

Neutrino spectrum via electroweak bremsstrahlung in bino-like dark matter annihilations

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based on K. Shudo and T.N., arXiv:1306.5901

Outline

1. Motivation: EW brems. in neutralino pair annihilations
2. Cross section for $\chi\chi \rightarrow W\ell\bar{\nu}_\ell$
3. Neutrino spectra from the Sun
4. Conclusions

1. Motivation

- Indirect detection of dark matter

WIMP, the lightest neutralino χ in the MSSM

$$\chi = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

Light slepton scenario in the pMSSM with heavy squarks

Cosmic rays from $\chi\chi \rightarrow \dots$ ($v_\chi \sim 10^{-3}$: NR)

Bino-like χ (higgsino-like, wino-like: $\chi\chi \rightarrow WW$)

- 2-body process: $\chi\chi \rightarrow f\bar{f}$

Dominant for bino-like neutralino DM, NR c.s. is helicity suppressed

$$(\sim m_f^2/m_\chi^2)$$

- Electromagnetic bremsstrahlung: $\chi\chi \rightarrow f\bar{f}\gamma$ Bergstrom (1989)

No helicity suppression (photon: $J = 1$), suppressed by α_{QED}

- Electroweak bremsstrahlung: $\chi\chi \rightarrow f\bar{f}'W, f\bar{f}'Z$

No helicity suppression (W/Z: $J = 1$)

Important for indirect detection through neutrino signals

Focus on $\chi\chi \rightarrow W\ell\bar{\nu}$

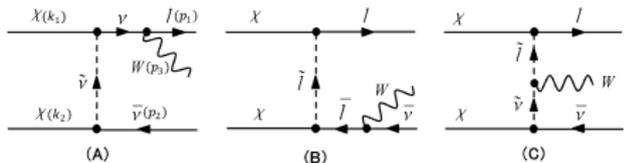
Note:

$\chi\chi \rightarrow WW^* \rightarrow W\ell\bar{\nu}$: included in $\chi\chi \rightarrow WW$ for $m_\chi > m_W$

$\chi\chi \rightarrow WW^* \rightarrow Wt\bar{b}$: smaller than WW (no helicity suppression)

$\chi\chi \rightarrow t\bar{t}^* \rightarrow Wt\bar{b}$: included in $\chi\chi \rightarrow t\bar{t}$ or smaller than WW

$\chi\chi \rightarrow \ell^{+\ast}\ell^- \rightarrow W\ell\bar{\nu}$: never included in 2-body processes



Literatures

Leptophilic DM model: Bell et al., arXiv:1104.3823, 1206.2977.

Gamma-rays: Bergstrom et al. (2008), Barger et al., arXiv:1111.4523,

Toma, arXiv:1307.6181, Bringmann–Calore, arXiv:1308.1089.

\bar{p} , longitudinal W : Garny et al., arXiv:1105.5367

ISR: Ciafaloni et al., arXiv:1107.4453

Relic abundance: Ciafaloni et al., arXiv:1305.6391.

SUSY: Chen–Kamionkowski (1998), Baro et al. (2011).

pMSSM parameters

- gaugino masses $\frac{1}{2}(M_1 \widetilde{B}\widetilde{B} + M_2 \widetilde{W}^a \widetilde{W}^a + M_3 \widetilde{g}^\alpha \widetilde{g}^\alpha)$
- Higgsino masses $\mu \widetilde{H}_1 \widetilde{H}_2 + \text{h.c.}$ A : Pseudoscalar Higgs
- Higgs masses $\mu^2(|H_1|^2 + |H_2|^2) + \dots$
 $\rightarrow \tan \beta = \langle H_2^0 \rangle / \langle H_1^0 \rangle, m_A^2 |A|^2$
- sfermion masses $m_{\widetilde{q}_i}^2 |\widetilde{q}_i|^2 + m_{\widetilde{\ell}_i}^2 |\widetilde{\ell}_i|^2 + \dots$
- scalar 3-point $A_t \widetilde{t}_R^\dagger \widetilde{q}_{3L} H_2 + A_b \widetilde{b}_R^\dagger \widetilde{q}_{3L} H_1 + A_\tau \widetilde{\tau}_R^\dagger \widetilde{\ell}_{3L} H_1$

cf) Dangerous op. (forbidden by R-parity)

