TeV scale SUSY B-L and Higgs Mass Corrections

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TeV Scale B-L

S.K. (2006)

- The minimal extension is based on the gauge group

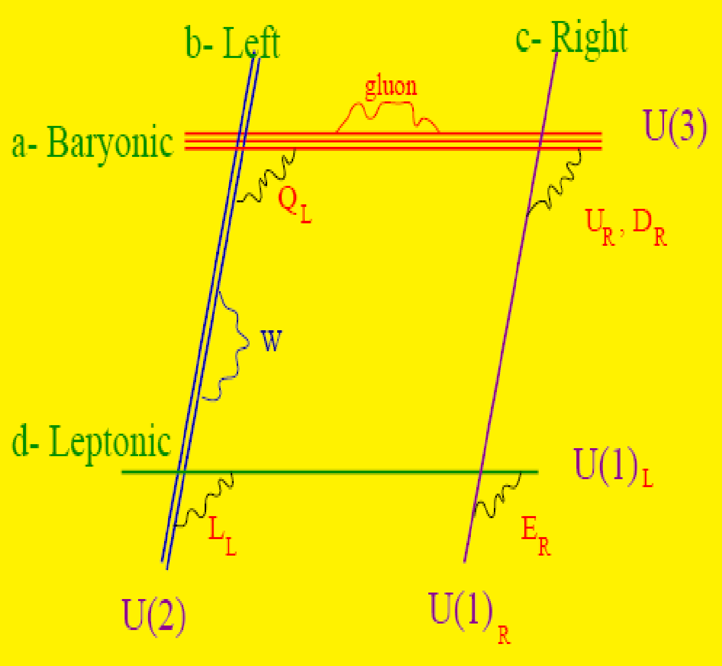
$$G_{B\text{-}L} \equiv SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B\text{-}L}$$

- This model can account for the light neutrino masses
- New particles are predicted:
  - Three SM singlet fermions (right handed neutrinos) (cancellation of gauge anomalies)
  - Extra gauge boson corresponding to B−L gauge symmetry
  - Extra SM singlet scalar (heavy Higgs)
- These new particles have Interesting signatures at the LHC

SUSY B-L from Intersecting D-Branes

Ibanez, et al. JHEP (2001)

- With these stacks of branes, the gauge group *U(3) x U(2) x U(1) x U(1)* is obtained.
- Also right-handed neutrino must exist.
- Two linear combinations of the four associated U(1)'s are non-anomalous: $U(1)_Y$ and $U(1)_{B-L}$.
- The anomaly of the other two U(1)'s are canceled by Green Schwarz mechanism.
- Thus the gauge group $SU(3) \times SU(2) \times U(1)_Y \times U(1)_{B-L}$ is naturally obtained.



- *N=1* Supersymmetric $SU(3) \times SU(2) \times U(1)_Y \times U(1)_{B-L}$ is naturally derived in Strongly coupled heterotic string theory Braun, He, Ovrut, Pantev (2005)
- Recently, it was show that SUSY B-L can be constructed as a realistic D-brane model on del Pezzo singularity Dolan, Krippendorf, Quevedo, (2011)

TeV scale B-L from GUT

- G_{B-L} can be obtained from SO(10) in the following branching rule:

$$SO(10)$$

$$\Downarrow$$

$$SU(4)_C \times SU(2)_L \times SU(2)_R$$

$$\Downarrow$$

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

$$\Downarrow$$

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

AT scale ~ GUT though (1,1,1) in 54_H or 210_H.

