Phenomenology of Nonuniversal Gaugino Mass Models

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ABSTRACT

- DM relic density and the muon g-2 anomaly favour relatively light EW superparticles $(\tilde{B}, \tilde{W}, \tilde{l})$
- But Higgs mass ~ 125 GeV favour heavy (Tev scale) squarks & gluinos
- The two can be naturally reconciled in simple NUGM models based on SU(5) SUSY GUT
- We shall discuss the phenomenology of these models
- We shall also discuss briefly the DM phenomenology of a NUGM model based on AMSB

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

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

Ellis et al.
M. Drees
1985

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

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

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

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

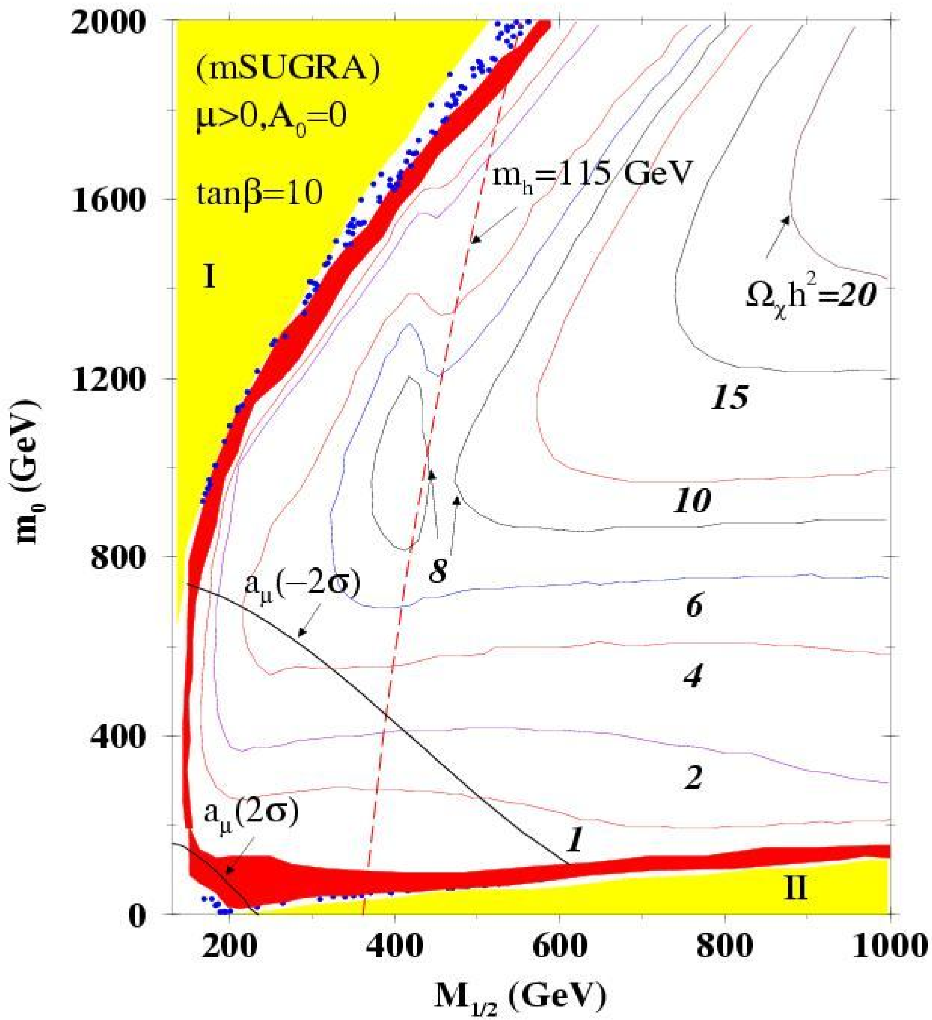
$$F_S = 200 \Rightarrow M_{1,2,3}^G = (10, 2, 1) \times m_{1/2} \Rightarrow M_1 \cong 4 m_{1/2} > \mu \Rightarrow \tilde{H} - LSP$$

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

Chattopadhyay & Roy(2003), Huitu et al(2000), Anderson et al(2000), …

Bino LSP => generic over-abundance of DM relic density
Higgsino LSP => under-abundance of DM relic density for LSP mass < 1 TeV.

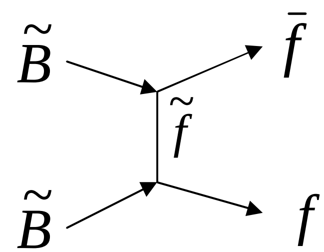
Chattopadhyay et al (2003)



$m_0 \sim m_{1/2} \to$ TeV (Bino LSP)

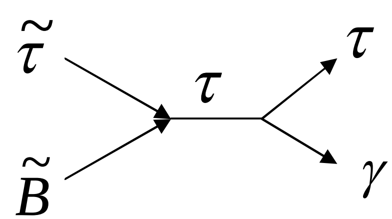
$m_h > 115$ GeV $\Rightarrow m_{1/2} > 400$ GeV ($M_1 > 2M_Z$)
$\Rightarrow$ also large sfermion mass

Bino does not carry any gauge charge
$\Rightarrow$ Pair annihilate via sfermion exch

