Phenomenological implications in a $B-L$ extension of the MSSM

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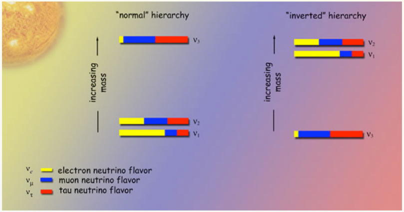
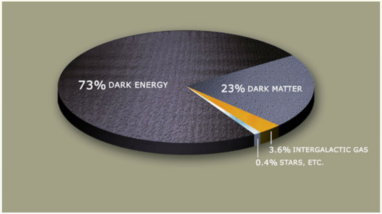
Outline

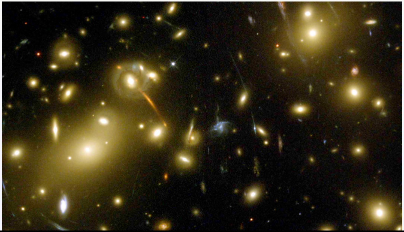
Beyond SM

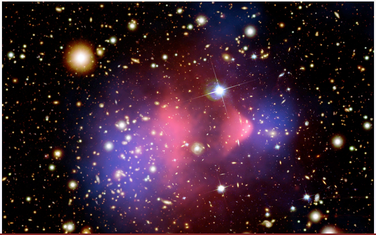
Observational inconsistencies are motivating to look for physics beyond the SM,

- It can not explain neutrino masses,
- It does not explain the origin of the cosmological ingredients,
- Galactic Rotation Curves
- Gravitational Lensing
- "Bullet Cluster"...









Neutrino mass in SM extensions

- In the SM, the $B-L$ current is conserved to all orders in perturbation theory.
- In the SM, there is only one helicity state per generation for neutrinos.
- Without the right handed component, it is not possible to construct a Dirac mass for neutrinos.
- The inclusion of right handed neutrinos preserve $B-L$ anomaly free.
- The Majorana term breaks $B-L \Rightarrow$ it must be broken somehow.

It has been studied the lagrangian,

$$\delta\mathcal{L} = h\sigma\bar{\nu}_R^c\nu_R + h'\bar{L}\tilde{H}\nu_R$$

and it has a direct connection with the DM problem and the barionic asymmetry of the universe.

- The Majorana term breaks explicitly the $B-L$ global symmetry.
- It suggest as a natural symmetry to $SU(2)_L \times U(1)_Y \times U(1)_{B-L}$.
- It is needed to include 3 families of right handed neutrinos to preserve anomaly cancelation.

The supersymmetric $B-L$ model

With the extra gauge group $U(1)_{B-L}$, the most general superpotential has the following extra terms,

$$\Delta W = \bar{N}\mathbf{Y}_N^D L H_u + N\mathbf{Y}_N^M N\sigma_1 + \mu'\sigma_1\sigma_2,$$

where under $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$ the extra superfields transform as

$$\bar{N} = (\mathbf{1},\mathbf{1},0,+1) \quad \sigma_1 = (\mathbf{1},\mathbf{1},0,-2) \quad \sigma_2 = (\mathbf{1},\mathbf{1},0,+2)\,.$$

The extra Kähler potential is,

$$\Delta K \quad = \quad \hat{N}^\dagger e^{2V}\hat{N} + \hat{\sigma}_1^\dagger e^{2V}\hat{\sigma}_1 + \hat{\sigma}_2^\dagger e^{2V}\hat{\sigma}_2,$$

And for gauge part,

$$W^{\alpha}_{(B-L)}W_{\alpha(B-L)}|_{\theta\theta} = -2i\lambda\sigma^\mu\partial_\mu\bar{\lambda} + D^2 - \frac{1}{2}A_{\mu\nu}A^{\mu\nu} - \frac{i}{4}\tilde{A}_{\mu\nu}A^{\mu\nu}$$

The soft breaking term, which involves the new scalars is,

$$\begin{aligned}\Delta\mathcal{L}_{SB} =& \frac{1}{2}M_{B-L}\tilde{Z}_{B-L}\tilde{Z}_{B-L} + \tilde{\bar{N}}\mathbf{h}_N^D\tilde{L}H_u + \tilde{N}^c\mathbf{h}_N^M\tilde{N}\sigma_1 + B'\sigma_1\sigma_2 \\ &+ m^2_{\sigma_1}\sigma_1^\dagger\sigma_1 + m^2_{\sigma_2}\sigma_2^\dagger\sigma_2 + \tilde{N}^\dagger m_N^2\tilde{N}\end{aligned}$$

