SUSY $U(1)_{B-L}$ Model
"BLSSM"

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NExT Meeting RAL

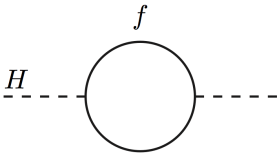
May 9, 2018

Outline

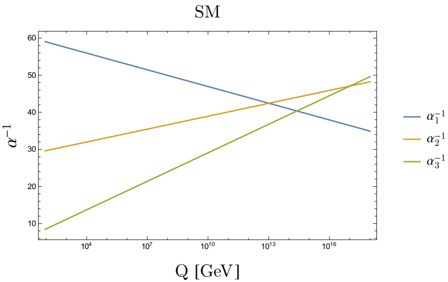
In collaboration with L. Delle Rose, S. Khalil, S. Kulkarni, C. Marzo, S. Moretti, C.S. Ün [arXiv: 1712.05232]

Motivations

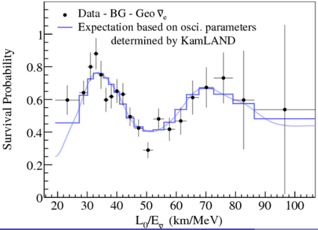
- Hierarchy Problem



- Unification



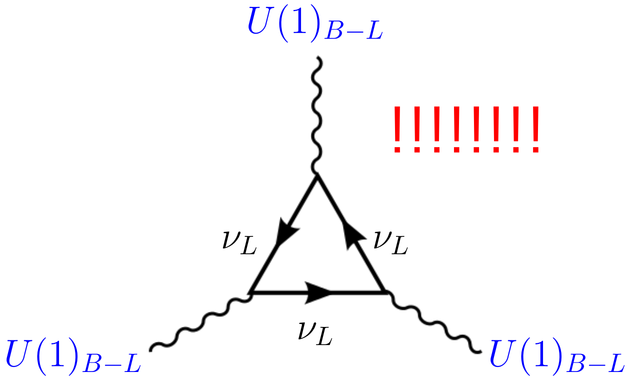
- Non-vanishing Neutrino Masses



- Dark Matter

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)



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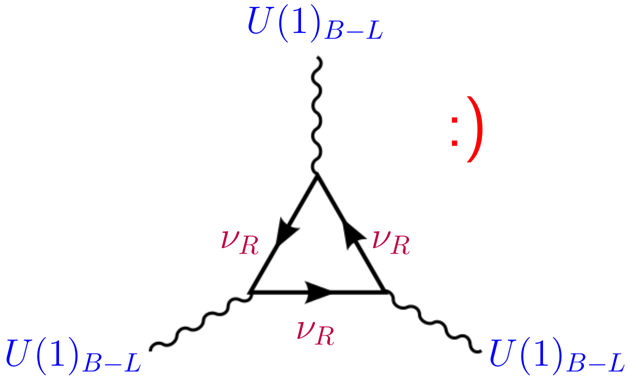


Explaining the BLSSM – "SSM"

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 $U(1)_{B-L}$)

BLSSM Review

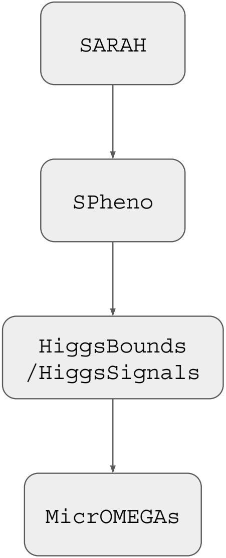
- Superpotential:

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

- Type-I see-saw mechanism, RH neutrinos have $\lesssim$ TeV mass, with small Yukawa couplings, $Y_\nu \sim \mathcal{O}(10^{-6})$
- 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 $g_{bl} \simeq 0.5$
- "Constrained" model considered, with universal scalar/gaugino masses

