Dark Matter Detection in Supersymmetric models with Non-universal Gaugino Masses

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Outline

- Introduction
  - ⋆ Review of the mSUGRA Model
  - ⋆ Motivation of Non-universal Gaugino Mass Models
- Non-universal Gaugino Masses

  in collaboration with

  H. Baer (FSU), T. Krupovnickas (BNL), A. Mustafayev (Univ. of Kansas), S. Profumo (Caltech) and X. Tata (Univ.of Hawaii)

  - ⋆ Mixed Wino Dark Matter (MWDM):JHEP 0507 (2005) 065
  - ⋆ Bino-Wino Co-Annihilation Scenario (BWCA):JHEP 0512 (2005) 011
  - ⋆ Low M3 Dark Matter Scenario (LM3DM):JHEP 0604 (2005) 041
- Conclusions

Review of the mSUGRA Model

- **Parameter Space :**

  m_0, $m_{1/2}$, A_0, tanβ, $sign(\mu)$

- **WMAP allowed Regions :**

  (Green colored regions)

  Region 1. $\tilde{\tau}$ co-annihilation region at low m_0

  Region 2. bulk region at low m_0 and $m_{1/2}$

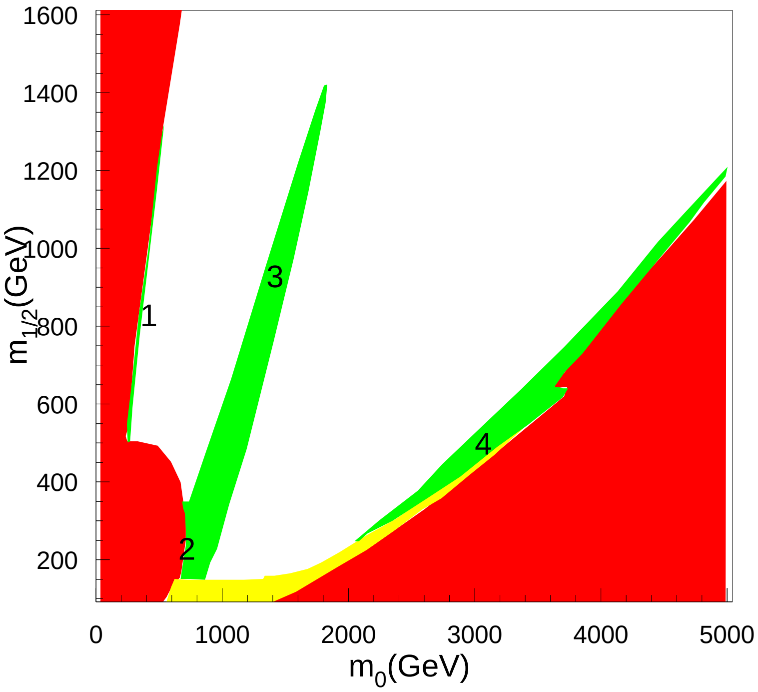
  – light sleptons (LEP2 excluded)

  Region 3. *A*-funnel

  – **H**, **A** resonance annihilation

  Region 4. FP/HB region at large m_0

  – mixed higgsino dark matter (MHDM):
  low μ



- **Limitation of mSUGRA :**

  In most of the parameter space of the mSUGRA model, a value of neutralino relic density is beyond the WMAP bound $\Omega_{CDM}h^2 = 0.111 \pm 0.01$

Non-Universal Gaugino Mass Models

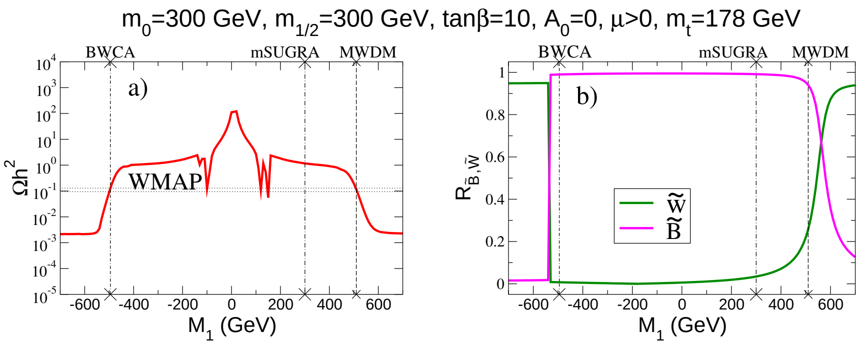
- M_1, M_2, M_3 are gauginos of $U(1)$, $SU(2)$ and $SU(3)$ respectively
- In mSUGRA : minimal gauge kinetic function f_{AB}
  $\longrightarrow$ equal gaugino masses at GUT scale : $M_1 = M_2 = M_3 = m_{1/2}$
- Motivation for non-universal gaugino mass models :
  - $*$ non-minimal f_{AB} in SUGRA models,
    e.g. $f_{AB} \ni 1, 24, 75, 200$ in $SU(5)$ SUSY GUTs
  - $*$ various string models, e.g. KKLT model
    :H. Baer, E.-K. Park, X. Tata and T. T. Wang,
    hep-ph/0703024; Phys. Lett. B641 (2006) 447; JHEP 0608 (2006) 041
  - $*$ extra-dim SUSY GUTs with gaugino mediated SUSY breaking,
    e.g. Dermisek-Mafi $SO(10)$ model
- Generally, the lightest neutralino mass eigenstate is determined by the content of the LSP $\tilde{z}_1 = v_1^{(1)}\psi_{h_u^0} + v_2^{(1)}\psi_{h_d^0} + v_3^{(1)}\lambda_3 + v_4^{(1)}\lambda_0$

