Sneutrino Dark Matter in the BLSSM

Simon J. D. King

Young Theorists Forum 10

January 10, 2018

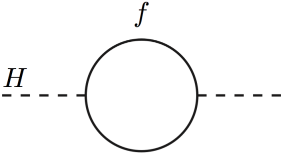
UNIVERSITY OF Southampton

Outline

In collaboration with L. Delle Rose, S. Khalil, S. Kulkarni, C. Marzo, S. Moretti, C.S. Ün [arXiv: 1712.05232]

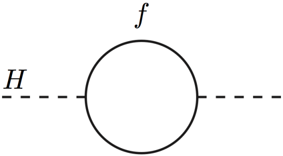
Motivations

- Hierarchy Problem, Unification, . . .



Motivations

- Hierarchy Problem, Unification, ...

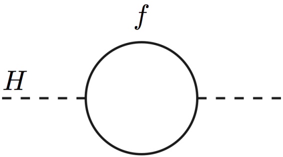


- Dark Matter

Figure: Chandra X-ray Observatory

Motivations

- Hierarchy Problem, Unification, . . .



- Dark Matter
- Non-vanishing Neutrino Masses

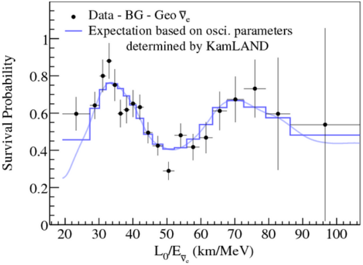
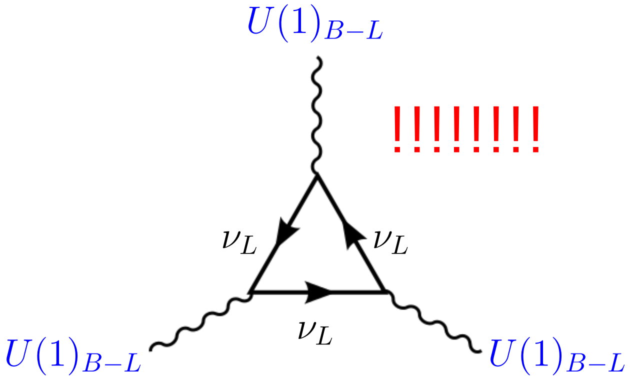


Figure: Chandra X-ray Observatory // KamLAND experiment, 0801.4589

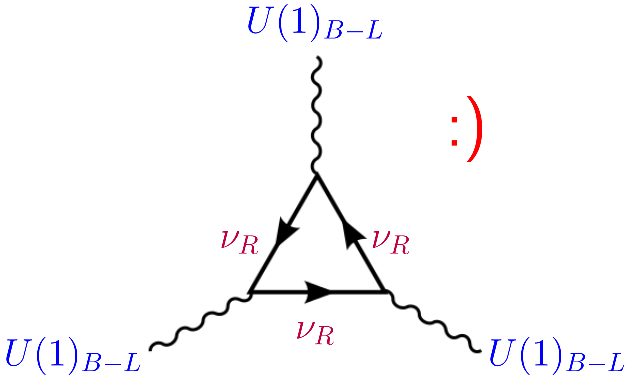
Explaining the BLSSM – "B-L"

- SM has exact B-L conservation
- Promote accidental, global symmetry to local. SM gauge group now extended to: $G_{B-L} = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$
- anomaly cancellation - require SM singlet fermion (right-handed neutrinos)



Explaining the BLSSM – "B-L"

- SM has exact B-L conservation
- Promote accidental, global symmetry to local. SM gauge group now extended to: $G_{B-L} = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$
- anomaly cancellation - require SM singlet fermion (right-handed neutrinos)



Explaining the BLSSM – "SSM"

