TeV-Scale Seesaw with Loop-Induced Dirac Mass Term and Dark Matter from $U(1)_{B-L}$ Gauge Symmetry Breaking

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S. Kanemura, T.N., H. Sugiyama, Phys. Lett. B703:66–70
S. Kanemura, T.N., H. Sugiyama, Phys. Rev. D 85, 033004

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1.Introduction

WIMP DM: $M_{DM} \sim O(100\text{–}1000)$GeV
U(1)x breaking at (1–10)TeV;
→ naturally explain the dark matter mass.

Neutrino must have tiny masses ($\lesssim O(0.1)$eV)
Right handed neutrino and U(1)x;
→ naturally explain neutrino masses
at O(1–10)TeV physics at loop level.

TeV scale physics cloud explain
mass of dark matter and
tiny neutrino masses.

1.Introduction

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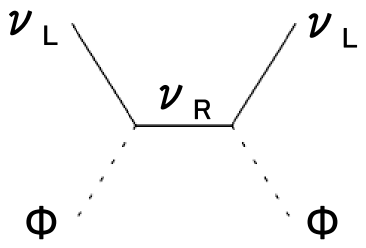
TeV scale physics cloud explain
mass of dark matter and
tiny neutrino masses.

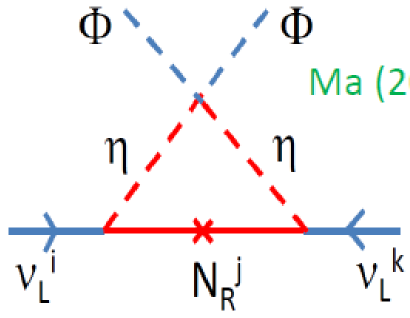
We consider this case

1.Introduction

neutrino masses

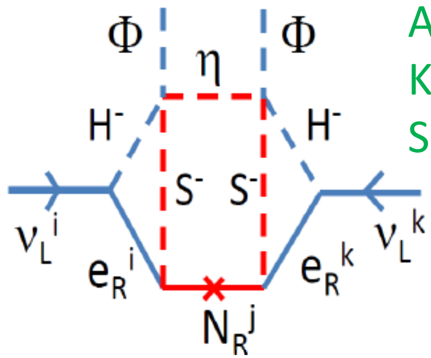


M ∼ O(1) TeV
→ y ∼ O(10^{-6})



Ma (2006)

M ∼ O(1) TeV
→ y ∼ O(10^{-4})



Aoki, Kanemura, Seto(2008)

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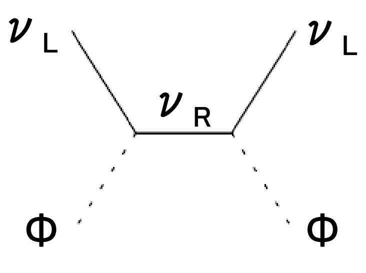
1.Introduction

neutrino masses



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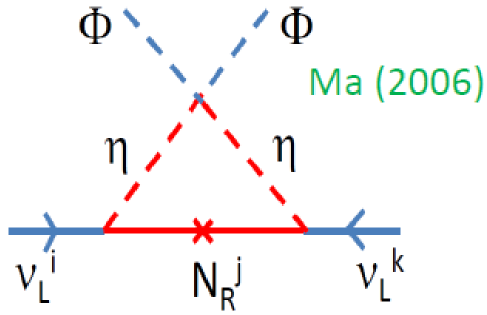

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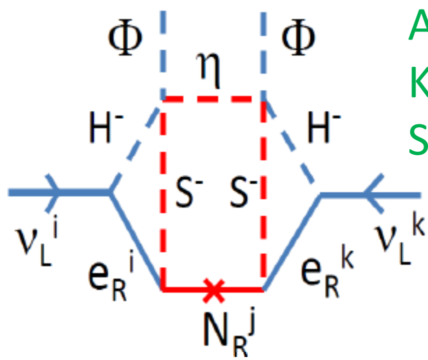

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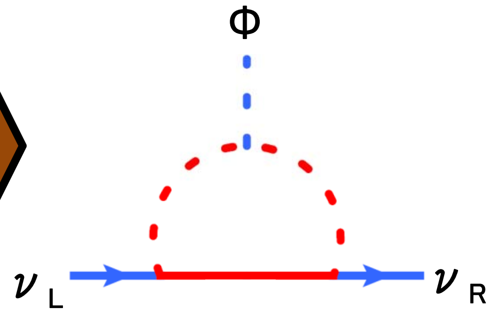

