Dark Matter in SUGRA Models with Nonuniversal Gaugino Masses

D. P. Roy

Homi Bhabha Centre for Science Education

Tata Institute of Fundamental Research

Mumbai – 400088, India

Outline

SUGRA Models with Nonuniversal Gaugino Masses

$$SU(5) \Rightarrow 24 \times 24 = 1(\tilde{B}) + 24(\tilde{B}) + 75(\tilde{H}) + 200(\tilde{H}) : gaugino - mass$$

- Bulk Annihilation of Bino LSP via Sfermion exchange suppressed by the large Sfermion mass limit from LEP => Generic Overabundance of Bino DM relic density
- Efficient Annihilation of Higgsino LSP via W/Z exchange => Underabundance of relic density LSP mass < 1 TeV

- Bulk Annihilation Region of Bino LSP in 1+24, 1+75 & 1+200 Models : Implication for LHC Signal
- Mixed Bino-Higgsino & Bino-Wino-Higgsino LSP in 1+75 and 1+200 Models : Implications for DM and LHC Expts.

- Wino and Higgsino LSP in AMSB Model: TeV scale LSP mass for right relic density => Implications for DM Expts.

Nonuniversal gaugino mass models of SUGRA

n	M_3^G	M_2^G	M_1^G
1	1	1	1
24	1	$-3/2$	$-1/2$
75	1	3	-5
200	1	2	10

$$M_i^G \equiv M_{\lambda i} \in \frac{\langle F_S \rangle_{ij}}{M_{Pl}} \lambda_i \lambda_j ; i \,\&\, j = 1,2,3$$

$$SU(5): F_S \supset 24 \otimes 24 = 1 + 24 + 75 + 200$$

$$F_S = 1 \Rightarrow M_{1,2,3}^G = m_{1/2} (Universal) \Rightarrow M_1 \cong 0.4 m_{1/2} < \mu \cong \sqrt{2} m_{1/2} : \tilde{B} - LSP$$

$$F_S = 24 \Rightarrow M_{1,2,3}^G = (-1/2, -3/2, 1) \times m_{1/2} \Rightarrow |M_1| \cong 0.2 m_{1/2} < \mu : \tilde{B} - LSP$$

$$F_S = 75 \Rightarrow M_{1,2,3}^G = (-5, 3, 1) \times m_{1/2} \Rightarrow |M_1| \cong 2 m_{1/2} > \mu \Rightarrow \tilde{H} - LSP$$

$$F_S = 200 \Rightarrow M_{1,2,3}^G = (10, 2, 1) \times m_{1/2} \Rightarrow M_1 \cong 4 m_{1/2} > \mu \Rightarrow \tilde{H} - LSP$$

$$\mu^2 + M_Z^2 / 2 \cong -0.1 m_0^2 + 2.1 M_3^{G2} - 0.2 M_2^{G2} + 0.2 M_3^G M_2^G$$

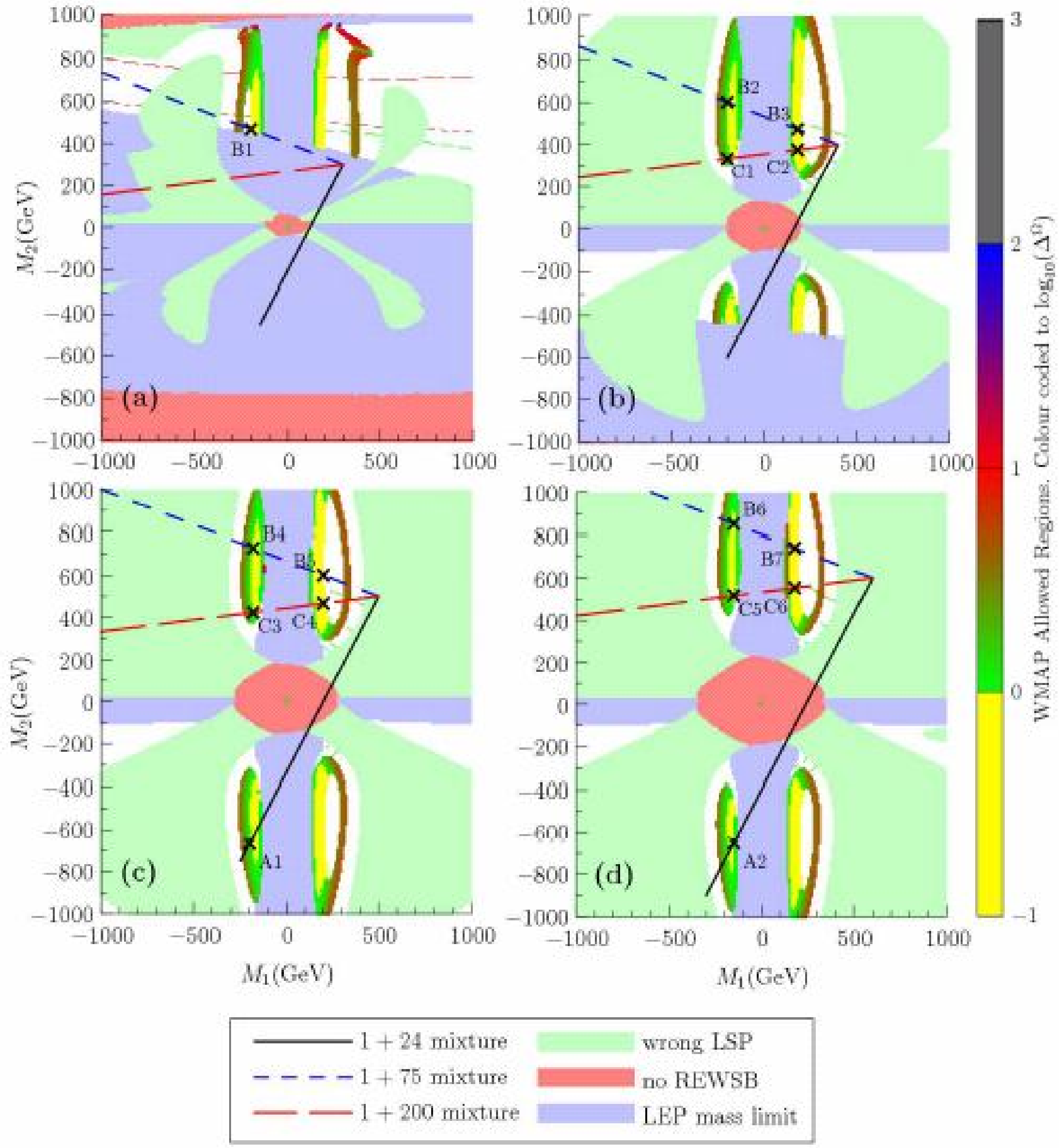
Chattopadhyay & Roy, Huitu et al, Anderson et al, …

