Baryon and lepton number violation in anomalous $U(1)_H$ models

Work partially based on D. Aristizábal, D. Restrepo, O.Z. Phys. Rev. D **80**, 055010 (2009)

Oscar Zapata

Escuela de Ingeniería de Antioquia
(Medellín, Colombia)

July 13, 2011

Outline

Motivation

- A problem with the standard model is that the dimensionless Yukawa couplings $h_{ij}^{u,l,d}$ are expected to be order unity, suggesting that all fermion masses should be close to the electroweak scale.
- In the SSM, the conservation of R-parity symmetry forbids operators that break lepton and baryon number. When R-parity is not conserved, these operators can lead to the LSP decay, single sparticle production, etc., having profound implications in colliders searches and dark matter. In these kind of scenarios most of the analysis have been carried out by *ad hoc* selections of particular sets of R-parity violating couplings and/or by assuming tiny couplings.

Motivation

Build a general framework based on a anomalous $U(1)_H$ flavor symmetry, in which the allowed B/L violating couplings and their relative sizes arise from generic considerations rather than from *ad hoc* choices.

Motivation

- A problem with the standard model is that the dimensionless Yukawa couplings $h_{ij}^{u,l,d}$ are expected to be order unity, suggesting that all fermion masses should be close to the electroweak scale.
- In the SSM, the conservation of R-parity symmetry forbids operators that break lepton and baryon number. When R-parity is not conserved, these operators can lead to the LSP decay, single sparticle production, etc., having profound implications in colliders searches and dark matter. In these kind of scenarios most of the analysis have been carried out by *ad hoc* selections of particular sets of R-parity violating couplings and/or by assuming tiny couplings.

Motivation

Build a general framework based on a anomalous $U(1)_H$ flavor symmetry, in which the allowed B/L violating couplings and their relative sizes arise from generic considerations rather than from *ad hoc* choices.

Motivation

- A problem with the standard model is that the dimensionless Yukawa couplings $h_{ij}^{u,l,d}$ are expected to be order unity, suggesting that all fermion masses should be close to the electroweak scale.
- In the SSM, the conservation of R-parity symmetry forbids operators that break lepton and baryon number. When R-parity is not conserved, these operators can lead to the LSP decay, single sparticle production, etc., having profound implications in colliders searches and dark matter. In these kind of scenarios most of the analysis have been carried out by *ad hoc* selections of particular sets of R-parity violating couplings and/or by assuming tiny couplings.

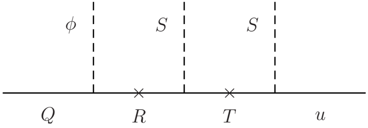
Motivation

Build a general framework based on a anomalous $U(1)_H$ flavor symmetry, in which the allowed B/L violating couplings and their relative sizes arise from generic considerations rather than from *ad hoc* choices.

Froggat-Nielsen mechanism

The approach to account for the fermion mass hierarchy is based in an hypothetical $U(1)_H$ symmetry (at high energies) which is spontaneously broken by vev of one flavon field S of horizontal charge $H[S] = -1$.

$$\mathcal{L} = \bar{Q}\phi_{(0)}R + \bar{R}S_{(-1)}T + \bar{T}S_{(-1)}u$$



At low energies:

$$\mathcal{L}_{eff} \sim \left(\frac{\langle S\rangle}{M_P}\right)^n \bar{Q}\phi u = \theta^n \bar{Q}\phi u,$$
$$n = n_Q + n_\phi + n_u = 2.$$

Charged fermion masses hierarchy

$$m_u : m_c : m_t \simeq \theta^8 : \theta^4 : 1\,,$$
$$m_d : m_s : m_b \simeq \theta^4 : \theta^2 : 1\,,$$
$$m_e : m_\mu : m_\tau \simeq \theta^5 : \theta^2 : 1\,,$$
$$V_{us} \simeq \theta\,,\;\; V_{cb} \simeq \theta^2\,,$$

with $\theta \approx 0.22.$

Supersymmetric Standard Model

The superpotential

$$\begin{aligned} W = {} & h^u_{ij}\widehat{H}_u\widehat{Q}_i\widehat{u}_j + h^l_{ij}\widehat{H}_d\widehat{L}_j\widehat{l}_k + h^d_{ij}\widehat{H}_d\widehat{Q}_j\widehat{d}_k \\ & + \mu_0\widehat{H}_d\widehat{H}_u \\ & + \mu_i\widehat{L}_i\widehat{H}_u \\ & + \lambda_{ijk}\widehat{L}_i\widehat{L}_j\widehat{l}_k + \lambda'_{ijk}\widehat{L}_i\widehat{Q}_j\widehat{d}_k \\ & + \lambda''_{ijk}\widehat{u}_i\widehat{d}_j\widehat{d}_k , \end{aligned}$$

- $W \Rightarrow B$ and L violation and therefore fast proton decay.
- To avoid it is imposed R-parity, obtaining the MSSM. μ_i, λ_{ijk}, λ'_{ijk} and λ''_{ijk} are forbidden.
- Because R_P conservation LSP is stable and DM candidate.
- However, either B or L violation can exist.

