Dark matter searches in the Bino-Wino Co-Annihilation(BWCA) and Mixed Wino Dark Matter(MWDM) scenarios

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Outline

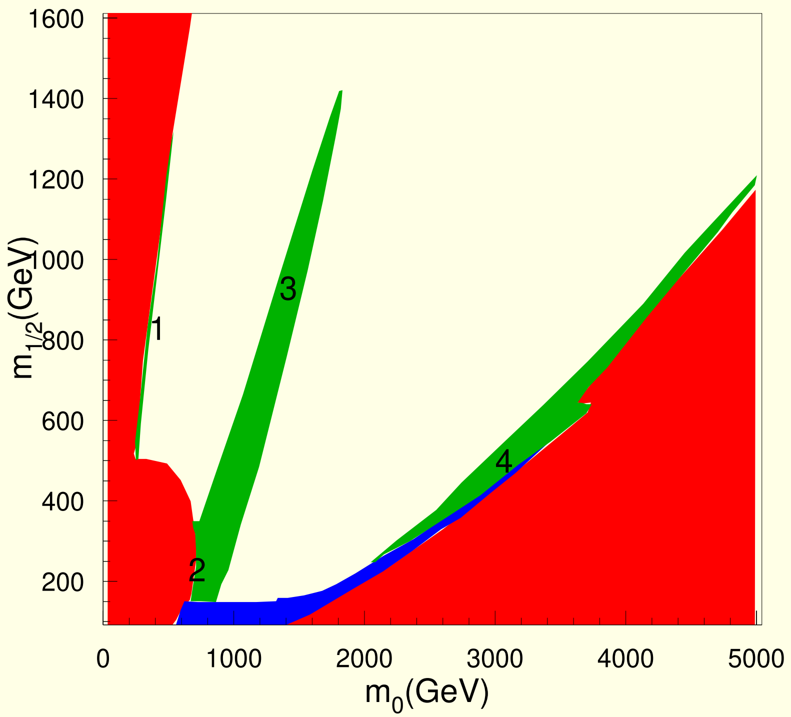
- Introduction
- Review of the mSUGRA Model
- Non-universal Gaugino Masses
- Direct and Indirect detection of Neutralino CDM
- Neutralino Radiative decay
- BWCA dark matter and MWDM at Colliders
- Conclusions

Introduction

- Dark Matter(DM)
  - Missing non-baryonic matter of the universe is in the form of dark matter
  - Cold Dark Matter(CDM) is strongly favored
- Relic Density
  - Flat universes in the ΛCDM cosmological model are characterized by baryon density, matter density, vacuum density, expansion rate(h)
  - From the WMAP results, the cold dark matter density of the universe is $\Omega_{CDM}h^2 = 0.111^{+}_{-}0.01$
- The Lightest Supersymmetric Particle(LSP) as a candidate for CDM
  - The lightest neutralino is a attractive candidate $\longleftarrow$neutral and stable if R-parity is conserved

Review of the mSUGRA Model

- Parameter Space
  - m_0, $m_{1/2}$, A_0, $\tan\beta$, $sign(\mu)$
- WMAP allowed Regions
  1. $\tilde{\tau}$ co-annihilation region
  2. bulk region (excluded by LEP2 bound, BF$(b \to s\gamma)$)
  3. A-funnel
  4. FP/HB region



- Limitation of mSUGRA
  $\Longrightarrow$ In most of the parameter space of the mSUGRA model, a value of neutralino relic density is beyond the WMAP bound.

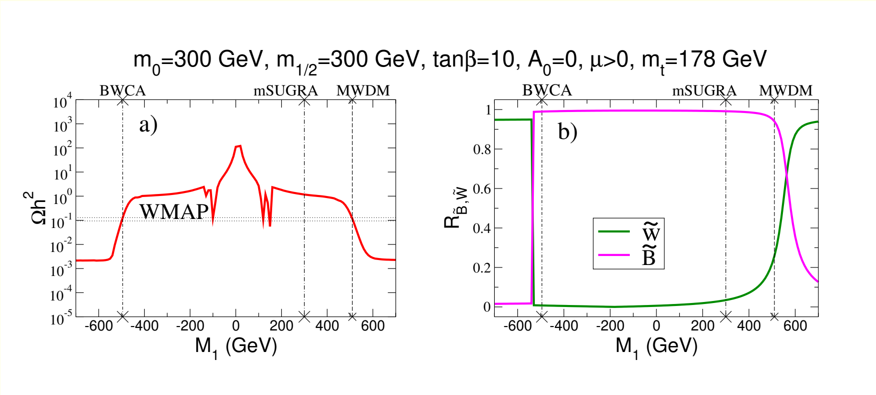
Non-universal Gaugino Masses

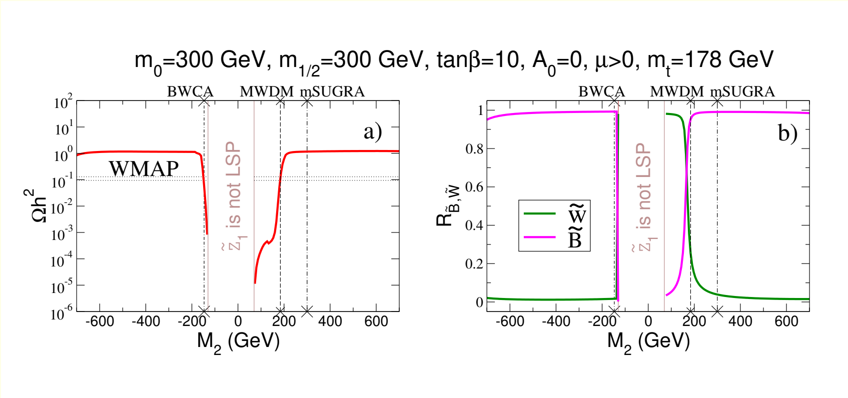
- $M_1 \neq M_2$ at $Q = M_{GUT}$ M_1 : mass of the hypercharge U(1) gaugino at EW scale $\rightarrow$ B-ino mass
  M_2 : mass of the SU(2) gaugino at EW scale $\rightarrow$ W-ino mass