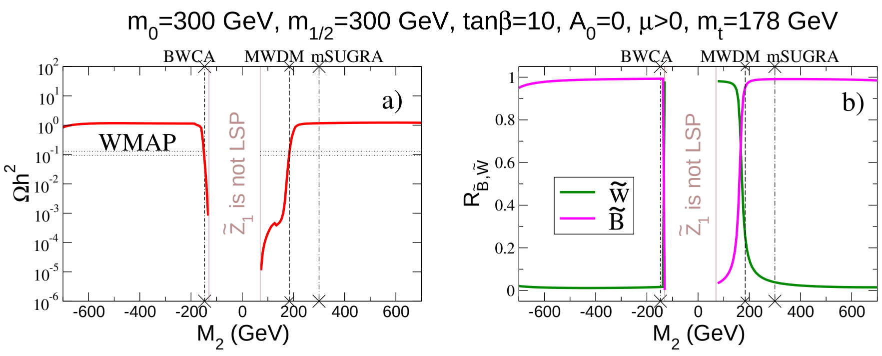
  Here, $R_{\tilde{w}} = |v_3^{(1)}|$, $R_{\tilde{B}} = |v_4^{(1)}|$ and $R_{\tilde{H}} = \sqrt{|v_1^{(1)}|^2 + |v_2^{(1)}|^2}$: W-ino, B-ino and Higgsino

Non-Universal Gaugino Mass Models

- Several ways which can increase the annihilation rate of a bino LSP without gaugino mass universality
  - ∗ by increasing the wino content of the LSP by reducing the ratio M_2/M_1 (MWDM) :
    - $M_1 \neq M_2 = M_3 = m_{1/2}$ or $M_2 \neq M_1 = M_3 = m_{1/2}$
    - parameter space : m_0, $m_{1/2}$, M_1(or M_2), A_0, tanβ, $sign(\mu)$
  - ∗ by allowing co-annihilation between high bino-like and wino-like states (BWCA scenario) :
    - M_1 and M_2 are of opposite sign
    - parameter space : m_0, $m_{1/2}$, M_1(or M_2), A_0, tanβ, $sign(\mu)$
  - ∗ by increasing the higgsino content of the LSP by decreasing the gluino mass (LM3DM) :
    - $M_3 \neq M_1 = M_2 = m_{1/2}$
    - parameter space : m_0, $m_{1/2}$, M_3, A_0, tanβ, $sign(\mu)$

MWDM, BWCA : Neutralino Relic Density and Binoness/Winoness





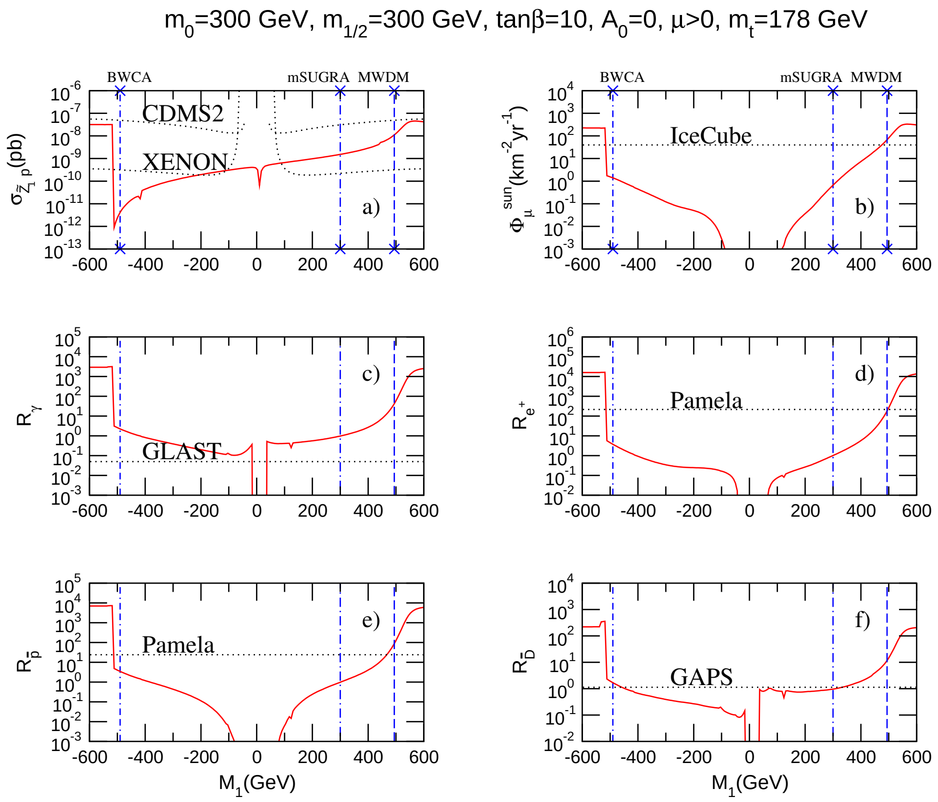
- $\ast$ IsaReD program (Baer, Belyaev, Balazs)
- $\ast$ As $|M_1|(|M_2|)$ increases(decreases) past its mSUGRA value,

  $\longrightarrow$ $\tilde{Z}_1$ becomes wino-like(MWDM) or bino-like but $m_{\tilde{Z}_1} \sim m_{\tilde{W}_1}$ (BWCA)

