Reduced $SU(3)$ Gaugino Mass: Consequences for Dark Matter and Collider Searches

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(after Sept.1 – University of Kansas)

Outline

- ⋆ Overview of mSUGRA
- ⋆ SUGRA with non-universal gaugino masses
- ⋆ Prospects for DM searches
- ⋆ Prospects for colliders
- ⋆ Conclusions

In collaboration with H. Baer, E.-K. Park (FSU), S. Profumo (Caltech) and X. Tata (Univ. of Hawaii): *JHEP* 0604 (2006) 041

minimal SUGRA model

- ⋆ Well known parameter space: $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$
- ⋆ Most parameter choices excuded by WMAP result $\Omega_{CDM}h^2 = 0.111 \pm 0.01$
- ⋆ Regions with correct neutralino relic density:
  - bulk region at low m_0 and $m_{1/2}$ - light sleptons
  - stau coannihilation region at low m_0
  - HB/FP region at large m_0 - mixed higgsino dark matter (MHDM)
  - A-funnel - $H,\ A$ resonance annihilation
  - stop coanihilation region for particular A_0
  - h resonance annihilation at low $m_{1/2}$

Gaugino mass terms in MSSM

- mSUGRA has minimal gauge kinetic function f_{AB}
  $\rightarrow$ equal gaugino masses at GUT scale

- Motivation for gaugino mass non-universality:
  - ⋆ non-minimal f_{AB} in SUGRA models,
    e.g. $f_{AB} \ni 1,\ 24,\ 75,\ 200$ in $SU(5)$ SUSY GUTs
  - ⋆ various string models, e.g. KKLT model
    (see talk by X. Tata in "MSSM" section)
  - ⋆ extra-dim SUSY GUTs with gaugino mediated SUSY breaking,
    e.g. Dermisek-Mafi $SO(10)$ model

$\Longrightarrow$ Adopt independent gaugino masses at GUT scale

- ⋆ M_1 *or* $M_2 \neq m_{1/2}$ – MWDM and BWCA scenarios
  (see talk by E.-K. Park in "Cosmology III: The Dark Side" section)
- ⋆ $|M_3| \ll M_1 \simeq M_2$ – Low M3 Dark Matter (LM3DM scenario)

Also Belanger *et al* (2005); Mambrini and Nezri (2005).

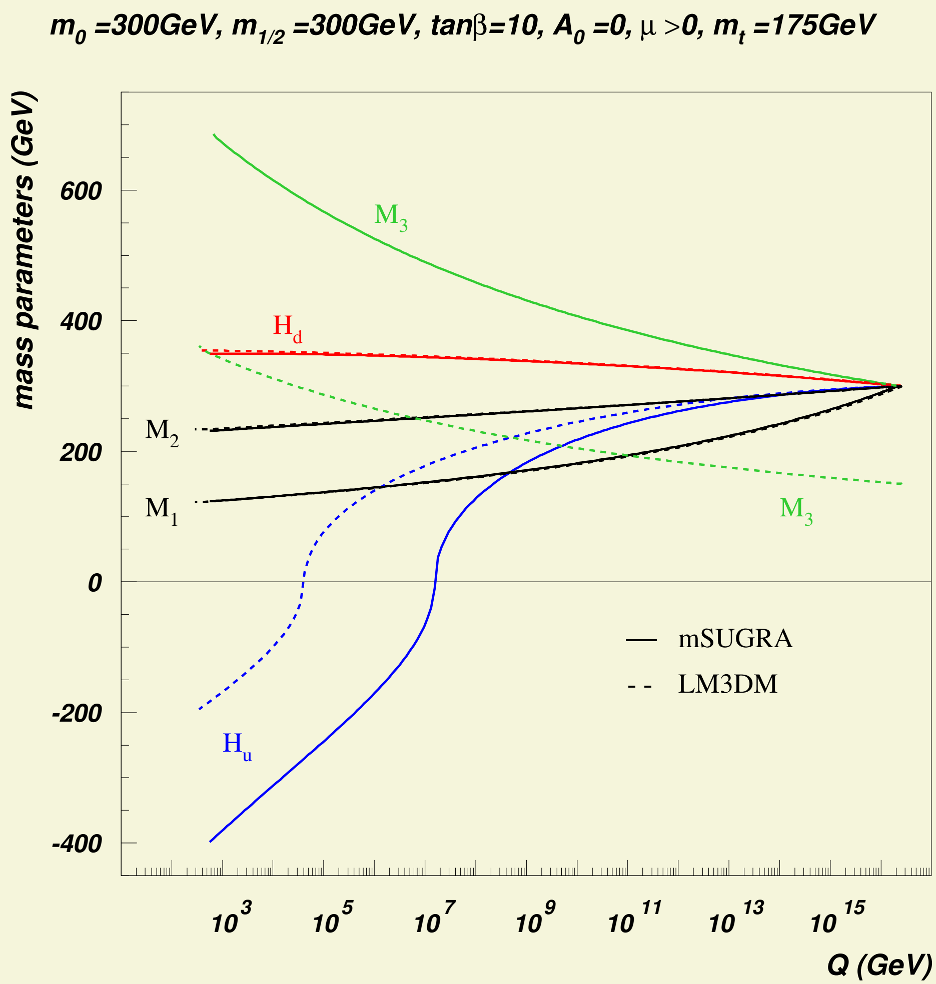
Low M_3 model

- Parameter space:
  $m_0,\ m_{1/2},\ M_3,\ sign(\mu),\ A_0,\ \tan\beta$
- Allow M_3 take negative values
- Mild evolution of $m^2_{H_d}$ due to small Yukawas $f_b,\ f_\tau$
- Lighter squarks and gluons
  $\rightarrow$ reduced effect of f_t on $m^2_{H_u}$
  $\Rightarrow$ smaller $|\mu|$

$$\frac{dm^2_{H_u}}{dt} \propto f_t^2 X_t, \quad \frac{dm^2_{H_d}}{dt} \propto f^2_{b,\tau} X_{b,\tau}$$

