Fine-Tuning in the BLSSM

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Motivation

Two direct problems with the Standard Model (SM) are the lack of any **Dark Matter** (DM) candidates and non-vanishing **neutrino masses**. Indirect problems include the **hierarchy problem**, where the Higgs mass is fine-tuned to 1 part in $\approx 10^{30}$.

To fix the hierarchy problem, one may exploit SUperSYmmetry (SUSY), which introduces an extra boson (fermion) for each fermion (boson) in the SM. However, simply adding three **Right-Handed (RH) neutrinos** and a see-saw mechanism to explain neutrino masses would explicitly **break lepton number conservation** via processes like neutrinoless double-beta decay.

The Baryon number—Lepton number Supersymmetric Standard Model (BLSSM) offers a solution to all of these issues.

Explaining the BLSSM

In the SM, we have exact $B-L$ conservation. We may promote this accidental, global symmetry into a local one by extending the SM gauge group to:

$$G_{B-L} = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

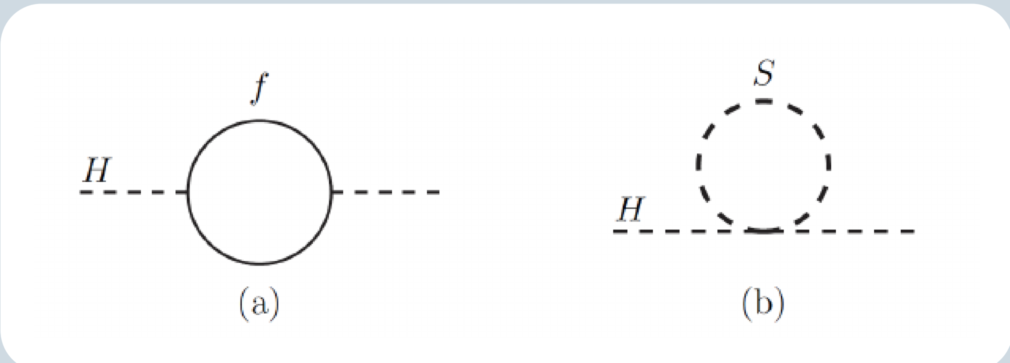
By the **anomaly cancellation** condition, the total charge of the SM must be 0 under any $U(1)$ gauge group, so we must add RH SM singlet fermions (the neutrinos). This extra $U(1)_{B-L}$ is broken by a new scalar, η, so we may dynamically have lepton minus baryon number violating processes (e.g. neutrinoless double-beta decay). Breaking this $U(1)$ also generates a mass for a new Z', as it does in the SM for the Z.

Hierarchy Problem

The Higgs will receive quantum corrections to its **mass** due to self-energy diagrams, such as the Dirac fermion loop in (a). These are divergent diagrams, so we must introduce a cut-off in the loop momentum, $\boldsymbol{\Lambda_{UV}}$, at the scale where new physics appears. For a Dirac fermion of mass m_f and coupling to the Higgs $\mathcal{L} \supset -\lambda_f H\bar{f}f$, we find a correction to the Higgs' bare mass:

$$m_H^2 = m_0^2 + \Delta m_H^2 = m_0^2 - \frac{|\lambda_f|^2}{8\pi^2}\Lambda_{UV}^2 + \cdots = (125\text{GeV})^2$$

The bare mass squared of the Higgs must be of the order Λ_{UV}. If new physics is to be around Grand Unified Theories (GUT) scale, then the bare Higgs mass must be fine-tuned to $m_H^2/\Lambda_{UV}^2 \approx$ **1 in $\mathbf{10^{30}}$**!