  $\longrightarrow$ relic density decreases

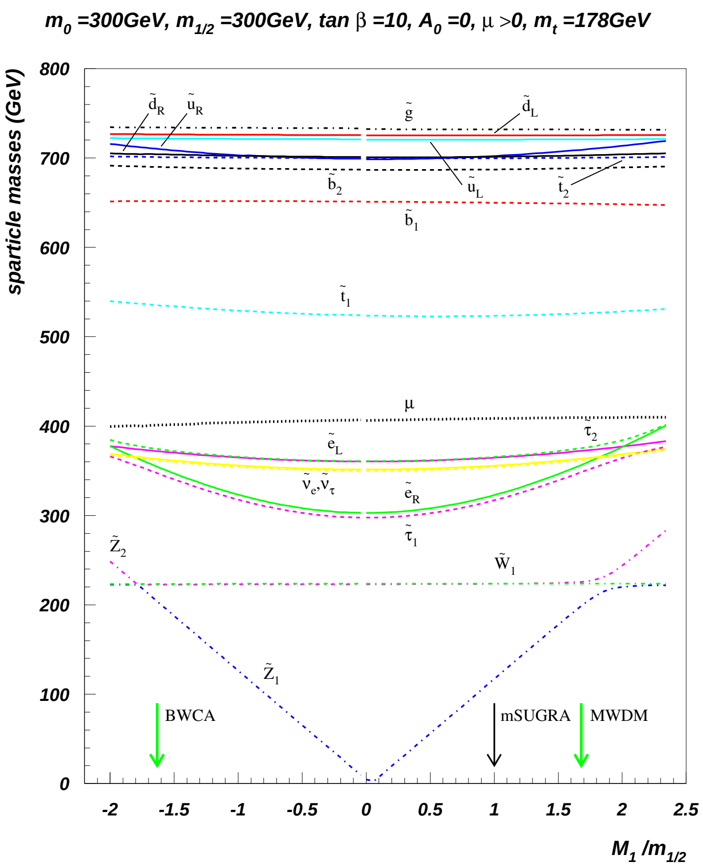
  $\longrightarrow$ WMAP $\Omega_{CDM}h^2$ value is reached

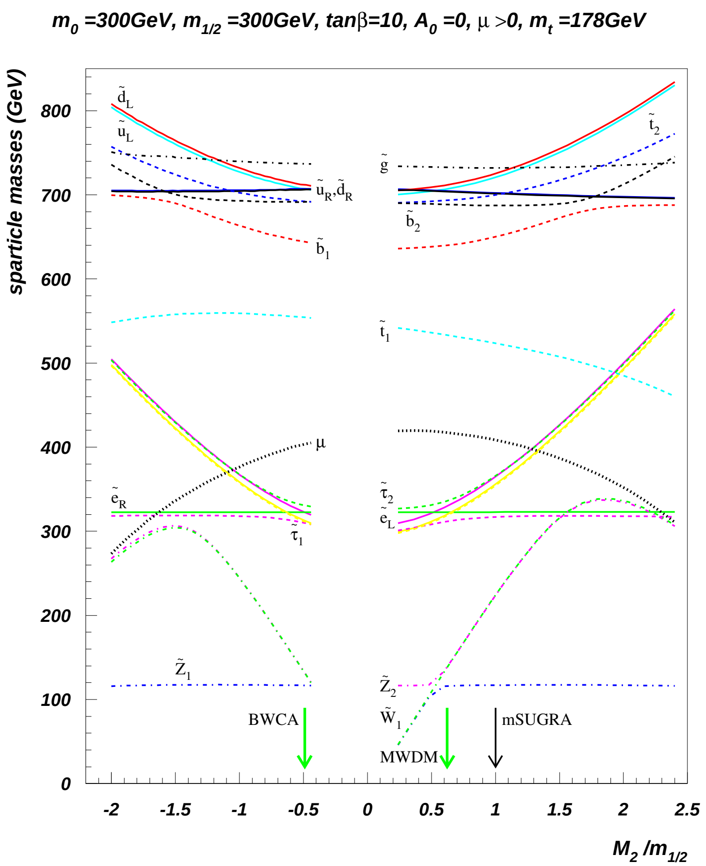
MWDM, BWCA : Direct and Indirect Dark Matter Detection Rates



- $*$ DarkSUSY P. Gondolo, J. Edsjo, P. Ullio, L. Bergstom, M. Schelke and E.A. Baltz JCAP 0407 (2004) 008 [astro-ph/0406204]
- $*$ MWDM : All rates are detectable when the WMAP point is reached
- $*$ BWCA : Generally, At or Below levels expected in the mSUGRA model
- $*$ Direct and Indirect detection experiments could serve to discriminate between these two scenarios

