Supersymmetric gauged $U(1)_B \times U(1)_L$ *Model*

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with

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Contents

1. Introduction

- We discuss supersymmetric model with $U(1)_B$ and $U(1)_L$ gauge symmetries.
- Baryon symmetry and Lepton symmetry forbid the operator to cause proton decay. However, they must be broken to realize Baryon asymmetry.

- Our scenario is …

  The both symmetries are broken around TeV scale.

  (We do not discuss U(1)L sector in this talk.)

- *T.R. Dulaney*, *P. F. Perez*, and *M.B. Wise* suggested the non-SUSY model with $U(1)_B \times U(1)_L$. (1002.1754;1005.0617[hep-ph])

  They discussed how to realize Baryon asymmetry, and found that **the extension of $U(1)_B$ symmetry naturally gives a cold dark matter (CDM) candidate**.

- In the experiments concerned with DM, there are many signals which we can expect to relate to DM physics. The direct searches (*DAMA, CoGeNT etc.*) suggest light DM, and the indirect (*PAMELA etc.*) heavy DM.

- The extension of MSSM to $U(1)_B$ and $U(1)_L$, we discuss here, provides several DM candidates. Our model provides DM physics and experiments with interesting observations.

Furthermore, this model suggests a lot of interesting aspects, such as higgs physics, flavor physics and so on.

In this talk, I introduce DM candidates and focus on ~7GeV CDM, discussed in 1007.1005 [hep-ph] by Hooper, Collar, Hall and McKinsey .

Then we discuss several experimental constraints.

2. $U(1)_B \times U(1)_L$ Model

In MSSM, Baryon symmetry and Lepton symmetry are good symmetries at classical level.

$$U(1)_B : Q^i \to e^{\frac{ig_B}{3}} Q^i, U^i \to e^{\frac{-ig_B}{3}} U^i$$

$$U(1)_L : L^i \to e^{ig_L} L^i, E^i \to e^{-ig_L} E^i$$

However, these symmetries are anomalous,

$$SU(2)^2 U(1)_B = \frac{3}{2}, \quad U(1)_Y^2 U(1)_B = -\frac{3}{2}$$

$$SU(2)^2 U(1)_L = \frac{3}{2}, \quad U(1)_Y^2 U(1)_L = -\frac{3}{2}$$

where right-handed neutrino, N_i, are added.

Extra chiral superfields must be added to built gauged B and L model.

field contents

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

Field	Charges	Fields	Charges
Q^i	$(3, 2, 1/6; 1/3, 0)$	Q'	$(\bar{3}, 2, -1/6; -1, 0)$
U^i	$(\bar{3}, 1, -2/3; -1/3, 0)$	U'	$(3, 1, 2/3; 1, 0)$
D^i	$(\bar{3}, 1, +1/3; -1/3, 0)$	D'	$(3, 1, -1/3; 1, 0)$
L^i	$(1, 2, -1/2; 0, 1)$	L'	$(1, 2, 1/2; 0, -3)$
E^i	$(1, 1, 1; 0, -1)$	E'	$(1, 1, -1; 0, 3)$
N^i	$(1, 1, 0; 0, -1)$	N'	$(1, 1, 0; 0, 3)$
H_u	$(1, 2, 1/2; 0, 0)$	H_d	$(1, 2, -1/2; 0, 0)$
X_B	$(1, 1, 0; 2/3, 0)$	$\overline{X_B}$	$(1, 1, 0; -2/3, 0)$
S_L	$(1, 1, 0; 0, 2)$	$\overline{S_L}$	$(1, 1, 0; 0, -2)$
S_B	$(1, 1, 0; n_B, 0)$	$\overline{S_B}$	$(1, 1, 0; -n_B, 0)$
X_L	$(1, 1, 0; n_L, 0)$	$\overline{X_L}$	$(1, 1, 0; -n_L, 0)$

Extra Quarks (chirality is opposite.)

They break U(1)L and U(1)B.

$n_B \neq \pm\frac{2}{3}, n_L \neq \pm 2$ to forbid couplings between SM particles and $S_B(\bar{S}_B), X_L(\bar{X}_L)$.

