B-L Neutralino Dark Matter

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Outline

- Beyond SM
  - Neutrinos and Cosmology
  - Neutrino mass in SM extensions
- B-L Model
  - The supersymmetric B-L model
  - RGE
  - Neutrinos and Higgses
  - B-L neutralinos
- Conclusions

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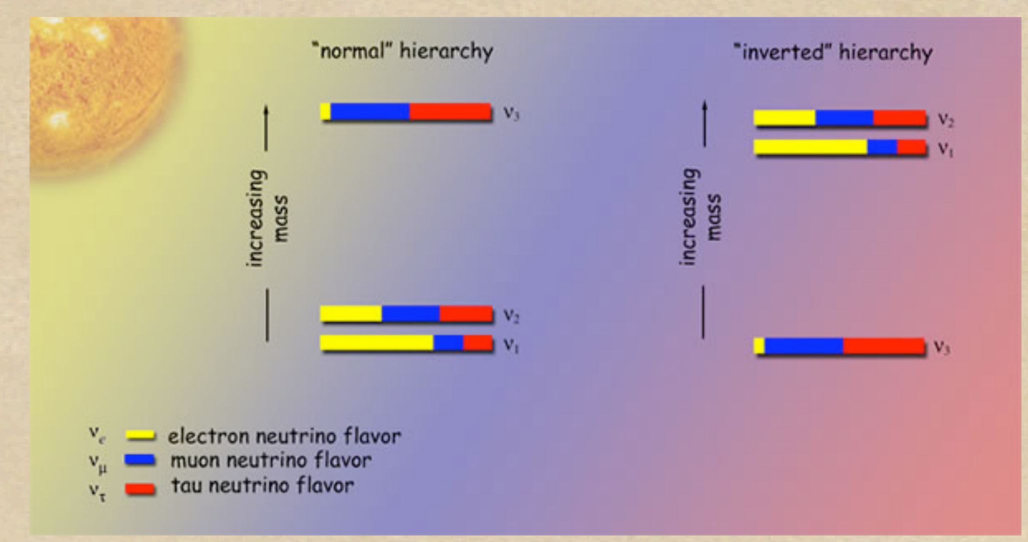

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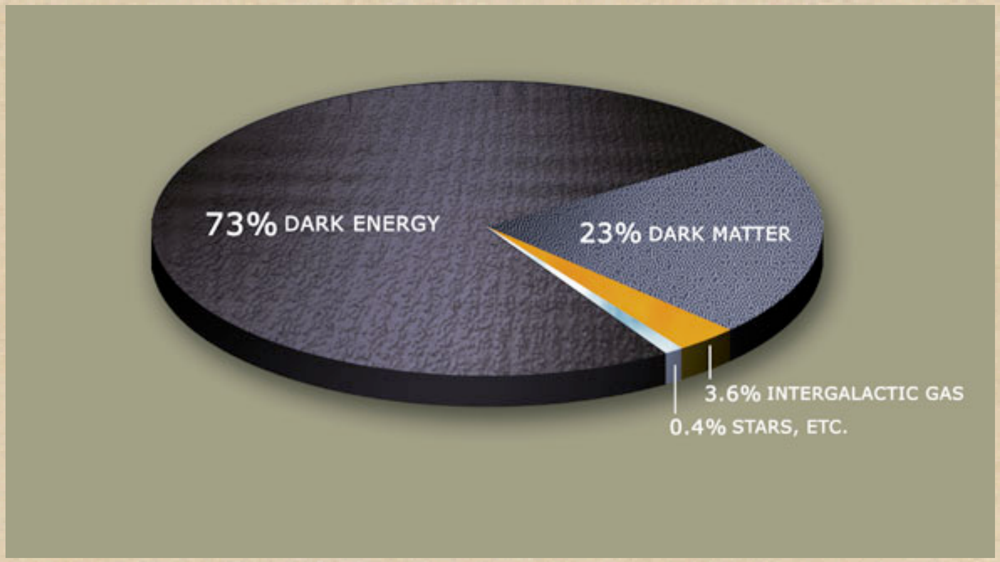

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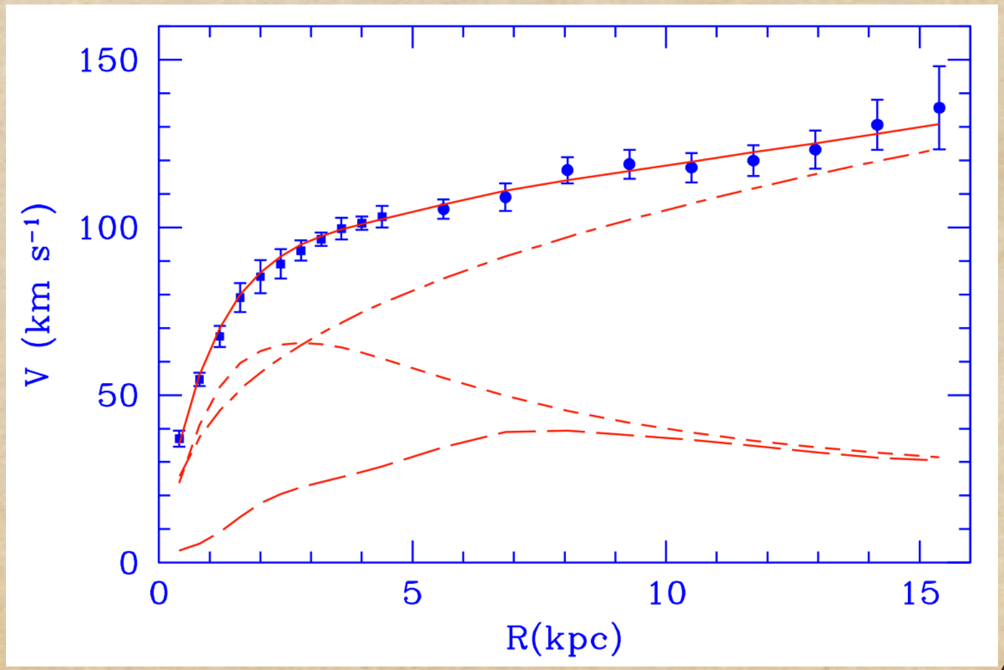

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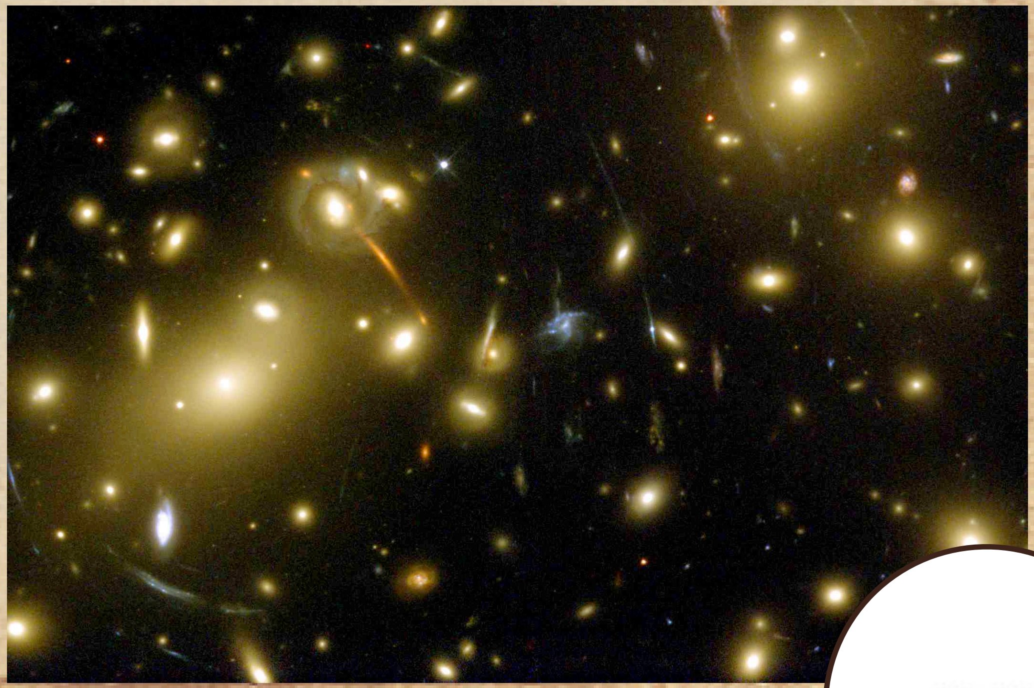

