Supersymmetric Dark Matter with Nonuniversal Gaugino Masses and Yukawa Unifications

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References: Nonuniversal Gaugino Masses/GUT

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Introduction

- In minimal supergravity (mSUGRA) or CMSSM one starts from the unification scale ($Q = M_G \sim 2 \times 10^{16}$ GeV) with the following universal input parameters m_0, $M_{1/2}$, and A_0 for the scalar, gaugino and trilinear terms respectively
- RG evolutions determine the low energy parameters.
- Radiative breaking of electroweak symmetry is used which gives μ at $Q = M_Z$:

$$\frac{1}{2}M_Z^2 = \frac{m_{H_D}^2 - m_{H_U}^2 \tan^2\beta}{\tan^2\beta - 1} - |\mu|^2 + \Delta_R, \quad (1)$$

$$\sin 2\beta = \frac{-2B\mu}{m_{H_D}^2 + m_{H_U}^2 + 2\mu^2} \quad (2)$$

where, $\tan\beta = < H_U > / < H_D >$. Δ_R comes from the one loop radiative correction to the Higgs potential.

Nonuniversal Scenarios: Motivation

- Nature of Planck scale physics is not very clear yet— possibility of a curved Kähler potential and nongauge singlet gauge kinetic energy functions can result in non-minimal supergravity type of models
- Nonuniversalities in the scalar sector are severely constrained by FCNC limits. However, the bounds are not so stringent for the Higgs doublet scalar sector and the third generation scalars.
- Here we consider nonuniversalities only in gaugino masses
- Motivation: Yukawa unifications like $b - \tau$ unification can not be achieved for $\mu > 0$ for mSUGRA whereas $g_\mu - 2$ result indicates $\mu > 0$ as well as $b \to s + \gamma$ favours the same sign of μ. $b - t - \tau$ unification however could be achieved with the introduction of D-terms in a limited range of parameter space

Nonuniversal Gaugino Masses

- Gaugino masses depend on the gauge kinetic energy functions $f_{\alpha\beta}(\Phi)$, where Φ is a chiral superfield (if we consider SU(5) $\alpha, \beta =$1,2....24)
- Gauge Kinetic Energy Function $\Rightarrow$ Gauge singlet part + Non-gauge singlet part (mSUGRA has only the gauge singlet part)
- $f_{\alpha\beta}(\Phi)$ transforms like the symmetric product of adjoints. Considering SU(5)

$$(24 \times 24)_{SYMM} = 1 + 24 + 75 + 200 \tag{3}$$

- Gaugino masses come from a condensation of the F-component of Φ with the above representations ie. $r = 1, 24, 75, 200$
- We will consider only the $r = 24$ case which satisfies our motivation of doing the analysis. For this case one finds: At $Q = M_G$: $M_3 : M_2 : M_1 = 2 : -3 : -1$ which leads to $M_3 : M_2 : M_1 = 12 : -6 : -1$ at $Q = M_Z$ (in mSUGRA: the ratio is $6 : 2 : 1$ at $Q = M_Z$)
- We also have identified similar scenarios in SO(10) while satisfying $b - t - \tau$ unifications besides the other constraints

Yukawa Unifications and b-quark SUSY correction

- $\lambda_b - \lambda_\tau$ unification as well as $\lambda_t - \lambda_b - \lambda_\tau$ Yukawa unifications crucially depend on the supersymmetric correction to the b quark mass
- $$m_b(M_Z) = \lambda_b(M_Z)\frac{v}{\sqrt{2}}\cos\beta(1+\Delta_b) \qquad (4)$$

  where Δ_b is loop correction to m_b The largest contribution comes from the gluino piece:

$$\Delta_b^{\tilde{g}} = \frac{2\alpha_3\mu M_{\tilde{g}}}{3\pi}\tan\beta I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, M^2_{\tilde{g}}) \qquad (5)$$

$$I(a,b,c) = \frac{abln(a/b) + bcln(b/c) + acln(c/a)}{(a-b)(b-c)(a-c)} \qquad (6)$$

Since I is always positive, $\Delta_b^{\tilde{g}}$ is negative when $\mu M_{\tilde{g}}$ is negative ($\Rightarrow \mu > 0, M_{\tilde{g}} < 0$ or $\mu < 0, M_{\tilde{g}} > 0$)

$$\Delta_b^{\tilde{\chi}^+} = \frac{Y_t\mu A_t}{4\pi}\tan\beta I(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, \mu^2) \qquad (7)$$