Supersymmetric Standard Model

The superpotential

$$
\begin{aligned}
W = & \; h^u_{ij}\widehat{H}_u\widehat{Q}_i\widehat{u}_j + h^l_{ij}\widehat{H}_d\widehat{L}_j\widehat{l}_k + h^d_{ij}\widehat{H}_d\widehat{Q}_j\widehat{d}_k \\
& + \mu_0\widehat{H}_d\widehat{H}_u \\
& + \mu_i\widehat{L}_i\widehat{H}_u \\
& + \lambda_{ijk}\widehat{L}_i\widehat{L}_j\widehat{l}_k + \lambda'_{ijk}\widehat{L}_i\widehat{Q}_j\widehat{d}_k \\
& + \lambda''_{ijk}\widehat{u}_i\widehat{d}_j\widehat{d}_k,
\end{aligned}
$$

- $W \Rightarrow B$ and L violation and therefore fast proton decay.
- To avoid it is imposed R-parity, obtaining the MSSM. μ_i, λ_{ijk}, λ'_{ijk} and λ''_{ijk} are forbidden.
- Because R_P conservation LSP is stable and DM candidate.
- However, either B or L violation can exist.

Supersymmetric Standard Model

The superpotential

$$
\begin{aligned}
W = {} & h^u_{ij}\widehat{H}_u\widehat{Q}_i\widehat{u}_j + h^l_{ij}\widehat{H}_d\widehat{L}_j\widehat{l}_k + h^d_{ij}\widehat{H}_d\widehat{Q}_j\widehat{d}_k \\
& + \mu_0\widehat{H}_d\widehat{H}_u \\
& + \mu_i\widehat{L}_i\widehat{H}_u \\
& + \lambda_{ijk}\widehat{L}_i\widehat{L}_j\widehat{l}_k + \lambda'_{ijk}\widehat{L}_i\widehat{Q}_j\widehat{d}_k \\
& + \lambda''_{ijk}\widehat{u}_i\widehat{d}_j\widehat{d}_k,
\end{aligned}
$$

- $W \Rightarrow B$ and L violation and therefore fast proton decay.
- To avoid it is imposed R-parity, obtaining the MSSM. μ_i, λ_{ijk}, λ'_{ijk} and λ''_{ijk} are forbidden.
- Because R_P conservation LSP is stable and DM candidate.
- However, either B or L violation can exist.

Supersymmetric Standard Model

The superpotential

$$W = h^u_{ij}\widehat{H}_u\widehat{Q}_i\widehat{u}_j + h^l_{ij}\widehat{H}_d\widehat{L}_j\widehat{l}_k + h^d_{ij}\widehat{H}_d\widehat{Q}_j\widehat{d}_k$$
$$+ \mu_0\widehat{H}_d\widehat{H}_u$$
$$+ \mu_i\widehat{L}_i\widehat{H}_u$$
$$+ \lambda_{ijk}\widehat{L}_i\widehat{L}_j\widehat{l}_k + \lambda'_{ijk}\widehat{L}_i\widehat{Q}_j\widehat{d}_k$$
$$+ \lambda''_{ijk}\widehat{u}_i\widehat{d}_j\widehat{d}_k,$$

- $W \Rightarrow B$ and L violation and therefore fast proton decay.
- To avoid it is imposed R-parity, obtaining the MSSM. μ_i, λ_{ijk}, λ'_{ijk} and λ''_{ijk} are forbidden.
- Because R_P conservation LSP is stable and DM candidate.
- However, either B or L violation can exist.

Supersymmetric Standard Model

The superpotential

$$
\begin{aligned}
W = {} & h^u_{ij}\widehat{H}_u\widehat{Q}_i\widehat{u}_j + h^l_{ij}\widehat{H}_d\widehat{L}_j\widehat{l}_k + h^d_{ij}\widehat{H}_d\widehat{Q}_j\widehat{d}_k \\
& + \mu_0\widehat{H}_d\widehat{H}_u \\
& + \mu_i\widehat{L}_i\widehat{H}_u \\
& + \lambda_{ijk}\widehat{L}_i\widehat{L}_j\widehat{l}_k + \lambda'_{ijk}\widehat{L}_i\widehat{Q}_j\widehat{d}_k \\
& + \lambda''_{ijk}\widehat{u}_i\widehat{d}_j\widehat{d}_k,
\end{aligned}
$$

- $W \Rightarrow B$ and L violation and therefore fast proton decay.
- To avoid it is imposed R-parity, obtaining the MSSM. μ_i, λ_{ijk}, λ'_{ijk} and λ''_{ijk} are forbidden.
- Because R_P conservation LSP is stable and DM candidate.
- However, either B or L violation can exist.