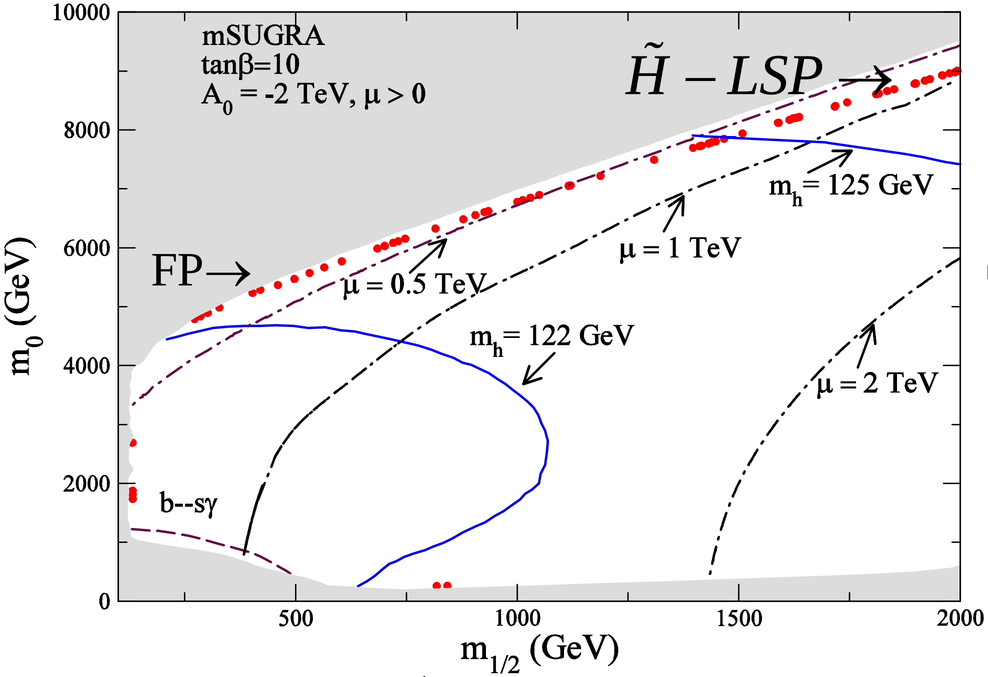


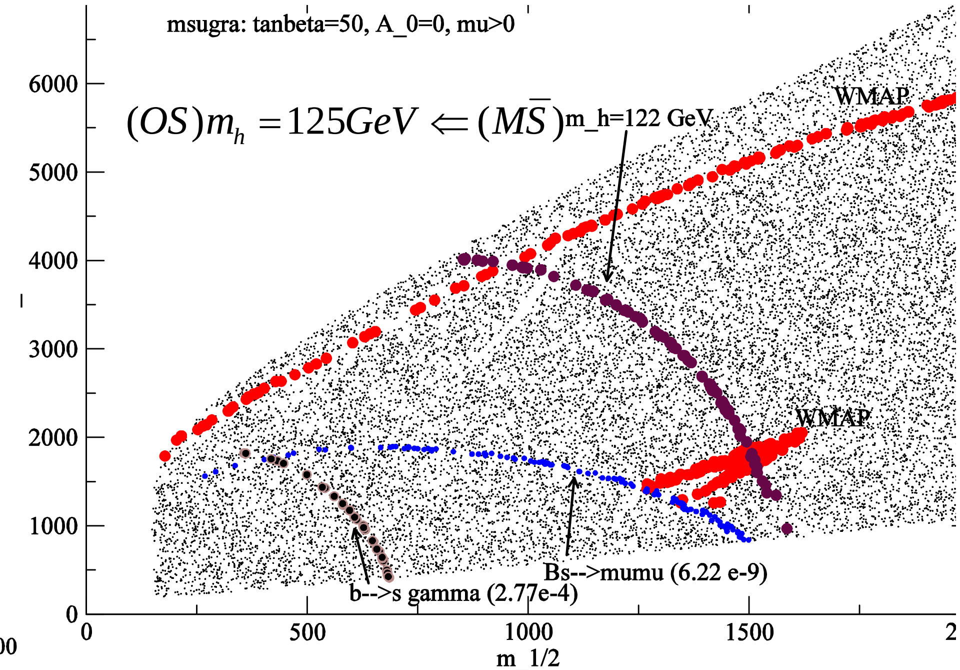
Large sfermion mass $\Rightarrow$ too large Ωh^2
Except for the stau co-ann. region

$m_{\tilde{\tau}} \cong m_{\tilde{B}}$



$m_h \sim 125$ GeV => m_0 & $M_{1/2} >$ 1 TeV

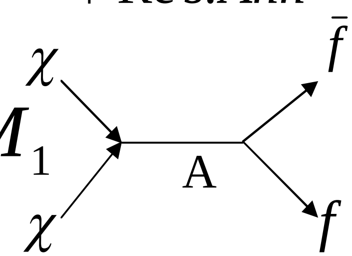




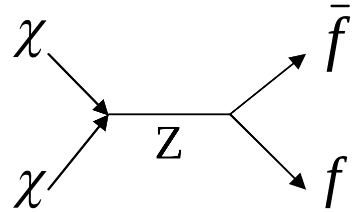
$\uparrow \tilde{\tau} - CA$ $\uparrow$ Re s.Ann

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

$$\tilde{\tau} - CoAnn: m_{\tilde{\tau}} \cong M_1 (within \approx 10\%) \quad \text{Re}\, s.Ann: M_A \cong 2M_1$$



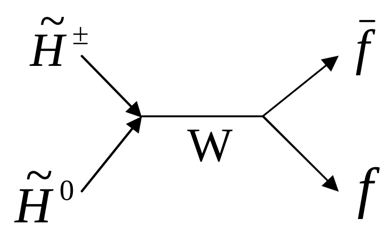
$$Focus - Pt: \mu \cong M_1 (\chi = \tilde{B} - \tilde{H})$$