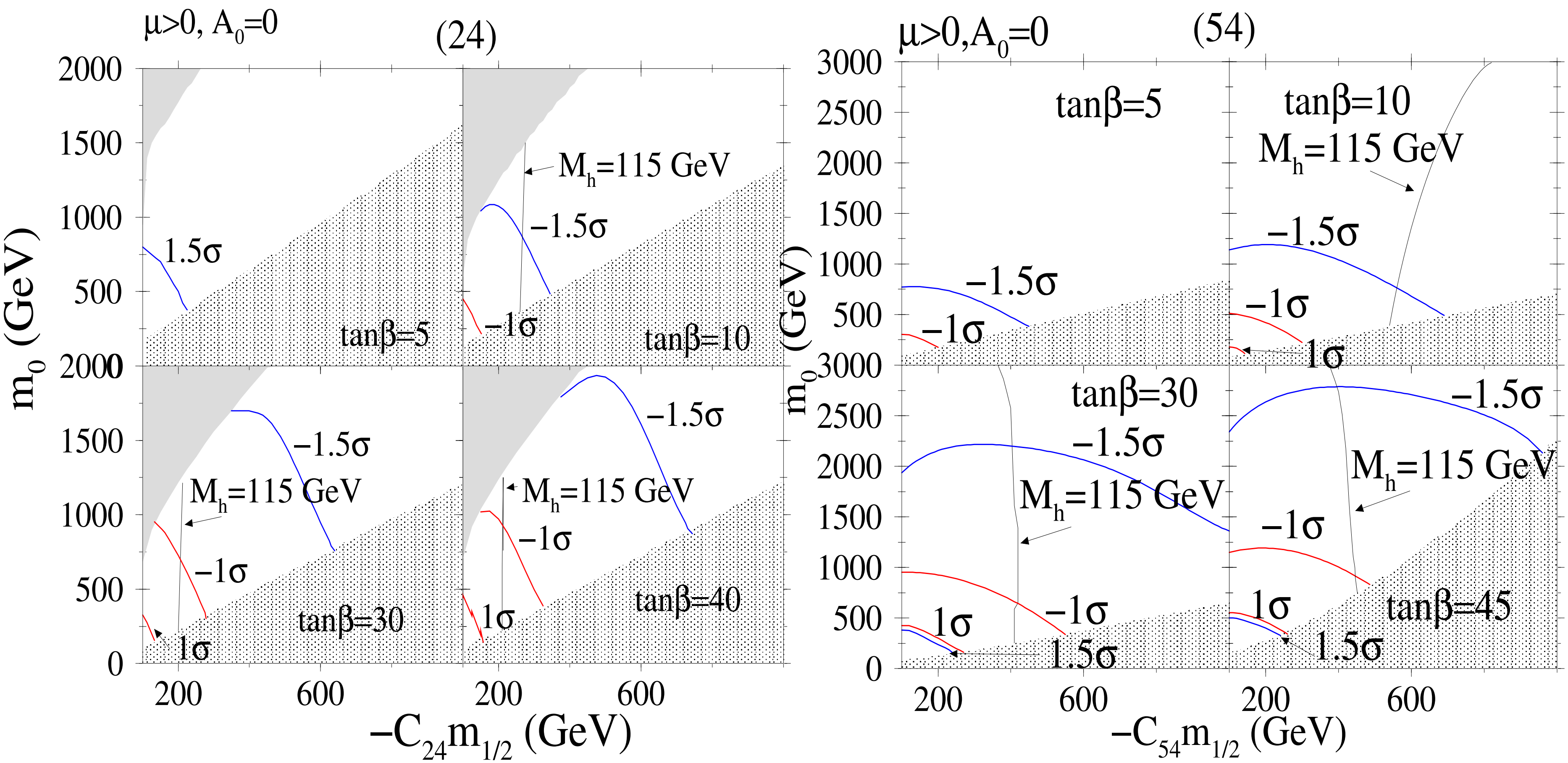
where $Y_t = \lambda_t^2/4\pi$

b-quark SUSY correction contd.

• $\lambda_b - \lambda_\tau$ unification requires a negative Δ_b. Hence in mSUGRA one finds $b-\tau$ unification only for $\mu < 0$.

- One finds that with $\mu > 0$, and $m_3(M_{GUT}) < 0$, the RG evolution of the gaugino masses upto M_Z will be such that, at the scale M_Z, $\mu m_2 > 0$ and $\mu M_{\tilde{g}} < 0$.
- Thus $b-\tau$ unification (essentially an appropriate negative amount for Δ_b) and the important constraints from $g_\mu - 2$ as well as $b \to s + \gamma$ can be simultaneously satisfied for the $r = 24$ case of SU(5) in contrast to the other cases like $r = 75$ and $r = 200$. $>$

Figures: m_0 vs $m_3(M_G)$



$C_{24}m_{1/2} = 0.5m_3(M_G)$ and $C_{54}m_{1/2} = 0.5m_3(M_G)$

Results: parameter ranges

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- Unlike mSUGRA $b - \tau$ unification allows a broader range of $\tan\beta$: $10 < \tan\beta < 45$. When $b \to s + \gamma$ and a_μ^{SUSY} constraints are imposed: $25 < \tan\beta < 45$.