- Generally, the lightest neutralino mass eigenstate is determined by the content of the LSP $\tilde{z}_1 = v_1^{(1)}\psi_{h_u^0} + v_2^{(1)}\psi_{h_d^0} + v_3^{(1)}\lambda_3 + v_4^{(1)}\lambda_0$
  $R_{\tilde{w}} = |v_3^{(1)}|$, $R_{\tilde{B}} = |v_4^{(1)}|$, $R_{\tilde{H}} = \sqrt{|v_1^{(1)}| + |v_2^{(1)}|}$:$W$-ino, B-ino, Higgsino respectively

- 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_1/M_2 (MWDM)
  - by allowing co-annihilation between high bino-like and wino-like states: M_1 and M_2 are of opposite sign (BWCA)
  - by increasing the higgsino content of the LSP by decreasing the gluino mass (MHDM) : talk by A.Mustafayev
  - "well tempered neutralino" N. Arkani-Hamed, A. Delgado, G.F. Giudice

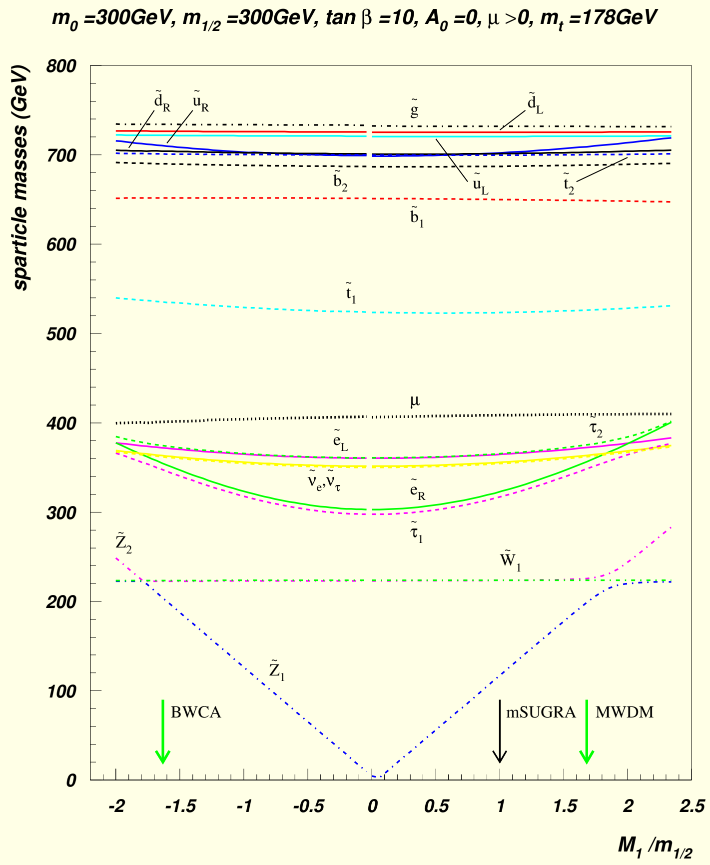
- Plots of relic density $\Omega_{\tilde{Z}_1} h^2$ and Bino/Wino component of $\tilde{Z}_1$

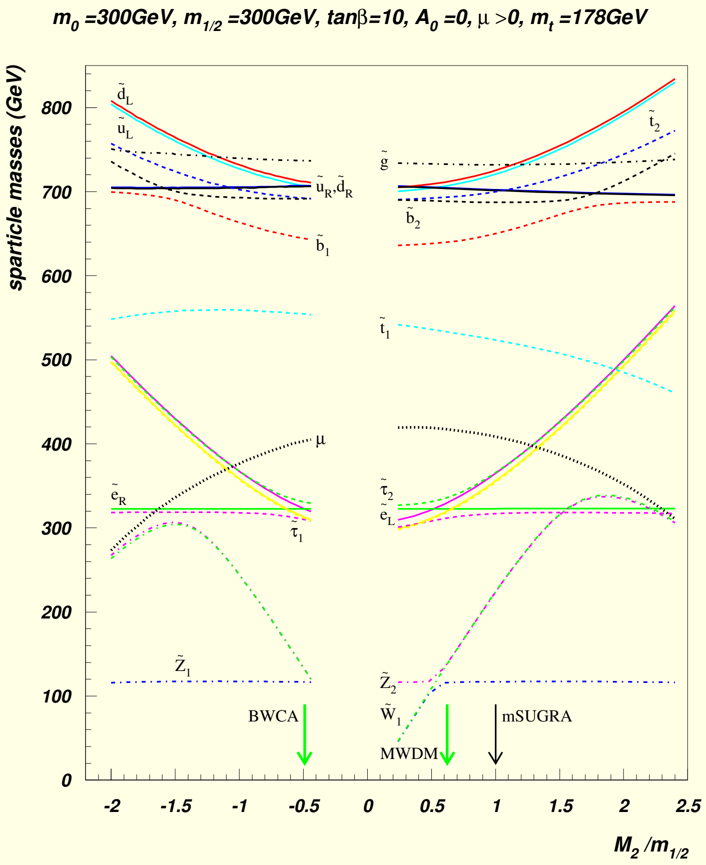




$*$ As $|M_1|(|M_2|)$ increases(decreases) past its mSUGRA value,
$\longrightarrow$ $\tilde{Z}_1$ becomes wino-like(MWDM) or bino-like but close to wino-like(BWCA)
$\longrightarrow$ relic density decreases
$\longrightarrow$ WMAP $\Omega_{CDM} h^2$ value is reached