Using a supersymmetric model extended by a anomalous $U(1)_H$ flavor symmetry, is possible obtain either lepton or baryon number violation, in addition to the fermion mass hierarchy.
The effective bilinear and trilinear $\not{R}_P$ terms are given by

$$\mu_\alpha \sim \begin{cases} M_P \theta^{n_\alpha} & n_\alpha \geq 0 \\ m_{3/2}\theta^{|n_\alpha|} & n_\alpha < 0 \\ 0 & n_\alpha \text{ fractional} \end{cases}$$

$$\lambda_T \sim \begin{cases} \theta^{n_\lambda} & n_\lambda \geq 0 \\ (m_{3/2}/M_P)\theta^{|n_\lambda|} & n_\lambda < 0 \\ 0 & n_\lambda \text{ fractional} \end{cases}$$

$n_\alpha = L_\alpha + H_u, \qquad n_\lambda = L_i + L_j + \ell_k.$
To solve μ problem $\Rightarrow n_0 = -1$.
Maximum magnitude for individual charges: $|n| < 10$.

Constraints

In order to obtain a viable flavor model, the $U(1)_H$ charges must satisfy several phenomenological and theoretical constraints.

- 8 phenomenological constrains corresponding to six mass ratios for the charged fermions and two quarks mixing angles.
- Reproduce the third generation fermion masses $h_t Q_3 U_3^c \phi_u + h_b Q_3 D_3^c \phi_d \theta^x + h_\tau L_3 \ell_3^c \phi_d \theta^x$.

$$m_t \sim \langle \phi_u \rangle \Rightarrow \phi_u + u_3 + Q_3 = 0,$$
$$m_b \sim m_\tau \Rightarrow \phi_d + d_3 + Q_3 = \phi_d + \ell_3 + L_3 = x,$$

  where it is used $\tan\beta \simeq \theta^{x-3}$, with $x = 0, 1, 2, 3$ to satisfy phenomenological condition of $\tan\beta \sim (1, 90)$.
- 3 conditions from anomaly cancellation.

Constraints

In order to obtain a viable flavor model, the $U(1)_H$ charges must satisfy several phenomenological and theoretical constraints.

- 8 phenomenological constrains corresponding to six mass ratios for the charged fermions and two quarks mixing angles.
- Reproduce the third generation fermion masses $h_t Q_3 U_3^c \phi_u + h_b Q_3 D_3^c \phi_d \theta^x + h_\tau L_3 \ell_3^c \phi_d \theta^x$.

$$m_t \sim \langle \phi_u \rangle \Rightarrow \phi_u + u_3 + Q_3 = 0,$$
$$m_b \sim m_\tau \Rightarrow \phi_d + d_3 + Q_3 = \phi_d + \ell_3 + L_3 = x,$$

  where it is used $\tan\beta \simeq \theta^{x-3}$, with $x = 0, 1, 2, 3$ to satisfy phenomenological condition of $\tan\beta \sim (1, 90)$.
- 3 conditions from anomaly cancellation.

Constraints

In order to obtain a viable flavor model, the $U(1)_H$ charges must satisfy several phenomenological and theoretical constraints.

- 8 phenomenological constrains corresponding to six mass ratios for the charged fermions and two quarks mixing angles.
- Reproduce the third generation fermion masses $h_t Q_3 U_3^c \phi_u + h_b Q_3 D_3^c \phi_d \theta^x + h_\tau L_3 \ell_3^c \phi_d \theta^x$.

$$m_t \sim \langle \phi_u \rangle \Rightarrow \phi_u + u_3 + Q_3 = 0,$$
$$m_b \sim m_\tau \Rightarrow \phi_d + d_3 + Q_3 = \phi_d + \ell_3 + L_3 = x,$$

  where it is used $\tan\beta \simeq \theta^{x-3}$, with $x = 0, 1, 2, 3$ to satisfy phenomenological condition of $\tan\beta \sim (1, 90)$.
- 3 conditions from anomaly cancellation.

Constraints

In order to obtain a viable flavor model, the $U(1)_H$ charges must satisfy several phenomenological and theoretical constraints.

- 8 phenomenological constrains corresponding to six mass ratios for the charged fermions and two quarks mixing angles.
- Reproduce the third generation fermion masses $h_t Q_3 U_3^c \phi_u + h_b Q_3 D_3^c \phi_d \theta^x + h_\tau L_3 \ell_3^c \phi_d \theta^x$.

$$m_t \sim \langle \phi_u \rangle \Rightarrow \phi_u + u_3 + Q_3 = 0,$$
$$m_b \sim m_\tau \Rightarrow \phi_d + d_3 + Q_3 = \phi_d + \ell_3 + L_3 = x,$$

  where it is used $\tan\beta \simeq \theta^{x-3}$, with $x = 0, 1, 2, 3$ to satisfy phenomenological condition of $\tan\beta \sim (1, 90)$.
- 3 conditions from anomaly cancellation.

