A SUSY $SO(10)$ GUT with 2 Intermediate Scales

Manuel Drees

Bonn University & Bethe Center for Theoretical Physics

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Based on:

MD, Ju Min Kim, arXiv:0810.1875v1 (JHEP);

MD, Ju Min Kim, Eun-Kyung Park, to appear very soon

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- Instead, in $SO(10)$: ν_R required to fill $\underline{16}$ with matter (s)fermions!
- Naturally allows to implement see–saw mechanism!

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- Need $m_{\nu_3} > 50$ meV!
- $\Longrightarrow$ need $M_{\nu_R} \leq 5 \cdot 10^{14}$ GeV!

The model

Ref: al. et Senjanovic, Nucl. Phys B597 (2001) 89

$SO(10) \longrightarrow SU(4) \otimes SU(2)_L \otimes SU(2)_R \otimes D$ at M_X using $\underline{54}$

$\longrightarrow SU(3)_C \otimes U(1)_{B-L} \otimes SU(2)_L \otimes SU(2)_R$ at M_C using $\underline{45}$

$\longrightarrow SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ at M_R using $\underline{126}, \overline{\underline{126}}$

D: Discrete symmetry, ensures parity (same L and R couplings)

Higgs fields

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$$\begin{aligned}
54 &= (1,1,1) \oplus (20,1,1) \oplus (1,3,3) \oplus (6,2,2)\,; \\
45 &= (15,1,1) \oplus (1,1,3) \oplus (1,3,1) \oplus (6,2,2)\,; \\
\overline{126} &= (10,1,3) \oplus (\overline{10},3,1) \oplus (15,2,2) \oplus (6,1,1)\,; \\
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\end{aligned}$$

Decomposition under $SU(4) \otimes SU(2)_L \otimes SU(2)_R$; components obtaining vev are written first.

Higgs spectrum

State	Mass
all of $\underline{54}$ all of $\underline{45}$, except $(15,1,1)_{45}$ all of $\underline{126}$ and $\overline{\underline{126}}$, except $\underline{10}$, $\overline{\underline{10}}$ of $SU(4)$	M_X
$(\overline{10},3,1)_{\overline{126}}$ and $(10,3,1)_{126}$ $\underline{3}$, $\underline{6}$ of $SU(3)_C$ in $(10,1,3)_{\overline{126}}$ and $(\overline{10},1,3)_{126}$ color triplets of $(15,1,1)_{45}$	M_C
$(\delta^0 - \overline{\delta}^0), \quad \delta^+, \quad \overline{\delta}^-$	M_R
color octet and singlet of $(15,1,1)_A$	$\tilde{M}_1 \equiv \max\left[\frac{M_R^2}{M_C}, \frac{M_C^2}{M_X}\right]$
$(\delta^0 + \overline{\delta}^0), \quad \delta^{++}, \quad \overline{\delta}^{--}$	$\tilde{M}_2 \equiv M_R^2/M_X$

$\delta = (1,1,3)_{126}; \; \overline{\delta} = (1,1,3)_{\overline{126}}$

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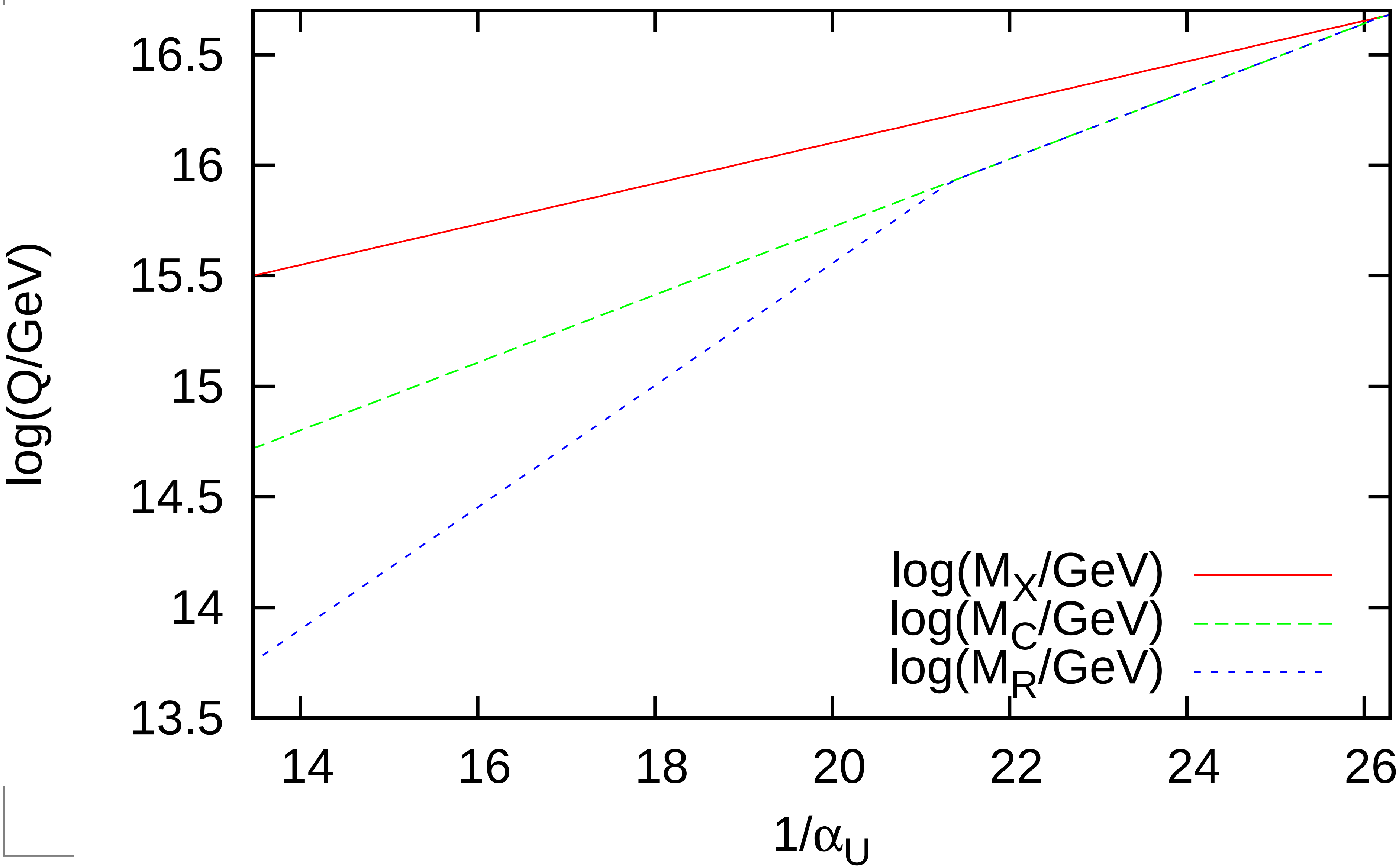
- In particular, $M_X = M_C = M_R$ remains possible: allows smooth transition to "Grand Desert"
- Introduce second pair of $\underline{10}$, $\overline{10}$ with mass M_2, to allow more realistic fermion masses (see below).

