Sneutrino Dark Matter and IceCube

Rouzbeh Allahverdi

University of New Mexico

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In collaboration with:

S. Bornhauser (UNM), K. Richardson-McDaniel (UNM)

B. Dutta (Texas A&M)

Sneutrino Dark Matter:

In MSSM dark matter is a fermion (neutralino or gravitino).

The only scalar candidate LH sneutrino is ruled out by direct detection experiments.

RH sneutrino $\tilde{N}$ a viable candidate (RH neutirno N needed to explain neutrino masses and mixings).

$\tilde{N}$ a singlet under the SM gauge group, has only Yukawa couplings, too small to yield acceptable thermal relic density.

Need new gauge interactions.

The simplest extension of gauge includes a gauged $U(1)_{B-L}$ symmetry (B= baryon number, L= lepton number).
Mohapatra, Marshak 1980

- Anomaly cancelation requires the existence of three fermions that are SM singlets with L=+1, i.e. RH neutrinos.

- $U(1)_{B-L}$ gauge couplings unifies with the SM gauge couplings.
- $U(1)_{B-L}$ embedded in GUTs larger than $SU(5)$.

If $U(1)_{B-L}$ is broken around TeV, we can also get:

- Thermal sneutrino dark matter.

- Radiaitve breaking of the symmetry.

Field content and B-L charge assignments:

	Q	L	N	H_1'	H_2' (+ SUSY Partners)
Q_{B-L}	+1/6	-1/2	-1/2	+1	-1

Also one gauge boson Z' (+ SUSY partner), $g_{B-L} \sim 0.4$.

Tevatron and LEP bound: $m_{Z'} > 1.5 TeV$.

The B-L spontaneously broken by the new Higgs VEVs:

$$\langle H_1' \rangle, \langle H_2' \rangle \qquad \tan\beta' \equiv \frac{\langle H_2' \rangle}{\langle H_1' \rangle}$$

There are three Higgs fields in the B-L sector:

ϕ $$m_\phi^2 < m_{Z'}^2 \cos^2 2\beta'$$

Φ, A $$m_\Phi, m_A \sim m_{Z'}$$

$$\tan\beta' \approx 1 \Rightarrow m_\phi << m_{Z'}$$

One of the B-L Higgses can be very light.

Sneutrino $\tilde{N}$ is the LSP in parts of the parameter space.

Sneutrino Capture and Annihilation in the Sun:

Sneutrinos get captured by the Sun and pair annihilate:

$$N(t) = \sqrt{\frac{C}{A}} \tanh \sqrt{CA}t$$

$C:$ Capture rate, depends on $\sigma_{\tilde{N}-proton}$.

$A:$ Related to σ_{ann} (at present time).

Equilibration time: $\tau_{eq} = \left(\sqrt{CA}\right)^{-1}$

$$t > \tau_{eq} \Rightarrow \Gamma_A = \frac{C}{2}$$

$\tilde{N}$ interacts with quarks via Z' exchange.

No spin-dependent contribution (B-L is vectorial).

LEP bound: Carena, *et al.*, PRD70, 093009 (2004)

$$\frac{m_{Z'}}{g_{B-L} Q_L} > 6TeV$$

$$\Rightarrow \sigma_{\tilde{N}-proton} \propto \left(\frac{g_{B-L} Q_L}{m_{Z'}} \right)^4 \leq 8 \times 10^{-9}\, pb$$

Annihilation channels in the S-wave dominant at present:

$\tilde{N}\tilde{N} \rightarrow NN$ S-wave

$\tilde{N}\tilde{N}^* \rightarrow \phi\phi$ S-wave, possible if $m_\phi < m_{\tilde{N}}$

(annihilation to Φ, A kinematically forbidden or suppressed).

In contrast:

$\tilde{N}\tilde{N}^* \rightarrow f\bar{f}$ P-wave, totally negligible

$$\Rightarrow \sigma_{ann} \geq \sigma_{freeze-out} = 3\times 10^{-26}\, cm^3/\mathrm{sec}$$

This results in:

$$\tau_{eq} \leq \tau_{solar} \approx 4.5 Gyr$$

Thus snuetrino capture and annihilation:\ reaches equilibrium in the Sun.

Total annihilation rate does not depend on the details of σ_{ann} (e.g., non-relativistic enhancement enhancement).