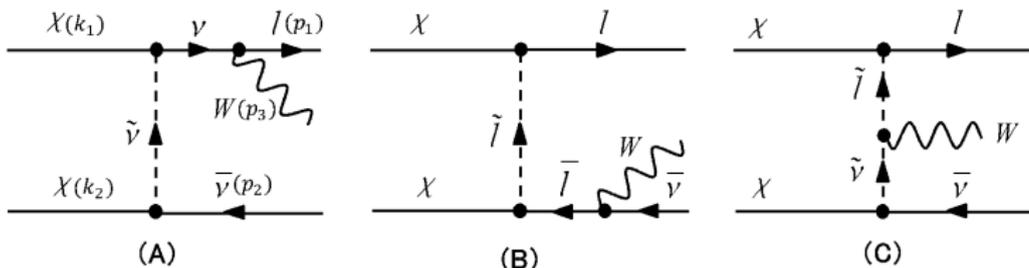
(SM particles: $R = 1$, SUSY particles: $R = -1$)

$W_{RPV} = U^c D^c D^c, D^c L Q, E^c L L \rightarrow \Delta B, \Delta L \neq 0$

(proton decay)

R-parity \rightarrow LSP stable (DM)

2. Cross section for $\chi\chi \rightarrow W\ell\bar{\nu}_\ell$



No helicity suppression: gauge boson carries $J = 1$

- Final state radiation (FSR): diagram A and B

$$\sim 1/m_{\tilde{\ell}}^2 \text{ for } m_{\tilde{\ell}} \gg m_\chi$$

- Virtual internal brems. (VIB): diagram C

$$\sim 1/m_{\tilde{\ell}}^4 \text{ for } m_{\tilde{\ell}} \gg m_\chi$$

- Initial state radiation (ISR)

Negligible for bino-like LSP (relevant for wino-like LSP)

- S-channel contributions: subdominant

Differential cross section

$$\frac{d^2(\sigma\nu)_{W\ell\bar{\nu}}}{dE_W dE_\nu} = \frac{1}{512\pi^3 m_\chi^2} \sum_{\text{spins}} \left| \mathcal{M}_A + \mathcal{M}_B + \mathcal{M}_C + (\text{u-channel}) \right|^2$$

For $m_{\tilde{\ell}} \gtrsim m_\chi$

EW brems.

$$(\sigma\nu)_{W\ell\bar{\nu}} \sim \alpha_Y^2 \alpha_W \frac{1}{m_\chi^2}$$

\gg

2-body

$$(\sigma\nu)_{\tau^+\tau^-} \sim \alpha_Y^2 \frac{m_\tau^2}{m_{\tilde{\ell}}^4}$$

For $m_{\tilde{\ell}} \gg m_\chi$

$$\mathcal{M}_A + \mathcal{M}_B \sim 1/m_{\tilde{\ell}}^4, \quad \mathcal{M}_C \propto 1/m_{\tilde{\ell}}^4$$