Relation between scales



Superpotential above M_C

$$W = Y_1 F^c F \Phi_1 + \frac{1}{2} Y_N \left(F^c \bar{\Sigma}_R F^c + F \bar{\Sigma}_L F \right)$$

$F = (4, 2, 1)$: left–handed matter fields
$F^c = (\bar{4}, 1, 2)$: right–handed matter fields
$\Phi_{1,2} = (1, 2, 2)$: Higgs bi–doublets
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Y_N generates ν_R mass!

Superpotential between M_R and M_C

$$W = Y_{q_1} Q^c Q \Phi_1 + Y_{l_1} L^c L \Phi_1 + \frac{1}{2} Y_N L^c \bar{\delta} L^c$$

$Q^c = (\bar{3}, 1, 2, -1/3)$: right–handed quarks
$Q = (3, 2, 1, 1/3)$: left–handed quarks
$L^c = (1, 1, 2, 1)$: right–handed leptons
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$\bar{\delta} = (1, 1, 3, -2)$: breaks $SU(2)_R \otimes U(1)_{B-L} \rightarrow U(1)_Y$.

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Matching condition at $E = M_C$:

$$Y_{q_1} = Y_{l_1} = Y_1$$

Superpotential between M_R and $\tilde{M}_2$

$$W = Y_{u_1} U^c Q H_{u_1} + Y_{d_1} D^c Q H_{d_1} + Y_{l_1} E^c L H_{d_1} + \frac{1}{2} Y_N E^c \bar{\delta}^{--} E^c$$

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$$H_{u,d} = \cos\varphi_{u,d} H_{(u,d)_1} + \sin\varphi_{u,d} H_{(u,d)_2} \Longrightarrow Y_{u,d} = Y_{(u,d)_1} \cos\varphi_{u,d}$$

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$$\Longrightarrow \cos\varphi_d = \frac{Y_d(M_2)}{Y_u(M_R)} \left[\frac{g_1^2(M_R)}{g_1^2(M_2)} \right]^{1/60}$$

$\Longrightarrow Y_{d_1} \simeq Y_{u,1}$: always in “large $\tan\beta$” scenario for $E \geq \tilde{M}_2$!

Gaugino masses

Assume unified boundary conditions: scalar mass m_0, gaugino mass $M_{1/2}$, single parameter A_0.

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E.g. for $M_X = 3 \cdot 10^{15}$ GeV (minimal value):

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Ratios $M_1 : M_2 : M_3$ same as in mSUGRA!

Sfermion masses ($1^{\rm st}$ generation)

For fixed M_i, get larger gaugino loop contributions to sfermion masses; partly cancels previous effect when expressed in terms of $M_{1/2}$:

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$c_{\tilde e_R} = 0.15$ (as in mSUGRA);
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$m_{\tilde e_R} \geq 1.68|M_1|$: No co–annihilation of $\tilde\chi_1^0$ with $\tilde e_R$, $\tilde\mu_R$!
$m_{\tilde e_L} \geq |M_2|$: No $\widetilde{W} \to \tilde\ell_L$ decays!
$m_{\tilde q} \geq 0.75 m_{\tilde g}$: Similar to mSUGRA