How about the final states?

What is the branching ratio for producing LH neutrino form annihilation of RH sneutrinos?

Neutrino Flux from Sneutrino Annihilation:

Case 1: Heavy B-L Higgses (generic case).

$$\tilde{N}\tilde{N} \rightarrow NN$$ 100%

$$\sigma_{ann} = 3 \times 10^{-26}\, cm^3/\sec$$

$$N \rightarrow \nu h^0$$

(h^0 the lightest MSSM Higgs)

Decay to heavier MSSM Higgses kinematically suppressed or forbidden.

LH neutrinos produced in two-body decays.

Case 2: Lightest B-L Higgs light ϕ .

Can explain PAMELA via Sommerfeld enhancement.

R.A., Dutta, Richardson-McDaniel, Santoso

PRD 79, 075005 (2009) & PLB 677, 172 (2009)

$$\tilde{N}\tilde{N} \to \phi\phi$$ ~90%

$$\tilde{N}\tilde{N} \to NN$$ ~10%

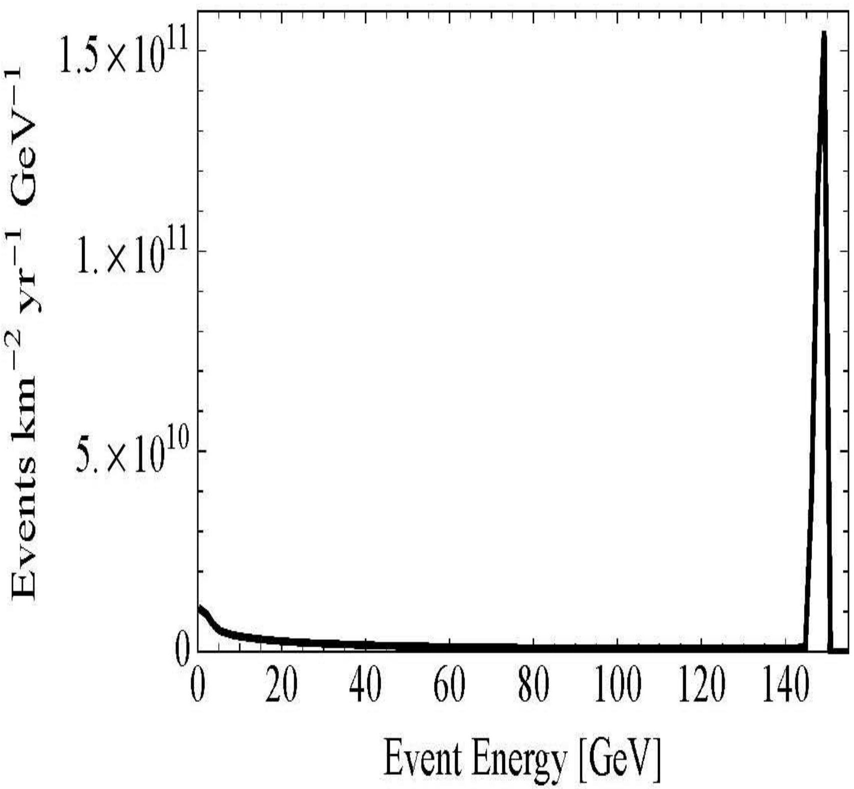
$$\sigma_{ann} = 3\times10^{-23}\, cm^3/\mathrm{sec}$$