Standard model fields H–charges

In this stage, we have 13 conditions and 17 charges: we are left with four parameters that we choose to be n_i $(i = 1, 2, 3)$ and x Mira, Nardi, Restrepo, Valle, PLB(2000).

$$
\begin{aligned}
Q_3 &= -\frac{-3x(x+10) + (x+4)n_1 + (x+7)n_2 + (x+9)n_3 - 67}{15(x+7)} \\
L_3 &= \frac{2(x+1)(3x+22) - (2x+23)n_1 - 2(x+7)n_2 + (13x+97)n_3}{15(x+7)}
\end{aligned}
$$

$$
\begin{array}{cc}
L_2 = L_3 + n_2 - n_3, & L_1 = L_3 + n_1 - n_3 \\
H_u = n_3 - L_3, & H_d = -1 - H_u \\
u_3 = -Q_3 - H_u, & d_3 = -Q_3 - H_d + x \\
l_3 = -L_3 - H_d + x, & Q_1 = 3 + Q_3 \\
Q_2 = 2 + Q_3, & u_1 = 5 + u_3 \\
u_2 = 2 + u_3, & d_1 = 1 + d_3 \\
d_2 = d_3, & l_1 = 5 - n_1 + n_3 + l_3 \\
l_2 = 2 - n_2 + n_3 + l_3, &
\end{array}
$$

Note that $n_0 = -1 \Rightarrow$ solution μ problem.

R_p conserving operators

$$h^u = \begin{pmatrix} \theta^8 & \theta^5 & \theta^3 \\ \theta^7 & \theta^4 & \theta^2 \\ \theta^5 & \theta^2 & 1 \end{pmatrix} \qquad h^d = \theta^x \begin{pmatrix} \theta^4 & \theta^3 & \theta^3 \\ \theta^3 & \theta^2 & \theta^2 \\ \theta & 1 & 1 \end{pmatrix}$$

$$H[h^l_{ij}] = \begin{bmatrix} x+5 & x+n_1-n_2+2 & x+n_1-n_3 \\ x-n_1+n_2+5 & x+2 & x+n_2-n_3 \\ x-n_1+n_3+5 & x-n_2+n_3+2 & x \end{bmatrix}$$

R_p violating operators

$$H[\mu_i] = n_i$$

$$H \begin{bmatrix} \lambda_{211} & \lambda_{212} & \lambda_{213} \\ \lambda_{311} & \lambda_{312} & \lambda_{313} \\ \lambda_{231} & \lambda_{232} & \lambda_{233} \end{bmatrix} = \begin{bmatrix} x + n_2 + 6 & x + n_1 + 3 & x + N - 2n_3 + 1 \\ x + n_3 + 6 & x + N - 2n_2 + 3 & x + n_1 + 1 \\ x + N - 2n_1 + 6 & x + n_3 + 3 & x + n_2 + 1 \end{bmatrix}$$

$$H[\lambda'_{ijk}] = \begin{bmatrix} x + n_i + 5 & x + n_i + 4 & x + n_i + 4 \\ x + n_i + 4 & x + n_i + 3 & x + n_i + 3 \\ x + n_i + 2 & x + n_i + 1 & x + n_i + 1 \end{bmatrix}$$

$$H \begin{bmatrix} \lambda''_{211} & \lambda''_{212} & \lambda''_{213} \\ \lambda''_{311} & \lambda''_{312} & \lambda''_{313} \\ \lambda''_{231} & \lambda''_{232} & \lambda''_{233} \end{bmatrix} = \begin{bmatrix} 6 & 3 & 1 \\ 6 & 3 & 1 \\ 5 & 2 & 0 \end{bmatrix} + n_{\lambda''}\mathbf{1}$$

where $n_{\lambda''} = \frac{1}{3}(3x + n_1 + n_2 + n_3 - 1)$ and $N = n_1 + n_2 + n_3$.

Choosing n_i charges

Once n_i are fractional it is obtained

- All λ'_{ijk} are forbidden.
- All λ_{ijk} with repeated indexes are also forbidden.

Several possibilities

- Choose the fractional n_i charges such that all the L and B violating terms in the superpotential also have fractional charges. R_p and P_6 discrete symmetries respectively, are obtained as remnants of a spontaneously broken $U(1)_H$.
- If $n_{1,2,3}$ not half-integers and $n_{\lambda''} = (n_1 + n_2 + n_3 - 1)/3$ integer, we have only trilinear B violating terms λ'' in the supersymmetric Lagrangian.

Choosing n_i charges

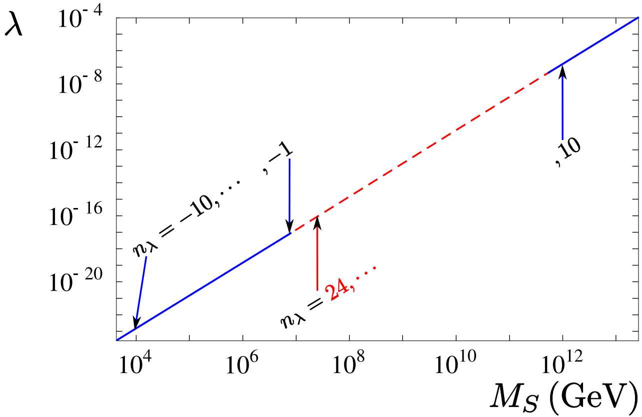
- Models with only a single nonvanishing λ_{ijk} and vanishing λ'' couplings. In models in which there is an integer trilinear charge n_λ and the charges n_j, n_k and n_{jk} are not half-integers only a single λ coupling is allowed.
- Models in which a single λ_{ijk} and all the λ'' are nonvanishing. As in the previous case $n_{\lambda_{ijk}}$ must be an integer and in addition the corresponding n_k must be a half-integer as to guarantee an integer N . Moreover, x and the resulting N should *conspire* to yield a set of integer $n_{\lambda''}$ charges.
- Models with nonvanishing λ_{ijk} and λ_{jki}. These models result once the $n_{\lambda_{ijk}}$ is an integer and n_j a half-integer. In this case $n_{\lambda_{jki}}$ turn out to be an integer allowing the λ_{jki} as required. Nonvanishing λ_{ijk} and λ_{ikj} are also possible but never the three couplings simultaneously.