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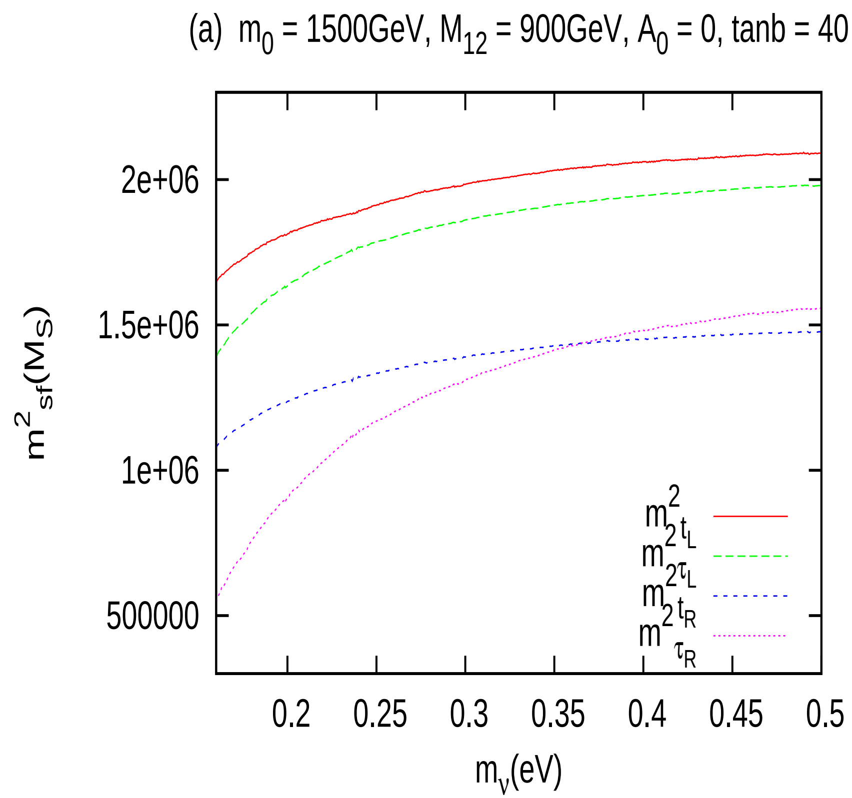
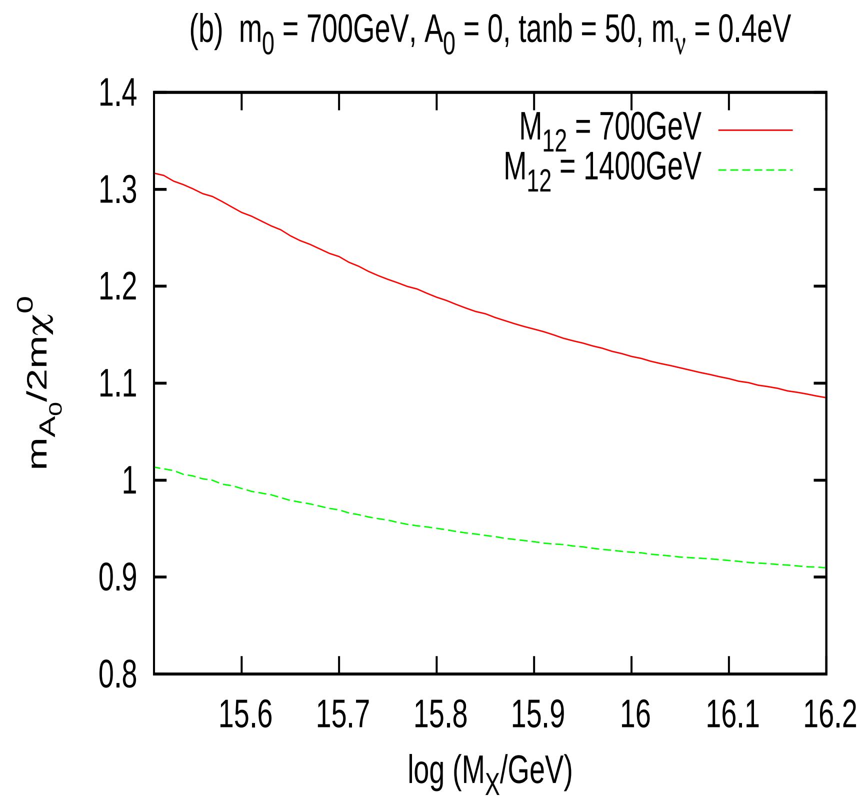
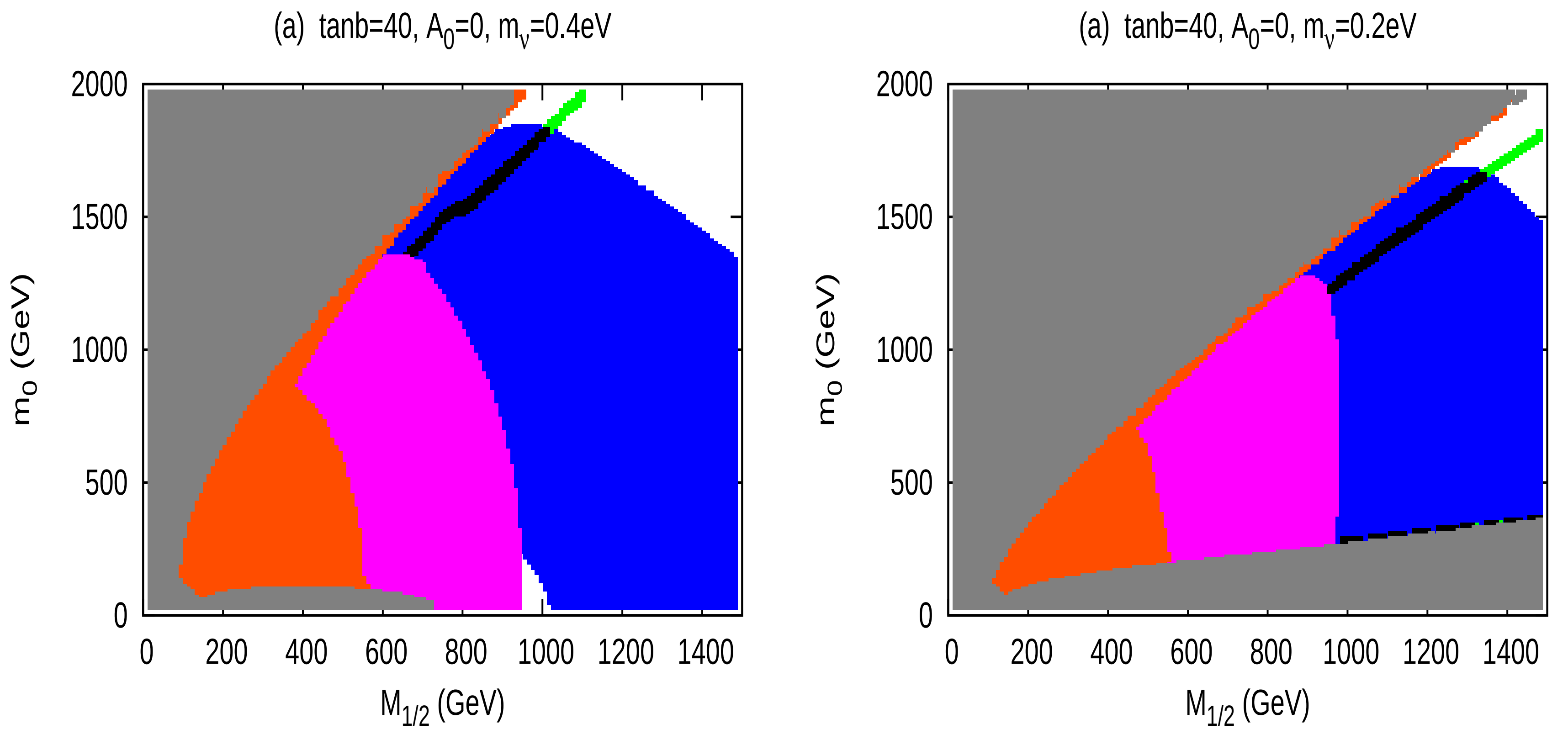
$m_{\nu_3} \propto \frac{m_t^2}{Y_N M_R} \Longrightarrow$ smaller m_{ν_3} implies larger Y_N!