MWDM, BWCA : Various Sparticle Masses with Varying M_1, M_2



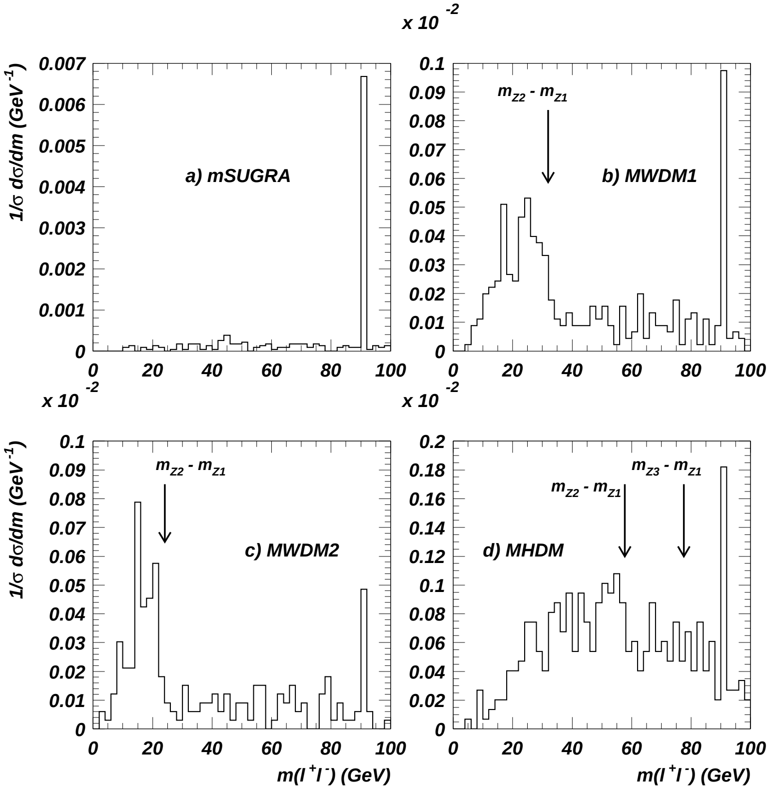


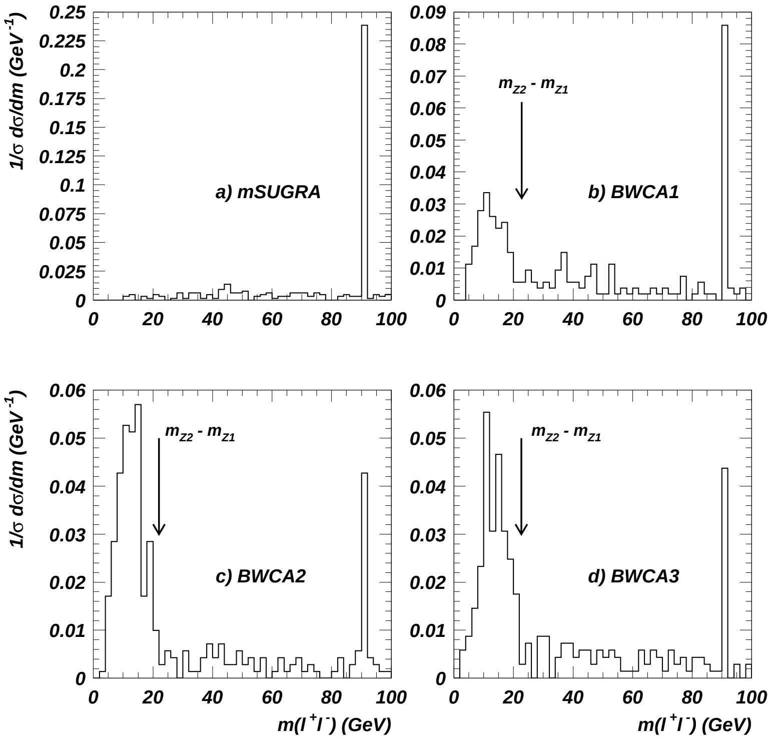
- ISAJET (H. Baer, F.E. Paige, S.D. Protopopescu, and X. Tata)
- mSUGRA : large mass gap between $\tilde{Z}_2$ and $\tilde{Z}_1$ (or $\tilde{W}_1$ and $\tilde{Z}_1$)
- BWCA and MWDM : $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ mass gap decreases

  $\Longrightarrow$ most points in m_0 *vs.* $m_{1/2}$ plane can become WMAP allowed

MWDM, BWCA : CERN LHC Searches

- Dilepton Distributions from SUSY events: $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 l\bar{l}$ open



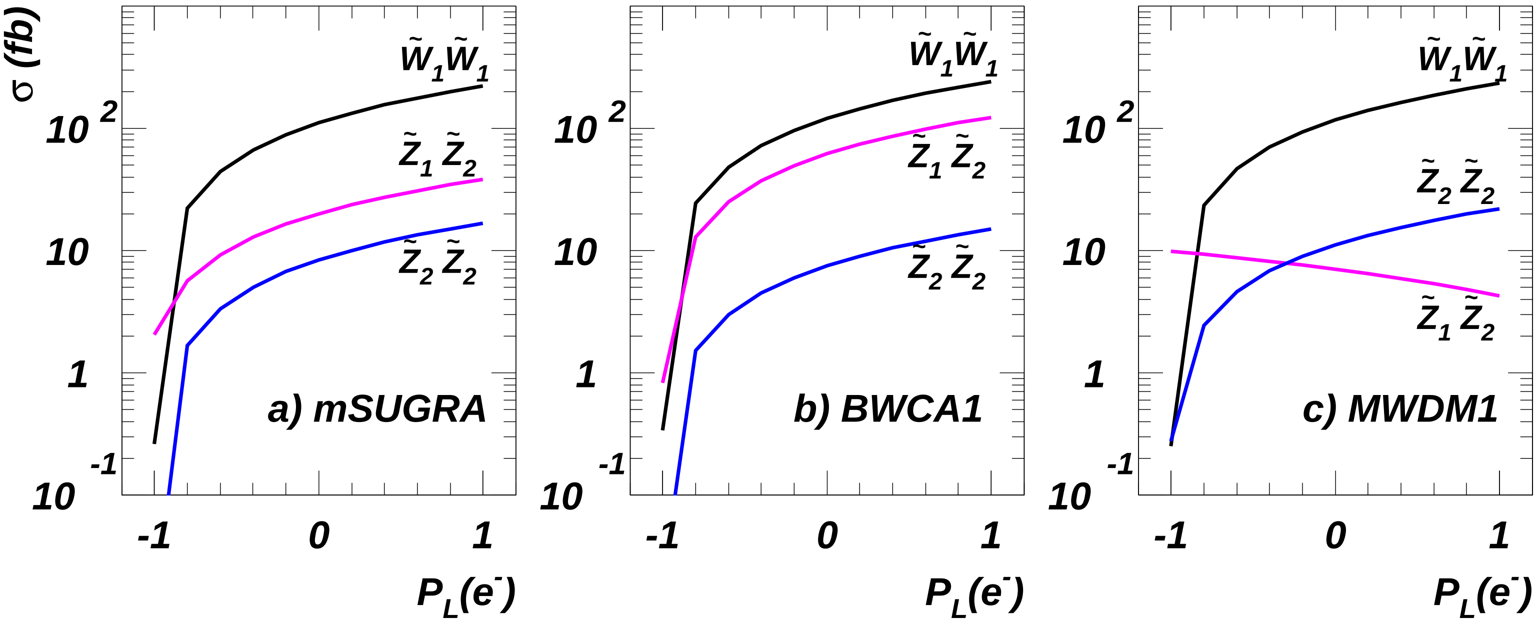


$*$ mSUGRA: sharp peak at $m(l^+l^-) \sim M_Z$ from $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 Z^0$ decays

$*$ MWDM, BWCA: Z^0 peak from $\tilde{Z}_3$, $\tilde{Z}_4$, $\tilde{W}_2$ decays + continuum distribution $m(l^+l^-) < m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ from 3 body decays $\tilde{Z}_2 \longrightarrow \tilde{l}\bar{l}, l\bar{\tilde{l}} \longrightarrow \tilde{Z}_1 l\bar{l}$ or $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 l\bar{l}$