Chiral Superfield		Spin 0	Spin 1/2	G_{B-L}
Quarks/Squarks, (x3 generations)	$\hat{Q}$	$(\tilde{u}_L \tilde{d}_L) \equiv \tilde{Q}_L$	$(u_L d_L)$	$(\mathbf{3},\ \mathbf{2},\ \frac{1}{6},\ \frac{1}{6})$
	$\hat{U}$	$\tilde{u}_R^*$	$\bar{u_R}$	$(\bar{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3},\ -\frac{1}{6})$
	$\hat{D}$	$\tilde{d}_R^*$	$\bar{d_R}$	$(\bar{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3},\ -\frac{1}{6})$
Leptons/Sleptons, (x3 generations)	$\hat{L}$	$(\tilde{\nu}_L \tilde{e}_L) \equiv \tilde{L}_L$	$(\nu_L e_L)$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ -\frac{1}{2})$
	$\hat{E}$	$\tilde{e}_R^*$	$\bar{e_R}$	$(\mathbf{1},\ \mathbf{1},\ 1,\ \frac{1}{2})$
Higgs/Higgsinos	$\hat{H}_u$	$(H_u^+ H_u^0)$	$(\tilde{H}_u^+ \tilde{H}_u^0) \equiv \tilde{H}_u$	$(\mathbf{1},\ \mathbf{2},\ \frac{1}{2},\ 0)$
	$\hat{H}_d$	$(H_d^0 H_d^-)$	$(\tilde{H}_d^0 \tilde{H}_d^-) \equiv \tilde{H}_d$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ 0)$

Vector Superfields	Spin 1/2	Spin 1	G_{B-L}
Gluino, gluon	$\tilde{g}$	g	(**8**, **1**, 0,0)
Wino/W bosons	$\tilde{W}^\pm\ \tilde{W}^0$	$W^\pm W^0$	(**1**, **3**, 0, 0)
Bino / B boson	$\tilde{B}^0$	B^0	(**1** **1**, 0, 0)

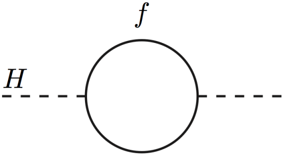
Explaining the BLSSM – “SSM”

- Content in addition to MSSM:

Chiral Superfield		Spin 0	Spin 1/2	G_{B-L}
RH Sneutrinos / Neutrinos (x3)	$\hat{\nu}$	$\tilde{\nu}_R^*$	$\bar{\nu_R}$	$(\mathbf{1}, \mathbf{1}, 0, \frac{1}{2})$
Bileptons/Bileptinos	$\hat{\eta}$	η	$\tilde{\eta}$	$(\mathbf{1}, \mathbf{1}, 0, -1)$
	$\hat{\bar{\eta}}$	$\bar{\eta}$	$\tilde{\bar{\eta}}$	$(\mathbf{1}, \mathbf{1}, 0, 1)$
Vector Superfields		**Spin 1/2**	**Spin 1**	G_{B-L}
BLino / B' boson		$\tilde{B}'^0$	B'^0	$(\mathbf{1}\ \mathbf{1}, 0, 0)$

- Three extra RH neutrinos + SUSY partner (from anomaly cancellation condition)
- Two extra Higgs (for breaking gauged $U(1)_{B-L}$)
- One B' + SUSY partners (from broken $U(1)_{B-L}$)

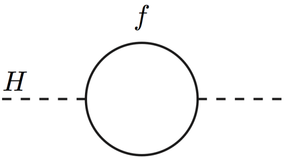
Hierarchy Problem



$$= -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{NP}^2 + \ldots$$

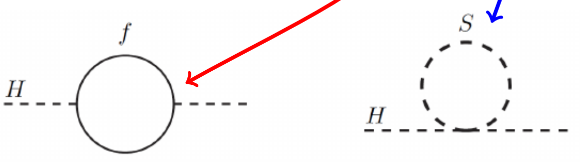
- Self energy correction to bare Higgs mass. Treating Λ_{NP} at GUT scale (10^{16}GeV) means the bare Higgs mass is fine-tuned to $m_H^2/\Lambda_{UV}^2 \sim$ **1 in $\mathbf{10^{30}}$**!