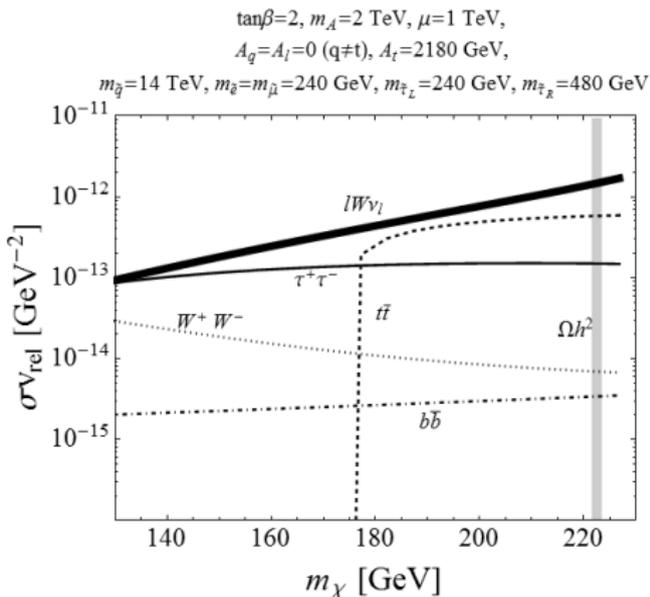
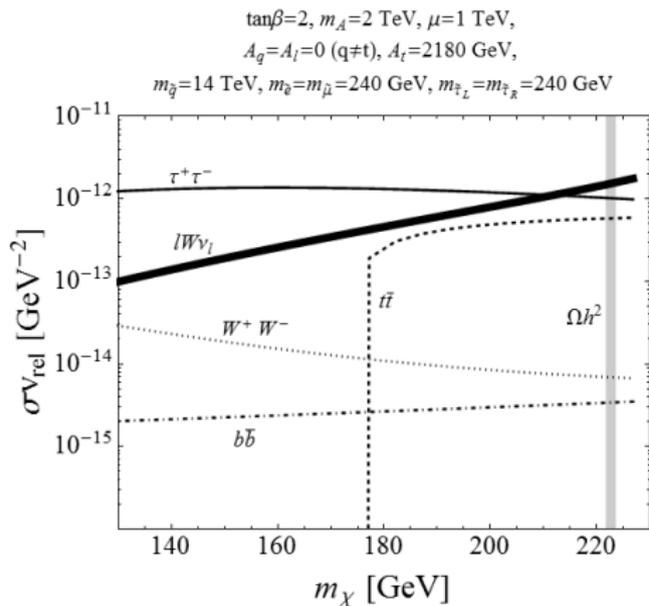
$$(\sigma\nu)_{W\ell\bar{\nu}} \sim \alpha_Y^2 \alpha_W \frac{m_\chi^6}{m_{\tilde{\ell}}^8}$$

\ll

$$(\sigma\nu)_{\tau^+\tau^-}$$

$\sigma\nu$ VS m_χ

Shudo–T.N. (2013)



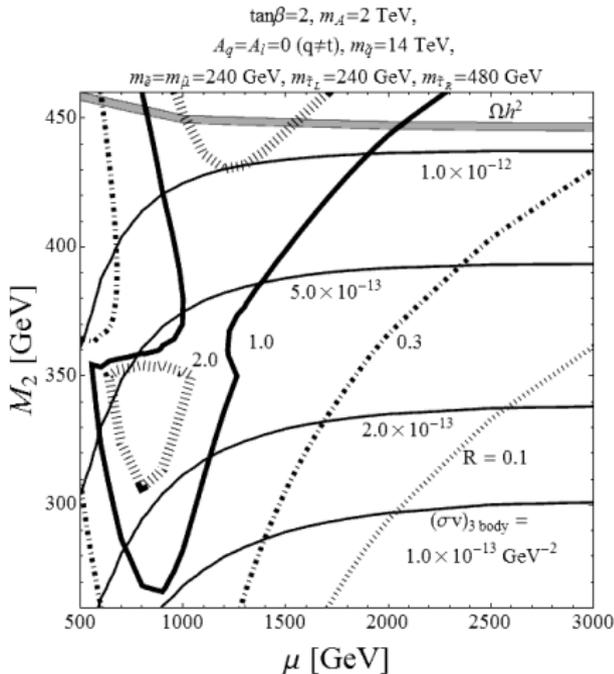
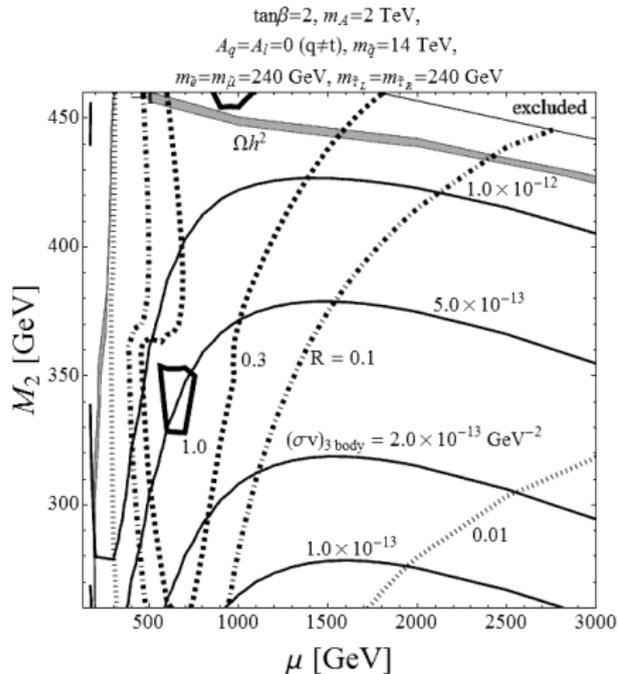
$m_1 \sim m_2/2$ (m_3 : large enough)