$$\langle F_S \rangle = (1 - \kappa) \langle F_1 \rangle + \kappa \langle F_{24,75,200} \rangle$$

Bino LSP in Non-universal Gaugino Mass Model

King, Roberts & Roy, JHEP 07

M3 = 300, 400, 500 & 600 GeV



Bulk annihilation region of Bino DM (yellow) allowed in Non-universal gaugino mass models

$$m_0 = 70GeV$$

Light right sleptons
Even left sleptons lighter than Wino
=>Large leptonic BR of SUSY
Cascade decay via Wino at LHC

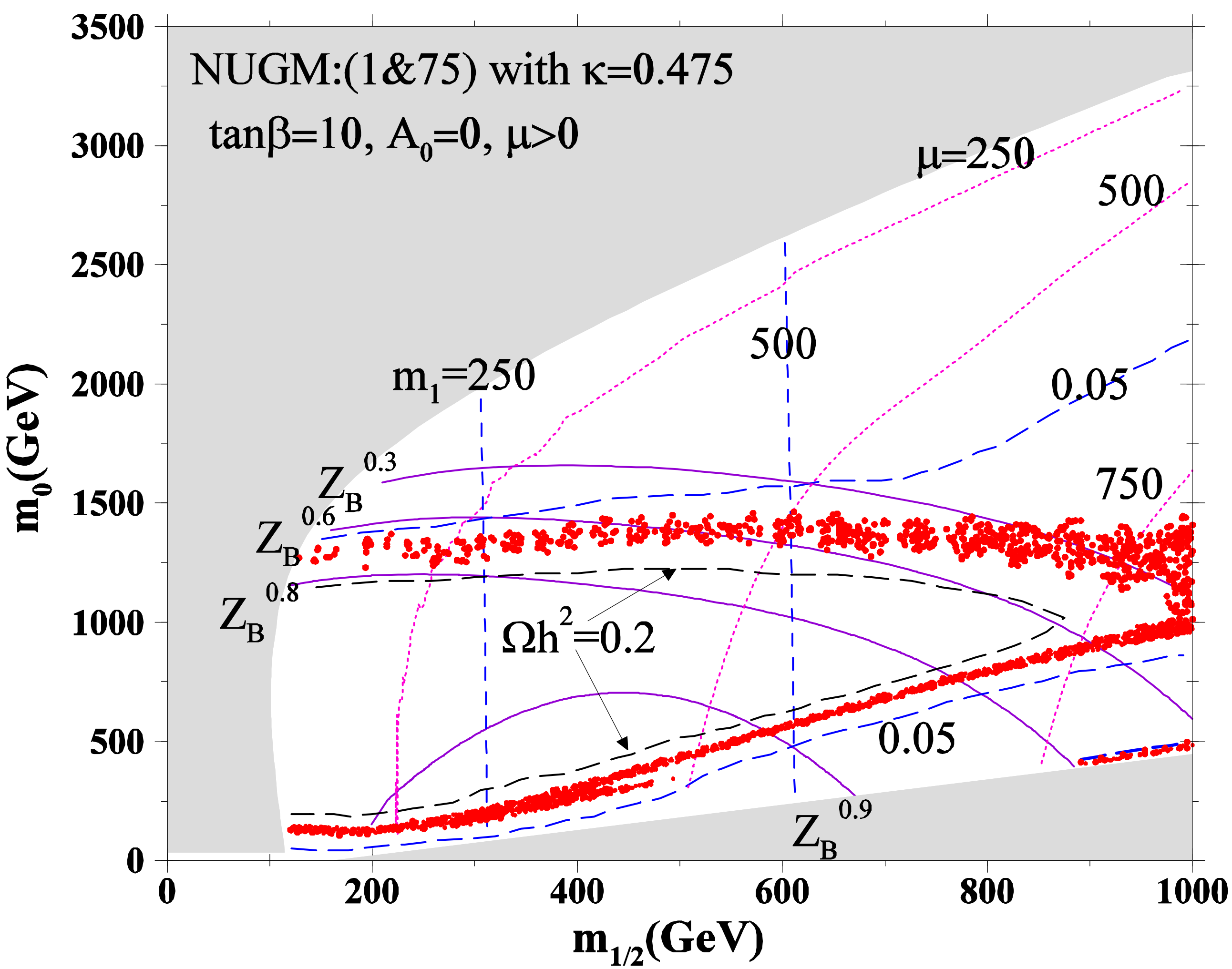
$$\chi_1^0 + \chi_1^0 \xrightarrow{\tilde{e}} e^+ + e^- + \gamma$$

Hard Positron Signal (PAMELA?)