Superpotential for extra superfields

The difference is only chirality.
Extra quark and lepton mass terms are

Quark sector: $Y_u^{'} Q^{'} U^{'} H_d + Y_d^{'} Q^{'} D^{'} H_u$

Lepton sector: $Y_l^{'} L^{'} E^{'} H_u + Y_\nu^{'} L^{'} N^{'} H_d$

In order to avoid stable charged particles and generate neutrino masses, the couplings between extra B and L symmetric superfields and MSSM fields are given by

$$\lambda_{Qi} X_B Q^{'} Q^i + \lambda_{Ui} \overline{X_B} U^{'} U^i + \lambda_{Di} \overline{X_B} D^{'} D^i$$

$$\lambda_{Ei} \overline{S_L} E^{'} E_i + \lambda_i S_L L^{'} L_i + \lambda_{ij} N^i N^j S_L + \lambda_{Ni} N_i \overline{S_L} N^{'}$$

Assumptions to avoid large FCNC are

$$\langle X_B \rangle = \langle \overline{X}_B \rangle = 0$$

$$\langle S_L \rangle, \langle \overline{S}_L \rangle \neq 0, \quad \lambda_{Ei}, \lambda_i \approx 0$$

3. CDM in the $U(1)_B \times U(1)_L$ Model

The symmetries of cold dark matter (CDM)

1) The B and L charges of S_B and S_L are $n_B=2k/3$ $(k=2,3,\ldots)$ and $n_L=2k$ $(k=2,3,\ldots)$,

$U(1)_B$ breaking: $\langle S_B \rangle, \langle \bar{S}_B \rangle \neq 0 \Longrightarrow Z_2^B$

$U(1)_L$ breaking: $\langle S_L \rangle, \langle \bar{S}_L \rangle \neq 0 \Longrightarrow Z_2^L$

$\Big\}$ ***R-parity*** $(-1)^{3B+L+2j}$

R-parity even: q, X_B, S_B, S_L

odd: $\tilde{q}, \tilde{X}_B, \tilde{S}_B, \tilde{S}_L$

2) Global $U(1)$ symmetries can be assigned, because of

$$\langle X_B \rangle = \langle \bar{X}_B \rangle = 0, \langle X_L \rangle = \langle \bar{X}_L \rangle = 0.$$

$U(1)_{XB}$: $X_B \to e^{i\alpha} X_B, Q' \to e^{-i\alpha} Q', U' \to e^{-i\alpha} U'$

$U(1)_{XL}$: $X_L \to e^{i\alpha} X_L, \bar{X}_L \to e^{-i\alpha} \bar{X}_L$

five candidates for DM

$$(\lambda_B, \tilde{S}_B, \overline{\tilde{S}_B}) \Rightarrow \chi_B^1$$

$$(\lambda_L, \tilde{S}_L, \overline{\tilde{S}_L}) \Rightarrow \chi_L^1$$

$$\left(\tilde{B}, \tilde{W}^3, \tilde{H}_u, \tilde{H}_d\right) \Rightarrow \hat{\chi}_1^0$$

χ_1^0 **(Lightest component)**

There is mixing at one-loop.

$$\left(X_B, \overline{X}_B{}^*\right) \Rightarrow X_B^l$$ **(Lightest complex scalar)**

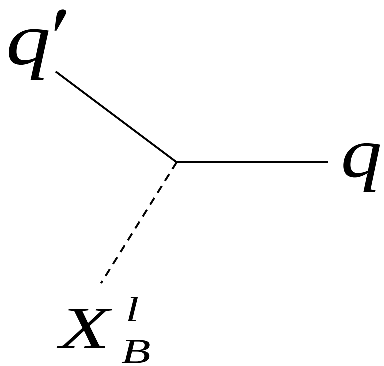
$$\left(\tilde{X}_B, \overline{\tilde{X}}_B{}^+\right) \Rightarrow \tilde{X}_B$$ **((U(1)XB charged) dirac fermion)**

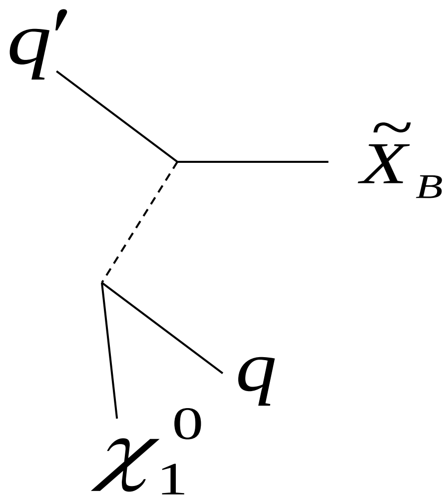
$$\left(X_L, \overline{X}_L{}^*\right) \Rightarrow X_L^l$$ **(Lightest complex scalar)**