$$g_{Z\chi\chi} \propto c_3^2 - c_4^2$$

$$\tilde{H} - LSP: M_{\tilde{H}^{\pm,0}} \cong \mu \cong 1TeV$$

$$(m_\phi \approx m_0 > 7TeV)$$



$$g_{A\chi\chi}, g_{H\chi\chi} \propto c_{1,2}c_{3,4}$$

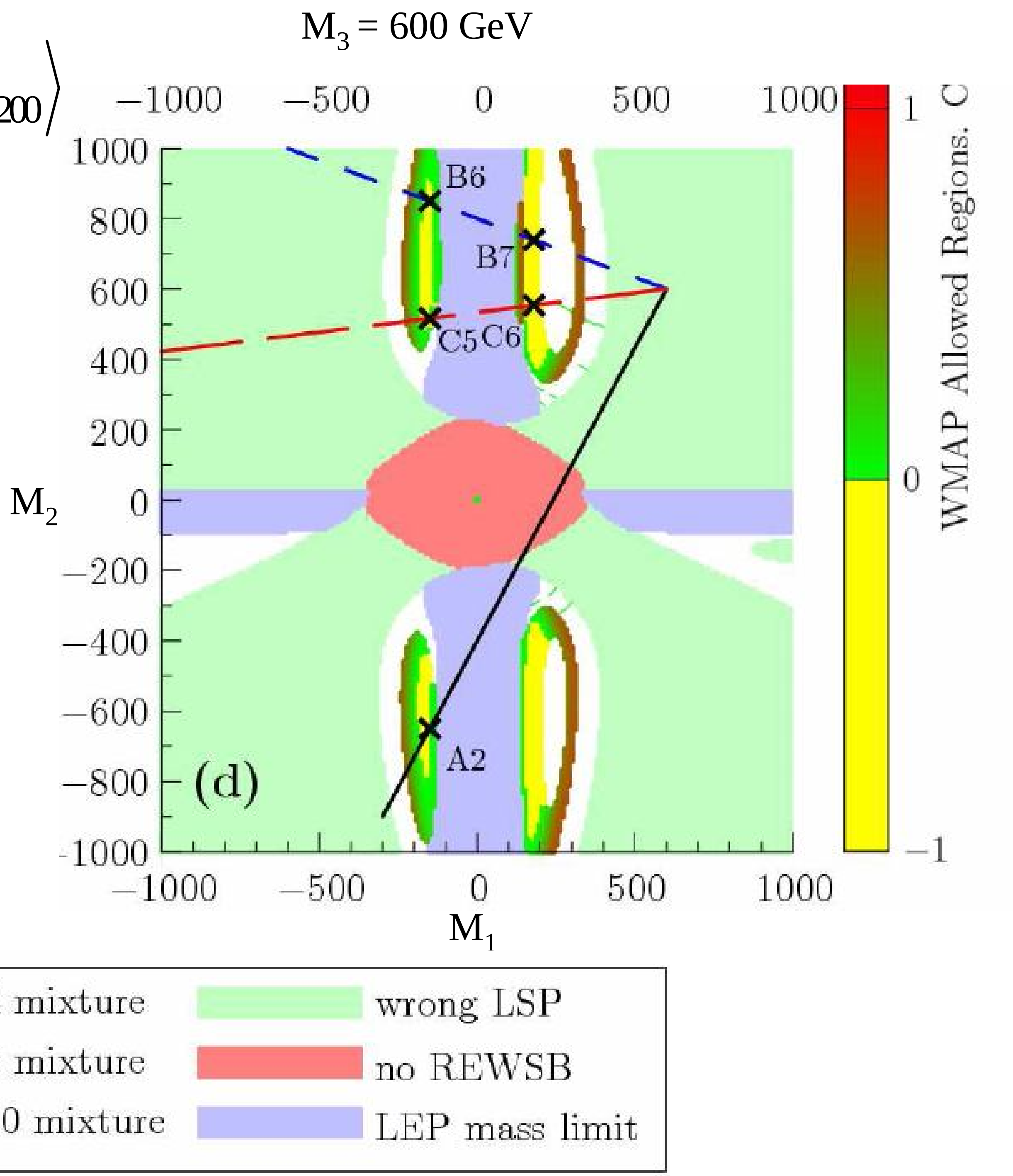
Chattopadhyay et al.’13

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

King, Roberts & Roy, JHEP 07

Bino LSP in NUGM

Bulk annihilation region of Bino DM (yellow) allowed in Non-universal gaugino mass models (m_0 = 70 GeV)



Mohanty, Rao & Roy (JHEP'12)

M_3^G= 800 GeV => TeV Sc squark/gluino
+ A_0 = -1300GeV => m_h ~ 125GeV

M_1^G = 250 GeV =>
Light bino DM & right sleptons ~ 100 GeV
=> Bulk annihilation region of DM

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

(1+200) model: relatively light wino
=> BNL muon (g-2) signal

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

Hard Positron Signal (PAMELA?)

$M_1^G = 250$ GeV, $M_3^G = 800$ GeV, $m_0 = 80$ GeV

Particle	Mass (GeV)	
	(1+75) model	(1+200) model
$\tilde{\chi}_1^0$ (bino)	101	101
$\tilde{\chi}_2^0$ (wino)	789	593
$\tilde{\chi}_3^0$ (higgsino)	1197	1218
$\tilde{\chi}_4^0$ (higgsino)	1206	1223
$\tilde{\chi}_1^+$ (wino)	789	592
$\tilde{\chi}_2^+$ (higgsino)	1206	1223
M_1	103	103
M_2	780	581
M_3	1728	1732
μ	1197	1217
$\tilde{g}$	1766	1767
$\tilde{\tau}_1$	109	111
$\tilde{\tau}_2$	649	478
$\tilde{e}_R, \tilde{\mu}_R$	128	128
$\tilde{e}_L, \tilde{\mu}_L$	631	477
$\tilde{t}_1$	1056	1096
$\tilde{t}_2$	1488	1455
$\tilde{b}_1$	1459	1421
$\tilde{b}_2$	1519	1524
$\tilde{q}_{1,2,R}$	$\sim$ 1531	$\sim$ 1536
$\tilde{q}_{1,2,L}$	$\sim$ 1643	$\sim$ 1597