Hierarchy Problem



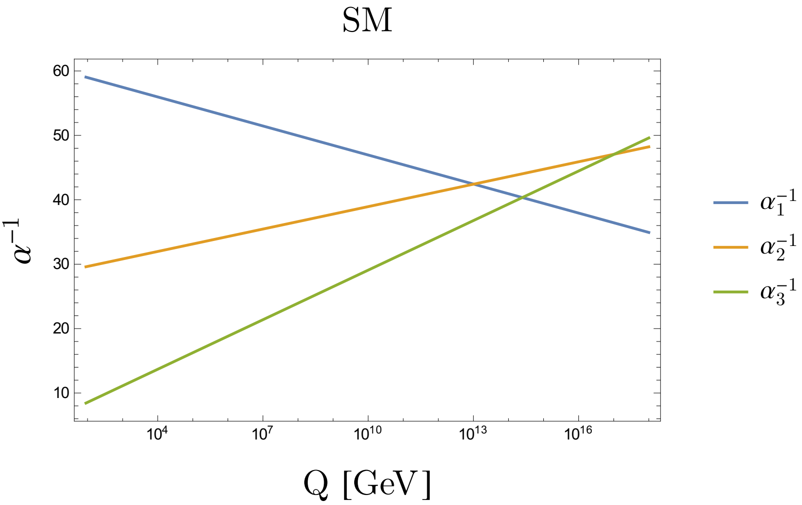
$$= -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{NP}^2 + \ldots$$

- Self energy correction to bare Higgs mass. Treating Λ_{NP} at GUT scale (10^{16}GeV) means the bare Higgs mass is fine-tuned to $m_H^2/\Lambda_{UV}^2 \approx$ **1 in 10^{30}**!
- Supersymmetry - for every fermion, there is a scalar partner providing the opposite sign contribution



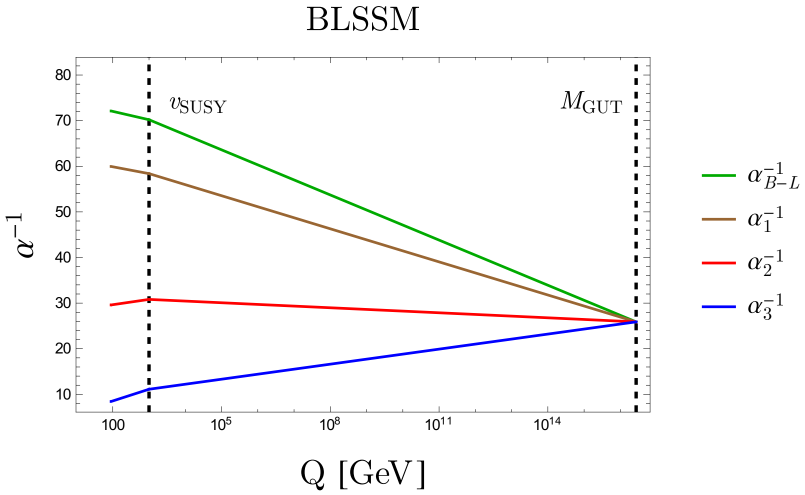
Unification of Gauge Couplings

- Gauge couplings in the SM *almost* unify



Unification of Gauge Couplings

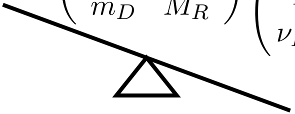
- In SUSY, they perfectly hit!



Non-vanishing Neutrino Masses I

- ν_L have mass!
- Introducing RH neutrinos can explain mass for ν_L

$$(\bar{\nu_L}\bar{\nu_R^c})\begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix}\begin{pmatrix} \nu_L^c \\ \nu_R \end{pmatrix}$$



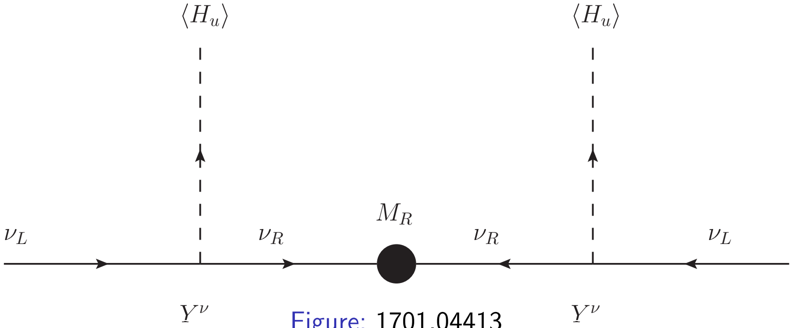
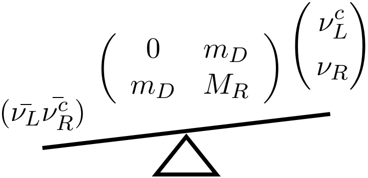