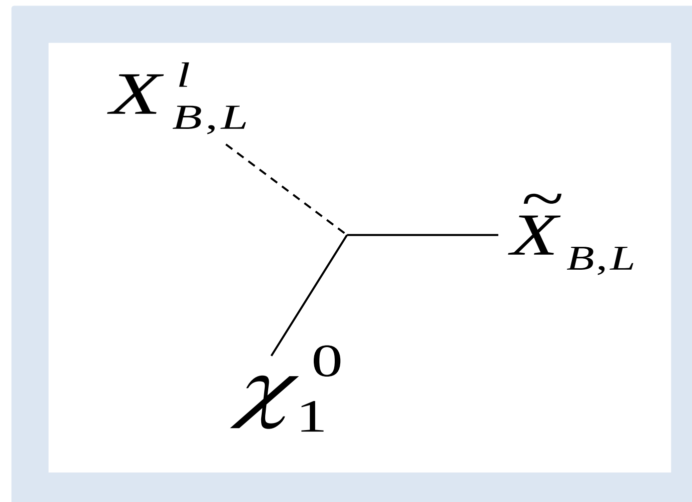
$$\left(\tilde{X}_L, \overline{\tilde{X}}_L{}^+\right) \Rightarrow \tilde{X}_L$$ **((U(1)XL charged) dirac fermion)**

- 3 particles of them can be stable, because of 3 global symmetries, *U(1)XB*, *U(1)XL*, and *R-parity*.