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
- Current Higgs constraints are applied in HiggsBounds / HiggsSignals
- MicroOMEGAs finds the relic density
- Finally, enforce spectra to satisfy SUSY mass bounds from LHC



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)

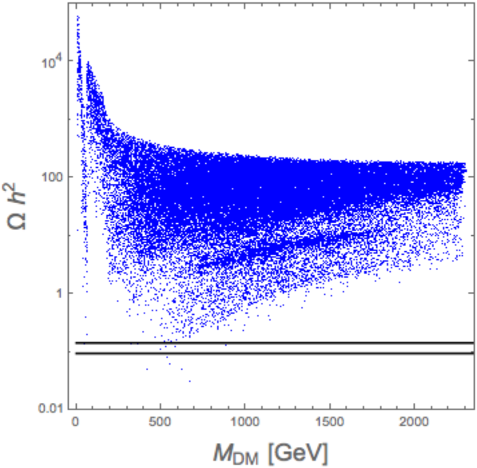


Figure: 1702.01808

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 ($\tilde{B}'^0$)

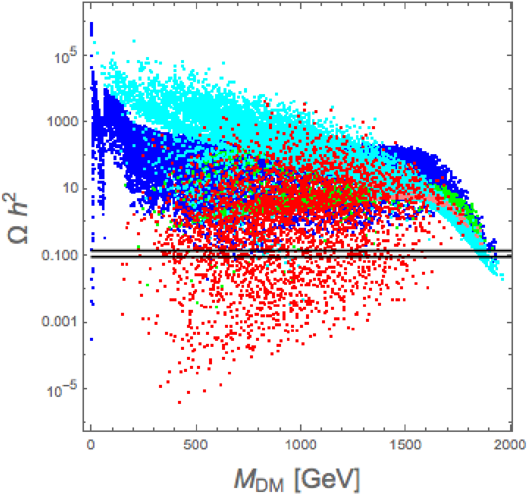
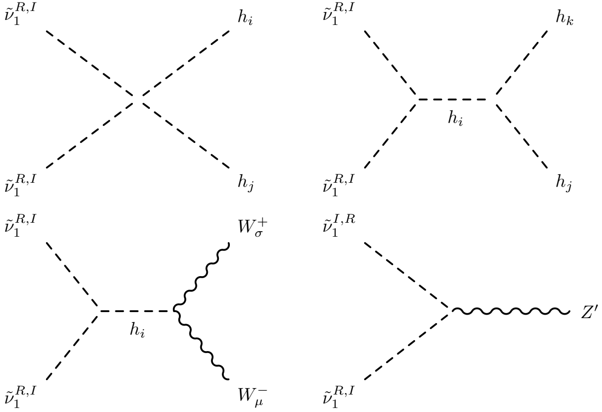


Figure: 1702.01808

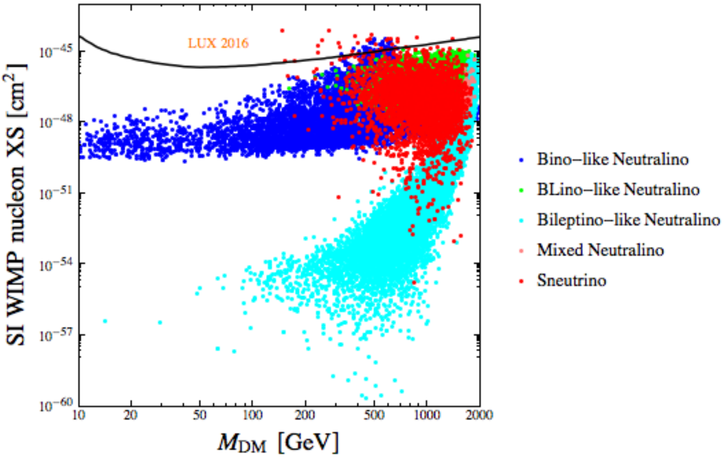
RH Sneutrino Interactions

- 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



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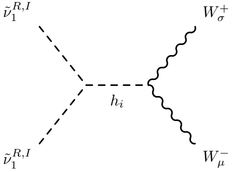
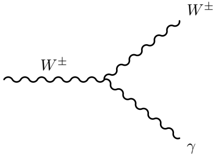
Indirect Detection: Fermi-LAT