Figure: 1701.04413

Non-vanishing Neutrino Masses I

- ν_L have mass!
- Introducing RH neutrinos can explain mass for ν_L
- Large RH mass can explain small LH mass in a see-saw mechanism



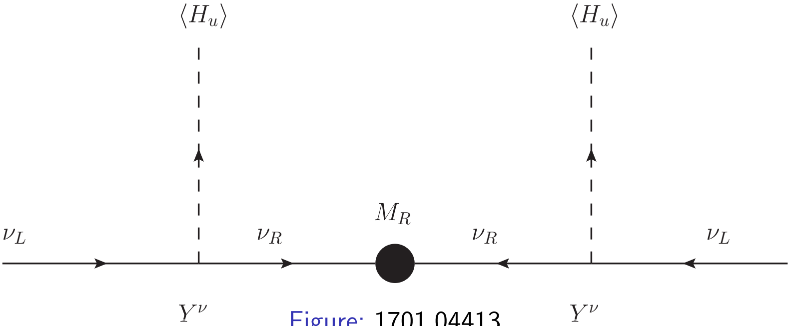


Figure: 1701.04413

Non-vanishing Neutrino Masses II

- ...However, this leads to $B - L$ violation, as in $0\nu 2\beta$-decay

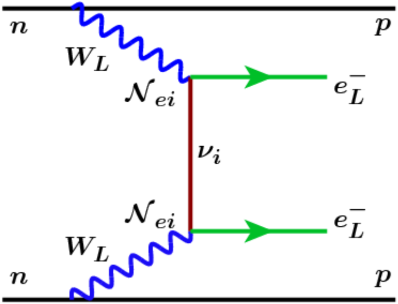


Figure: 1301.4784

- In BLSSM, gauge symmetry is broken with a Higgs mechanism

BLSSM Review

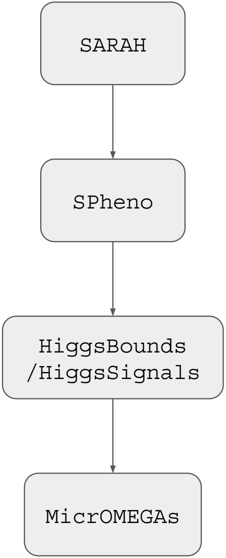
- Superpotential:

$$\begin{aligned} W &= \mu H_u H_d + Y_u^{ij} Q_i H_u u_j^c + Y_d^{ij} Q_i H_d d_j^c + Y_e^{ij} L_i H_d e_j^c \\ &+ Y_\nu^{ij} L_i H_u N_i^c + Y_N^{ij} N_i^c N_j^c \eta_1 + \mu' \eta_1 \eta_2 \end{aligned}$$

- Type-I see-saw mechanism, RH neutrinos have $\lesssim$ TeV mass
- $M_{Z'}$ fixed at 4 TeV, from LEP-II EWPOs and LHC di-lepton searches
- Complete universality at GUT scale, $g_{bl} = g_1 = g_2 = g_3, \; \tilde{g} = 0.$ From RGE evolution, at EW scale, $\tilde{g} \simeq -0.1$ and $g_{bl} \simeq 0.5$

Numerical work

- Mathematica package SARAH makes a spectrum generator based on SPheno
- SPheno then calculates the full spectrum, for 60,000 data points, over a range of the GUT parameters (m_0, $m_{1/2}$, A_0, μ, $B\mu$, μ', $B\mu'$)
- Current Higgs constraints are applied in HiggsBounds / HiggsSignals
- Finally, MicroOMEGAs finds the relic density.