Renormalization group equations

Gauge couplings

$$\alpha_i^{-1}(m)=c_i\left[\alpha_i^{-1}(m_Z)+(2\pi)^{-1}b_i\ \ln\left(\frac{m}{m_Z}\right)\right]$$

$$(c_1,c_2,c_3,c_{B-L})=(3/5,1,1,3/8),$$

$$(b_1,b_2,b_3,b_{B-L})=(-11,-1,3,-24).$$

Gaugino masses

$$\beta_{M_i}=2c_ig_i^2M_i,\text{where}\quad i=1,2,3,B-L$$

Yukawa and μ terms

$$\Delta\beta_{y_t}=y_t\left\{y_D^2-g_{B-L}^2/6\right\},\qquad \Delta\beta_{y_b}=-y_bg_{B-L}^2/6,$$

$$\Delta\beta_{y_\tau}=y_\tau\left\{y_D^2-3g_{B-L}^2/2\right\},\qquad \Delta\beta_\mu=\mu y_D^2,$$

$$\beta_{y_D}=y_D\left\{4y_D^2+3y_t^2+y_M^2-3g_1^2/5-3g_2^2-3g_{B-L}^2/2\right\},$$

$$\beta_{y_M}=y_M\left\{3y_M^2+4y_D^2-9g_{B-L}^2/2\right\},$$

$$2\beta_{\mu'}=\mu'\left\{y_M^2-3g_{B-L}^2\right\},$$

Soft parameters

$$\Delta\beta_{a_t}=a_t\left\{y_D^2-g_{B-L}^2/6\right\}+y_t\left\{2a_Dy_D+g_{B-L}^2M_{B-L}/3\right\},$$

$$\Delta\beta_{a_b}=-a_bg_{B-L}^2/6+y_bg_{B-L}^2M_{B-L}/3,$$

$$\Delta\beta_{a_\tau}=a_\tau\left\{y_D^2-3g_{B-L}^2/2\right\}+y_\tau\left\{2a_Dy_D+3g_{B-L}^2M_{B-L}\right\},$$

$$\begin{aligned}\beta_{a_D}=\ & a_D\left\{12y_D^2+3y_t^2+2y_M^2+y_\tau^2-3g_1^2/5-3g_2^2-3g_{B-L}^2/2\right\}\\ &+y_D\left\{6a_ty_t+2a_My_M+a_\tau y_\tau+6g_1^2M_1/5+6g_2^2M_2\right.\\ &\left.+3g_{B-L}^2M_{B-L}\right\},\end{aligned}$$

$$\beta_{a_M}=a_M\left\{15y_M^2+8y_D^2-9g_{B-L}^2/2\right\}+\left\{8a_Dy_D+9g_{B-L}^2M_{B-L}\right\}.$$

Higgs masses

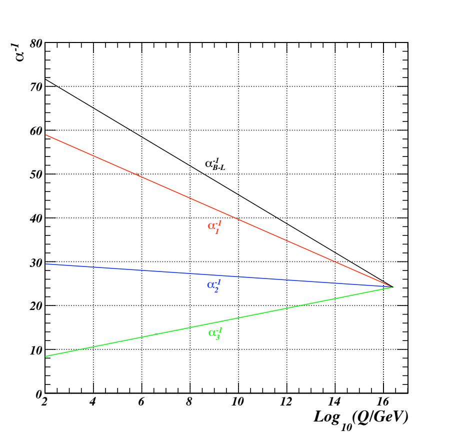
$$\Delta\beta_{m_{H_u}^2}=2y_D^2\left\{m_{H_u}^2+m_{L_3}^2+m_{N_3}^2\right\}+2a_D^2,\qquad \Delta\beta_{m_{H_d}^2}=0,$$

$$\beta_{m_{\sigma_1}^2}=2y_M^2\left\{m_{\sigma_1}^2+m_{N_3}^2\right\}+2a_M^2-12g_{B-L}^2M_{B-L}^2-3g_{B-L}^2S'/2,$$

$$\beta_{m_{\sigma_2}^2}=-12g_{B-L}^2M_{B-L}^2+3g_{B-L}^2S'/2,$$

$$S'=2m_{\sigma_2}^2-2m_{\sigma_1}^2+Tr[2m_Q^2-2m_L^2+m_u^2+m_d^2-m_e^2-m_N^2].$$