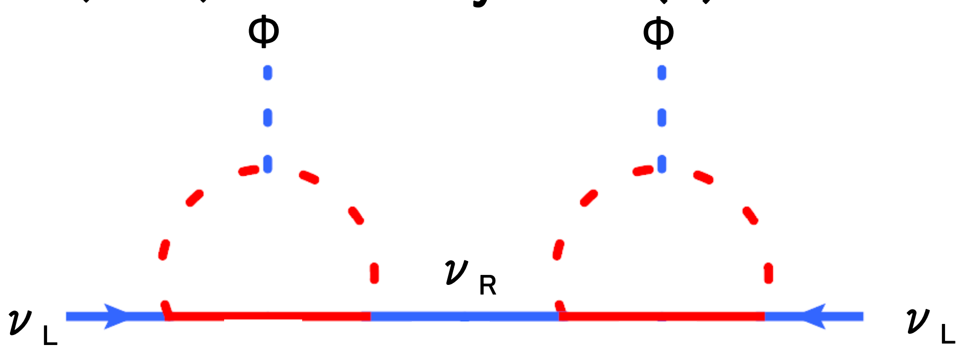

M ∼ O(1) TeV → y ∼ O(10^{-2}–10^{-1})

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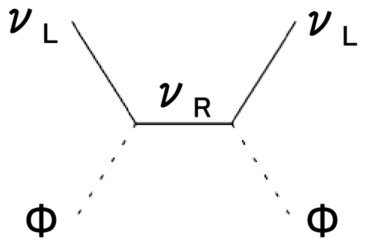
neutrino masses



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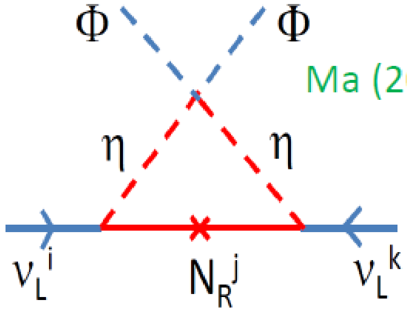

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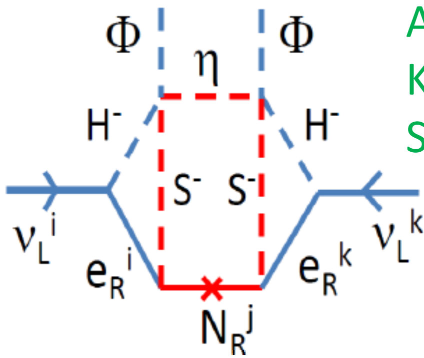

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M ∼ O(1) TeV
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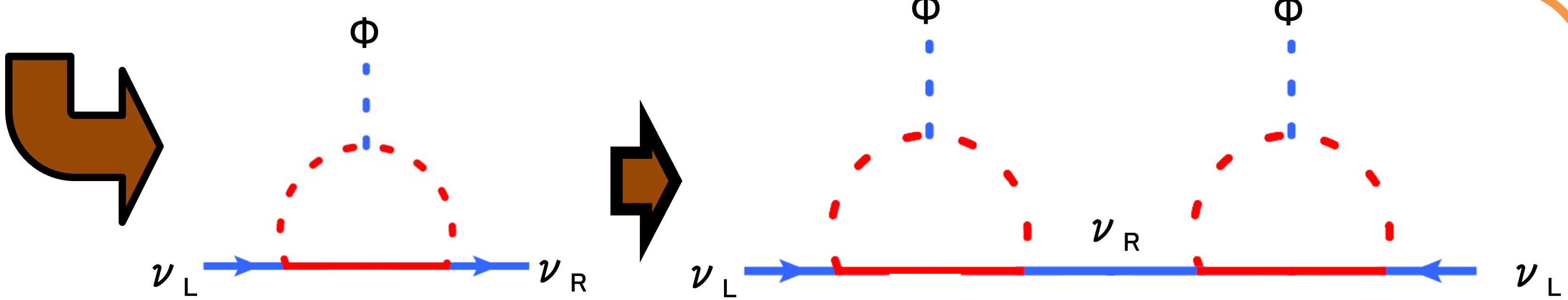


M ∼ O(1) TeV → y ∼ O(10^{-2}–10^{-1})