Particle	Mass (GeV)
$\tilde{\chi}_1^0$ (bino)	78.1
$\tilde{\chi}_2^0$ (wino)	457
$\tilde{\chi}_3^0$ (higgsino)	614
$\tilde{\chi}_4^0$ (higgsino)	636
$\tilde{\chi}_1^+$ (wino)	461
$\tilde{\chi}_2^+$ (higgsino)	635
M_1	81
M_2	470
μ	611
$\tilde{g}$	1150
$\tilde{\tau}_1$	104
$\tilde{\tau}_2$	399
$\tilde{e}_R, \tilde{\mu}_R$	115
$\tilde{e}_L, \tilde{\mu}_L$	399
$\tilde{t}_1$	793
$\tilde{t}_2$	1025
$\tilde{b}_1$	980
$\tilde{b}_2$	1000
$\tilde{q}_{1,2,R}$	$\sim$ 1005
$\tilde{q}_{1,2,L}$	$\sim$ 1070

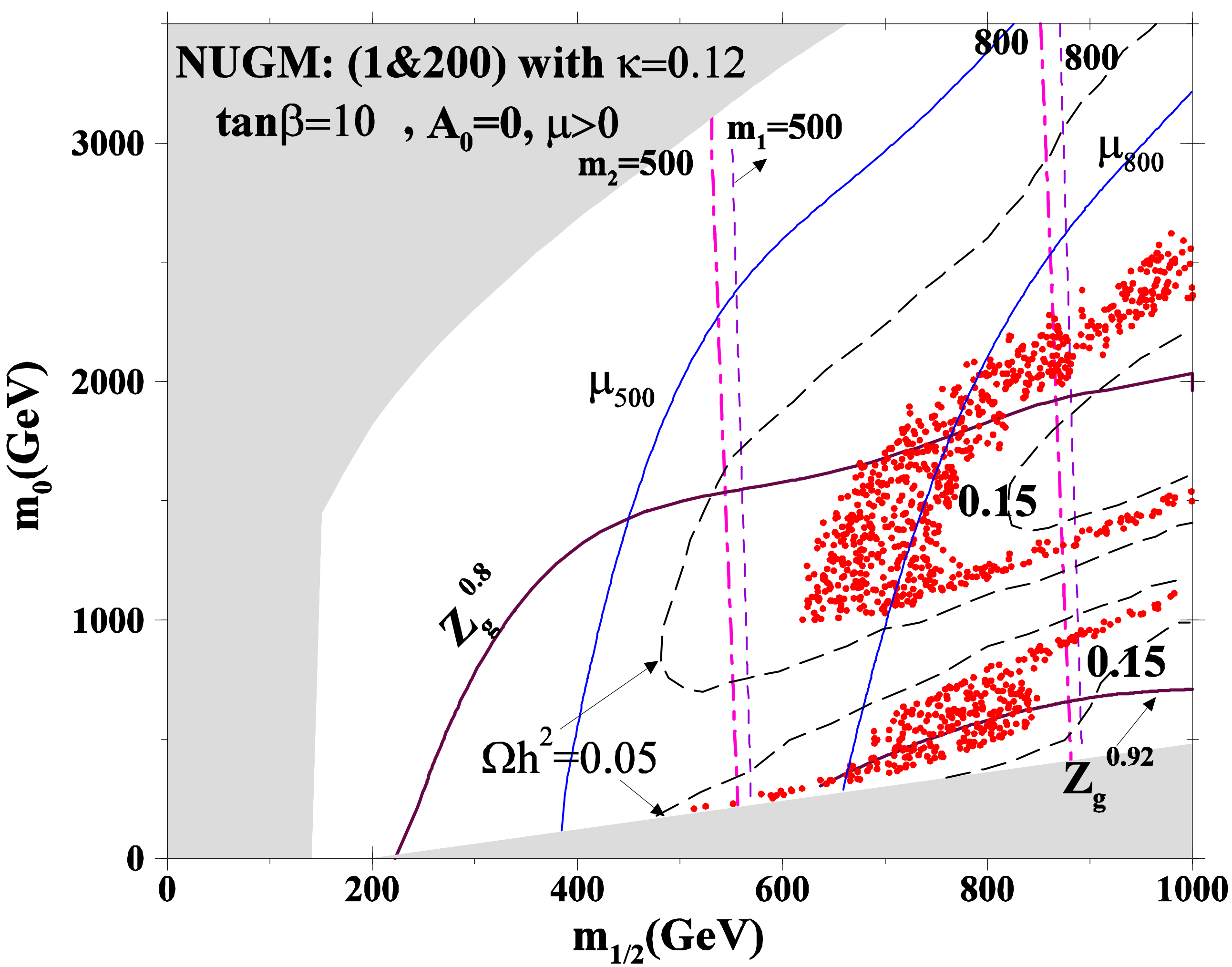
Mixed bino-higgsino LSP (DM)
1+75 Model
Chattopadhyay, Das & Roy, PRD 09

$$m_{1/2} = (1-\kappa)m_{1/2}^{1} + \kappa m_{1/2}^{75}; \kappa = 0.475$$



$$1 + 200 Model \Rightarrow m_{1/2} = (1-\kappa) m^{1}_{1/2} + \kappa m^{200}_{1/2}; \kappa = 0.12$$

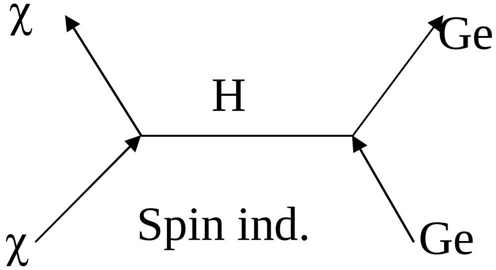
Mixed bino-wino-higgsino LSP (DM)