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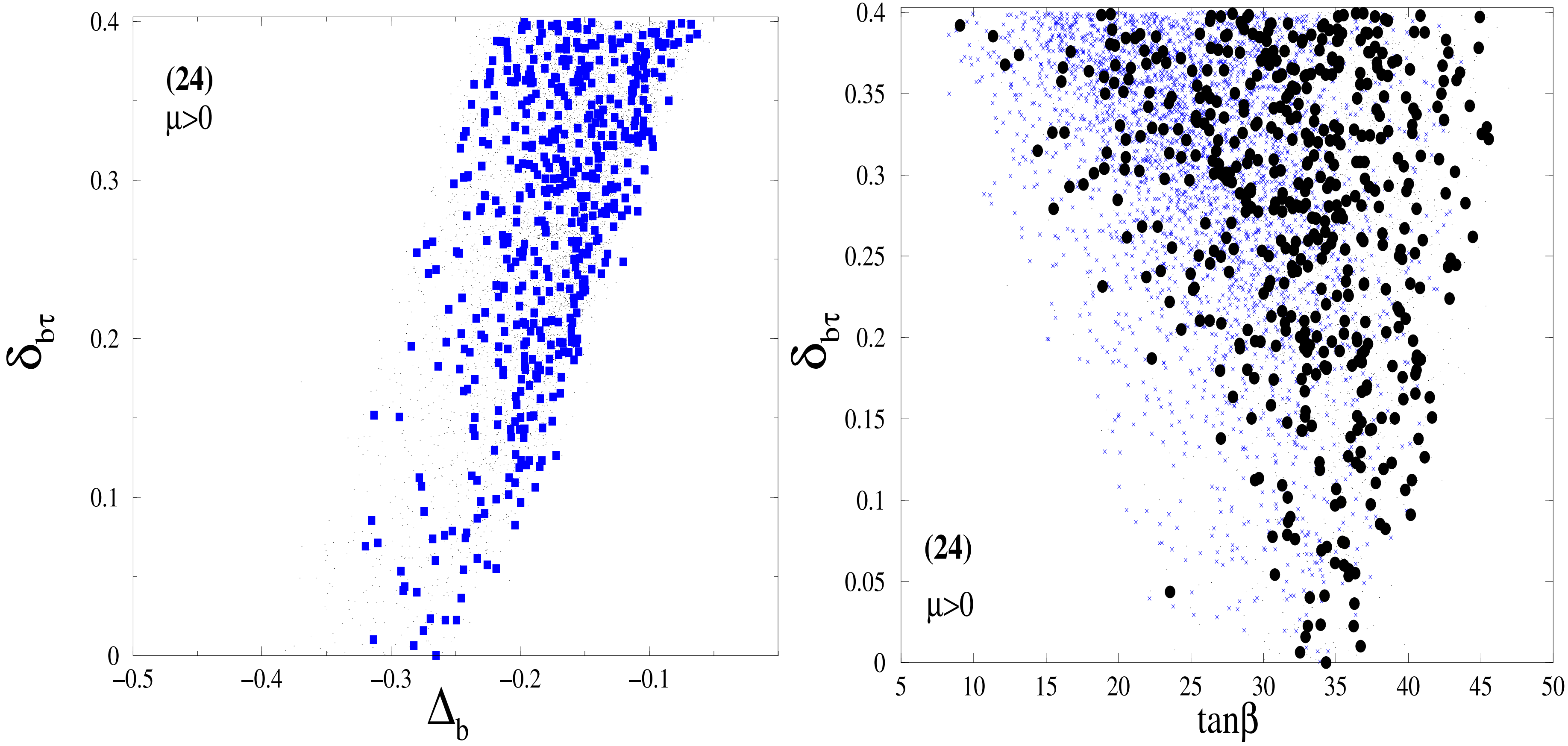
- Unlike mSUGRA $b - \tau$ unification allows a broader range of $\tan\beta$: $10 < \tan\beta < 45$. When $b \to s + \gamma$ and a_μ^{SUSY} constraints are imposed: $25 < \tan\beta < 45$.
- $400\ \mathrm{GeV} < m_0 < 1200\ \mathrm{GeV}$, $-200\ \mathrm{GeV} < C_{24} m_{1/2} = 0.5 m_3(M_G) < 0$ and $-2\ \mathrm{TeV} < A_0 < -500\ \mathrm{GeV}$