Effect on the spectrum





Survey of parameter space



Grey: no ESWB or tachyonic sfermion; red: mass bounds; pink: $b \to s\gamma$ excluded; blue: favored by g_μ; green: DM allowed; black: all ok

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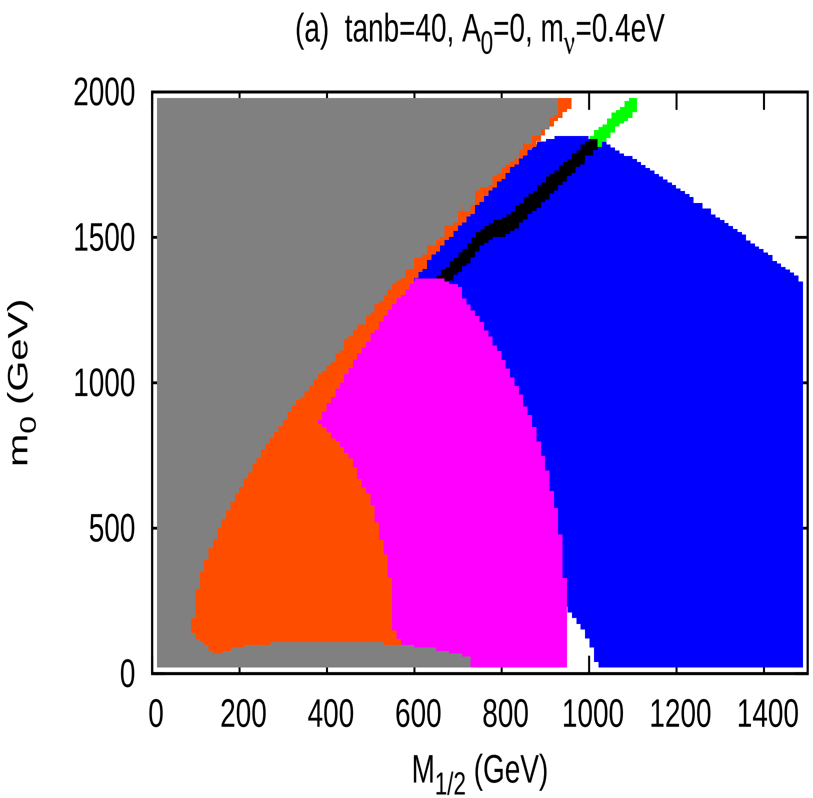