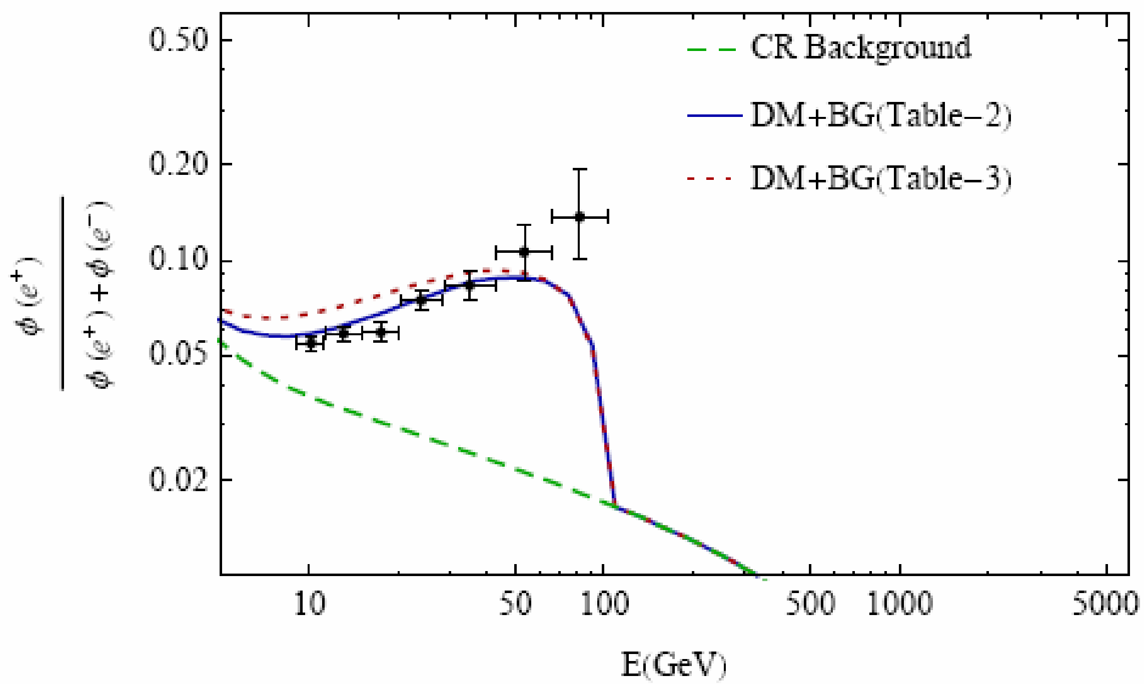


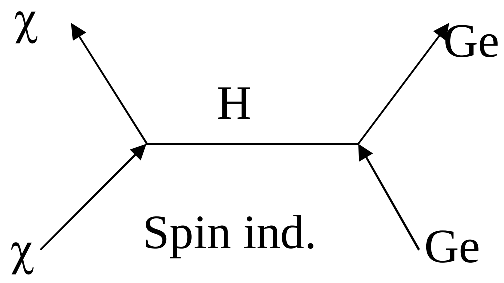
Figure 2: Ratio of the positron flux to the total $(e^- + e^+)$ flux vs energy for a 100 GeV DM in the 1+75 model , with PAMELA data shown for comparison. The solid line denotes the result for the spectrum in Table 2 and the dotted line for Table 3. The boost in the annihilation cross section is taken to be 7000 and 10000 respectively.

Mohanty, Rao & Roy (JHEP'12)

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

1. Direct Detection (CDMS, XENON,…)

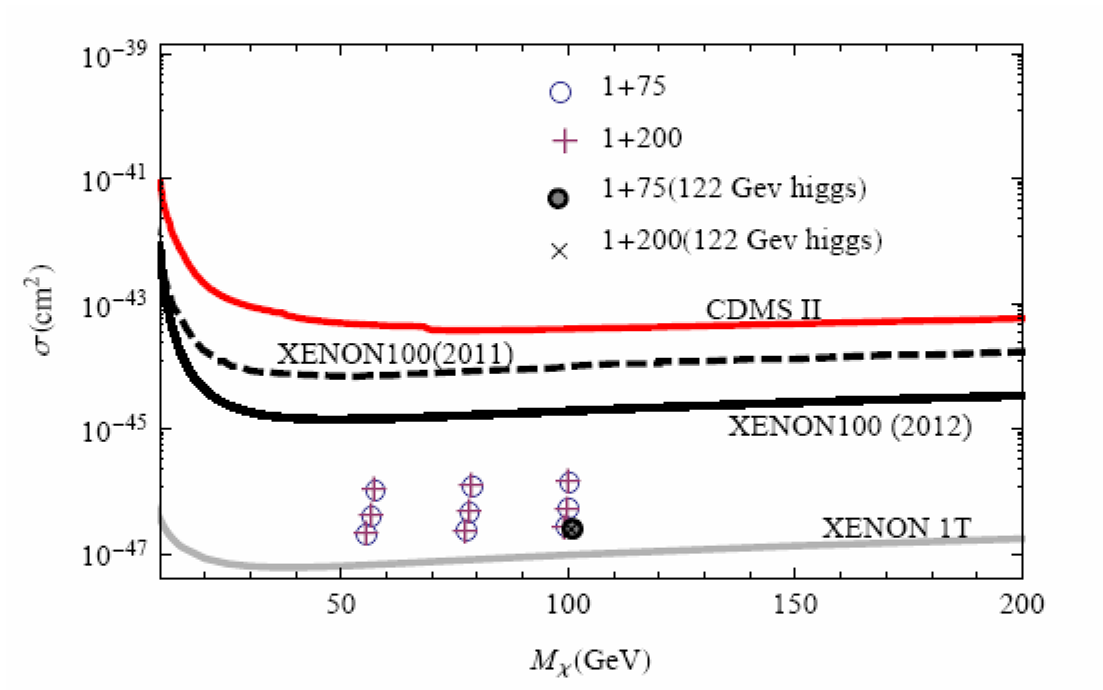
$$\chi = c_1\tilde{B} + c_2\tilde{W} + c_3\tilde{H}_d + c_4\tilde{H}_u$$