Figures: $\delta_{b\tau} - \Delta_b$ and $\delta_{b\tau} - \tan\beta$

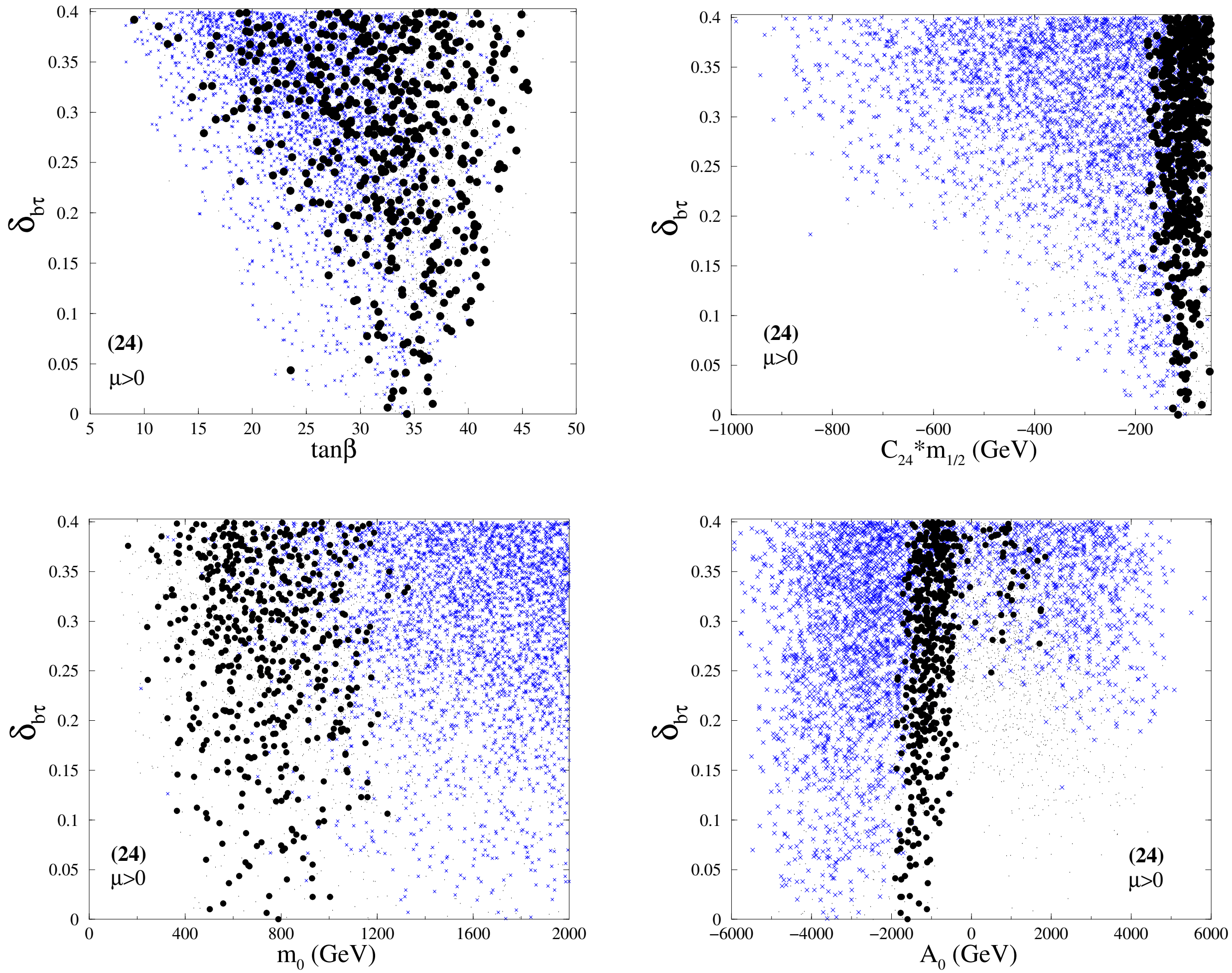


Left:dots:$b - \tau$ unification, squares: $b \rightarrow s + \gamma$ and a_μ

Right: dots:$b - \tau$ unification, cross:$b \rightarrow s + \gamma$ and circles: a_μ

Figures: 4 Figs with $b - \tau$ unification for (24)

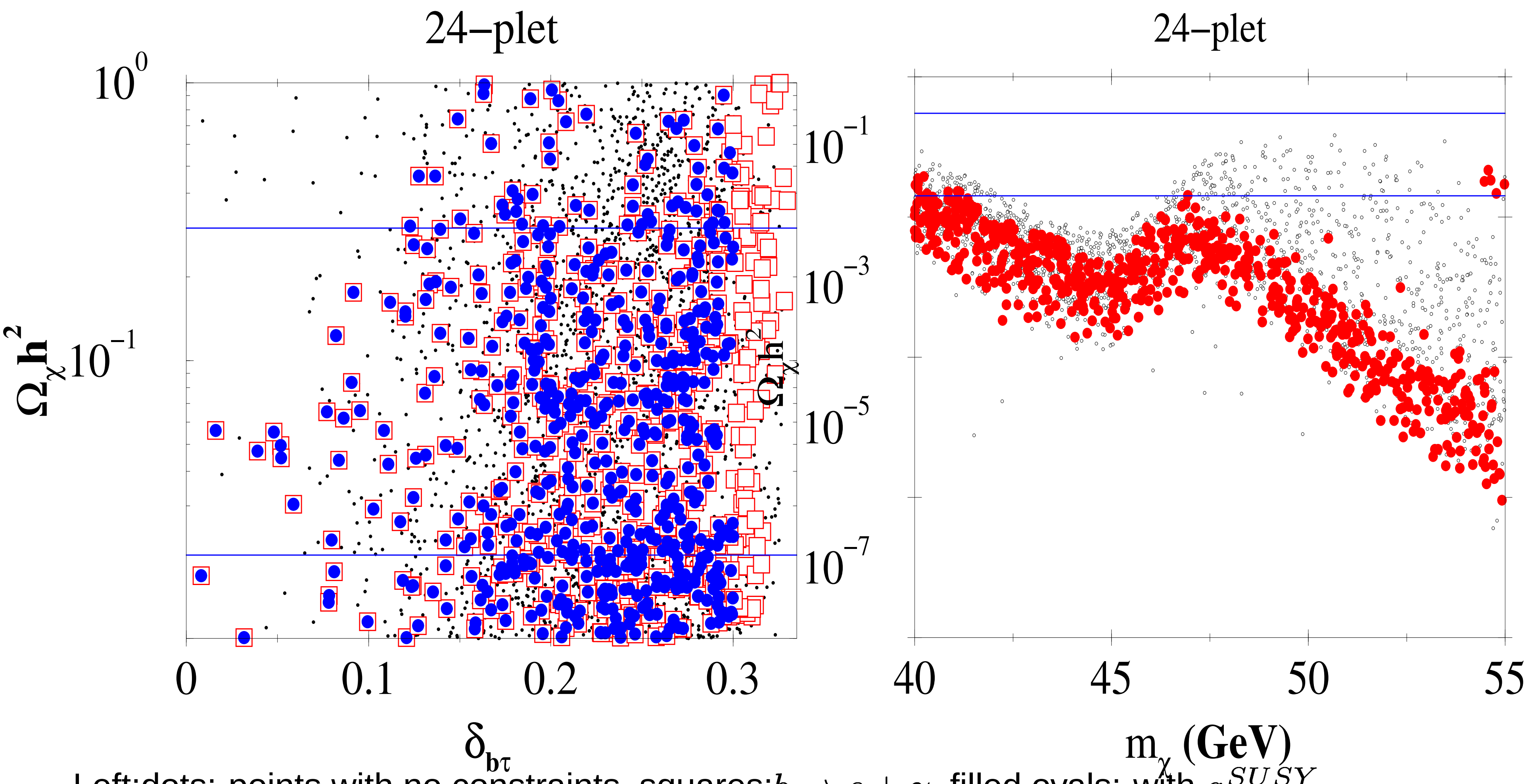
$\tan\beta < 55$, $m_0 < 2$ TeV, $-1\text{TeV} < C_{24} m_{1/2} = 0.5 \times m_3(M_G) < 1$ TeV,
-6 TeV $< A_0 < 6$ TeV