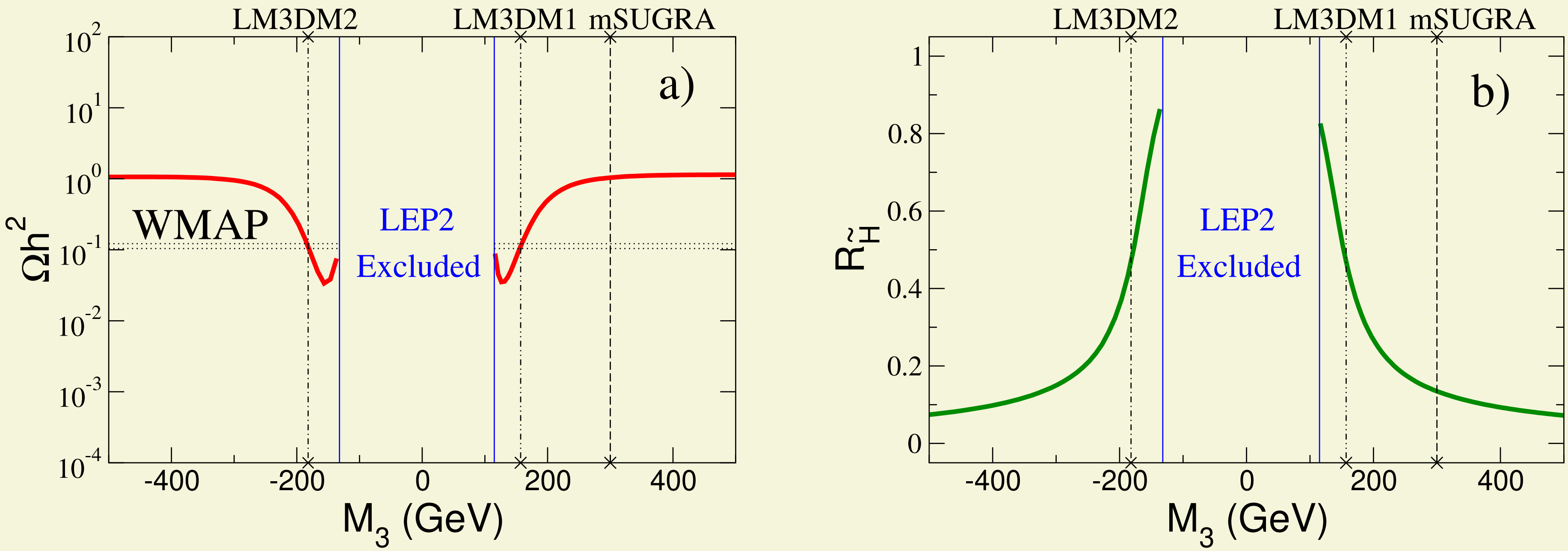
where $X_t = m^2_{Q_3} + m^2_{\tilde{t}_R} + m^2_{H_u} + A_t^2$

$$\mu^2 = \frac{m^2_{H_d} - m^2_{H_u}\tan\beta}{\tan^2\beta - 1} - \frac{M_Z^2}{2} \simeq -m^2_{H_u}$$



Neutralino relic density *vs* M_3

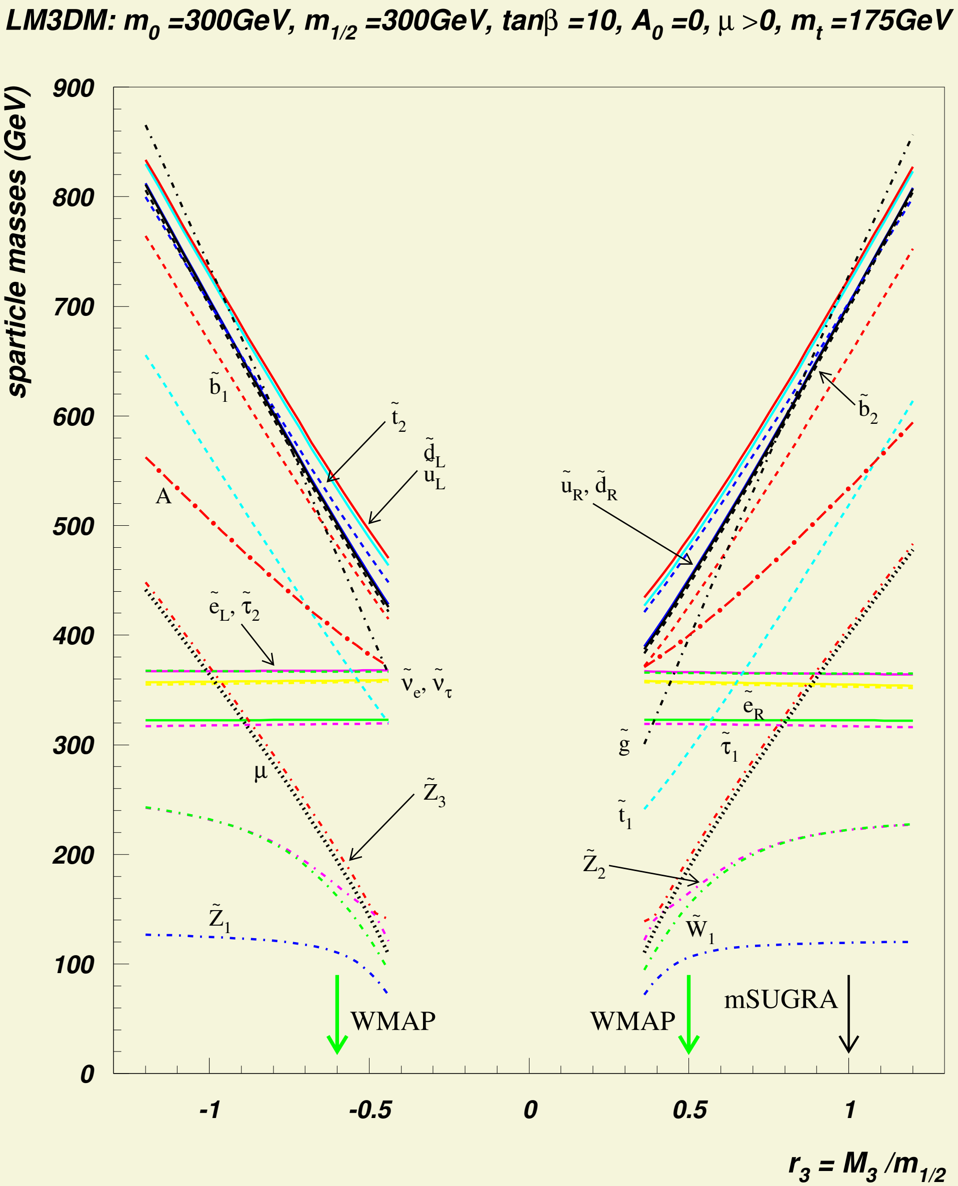
m_0=300 GeV, $m_{1/2}$=300 GeV, tanβ=10, A_0=0, μ>0, m_t=175 GeV