$W\ell\bar{\nu}$ can be dominant for $m_\chi \lesssim m_{\tilde{\tau}}$.

Relic density $\Omega_\chi h^2 \sim 0.11$: slepton coannihilations.

Contours in (M_2, μ) plane

Shudo-T.N. (2013)



EW brems. can be dominant with the observed $\Omega_\chi h^2$.

Less important for large $\tan\beta$. ($\tau^+\tau^-$ enhanced)

3. Neutrino spectra from the Sun

Primary neutrino spectrum via $\chi\chi \rightarrow W\ell\bar{\nu}$

$$\frac{d(\sigma\nu)_{W\ell\bar{\nu}}}{dE_\nu} = \int_{E_W^{\min}(E_\nu)}^{E_W^{\max}} dE_W \frac{d^2(\sigma\nu)_{W\ell\bar{\nu}}}{dE_W dE_\nu}$$

where

$$E_W^{\min}(E_\nu) = m_\chi - E_\nu + \frac{m_W^2}{m_\chi - E_\nu}, \quad E_W^{\max} = m_\chi \left(1 + \frac{m_W^2}{4m_\chi^2}\right).$$

Secondary neutrino spectrum via W-boson decay

$$\left. \frac{d(\sigma\nu)_{W\ell\bar{\nu}}}{dE_\nu} \right|_{\text{from } W} = \int_{m_W}^{E_W^{\max}} dE_W \frac{d(\sigma\nu)_{W\ell\bar{\nu}}}{dE_W} \left[\left(\frac{dN_\nu}{dE_\nu} \right)_W (E_W, E_\nu) \right]$$

Neutrino distributions (from the center of the Sun):

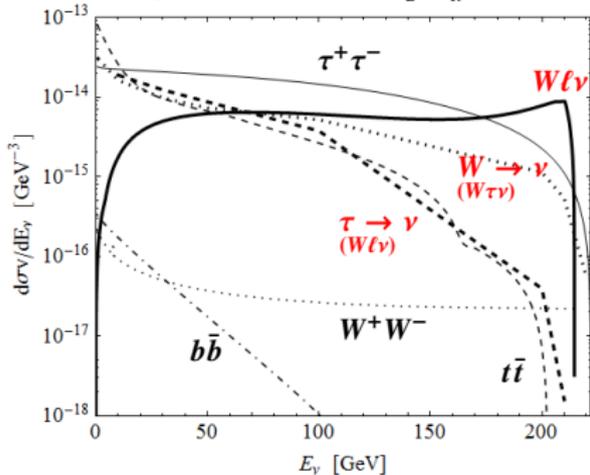
$$\left(\frac{dN_\nu}{dE_\nu} \right)_W, \left(\frac{dN_\nu}{dE_\nu} \right)_t, \left(\frac{dN_\nu}{dE_\nu} \right)_b, \left(\frac{dN_\nu}{dE_\nu} \right)_\tau$$