Below GUT scale (15,1,3) Higgs

At TeV scale via (1,1,0,2) Higgs

SUSY & B-L radiative symmetry breaking

S.K., A. Masiero, 2007

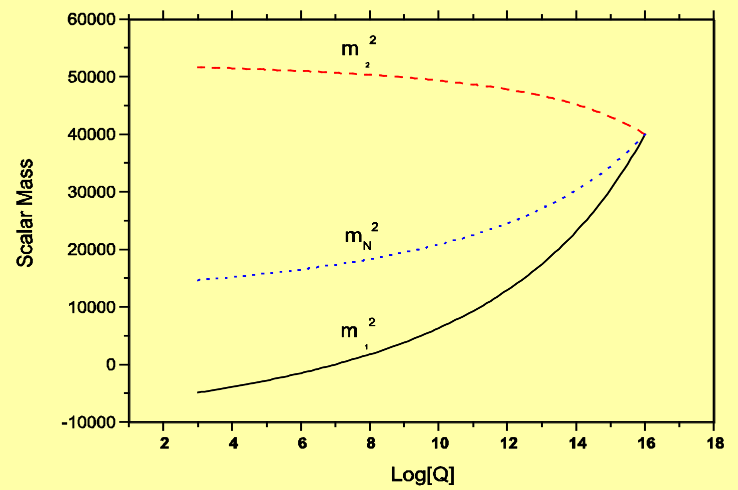
In a SUSY context, we can nicely correlate the B-L and SUSY scales through the mechanism of radiative breaking of the B-L symmetry.

The minimal SUSY version of B-L model has the following superpotential:

$$\begin{aligned} W &= (h_U)_{ij} Q_i H_2 U_j^c + (h_D)_{ij} Q_i H_1 D_j^c + (h_L)_{ij} L_i H_1 E_j^c + (h_\nu)_{ij} L_i H_2 N_j^c \\ &+ (h_N)_{ij} N_i^c N_j^c \chi_1 + \mu H_1 H_2 + \mu' \chi_1 \chi_2. \end{aligned}$$

The RGE of relevant scalar masses are:

$$\begin{aligned} \frac{dm_{\chi_1}^2}{dt} &= 6\tilde{\alpha}_{B-L} M_{B-L}^2 - 2\tilde{Y}_{N_3}\left(m_{\chi_1}^2 + 2m_{N_3}^2 + A_{N_3}^2\right), \\ \frac{dm_{N_3}^2}{dt} &= \frac{3}{2}\tilde{\alpha}_{B-L} M_{B-L}^2 - \tilde{Y}_{N_3}\left(m_{\chi_1}^2 + 2m_{N_3}^2 + A_{N_3}^2\right). \end{aligned}$$



From M_X to M_W, $m^2_{\chi 1}$ and $m^2_{\chi 2}$ are renormalized differently.

At O(1)TeV, $m^2_{\chi 1}$ becomes negative, the minimization condition is satisfied and the B-L gauge symmetry is broken.

$$\mu'^2 = \frac{m_{\chi_2}^2 - m_{\chi_1}^2 \tan^2\theta}{\tan^2\theta - 1} - \frac{1}{4} M_{Z_{B-L}}^2. \qquad \sin 2\theta = \frac{2\mu_3^2}{\mu_1^2 + \mu_2^2}.$$

Neutrino Masses & B-L scale

- If the B-L charge of singlet scalar χ is +2:

	l_L	e_R	ν_R	ϕ	χ
$SU(2)_L$ x $U(1)_Y$	(2,-1/2)	(1,-1)	(1,0)	(2,-1/2)	(1,0)
$U(1)_{B\text{-}L}$	-1	-1	-1	0	2

- A type I seesaw can be obtained from: $L_{B-L} \supset \lambda_\nu \bar{l}\tilde{\phi}\nu_R + \frac{1}{2}\lambda_{\nu_R}\overline{\nu_R^c}\chi\nu_R + h.c.$

- Majorana mass , after B-L symmetry breaking is generated: $M_R = \lambda_{\nu_R} v'$

$$v' \sim O(TeV),\ \lambda_{\nu_R} \sim O(1) \Rightarrow M_R \approx O(TeV) \qquad m_D = \lambda_\nu v$$

- Dirac mass (after Electroweak symmetry breaking):

$$\begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} \Longrightarrow \quad m_{\nu_L} = -m_D M_R^{-1} m_D^T,$$

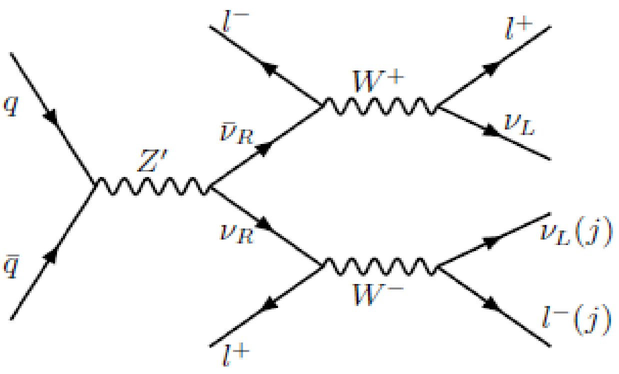
- Thus:

$$m_D \approx O(10^{-4})GeV \Rightarrow \lambda_\nu \sim \lambda_e$$

Signatures for ν_R at the LHC

S.K., Huitu, Okada, Rai (2008)