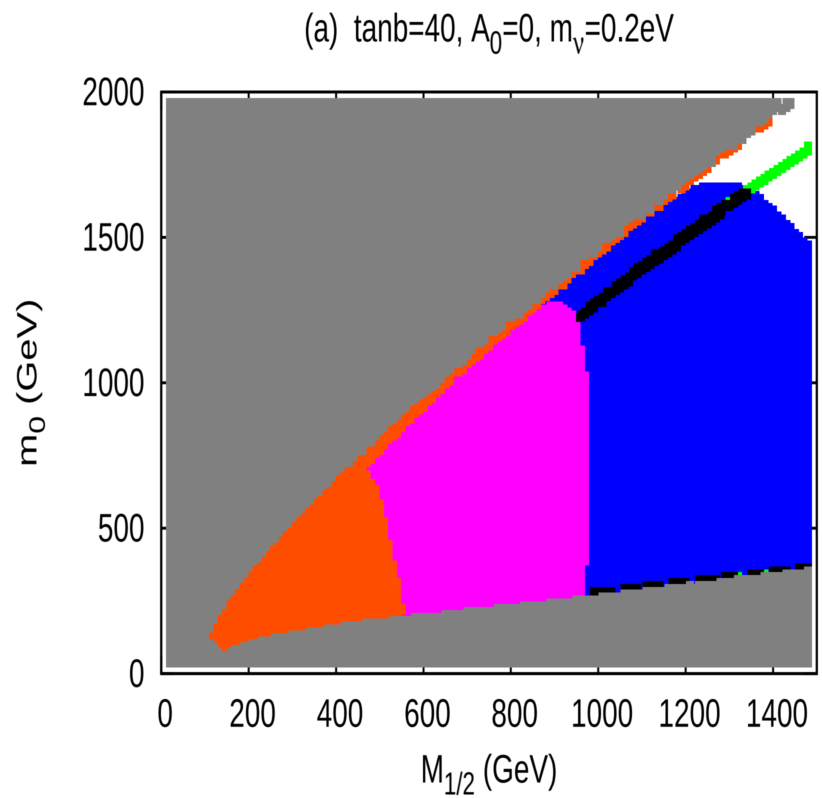

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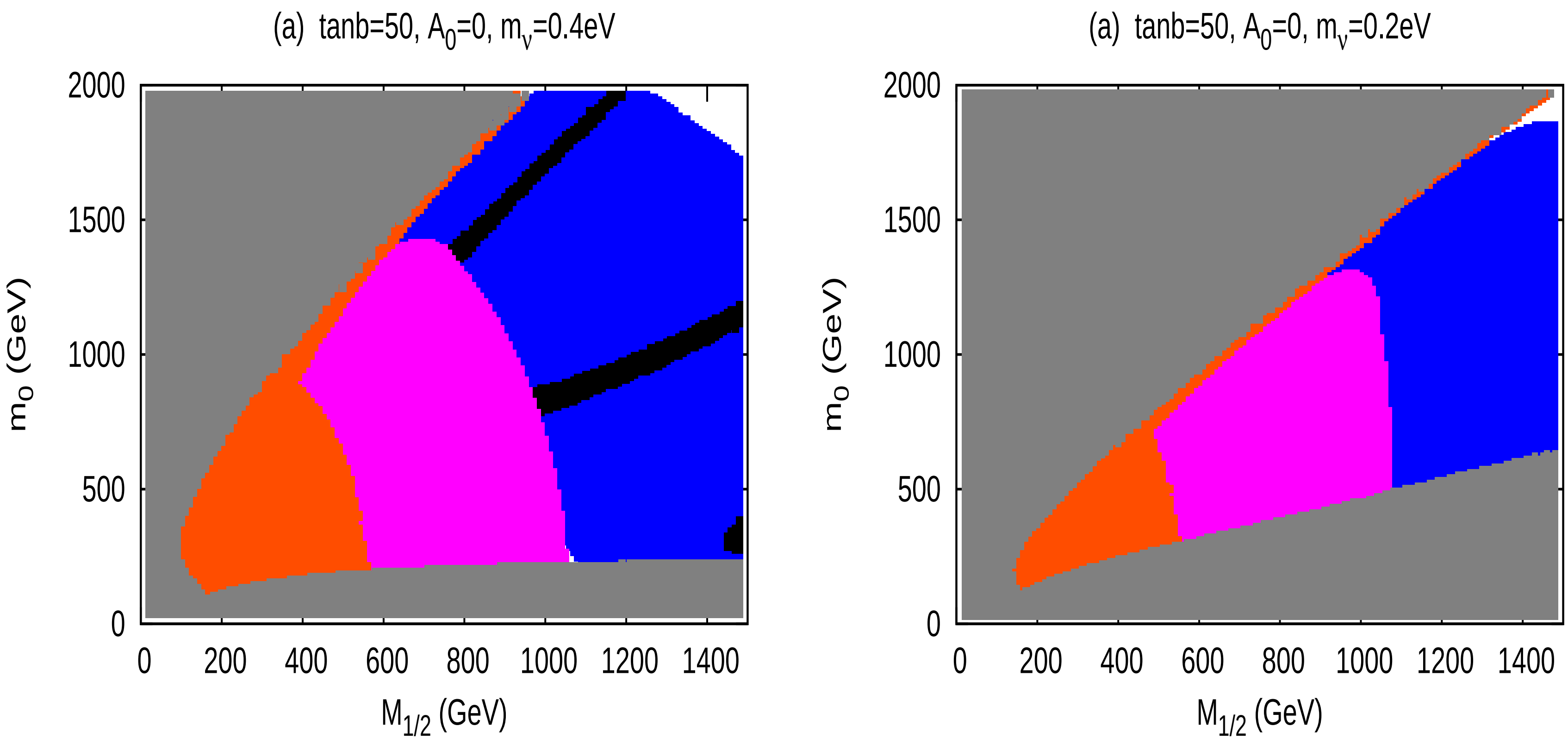
In mSUGRA: don't find allowed region (DM & g_μ) with $m_0^2 \gg M_{1/2}^2$!

Same for $\tan\beta = 50$



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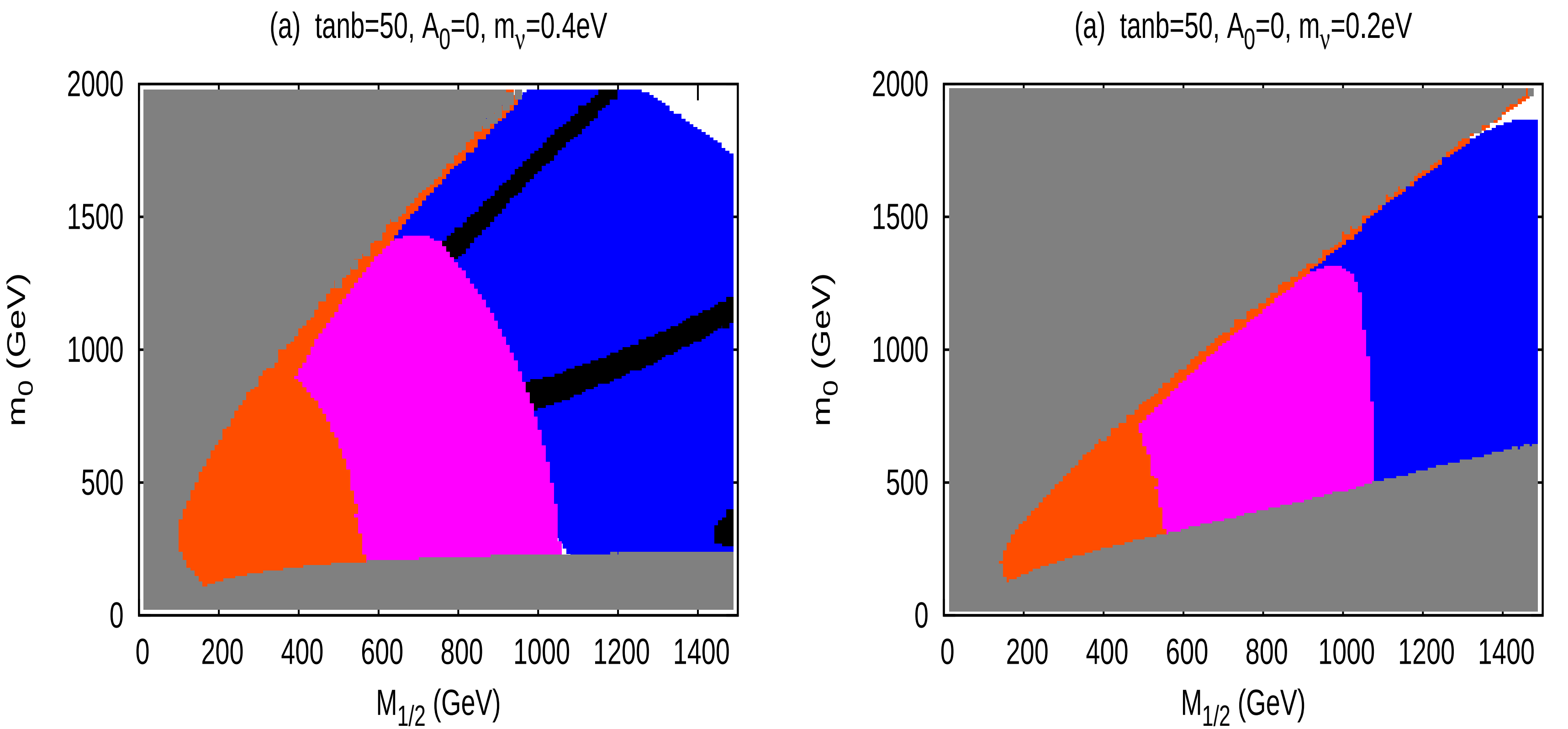