- ***Important vertex***





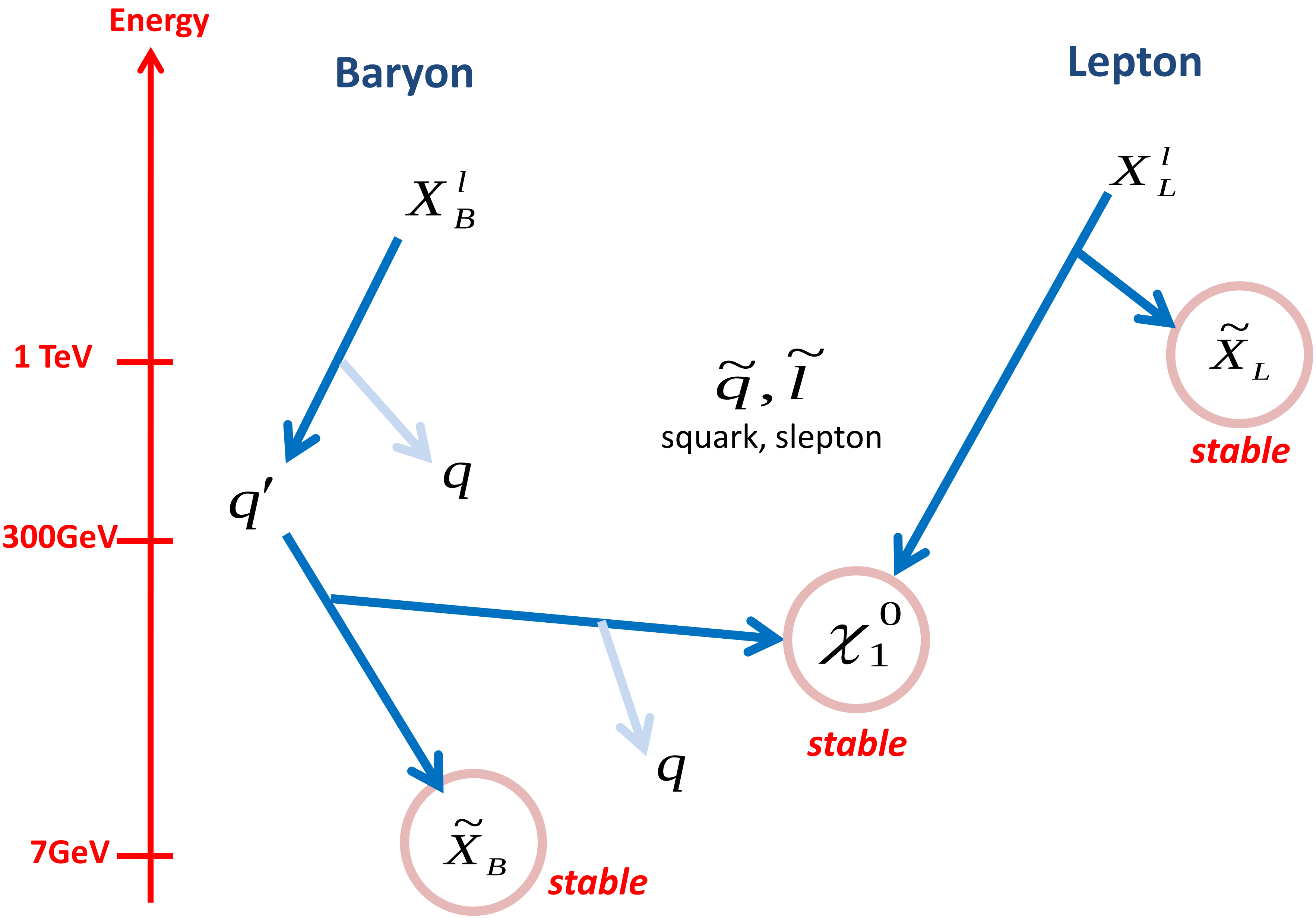


2 of 5 decay to 2 CDM.

- ➢ *q'* limits the masses of CDM.
- ➢ *q'* is charged under U(1)XB, so at least one of X_B^l and $\tilde{X}_B$ must be smaller than *q'*.
- ➢ R-parity of *q'* is even, so it cannot decay to only $\tilde{X}_B$ and quarks.

<u>I introduce the scenario that $\tilde{X}_B$ is the lightest.</u>
We assume that SUSY particles, such as squarks and sleptons, are very heavy, around 1 TeV.

Example



Energy
1 TeV
300GeV
7GeV
Baryon
Lepton
X_B^l
X_L^l
q'
q
q
$\tilde{q}, \tilde{l}$
squark, slepton
$\tilde{X}_L$
stable
χ_1^0
stable
$\tilde{X}_B$
stable

4. ~ 7 GeV Dark Matter

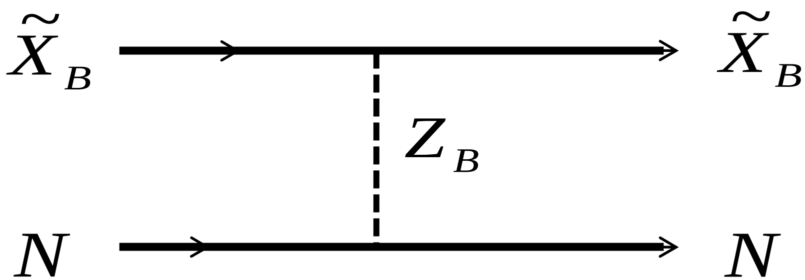
- D. Hooper, J.I. Collar, J. Hall and D. McKinsey (1007.1005 [hep-ph]) suggest

$$m_{DM} \cong 7GeV, \quad \sigma_{SI} \cong 2\times 10^{-40}\, cm^2.$$

- *Direct detection vs Relic density* due to vector current coupling

Direct detection

U(1)B charged particles scatters with Nuclei through *ZB* boson (*squark'*),



χ_1^0 also scatters

$$g_B^2 \Leftrightarrow g_B^2\left(\left|U_{S_B 1}\right|^2 + \left|U_{\bar{S}_B 1}\right|^2\right)$$

$$\sigma_{SI} = BQ_X^2 Q_N^2 \frac{\mu_X^2}{\pi}\left(\frac{g_B}{M_{Z_B}}\right)^4 \Leftrightarrow \left(\frac{g_B}{M_{Z_B}}\right)^4 = \frac{\sigma_{SI}\pi}{\mu_X^2 Q_X^2 Q_N^2 B}$$

Roughly, $\frac{M_{Z_B}}{g_B} \sim O(TeV)$. It must explain relic density, $\Omega h^2_{CDM} \cong 0.11.$

Relic density

$$\frac{dn_X}{dt}+3Hn_X=-\langle\sigma v\rangle\left(n_X^2-n_{eq}^2\right)$$

As well known, the Boltzmann equation is approximatelly estimated as

$$\Omega h^2\cong 0.1\times\left(\frac{1pb}{\langle\sigma v\rangle}\right).$$

Annihilation cross section of $\tilde{X}_B$ through *ZB* boson is

$$\sigma v\cong\frac{A_{an}\left(m_{DM},M_{Z_B}\right)Q_X^2}{\pi}\left(\frac{g_B}{M_{Z_B}}\right)^4\left(m_{DM}^2\sum_q Q_q^2+\cdots\right)$$

S-wave

Boson case is p-wave,
no S-wave.