- Plots of various sparticle masses with varying M_1, M_2



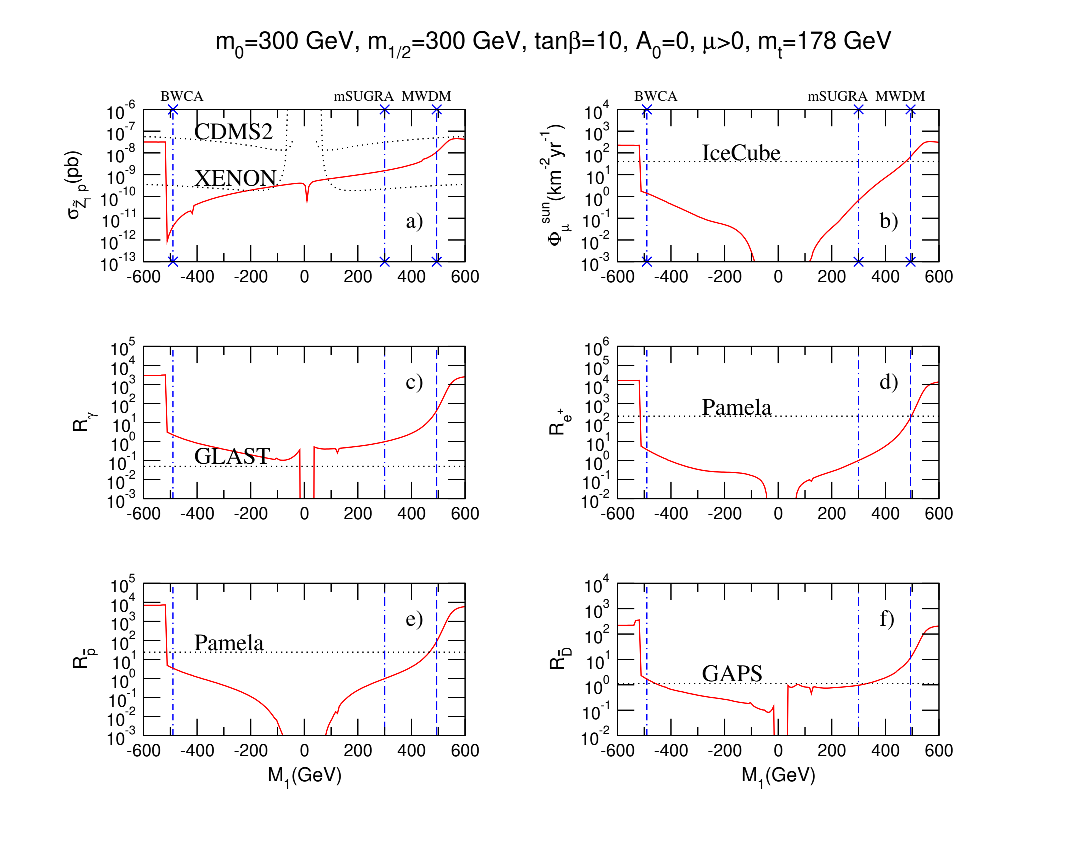


  - $*$ mSUGRA : large mass gap between $\tilde{Z}_2$ and $\tilde{Z}_1$
  - $*$ BWCA and MWDM : $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ mass gap decreases $\longrightarrow$ most points in m_0 *vs.* $m_{1/2}$ plane can become WMAP allowed

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 $\bar{p}$: $d\Phi(\bar{p})/dEd\Omega = 3.38\times10^{-9}\bar{p}\mathrm{s/cm^2/s/sr}$(Pamela)
    - detection of $\bar{D}$: $d\Phi(\bar{D})/dEd\Omega = 2.6\times10^{-13}\mu\mathrm{s/km^2/yr}$(GAPS)

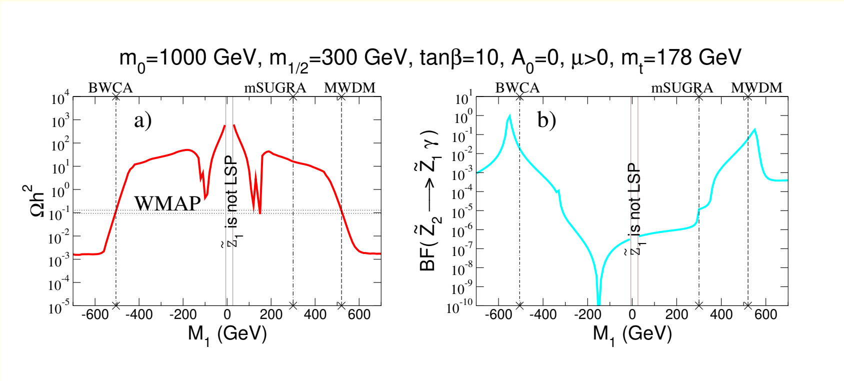
- Rates for Direct and Indirect Detection of Neutralino Dark Matter