We consider this case

2.Model

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

	s	η	$(\Psi_R)_i$	$(\Psi_L)_i$	$(\nu_R)_i$	σ
$SU(2)_I$	$\mathbf{\underline{1}}$	$\mathbf{\underline{2}}$	$\mathbf{\underline{1}}$	$\mathbf{\underline{1}}$	$\mathbf{\underline{1}}$	$\mathbf{\underline{1}}$
$U(1)_Y$	0	1/2	0	0	0	0
$U(1)_{B-L}$	1/2	1/2	−1/2	3/2	1	2

- new matter particle:
  - B−L Higgs σ
  - Right handed neutrino $\nu_R^{1,2}$
  - $SU(2)_I$ singlet scalar s
  - $SU(2)_I$ doublet scalar η
  - $SU(2)_I$ singlet chiral fermion $\Psi_{R,L}^{1,2}$

Half unit of $U(1)_{B-L}$ charge

$U(1)_{B-L}$ protect: Tree-level $L\Phi\nu_R$
Majorana mass of ν_R
Dirac mass of Ψ

2.Model

$U(1)_{B-L}$ breaking

- ν_R, Ψ_R and Ψ_L

$$\mathcal{L}_{\text{Yukawa}} = -(y_R)_i \overline{(\nu_R)_i^c} (\nu_R)_i (\sigma^0)^* - (y_\Psi)_i \overline{(\Psi_R)_i} (\Psi_L)_i (\sigma^0)^*$$

$$\rightarrow \frac{(M_R)_{ii}}{2} = (y_R)_{ii} \frac{v_\sigma}{\sqrt{2}}, \qquad (M_\Psi)_{ii} = (y_\Psi)_{ii} \frac{v_\sigma}{\sqrt{2}}.$$

Electroweak symmetry breaking

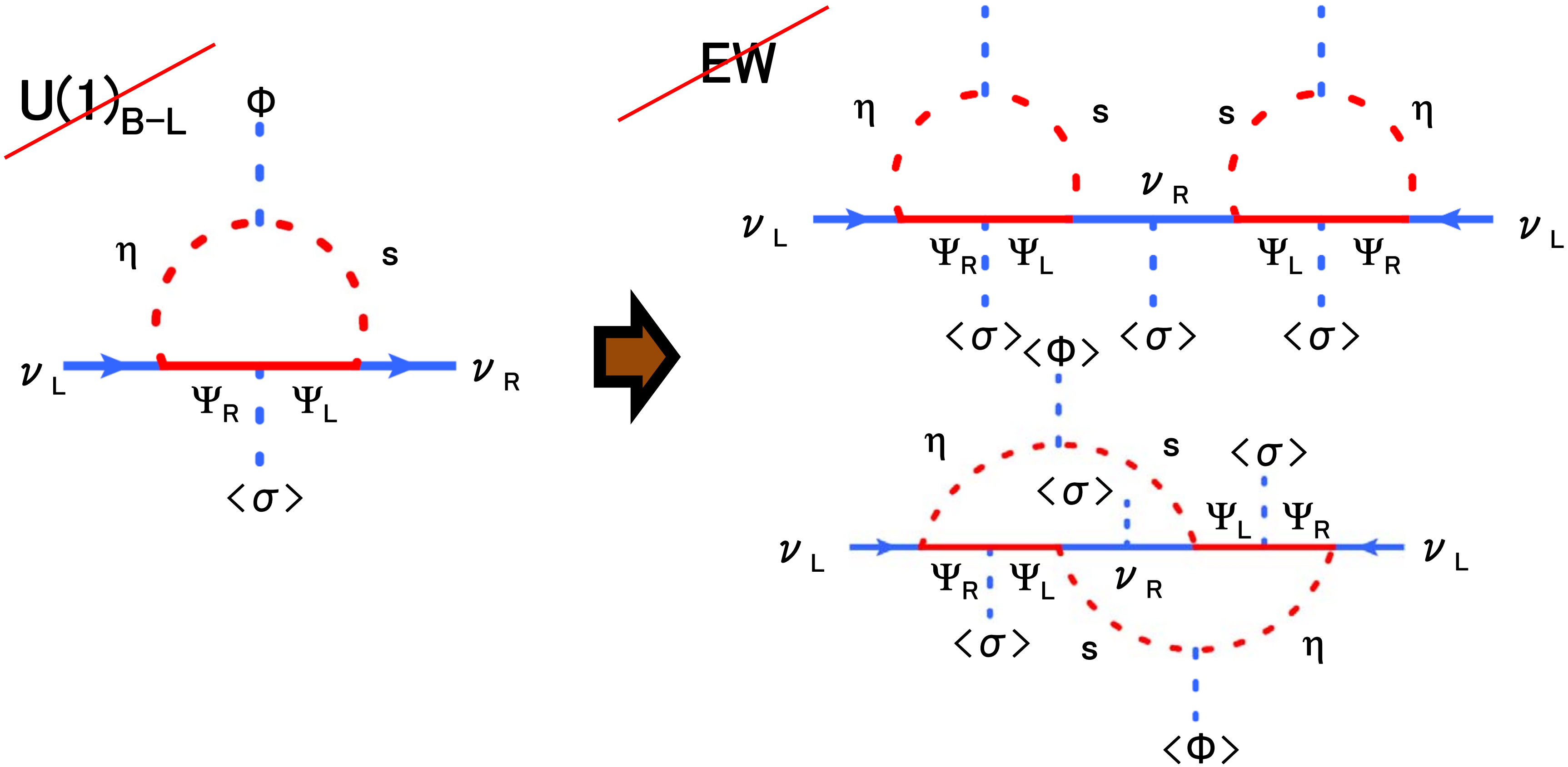
- ϕ, σ, s and η → Physical state: h,H,S1,S2, $\eta^{\pm}$