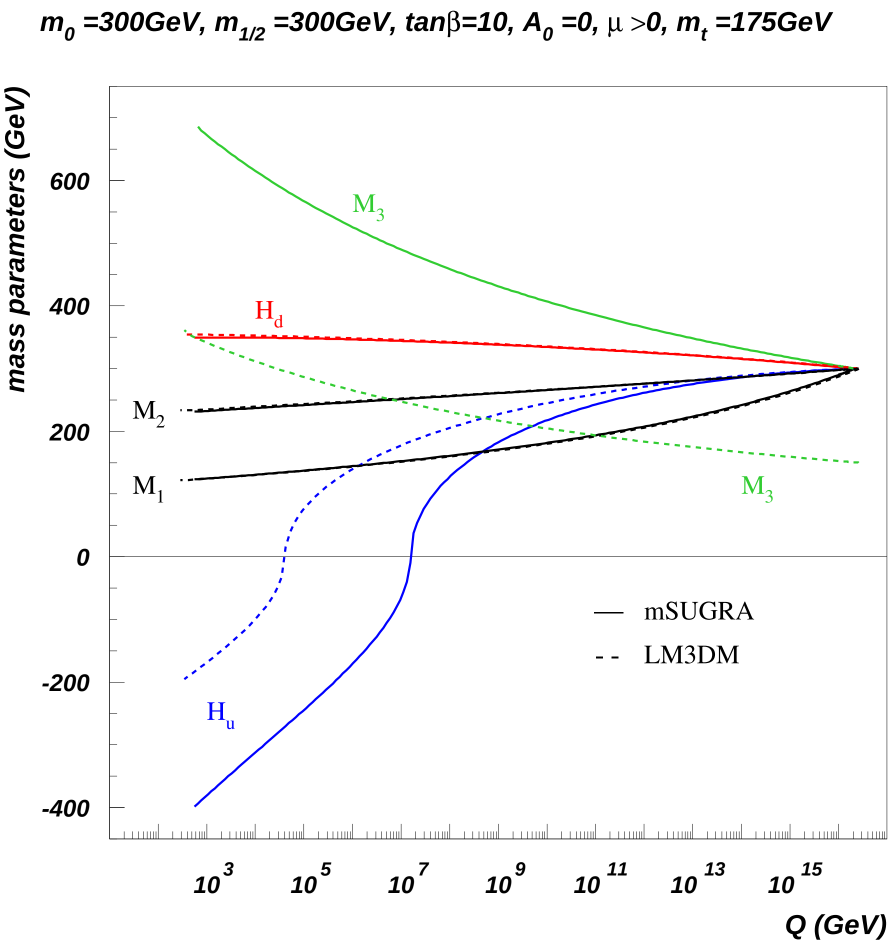
MWDM, BWCA : ILC Searches

Cross Section *vs.* Electron Beam Polarization at ILC



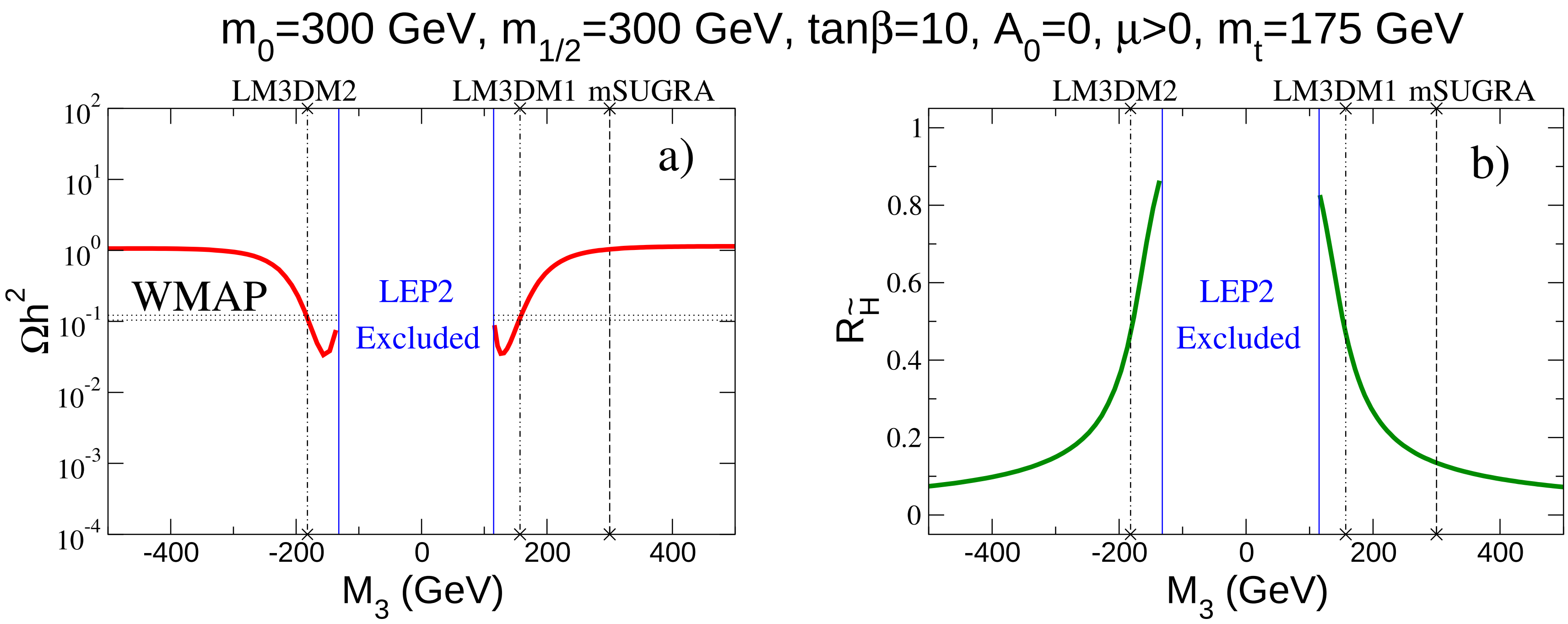
- $*$ In all cases, $\tilde{W}_1$ and $\tilde{Z}_2$ are mainly wino-like $\longrightarrow$ $\sigma(\tilde{W}_1\tilde{W}_1)$ and $\sigma(\tilde{Z}_2\tilde{Z}_2)$ are similar to one another
- $*$ $e^+e^- \longrightarrow \tilde{Z}_1\tilde{Z}_2$ process are quite different
  - — MWDM: $\tilde{Z}_1$ is photino-like, $\tilde{Z}_2$ is zino-like $\longrightarrow$ $e\tilde{e}_L$ coupling suppressed
  - — BWCA: very large $\tilde{Z}_1\tilde{Z}_2$ production cross section for $P_L(e^-)$