Unification



Low energy value for the $B-L$ gauge coupling is

$$g_{B-L}(m_Z) \approx 0.2565$$

This value put a constraint on the associated $B-L$ gauge boson given by LEP

$$M_{B-L}/g_{B-L} > 6\,TeV$$

M. Carena et al.
Phys. Rev. D 70, 093009 (2004)

Therefore $M_{B-L} > 1.5$ TeV

Sparticle spectrum

RGE sparticle masses

$$\Delta\beta_{m^2_{Q_3}} = -g^2_{B-L}M^2_{B-L}/3 + g^2_{B-L}S'/4,$$

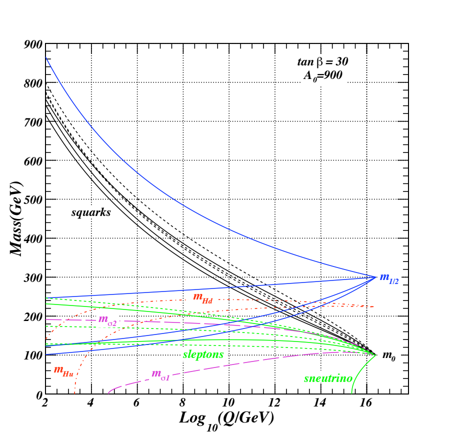
$$\Delta\beta_{m^2_{u_3}} = -g^2_{B-L}M^2_{B-L}/3 + g^2_{B-L}S'/4,$$

$$\Delta\beta_{m^2_{d_3}} = -g^2_{B-L}M^2_{B-L}/3 + g^2_{B-L}S'/4,$$

$$\Delta\beta_{m^2_{e_3}} = -3g^2_{B-L}M^2_{B-L} - 3g^2_{B-L}S'/4,$$

$$\Delta\beta_{m^2_{L_3}} = 2y^2_D\left\{m^2_{H_u} + m^2_{L_3} + m^2_{N_3}\right\} + 2a^2_D - 3g^2_{B-L}M^2_{B-L} - 3g^2_{B-L}S'/4,$$

$$\beta_{m^2_{N_3}} = 4y^2_D\left\{m^2_{H_u} + m^2_{L_3} + m^2_{N_3}\right\} + 4y^2_M\{m^2_{\sigma_1} + m^2_{N_3}\} + 4(a^2_M + a^2_D) - 3g^2_{B-L}M^2_{B-L} - 3g^2_{B-L}S'/4,$$



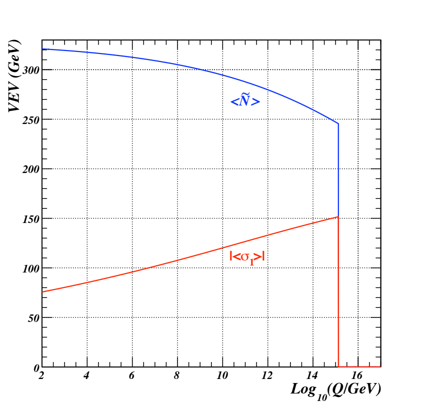
$U(1)_{B-L}$ is broken by $\langle\sigma_1\rangle$ and $\langle\tilde{N}\rangle$

Moreover, right-handed neutrino vev will contribute to the mass of the associated $B-L$ gauge boson, $M^2_{B-L} = g^2_{B-L}(4v^2_{\sigma_1} + 4v^2_{\sigma_2} + v^2_{\tilde{N}})$

$B-L$ breaking

$\tilde{N}$ becomes negative so fast, so it is worth asking the vev scale at low energies; the potential includes a mixing with the σ_1, therefore,

$$V(\tilde{N},\sigma_1) = \left(|y_M|^2 + \frac{1}{8}g_{B-L}^2\right)|\tilde{N}|^4 + m_N^2|\tilde{N}|^2 + \frac{1}{8}g_{B-L}^2|\sigma_1|^4 + \left\{\mu' + m_{\sigma_1}^2\right\}|\sigma_1|^2$$
$$+ 4|y_M|^2|\tilde{N}|^2|\sigma_1|^2 + a_M\sigma_1|\tilde{N}|^2$$



Even if both fields acquire a vev almost at the GUT scale, their vevs are at the GeV scale.

The phase appearing for $\langle\sigma_1\rangle$ has been considered for Inflation and Baryogenesis models.

D. Delepine et al.
Phys. Rev. Lett. 98, 161302 (2007)

Neutrino mass

Neutrino mass matrix can be obtained by a double *see saw* mechanism. And this feature rise by the fact that the neutrinos and neutralinos are mixed in the same mass matrix.
P. Fileviez-Perez and S. Spinner, Phys. Lett. B 673, 251 (2009).
The mass mixing between neutrinos and neutralinos has the following form,

$$\mathbf{M}_{\nu\tilde{\chi}^0} = \begin{pmatrix} 0 & \frac{y_D v s_\beta}{\sqrt{2}} & \mathbf{\Lambda} \\ \frac{y_D v s_\beta}{\sqrt{2}} & \frac{y_M v_{\sigma_1}}{\sqrt{2}} & \mathbf{\Omega} \\ \mathbf{\Lambda}^T & \mathbf{\Omega}^T & \mathbf{M}_{\tilde{\chi}^0} \end{pmatrix}$$