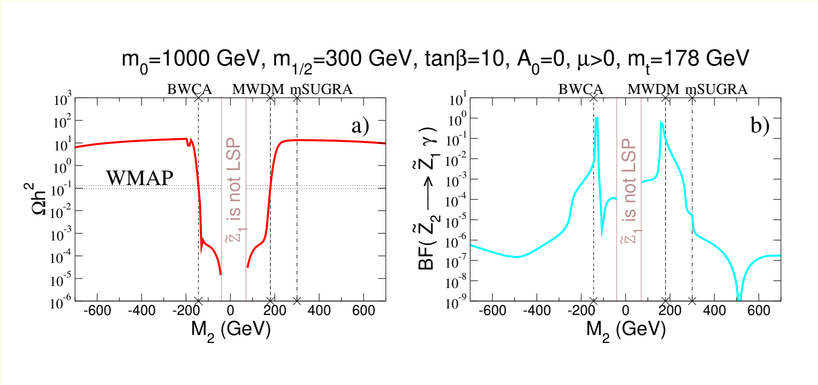


  - $*$ MWDM : All rates are detectable when the WMAP point is reached
  - $*$ BWCA : Generally, At or Below levels expected in the mSUGRA model
  - $*$ Direct and Indirect detection experiments could serve to discriminate between these two scenarios

Neutralino Radiative Decay

- Usually, $\tilde{Z}_2$ decays via $\tilde{Z}_2 \to \tilde{Z}_1 f \bar{f}$
- If $\tilde{Z}_1$ and $\tilde{Z}_2$ are close in mass, the radiative decay $\tilde{Z}_2 \to \tilde{Z}_1 \gamma$ at loop level increases





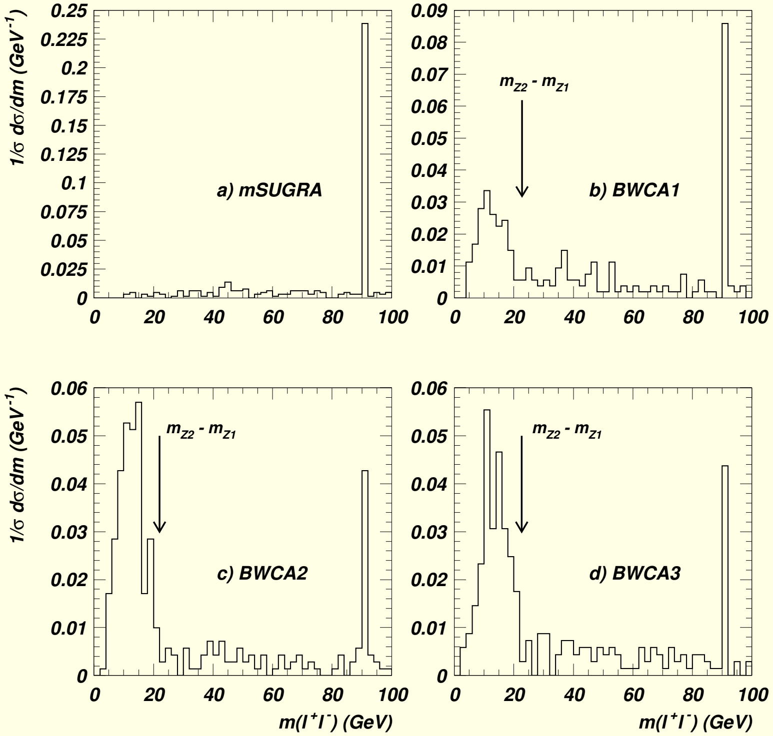
- In the BWCA(MWDM) scenarino $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ is small $\longrightarrow$ the branching fraction can reach $\sim 50\%(\sim 10\%)$
- A considerable fraction of SUSY events at colliders to contain hard isolated photons via the decay of $\tilde{Z}_2$ is expected

BWCA dark matter and MWDM at Colliders

- If $\tilde{Z}_2 \longrightarrow \tilde{l}\bar{l}, \bar{\tilde{l}}l \longrightarrow \tilde{Z}_1 l\bar{l}$ or $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 l\bar{l}$ are open ($l = e$ or μ), $\Longrightarrow$ good prospects for measuring the $\tilde{Z}_2$ - $\tilde{Z}_1$ mass gap at the CERN LHC and possibly at the Fermi Tevatron
- BWCA DM and MWDM have typically small $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ mass gap
  - In the mSUGRA case, most of the parameter space has $m_{\tilde{Z}_2} - m_{\tilde{Z}_1} > 90$ GeV, $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 Z^0$ or $\tilde{Z}_1 h$ "spoiler" decays dominant
  - In the BWCA and MWDM cases, the mass gap is much smaller
    - spoiler decays are closed, 3-body decays are open
    - $l\bar{l}$ mass edge always visible at LHC
  - $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 \gamma$ enhanced

CERN LHC Searches

- SUSY events generating using Isajet $7.72'$
- Dilepton Distributions from four different SUSY events



a) mSUGRA: sharp peak at $m(l^+l^-) \sim M_Z$ from $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 Z^0$ decays
b) BWCA1: Z^0 peak from $\tilde{Z}_3$, $\tilde{Z}_4$, $\tilde{W}_2$ decays + continuum distribution $m(l^+l^-) < m_{\tilde{Z}_2} - m_{\tilde{Z}_1} = 22.7GeV$
c)(d)) BWCA2(3): Z^0 peak + continuum distribution $m(l^+l^-) < m_{\tilde{Z}_2} - m_{\tilde{Z}_1} = 21.8GeV$

Linear e^+e^- collider(ILC)