Low M3 Dark Matter



- Mild evolution of $m^2_{H_d}$ due to small Yukawa coupling f_b, f_τ
- Lighter squarks and gluinos → reduced effect of f_t on $m^2_{H_u}$ ⇒ smaller μ
- $\frac{dm^2_{H_d}}{dt} \propto f^2_{b,\tau} X_{b,\tau}, \ \frac{dm^2_{H_u}}{dt} \propto f_t^2 X_t$
  where,
  $X_t = m^2_{Q3} + m^2_{\tilde{t}_R} + m^2_{H_u} + A^2_t$
  $X_b = m^2_{Q3} + m^2_{\tilde{b}_R} + m^2_{H_d} + A^2_b$
  $X_\tau = m^2_{L3} + m^2_{\tilde{\tau}_R} + m^2_{H_d} + A^2_\tau$
- $\mu^2 = \frac{m^2_{H_d} - m^2_{H_u} tan\beta}{tan^2\beta - 1} - \frac{M_Z^2}{2} \simeq -m^2_{H_u}$

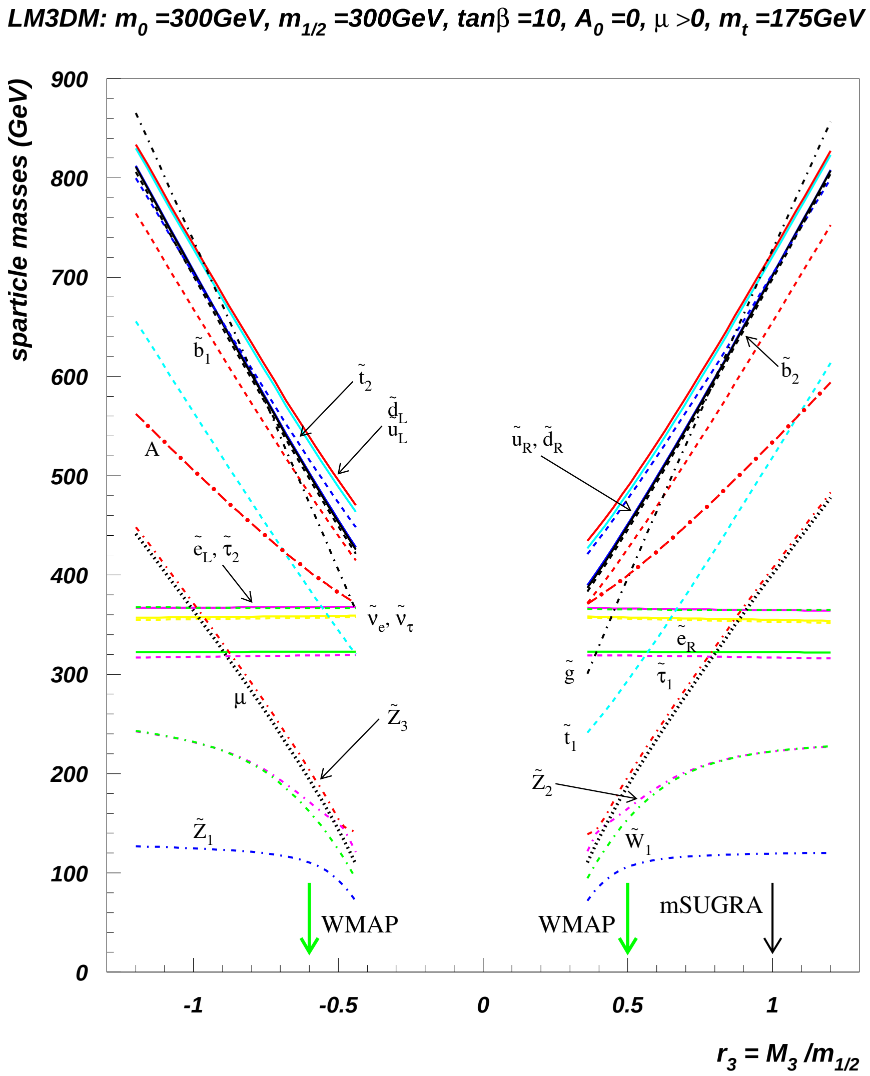
LM3DM : Neutralino Relic Density and Higgsino component of $\tilde{Z}_1$