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- Galactic rotation curves,
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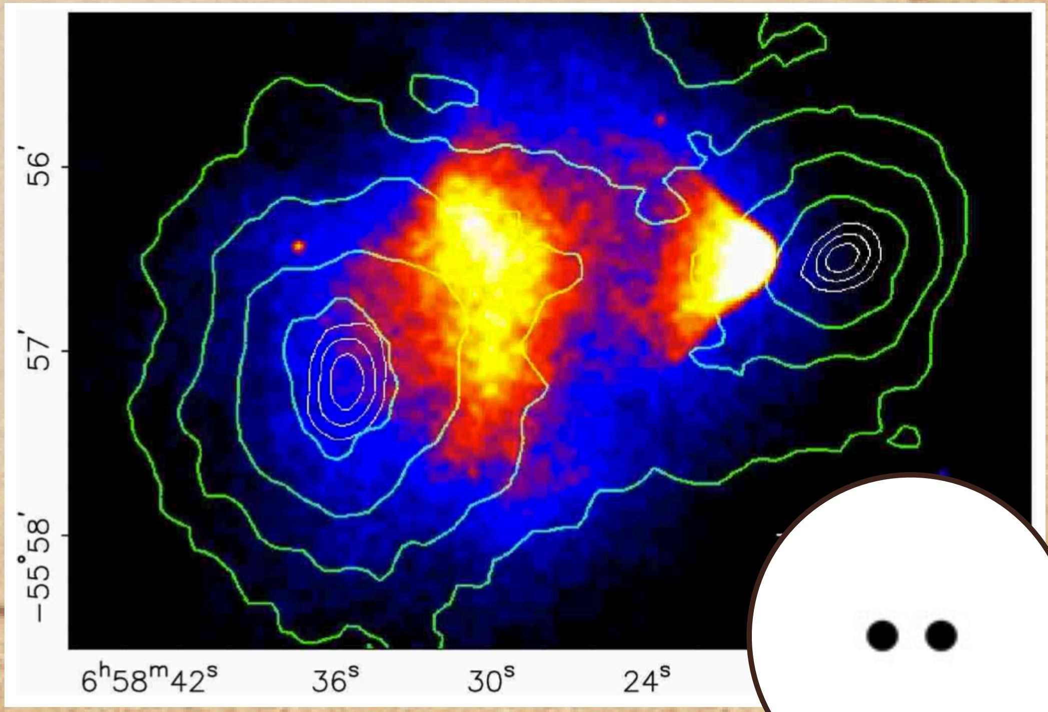
- "Bullet Cluster", ...



Neutrino mass in SM extensions

- In the SM, there is only one helicity state per generation for neutrinos
- We also know that B-L current is conserved to all orders in perturbation theory.
- The inclusion of RHN preserve B-L anomaly free
- The Majorana term breaks B-L, so it must be broken somehow.

In general, neutrino masses can be originated via the lagrangian,

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

- If the Higgs mechanism is responsible for the particle mass generation, breaking of a symmetry could explain neutrino masses too. The previous lagrangian suggest the breaking of B-L.
- Including SUSY one can have an estimation of the value of parameters at low energies using the RGE formalism.

...

The supersymmetric B-L model

The superpotential that contain neutrino masses is,

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

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

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

Kinetic terms are also included,

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

the gauge part,

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

and the soft breaking terms,

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

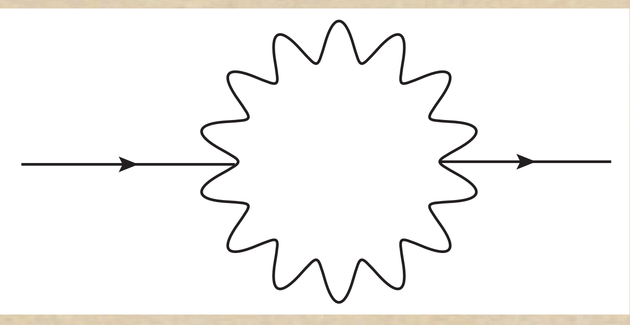
R-parity is no longer imposed. B-L symmetry forbids R-parity violating terms.

...

RGE

RGE are more complicated in this model. Mixing between the unitary groups are coming even at one loop due to,

$$\mathcal{L} \subset \bar{\psi}^k \gamma_\mu Y^a_{kk} \psi^k g_{ab} A^\mu_b \Rightarrow$$