Bino, Higgsino & Wino LSP Signals in Dark Matter Detection Expts

1. Direct Detection (CDMS, XENON,…)

$$\chi = c_1\tilde{B} + c_2\tilde{W} + c_3\tilde{H}_d + c_4\tilde{H}_u$$

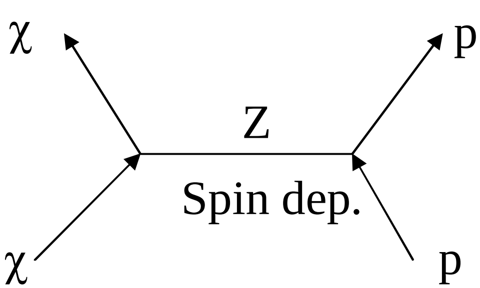


$$g_{Z\chi\chi} \propto c_3^2 - c_4^2 \;\&\; g_{H\chi\chi} \propto c_{1,2}c_{3,4}$$

Best for mixed DM $\rightarrow \;\; \chi \simeq \tilde{B}/\tilde{W} - \tilde{H}$

Not for pure bino, wino or higgsino DM

2. Indirect Detection via HE ν from χχ annihilation in the Sun (Ice Cube,Antares)



$$R^{ann.}_{\chi\chi} = R^{trap}_{\chi} \propto \sigma_{\chi p} \propto g^2_{Z\chi\chi} \propto (c_3^2 - c_4^2)^2$$

$$\Rightarrow OK.for\,\chi = mixed(\tilde{B} - \tilde{H})$$

$$\Rightarrow Not.for\,\chi \cong \tilde{B},\tilde{W} \;\&\; \tilde{H} \equiv \tilde{H}_d \pm \tilde{H}_u$$

Roy, PRD '10

$(\alpha_{75} \equiv \kappa)$

Fig 1. Prediction of the (1+75) model compared with the putative signal corridor of the two candidate events of the CDMS II expt. The blue dots denote the WMAP DM relic density compatible points.

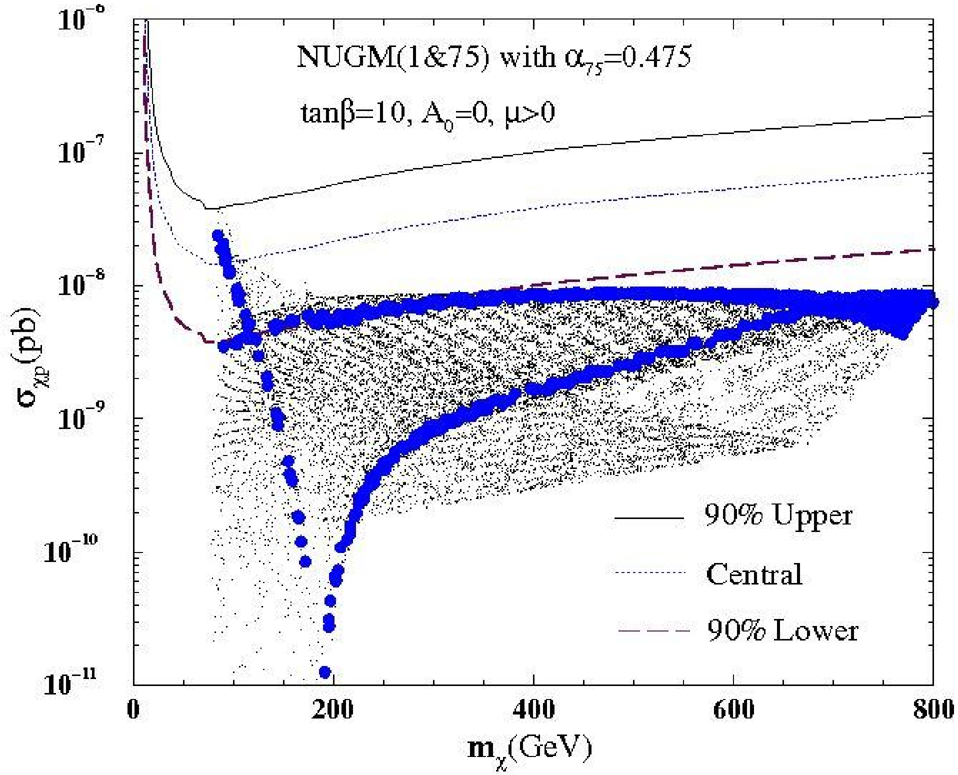


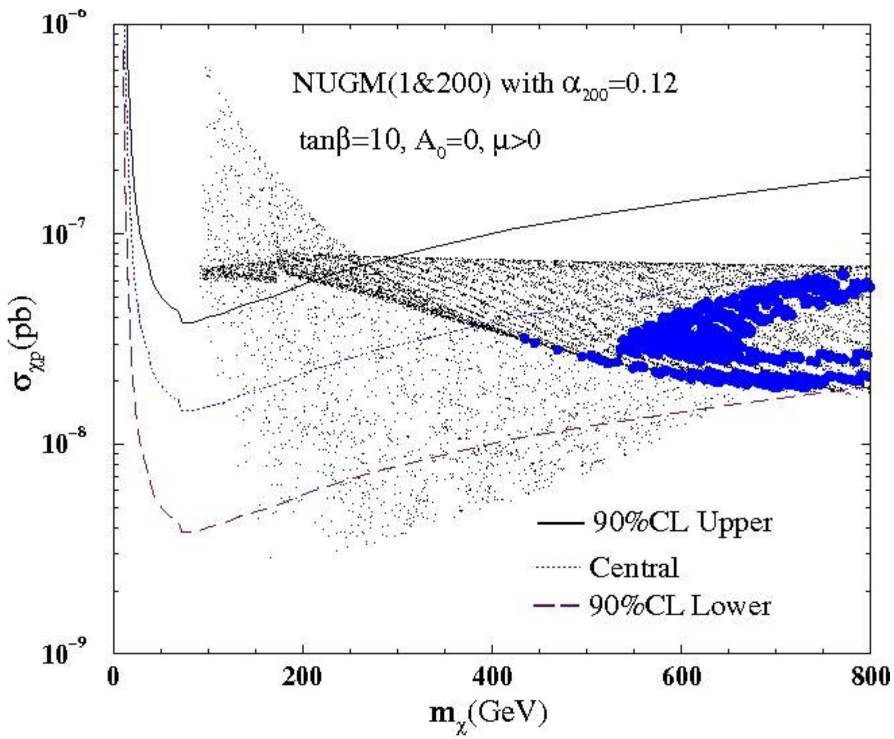
Table 1. Superparticle masses (in GeV) for a WMAP compatible point in the intersection region of the (1 + 75) model prediction with the CDMS II candidate events of Fig 1, corresponding to $m_{1/2}$ = 144 GeV and m_0 = 1255 GeV. All the remaining sfermion and Higgs boson masses are around 1250 GeV.

