Little Higgs Model with U-parity and Dark Matter

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Motivations

- T-parity in the little higgs models suffers from the known Wess-Jumino-Witten(WZW) terms which contain anomalies from UV physics of a given model so that this parity can be broken.

- Because this T-parity makes a lowest mass T-parity odd particle stable and a dark matter candidate, we need another mechanism instead of this T-parity.

U-parity

- This U-parity is a residual discrete gauge symmetry after spontaneous symmetry breaking.

- Therefore this discrete symmetry can give a dark matter candidate which is different from that of T-parity.
  (for example, the that of the Littlest Higgs model is B' gauge boson.)

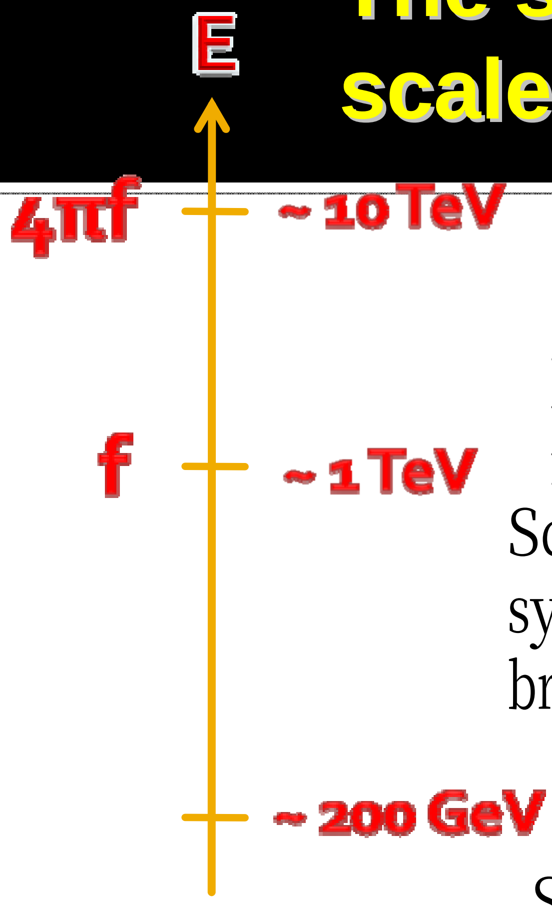
- U-parity does not suffer from the WZW terms, that is to say this parity does not be broken under the UV-anomaly.

Mini little higgs(MLH)

Mini Little Higgs and Dark Matter.
Yang Bai
Phys.Lett.B666:332-335,2008

- For the simplicity we use Mini little higgs model. This model has the most minimal extension of the gauge group of the standard model(SM).
- This model only has additional top partner ψ, singlet scalar S and massive gauge boson Z'.
- Unlike the Littlest Higgs model since there is no counter partner which cancels the contributions from the charged gauge bosons Ws, we use different method.
- This method is that we use U(1) charge assignments of the singlet S to make the cut-off squared contribution to the Higgs mass smaller than the logarithmical divergence part.