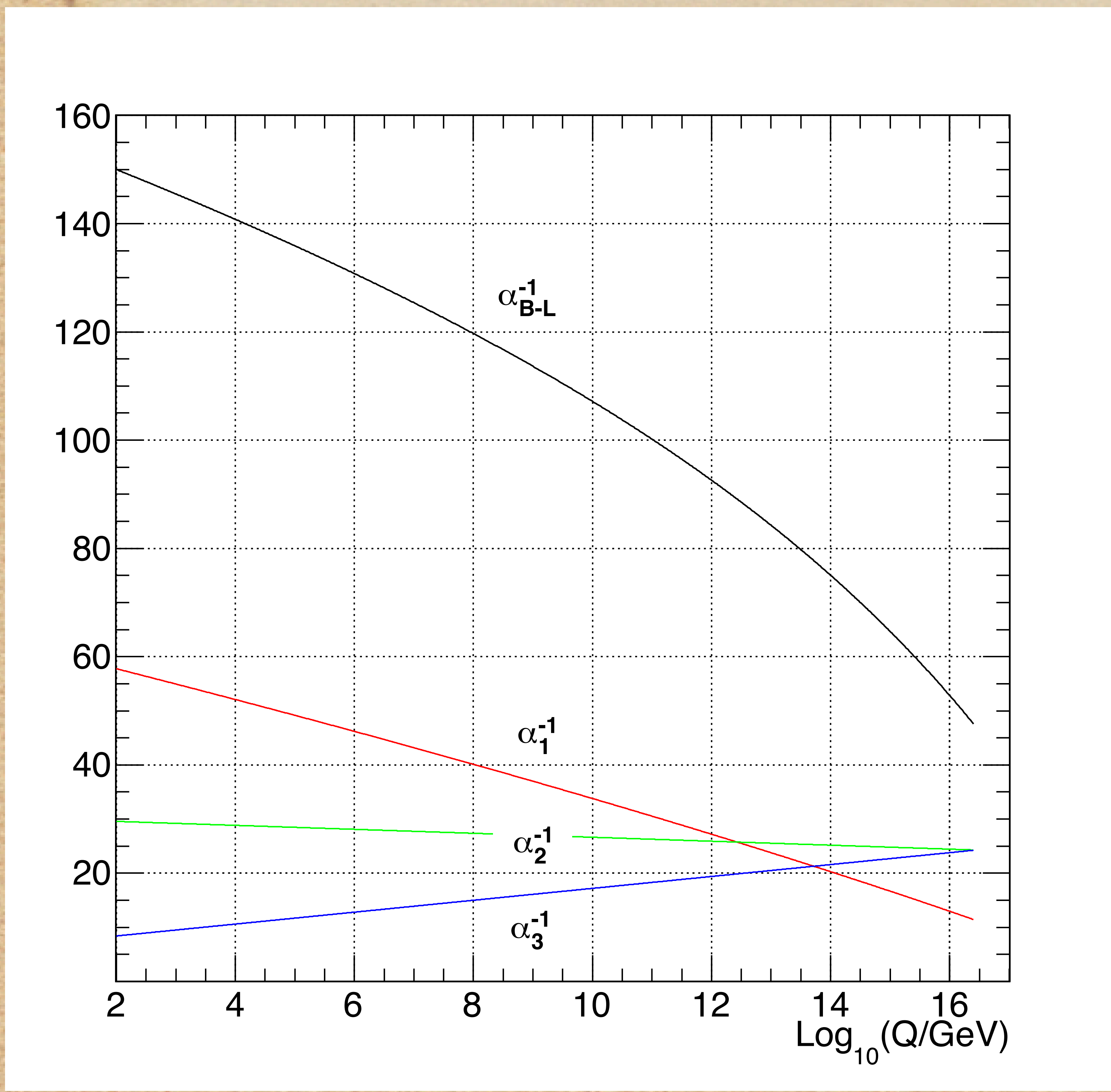
$$\neq 0$$

which, due to non zero beta-function for the mixing term, one needs to define an effective coupling and gaugino masses.
In this sense, one have the running of the gauge couplings in terms of,

$$\beta^{(1)}_{ab} = \frac{1}{16\pi} g_{ka} g_{kb}$$

and for gaugino masses the beta-functions need a similar treatment.
Nevertheless, once the gauge structure is fixed, 1-loop RGE can be computed and solved.

Diagonalizing the unitary couplings, the effective running is determined to be,



Unification is not achieved at one loop. But it might be fixed considering threshold effects.