taken from Cirelli et al. (NPB 727, 2005): PYTHIA

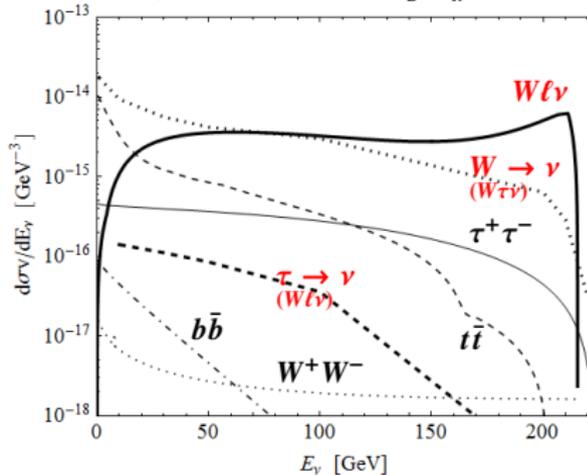
Neutrino spectra

Shudo-Nihei (2013)

$\tan\beta=2$, $M_2=450$ GeV, $m_A=2$ TeV, $\mu=1$ TeV,
 $A_g=A_I=0(q\neq t)$, $A_t=2180$ GeV,
 $m_{\tilde{g}}=14$ TeV, $m_{\tilde{g}}=m_{\tilde{\mu}}=240$ GeV, $m_{\tilde{t}_L}=m_{\tilde{t}_R}=240$ GeV



$\tan\beta=2$, $M_2=450$ GeV, $m_A=2$ TeV, $\mu=1.5$ TeV,
 $A_g=A_I=0(q\neq t)$, $A_t=2$ TeV,
 $m_{\tilde{g}}=14$ TeV, $m_{\tilde{g}}=m_{\tilde{\mu}}=240$ GeV, $m_{\tilde{t}_L}=m_{\tilde{t}_R}=480$ GeV



Energetic neutrinos from $\chi\chi \rightarrow W\ell\bar{\nu}_\ell$

$W\ell\bar{\nu}$ can give characteristic signals around $E_\nu \lesssim m_\chi$ even when $(\sigma\nu)_{W\ell\bar{\nu}}$ is subdominant.

4. Conclusions

Electroweak bremsstrahlung $\chi\chi \rightarrow W\ell\bar{\nu}$ for bino-like LSP in the pMSSM.

Light slepton scenario with extremely heavy squarks

- $\chi\chi \rightarrow W\ell\bar{\nu}$ can be dominant with correct relic abundance.
No helicity suppression, $\Omega_\chi h^2$: slepton coann.
- Neutrino spectra from the Sun (at injection)
Energetic neutrinos from $\chi\chi \rightarrow W\ell\bar{\nu}_\ell$.
 $W\ell\bar{\nu}$ can give characteristic signals even when $(\sigma\nu)_{W\ell\bar{\nu}}$ is subdominant.
- Future works: extensive parameter scan, neutrino flux

Supplements

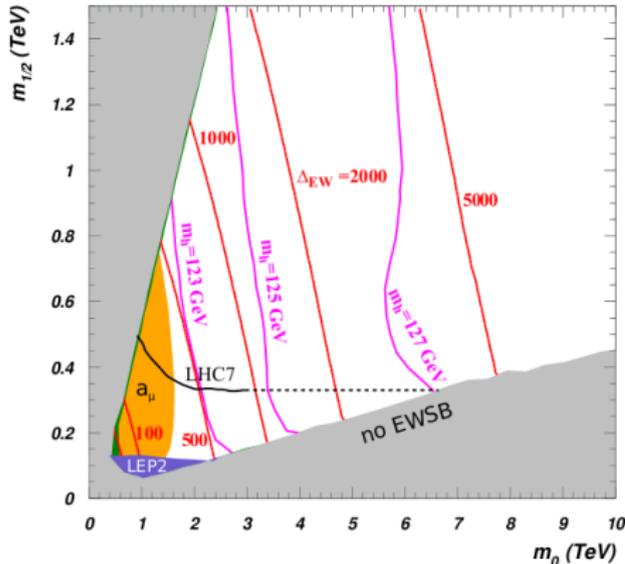
MSSM particle contents

spin = 0	1/2	1
$\tilde{q} \tilde{u} \tilde{d}$ squark	$q u d$ quark	
$\tilde{l} \tilde{e}$ slepton	$l e$ lepton	
$H_1 H_2$ higgs	$\tilde{H}_1 \tilde{H}_2$ higgsino	
	$\tilde{B} \tilde{W}^a \tilde{g}^\alpha$ gaugino	$B_\mu W_\mu^a g_\mu^\alpha$ gauge