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_r^0 \\ \sigma_r^0 \end{pmatrix}, \quad \begin{pmatrix} s_1^0 \\ s_2^0 \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \eta^0 \\ s^0 \end{pmatrix}$$

Remnant global $U(1)_{DM}$ remains on half unit of $U(1)_{B-L}$ charged particles after SSB of $U(1)_{B-L}$. $U(1)_{DM}$ guarantees the stability of dark matter. We assume that the Ψ^1 is the lightest $U(1)_{DM}$ particle case.

3.Neutrino mass and dark matter

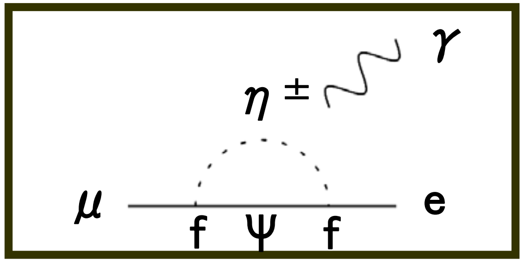
Masses of neutrino



The O(0.1) eV neutrino masses can be naturally deduced from **TeV scale physics**.

3.Neutrino mass and dark matter

LFV constraint

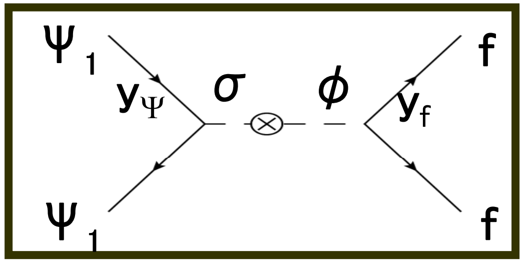


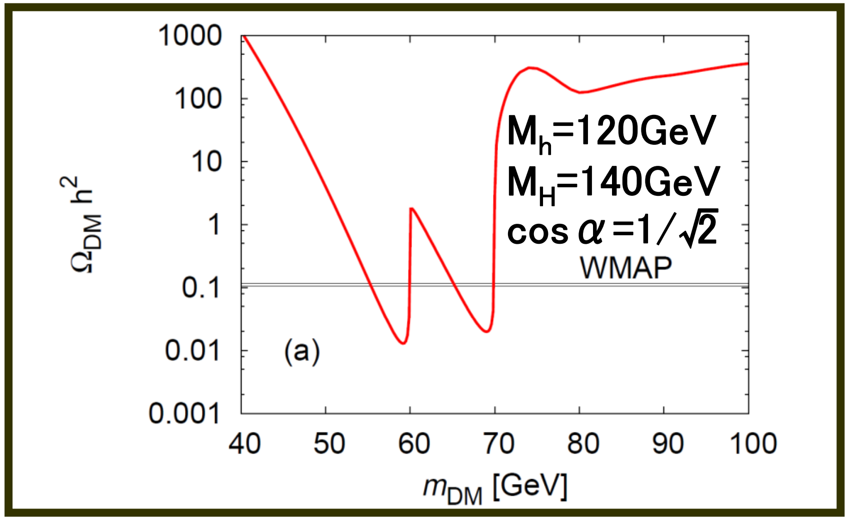
Experimental upper bound:

BR($\mu \rightarrow e, \gamma$) $< 2.4 \times 10^{-12}$ J. Adam et al.(2011)

Our model can be satisfied this value.