- $m_{\tilde{Z}_2}$, $m_{\tilde{W}_1}$ and $m_{\tilde{Z}_1}$ can be inferred from $\tilde{W}_1^+\tilde{W}_1^- \longrightarrow \bar{l}\nu_l\tilde{Z}_1 + q\bar{q}\tilde{Z}_1$ (dijet events)
- $\tilde{W}_1^+\tilde{W}_1^-$, $\tilde{Z}_1\tilde{Z}_2$, $\tilde{Z}_2\tilde{Z}_2$ production cross sections can be measured as a function of beam polarization

$$P_L(e^-) = f_L - f_R$$

$$f_L = \frac{n_L}{n_L + n_R} = \frac{1 + P_L}{2}$$

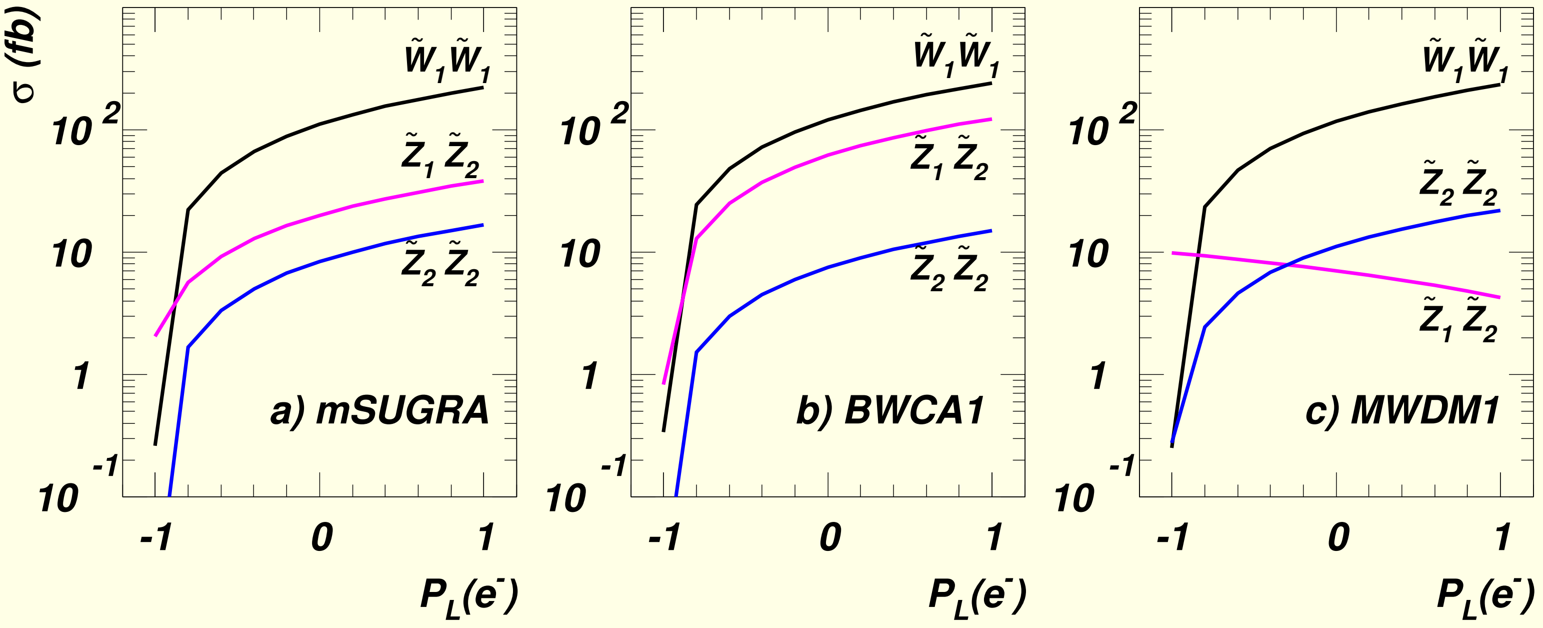
$$f_R = \frac{n_R}{n_L + n_R} = \frac{1 - P_L}{2}$$