$\chi^0_1(\chi)$	χ^0_2	χ^0_3	χ^0_4	$\chi^\pm_1$	$\chi^\pm_2$	$\tilde{g}$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	h^0
103	120	168	270	121	270	433	760	1063	1054	112

$$\sigma_{\chi p} = 3.8\times10^{-9}\ pb$$

Low gluino mass (≤ 800 GeV) => Viable LHC Signal at 7 TeV.

Fig 2. Prediction (1+200) model prediction with the putative signal corridor, corresponding to the two candidate events of the CDMS II expt. Blue dots correspond to the points, compatible with the WMAP DM relic density.



$m_{1/2}$	m_0	$\chi^0_1(\chi)$	χ^0_2	χ^0_3	χ^0_4	χ^+_1	χ^+_2	$\tilde{g}$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	h^0
725	1450	633	657	794	822	643	818	1700	1460	1813	1801	117
900	1357	798	818	985	1009	807	1005	2045	1649	2013	2001	118

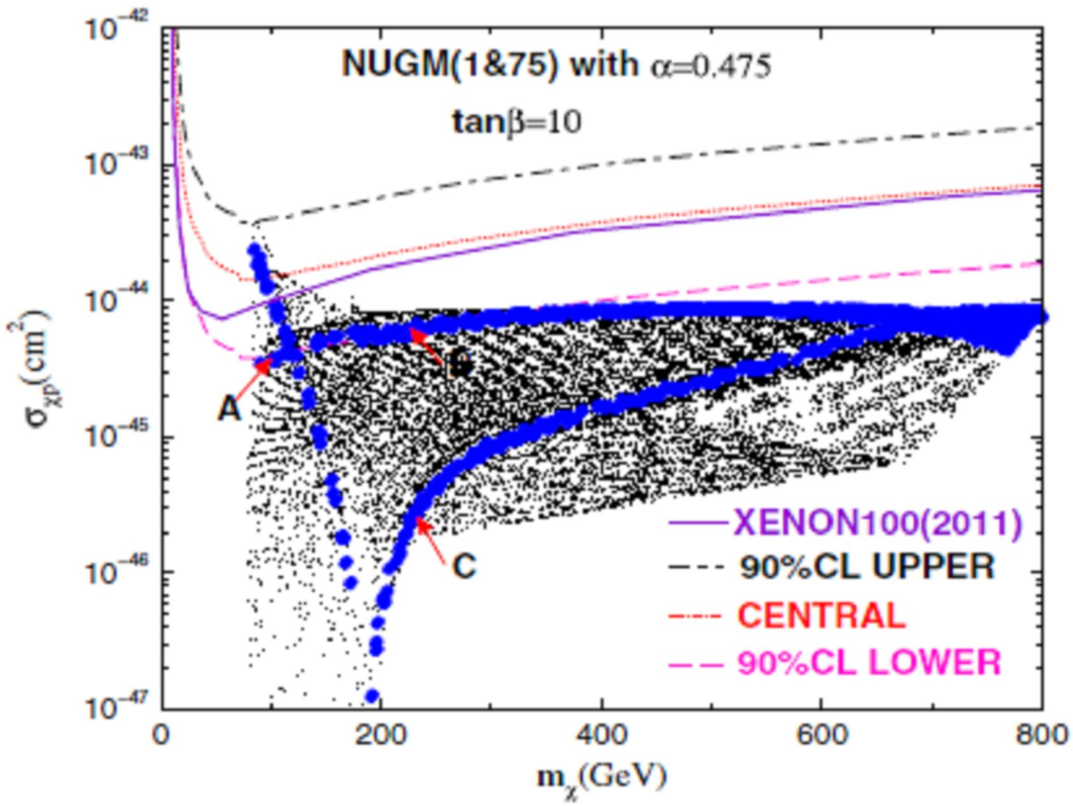
(Other squark masses are in the 2000-2200 GeV range)

Inverted Hierarchy => Decay of the gluino pair via stop

⇒3-4 top quarks in addition to the missing- E_T (like the focus pt. region)

⇒Multiple isolated leptons and b-tags + missing-E_T .

⇒Gluino mass of 2.0-2.5 TeV requires LHC at 14TeV



Guchait, Sengupta & DPR
PRD 85, 035024 (2012)

TABLE I. Mass spectrum (in GeV) for the three representative parameter points (A) $m_{1/2} = 144$ GeV, $m_0 = 1255$ GeV, (B) $m_{1/2} = 300$ GeV, $m_0 = 1325$ GeV, (C) $m_{1/2} = 300$ GeV, $m_0 = 185$ GeV. For all cases $\tan\beta = 10$ and $A_0 = 0$.

Model	$\tilde{g}$	$\tilde{q}_L$	$\tilde{q}_R$	$\tilde{t}_1$	$\tilde{b}_1$	$\tilde{e}_l$	$\tilde{\tau}_1$	χ_1^0	χ_2^0	χ_1^+	χ_2^+
A	433	1280	1274	759	1054	1263	1246	104	122	123	271
B	793	1480	1440	902	1246	1375	1327	227	256	257	501
C	722	750	660	483	649	437	237	231	301	302	490

TABLE V. The signal and background events after, same as Table III, but for jets + $\not{E}_T$ final states. The kinematic selection cuts are described in the text. The last two columns present the number of events with respective luminosities as shown.