- mSUGRA: $\widetilde{Z}_1$ is almost pure bino, $\Omega h^2 \simeq 1.3$
- LM3DM: $M_3 = 200$GeV, $\widetilde{Z}_1$ is mixed higgsino-bino
  $\Rightarrow$ enhanced $\widetilde{Z}_1\widetilde{Z}_1 \to W^+W^- \Rightarrow \Omega h^2 \simeq 0.11$

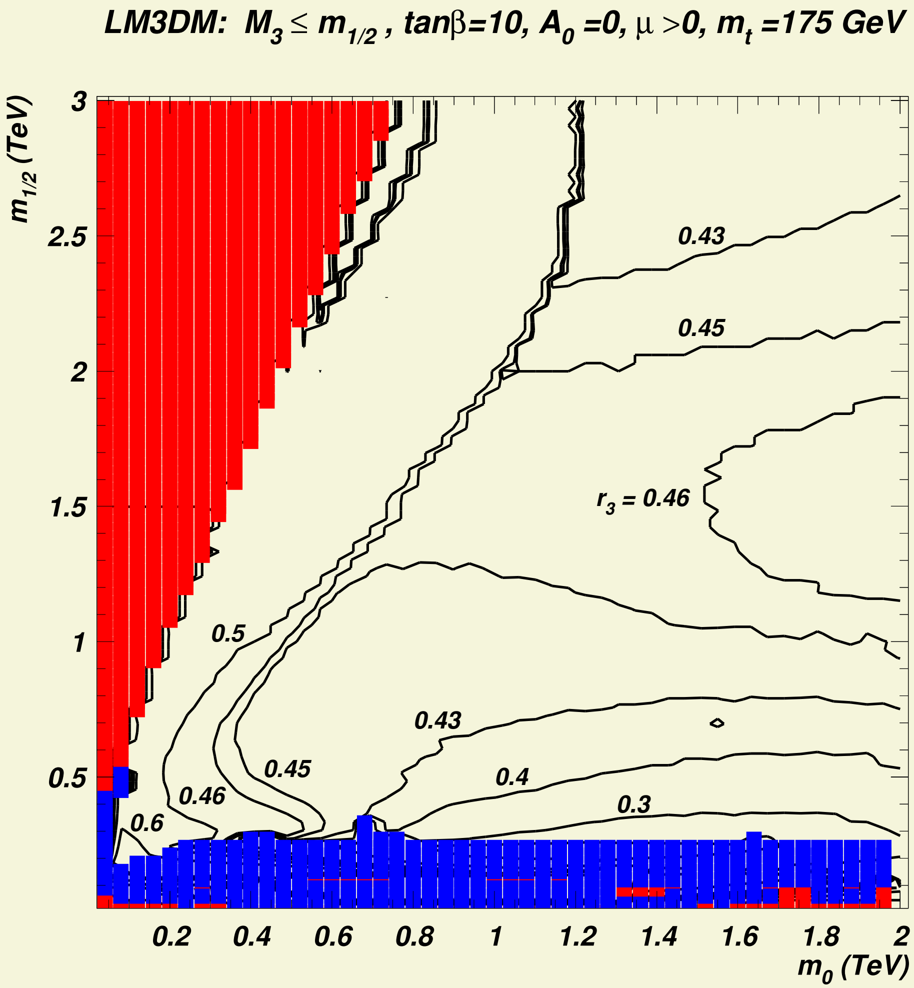
Sparticle mass spectrum

- Mass scale of squarks and sleptons less hierarchical
- Lighter gluino
- Very light stop
- Small $\widetilde{Z}_2 - \widetilde{Z}_1$ and $\widetilde{W}_1 - \widetilde{Z}_1$ mass gaps $\simeq$ 50GeV due to low $|\mu|$