The symmetries and energy scale of the MLH



Cut-off Scale of the Mini little higgs model

Scale of global symmetry breaking

Scale of Electro-Weak symmetry breaking

$$SU_{EW}(2) \times U(1)_1 \times U(1)_2$$

$$\downarrow$$

$$SU_{EW}(2) \times U_Y(1) \times Z_2$$

$$\downarrow$$

$$U_Q(1) \times Z_2$$

Charge assignments on particle spectrum

Fields	$SU(3)$	$SU(2)_L$	$U(1)_1$	$U(1)_2$	Y	Q
$Q_L = \begin{pmatrix} t_L \\ b_L \end{pmatrix}$	3	2	$z_1[Q]$	$z_2[Q]$	$\frac{1}{6}$	$\frac{2}{3}, -\frac{1}{3}$
t_R	3	1	$z_1[t_R]$	$z_2[t_R]$	$\frac{2}{3}$	$\frac{2}{3}$
b_R	3	1	$z_1[b_R]$	$z_2[b_R]$	$-\frac{1}{3}$	$-\frac{1}{3}$
$E_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	2	$z_1[E_L]$	$z_2[E_L]$	$-\frac{1}{2}$	0,-1
ν_R	1	1	$z_1[\nu]$	$z_2[\nu]$	0	0
e_R	1	1	$z_1[e_R]$	$z_2[e_R]$	-1	-1
ψ_L	3	1	$z_1[\psi_L]$	$z_2[\psi_R]$	$\frac{2}{3}$	$\frac{2}{3}$
ψ_R	3	1	$z_1[\psi_R]$	$z_2[\psi_R]$	$\frac{2}{3}$	$\frac{2}{3}$
$H = \begin{pmatrix} h+ \\ h^0 \end{pmatrix}$	1	2	$z_1[H]$	$z_2[H]$	$\frac{1}{2}$	1,0
S	1	1	$z_1[S]$	$z_2[S]$	0	0
X_1	1	1	$z_1[X_1]$	$z_2[X_1]$	0	0
X_2	1	1	$z_1[X_2]$	$z_2[X_2]$	0	0

Requirements of applying for U-parity in the MLH

- All particles including additional particles (ψ, S and Z') and dark matter candidates(X) satisfy following conditions to assign suitable U(1) charges.

- Yukawa couplings (Yukawa constraints).
  These couplings contain the top partner ψ and singlet S to cancel the contributions from top quark to higgs boson mass.

- Anomaly cancellation conditions.
  In addition to free of gauge anomaly for each U(1)
  we need to check mixed anomaly cancellation conditions (U(1)-U(1)').

Yukawa couplings (or constraints)

- Because of hypercharge relations, $H_1 : \quad z_1[F] + z_2[F] = Y_F$
  we just have to check on U(1)' sector. If U(1)' charge assignments satisfy anomaly cancellation conditions (B1,B2,B3,B4), automatically U(1) charge assignments satisfy own anomaly cancellation parts (A1,A2,A3,A4)

$$\mathcal{L}_{Yukawa,\ SM} = y_1\ \bar{Q}_L \tilde{H} t_R + \lambda_b\ \bar{Q}_L H b_R + \lambda_e\ \bar{E}_L H e_R + \lambda_\nu \bar{E}_L \tilde{H} \nu_R + h.c$$

$$Y_U \ : \quad -z_i[Q_L] - z_i[H] + z_i[t_R] = 0$$

$$Y_D \ : \quad -z_i[Q_L] + z_i[H] + z_i[b_R] = 0$$

$$Y_E \ : \quad -z_i[E_L] + z_i[H] + z_i[e_R] = 0$$

$$Y_N \ : \quad -z_i[E_L] - z_i[H] + z_i[\nu_R] = 0$$

$$\mathcal{L}^{additional}_{Yukawa} = y_1 \bar{\psi}_L S t_R + y_2 f \bar{\psi}_L \psi_R + h.c$$

$$Y_S \ : \quad -z_i[\psi_L] + z_i[S] + z_i[t_R] = 0$$

Dark matter candidates and Yukawa constraints

Mass terms of Majorana fermion,

$$\mathcal{L} = \lambda_{X,i} S \left(X_i^T C^{-1} X_i \right) + h.c$$

Yukawa constraints of mass terms above,

$$Y_X : \quad z_i[S] + 2z_i[X_i] = 0$$

Mass terms of Dirac fermion,

$$\mathcal{L}_{Dirac} = \lambda_{X,i} S \bar{X}_{i,L} X_{i,R} + h.c.$$

Yukawa constraints of mass terms above,

$$Y_{Xd} : \quad z_i[S] - z_i[X_{i,L}] + z_i[X_{i,R}] = 0 \ .$$

In Majorana case,
these fermions always have the half of z_2[S] charge so that these have Z_2 odd parity under z_2[S] mod 2 automatically.
These must be stable.
In other hand,

Dirac fermions can have arbitrary z_2[S] charge and may not be stable.

