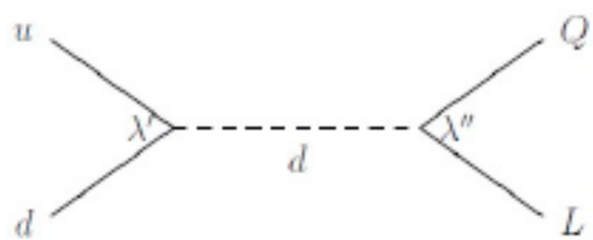
Dark Matter and N=1 Supersymmetry Models

Consider an N=1 supersymmetric model with a realistic gauge group and spectrum (at least containing the MSSM, perhaps with right-handed neutrino multiplets). Rapid proton decay can occur via



To prevent this, one typically invokes R-parity, an ad hoc $\mathbb{Z}_2$ symmetry given by

$$(-1)^{3(B-L)+2s}$$

bino, zino, 2 Higgsinos

$\Rightarrow$ Lightest supersymmetric particle (LSP) does not decay.
$\Rightarrow$ To be consistent with dark matter must be a neutralino or a gravitino. Puts constraints on SUSY model building.

Another way to prevent rapid proton decay is to extend the gauge group to

Z. Marshall, A. Purves, S. Spinner, B.A.O.

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

with $U(1)_{B-L}$ spontaneously broken at a relatively low scale. For the MSSM spectrum with right-handed neutrinos this extension is anomaly free--the B-L MSSM.

The B-L MSSM can arise "naturally" in string theory.

Since $\mathbb{Z}_2 \subset U(1)_{B-L}$ $\Rightarrow$ suppresses proton decay!

The "Higgs" for the breaking of B-L is the third family right-handed sneutrino. Since this is odd in B-L, the VEV spontaneously breaks R-parity!

$\Rightarrow$

There are three distinct phenomena that can occur in the the B-L MSSM that sharply distinuish it from the MSSM.

- Since R-parity is violated in the minimal $B - L$ MSSM, it is now possible that the lightest supersymmetric particle (LSP)[2] can carry color and/or electric charge without coming into conflict with astrophysical data. This is because the LSP can now decay sufficiently quickly via R-parity violating operators. Furthermore, the specific nature of this theory–which exactly specifies the R-parity violating vertices and their relative strengths–determines all LSP decay products and their branching ratios.

[2] We use the term LSP to refer to the lightest supersymmetric particle *relevant for collider physics.*

Example: the lightest scalar top can be the LSP. In general, it it decays as a "lepto-quark", with both top and bottom quarks. However, if it is a generic admixture of left and right stops, then it predominantly decays as

$$\tilde{t}_1 \longrightarrow b\, \ell_i^+ \;, \quad i = 1, 2, 3$$

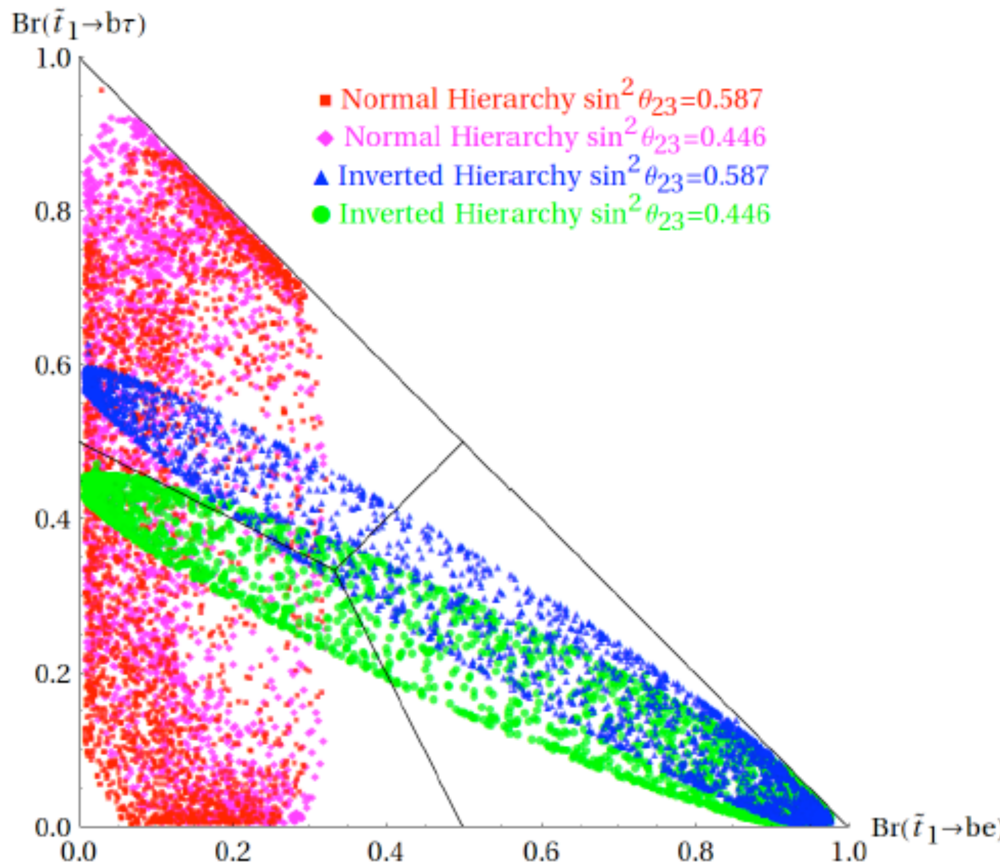
where the leptons are the positron, anti-muon and anti-tau respectively.