Proc	Cross section (pb)	N	$T \leq 0.95$	$R_T \leq .9$	$\not{E}_T \geq 200$	$H_T \geq 500$	$n_b \geq 3$	1 fb^{-1}	5 fb^{-1}
A: $\tilde{g}\,\tilde{g}$	5.84	10 k	6900	3170	446	301	32	6.6	33.0
A: $\tilde{q}\,\tilde{g}$	0.28	10 k	8332	4356	2042	2002	315	3.4	17.0
Total								10	50
B: $\tilde{g}\,\tilde{g}$	0.06	10 k	8708	5901	2901	2584	779	2.07	10.35
B: $\tilde{q}\,\tilde{g}$	0.018	10 k	9100	6263	4212	4177	1322	1.02	5.1
Total								3.09	15.45
C: $\tilde{g}\,\tilde{g}$	0.1	10 k	7623	3700	2888	1761	404	1.13	5.65
C: $\tilde{q}\,\tilde{g}$	0.57	10 k	5933	1984	1145	1030	121	1.82	9.1
C: $\tilde{q}\,\tilde{q}$	0.55	10 k	3326	729	433	385	17	0.3	1.5
Total								3.25	16.25
$t\bar{t}$									
5–200	143.5	100 k	37162	14548	21	14	0	0	0
200–500	16.32	50 k	27831	8559	109	54	3	0.48	2.4
500–inf	0.16	10 k	1741	482	68	64	7	0.09	0.45
Total								0.57	2.85
QCD									
300–500	873	1 M	194636	27532	7	5	0	0	0
500–800	43.1	100 k	19100	2329	9	9	0	0	0
200–300	6983	1 M	123	14	0	0	0	0	0

Wino LSP (mAMSB model)

SUSY braking in HS in communicated to the OS via the Super-Weyl Anomaly Cont. (Loop)

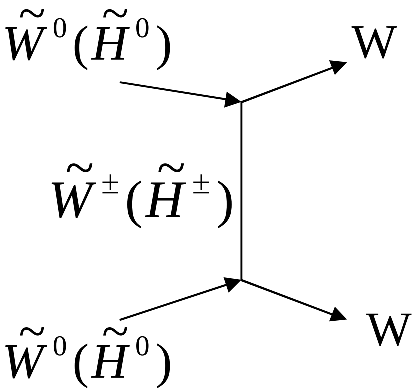
$$M_\lambda = \frac{\beta_g}{g} m_{3/2} \Rightarrow M_1 = \frac{33}{5}\frac{g_1^2}{16\pi^2} m_{3/2}, M_2 = \frac{g_2^2}{16\pi^2} m_{3/2}, M_3 = -3\frac{g_3^2}{16\pi^2} m_{3/2}$$

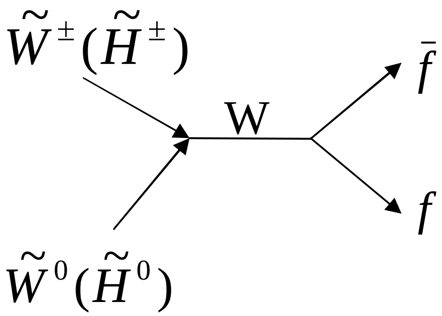
$$A_y = -\frac{\beta_y}{y} m_{3/2} \ \& \ m_\phi^2 = -\frac{1}{4}\left(\frac{\partial\gamma}{\partial g}\beta_g + \frac{\partial\gamma}{\partial y}\beta_y\right) m_{3/2}^2 + m_0^2$$

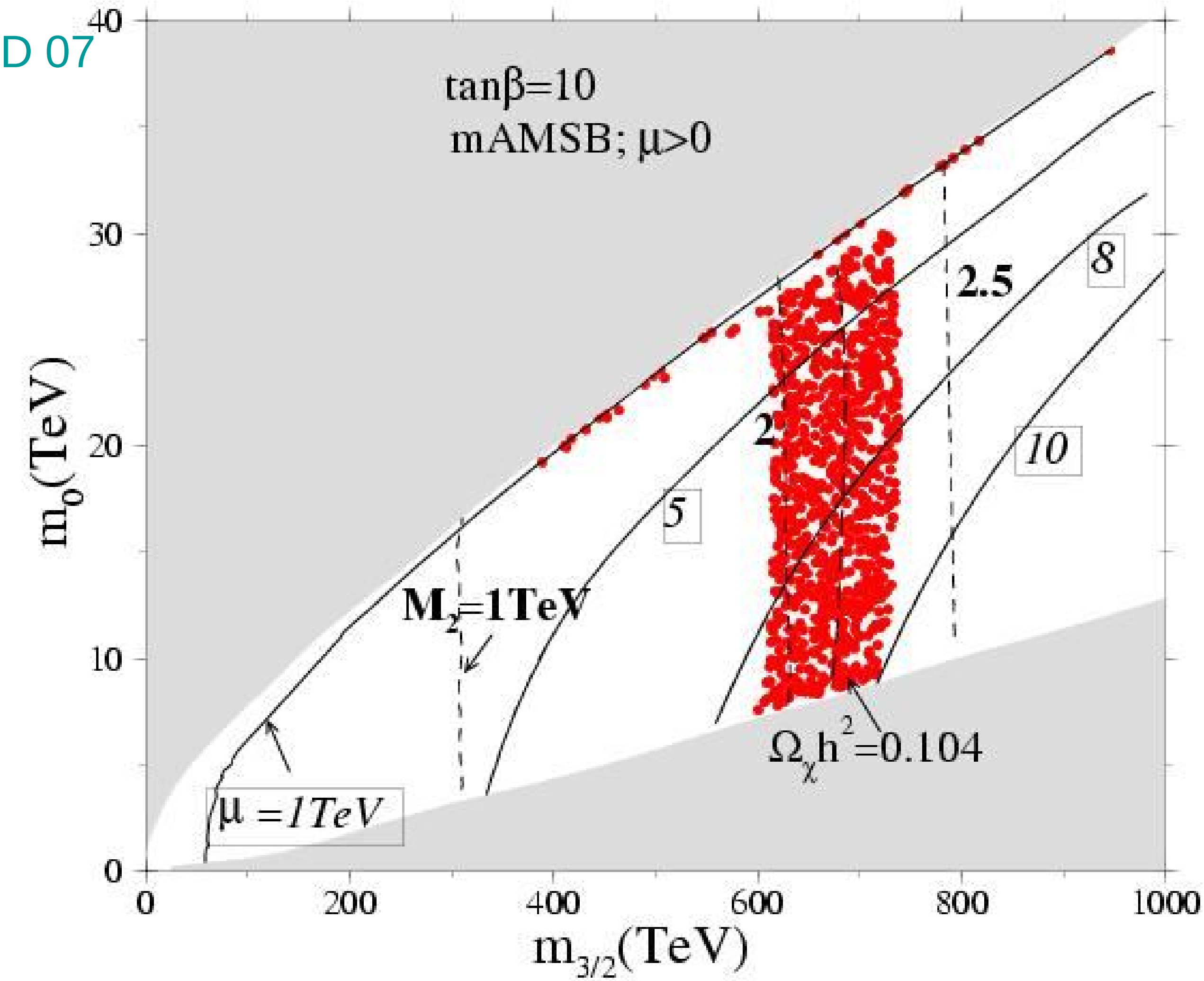
$m_{3/2}$, m_0 , tan β, sign (μ)