In right frame, DM relic density too small everywhere

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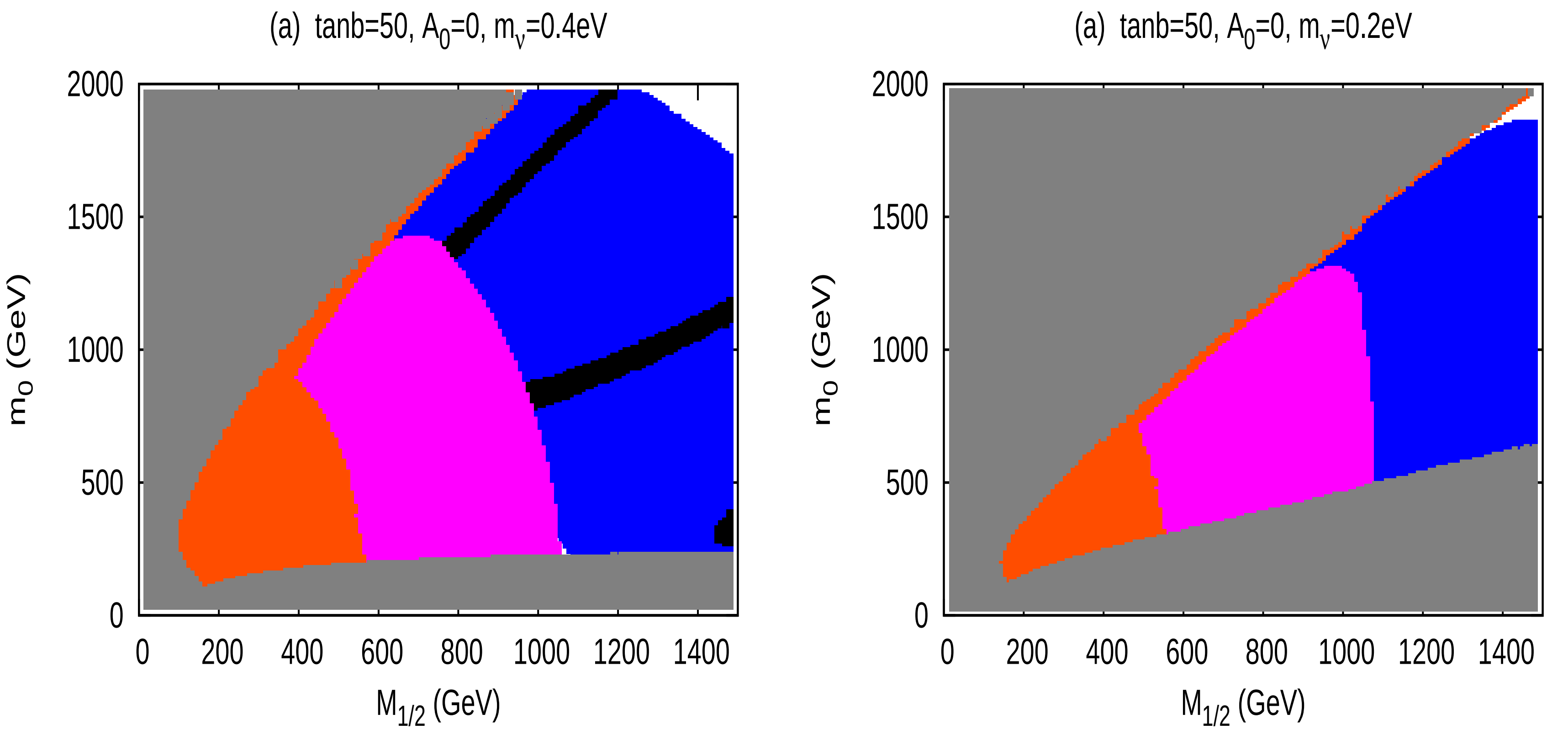

In right frame, DM relic density too small everywhere

$\sim 50\%$ of plane DM–allowed for $\tan\beta = 49$!

Impact on DM searches

For $m_0 \gg M_{1/2}$: ("focus point", but no focussing in this scenario!) Very similar to mSUGRA, if $m_{\tilde{\chi}_1^0}$, $\Omega_{\tilde{\chi}_1^0}$ are fixed.

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$\Longrightarrow$ more higgsino–gaugino mixing
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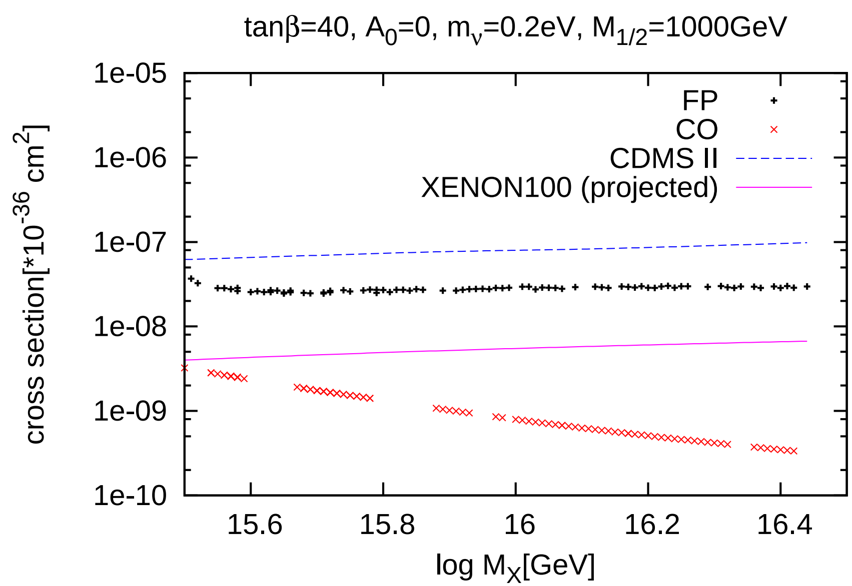