P_L : beam polarization

$n_{L,R}$: the number of left(right) polarized electron in the beam

$f_{L,R}$: fraction of left(right) polarized electron in the beam

Cross Section *vs.* electron beam polarization $P_L(e^-)$

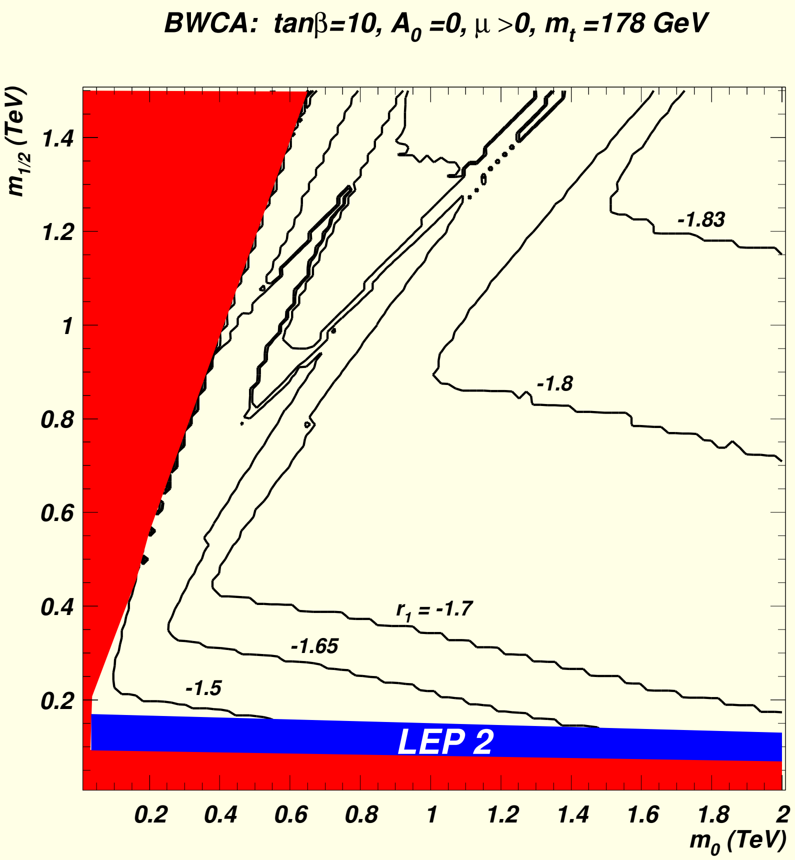


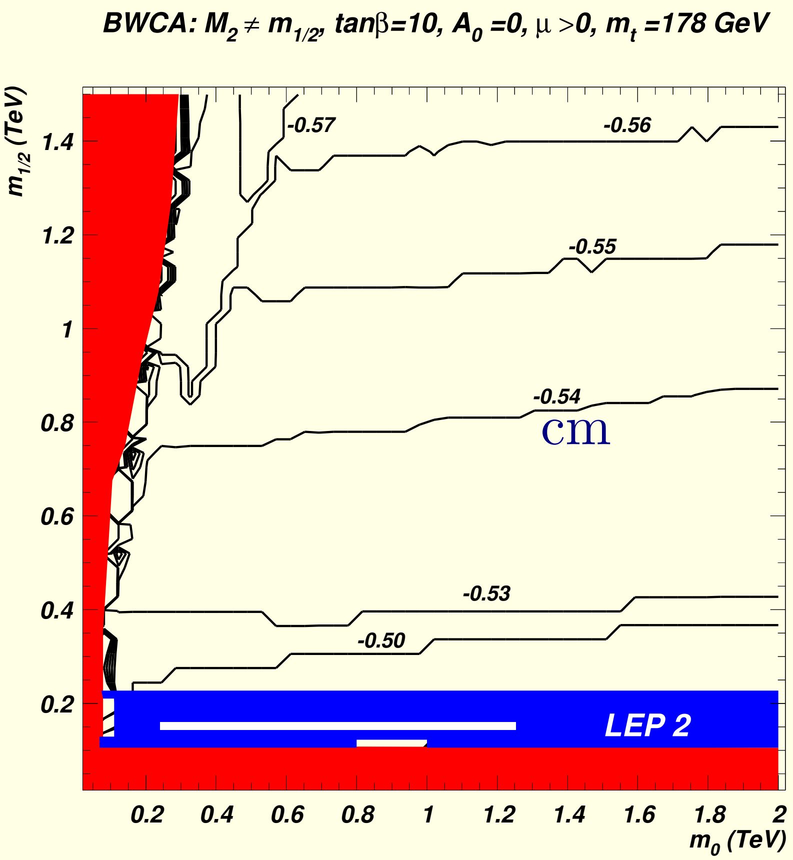
- In all cases, $\tilde{W}_1$and $\tilde{Z}_2$ are mainly wino-like $\longrightarrow$ $\sigma(\tilde{W}_1\tilde{W}_1)$ and $\sigma(\tilde{Z}_2\tilde{Z}_2)$ are similar to one another
- $e^+e^- \longrightarrow \tilde{Z}_1\tilde{Z}_2$ process are quite different
  - MWDM: $\tilde{Z}_1$ is photino-like,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

Conclusions

- If DM in nature is indeed composed of BWCA DM($M_1 \sim -M_2$) or MWDM($M_1 \sim M_2$)
  - $\tilde{Z}_2 - \tilde{Z}_1$ 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
- In order to pin down the existence of BWCA DM or MWDM
  - 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; $\tilde{Z}_2 \longrightarrow \tilde{Z}_1\gamma$
  - At the ILC, $\tilde{Z}_1$, $\tilde{Z}_2$, $\tilde{W}_1$ masses, $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ mass gap and $W_1^+\tilde{W}_1^-$, $\tilde{Z}_1\tilde{Z}_2$, $\tilde{Z}_2\tilde{Z}_2$ production cross sections as a function of beam polarization should be able to measurable. But, in the BWCA case, $\tilde{Z}_1\tilde{Z}_2$ production should occur at enhanced rates relative to mSUGRA and MWDM

Contours of $r_1 \equiv M_1/m_{1/2}$ and $r_2 \equiv M_2/m_{1/2}$ in $m_0 vs. m_{1/2}$ plane