Relic abundance of Ψ^1

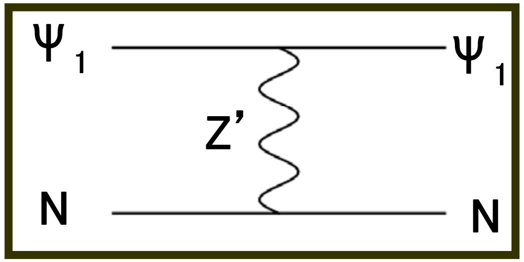




Okada and Seto (2010)

Kanemura, Seto and Shimomura (2011)

Direct detection of Ψ^1



Experimental bound at $m_{DM} \sim 57$GeV(XENON100):

$\sigma(\Psi_1 N \rightarrow \Psi_1 N)$ $= 8 \times 10^{-45} cm^2$ E. Aprile et al. (2011)

Our model can be satisfied this value.

3.Neutrino mass and dark matter

Parameter set

- neutrino oscillation
- LFV
- LEP
- DM abundance
- DM direct detection

Normal Hierarchy, Tri−bi maximal

$$f_{ij} = \begin{pmatrix} -0.00726 & 0.00667 \\ -0.0523 & 0.0206 \\ -0.0378 & 0.0723 \end{pmatrix} \qquad h_{ij} = \begin{pmatrix} -0.119 & 0.150 \\ 0.150 & 0.150 \end{pmatrix}$$

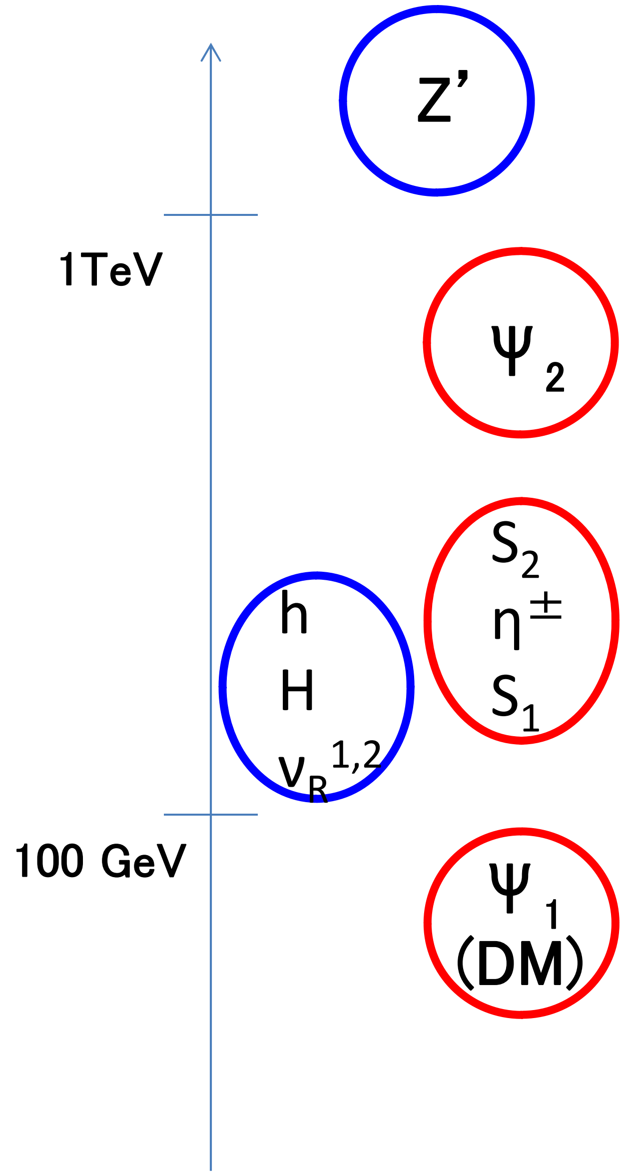
$M_R = 250$ GeV , $M_{\psi 1} = 57.0$ GeV , $M_{\psi 2} = 800$ GeV