Direct scattering leads

$$\Omega h^2\simeq O(10)\times\left(\frac{BQ_N^2}{A_{an}\sum Q_q^2}\right)$$

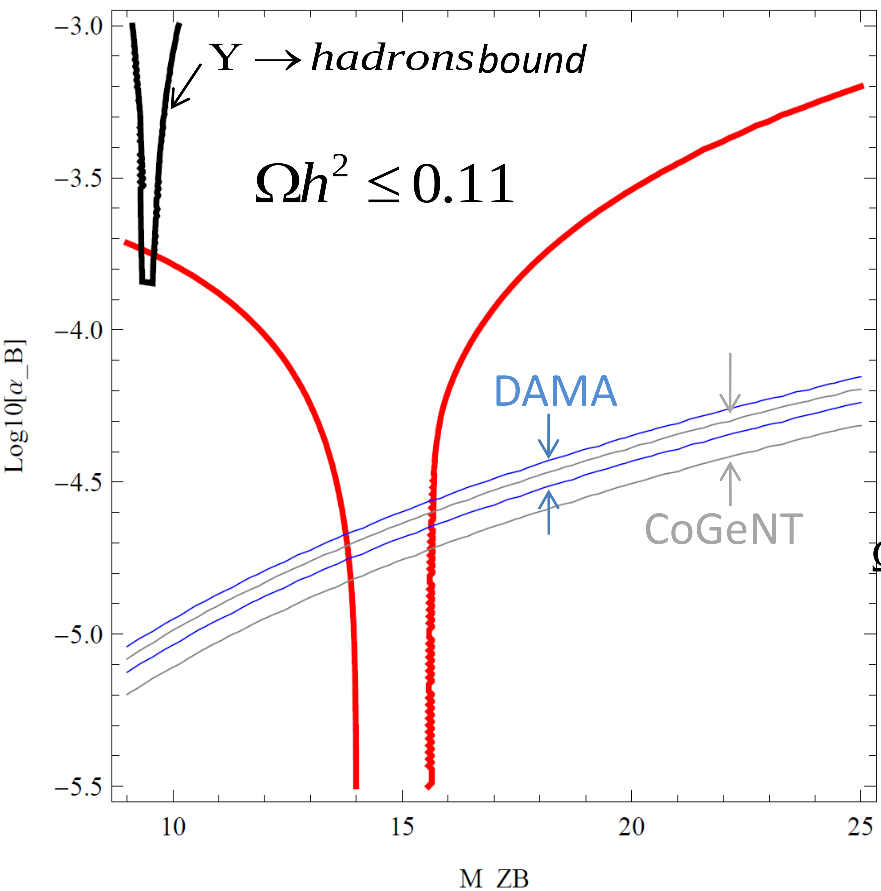
for $m_{DM}\cong 7GeV.$

$B=1$, for dirac fermion and boson

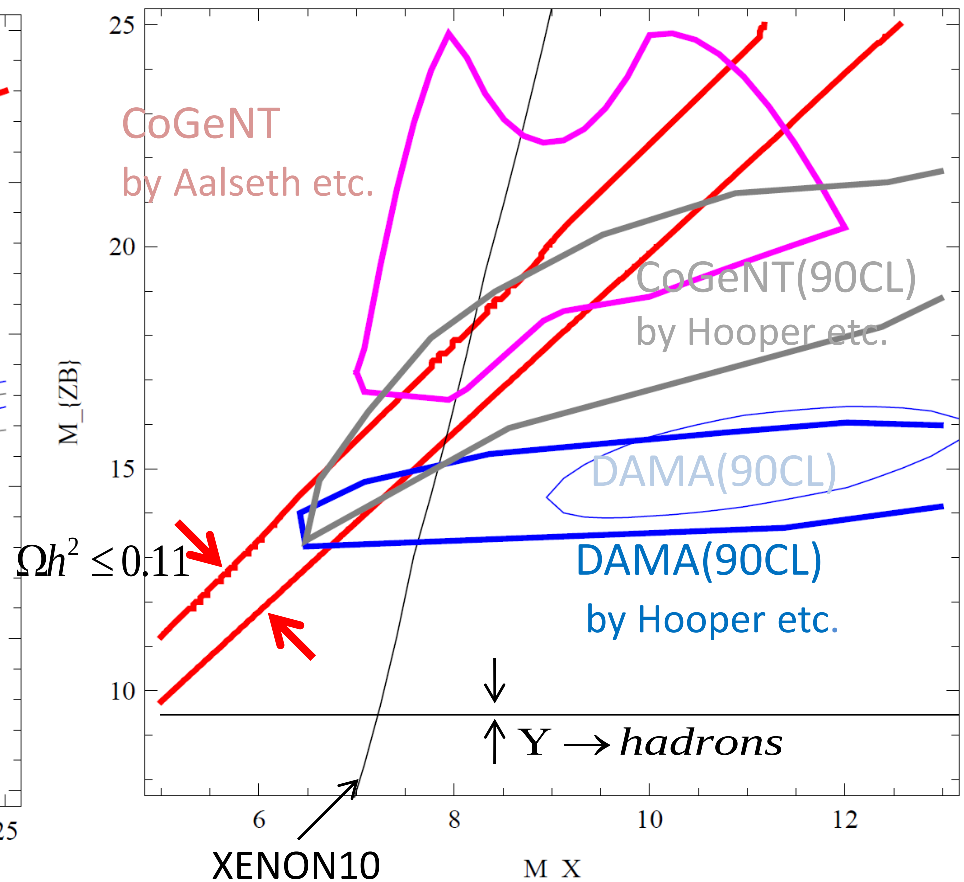
$A_{an}\left(m_{DM},M_{Z_B}\right)$ must be large to explain the relic density, around 0.11.

We use resonance enhancement.

g_B vs M_{Z_B} (m_X=7 GeV)



m_X vs M_{Z_B} ($\alpha_B \sim 2\times10^{-5}$)



$$A_{an}\left(m_{DM}, M_{Z_B}\right) = \frac{M_{Z_B}^4}{\left(M_{Z_B}^2 - m_X^2\right)^2 + M_{Z_B}^2 \Gamma_{Z_B}^2} \geq O(10)$$

Very small mass and coupling are required,

$$\alpha_B \sim 2\times10^{-5}, M_{Z_B} \sim 2m_X .$$

5. Constraints

- Constraints on very light Z_B boson mass have been discussed.
- For example, the hadoronic decay width of Z boson require $\alpha_B < 0.2$. Upsiron decay to hadrons gives the strongest constraint.

(PRL74,3122(1995) by C.D.Carone and H. Murayama, PLB443, 352(1998) by A.Aranda and C.D.Carone.)

Our model has enough small *U(1)B* gauge coupling.

- On the other hand, kinematic mixing must be enough small to avoid conflicts with experiments.

$$Tr\left(BY\right) \neq 0$$

- Other stable particles also contribute to the relic density. There are a lot of arguments about heavy DM and scalar DM,

Scalar DM with yukawa:PLB670,37(2008) by J.L.Feng, J.Kumar, L.E.Strigari

MSSM DM: PR267,195(1996), by G.Jungman, M.Kamionkowski, K.Griest, etc.

- Our model predicts very light scalar.

$\left(S_B, \bar{S}_B\right)$, which correspond to Higgs, give this lightest scalar.

$$m_{S1}^2 \le M_{Z_B}^2 \cos^2 2\beta_B + \alpha_B M_{Z_B}^2 \cos^2 2\beta_B f\left(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2\right)$$