DM Review in MSSM

- LSP stable from R-parity (ad-hoc)

- Allowed Candidates:
- Bino ($\tilde{B}^0$)
- ~~LH Sneutrino ($\tilde{\nu}_L$)~~ (Z interactions)
- ~~Higgsino / Wino~~ (Direct Detection LUX)

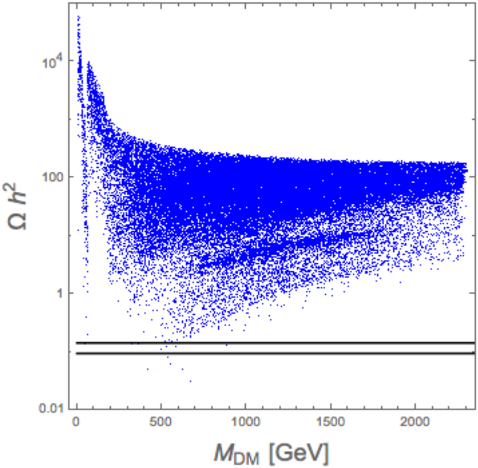


Figure: 1702.01808

DM Review in BLSSM

- Natural R-parity: $R = (-1)^{3(B-L)+2S}$. If $B - L$ broken by Higgs with even $B - L$ charge, then Z_2 remains unbroken
- Allowed candidates:
- Bino ($\tilde{B}^0$)
- Sneutrino ($\tilde{\nu}_R^*$)
- Bileptino ($\tilde{\eta}$, $\tilde{\bar{\eta}}$)
- BLino ($\tilde{B}'^0$)

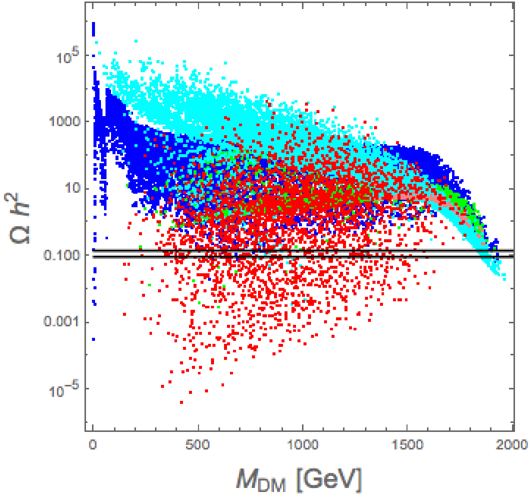
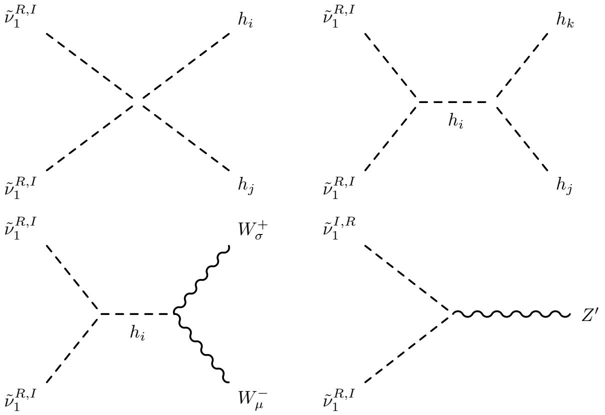


Figure: 1702.01808

RH Sneutrino Interactions

- RH sneutrinos and RH anti-sneutrinos mix, $\tilde{\nu}_R$ and $\tilde{\nu}_R^*$ no longer mass eigenstates due to $\Delta L = 2$ operator, in $M_N N^c N^c$ mass term
- Physical mass states are either CP-even or CP-odd. Either can be lightest, so both are valid LSP candidates



Direct Detection

- RH Sneutrino interact through heavy Higgs & Z' interactions → not too constrained