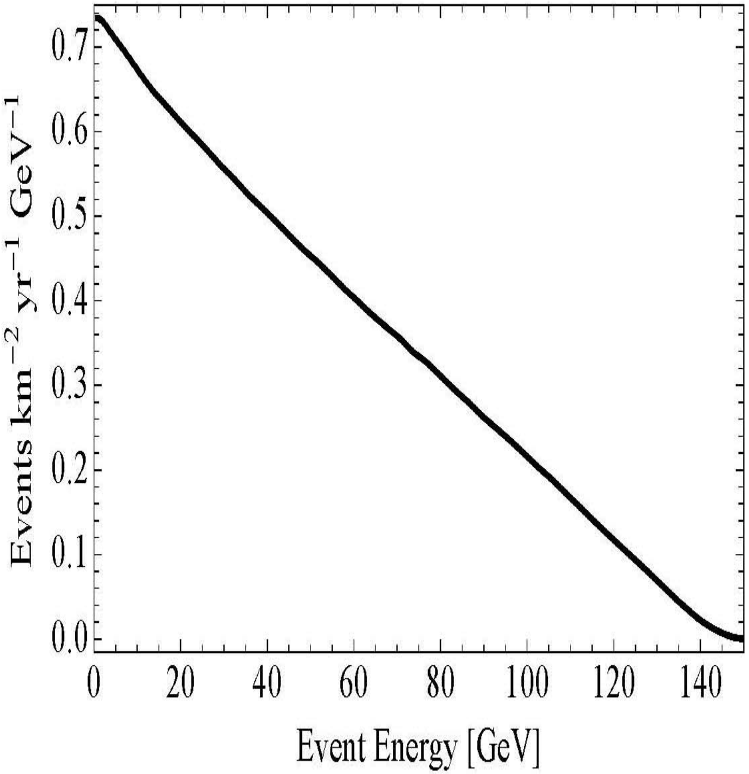
$$\Gamma_{\phi\to f\bar{f}} \propto g_{B-L}^6 Q_f^4 m_f^2$$

$$\phi \to \tau^+\tau^-$$ 74%

$$\phi \to b^+b^-$$ 16%

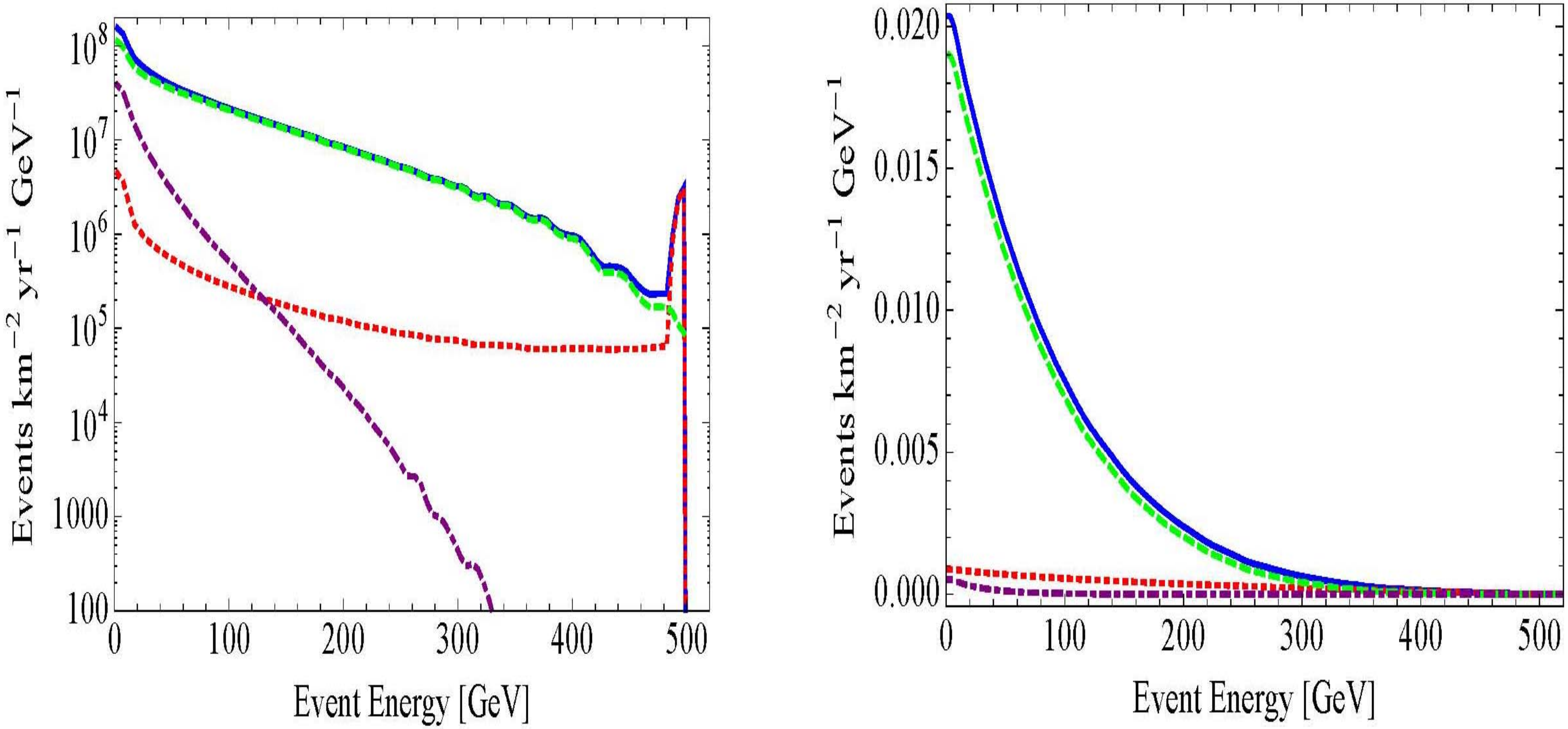
LH neutrinos produced in three-body decays of taus.