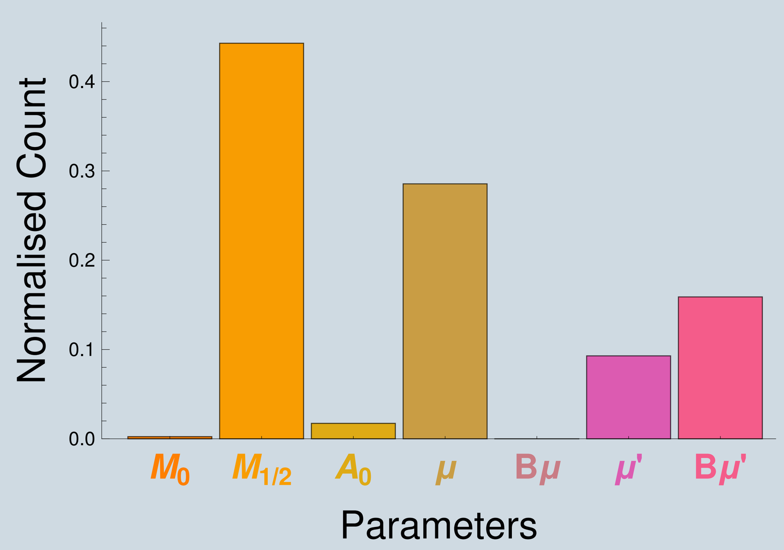


In SUSY, for each fermionic diagram, like (a), there exists a scalar superpartner which contributes an **opposite** sign, like (b), and vice-versa. However, as the SUSY partners masses are pushed higher by LHC bounds, the "…" $\propto m_f^2$ terms will now grow larger and require their own fine-tuning of the order m_H^2/m_{SUSY}^2.

Fine-Tuning

The fine-tuning in a given model is estimated by the quantity Δ [1, 2]; defined to be the change in squared mass of the SM Z-boson, due to a shift in the fundamental parameters a_i in a model. For the BLSSM, these are the: unification masses for scalars, gauginos (m_0, $m_{1/2}$), universal trilinear coupling (A_0), the quadratic superpotential parameters μ, μ' and the quadratic soft SUSY terms $B\mu$ and $B\mu'$.

$$\Delta = Max\left\{\left|\frac{a_i}{M_Z^2}\frac{\partial M_Z^2(a_i,m_t)}{\partial a_i}\right|\right\}$$



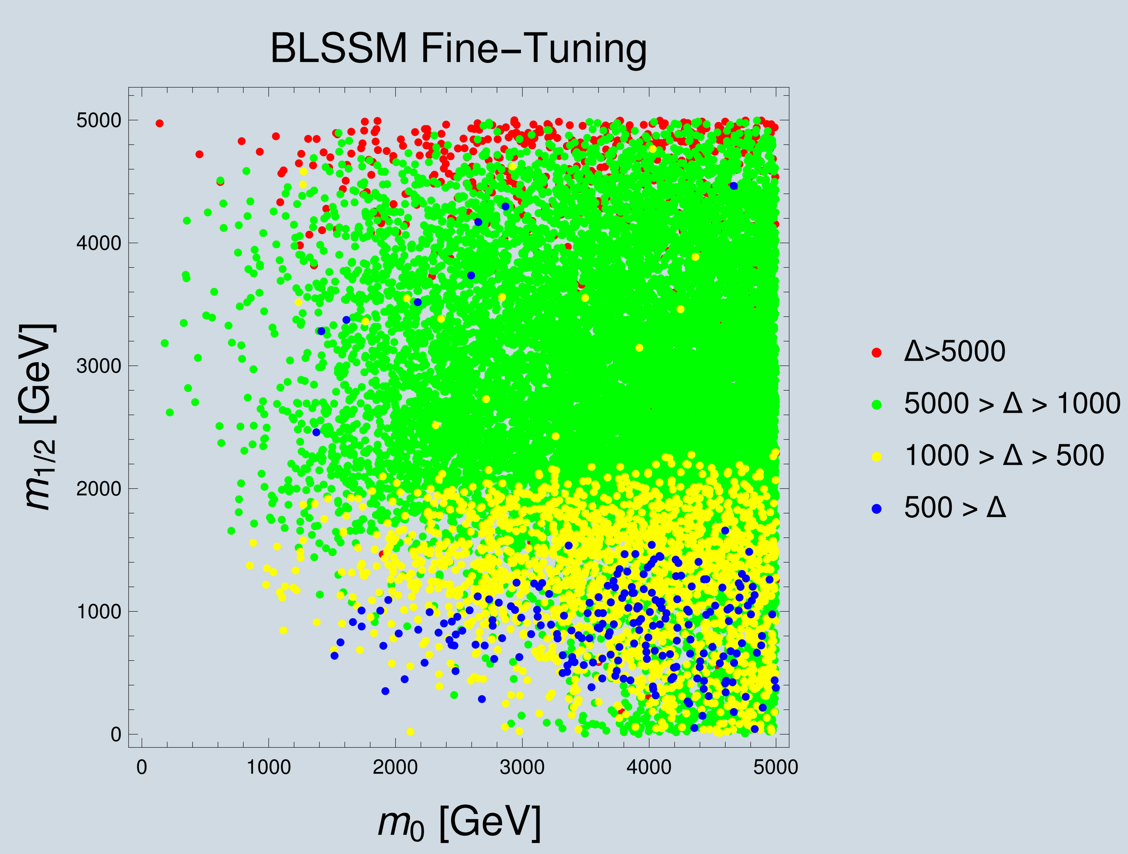
This plot counts the number of times each parameter's fine-tuning has been the dominant contribution. We see that $m_{1/2}$ is most often what determines the fine-tuning.