- The "Higgs" field that spontaneously breaks $U(1)_{B-L}$ in this minimal model is at least one of the right-handed sneutrinos. It follows that the neutrino sector in this theory is intimately related to the R-parity violating operators and, hence, to the allowed decay products of the LSP and their branching ratios. Put the other way, observation at the LHC of the relative branching ratios of the LSP decays can directly inform specific issues in the neutrino mass matrix–specifically, whether

$\Rightarrow$ there is a "normal" or an "inverted" neutrino mass hierarchy and can potentially remove the ambiguity in the measurement of the θ_{23} mixing angle, which can be one of two measured central values.

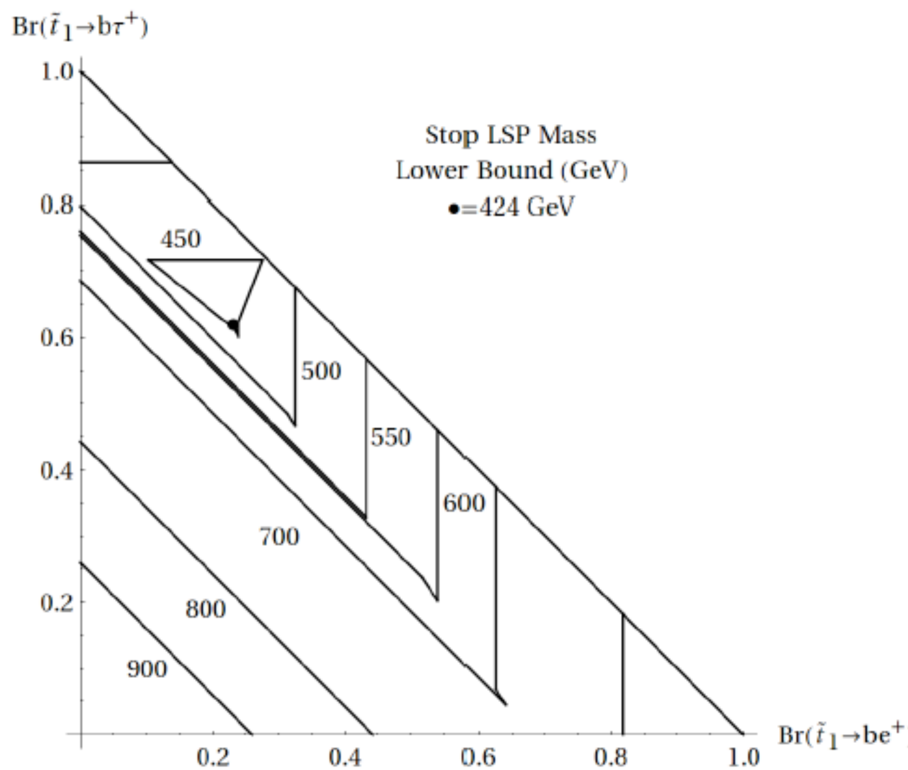
Scan over 12 input parameters using "normal" and "inverted" neutrino hierarchy and

$$\mathrm{Br}(\tilde{t}_1 \to b\, e^+) + \mathrm{Br}(\tilde{t}_1 \to b\, \mu^+) + \mathrm{Br}(\tilde{t}_1 \to b\, \tau^+) = 1 \quad \Rightarrow$$



- As mentioned above, the minimal $B - L$ theory exactly specifies the allowed R-parity violating decays of the LSP. For a chosen LSP, these decay signatures, which are disallowed within the R-parity invariant MSSM, can be rather unique. Data on such decays at the LHC can then be used to put a lower bound on the LSP mass.

Example: For a stop LSP we find



But: In this context what is dark matter??

gravitino? moduli?