$M_{S1} = 200$ GeV, $M_{S2} = 300$ GeV ,

$M_h = 120$ GeV, $M_H = 140$ GeV,

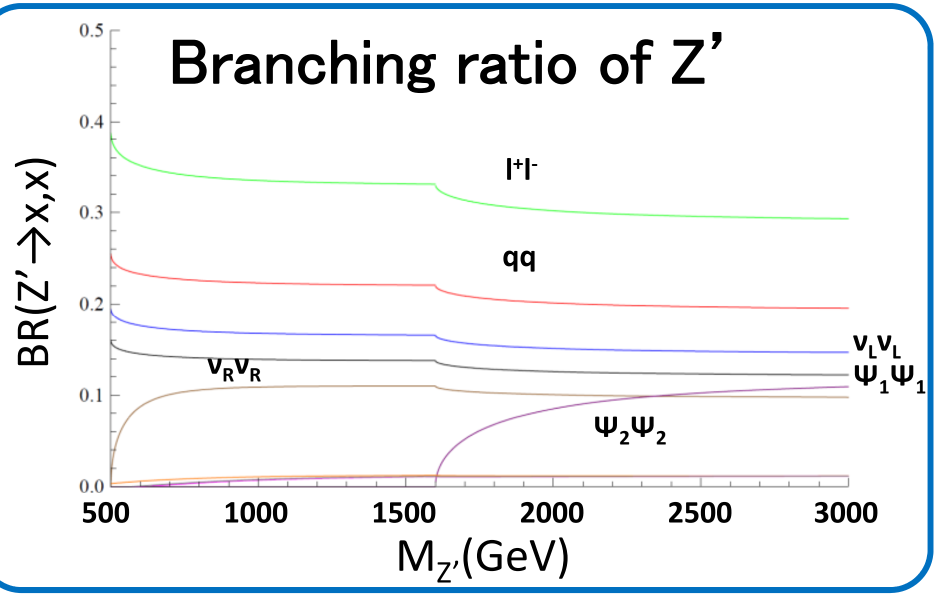
$M_{\eta^\pm} = 280$ GeV, $\cos\theta = 0.05$, $\cos\alpha = 1/\sqrt{2}$,

$g_{B-L} = 0.2$, $M_{Z'} = 2000$GeV, $v_\phi = 246$ GeV, $v_\sigma = 5$ TeV



4.Phenomenology

Physics of Z'



$\Gamma(Z' \to XX) \propto (B\text{−}L\ \text{charge})^2$

Z' decay into

invisible about 30%

Z' production cross section at the LHC for $\sqrt{s}$ = 14 TeV , $M_{Z'}$= 2000 GeV and g_{B-L}= 0.2 then 70 pb.

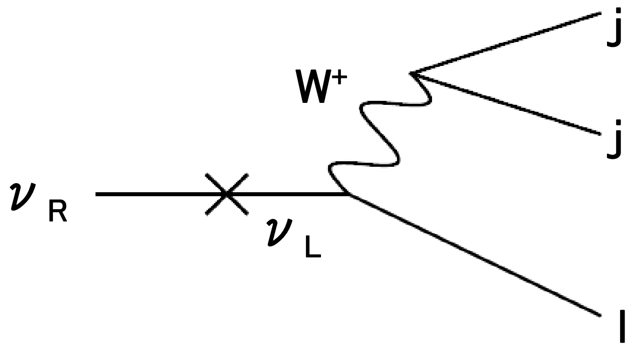
L. Basso, A. Belyaev, S.Moretti and C. H. Shepherd-Themistocleous (2009)

Our model can be tested by the measuring decay of the Z'

4.Phenomenology

Physics of ν_R

$\mathrm{BR}(\nu_R \to XY)$			
$W^{\pm}\ell^{\mp}$	$Z\nu_L$	$h^0\nu_L$	$H^0\nu_L$
0.53	0.28	0.10	0.09



- ν_R are light masses (O(100) GeV) and not stable.
- ν_R are produced about 1200 pair from decay of 7000 Z' at the LHC for $\sqrt{s}$ = 14 TeV with 100 fb^{-1} data.
- The mass of ν_R can be reconstructed by $jjl^{\pm}$