$$g_{H\chi\chi} \propto c_{1,2}c_{3,4}$$

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

Not for pure bino, wino or higgsino DM



Mohanty, Rao & Roy
JHEP ' 2012

SUSY Spectrum, Higgs mass
& Muon g-2 in (1+200) model

Mohanty, Rao & Roy JHEP2013

bino & right-slepton mass ~ 100 GeV
=> bulk ann. Region of DM

wino & left-slepton mass : 400-600GeV
=> Muon g-2

⇒squark/gluino mass < 2000 GeV
Observable signal @14 TeV LHC
via cascade decay

All masses in GeV

Particle	$M_1^G = 220$	$M_1^G = 200$			
	$M_3^G = 600$	$M_3^G = 600$	$M_3^G = 700$	$M_3^G = 800$	$M_3^G = 900$
$\tilde{\chi}_1^0$ (bino)	88.8	80.2	79.9	79.6	79.1
$\tilde{\chi}_2^0$ (wino)	445	443	516	589	662
$\tilde{\chi}_3^0$ (higgsino)	1032	1031	1132	1233	1333
$\tilde{\chi}_4^0$ (higgsino)	1036	1036	1137	1237	1337
$\tilde{\chi}_1^\pm$ (wino)	445	443	516	589	662
$\tilde{\chi}_2^\pm$ (higgsino)	1036	1037	1137	1237	1337
M_1	90.1	81.4	81.1	80.8	80.4
M_2	437	435	506	577	648
M_3	1331	1331	1533	1734	1933
μ	1034	1033	1133	1233	1332
$\tilde{g}$	1354	1354	1561	1766	1969
$\tilde{\tau}_1$	103	97.4	96.2	93.6	89.8
$\tilde{\tau}_2$	381	379	429	480	532
$\tilde{e}_R, \tilde{\mu}_R$	138	134	133	133	132
$\tilde{e}_L, \tilde{\mu}_L$	374	373	425	477	530
$\tilde{t}_1$	748	749	920	1082	1240
$\tilde{t}_2$	1107	1107	1275	1441	1607
$\tilde{b}_1$	1056	1055	1232	1406	1576
$\tilde{b}_2$	1161	1161	1336	1509	1681
$\tilde{q}_{1,2,R}$	~ 1188	~ 1188	~ 1364	~ 1538	~ 1710
$\tilde{q}_{1,2,L}$	~ 1233	~ 1233	~ 1417	~ 1598	~ 1778
h	122	122	122	122	123
Muon $g-2$					
a_μ	2.22×10^{-9}	2.28×10^{-9}	1.89×10^{-9}	1.59×10^{-9}	1.37×10^{-9}
(δa_μ)	(0.83σ)	(0.75σ)	(1.24σ)	(1.61σ)	(1.89σ)

Table 2. Same as Table 1, but with $\tan\beta = 15$, $m_0 = 103$ GeV and $A_{t0} = A_{b0} = -1.4$ TeV.

SUSY Spectrum, Higgs mass & muon g-2
In a general NUGM (e.g. 1+75+200)
Mohanty, Rao & Roy JHEP 2013

M_1^G = 200 GeV => bino & right-slepton masses ~ 100 GeV => bulk ann. of DM

M_2^G ~ 500 GeV => wino & left-slepton masses ~ 400 GeV => muon g-2

M_3^G ~ 1500 GeV => squark & gluino masses of ~ 3000 GeV (beyond the reach of 14 TeV LHC)

⇒Viable signal at 14 TeV LHC from pair production of winos and/or sleptons via Drell-Yan process.

All masses in GeV			
Particle	$M_1^G = 200$, $M_2^G = 575$ and $M_3^G = 1500$		
	$m_0 = 117$ $\tan\beta = 10$	$m_0 = 160$ $\tan\beta = 15$	$m_0 = 201$ $\tan\beta = 20$
$\tilde{\chi}_1^0$ (bino)	74.8	75.0	75.2
$\tilde{\chi}_2^0$ (wino)	455	456	457
$\tilde{\chi}_3^0$ (higgsino)	1976	1965	1959
$\tilde{\chi}_4^0$ (higgsino)	1977	1967	1961
$\tilde{\chi}_1^\pm$ (wino)	455	456	457
$\tilde{\chi}_2^\pm$ (higgsino)	1978	1967	1961
M_1	76.7	76.7	76.8
M_2	437	437	438
M_3	3125	3126	3128
μ	1970	1960	1954
$\tilde{g}$	3178	3179	3180
$\tilde{\tau}_1$	93.9	97.7	104
$\tilde{\tau}_2$	375	402	434
$\tilde{e}_R, \tilde{\mu}_R$	139	176	214
$\tilde{e}_L, \tilde{\mu}_L$	363	379	398
$\tilde{t}_1$	2207	2212	2216
$\tilde{t}_2$	2535	2529	2520
$\tilde{b}_1$	2517	2510	2499
$\tilde{b}_2$	2724	2709	2689
$\tilde{q}_{1,2,R}$	~ 2738	~ 2741	~ 2745
$\tilde{q}_{1,2,L}$	~ 2748	~ 2751	~ 2754
h	123	123	122
Muon $g-2$			
a_μ (δa_μ)	2.67×10^{-9} (0.26σ)	2.7×10^{-9} (0.23σ)	2.54×10^{-9} (0.43σ)

Wino LSP (mAMSB model)

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

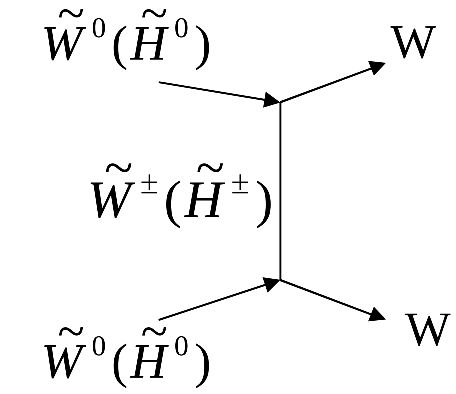
$$M_\lambda = \frac{\beta_g}{g} m_{3/2} \Rightarrow M_1 = \frac{33}{5}\frac{g_1^2}{16\pi^2} m_{3/2}, M_2 = \frac{g_2^2}{16\pi^2} m_{3/2}, M_3 = -3\frac{g_3^2}{16\pi^2} m_{3/2}$$

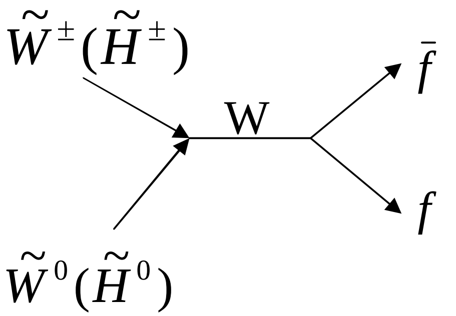
$$A_y = -\frac{\beta_y}{y} m_{3/2} \;\&\; m_\phi^2 = -\frac{1}{4}\left(\frac{\partial\gamma}{\partial g}\beta_g + \frac{\partial\gamma}{\partial y}\beta_y\right) m_{3/2}^2 + m_0^2$$