The lightest heavy neutrinos can be (pair) produced at LHC via Z'_{B-L} exchange



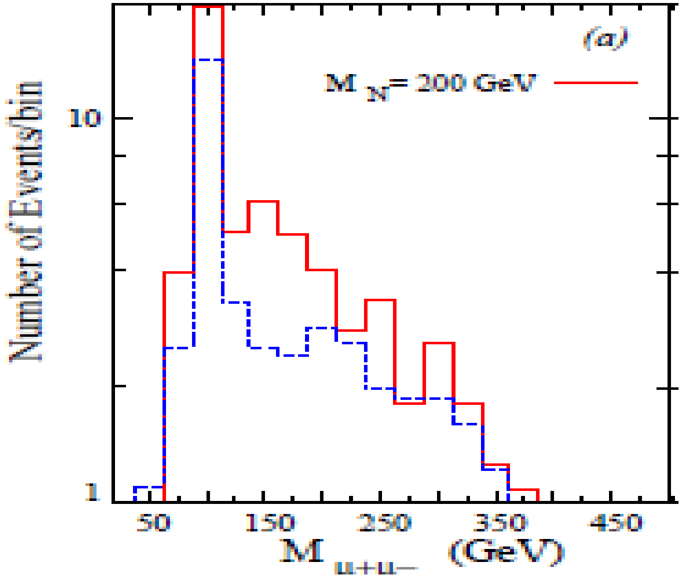
The main decay channel of ν_R pairs is through two W bosons.

Possible clean signals, which would enable reconstruction of both the ν_R and Z'_{B-L} masses, are those involving:

(i) two pairs of charged leptons and missing transverse energy

(ii) three charged leptons, two jets and missing transverse energy

Integrated luminosity ~ 300 fb^{-1} gives 71 events for the right handed neutrino mass of 200 GeV while it gives 46 events for the right handed neutrino mass of 400 GeV.



B-L Inverse Seesaw Mechanism

- Type-I seesaw mechanism implies $\lambda_\nu \sim 10^{-6}$, which may be unnatural small.
- If $U(1)_{B-L}$ is spontaneously broken by a SM singlet scalar χ with B-L charge =+1.
- SM singlet fermions S_1 with B-L =+2 and S_2 with B-L =-2 are introduced, an inverse seesaw mechanism may be implemented.
- The Lagrangian of the leptonic sector in this model is given by

$$\begin{aligned}
\mathcal{L}_{B-L} &= -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + i\,\bar{\ell}_L D_\mu \gamma^\mu \ell_L + i\,\bar{e}_R D_\mu \gamma^\mu e_R + i\,\bar{N}_R D_\mu \gamma^\mu N_R \\
&+ i\,\bar{S}_1 D_\mu \gamma^\mu S_1 + i\,\bar{S}_2 D_\mu \gamma^\mu S_2 + (D^\mu \phi)^\dagger D_\mu \phi + (D^\mu \chi)^\dagger D_\mu \chi - V(\phi, \chi) \\
&- \left(\lambda_e \bar{\ell}_L \phi e_R + \lambda_\nu \bar{\ell}_L \tilde{\phi} N_R + \lambda_N \bar{N}_R^c \chi S_2 + h.c.\right) - \frac{1}{M^3} \bar{S}_1^c \chi^{\dagger 4} S_1 - \frac{1}{M^3} \bar{S}_2^c \chi^4 S_2,
\end{aligned}$$

- **After B-L and EW symmetry breaking, the neutrino Yukawa interaction terms lead to the following mass terms:**

$$\mathcal{L}_m^\nu = m_D \bar{\nu}_L N^c + M_N N^c S_2 + \mu_S S_2^2$$

- **Where**

$$M_N = \frac{1}{\sqrt{2}}\lambda_N\, v', \qquad \mu_s = \frac{v'^4}{4M^3} \sim 10^{-10}\,\mathrm{GeV}.$$