LM3DM parameter space

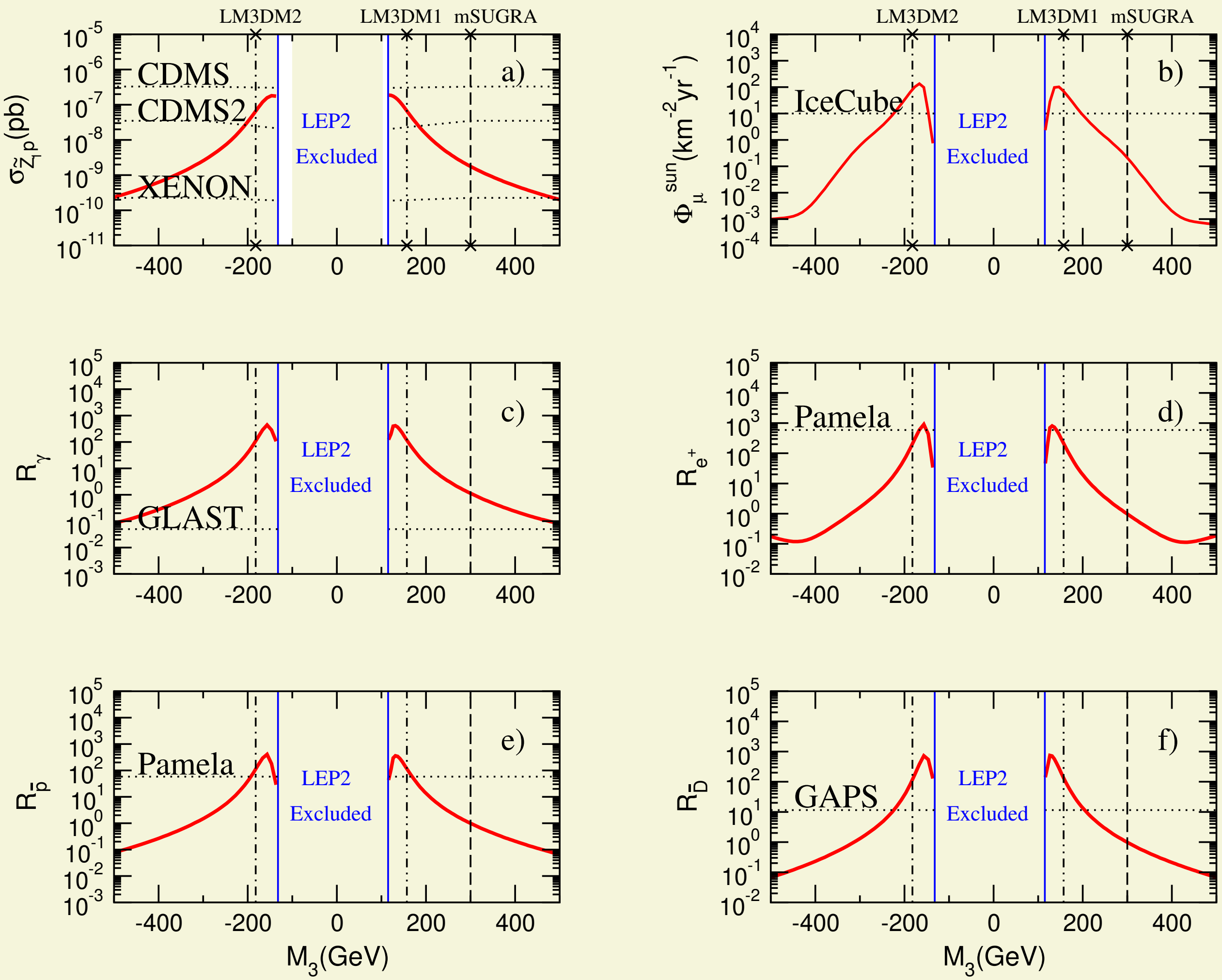
- By lowering M_3 any point in para space can be WMAP allowed
- Two distinct regions:
  $r_3 = \frac{M_3}{m_{1/2}} \gtrsim 0.5$ - bino DM
  $r_3 = \frac{M_3}{m_{1/2}} \lesssim 0.5$ - mixed higgsino DM



Direct/indirect DM detection rates

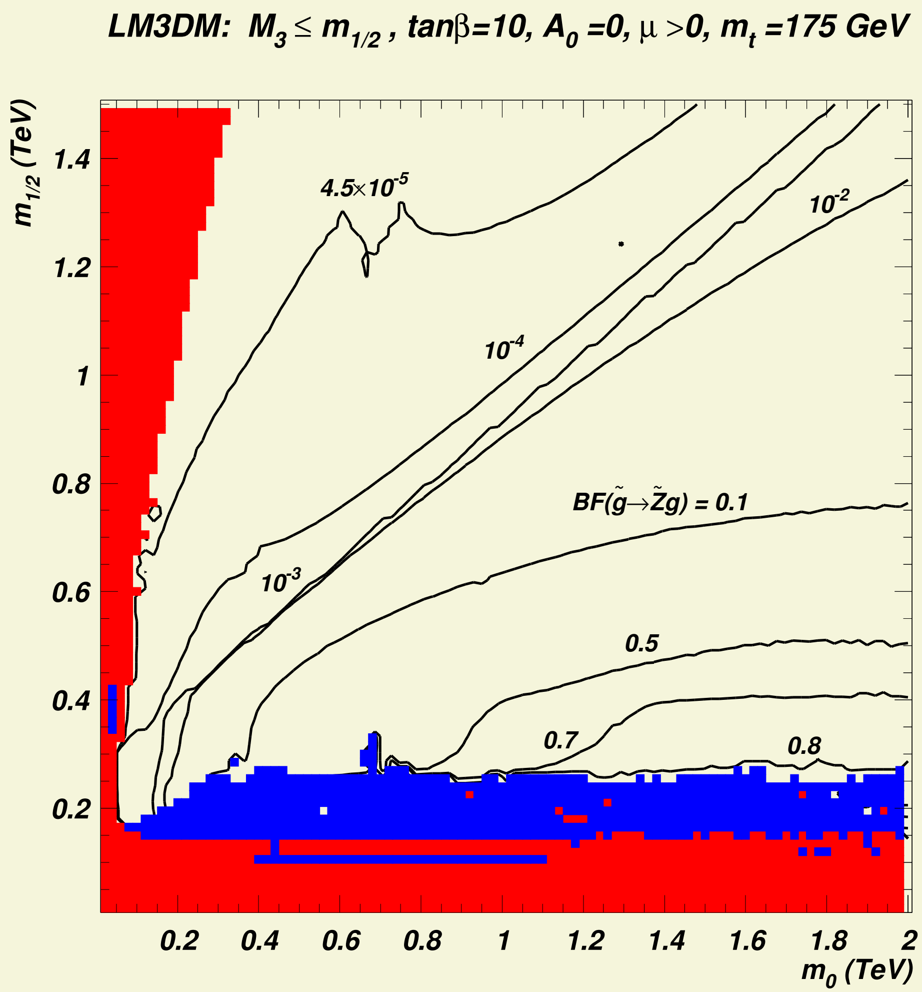
- Light squarks enhance $\widetilde{Z}_1 p$ scattering
- Increased $\sigma_{\widetilde{Z}p} \propto (N_h N_1)^2$ due to larger higgsino fraction N_h