Lepton number violating model

For neutralino as gaugino pure and when the sleptons are heavy and degenerate, the neutralino lifetime can be rewritten as

$$\tau_\chi \sim \left(\frac{M_S}{2\times 10^4\,\mathrm{GeV}}\right)^4 \left(\frac{10^{-23}}{\lambda}\right)^2 \left(\frac{2\times 10^3\,\mathrm{GeV}}{m_\chi}\right)^5 10^{26}\ \mathrm{sec}\,.$$

To obtain such suppression, we need that $\lambda_{ijk} \sim (m_{3/2}/M_p)\theta^{|n_\lambda|}$.



Baryon number violation

Once fixed n_i charges such that μ_i, λ_{ijk} and λ'_{ijk} are forbidden, we obtain

$$\begin{pmatrix} \lambda''_{112} & \lambda''_{212} & \lambda''_{312} \\ \lambda''_{113} & \lambda''_{213} & \lambda''_{313} \\ \lambda''_{123} & \lambda''_{223} & \lambda''_{323} \end{pmatrix} \sim \theta^{n_{\lambda''}} \begin{pmatrix} \theta^6 & \theta^3 & \theta \\ \theta^6 & \theta^3 & \theta \\ \theta^5 & \theta^2 & 1 \end{pmatrix}$$

The most important constraint on λ''_{ijk} are from neutron-antineutron oscillations and double nucleon decay, requiring $\lambda''_{112} \lesssim 10^{-7}$ and $\lambda''_{113} \lesssim 10^{-4}$ for $\tilde{m} \sim 200\,\mathrm{GeV}$.

$$\lambda''_{112} \lesssim 10^{-7} \Rightarrow \lambda''_{112} \lesssim \theta^{10} \Rightarrow n_\lambda \geq 4,$$
$$\Rightarrow \lambda''_{323} \lesssim \theta^4 \lesssim 10^{-3}.$$

Implications on collider searches

When R-parity conservation is assumed, the production of supersymmetric particles is in pairs, and the LSP is stable.

R-parity violation allows for the single production of supersymmetric particle and the decay of the LSP.

From the baryon number R_P violating terms, the LSP can decay directly or indirectly to quarks, and depending on whether the mass of the LSP is larger or smaller than the top quark mass, the top could be present on the final states.

It is clear that λ''_{323} coupling dominates over the other couplings, and the third generation quarks are to be present in the final states.

Given that the LSP is no longer stable due to R parity violation, in principle the LSP can be any supersymmetric particle: neutralinos, charginos, squarks, sleptones and gluinos.

Neutralino LSP

The lightest neutralino χ can decay to three quarks through virtual scalar exchange and the dominant decay mode will be $\chi \to tbs$. If the neutralino is lighter than top quark, then the dominant mode is $\chi \to cbs$. Therefore, horizontal symmetry allows for estimating relations between different ratios of branching ratios.

- $m_\chi > m_t$. Dominated by λ''_{323}, involving a top quark in the final state.

$$\frac{\mathrm{Br}(\chi \to tdb)}{\mathrm{Br}(\chi \to tsb)} \sim \frac{\mathrm{Br}(\chi \to tds)}{\mathrm{Br}(\chi \to tsb)} \sim \theta^2 \approx 0.05.$$

- $m_\chi < m_t$. Dominated by λ''_{223}.

$$\frac{\mathrm{Br}(\chi \to cdb)}{\mathrm{Br}(\chi \to csb)} \sim \frac{\mathrm{Br}(\chi \to cds)}{\mathrm{Br}(\chi \to csb)} \sim \theta^2 \approx 0.05,$$

$$\frac{\mathrm{Br}(\chi \to usb)}{\mathrm{Br}(\chi \to csb)} \sim \theta^6 \approx 1.5 \times 10^{-4}.$$

In either case, neutralino decays are dominated by heavy flavors, and should contain displaced vertices.

Slepton LSP

A non-vanishing λ''_{ijk} coupling leads to a 4-body decay of the $\tilde{\tau}$ or $\tilde{\nu}_\tau$. The slepton LSP has no direct decays to quarks mediated by λ''_{ijk} couplings. Initially slepton LSP decays via gauge couplings into a lepton and a virtual neutralino, then this indirectly decays into three quarks via λ'' couplings. In the final states of $\tilde{\tau}$ ($\tilde{\nu}_\tau$) decay are always involved a τ (ν_τ), an up quark and two down quarks of different generations.