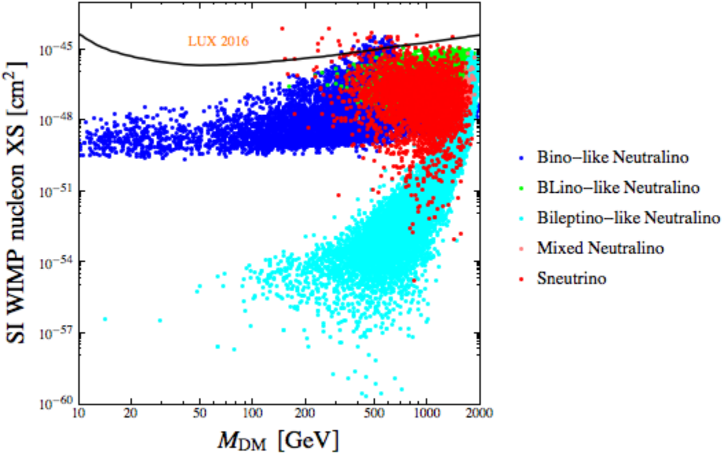
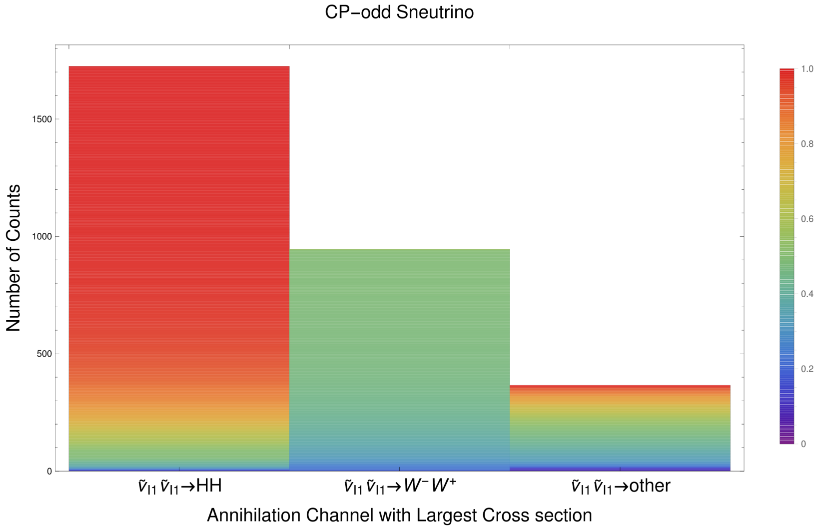


Figure: 1702.01808

Sneutrino DM Interactions

- Mostly annihilate to heavy CP-even Higgs
- Otherwise annihilate to W^+W^- pair if HH disallowed by mass

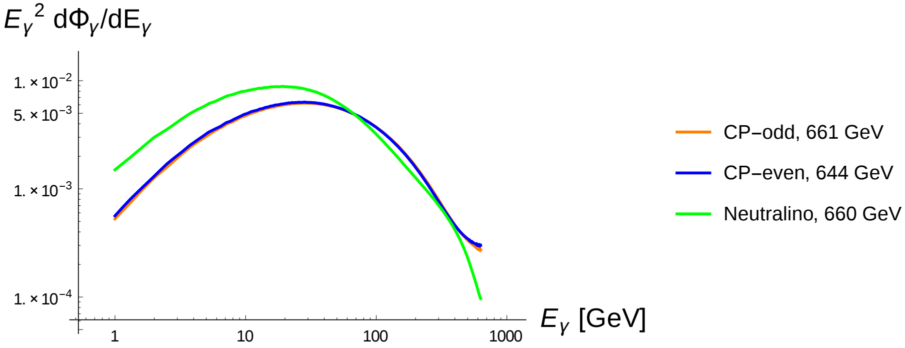


Fermi-LAT

- Indirect detection: annihilation of sneutrino DM in centre of galaxy producing charged products, which radiate photons
- $\tilde{\nu}\tilde{\nu} \to W^+W^-$