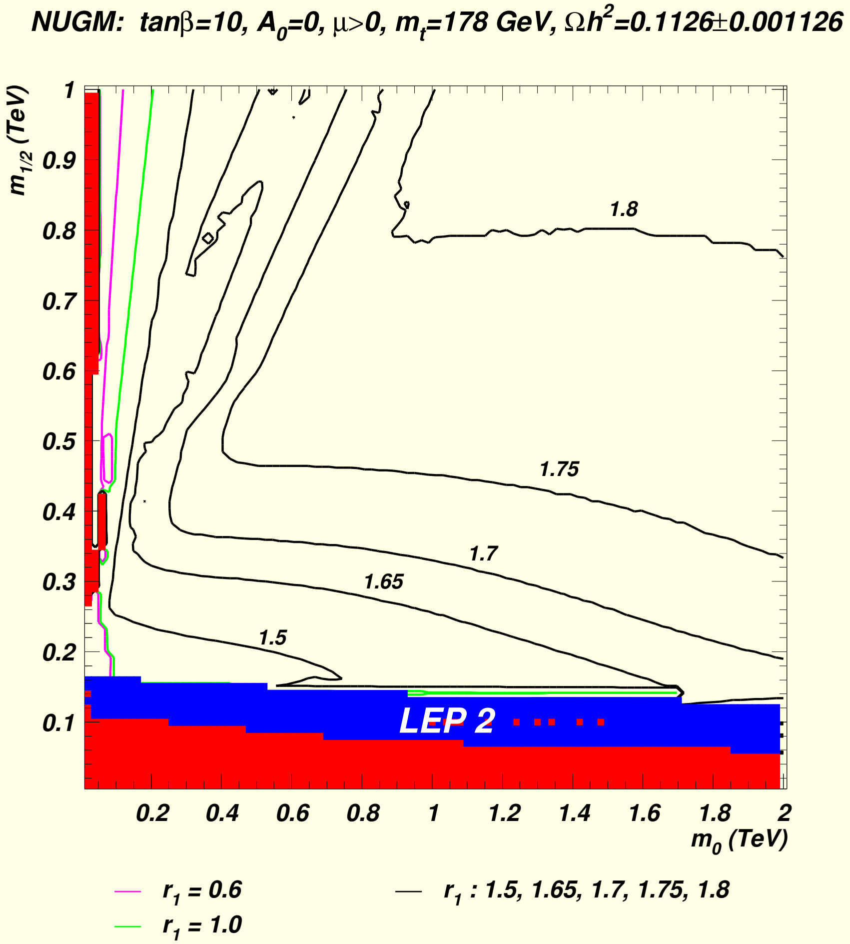


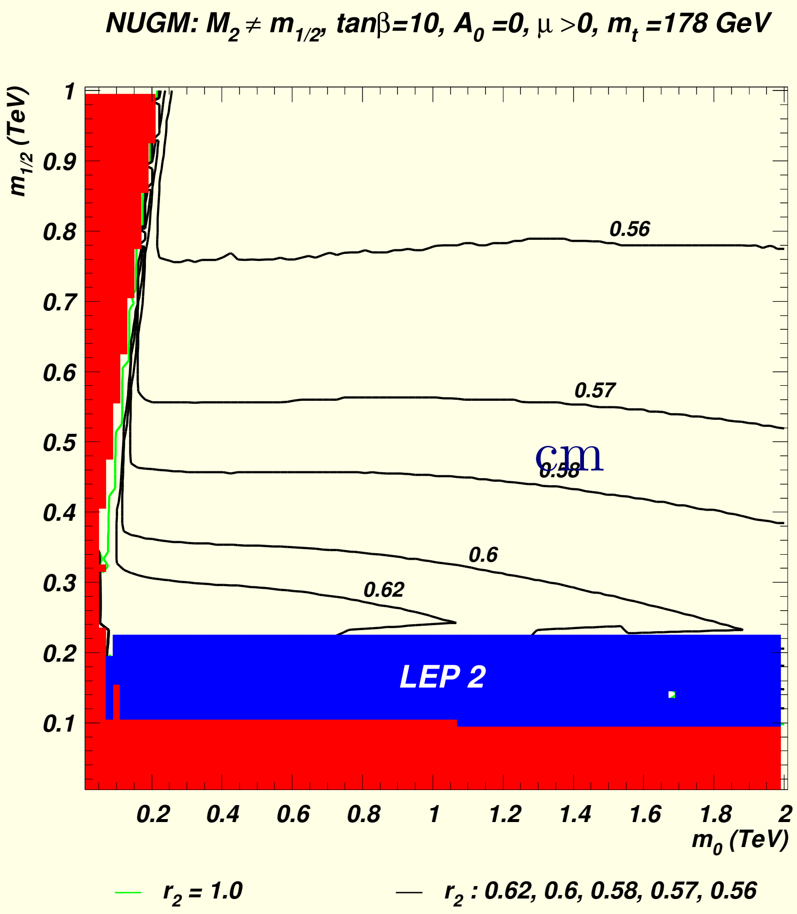


cm

∗ Every point in $m_0 vs. m_{1/2}$ plane can be WMAP allowed for BWCA

Contours of $r_1 \equiv M_1/m_{1/2}$ and $r_2 \equiv M_2/m_{1/2}$ in $m_0 vs. m_{1/2}$ plane