Anomaly cancellation conditions

Identifier	Anomaly	Anomaly cancelation condition
A_1	$U(1)_1 - [SU(2)_L]^2$	$\mathrm{tr}[z_1\tau^a\tau^b] = \frac{1}{2}\delta^{ab}\sum_{f_L} Z_{1,f_L}=0$ (doublet fermions only)
A_2	$U(1)_1 - [SU(3)_C]^2$	$\mathrm{tr}[z_1 t^a t^b] = \frac{1}{4}\delta^{ab}\sum_{q} Z_{1,q}=0$ (color triplet fermions only)
A_3	$U(1)_1 - [\mathrm{gravity}]^2$	$\mathrm{tr}[z_1] = \sum_f z_{1,f}=0$ ($U(1)_1$-charged fermion only)
A_4	$[U(1)_1]^3$	$\mathrm{tr}[z_1^3] = \sum_f z_{1,f}^3=0$ ($U(1)_1$-charged fermion only)
B_1	$U(1)_2 - [SU(2)_L]^2$	$\mathrm{tr}[z_2\tau^a\tau^b] = \frac{1}{2}\delta^{ab}\sum_{f_L} Z_{2,f_L}=0$ (doublet fermions only)
B_2	$U(1)_2 - [SU(3)_C]^2$	$\mathrm{tr}[z_2 t^a t^b] = \frac{1}{4}\delta^{ab}\sum_{q} Z_{2,q}=0$ (color triplet fermions only)
B_3	$U(1)_2 - [\mathrm{gravity}]^2$	$\mathrm{tr}[z_2] = \sum_f z_{2,f}=0$ ($U(1)_2$-charged fermion only)
B_4	$[U(1)_2]^3$	$\mathrm{tr}[z_2^3] = \sum_f z_{2,f}^3=0$ ($U(1)_2$-charged fermion only)
C_1	$[U(1)]^2 - U(1)_2$	$\mathrm{tr}[z_1^2 z_2] = \sum_f z_{1,f}^2\, z_{2,f}=0$
C_2	$U(1) - [U(1)_2]^2$	$\mathrm{tr}[z_1 z_2^2] = \sum_f z_{1,f}\, z_{2,f}^2=0$

General solutions from constraints.

$$\begin{pmatrix} z_2[Q_L] \\ z_2[t_R] \\ z_2[b_R] \\ z_2[E_L] \\ z_2[\nu_R] \\ z_2[e_R] \\ z_2[\psi_{L,R}] \\ z_2[H] \\ z_2[S] \end{pmatrix} = \frac{l_2}{3} \begin{pmatrix} -1 \\ -1 \\ -1 \\ 3 \\ 3 \\ 3 \\ -1 \\ 0 \\ 0 \end{pmatrix} + h_2 \begin{pmatrix} 0 \\ 1 \\ -1 \\ 0 \\ 1 \\ -1 \\ 1 \\ 1 \\ 0 \end{pmatrix} + s_2 \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 1 \end{pmatrix}$$

$$l_2 = z_2[E_L],\ h_2 = z_2[H] \text{ and } s_2 = z_2[S]$$

Simple solution examples

Fields	Q_L	t_R	b_R	E_L	ν_R	e_R	$\psi_{L,R}$	H	S
z_1	$\frac{1}{6}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	0	-1	$-\frac{7}{3}$	$\frac{1}{2}$	$\frac{5}{3}$
z_2	$\frac{1}{6}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	0	-1	-1	$\frac{1}{2}$	$-\frac{5}{3}$
z_1	$\frac{1}{6}$	$\frac{5}{3}$	$-\frac{4}{3}$	$-\frac{1}{2}$	1	-2	$\frac{10}{3}$	$\frac{3}{2}$	$\frac{5}{3}$
z_2	$\frac{1}{6}$	$-\frac{1}{3}$	$\frac{2}{3}$	$-\frac{1}{2}$	-1	0	-2	$-\frac{1}{2}$	$-\frac{5}{3}$

(1) L2=h2=1/2

(2) L2=-h2=1/2

(1) case shows that Z1 and Z2 charges of the particles are the same except ψ and S. So Z' gauge boson does not couple to these particle.