Therefore, at the mass of the Z,

$$g_{B-L}(m_Z) \approx 0.2894$$

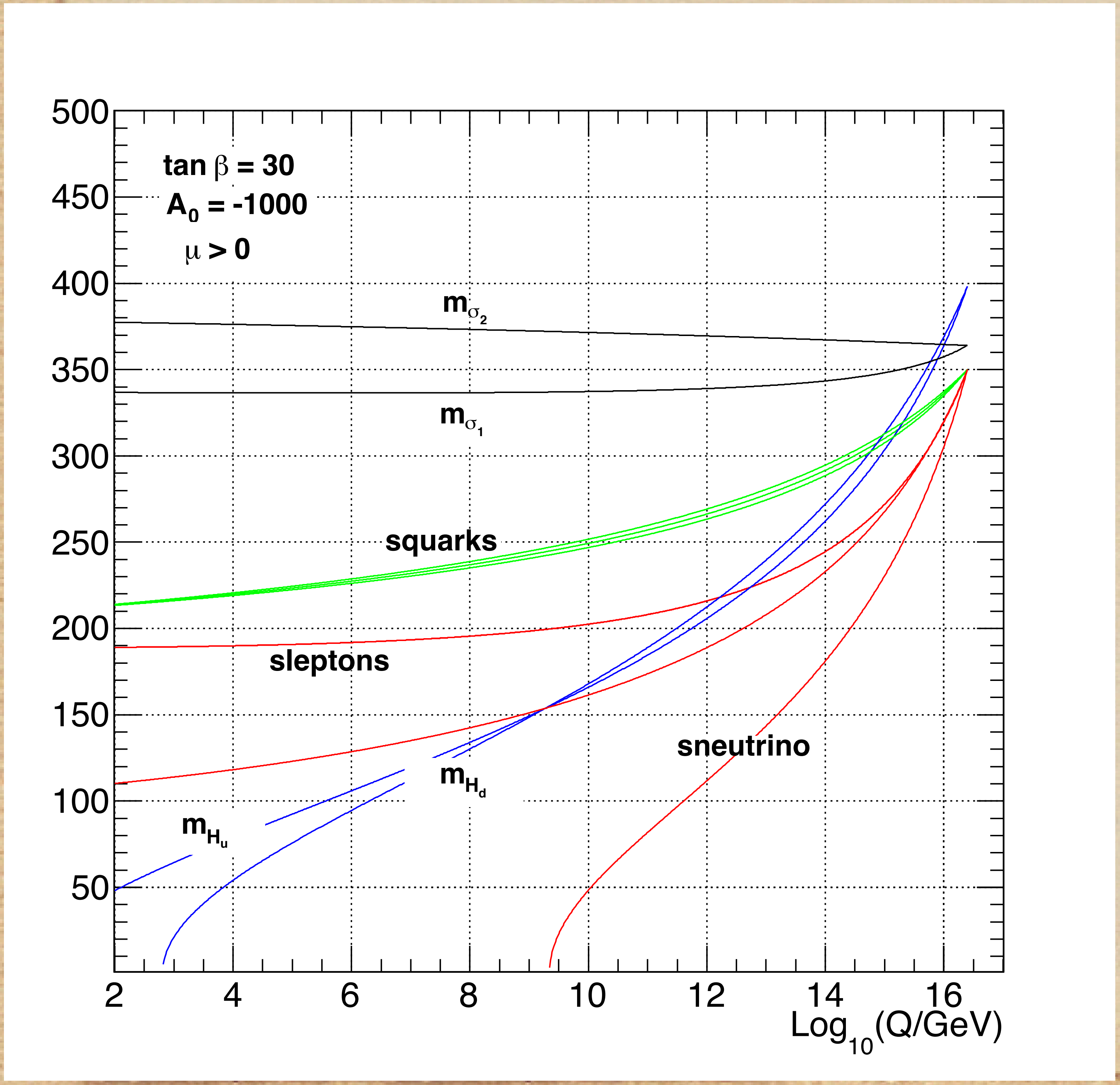
Besides, Z' searches has a limit on,

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

It means,

$$M_{B-L} > 1.7\ \mathrm{TeV}$$

Following the same spirit, one finds the running of the masses to be,



B-L broken due to

$$\langle \tilde{N} \rangle$$

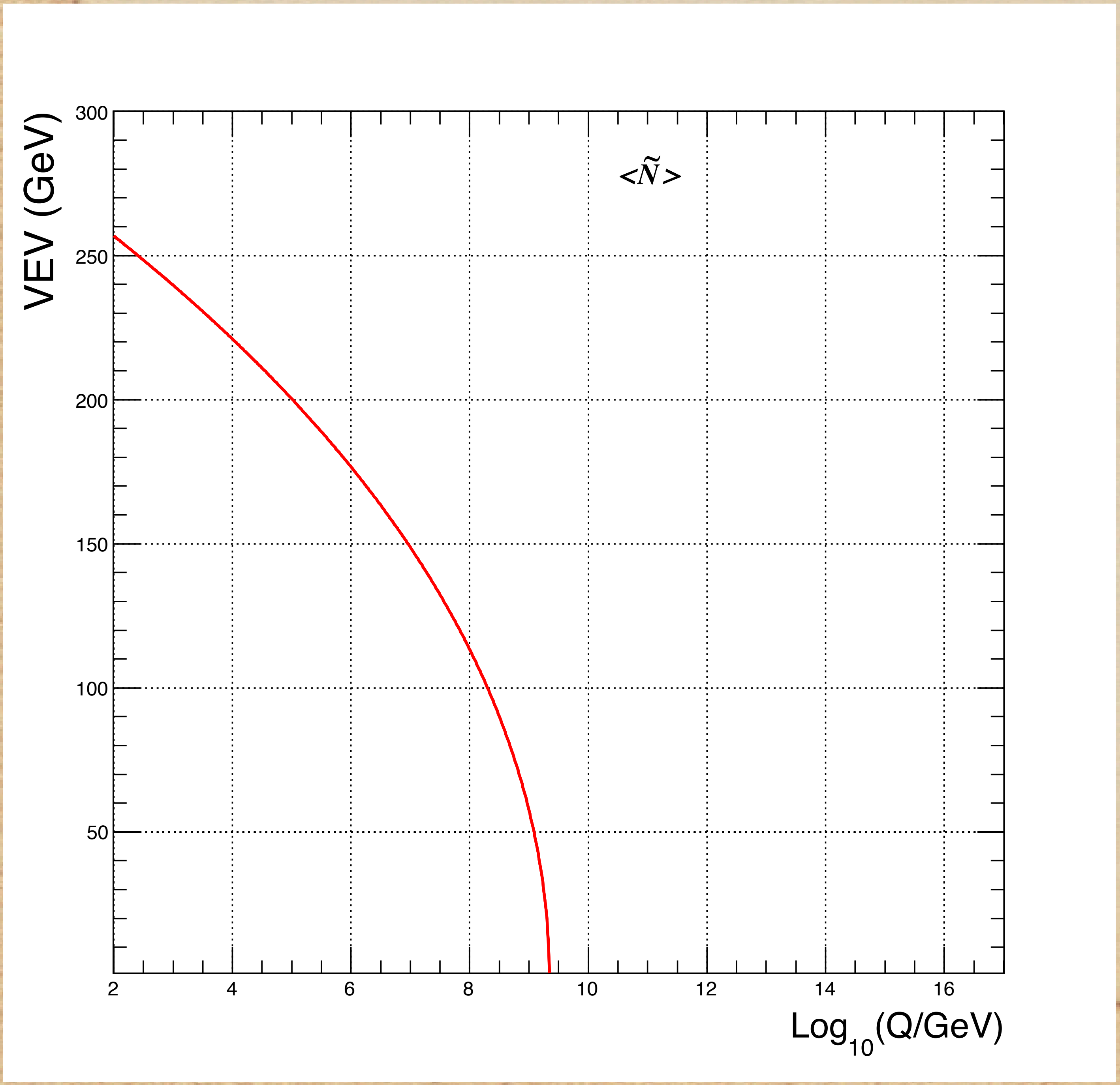
Sneutrino contributes to the mass of the B-L gauge boson. In the most general case,

$$M^2_{B-L} = g^2_{B-L}(4v^2_{\sigma_1} + 4v^2_{\sigma_2} + v^2_{\tilde{N}})$$

B-L breaking happens at high energies

The breaking of B-L can be analyzed by looking at the scalar potential,

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



VEV of the sneutrino remains at the GeV scale.

$$\langle \tilde{N} \rangle [m_Z] \approx 250 \text{ GeV}$$

It is sizable experimentally.

Neutrinos and Higgses

Neutrino masses can be extracted from a double see-saw mechanism.

Neutrinos and neutralinos are mixed are in the same mass matrix, therefore the first implementation will be with the complete mass matrix,

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

In the basis

$(\nu_L, N, \tilde{\chi}^0)$

where neutralino mass matrix in the basis,

$$\left(\tilde{\psi}^0\right)^T = (\tilde{B}^0 \quad \tilde{W}^0 \quad \tilde{H}_d^0 \quad \tilde{H}_u^0 \quad \tilde{Z}_{B-L}^0 \quad \tilde{\sigma}_1 \quad \tilde{\sigma}_2)$$

is,

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

Then, after the second see-saw, neutralino mass matrix elements are,

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

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

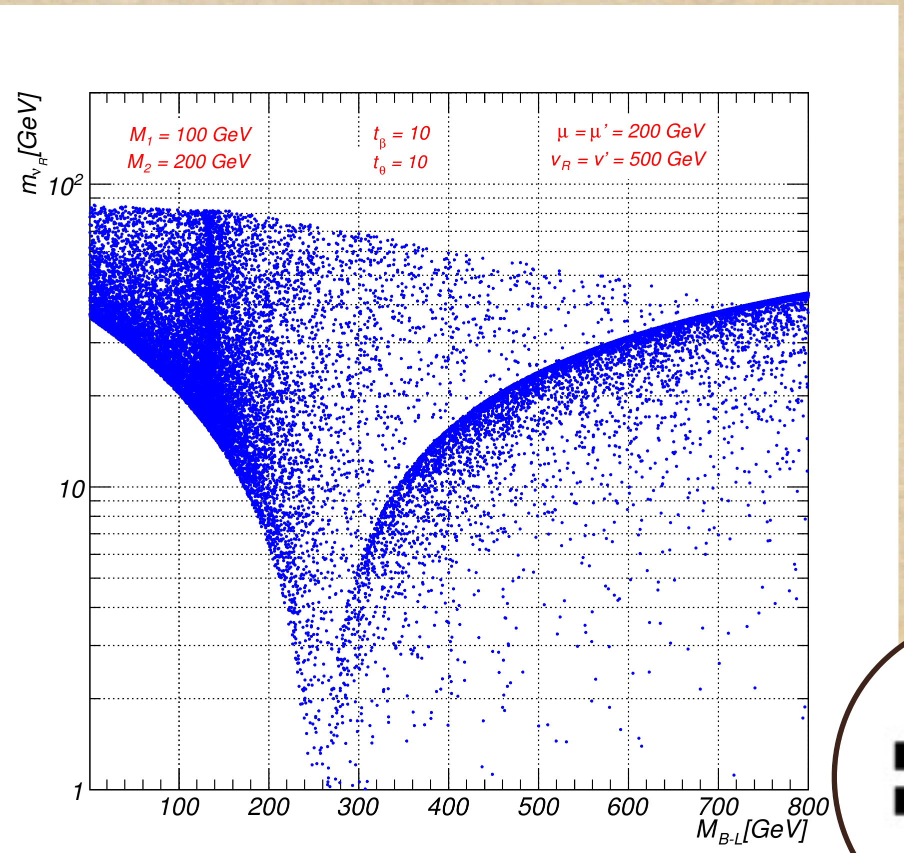
$$[M_\nu]_{22} = -\frac{2g_{B-L}^2 v_R^2}{M_{B-L}}.$$

A random scannig over the parameter space let the mass of RHN to be

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

by requiring the cosmological constraint,

$$\sum_i m_{\nu_i} < 2\ \text{eV}$$



Higgs

The MSSM Higgses have to be reanalyzed. With extra Higgses in the model, and with the vev of the sneutrino, the effective lagrangian reads as,