LHC signals: large m_0 region

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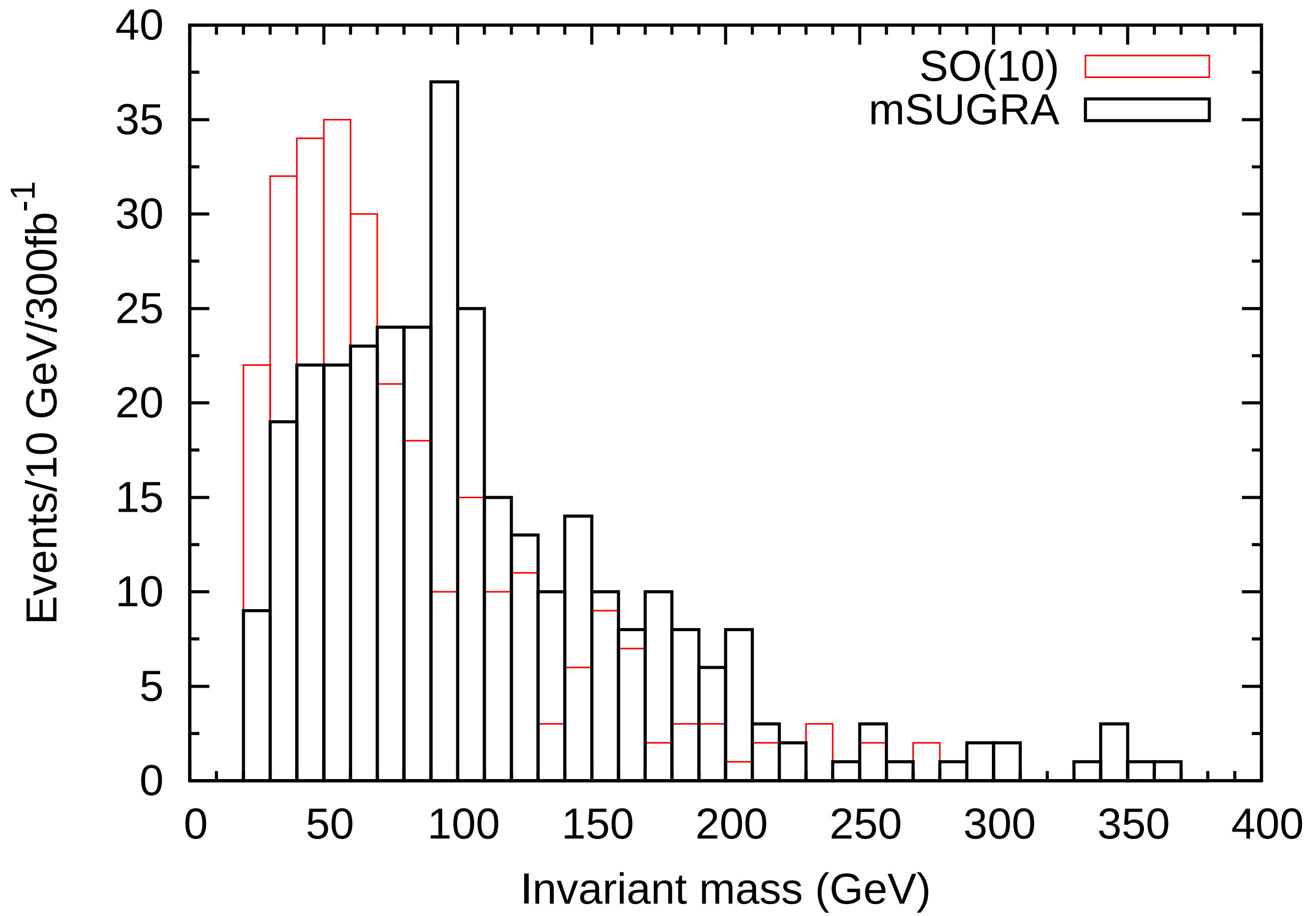
mSUGRA has much larger $|\mu|$:changes $\tilde{\chi}^0,\ \tilde{\chi}^\pm$ spectrum; can be checked via $\ell^+\ell^-$ invariant mass distribution!

$M_{\ell^+\ell^-}$ distribution ($m_0 \gg M_{1/2}$)



Only mSUGRA has Z^0 peak; $SO(10)$ model has softer spectrum

LHC signals: co–annihilation region

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Smaller $|\mu| \Longrightarrow$ smaller $m_{\tilde\chi^0_{3,4}},\ m_{\tilde\chi_2^\pm}$

$\Longrightarrow$ more $\tilde g \to \tilde\chi^0_{3,4},\ \tilde\chi_2^\pm$ decays

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In mSUGRA: either slightly change A_0 (option a) or slightly increase $\tan\beta$ (option b) to match $\Omega_{\tilde\chi_1^0}$ for fixed $m_{\tilde q},\ m_{\tilde g}$.

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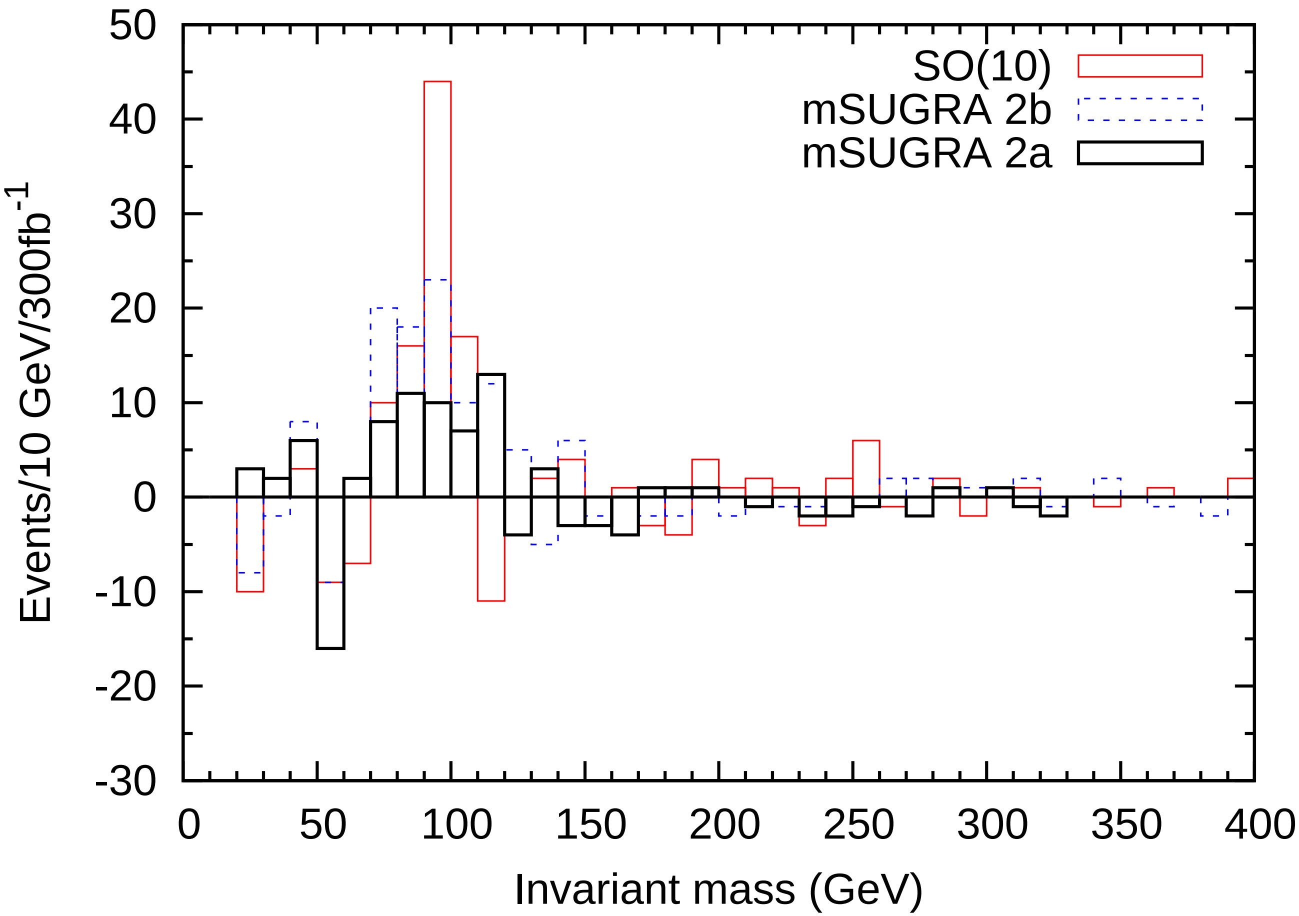
Smaller $|\mu| \Longrightarrow$ smaller $m_{\tilde\chi^0_{3,4}},\ m_{\tilde\chi_2^\pm}$