(2) case shows that right-handed particles have the opposite charges. Therefore only these particles can interact to Z' gauge bosons.

Problems

- Since general solutions except dark matter candidates completely satisfy anomaly and Yukawa constraints, dark matter candidates MUST cancel each other from themselves.

  Therefore at least we need two more dark matter fields.

- For the mixed case, Majorana plus Dirac also can not satisfied the anomaly conditions simply.

  We would like to choose minimal case because of minimal choice of d.o.f and simplicity for cancellation of anomalies.

Suggestions to solve these problems

- We may introduce more singlet scalars to avoid that all Majorana particles have the same U(1) charge via Yukawa coupling containing only one singlet S.

- We may introduce more doublet scalars to avoid that all Majorana particles have the same U(1) charge via Yukawa coupling containing only one singlet S.

Charges of the X and S particles

Note that all charges are rescaled by 3/5 to show clear relations among particles.

Fields	$SU(3)$	$SU(2)_L$	$U(1)_1$	$U(1)_2$	Y	Q
X_1	1	1	$-\frac{1}{2}$	$+\frac{1}{2}$	0	0
X_2	1	1	$+\frac{1}{2}$	$-\frac{1}{2}$	0	0
S	1	1	$+1$	-1	0	0
S'	1	1	-1	$+1$	0	0

Z2

Z2

We introduce the additional scalar S' to cancel the anomaly conditions, especially cubic U(1) and U(1)-grav.-grav. , and to make darkmatter candidates X_1 and X_2 stable.