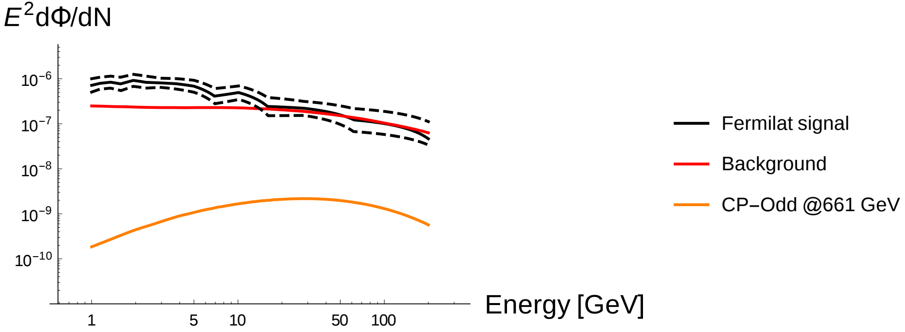
Photon Flux Distribution: Scalar vs Fermionic

- Shape of observed spectrum can differentiate DM candidates depending on spin (sneutrino spin 0, neutralino spin $1/2$)



Fermi-LAT: Background

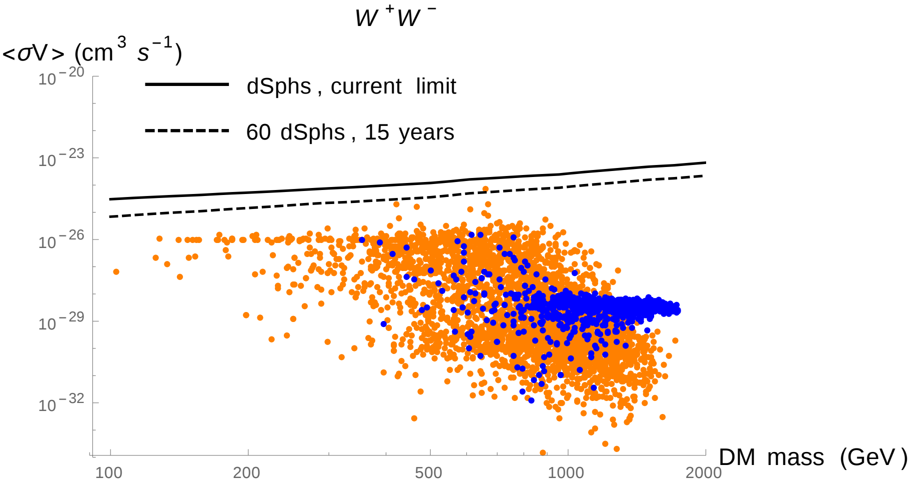
- Limiting factor is energy cut-off, future experiments will help this



.

Fermi-LAT: Current Status & Future Prospects

- Future indirect-detection experiments can detect sneutrino DM!
- Integrated flux over all energy range CP-odd CP-even



LHC Signatures

- No $SU(2)_L$ quantum numbers, interactions via $(Z,\ W^{\pm}) \propto Y_\nu \approx 0$
- Direct production: Higgs. Since LSP produced in pairs, any process would be invisible $pp \to h_i \to \tilde{\nu}_{LSP}\tilde{\nu}_{LSP}$ (MET only)
- Direct production: Z'. Strongly interact through $B-L$, but due to CP require $pp \to Z' \to \tilde{\nu}_{LSP}\ \tilde{\nu}_{NLSP}$

  $M_{Z'} = 4$TeV $\to \sigma = 0.025$ fb ↳ $\tilde{\nu}_{LSP} Z^{(*)}$ (Dilepton+MET)

  - *Indirect* production: sleptons pair production!

    $\tilde{l} \to W^{\pm}\tilde{\nu}_{LSP}$ only allowed, despite $\propto Y_\nu$

    $\tilde{l} \to \tilde{\chi}^0\ l$

    ↳ $\tilde{\nu}_{LSP}\nu_h$

    ↳ $(W^{\pm}l^{\mp}),\ (Z\nu_L)$

    $\Bigg\}\ \sigma \approx 0.1$fb

Conclusions

- The BLSSM ...
  - Solves the hierarchy problem
  - predicts light, non-vanishing left-handed neutrino masses
  - offers much larger parameter space than the MSSM
- RH Sneutrino DM...
  - Perfectly matches relic density limits
  - Evades direct-detection limits
  - May be probed by future indirect-detection experiments
  - Offers interesting collider signatures, which will be accessible during run-II

For more details, see:
arXiv: 1712.05232