Particle Content

We write the MSSM in **black** and the $U(1)_{B-L}$ specific particles in **red**. The full particle content of the BLSSM includes both of these contributions.

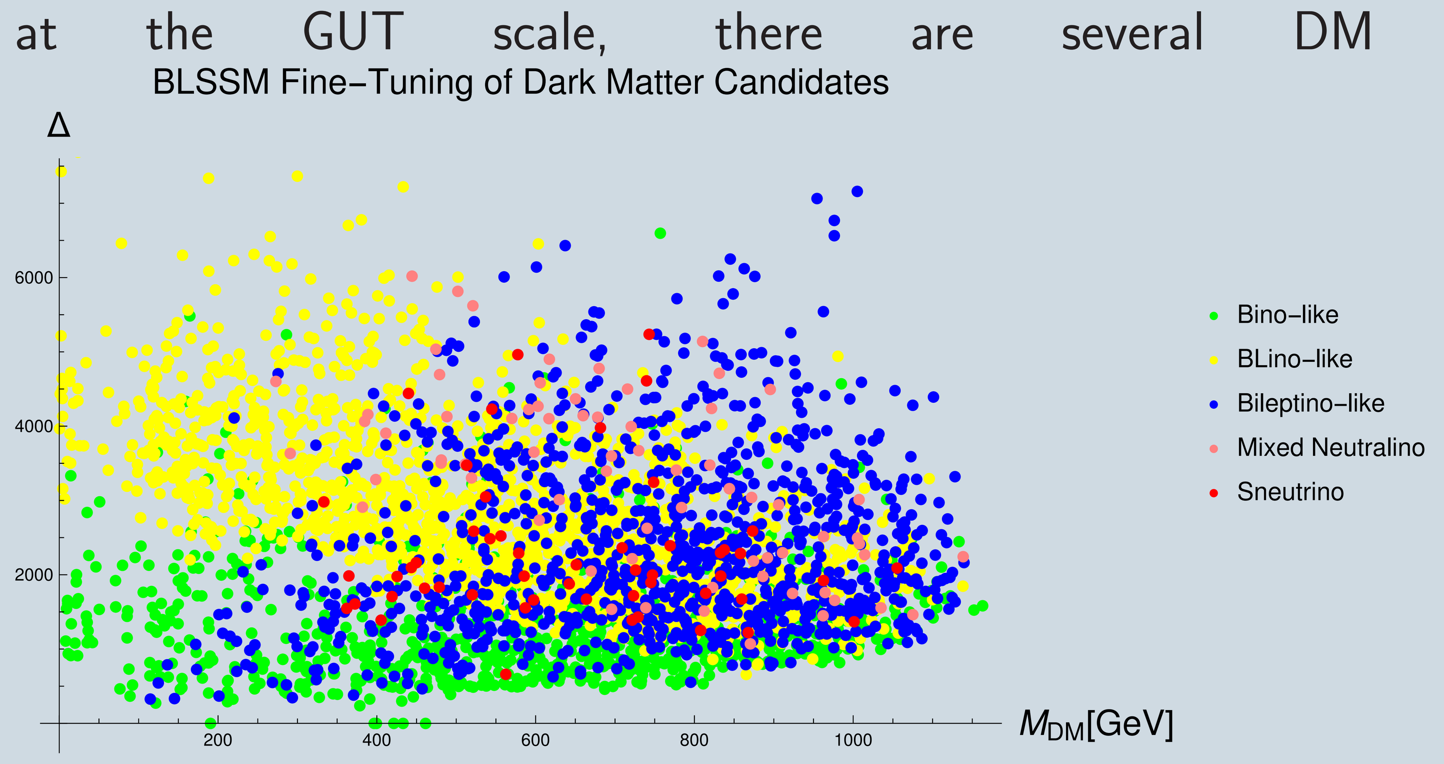
		Chiral Superfield		Spin 0	Spin 1/2	G_{B-L}
BLSSM	MSSM	Quarks/Squarks, (x3 generations)	$\hat{Q}$	$(\tilde{u}_L\tilde{d}_L) \equiv \tilde{Q}_L$	$(u_L d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6}, \frac{1}{6})$
			$\hat{U}$	$\tilde{u}_R^*$	$\bar{u}_R$	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3}, -\frac{1}{6})$
			$\hat{D}$	$\tilde{d}_R^*$	$\bar{d}_R$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}, -\frac{1}{6})$
		Leptons/Sleptons,	$\hat{L}$	$(\tilde{\nu}_L\tilde{e}_L) \equiv \tilde{L}_L$	$(\nu_L e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, -\frac{1}{2})$
		(x3 generations)	$\hat{E}$	$\tilde{e}_R^*$	$\bar{e}_R$	$(\mathbf{1}, \mathbf{1}, 1, \frac{1}{2})$
		Higgs/Higgsinos	$\hat{H}_u$	$(H_u^+ H_u^0)$	$(\tilde{H}_u^+\tilde{H}_u^0) \equiv \tilde{H}_u$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2}, 0)$
			$\hat{H}_d$	$(H_d^0 H_d^-)$	$(\tilde{H}_d^0\tilde{H}_d^-) \equiv \tilde{H}_d$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 0)$