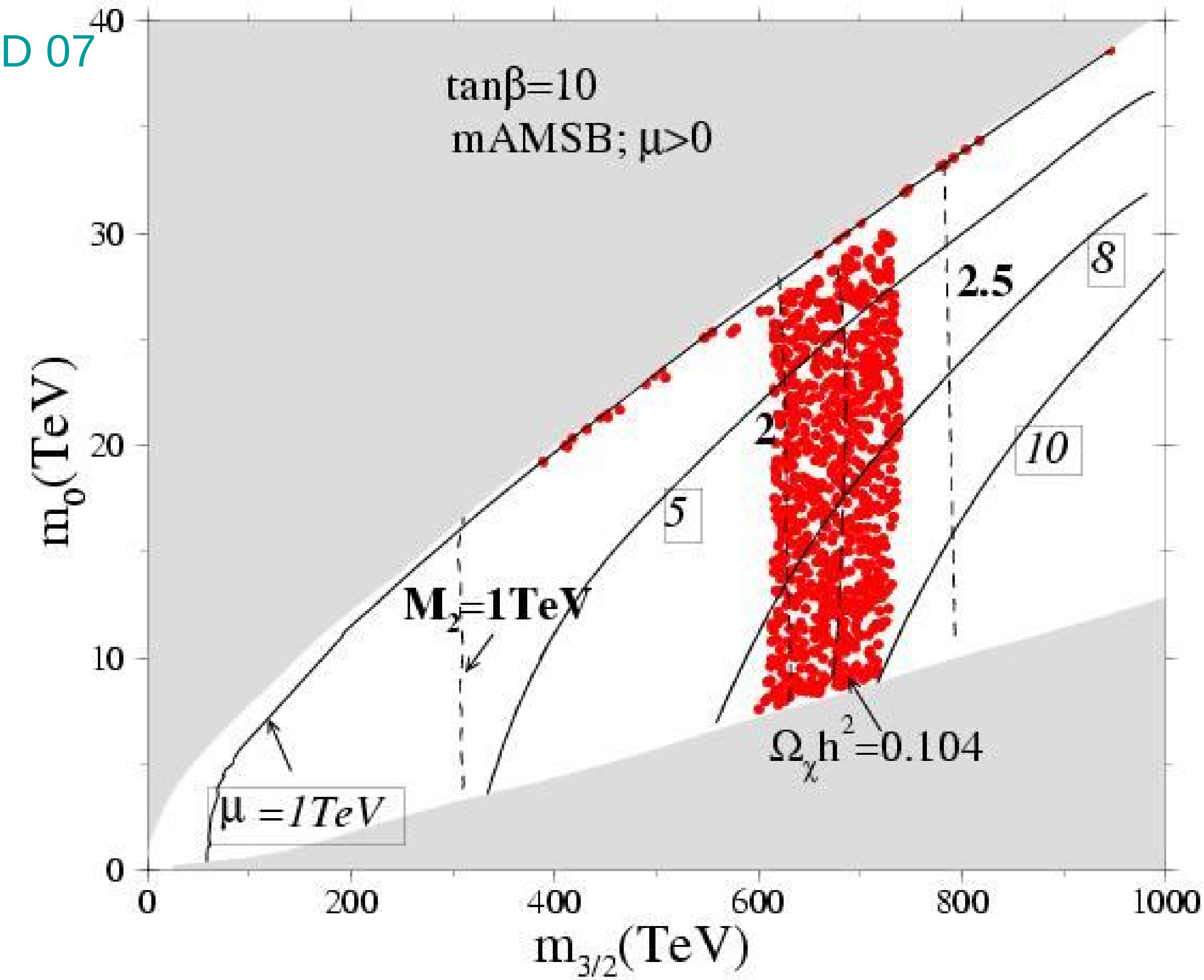
$m_{3/2}$, m_0 , tan β, sign (μ)

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

Chattopadhyay et al,PRD 07





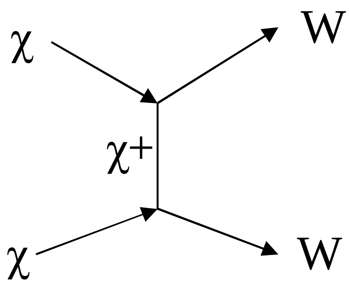


$$\tilde{W} - LSP : M_2 = 2.1 \pm 0.2 TeV \ \& \ \tilde{H} - LSP : \mu \cong 1 TeV \, (m_\phi = 10 - 30 TeV)$$

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

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

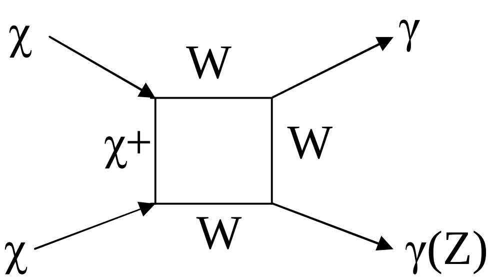
$$\chi \cong \tilde{H} \,\&\, \tilde{W}, \tilde{B}$$



$W \to \pi^0 s \to \gamma s$

$v\sigma \sim 10^{-26}\ cm^3/s$
$\Rightarrow$Cont. γ Ray Signal
(But too large $\pi^0 \to \gamma$ from Cosmic Rays)

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



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

Huge HE γ Bg from the Sag A* at the Galactic Centre => GC no good for DM search

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)
→ Increase of DM Annihilation CS and decrease of relic density at Resonance Peak

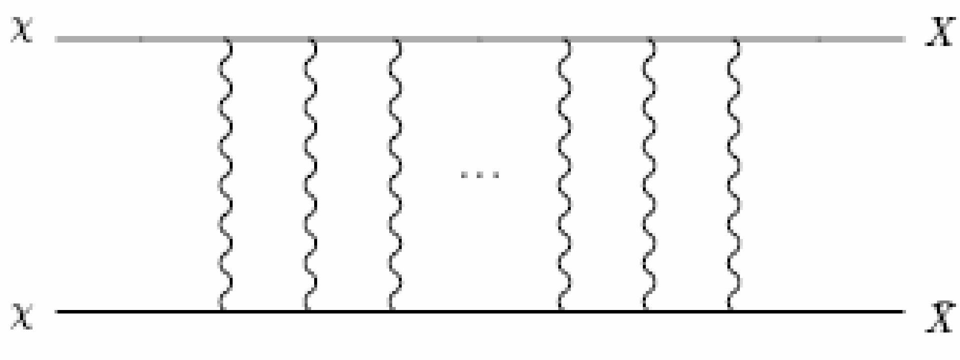


FIG. 1: Ladder diagram giving rise to the Sommerfeld enhancement for $\chi\chi \to X\overline{X}$ annihilation, via the exchange of gauge bosons.