4.Phenomenology

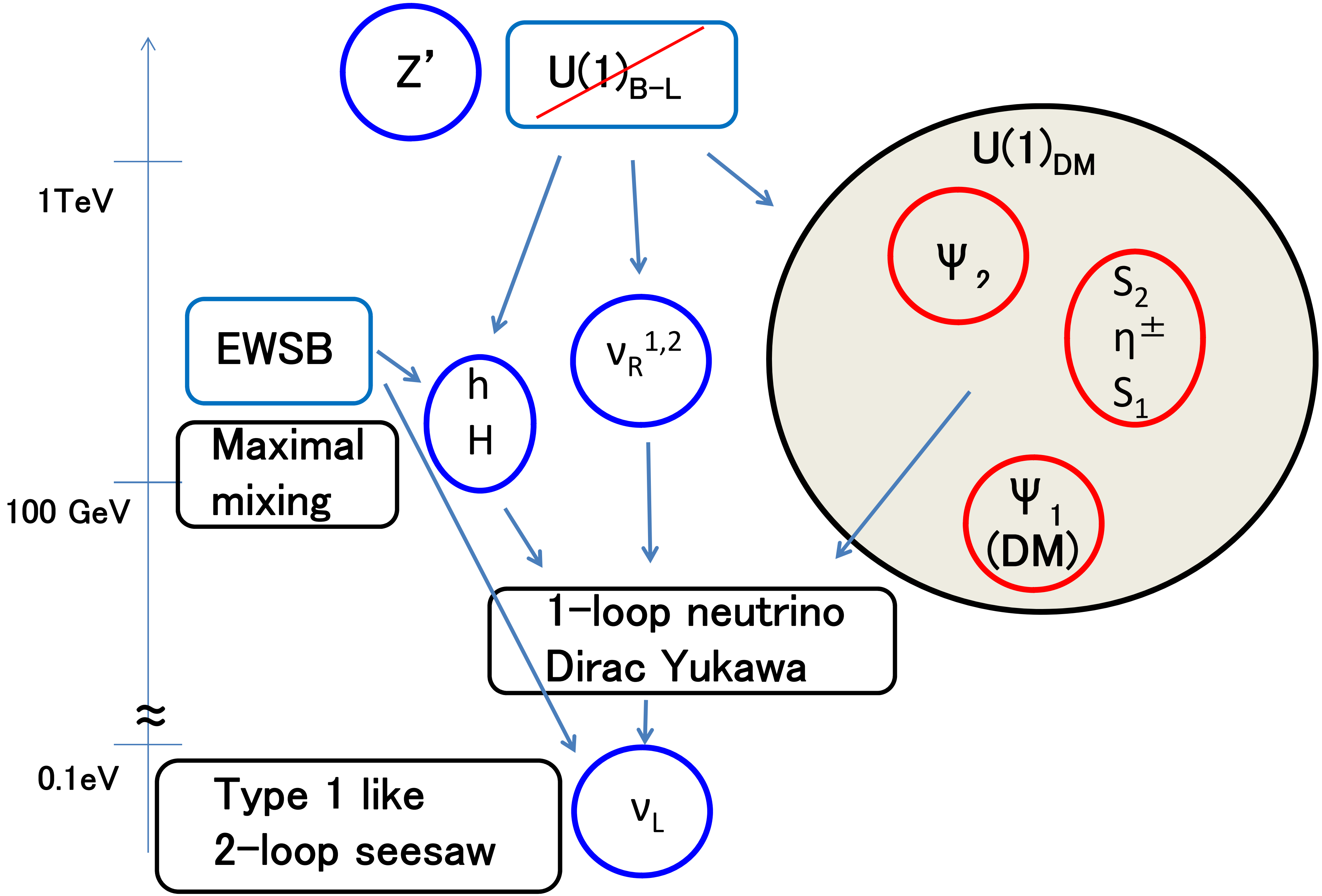
Physics of Higgs boson

- mixing angle between B-L Higgs σ and SM Higgs Φ

  $\alpha \sim \pi/4$ for the thermal abundance of Ψ^1.

$$\Gamma(h \to x,x) \sim \Gamma(H \to x,x) \sim \Gamma(h_{SM} \to x,x)/2$$

Two SM-like Higgs bosons whose masses are O(100) GeV with a about half width.