where we have taken the basis $(\nu_L, N, \tilde{\chi}^0)$. The neutralino mass matrix has been also modified and now read, in the basis
$\left(\tilde{\psi}^0\right)^T = (\tilde{B}^0 \quad \tilde{W}^0 \quad \psi_d^0 \quad \psi_u^0 \quad \tilde{Z}^0_{B-L} \quad \psi^0_{\sigma_1} \quad \psi^0_{\sigma_2})$, as,

$$\mathbf{M}_{\tilde{\chi}^0} = \begin{pmatrix} \mathbf{M}_{\tilde{\chi}^0_{\mathbf{MSSM}}} & \mathbf{0} \\ \mathbf{0} & \mathbf{M}_{\tilde{\chi}^0_{\mathbf{B-L}}} \end{pmatrix}$$

where all matrices are,

$$\mathbf{M}_{\tilde{\chi}^0_{\mathbf{MSSM}}} = \begin{pmatrix} M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix},$$

and

$$\mathbf{M}_{\tilde{\chi}^0_{\mathbf{B-L}}} = \begin{pmatrix} M_{B-L} & -2g_{B-L}v' s_{\beta_{B-L}} & 2g_{B-L}v' c_{\beta_{B-L}} \\ -g_{B-L}v' s_{\beta_{B-L}} & 0 & -\mu' \\ g_{B-L}v' c_{\beta_{B-L}} & -\mu' & 0 \end{pmatrix}$$

$$\begin{aligned} \mathbf{\Lambda} &= \begin{pmatrix} 0 & 0 & 0 & \frac{v_R y_D}{\sqrt{2}} & 0 & 0 & 0 \end{pmatrix}, \\ \mathbf{\Omega} &= \begin{pmatrix} \mathbf{0}_{1\times 4} & -\sqrt{2}g_{B-L}v_R & \frac{y_M v_R}{\sqrt{2}} & 0 \end{pmatrix}, \end{aligned}$$

Therefore, the neutrino mass matrix is given by,

$$[M_\nu]_{11} = \frac{v_R^2 y_D^2}{4\mu\left(t_\beta - \frac{M_1 M_2 \mu c_\beta^{-2}}{m_Z^2(M_1+M_2+(M_1-M_2)c_{2\theta_W})}\right)},$$

$$[M_\nu]_{12} = \frac{v y_D s_\beta}{\sqrt{2}},$$

$$[M_\nu]_{22} = \frac{v_{\sigma_1} y_M}{\sqrt{2}} - \frac{2g_{B-L}^2 v_R^2(\mu' - v' y_M c_\alpha)^2}{\mu'^2\left(M_{B-L} - 4g_{B-L}^2 s_{2\alpha}\frac{v'^2}{\mu'}\right)}.$$

A random scan over the parameter space let the mass of the right handed neutrino to be,

$$m_N > \mathcal{O}(1)\ \text{GeV},$$

by requiring the cosmological constraint $\sum_i m_{\nu_i} < 2$ eV to be satisfied.
J. Lesgourgues and S. Pastor, Phys. Rept. 429, 307 (2006).

Conclusions

- We have studied the supersymmetric extension of the gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$, where we have added a right handed neutrino superfield, and two extra $B-L$ Higgses.
- We calculated the renormalization group equations for all the parameters of the model.
- By requesting a unification at the GUT scale, we have calculated the associated gauge coupling $g_{B-L}(m_Z) \approx 0.2565$, implying immediately $M_{B-L} > 1.5\,TeV$
- The breaking of $U(1)_{B-L}$ is mediated by the sneutrino and the $B-L$ Higgs fields. Their vevs at low energies are under control due to the contributions of all the sparticles.
- By applying a double *see-saw* procedure, neutrinos can acquire a mass which can give solve some problems in the neutrino phenomenology.
- ...
- In this model the LSP is the associated $B-L$ gaugino ... DM implications ?!?!


Thanks...

Backup slides

Higgs masses

For computing the scalar masses, we need to consider all the scalar fields, therefore, in the basis $\Phi = \begin{pmatrix} \tilde{\nu}_L & \tilde{\nu}_L^\dagger & \tilde{N} & \tilde{N}^\dagger & \sigma_1 & \sigma_1^* & \sigma_2 & \sigma_2^* & H_u^0 & H_u^{0*} & H_d^0 & H_d^{0*} \end{pmatrix}^T$, we can write the lagrangian,

$$\mathcal{L} = \frac{1}{2}\Phi^T M_\Phi^2 \Phi,$$

such that M_Φ^2 is,

$$M_\Phi^2 = \begin{pmatrix} M_{B-L}^2 & M_{mix}^2 \\ (M_{mix}^2)^T & M_{MSSM-Higgs}^2 \end{pmatrix}$$

but M_{mix}^2 elements are proportional to the Yukawa parameters, therefore, we can neglect them, as first approximation, and the MSSM Higges and the $B-L$ ones are orthogonal.