Neutralino Relic Density

- Lightest neutralino can be a strong candidate for cold dark matter
- We imposed the limit $0.02 < \Omega_\chi h^2 < 0.3$ for the neutralino relic density limits. Here, Ω_χ is the ratio of neutralino relic density and critical matter density and h is the value of Hubble parameter in units of 100 km/s Mpc
- The upper limit of lightest neutralino when neutralino relic density constraint is imposed in addition to requiring appropriate Yukawa unifications, and the constraints from $b \to s + \gamma$ and a_μ^{SUSY}, is significantly smaller in both the nonuniversal gaugino mass scenarios of SU(5) and SO(10) (~ 75 GeV).
- Detection Rate: In the $r = 24$ nonuniversality case one has a broader range for $\sigma_{\chi p}$ (scalar) compared to what is found in mSUGRA
$4 \times 10^{-45} cm^2 \leq \sigma_{\chi p}\ (\mathrm{scalar}) \leq 4 \times 10^{-41} cm^2$
- The future dark matter detectors already propsed will probe the full parameter space of such nonuniversal gaugino mass scenarios

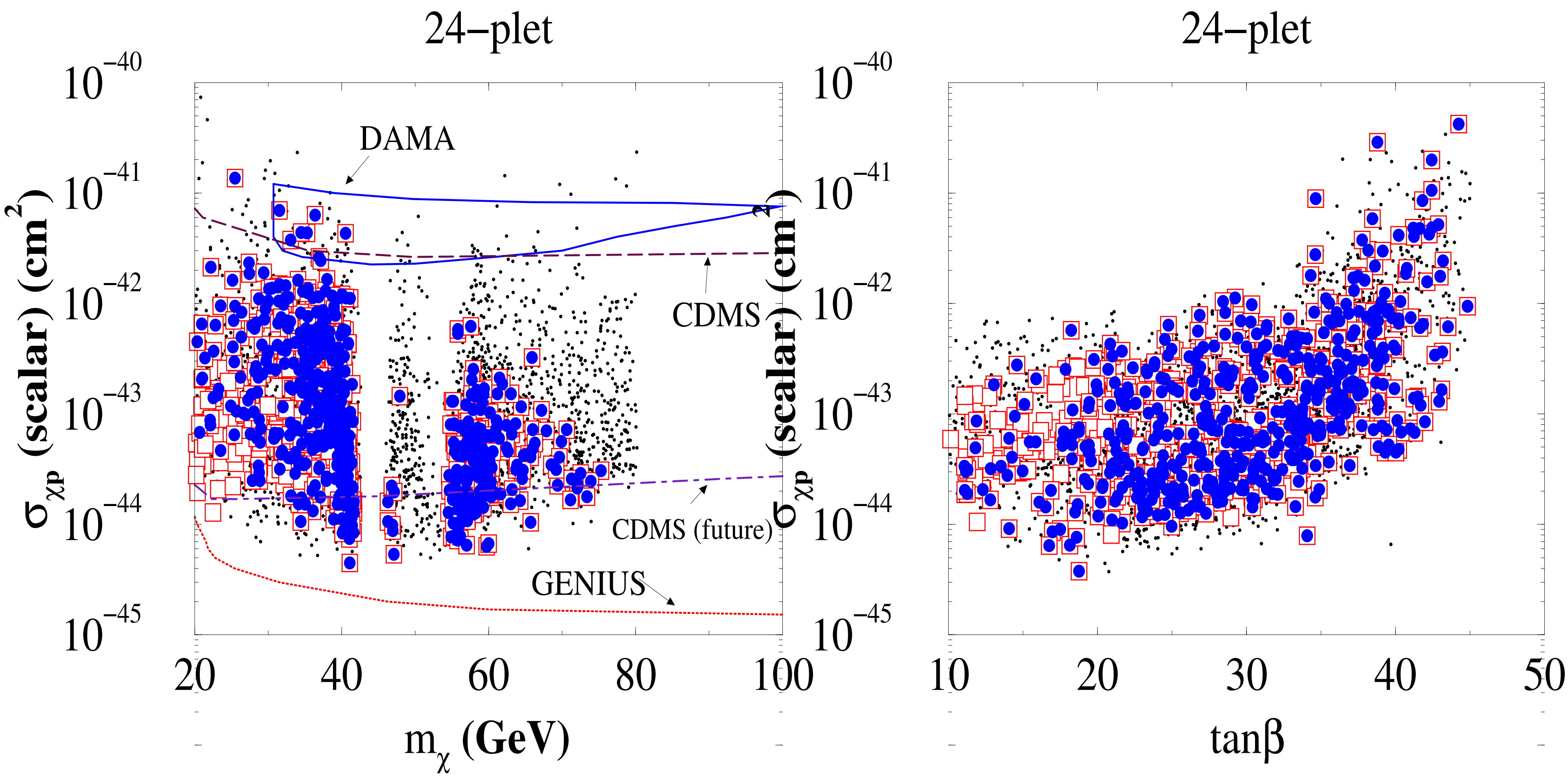
Figures: $\Omega_\chi h^2 - \delta_{b\tau}$ and $\Omega_\chi h^2 - m_\chi$ for (24)



Left:dots: points with no constraints, squares:$b \to s + \gamma$, filled ovals: with a_μ^{SUSY}

Right:dots: points with no constraint, filled ovals: $b \to s + \gamma$, a_μ^{SUSY} and $\delta_{b\tau} < 0.1$

Figures: $\sigma_{\chi p} - m_\chi$ and $\sigma_{\chi p} - \tan\beta$ for (24)



dots: points with a_μ^{SUSY}, squares:$b \to s + \gamma$, filled ovals: additionally $\delta_{b\tau} < 0.3$