RGE $\Rightarrow$ *$M_1 : M_2 : |M_3| \approx 2.8 : 1 : 7.1$ including 2-loop conts*

Chattopadhyay et al,PRD 07





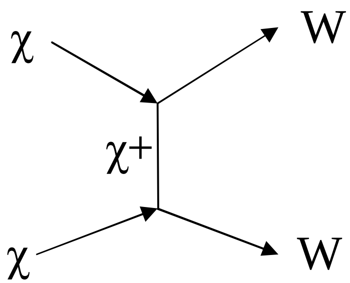


$$\tilde{W}-LSP: M_2 = 2.1 \pm 0.2 TeV \ \& \ \tilde{H}-LSP: \mu \cong 1 TeV \, (m_\phi = 10-30 TeV)$$

Robust results, independent of other SUSY parameters
(Valid in any SUSY model with Wino(Higgsino) LSP)

3. Detection of HE γ Rays from Galactic Centre in ACT (HESS,CANGAROO,MAGIC,VERITAS)

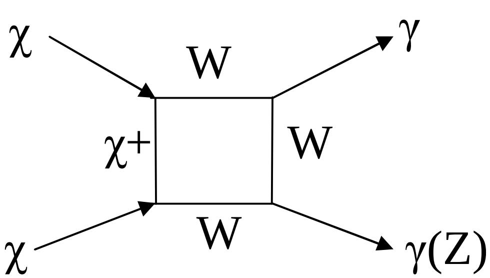
$$\chi \cong \tilde{H} \;\&\; \tilde{W}, \tilde{B}$$



W→π^0s→γs

vσ ~ 10^{-26} cm^3/s
⇒Cont. γ Ray Signal
(But too large π^0→γ from Cosmic Rays)

$$\tilde{B} - LSP \Rightarrow \chi\chi \xrightarrow{A} \bar{b}b, b \rightarrow \pi^0 s \rightarrow \gamma s$$



v$\sigma_{\gamma\gamma}$~ v$\sigma_{\gamma Z}$ ~ 10^{-27}-10^{-28} cm^3/s
⇒Discrete γ Ray Line Signal ($E_\gamma \approx m_\chi$)
(Small but Clean)

Reconciling Heavy Wino DM Model with the Relic Density and PAMELA Data with Sommerfeld Enhancement:

Mohanty, Rao & Roy: IJMP A27, 1250025 (2012)

$$\chi\chi \xrightarrow{\chi^{\pm}} W^{+}W^{-}$$

Enhanced by multiple W boson exchange ladder diagram (Sommerfeld Resonace)
$\rightarrow$ Increase of DM Annihilation CS and decrease of relic density at Resonance Peak

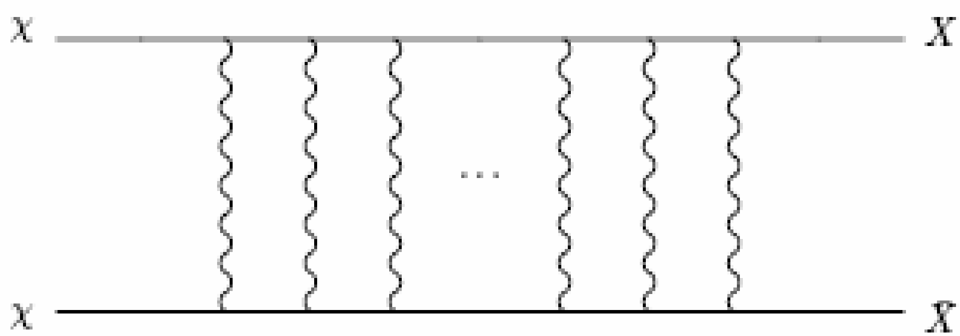


FIG. 1: Ladder diagram giving rise to the Sommerfeld enhancement for $\chi\chi \rightarrow X\overline{X}$ annihilation, via the exchange of gauge bosons.