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

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

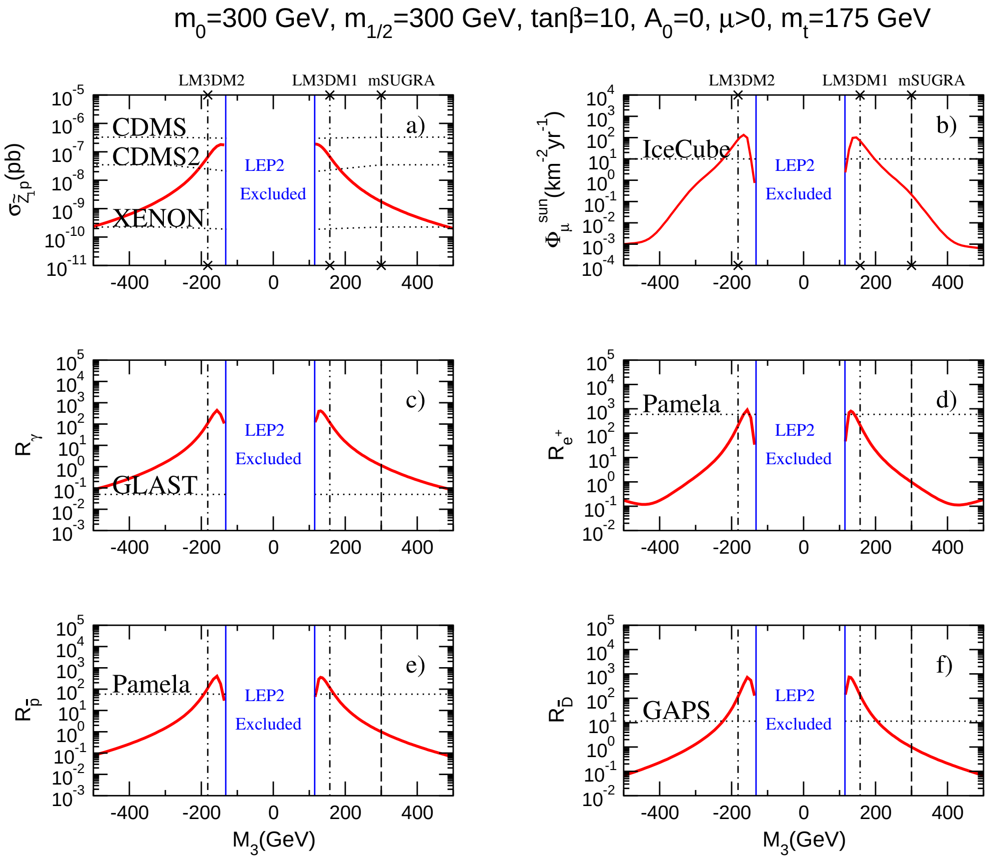
LM3DM : sparticle mass spectrum



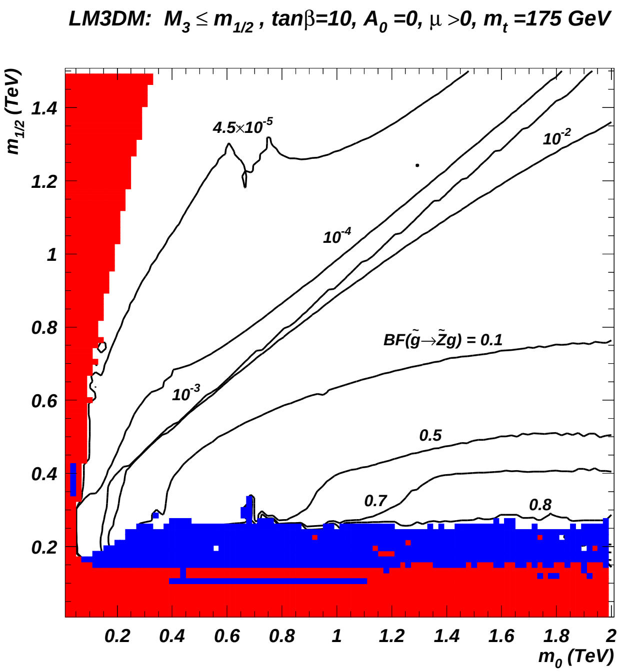
Compare to mSUGRA :

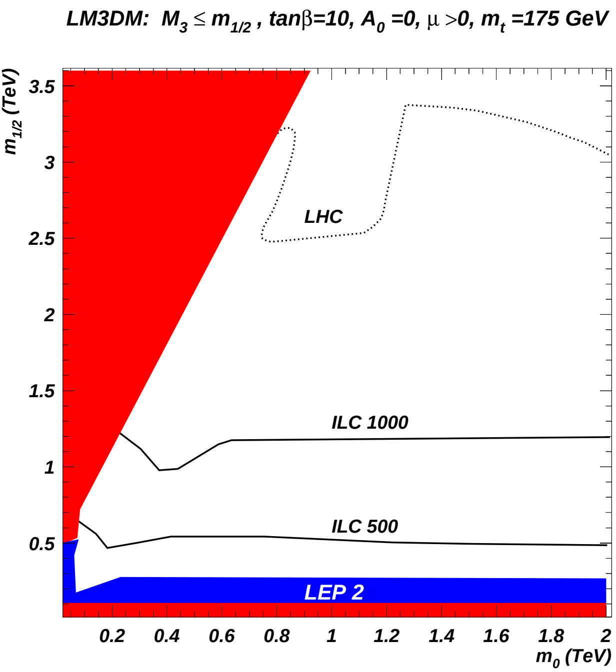
- Less mass hierarchy on squarks and sleptons
- Lighter gluino
- Very light stop
- Small $\tilde{Z}_2 - \tilde{Z}_1$ and $\tilde{W}_1 - \tilde{Z}_1$ mass gaps due to low $|\mu|$

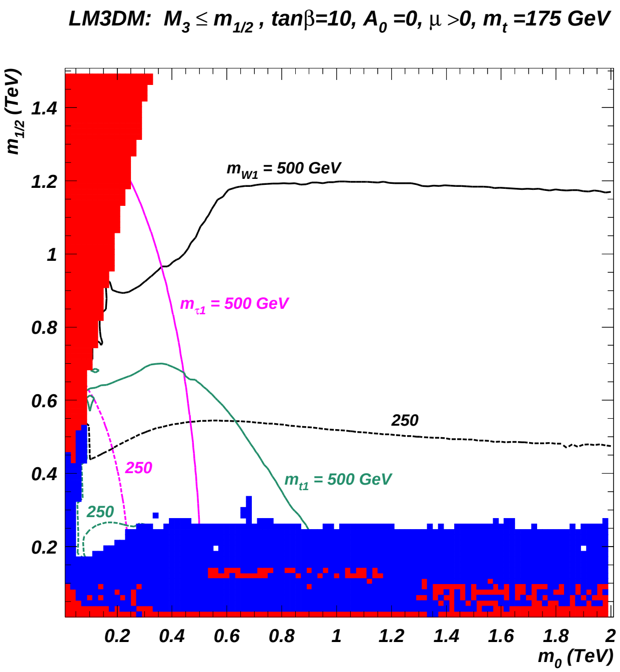
LM3DM : DD and IDD Rates for Low M3 Dark Matter