Muon neutrino events and muon events at the detector for a **case 1** sneutrino with 300 GeV mass.

(little sensitivity to the flavor composition of neutrinos proded in the Sun)



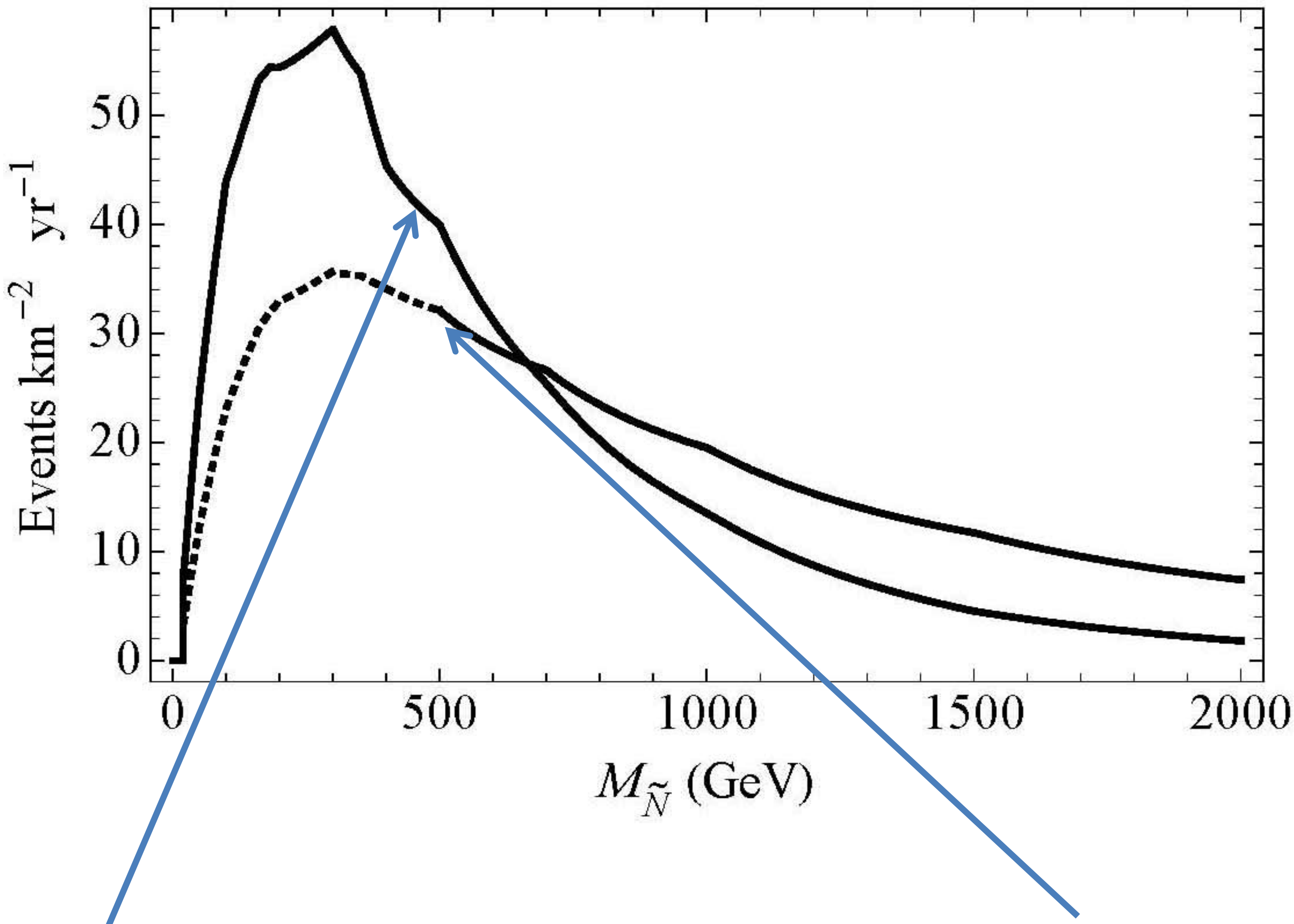
tau decay

bottom decay

N decay

Muon neutrino events and muon events at the detector for a **case 2** sneutrino with 1 TeV mass.

(essentially not sensitive to the flavor composition of neutrinos produced in the Sun)



Case 1 **Case 2**

Larger neutrino energies,

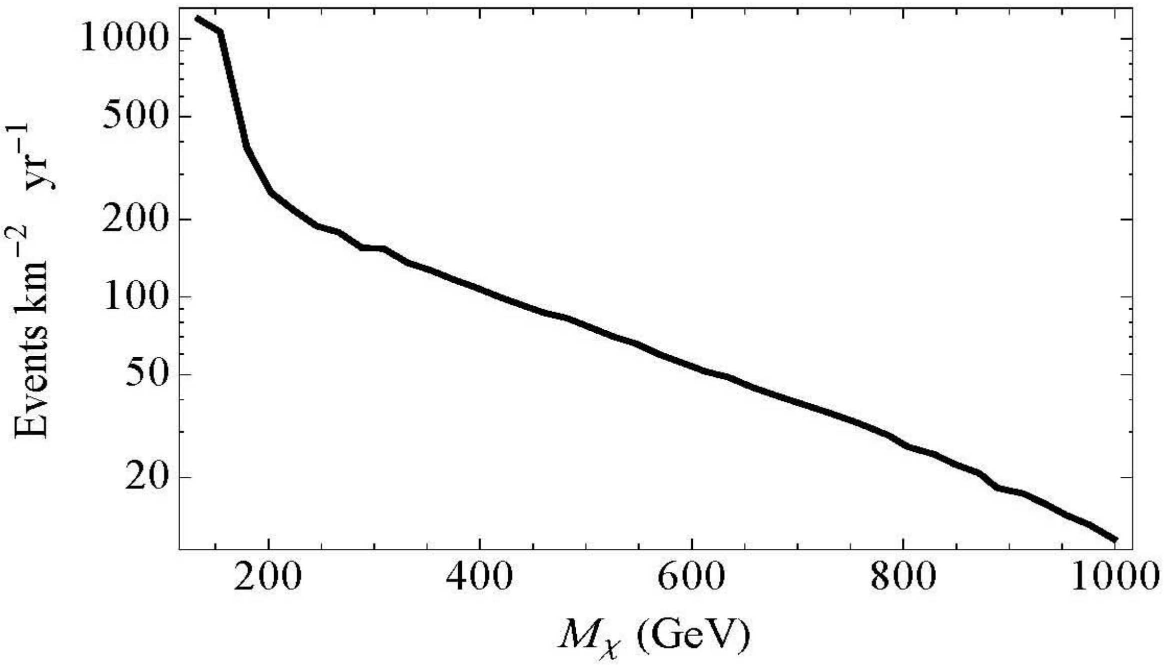
more muons at low masses

more scattering and absorption at high masses

Comparison with Neutrlino Dark Matter:

Only in the focus point region muon event rate is high enough.

Large Higgsino component, spin-dependent cross section is large (important inside the Sun, mainly hydrogen).



Sneutrino predicts roughly comparable rates, despite no SD contribution, because of leptonic final state.

Summary:

- $U(1)_{B-L}$ is well motivated model that accommodates thermal sneutrino dark matter.

- Sneutrino annihilation occurs in the S-wave, produces RH neutrinos (generic case), B-L Higgses (PAMELA case).

- Elastic scattering cross section upper bound $8\times10^{-9}\,pb$ from Z' mass limits.

- Capture and annihilation in the Sun equilibrates. Muon event rate can be as large as $100\,yr^{-1}km^{-2}$. Muon events from the Earth negligible (unless velocity distribution modified).

- Features in the muon spectrum from two-body decays.