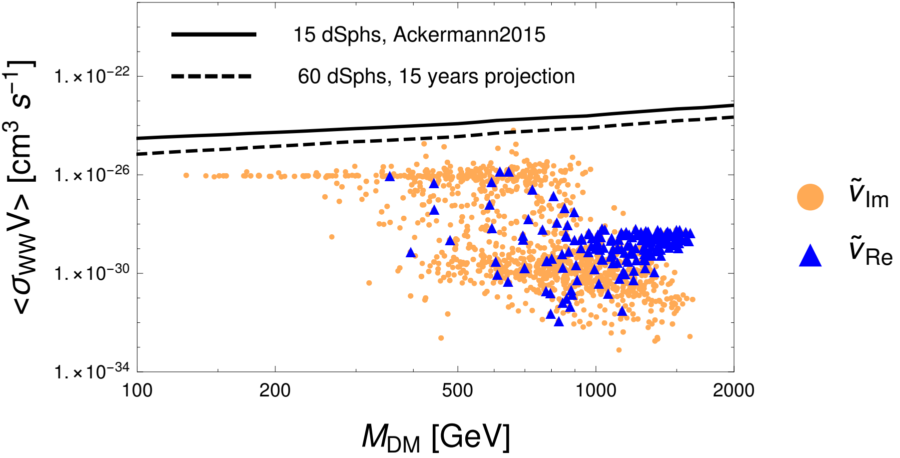
- Annihilation of DM in the centre of galaxies which produce charged products radiate high energy gamma rays which may be detected by the Fermi-LAT satellite





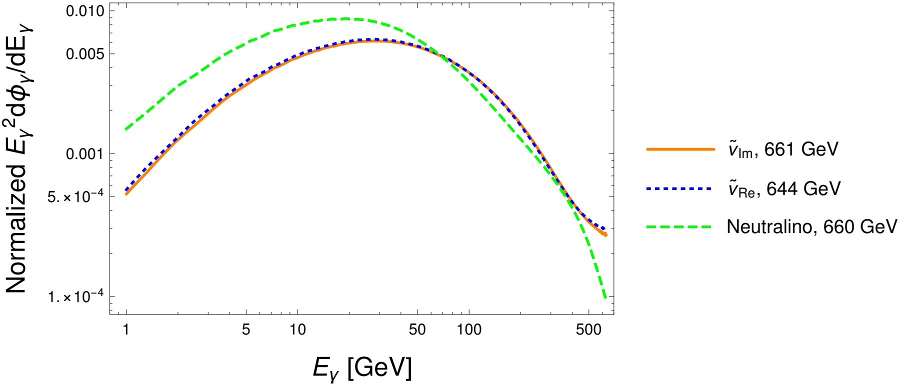
Fermi-LAT: Current Status & Future Prospects

- Integrated flux over all photon energies places limit on thermal cross section for annihilation
- Points comply with relic density upper limit range
- Future indirect-detection experiments can detect sneutrino DM!