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

where, the mass matrix is more complex,

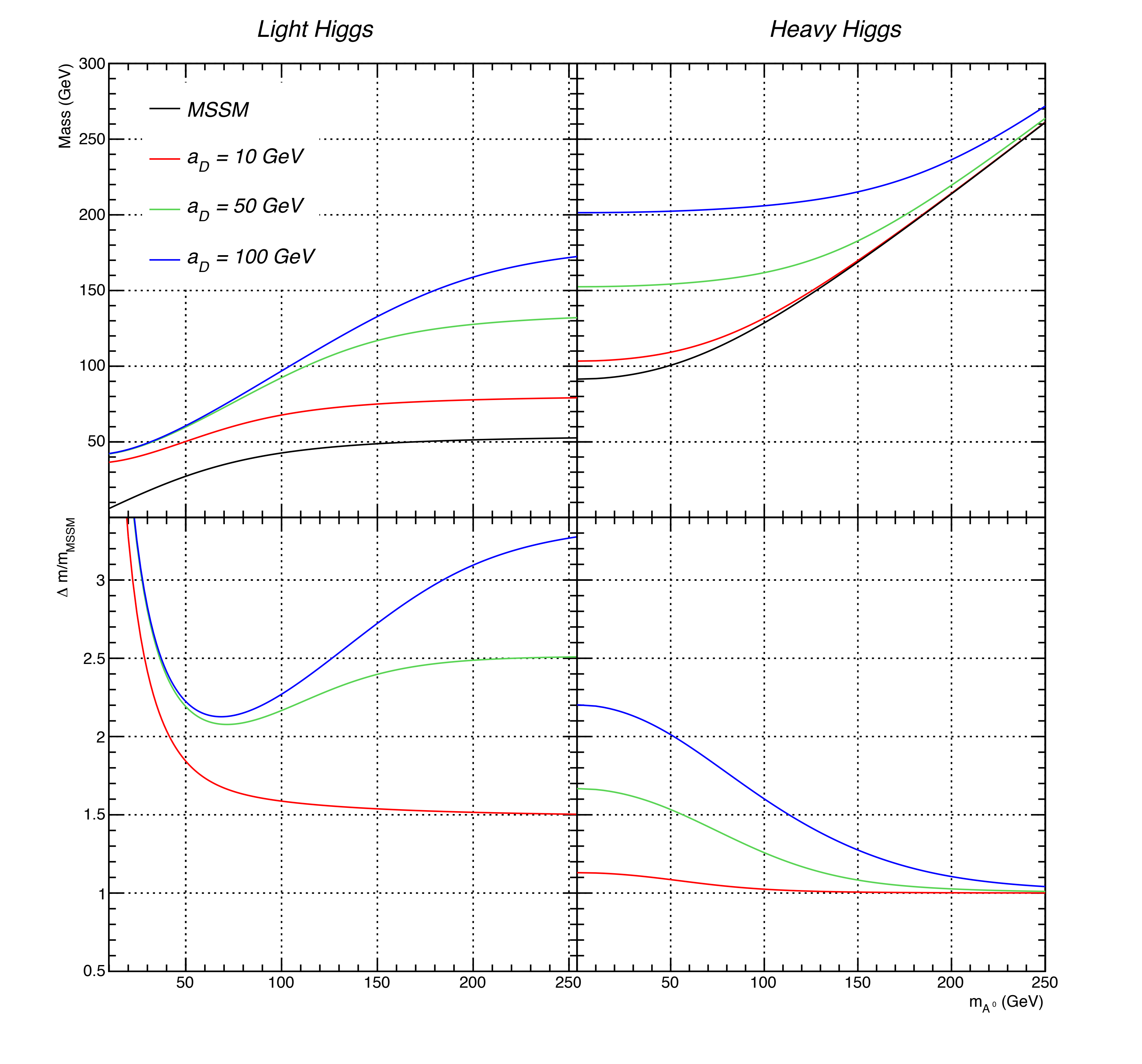
$$M_\Phi^2 = \begin{pmatrix} M_{B-L}^2 & M_{mix}^2 \\ (M_{mix}^2)^T & M_{MSSM}^2 \end{pmatrix}$$

in the basis,

$$(\Phi)^T = (\widetilde{\nu}_L, \widetilde{\nu}_L^\dagger, \widetilde{\nu}_R, h_u^0, h_d^0)$$

Minimization conditions reduces the number of parameters in the model.

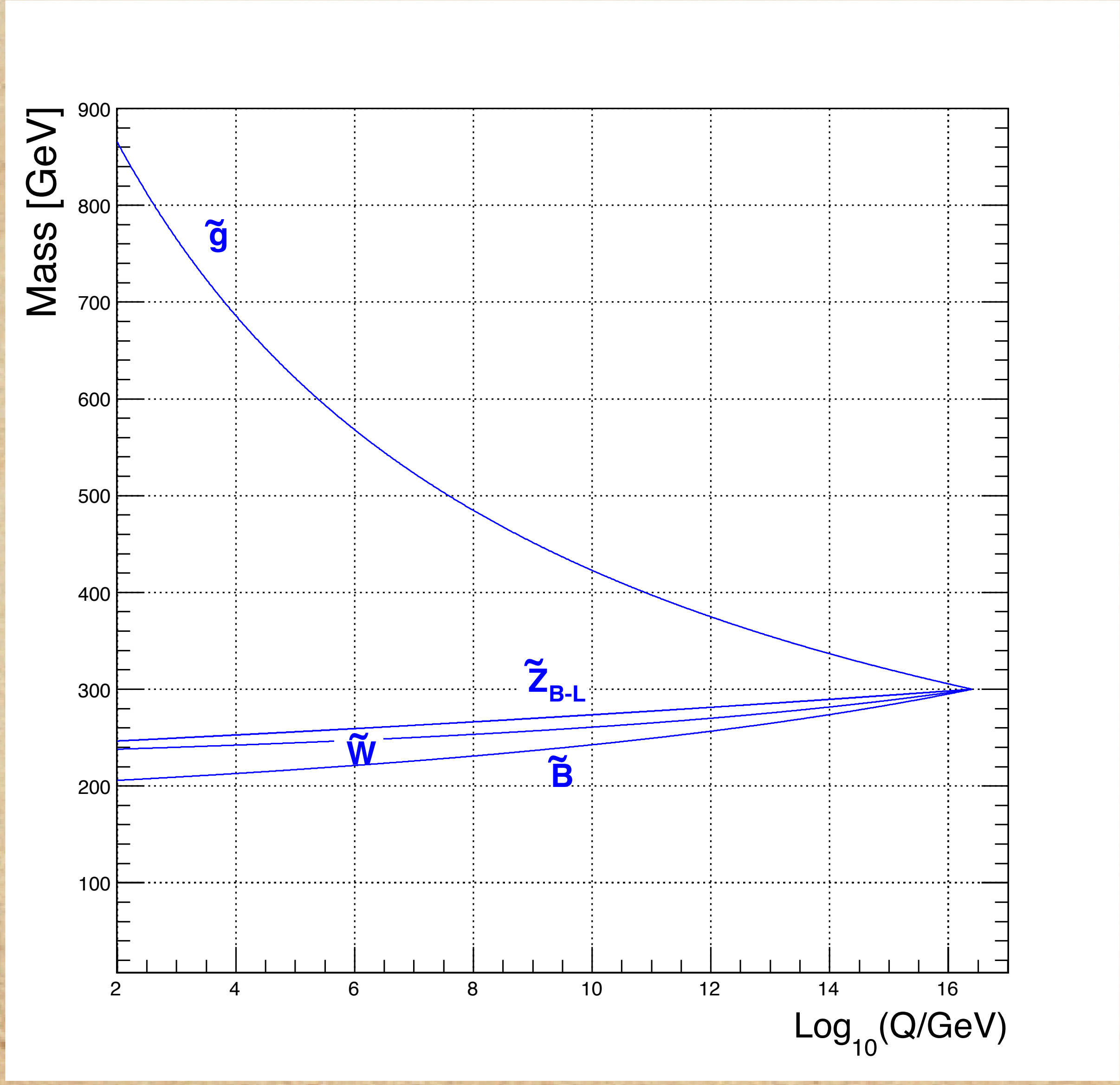
The MSSM Higgses are only sensitive to the soft parameter, a_D.