m$_0$=300 GeV, m$_{1/2}$=300 GeV, tanβ=10, A$_0$=0, μ>0, m$_t$=175 GeV



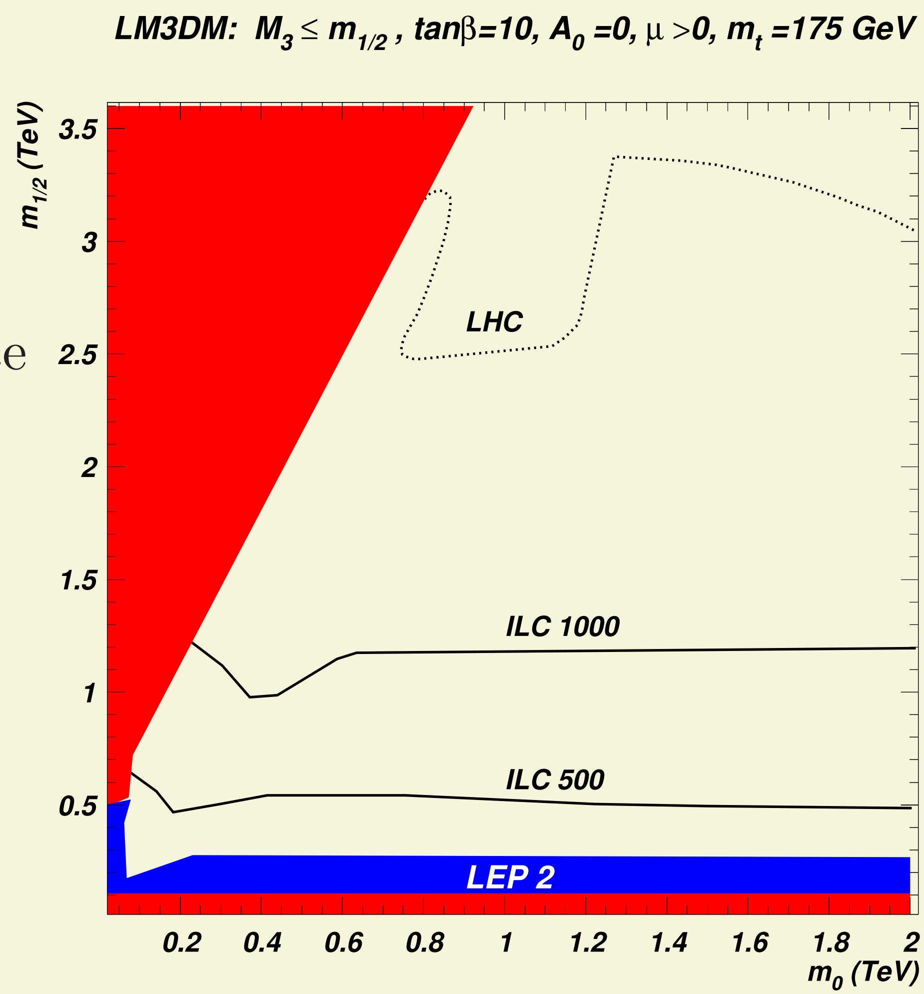
Tevatron signatures

- Lighter gluinos expected in LM3DM
  $\rightarrow$ larger pair production
  e.g. $m_{\tilde{g}} \simeq 183\text{GeV}$ for $m_{1/2} = 250\text{GeV}$
  $\sigma(p\bar{p} \rightarrow \tilde{g}\tilde{g}) \simeq 20\text{pb}$
  (in mSUGRA $m_{\tilde{g}} \simeq 400\text{GeV}$ and
  $\sigma(p\bar{p} \rightarrow \tilde{g}\tilde{g}) \simeq 30\text{fb}$)
- Heavy squarks at large m_0 and large higgsino component
  $\rightarrow \tilde{g} \rightarrow g\widetilde{Z}_i$ dominate
  $\Rightarrow 2j + E_T^{miss}$ events