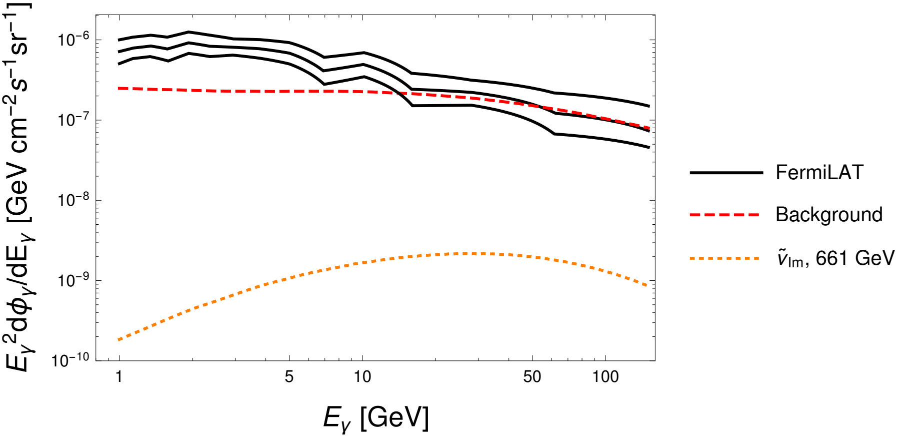
Photon Flux Distribution: Scalar vs Fermionic

- Measuring shape of photon distribution can differentiate DM candidates
- CP-odd and CP-even look identical, however neutralino takes different shape (possibly due to spin 0 vs $1/2$?)



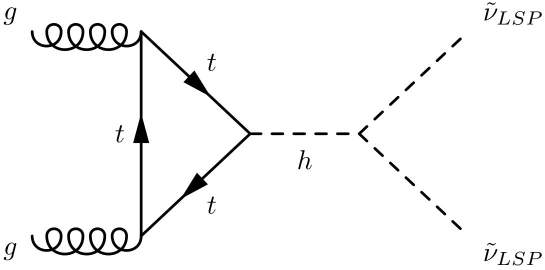
Fermi-LAT: Background

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



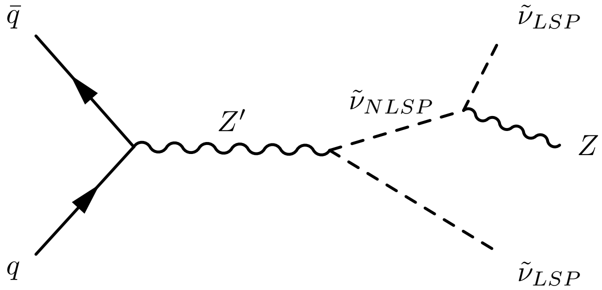
LHC Signatures I

- No $SU(2)_L$ quantum numbers, interactions via $(Z,\ W^{\pm}) \propto Y_\nu \approx 0$
- Scanned over several benchmark points using MadGraph
- Direct production: Higgs
- Problem - only MET signal (mono-jet, VBF with invisible Higgs decay). Not unique to model



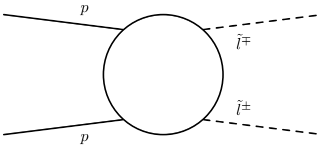
LHC Signatures II

- Direct production: Z'
- Dilepton signal $(Z \to l^+ l^-)$ + MET
- However Z' heavy (4 TeV) from heavy resonance searches $(e^+e^-,\ \mu^+\mu^-)$, so low cross section low $\sigma = 0.025$ fb

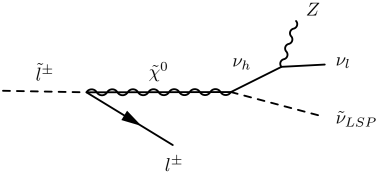


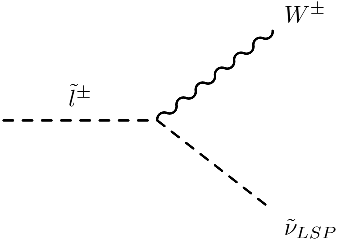
LHC Signatures III

- Indirect production: Slepton pair production! $\sigma \sim 0.1\text{fb}$



- Decay path of slepton: $\tilde{l}^{\pm} \rightarrow l^{\pm}\tilde{\chi}^0$
- May also have $\tilde{l}^{\pm} \rightarrow W^{\pm}\tilde{\nu}_{LSP}$ for points where $M_{\tilde{\chi}^0} > M_{\tilde{l}}$, despite small vertex coupling ($\propto Y_\nu$).





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