	Extra	RH Neutrinos / Sneutrinos (x3)	$\hat{\nu}$	$\tilde{\nu}_R^*$	$\bar{\nu}_R$	$(\mathbf{1}, \mathbf{1}, 0, \frac{1}{2})$
		Bileptons/Bileptinos	$\hat{\eta}$	η	$\tilde{\eta}$	$(\mathbf{1}, \mathbf{1}, 0, \text{-}1)$
			$\hat{\bar{\eta}}$	$\bar{\eta}$	$\tilde{\bar{\eta}}$	$(\mathbf{1}, \mathbf{1}, 0, 1)$
		Vector Superfields		Spin 1/2	Spin 1	G_{B-L}
BLSSM	MSSM	Gluino, gluon		$\tilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0,0)$
		Wino/W bosons		$\tilde{W}^\pm\ \tilde{W}^0$	$W^\pm W^0$	$(\mathbf{1}, \mathbf{3}, 0, 0)$
		Bino / B boson		$\tilde{B}^0$	B^0	$(\mathbf{1}\ \mathbf{1}, 0, 0)$
	Extra	BLino / B' boson		$\tilde{B}'^0$	B'^0	$(\mathbf{1}\ \mathbf{1}, 0, 0)$

Results of Scan



Using SARAH [3] and the SPheno [4, 5] tools, we have made scans over the fundamental parameters of the BLSSM theory. These points are checked with consistency to current Higgs data using HiggsBounds and HiggsSignals [6].

In our BLSSM model, with unified couplings and masses at the GUT scale, there are several DM candidates:



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