- **The 9x9 neutrino mass matrix takes the form:**

$$\begin{pmatrix} 0 & m_D & 0 \\ m_D & 0 & M_N \\ 0 & M_N & \mu_{S_2} \end{pmatrix}$$

- **The light and heavy neutrinos are given by**

$$m_{\nu_\ell} = \frac{m_D^2 \mu_S}{M_N^2 + m_D^2},$$

$$m_{\nu_{H,H'}} = \pm\sqrt{M_N^2 + m_D^2} + \frac{1}{2}\frac{M_N^2 \mu_{S_2}}{M_N^2 + m_D^2}.$$

- **light neutrino mass ~ eV is obtained for a TeV scale M_N, if $\mu_S \ll M_N$. No restriction imposed on the m_D.**

SUSY B-L With Inverse Seesaw

- In this mode, B-L is spontaneously broken by chiral singlet superfields χ_1 with a charge = +1 and χ_2 with −1.

- Also three chiral singlet superfields S_1 with charge +2 and three chiral singlet superfields S_2 with charge −2 are considered to implement the inverse seesaw mechanism.

- The superpotential of the leptonic sector of this model is

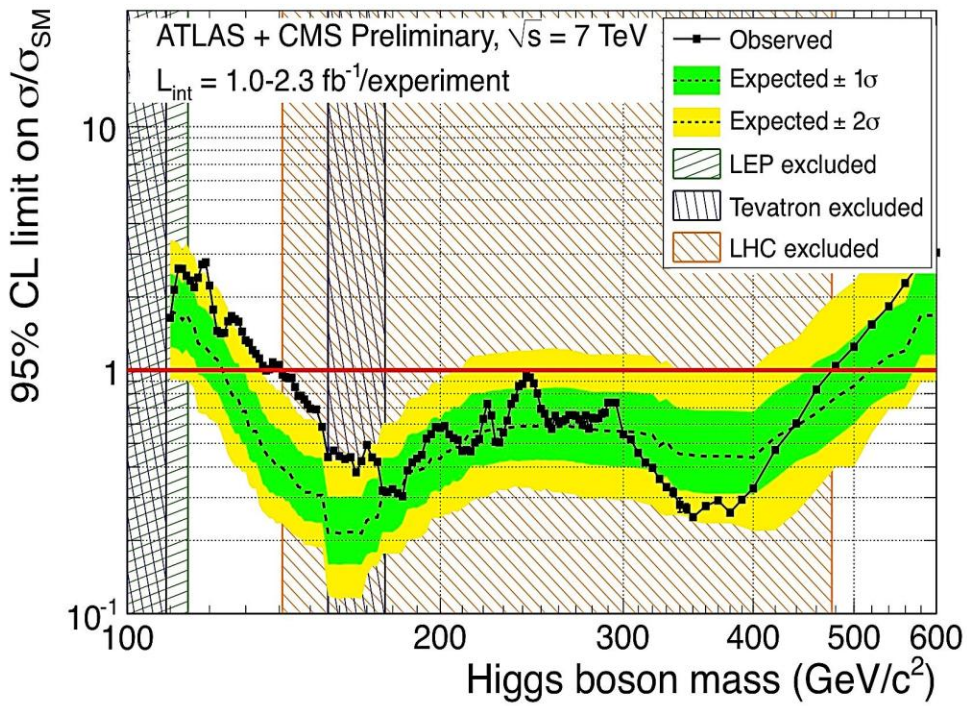
$$W = Y_e E^c L H_1 + Y_\nu N^c L H_2 + Y_S N^c \chi_1 S_2 + \mu H_1 H_2 + \mu' \chi_1 \chi_2 .$$