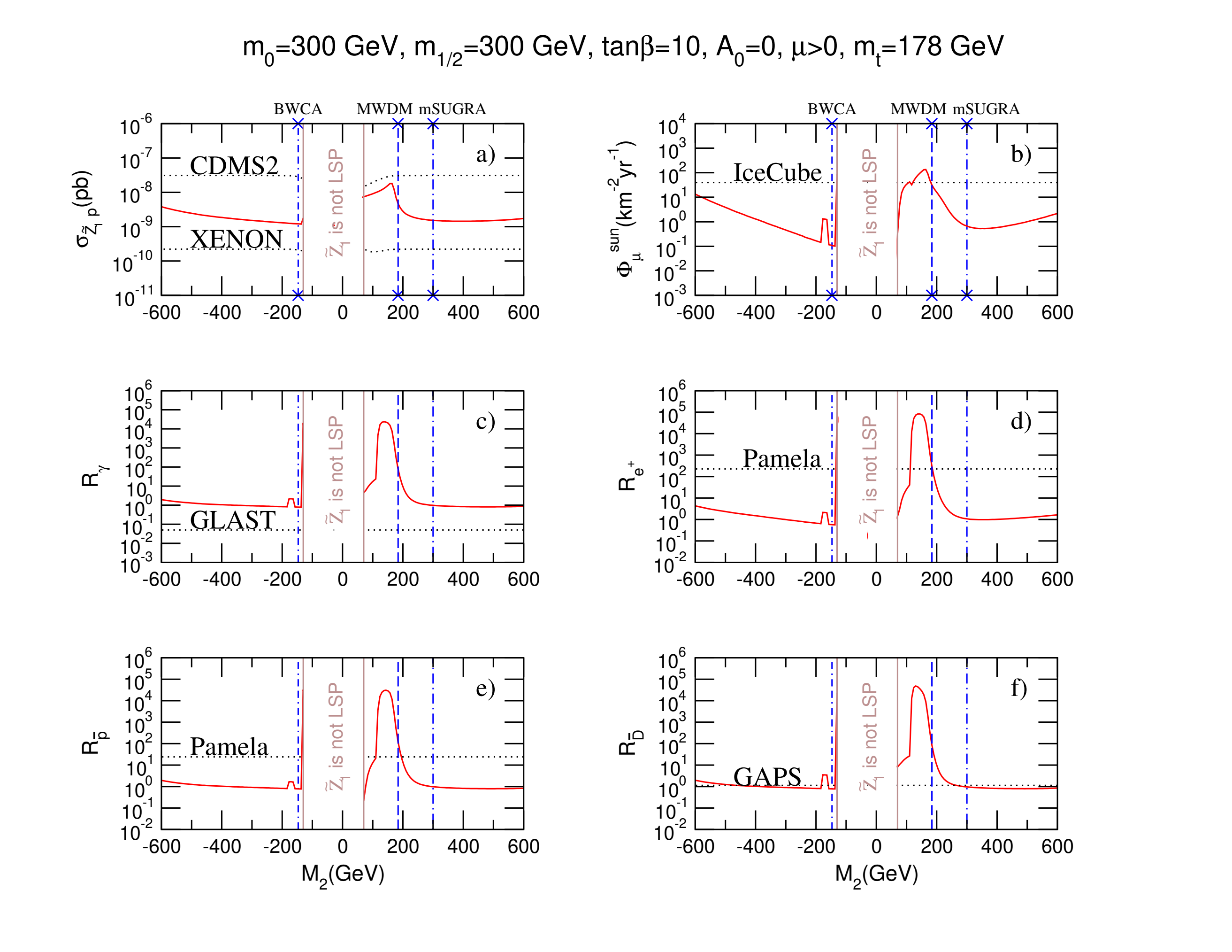




cm

* Every point in $m_0 vs. m_{1/2}$ plane can be WMAP allowed for MWDM

Rates for Direct and Indirect Detection of Neutralino Dark Matter



CERN LHC Reaches

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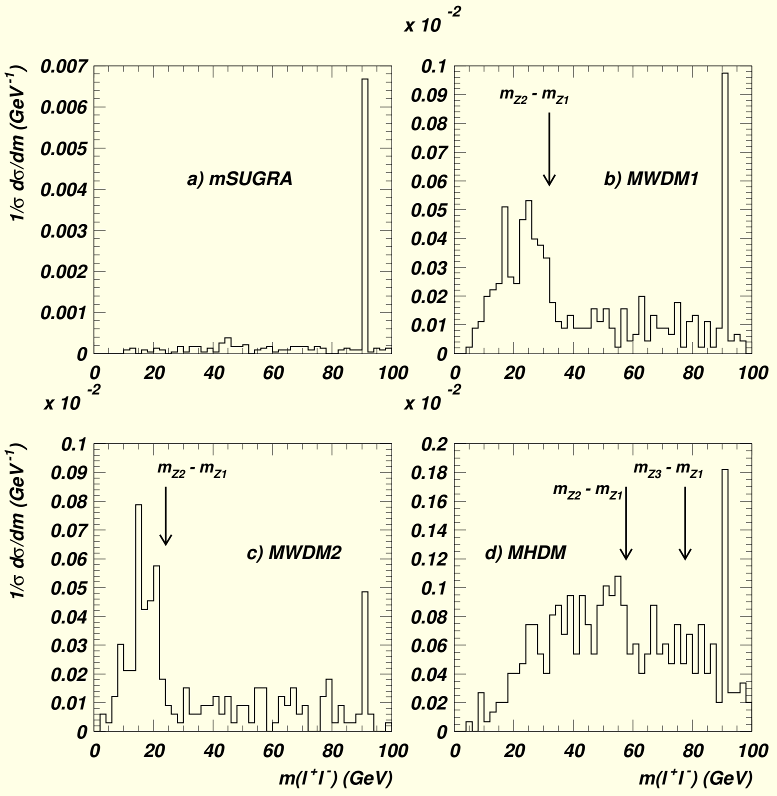

a) mSUGRA: sharp peak at $m(l^+l^-) \sim M_Z$ from $\tilde{Z}_2 \longrightarrow \tilde{Z}_1 Z^0$ decays

b) MWDM1: Z^0 peak from $\tilde{Z}_3$, $\tilde{Z}_4$, $\tilde{W}_2$ decays + continuum distribution $m(l^+l^-) < m_{\tilde{Z}_2} - m_{\tilde{Z}_1} = 31.9 GeV$

c) MWDM2: Z^0 peak + continuum distribution $m(l^+l^-) < m_{\tilde{Z}_2} - m_{\tilde{Z}_1} = 22.9 GeV$

d) MHDM: $m_{\tilde{Z}_2} - m_{\tilde{Z}_1}$ mass edge at 57.5 GeV should be visible