B-L Neutralino

Which is the LSP in the model ??

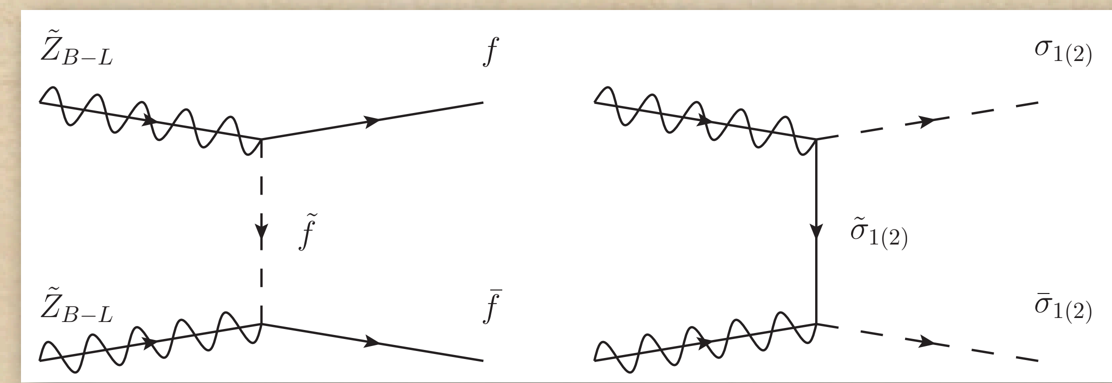
- Lightest neutralino is still B-like, but the B-L is relatively close
- Depending on the parameter space, one can get the B-L eigenstate be the lightest one.



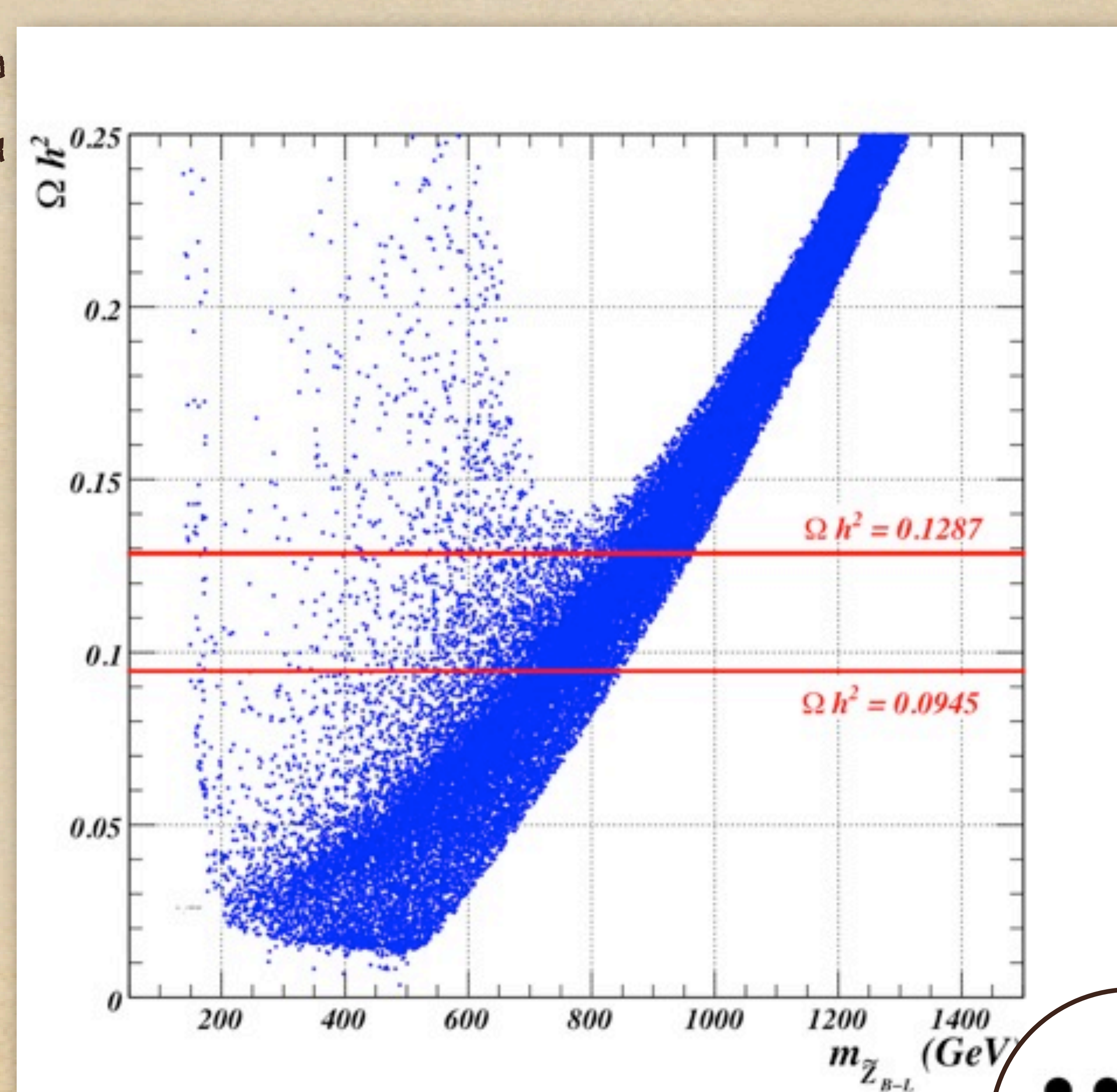
$$\mathbf{M}_{\tilde{\chi}^0_{\mathbf{B-L}}} = \begin{pmatrix} M_{B-L} & 0 & 0 \\ 0 & 0 & -\mu' \\ 0 & -\mu' & 0 \end{pmatrix}$$

Relic Density

If the DM component is dominated completely by the B-L gauge boson, the proceses that contribute to the Relic Density in which an sfermion or a sigma is exchanged in the t and u channel.