Experimental constraints

Baer et al (arXiv:1210.3019)

mSUGRA: $\tan\beta=50$, $A_0=-2m_{\mu}$, $\mu > 0$, $m_t=173.2$ GeV



$$m_H^2 \sim m_Z^2 \cos^2 2\beta + \Delta_{\text{loop}}^2 \quad \text{Okada-Yamaguchi-Yanagida}$$

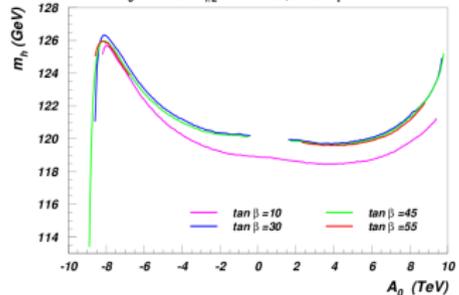
$$\Delta_{\text{loop}}^2 \sim \frac{3m_t^4}{2\pi^2 v^2} \left(\log \frac{\bar{M}_t^2}{m_t^2} + \frac{X_t^2}{\bar{M}_t^2} - \frac{X_t^4}{12\bar{M}_t^4} + \dots \right)$$

$$X_t = A_t - \mu \cot \beta \rightarrow \Delta_{\text{loop}}^2 \text{ maximized at } X_t \sim \sqrt{6} \bar{M}_t$$

$$m_H = 125 \text{ GeV} \rightarrow \text{large stop mass, large } A$$

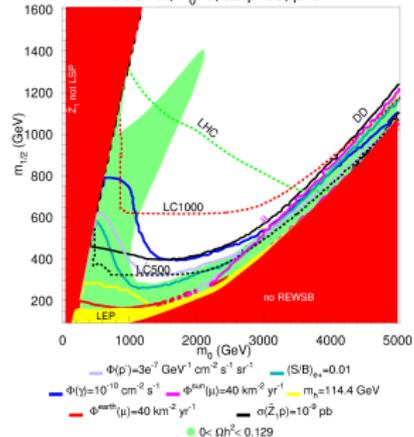
Baer-Barger-Mustafayev (2012)

mSUGRA: $m_0=4\text{TeV}$, $m_{1/2}=0.5\text{TeV}$, $\mu > 0$, $m_t=173.3$ GeV

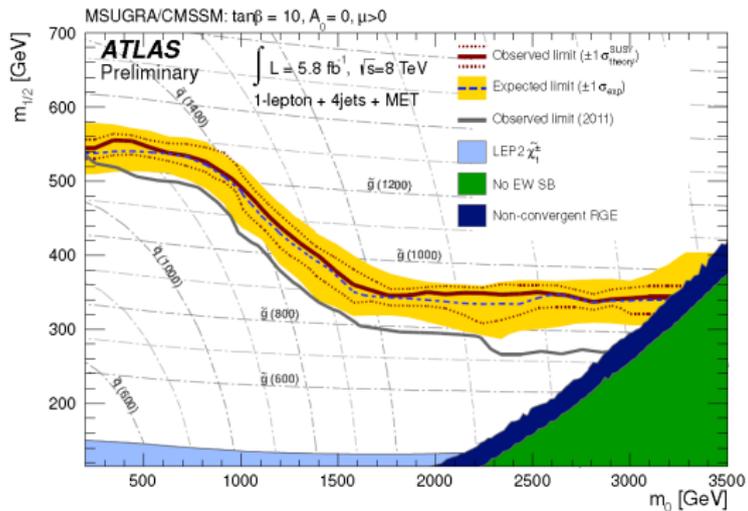


Baer et al (JCAP, 2004)

mSUGRA, $A_0=0$, $\tan\beta=55$, $\mu>0$



SUSY particle searches at LHC



Helicity suppression

$$\sigma(\chi\chi \rightarrow f\bar{f}) \propto \frac{m_f^2}{m_\chi^2}$$