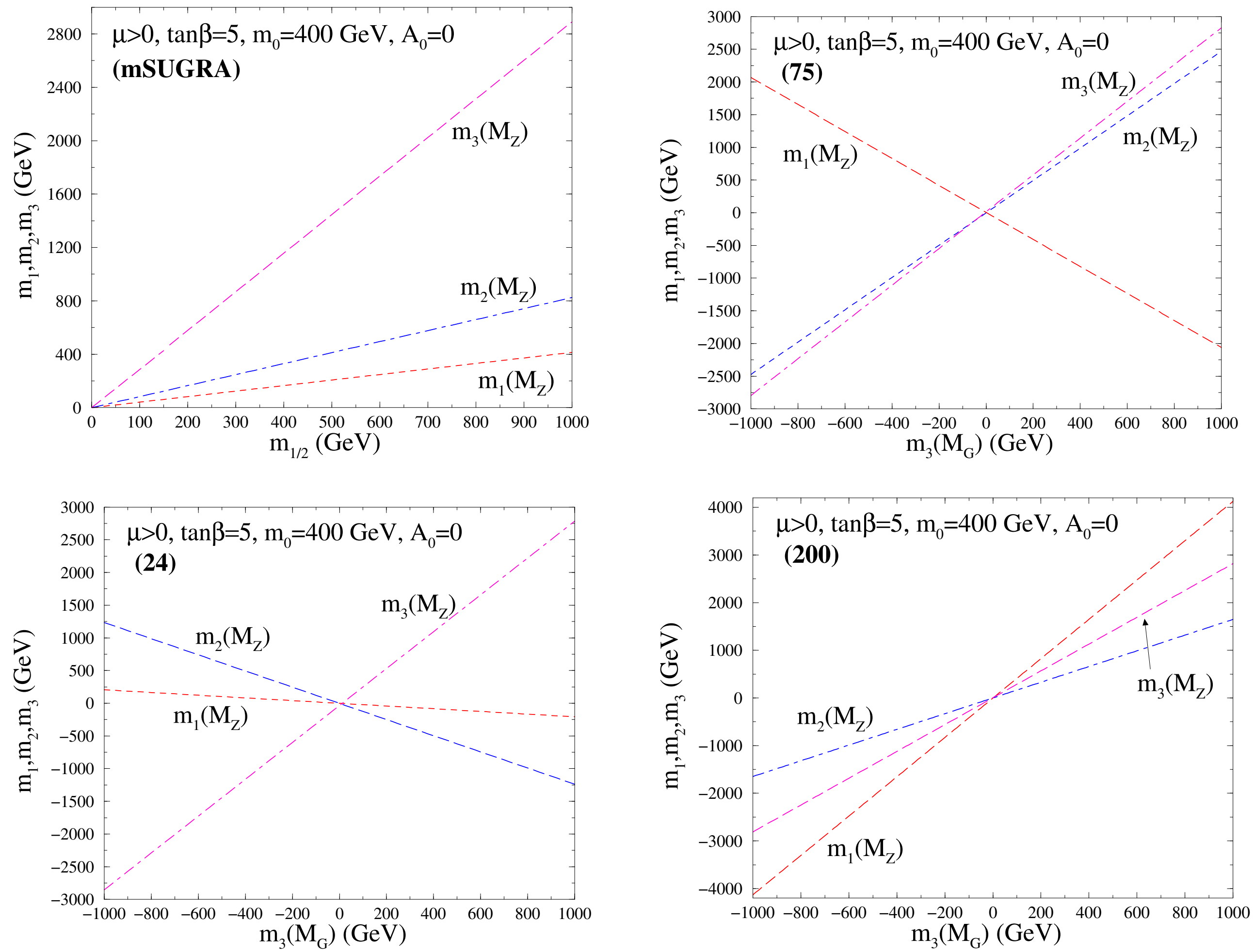
Relic density constraint imposed

Nonuniversal Gaugino Masses in SO(10)

- $$(45 \times 45)_{SYMM} = 1 + 54 + 210 + 770 \quad (7)$$
- $SO(10) \rightarrow SU(4) \times SU(2) \times SU(2) \rightarrow SU(3) \times SU(2) \times U(1)$
  At $Q = M_G$: $M_3 : M_2 : M_1 = 1 : -3/2 : -1$
- $SO(10) \rightarrow SO(2) \times SO(7) \rightarrow SU(3) \times SU(2) \times U(1)$
  At $Q = M_G$: $M_3 : M_2 : M_1 = 1 : -7/3 : 1$
- In both cases $r = 54$ is the candidate which satisfies similar constraints along with $b - t - \tau$ unification.
- Here we used $m^2_{H_d} = 1.5 m^2_0$ and $m^2_{H_u} = 0.5 m^2_0$ to achieve Radiative Electroweak Symmetry Breaking.

Figures: 4 Figs for gaugino masses for (24), (75) and (200)

gaugino masses:



Figures: Relic density combined display for (24)