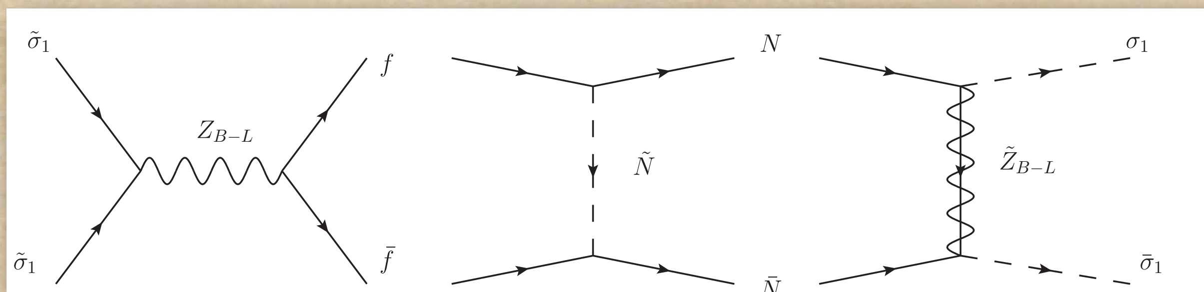


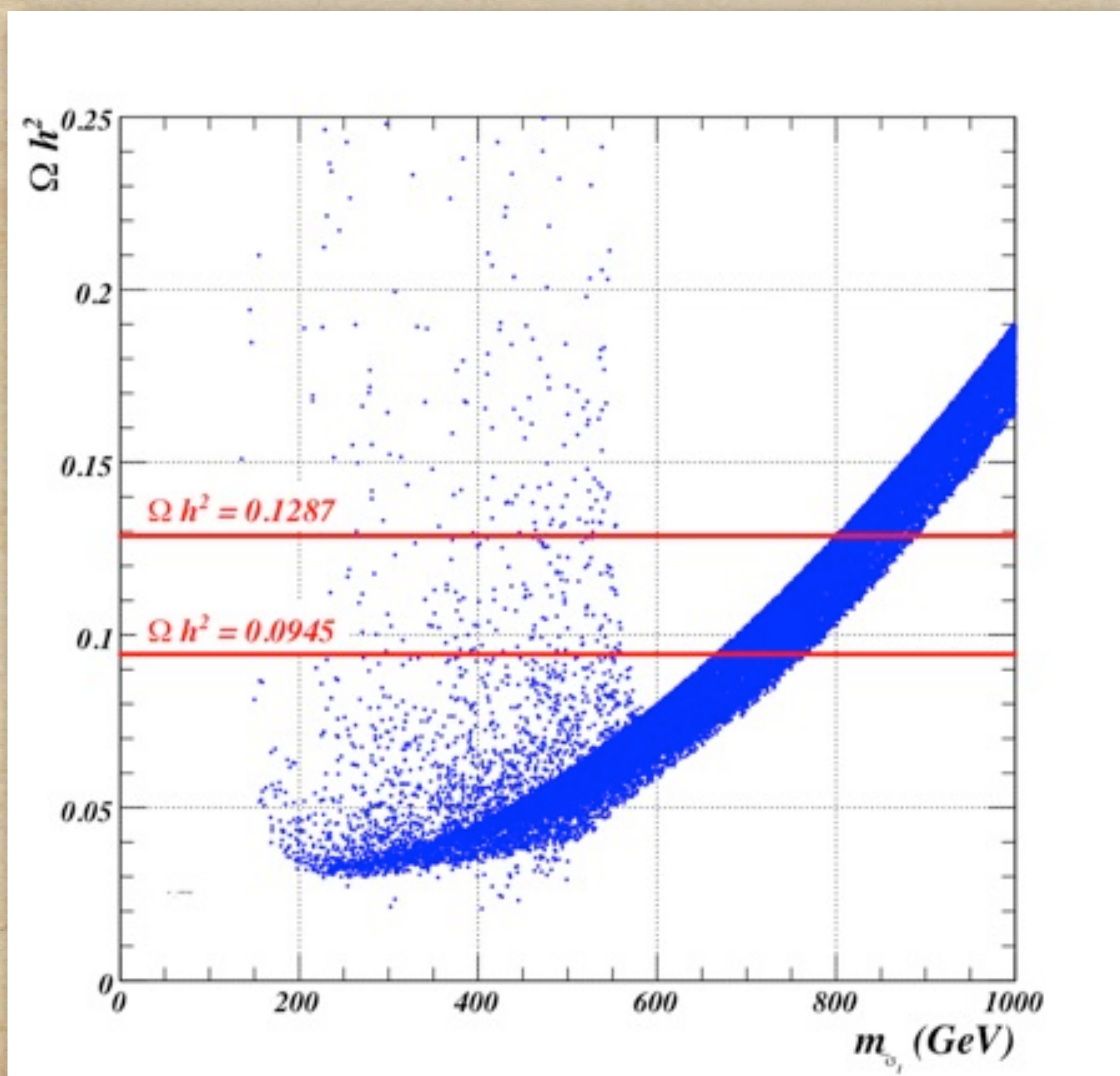
Points which satisfied all constraints have been used to compute the relic density



For a B-L gauge boson mass in the range between 150 and 900 GeV, we are in agreement with WMAP