- The relevant soft SUSY breaking terms, assuming the usual universality assumptions, are

$$\begin{aligned} -\mathcal{L}_{soft} &= \sum_\phi \tilde{m}^2_\phi |\phi|^2 + Y^A_\nu \tilde{N}^c \tilde{L} H_2 + Y^A_e \tilde{E}^c \tilde{L} H_1 + Y^A_S \tilde{N}^c \tilde{S}_2 \chi_1 + B\mu H_1 H_2 + B\mu' \chi_1 \chi_2 \\ &+ \frac{1}{2} M_1 \tilde{B}\tilde{B} + \frac{1}{2} M_2 \widetilde{W}^a \widetilde{W}^a + \frac{1}{2} M_3 \tilde{g}^a \tilde{g}^a + \frac{1}{2} M_{B-L} \tilde{Z}_{B-L} \tilde{Z}_{B-L} + h.c, \end{aligned}$$

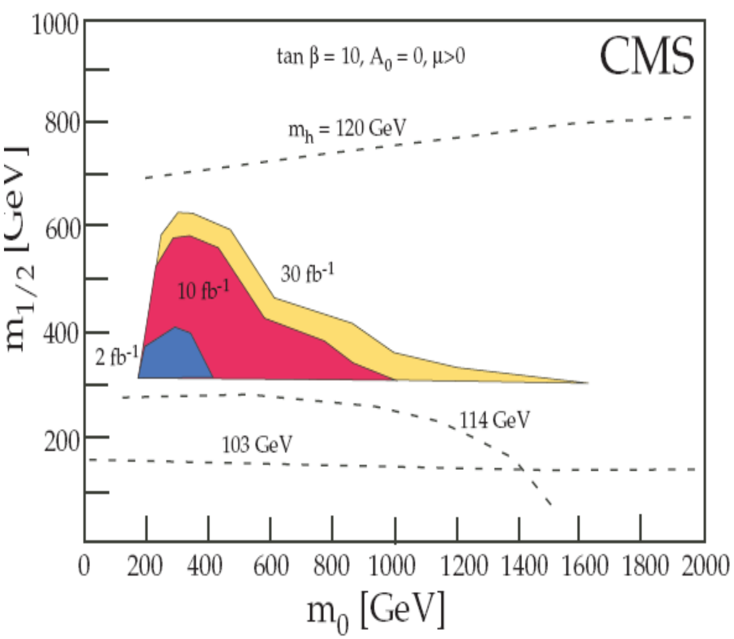
- The sneutrino mass matrix for one generation is 8x8 matrix, decomposed into 6x6 mass matrix in the basis of $(\tilde{\nu}_L, \tilde{\nu}_L^{\,+}, \tilde{N}, \tilde{N}^{\,+}, \tilde{S}_2, \tilde{S}_2^{\,+})^T$ and 2x 2 mass matrix of the basis: $(\tilde{S}_1, \tilde{S}_1^{\,+})^T$

Higgs Mass constraints on MSSM



CMS & ATLAS combined search excludes SM Higgs in the mass range 141-476 GeV.

Higgs decay into two photons led to a signal for Higgs mass ~ 125 GeV.



- **Within MSSM Mh ~ 125 GeV imposes a stringent constraint on universal gaugino mass: M1/2 > 800 GeV, which implies a very heavy SUSY particles.**

- **B-L corrections to Higgs mass are important for relaxing these constraints and keep light SUSY spectrum**

(s)neutrino correction to lightest Higgs

- **In MSSM, the mass of the lightest Higgs at one loop is given by**

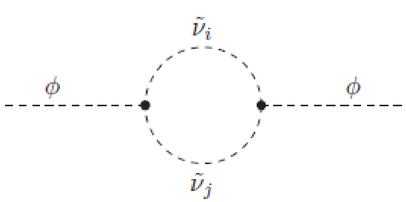
$$m_h^2 \leq M_Z^2 + \frac{3m_t^4}{4\pi^2 v^2} \ln\left(\frac{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2}{2m_t^2}\right)$$

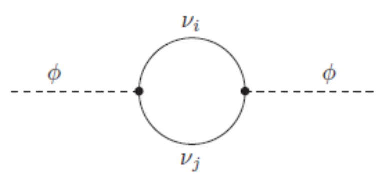
- **For stop mass of order TeV, this correction implies that**

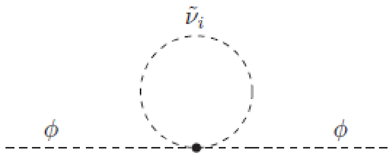
$$m_h^{\mathrm{MSSM}} \lesssim \sqrt{(90\ \mathrm{GeV})^2 + (100\ \mathrm{GeV})^2} \lesssim 135\ \mathrm{GeV}.$$