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

LM3DM at Colliders







- (a) Tevatron: Lighter gluinos expected in LM3DM → larger pair production
- (b) CERN LHC: Reduced squark and gluino masses ⇒ enhanced reach
- (c) ILC: Enhanced $\tilde{W}_1^+\tilde{W}_1^-$ production due to smaller μ

LM3DM at Colliders

- (a) Tevatron
  - Lighter gluinos expected in LM3DM → larger pair production
  - Heavy squarks at large m_0 and large higgsino component
- (b) CERN LHC
  - Reduced squark and gluino masses ⇒ enhanced reach
  - Small $\tilde{Z}_2 - \tilde{Z}_1$ or $\tilde{W}_1 - \tilde{Z}_1$ mass gap ⇒ $\tilde{Z}_2 \to l\bar{l}\tilde{Z}_1 \Rightarrow m(l^+l^-)$ mass edges over all parameter space
- (c) ILC
  - Enhanced $\tilde{W}_1^+\tilde{W}_1^-$ production due to smaller μ
  - Possible $\tilde{t}_1\bar{\tilde{t}}_1$ production
  - All charginos/neutralinos accesible
  - $\tilde{q} \to \tilde{g}q$ kinematically allowed ⇒ precise determination of $\tilde{q}$, $\tilde{g}$ masses

Conclusions

- Most of mSUGRA parameter space is excluded by WMAP bound
- New perspectives open with gaugino mass non-universalities in SUGRA
- If DM in nature is indeed composed of SUSY models with non-universal gaugino masses (MWDM($M_1 \sim M_2$), BWCA DM($M_1 \sim -M_2$) or LM3DM($|M_3| \ll M_1 \simeq M_2$))
  - $\tilde{Z}_2 - \tilde{Z}_1$ and $\tilde{W}_1 - \tilde{Z}_1$ mass gaps are reduced compared to the case with gaugino mass universality
  - Direct and Indirect detection experiments may discriminate between these scenarios
  - SUSY can be discovered at Tevatron via squarks and gluinos
  - CERN LHC should be able to measure $m_{\tilde{g}}$ and $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ mass gap from dilepton distribution from $\tilde{Z}_2 \longrightarrow l\bar{l}\tilde{Z}_1$ decay; $\tilde{Z}_2 \longrightarrow \tilde{Z}_1\gamma$ (spoiler 2-body decay closed)
  - At ILC, $W_1^+\tilde{W}_1^-$, $\tilde{Z}_1\tilde{Z}_2$, $\tilde{Z}_2\tilde{Z}_2$ production cross sections as a function of beam polarization should be able to measurable.

Direct and Indirect detection of Neutralino CDM

- Using DarkSUSY 4.1
- Direct, Indirect Detection
  - Direct Detection
    - Spin independent Neutralino-Proton scattering Cross section
      : CDMS2, XENON (sensitivity at the corresponding neutralino mass)
  - Indirect Detection
    - detection of μ : $\Phi(\mu) = 40\ \mu\mathrm{s/km^2/yr}$ (IceCube)
    - detection of γ : $\Phi(\gamma) = 10^{-10}\gamma\mathrm{s/cm^2/s}$ (GLAST)
    - detection of e^+ :
      $d\Phi(e^+)/dEd\Omega = 2.04\times10^{-9}\mathrm{e^+s/cm^2/s/sr}$(Pamela)
    - detection of $\bar{p}$: $d\Phi(\bar{p})/dEd\Omega = 3.38\times10^{-9}\bar{\mathrm{p}}\mathrm{s/cm^2/s/sr}$(Pamela)
    - detection of $\bar{D}$: $d\Phi(\bar{D})/dEd\Omega = 2.6\times10^{-13}\mu\mathrm{s/km^2/yr}$(GAPS)

MSSM particle content

Superfield	Bosons		Fermions		$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge							
$\hat{g}_{B\mu}$	gluon	$G_{B\mu}$	gluino	$\tilde{g}_B$	**8**	**1**	0
$\hat{W}_{A\mu}$	Weak	$W_{A\mu}$ $(W^{\pm}, Z)$	wino, zino	λ_A	**1**	**3**	0
$\hat{B}$	Hypercharge	B_μ (γ)	bino	λ_0	**1**	**1**	0
Matter							
$\hat{L}_i$	sleptons	$\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	leptons	$L_i = (\nu, e)_L$	**1**	**2**	-1
$\hat{E}_i$		$\tilde{E}_i = \tilde{e}_R$		$E_i = e_R$	**1**	**1**	2
$\hat{Q}_i$	squarks	$\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	quarks	$Q_i = (u, d)_L$	**3**	**2**	$1/3$
$\hat{U}_i$		$\tilde{U}_i = \tilde{u}_R$		$U_i = u_R^c$	$\bar{\mathbf{3}}$	**1**	$-4/3$
$\hat{D}_i$		$\tilde{D}_i = \tilde{d}_R$		$D_i = d_R^c$	$\bar{\mathbf{3}}$	**1**	$2/3$
Higgs							
$\hat{H}_d$	Higgses	H_d	higgsinos	$\tilde{H}_d$	**1**	$\bar{\mathbf{2}}$	-1
$\hat{H}_u$		H_u		$\tilde{H}_u$	**1**	**2**	1