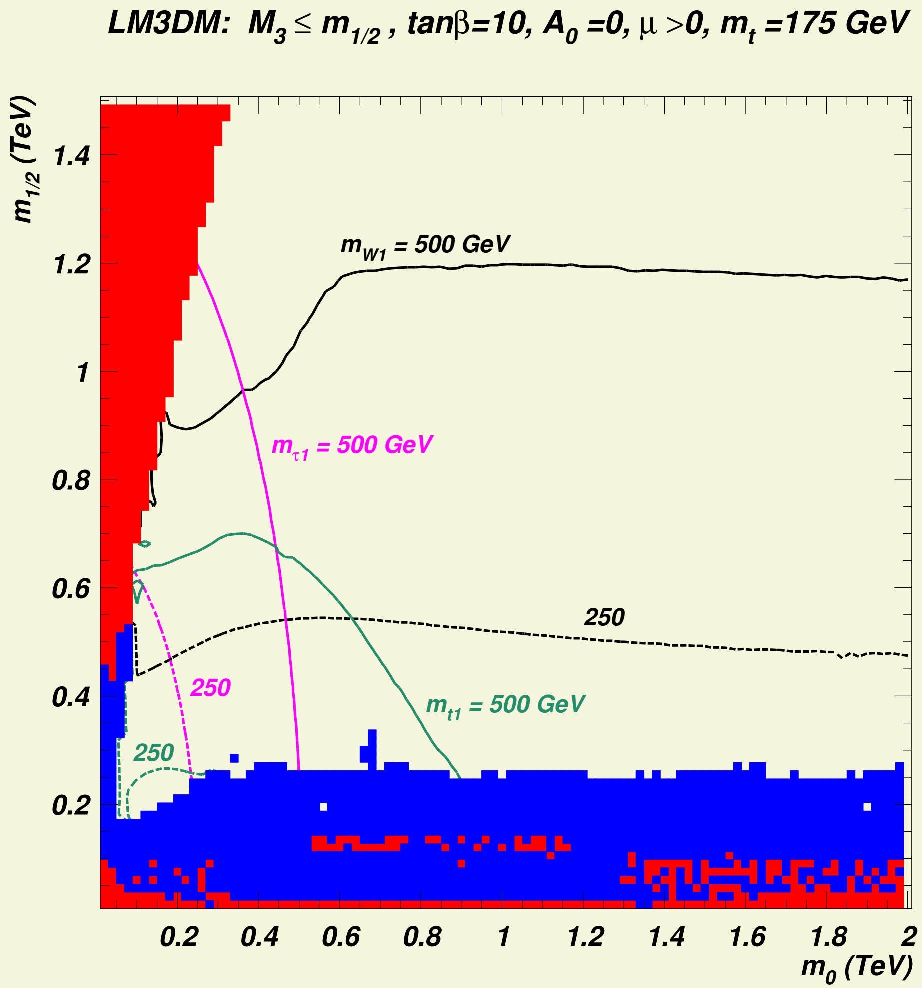
Prospects for LHC

- Reduced squark and gluino masses
  $\Rightarrow$ enhanced reach
- Small $\widetilde{Z}_2 - \widetilde{Z}_1$ mass gap $\Rightarrow$ $\widetilde{Z}_2 \to l\bar{l}\widetilde{Z}_1$
  $\Rightarrow$ $m(l^+l^-)$ mass edges over all para space
  (in mSUGRA for $m_{1/2} < 250$GeV)



LM3DM at ILC

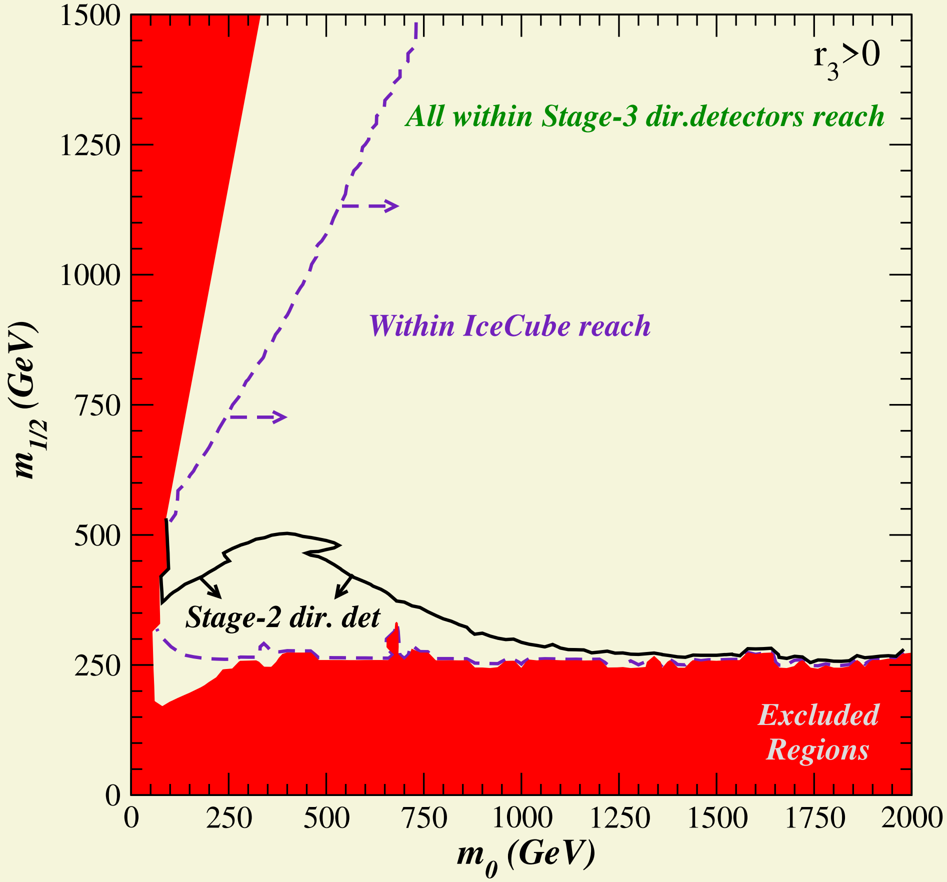
- Enhanced $\widetilde{W}_1^+\widetilde{W}_1^-$ production due to smaller μ
- Possible $\tilde{t}_1\bar{\tilde{t}}_1$ production
- All charginos/neutralinos accessible
- $\tilde{q} \to \tilde{g}q$ kinematically allowed
  $\Rightarrow$ precise determination of $\tilde{q}$, $\tilde{g}$ masses