If the DM component is dominated by, $\tilde{\sigma}_1$ we get





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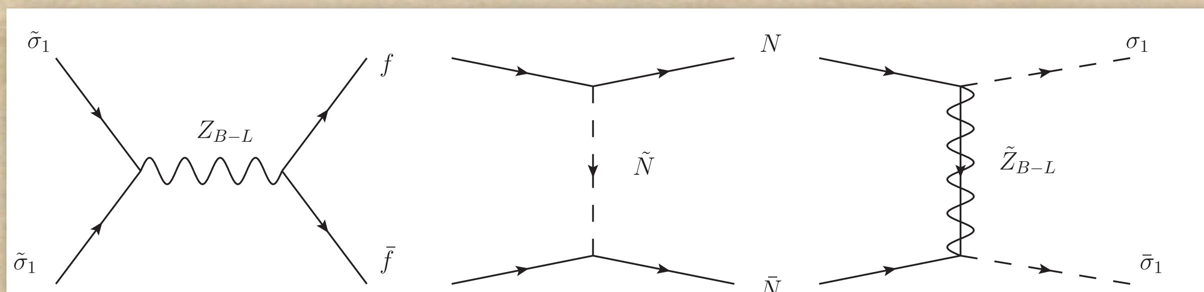
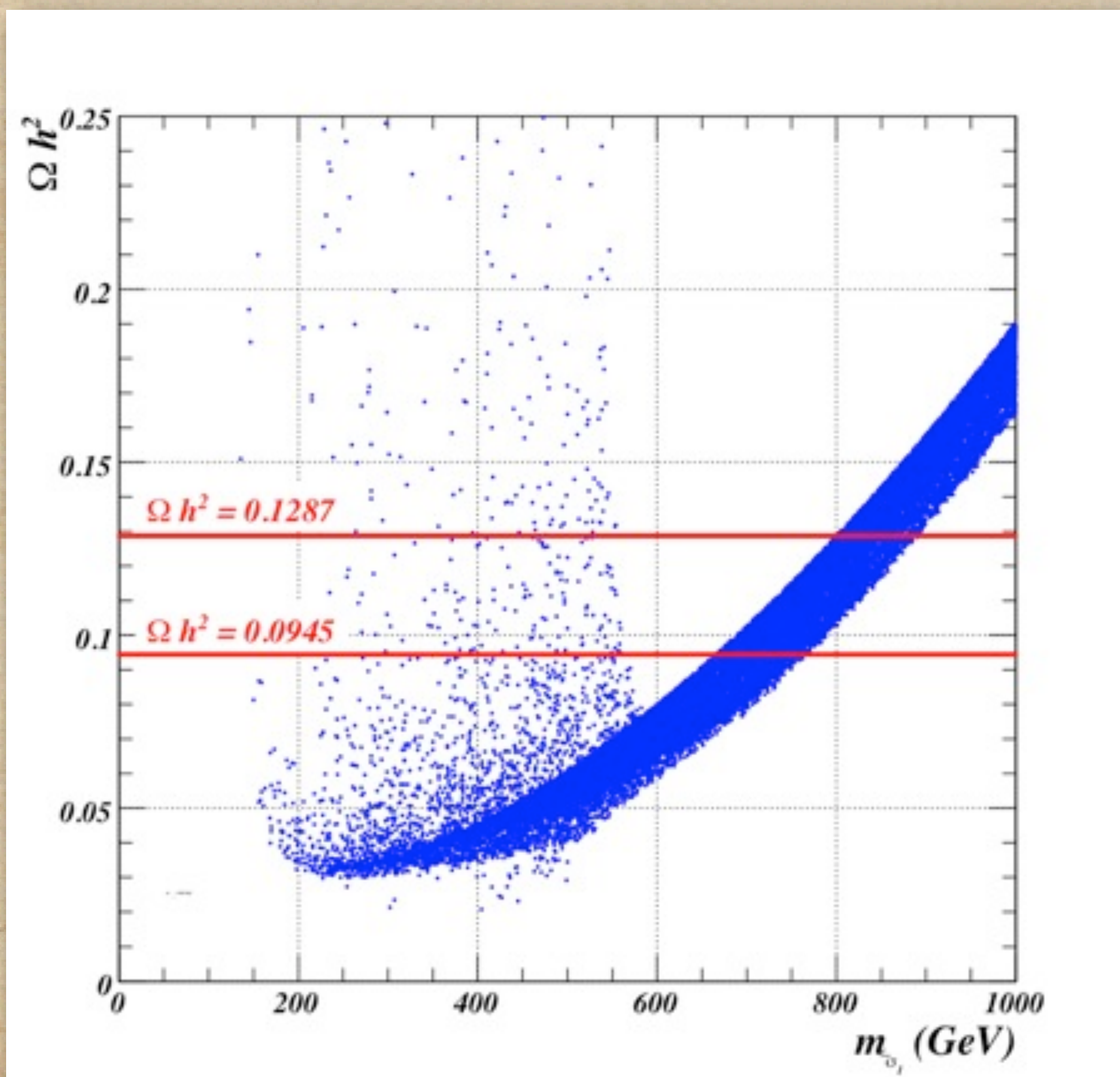
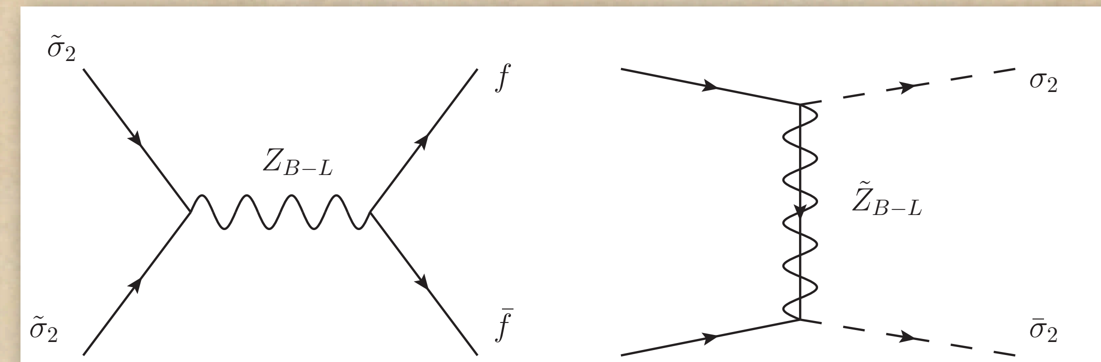
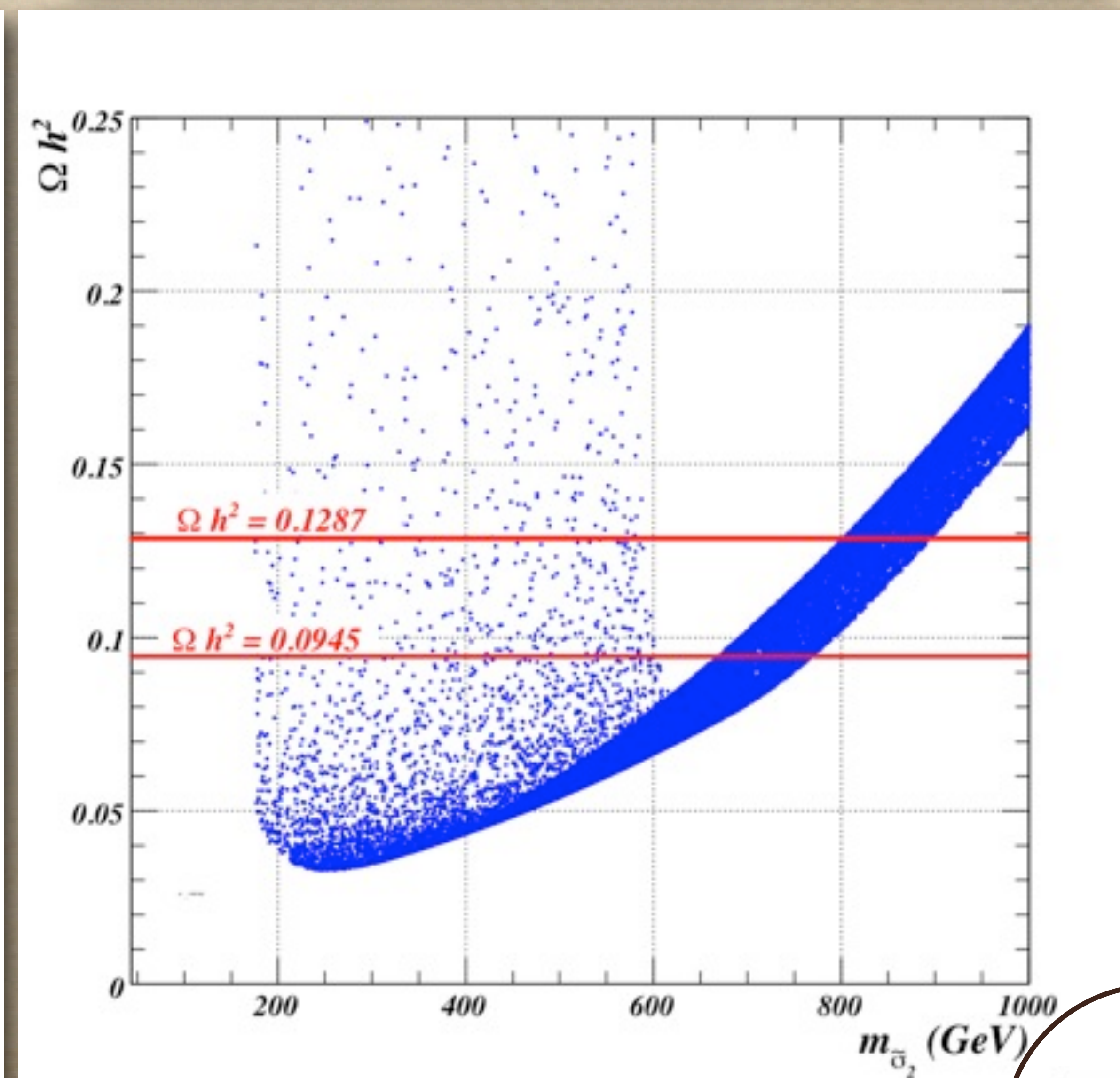




And, if the DM composition is $\tilde{\sigma}_2$ dominated, thus,





Conclusions

- We have studied the supersymmetric extension of a gauge group, where we have added a RHN superfield, and two extra B-L Higgs.
- We solved the renormalization group equations for all the parameters of the model.
- Breaking of B-L is mediated by the sneutrino fields. Its vev at low energies is under control due to contributions of all sparticles.
- By applying a double see-saw procedure, neutrinos can acquire a mass which can solve some problems in neutrino phenomenology.
- We have studied the contribution to the relic density by considering that the B-L sector contains the LSP.

- Thank you...