- $m^0_{\tilde{l}} > m_t$.

$$\frac{\mathrm{Br}(\tilde{l} \to ltdb)}{\mathrm{Br}(\tilde{l} \to ltsb)} \sim \frac{\mathrm{Br}(\tilde{l} \to ltds)}{\mathrm{Br}(\tilde{l} \to ltsb)} \sim \theta^2 \approx 0.05.$$

- $m_{\tilde{l}} < m_t$.

$$\frac{\mathrm{Br}(\tilde{l} \to lcdb)}{\mathrm{Br}(\tilde{l} \to lcsb)} \sim \frac{\mathrm{Br}(\tilde{l} \to lcds)}{\mathrm{Br}(\tilde{l} \to lcsb)} \sim \theta^2 \approx 0.05,$$

$$\frac{\mathrm{Br}(\tilde{l} \to lusb)}{\mathrm{Br}(\tilde{l} \to lcsb)} \sim \theta^6 \approx 1.5 \times 10^{-4}.$$

Sbottom LSP, Stop LSP

Through direct decays, the sbottom can decay into an up quark and a down quark.

- $m^0_{\tilde{b}} > m_t$.

$$\frac{\mathrm{Br}(\tilde{b} \to td)}{\mathrm{Br}(\tilde{b} \to ts)} \sim \theta^2 \approx 0.05.$$

- $m_{\tilde{b}} < m_t$. In this point we have that $\tilde{b} \to cs$ is the dominant decay.

$$\frac{\mathrm{Br}(\tilde{b} \to cd)}{\mathrm{Br}(\tilde{b} \to cs)} \sim \theta^2 \approx 0.05,$$

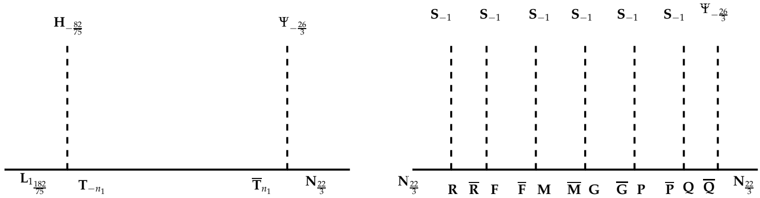
$$\frac{\mathrm{Br}(\tilde{b} \to us)}{\mathrm{Br}(\tilde{b} \to cs)} \sim \theta^6 \approx 1.1 \times 10^{-4}.$$

Stops also can decay directly into a two down quarks of different generations through the λ''_{3jk} coupling.

$$\frac{\mathrm{Br}(\tilde{t} \to bd)}{\mathrm{Br}(\tilde{t} \to bs)} \sim \frac{\mathrm{Br}(\tilde{t} \to sd)}{\mathrm{Br}(\tilde{t} \to bs)} \sim \theta^2 \approx 0.05.$$

It is not possible to obtain a consistent model with neutrino masses and with only trilinear baryon number violating couplings if we only consider one field which has H-charge -1. Therefore, it must be added to the model one new singlet superfield charged under $U(1)_H$: Ψ. The $H-$ charge of this superfield is fixed by new invariant diagrams for the Dirac and Majorana mass terms.

$$M_\nu \sim \theta^{-5} \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}, \quad 1 \sim \mathcal{O}(1).$$



Summary

- We have obtained a framework with minimal trilinear R-parity violation, founding charge assignments that allow one single or two λ couplings.
- We have studied the question about if it is possible obtain a framework with baryon number violation. By using a $U(1)_H$ horizontal gauge symmetry, we have found charge assignments that allow all λ'' couplings, being λ''_{3jk} the dominant ones.
- It is possible to obtain a neutrino matrix with a acceptable phenomenological texture with the inclusion of one flavon with fractional charge.
- The ratio of branching ratios for the LSP have been analyzed. Hence, it is possible to infer the main decay channels of the LSP.

Summary

- We have obtained a framework with minimal trilinear R-parity violation, founding charge assignments that allow one single or two λ couplings.
- We have studied the question about if it is possible obtain a framework with baryon number violation. By using a $U(1)_H$ horizontal gauge symmetry, we have found charge assignments that allow all λ'' couplings, being λ''_{3jk} the dominant ones.
- It is possible to obtain a neutrino matrix with a acceptable phenomenological texture with the inclusion of one flavon with fractional charge.
- The ratio of branching ratios for the LSP have been analyzed. Hence, it is possible to infer the main decay channels of the LSP.

Summary

- We have obtained a framework with minimal trilinear R-parity violation, founding charge assignments that allow one single or two λ couplings.
- We have studied the question about if it is possible obtain a framework with baryon number violation. By using a $U(1)_H$ horizontal gauge symmetry, we have found charge assignments that allow all λ'' couplings, being λ''_{3jk} the dominant ones.
- It is possible to obtain a neutrino matrix with a acceptable phenomenological texture with the inclusion of one flavon with fractional charge.
- The ratio of branching ratios for the LSP have been analyzed. Hence, it is possible to infer the main decay channels of the LSP.