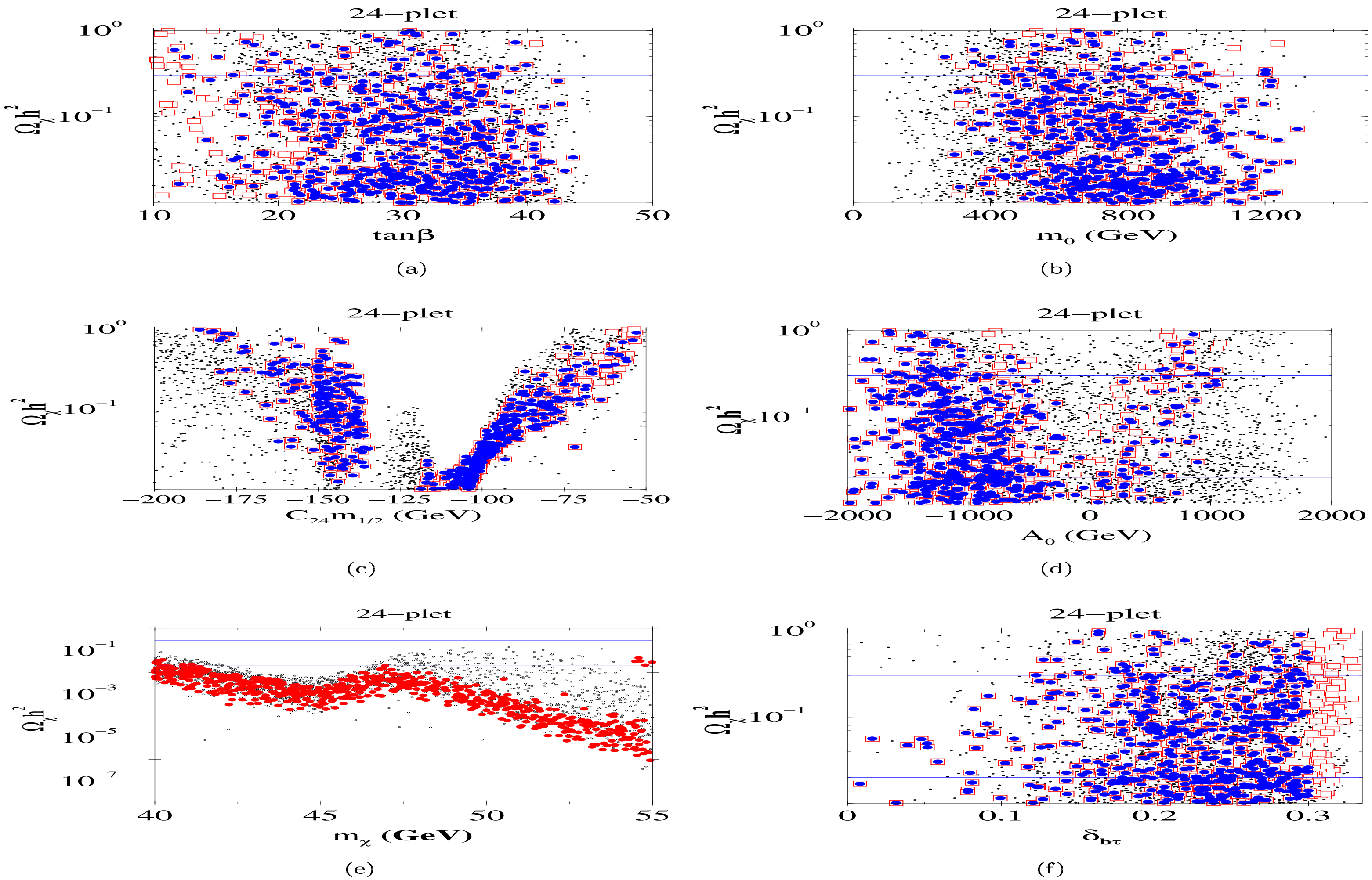


Figure 3:

Figures: Relic density combined display for (54)