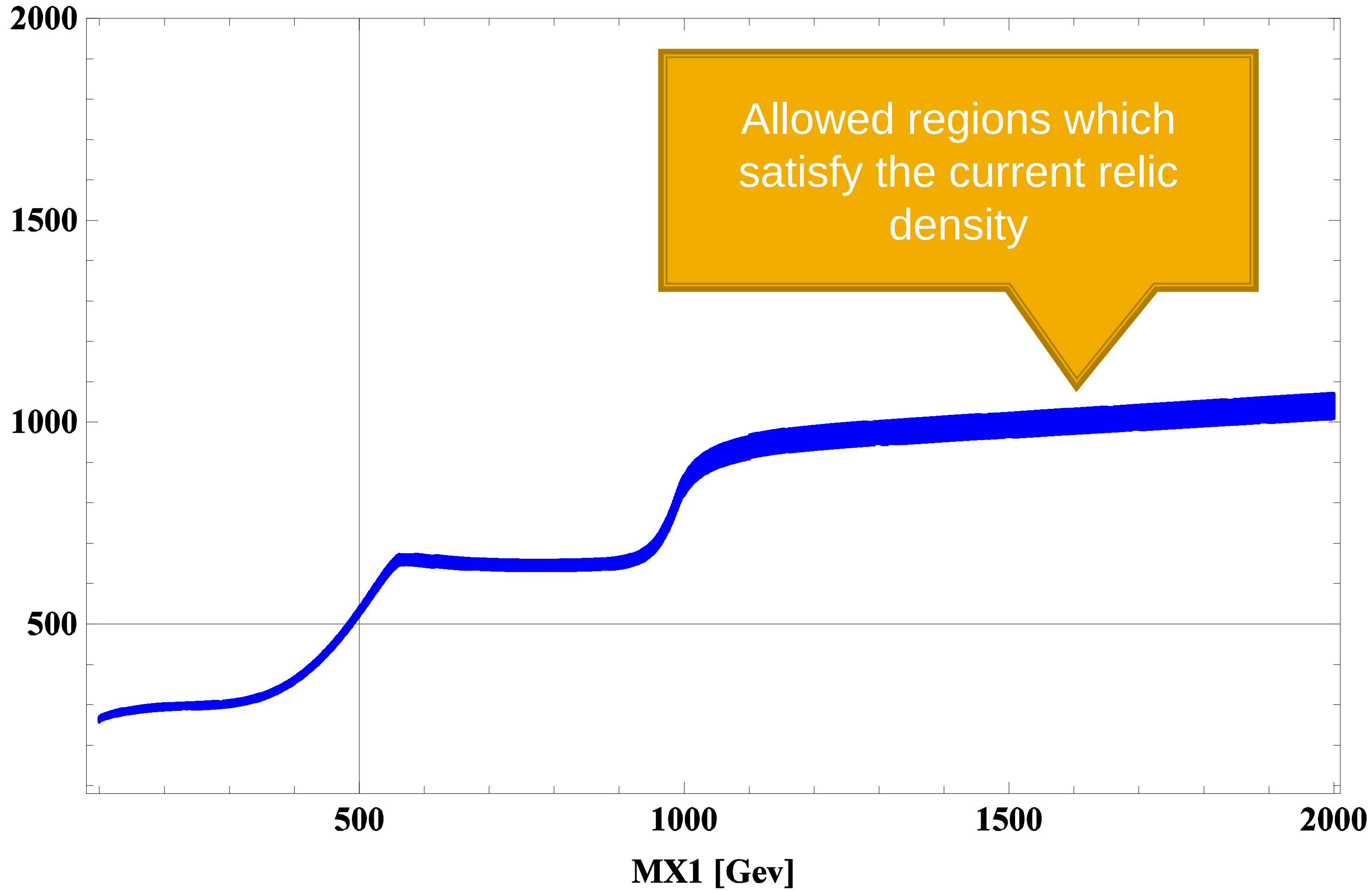
Residual Z2 symmetry (U-parity)

In general Zn naturally emerges after U(1)' is broken due to the vacuum expectation value of the singlet S. We assign the discrete parity as $N = z[S]$, $q[F]$ mod N

	Fields	Q_L	t_R	b_R	E_L	ν_R	e_R	$\psi_{L,R}$	H	S	S'	X_1	X_2
(1) L2=h2=1/2	U_1'	0	0	0	0	0	0	-4	0	10	-10	-5	5
	$\mathbf{U_2}$	1	1	1	1	1	1	1	1	1	1	-1	-1
(2) L2=-h2=1/2	U_1'	0	6	-6	0	6	-6	4	6	10	-10	-5	5
	$\mathbf{U_2}$	1	1	1	1	1	1	1	1	1	1	-1	-1