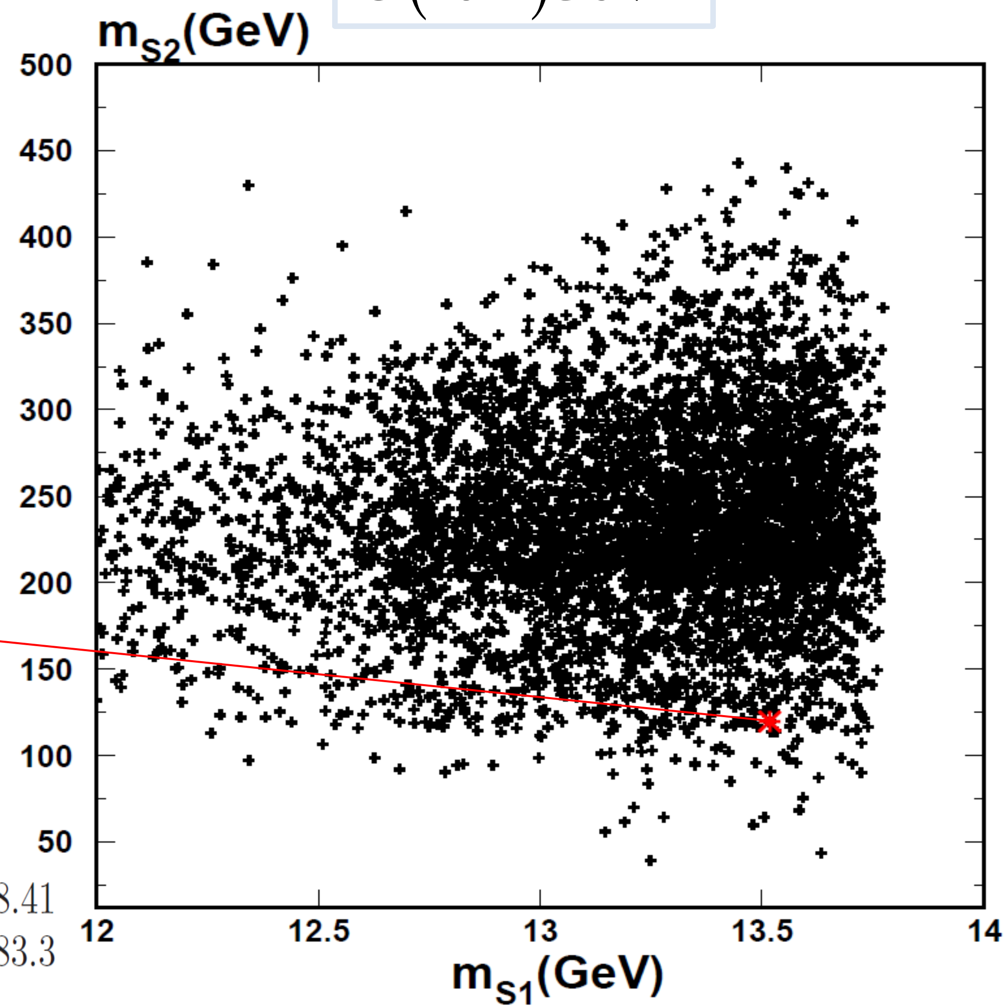
$O\left(10^{-3}\right) GeV^2$

- They do not couple with SM particles at tree level.
- The one-loop corrections are also strongly suppressed by small *U(1)B* coupling.

ex)

S_i	m_{S_i} GeV	$C^2_{S_i ZZ}$
S_1	13.5	0.506×10^{-7}
S_2	119.7	0.931×10^{-1}
S_3	283.3	0.100×10^{-6}
S_4	396.4	0.203
S_5	398.1	0.70257
S_6	495.8	0.114×10^{-2}

TABLE: $\sum_{i=1}^{6} C^2_{S_i ZZ} = 1$, $m_{t'} = 309.7$ GeV, $m_{b'} = 368.41$ GeV, $m_{\tau'} = 499.7$ GeV, $m_{P_H} = 297.0$ GeV, $m_{P_B} = 283.3$ GeV, $m_{P_L} = 401.1$ GeV.



6. Summary

- We discussed supersymmetric model with $U(1)_B \times U(1)_L$ gauge symmetries.
- This model provides a lot of interesting topics, such as Flavor physics, Higgs physics, dark matter, and so on. I introduced DM physics related to direct detections.
- There are several candidates for CDM and several scenarios. In any cases, 3 stable particles appear.
- In order to explain ~7GeV CDM of CoGeNT/DAMA, we considered very light Z_B mass and the resonance effect. $U(1)_B$ gauge coupling is also very small,

$$\alpha_B \sim 2\times 10^{-5}, M_{Z_B} \sim 2m_{DM}.$$

- I introduced several constraints, especially the predicted light scalar.