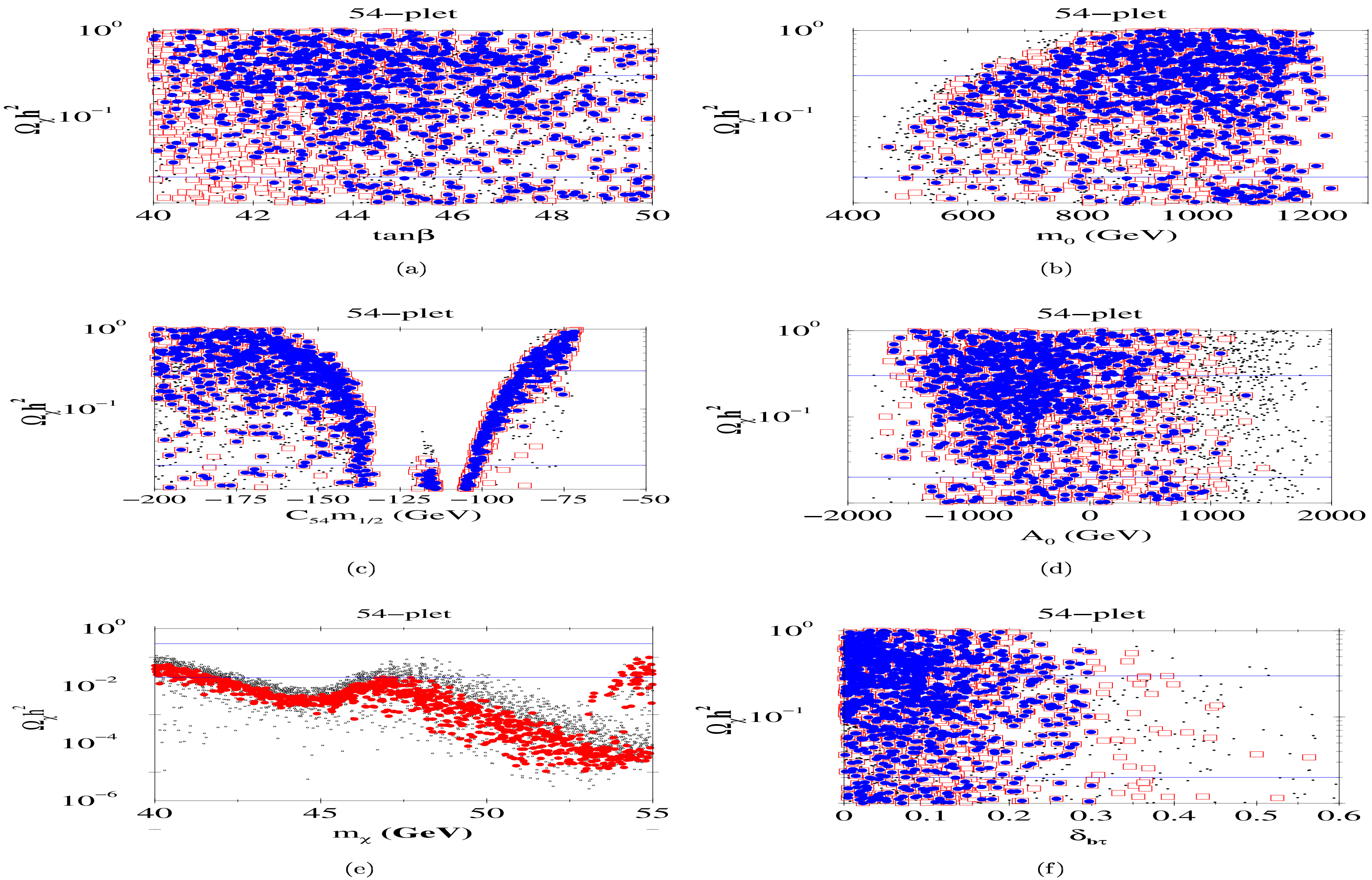


Figure 4:

Figures: Detection rates combined display for all

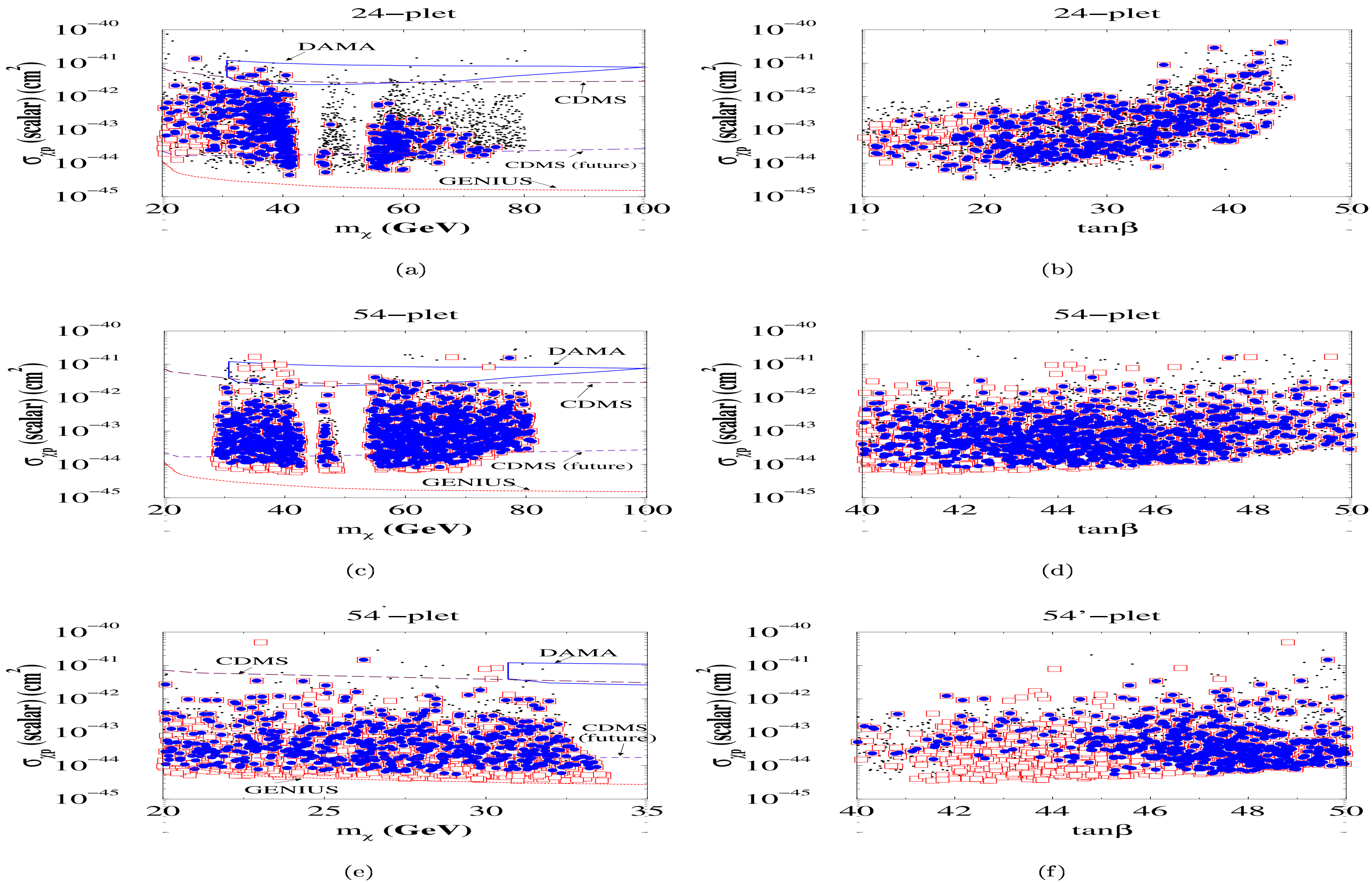


Figure 5:

Figures: Neutralino Dark Matter for mSUGRA