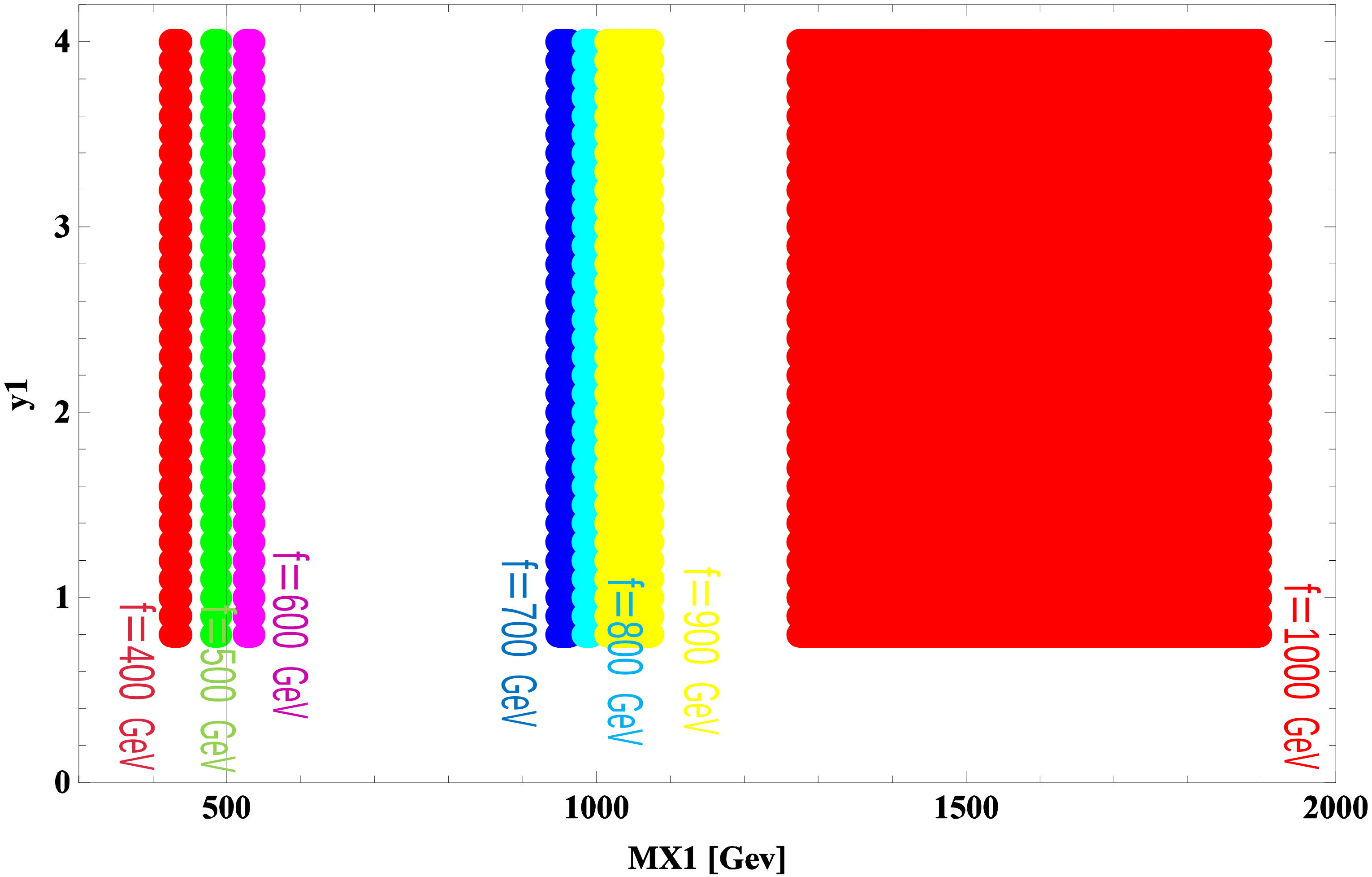
Numerical results and Relic density

Global symmetry breaking scale



The mass of the dark matter candidate X_1

Y1 parameter V.S Mx1



Summary

- We find that general solution sets which does not contain dark matter candidates X satisfy all constraints.

- When the Majorana particles get a mass from the V.E.V of singlets(S,S') via Yukawa couplings, these Majorana particles automatically have Z_2 odd parity under a residual discrete symmetry Z_2 and must be stable.

- In order to satisfy anomaly-free conditions minimaly, we need two right-handed Majorana particles (X_1,X_2).

[redacted]

- We find the sharply allowed parameter space of the Mx_1 and the f scale which satisfy the current relic density.
- We also find the lower bound of the parameter y1 which is connected to mixing and masses for the top and top partner.

Implications

- This U-parity can be obtained by the singlet scalar particles which break the symmetry of the little higgs models so there is a possibilities for the existence of U-parity.
- This parity can also give a different type of dark matter candidates while T-parity gives boson dark matters.