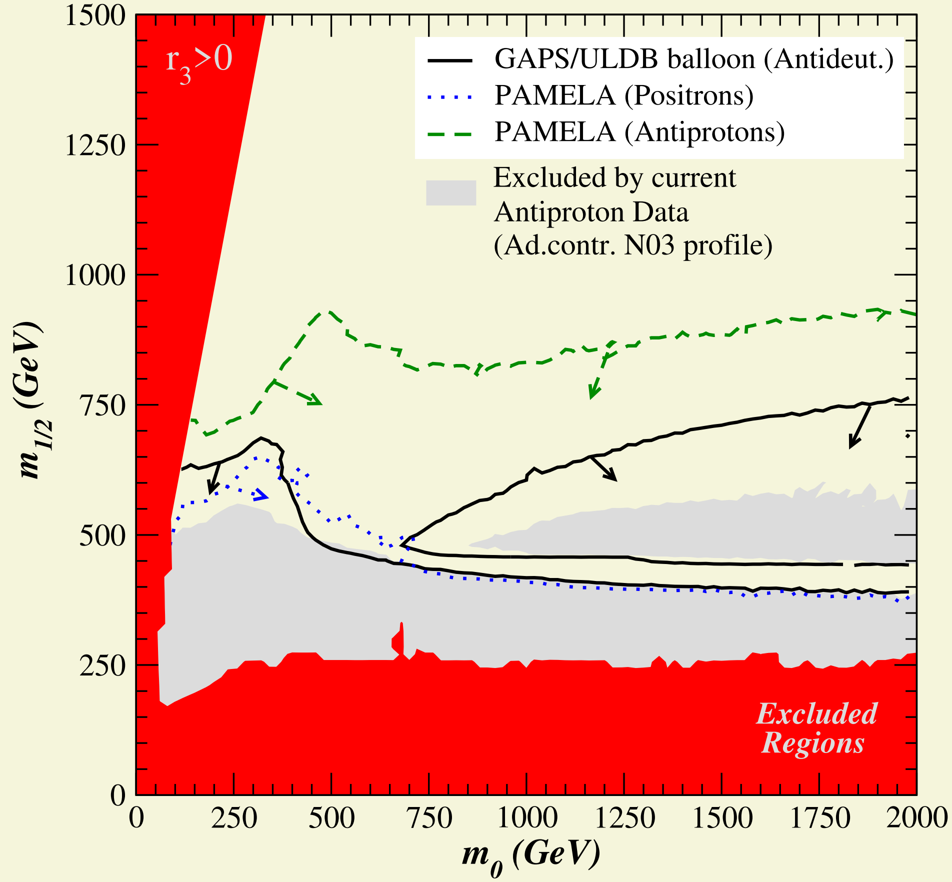
Conclusions

- Reducing $|M_3|$ allows $\widetilde{Z}_1$ relic density consistent with WMAP in almost any point of para space
- $|M_3| < m_{1/2}$ gives MHDM or BDM solutions
- MHDM has enhanced DM detection prospects
- LM3DM model has lighter squarks and gluinos
  $\Rightarrow$ SUSY can be discovered at Tevatron via gluino search
- LM3DM has dominantly 3-body decays of $\widetilde{Z}_2$ (spoiler 2-body modes closed)
  $\Rightarrow m_{\widetilde{Z}_2} - m_{\widetilde{Z}_1}$ mass edges likely observable over all para space at LHC
- At ILC all charginos and neutralinos possibly accessible, allowing complete reconstruction of gaugino-higgsino sector