Summary

- We have obtained a framework with minimal trilinear R-parity violation, founding charge assignments that allow one single or two λ couplings.
- We have studied the question about if it is possible obtain a framework with baryon number violation. By using a $U(1)_H$ horizontal gauge symmetry, we have found charge assignments that allow all λ'' couplings, being λ''_{3jk} the dominant ones.
- It is possible to obtain a neutrino matrix with a acceptable phenomenological texture with the inclusion of one flavon with fractional charge.
- The ratio of branching ratios for the LSP have been analyzed. Hence, it is possible to infer the main decay channels of the LSP.

Induced bilinear terms

The μ_i lead to a tree-level mixing between the neutrinos and neutralinos which is not suppressed by M_S, inducing two body decays of the lightest neutralino to gauge bosons and fermions. The λ, λ' couplings induce μ_i in the low energy Lagrangian by radiative corrections, even if they are set to zero at some high scale

$$\mu_i = \frac{\mu_0}{16\pi^2}\left[\lambda_{ijk}\left(\mathbf{h}_e^*\right)_{jk} + 3\lambda'_{ijk}\left(\mathbf{h}_d^*\right)_{jk}\right]\ln\left(\frac{M_X}{M_S}\right)$$

- If $\lambda_{i33} \sim 10^{-5}$, $M_X = 10^{16}$ GeV $\Rightarrow \mu_i/\mu_0 \sim 10^{-12}$. Compare with $\mu_i/\mu_0 \sim 10^{-23}$ required to $\tau_\chi \approx 10^{26}$s.
- The $U(1)_H$ symmetry automatically forbids all λ' the corresponding non-diagonal h^e_{jk}.

In this way, the horizontal symmetry in the context of split supersymmetry can rescue the possibility to have leptonically decaying dark matter as required to explain the cosmic-rays anomalies.

Induced bilinear terms

The μ_i lead to a tree-level mixing between the neutrinos and neutralinos which is not suppressed by M_S, inducing two body decays of the lightest neutralino to gauge bosons and fermions. The λ, λ' couplings induce μ_i in the low energy Lagrangian by radiative corrections, even if they are set to zero at some high scale

$$\mu_i = \frac{\mu_0}{16\pi^2}\left[\lambda_{ijk}\left(\mathbf{h}_e^*\right)_{jk} + 3\lambda'_{ijk}\left(\mathbf{h}_d^*\right)_{jk}\right] \ln\left(\frac{M_X}{M_S}\right)$$

- If $\lambda_{i33} \sim 10^{-5}$, $M_X = 10^{16}$ GeV $\Rightarrow \mu_i/\mu_0 \sim 10^{-12}$. Compare with $\mu_i/\mu_0 \sim 10^{-23}$ required to $\tau_\chi \approx 10^{26}$s.
- The $U(1)_H$ symmetry automatically forbids all λ' the corresponding non-diagonal h^e_{jk}.

In this way, the horizontal symmetry in the context of split supersymmetry can rescue the possibility to have leptonically decaying dark matter as required to explain the cosmic-rays anomalies.

Induced bilinear terms

The μ_i lead to a tree-level mixing between the neutrinos and neutralinos which is not suppressed by M_S, inducing two body decays of the lightest neutralino to gauge bosons and fermions. The λ, λ' couplings induce μ_i in the low energy Lagrangian by radiative corrections, even if they are set to zero at some high scale

$$\mu_i = \frac{\mu_0}{16\pi^2} \left[\lambda_{ijk} \left(\mathbf{h}_e^* \right)_{jk} + 3\lambda'_{ijk} \left(\mathbf{h}_d^* \right)_{jk} \right] \ln \left(\frac{M_X}{M_S} \right)$$

- If $\lambda_{i33} \sim 10^{-5}$, $M_X = 10^{16}$ GeV $\Rightarrow \mu_i/\mu_0 \sim 10^{-12}$. Compare with $\mu_i/\mu_0 \sim 10^{-23}$ required to $\tau_\chi \approx 10^{26}$s.
- The $U(1)_H$ symmetry automatically forbids all λ' the corresponding non-diagonal h^e_{jk}.

In this way, the horizontal symmetry in the context of split supersymmetry can rescue the possibility to have leptonically decaying dark matter as required to explain the cosmic-rays anomalies.