- **This upper limit on the lightest Higgs boson mass barely consistent with experimental data**

- **The genuine B − L corrections to the lightest SM-like Higgs boson mass can be obtained from one-loop radiative corrections, due to the right-handed neutrinos and sneutrinos,**







- The one-loop correction in the effective potential is given by the relation:

$$\Delta V = \frac{1}{64\pi^2}\ \mathrm{STr}\left[M^4\left(\log\frac{M^2}{Q^2}-\frac{3}{2}\right)\right]$$

where the supertrace is defined as follow:

$$\mathrm{STr} f(M^2) = \sum_i (-1)^{2J_i}(2J_i+1) f(m_i^2).$$

- ΔV, due to one generation of neutrinos and sneutrinos, is given by:

$$(\Delta V)_{\nu,\tilde{\nu}} = \frac{1}{64\pi^2}\left[\sum_{i=1}^{6} m_{\tilde{\nu}_i}^4\left(\log\frac{m_{\tilde{\nu}_i}^2}{Q^2}-\frac{3}{2}\right) - 2\sum_{i=1}^{3} m_{\nu_i}^4\left(\log\frac{m_{\nu_i}^2}{Q^2}-\frac{3}{2}\right)\right]$$

- For sneutrino masses given by

$$m^2_{\tilde{\nu}_{L_{1,2}}} = \tilde{m}^2, \qquad m^2_{\tilde{\nu}_{H_{3,4,5,6}}} = m_D^2 + M_N^2 + \tilde{m}^2.$$

- The Higgs mass corrections are given by

$$\delta M_{11} = \delta M_{12} = \delta M_{21} = 0,$$

$$\delta M_{22} = \frac{1}{16\pi^2}\left[\left(\frac{\partial m^2_{\tilde{\nu}_H}}{\partial v_2}\right)^2 \log\frac{m^2_{\tilde{\nu}_H}}{\hat{Q}^2} - \left(\frac{\partial m^2_{\nu_H}}{\partial v_2}\right)^2 \log\frac{m^2_{\nu_H}}{\hat{Q}^2}\right] = \frac{m_D^4}{4\pi^2 v_2^2}\log\frac{m^2_{\tilde{\nu}_H}}{m^2_{\nu_H}}.$$

- The complete one-loop matrix of squared CP even Higgs masses will be given by M_{tree} + ΔM, with

$$\Delta M = \begin{pmatrix} 0 & 0 \\ 0 & \delta_t^2 + \delta_\nu^2 \end{pmatrix}$$

- δ_t^2 refers to the (s)top contribution and δ_ν^2 is the (s)neutrino correction.

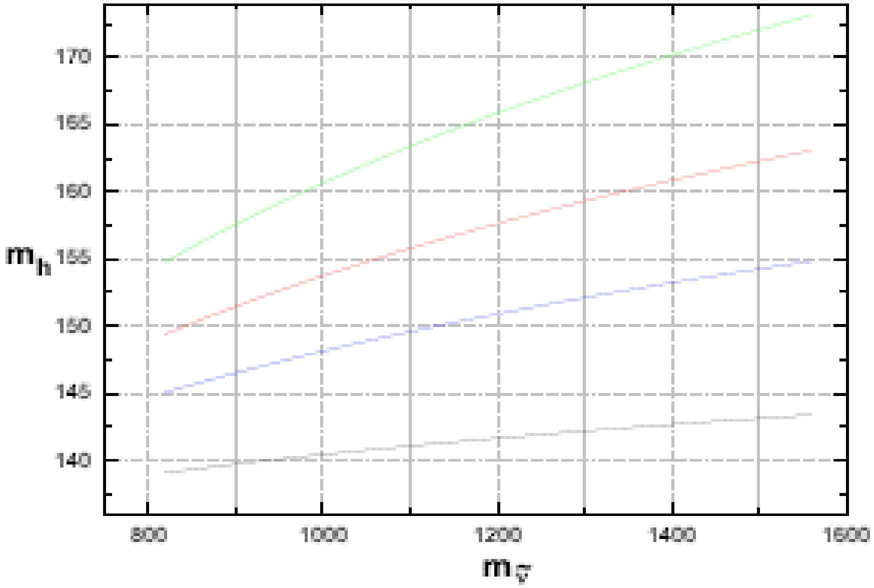
- In this case, the lightest Higgs boson mass is given by