DM searches

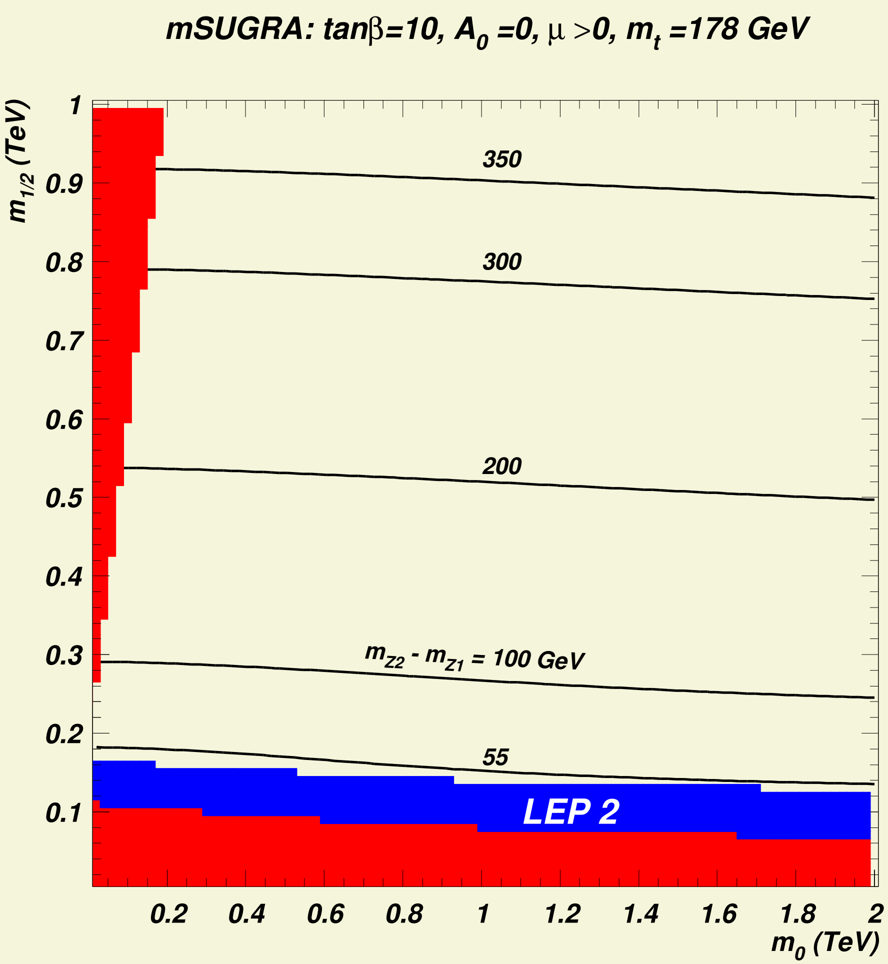


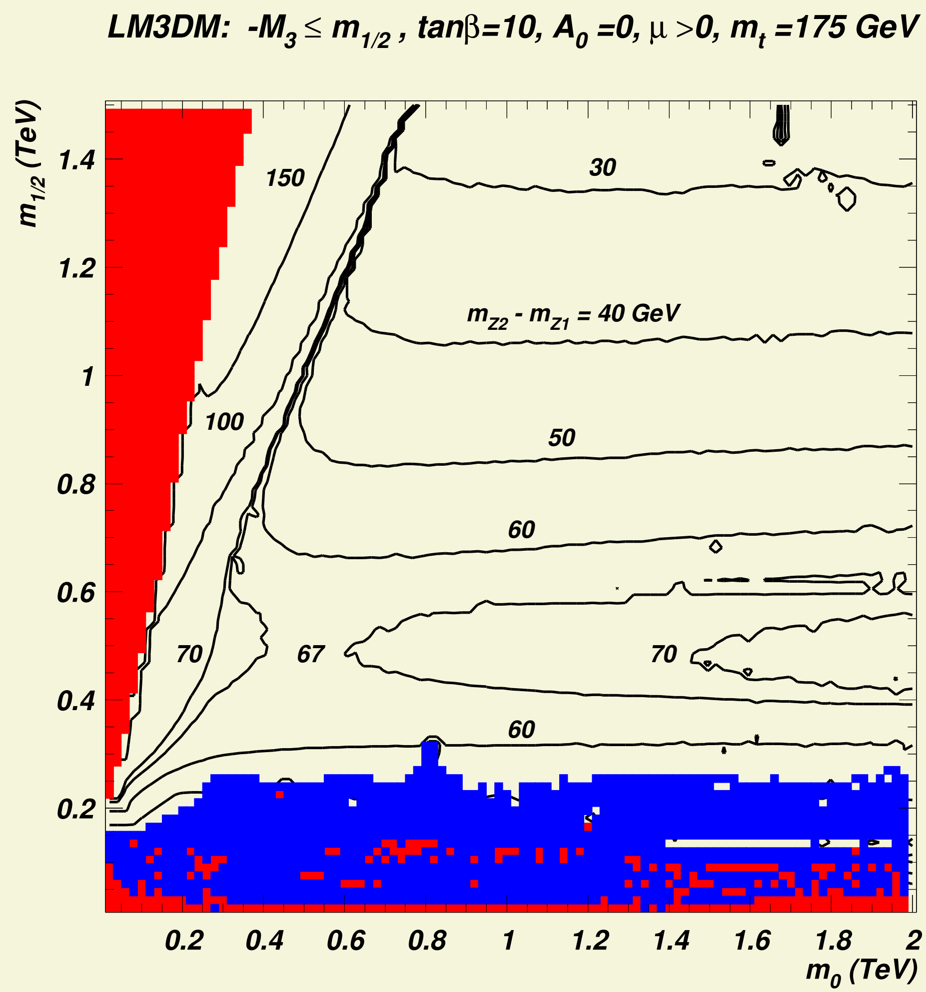
r3>0
All within Stage-3 dir.detectors reach
Within IceCube reach
Stage-2 dir. det
Excluded Regions
m1/2 (GeV)
m0 (GeV)
0
250
500
750
1000
1250
1500
1750
2000



r3>0
GAPS/ULDB balloon (Antideut.)
PAMELA (Positrons)
PAMELA (Antiprotons)
Excluded by current Antiproton Data (Ad.contr. N03 profile)
Excluded Regions
m1/2 (GeV)
m0 (GeV)
0
250
500
750
1000
1250
1500
1750
2000

$\widetilde{Z}_2 - \widetilde{Z}_1$ mass gap





MSSM RGEs: Higgs sector

$$\frac{dm_{H_u}^2}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2M_1^2 - 3g_2^2M_2^2 + \frac{3}{10}g_1^2S + 3f_t^2X_t\right)$$

$$\frac{dm_{H_d}^2}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2M_1^2 - 3g_2^2M_2^2 - \frac{3}{10}g_1^2S + 3f_b^2X_b + f_\tau^2X_\tau\right)$$

where $t = \log(Q)$, $f_{t,b,\tau}$ are the t, b and τ Yukawa couplings, and

$$X_t = m_{Q_3}^2 + m_{\tilde{t}_R}^2 + m_{H_u}^2 + A_t^2$$

$$X_b = m_{Q_3}^2 + m_{\tilde{b}_R}^2 + m_{H_d}^2 + A_b^2$$

$$X_\tau = m_{L_3}^2 + m_{\tilde{\tau}_R}^2 + m_{H_d}^2 + A_\tau^2$$