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

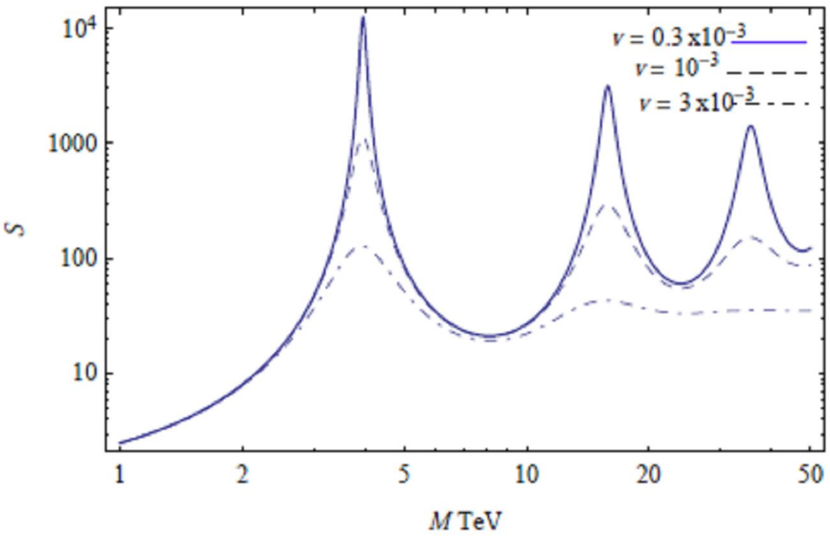
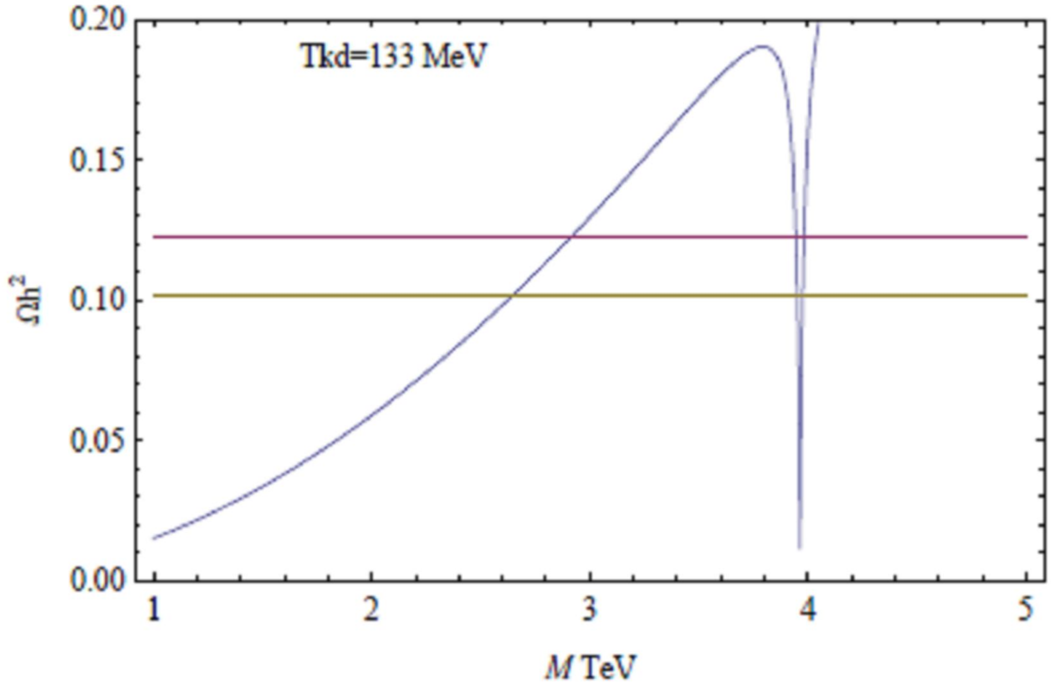
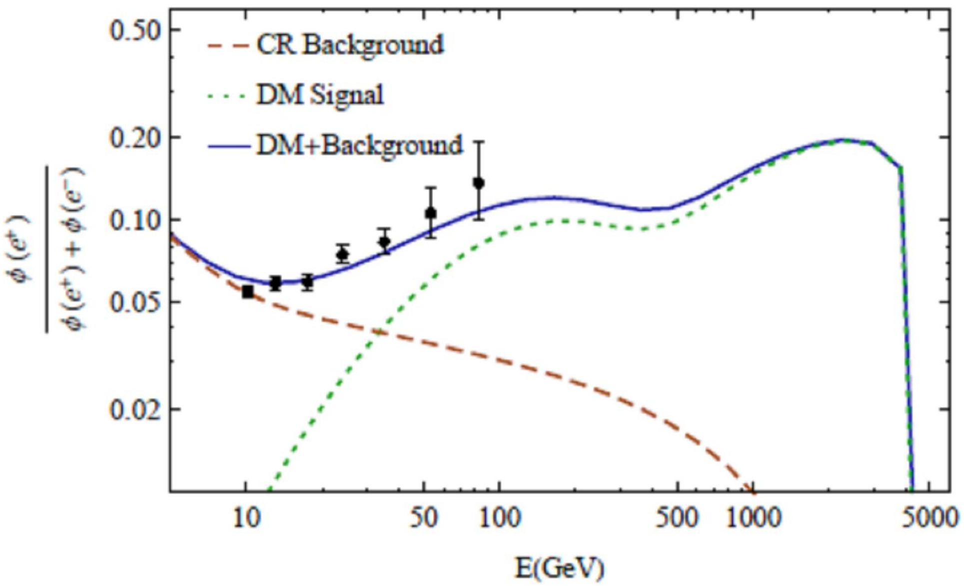


Fig. 1. Sommerfield enhancement from W exchange as a function of the DM mass for different relative velocities.