$\Longrightarrow$ more $\tilde g \to \tilde\chi^0_{3,4},\ \tilde\chi_2^\pm$ decays

$\Longrightarrow$ more $\tilde g \to Z^0$ on–shell in $SO(10)$!

Subtracted $M_{\ell^+\ell^-}$ distribution ($m_0 \ll M_{1/2}$)



$SO(10)$ has significantly more pronounced Z^0 peak

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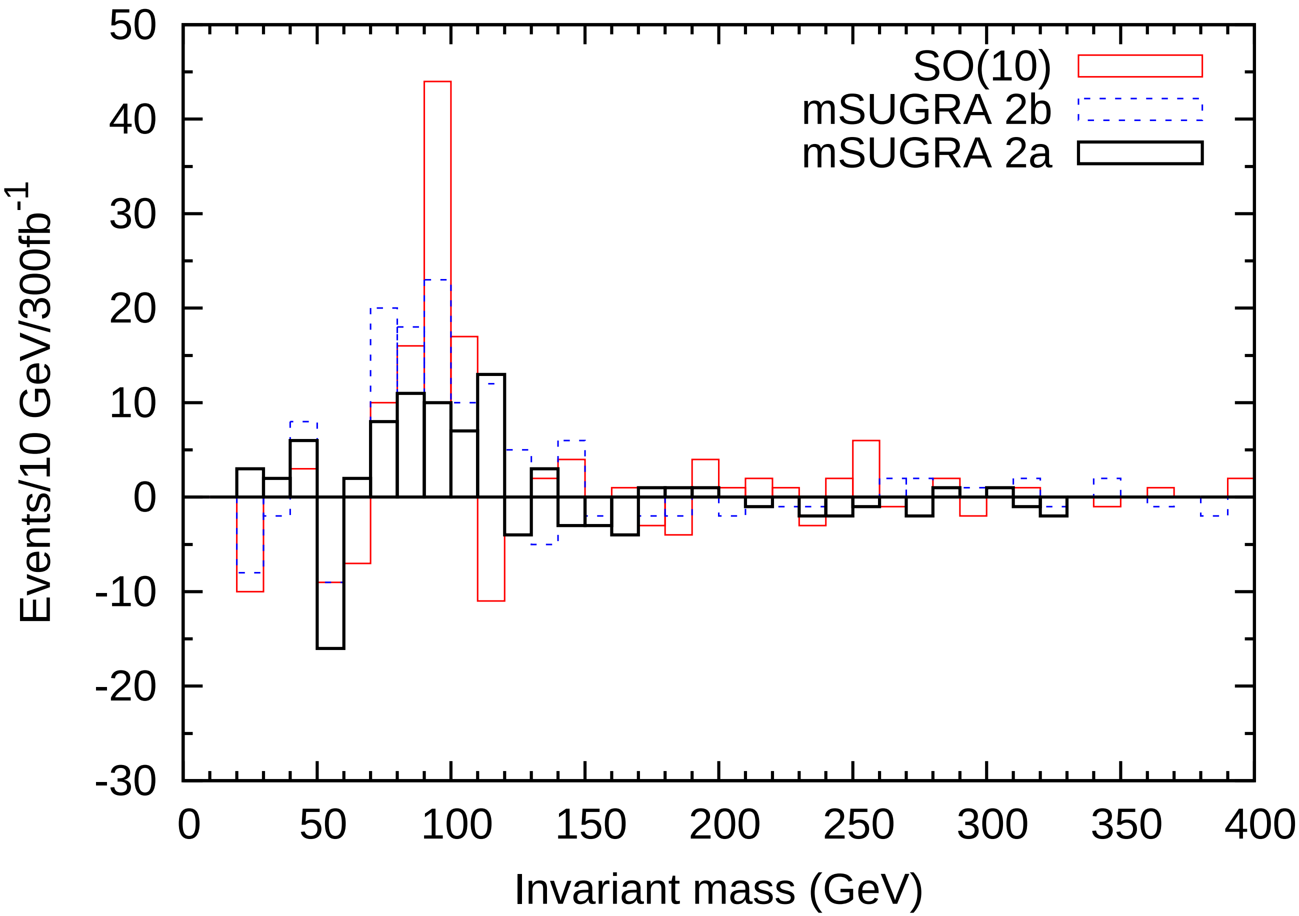

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$SO(10)$ model also has more like–sign di–lepton events: 492 vs. 422 (434).

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- To fix high–scale physics: need to know m_ν, proton lifetime!