$$m_h^2 = \frac{1}{2}(M_A^2 + M_Z^2 + \delta_t^2 + \delta_\nu^2)\left[1 - \sqrt{1 - 4\frac{M_Z^2 M_A^2 \cos^2 2\beta + (\delta_t^2 + \delta_\nu^2)(M_A^2 \sin^2\beta + M_Z^2 \cos^2\beta)}{(M_A^2 + M_Z^2 + \delta_t^2 + \delta_\nu^2)^2}}\right]$$

For $M_A \gg M_Z$ and $\cos 2\beta \simeq 1$, one finds that

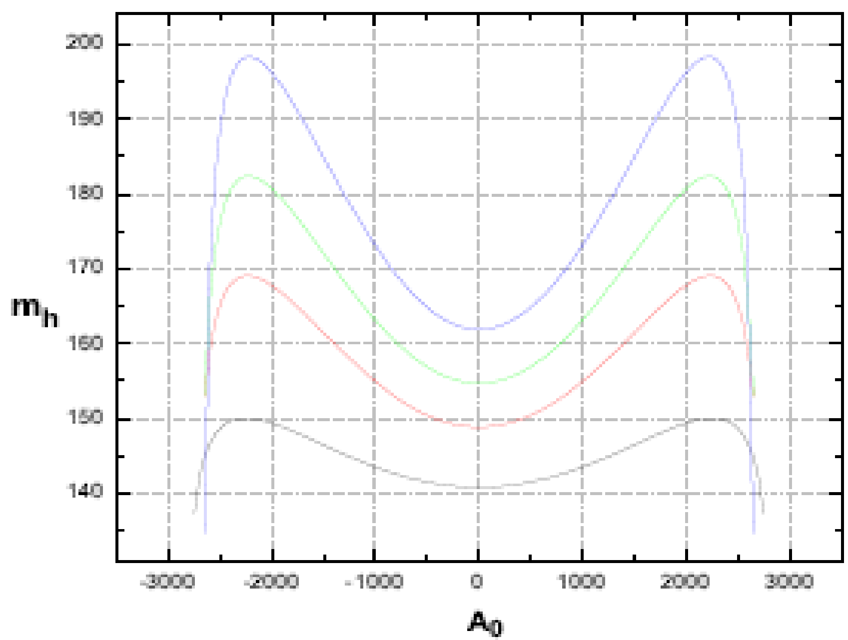
$$m_h^2 \simeq M_Z^2 + \delta_t^2 + \delta_\nu^2.$$

If $\tilde{m} \simeq \mathcal{O}(1)$ TeV, $Y_\nu \simeq \mathcal{O}(1)$ and $M_N \simeq \mathcal{O}(500)$ GeV, one finds that $\delta_\nu^2 \simeq \mathcal{O}(100)^2$, thus the Higgs mass will be of order $\sqrt{(90)^2 + \mathcal{O}(100)^2 + \mathcal{O}(100)^2} \simeq 170$ GeV.



Lightest Higgs boson mass versus right-handed sneutrino mass for M_N = 500 GeV, m_0 = 1 TeV, and Y_v =0.8, 1, 1.1, 1.2 (from bottom to up).

Lightest Higgs boson mass as a function of the triliniar coupling A_N for M = 400 GeV, m_0 = 1 TeV, and Y_v = 0.8, 1, 1.1, 1.2 (from bottom to up).



Summary

- The SM gauge group can be minimally extended by adding $U(1)_{B-L}$
- G_{B-L} contains three right handed neutrinos, extra gauge boson, and extra scalar Higgs.
- Neutrino masses and mixing can be accommodate in this type of models.
- Search for Z' at LHC via dilepton channels is promising.
- **In SUSY B-L with Inverse seesaw the light Higgs has a mass reaching easily 125, with no constraints on the SUSY spectrum.**
- **The right-handed sneutrino in the SUSY B-L model with inverse seesaw mechanism is also a viable candidate for cold DM**

Thank you