Hisano,Matsumoto.Nojiri'03
……………….
Lattanzi,Silk '09

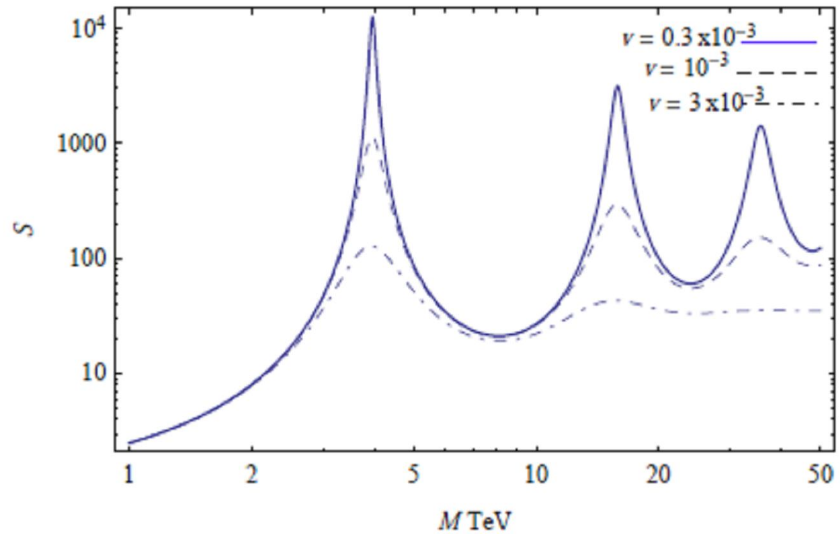
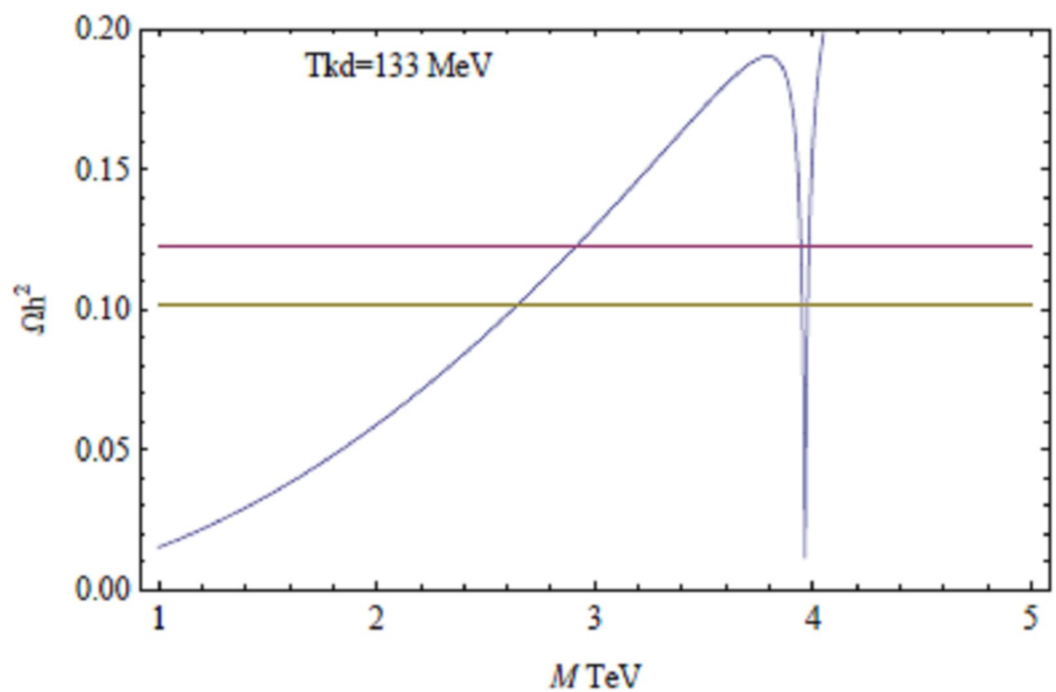


Fig. 1. Sommerfield enhancement from W exchange as a function of the DM mass for different relative velocities.



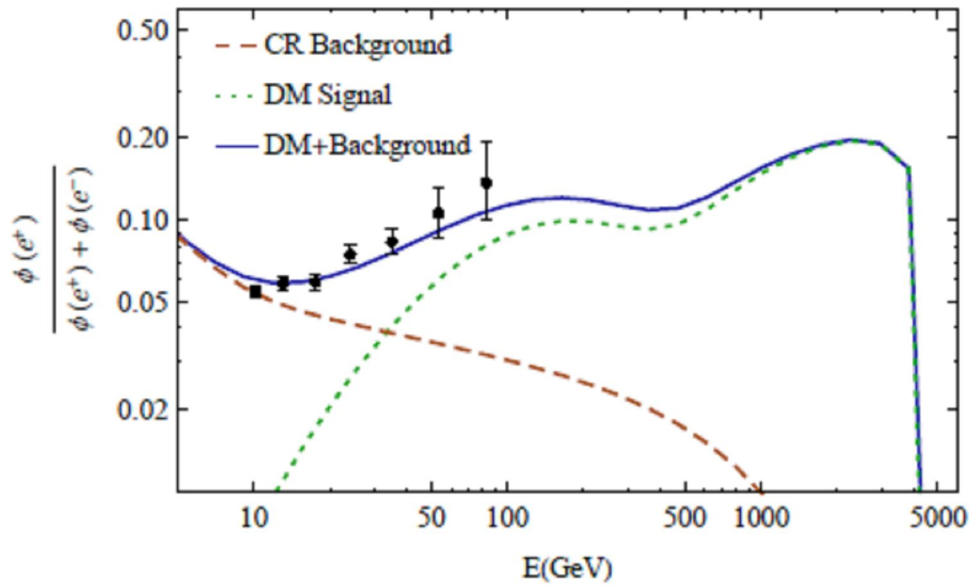


Fig. 9. Positron flux ratio for the 3.98 TeV wino DM compared with PAMELA data.[1] Dashed line shows background from cosmic ray secondary positrons.