Induced bilinear terms

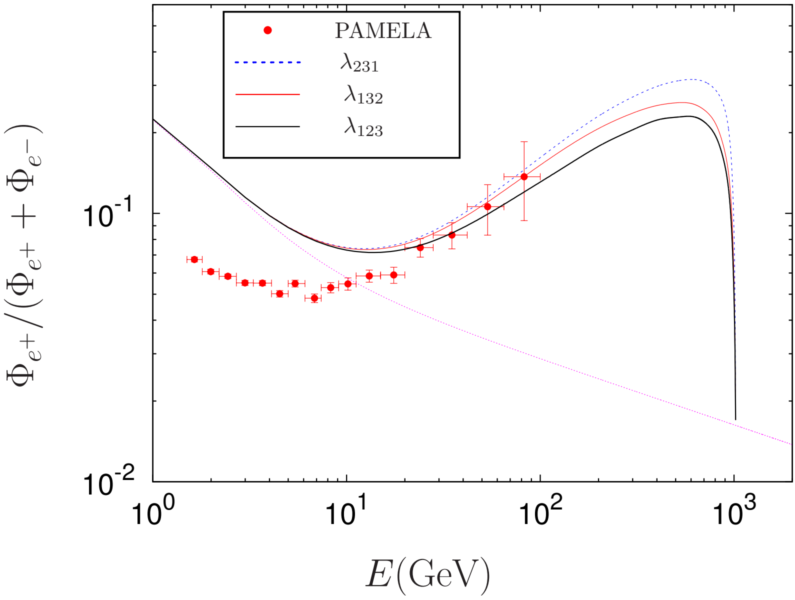
The μ_i lead to a tree-level mixing between the neutrinos and neutralinos which is not suppressed by M_S, inducing two body decays of the lightest neutralino to gauge bosons and fermions. The λ, λ' couplings induce μ_i in the low energy Lagrangian by radiative corrections, even if they are set to zero at some high scale

$$\mu_i = \frac{\mu_0}{16\pi^2}\left[\lambda_{ijk}\left(\mathbf{h}_e^*\right)_{jk} + 3\lambda'_{ijk}\left(\mathbf{h}_d^*\right)_{jk}\right]\ln\left(\frac{M_X}{M_S}\right)$$

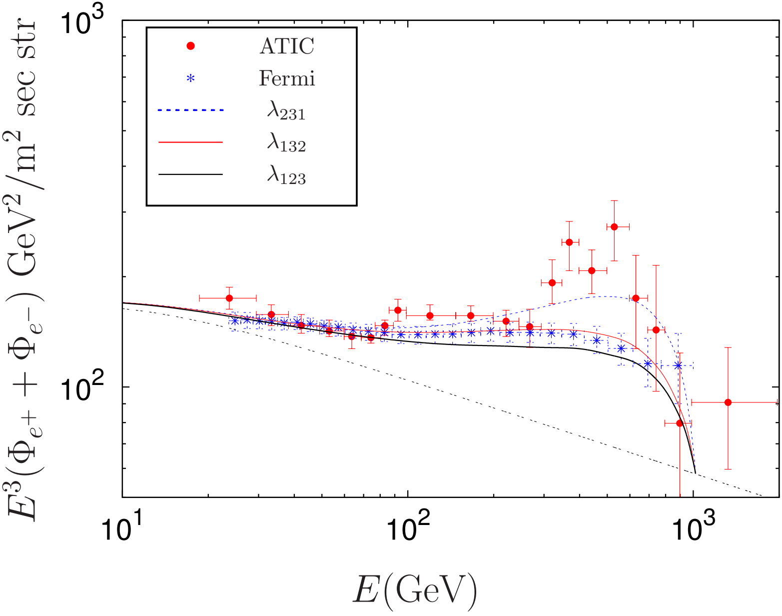
- If $\lambda_{i33} \sim 10^{-5}$, $M_X = 10^{16}$ GeV $\Rightarrow \mu_i/\mu_0 \sim 10^{-12}$. Compare with $\mu_i/\mu_0 \sim 10^{-23}$ required to $\tau_\chi \approx 10^{26}$s.
- The $U(1)_H$ symmetry automatically forbids all λ' the corresponding non-diagonal h^e_{jk}.

In this way, the horizontal symmetry in the context of split supersymmetry can rescue the possibility to have leptonically decaying dark matter as required to explain the cosmic-rays anomalies.

Positron fraction $\lambda = 3.2 \times 10^{-23}$, $\tau_\chi = 1.3 \times 10^{26}$ sec $m_\chi = 2038$ GeV



Electron + positron flux



Anomaly cancellation conditions

Anomalies generated by $U(1)_H$

$$\begin{aligned}
C_1 =& n_0 + \sum_i \left[\tfrac{1}{3}Q_i + \tfrac{8}{3}u_i + \tfrac{2}{3}d_i + L_i + 2\ell_i\right], \\
C_2 =& n_0 + \sum_i \left[3Q_i + L_i\right], \qquad C_3 = \sum_i \left[2Q_i + u_i + d_i\right], \\
C_1' =& \phi_u^2 - \phi_d^2 + \sum_i \left[Q_i^2 - 2u_i^2 + d_i^2 - L_i^2 + \ell_i^2\right].
\end{aligned}$$

The anomaly cancellation of C_n via GS mechanism gives following three conditions:

$$C_2 - \frac{C_1}{5/3} = 0, \qquad C_2 - C_3 = 0, \qquad C_1' = 0.$$

$g_3^2 = g_2^2 = \frac{5}{3}g_1^2 \Rightarrow$ canonical gauge unification.
$n_0 = -1$ is a model prediction $\Rightarrow$ solution to μ problem.