KAO, Vangioni

Summary

- CMSSM Dark Matter:

Bulk regions; stau-coannihilation; A-pole funnel; focus point

- Spectrum Uncertainties: Limits excludable regions;

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

- VCMSSM ($B_0 = A_0 - m_0$) ($m_0 = m_{3/2}$)
  - Restricted range for tan β for a given A_0.
    - – No funnels or focus point
    - – much of the parameter space predicts gravitino dark matter
- Gravitino Dark Matter
  - More parameter space allowed (including stau NLSP)
    - * Can not resolve Li problem