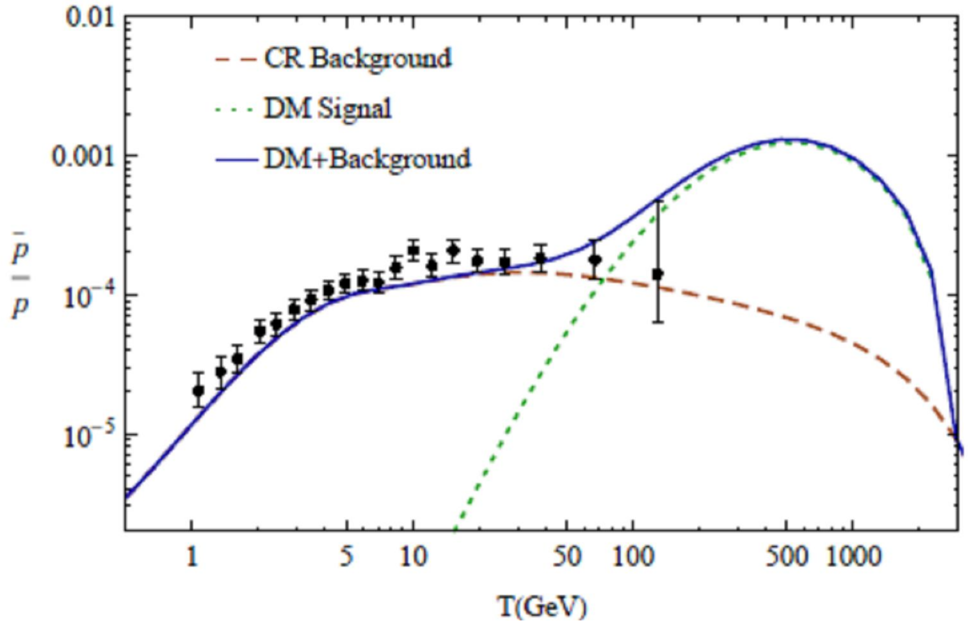
WMAP

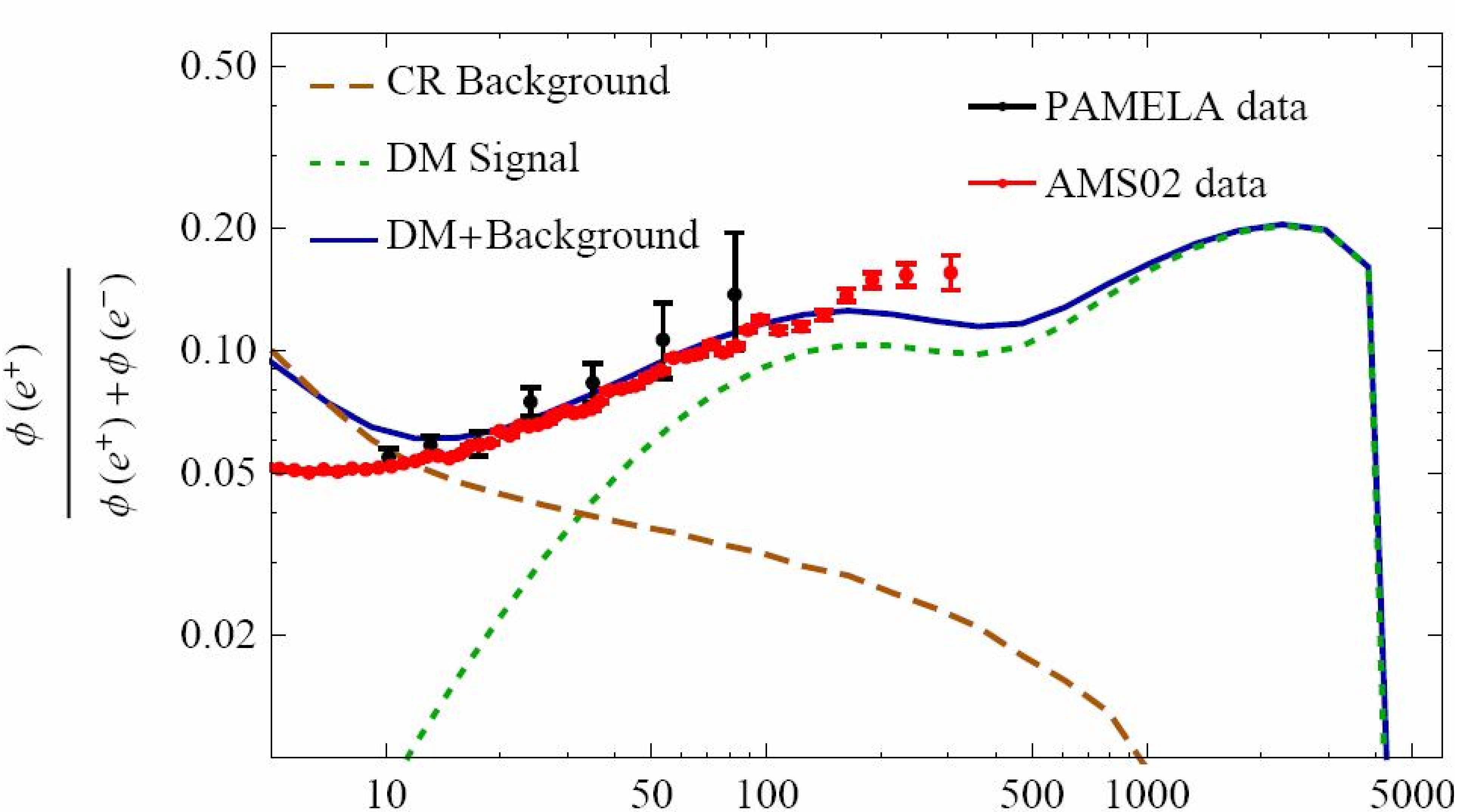
Feng, Kaplinghat & Yu 2010



Rao, Mohanty & Roy 2012

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.





0.50
0.20
0.10
0.05
0.02
10
50
100
500
1000
5000
CR Background
DM Signal
DM+Background
PAMELA data
AMS02 data
$\frac{\phi(e^+)}{\phi(e^+)+\phi(e^-)}$