Z'
$U(1)_{B-L}$
1TeV
$U(1)_{DM}$
Ψ_2
S_2
$\eta^{\pm}$
S_1
EWSB
h
H
$\nu_R^{1,2}$
Maximal mixing
100 GeV
Ψ_1 (DM)
1-loop neutrino Dirac Yukawa
≈
0.1eV
Type 1 like 2-loop seesaw
ν_L

5.Conclusion

① We consider the TeV-scale seesaw model in which $U(1)_{B-L}$ gauge symmetry can be the common origin of neutrino masses, the dark matter mass, and stability of the dark matter.

② Our model is compatible with current experiment data.

③ Our model can be tested by the measuring decay of the Z' boson.

④ The light ν_R (O(100)GeV) can be tested at the LHC.

⑤ Our model predict two SM–like Higgs bosons whose masses are O(100) GeV with about half width.

⑥ If we assume $U(1)_{B-L}$ gauge symmetry at the TeV-scale, we can explain masses of neutrino and dark matter.

Back up

Anomaly

Same of all B-L particle contribution:

$[U(1)_{B-L}]^3 \rightarrow 2$

$U(1)_{B-L} \rightarrow -1$

$U(1)_{B-L}$ anomaly is not cancel in our model

⇩

It would be resolved by some heavy singlet fermions with appropriate B-L charge.
For example;
Right hand: 1×9, $-1/2 \times 14$, $1/3 \times 9$
left hand: $3/2 \times 14$, $-5/3 \times 9$

ラグランジアン

U(1)$_{B-L}$ breaking

$$
\begin{aligned}
\mathcal{L}_{\rm int} \;=\;& \mathcal{L}_{\rm SMYukawa} - \{(y_R)_{ij}(\overline{\nu^c_R})_i(\nu_R)_i\sigma + h.c.\} - \{(y_\Psi)_i(\overline{\Psi}_R)_i(\Psi_L)_i\sigma + h.c.\} \\
& - \left(h_{ij}(\overline{\Psi}_L)_i(\nu_R)_j s + h.c.\right) - \left(f_{ij}(\overline{L_L})_i(\Psi_R)_j\eta^c + h.c.\right) - \left\{(y_3)_{ij}\,(\overline{\nu^c_R})_i(\Psi_R)_j s^* + h.c.\right\} \\
& -\mu_\phi^2\Phi^\dagger\Phi + \mu_s^2 s^\dagger s + \mu_\eta^2\eta^\dagger\eta - \mu_\sigma^2\sigma^\dagger\sigma + \lambda\left(\Phi^\dagger\Phi\right)^2 + \lambda_1\left(s^\dagger s\right)^2 + \lambda_2\left(\eta^\dagger\eta\right)^2 + \lambda_3(\sigma^\dagger\sigma)^2 \\
& +\lambda_4 s^\dagger s\eta^\dagger\eta + \lambda_5 s^\dagger s\Phi^\dagger\Phi + \lambda_6\eta^\dagger\eta\Phi^\dagger\Phi + \lambda_7\eta^\dagger\Phi\Phi^\dagger\eta \\
& +\lambda_8 s^\dagger s\sigma^\dagger\sigma + \lambda_9\eta^\dagger\eta\sigma^\dagger\sigma + \lambda_{10}\Phi^\dagger\Phi\sigma^\dagger\sigma + \left(\mu s\eta^\dagger\Phi + h.c.\right).
\end{aligned}
$$

~~U(1)$_{B-L}$~~

$$\frac{(M_R)_{ii}}{2} = (y_R)_{ii}\frac{v_\sigma}{\sqrt{2}}, \qquad (M_\Psi)_{ii} = (y_\Psi)_{ii}\frac{v_\sigma}{\sqrt{2}}, \qquad M_{Z'}^2 = 4g_{B-L}^2 v_\sigma^2$$

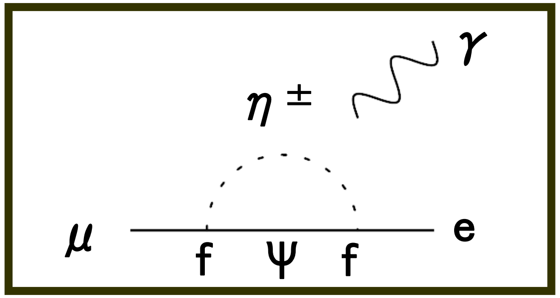
Remnant global U(1)$_{DM}$ remains on half unit of U(1)$_{B-L}$ charged particles after SSB of U(1)$_{B-L}$.

U(1)$_{DM}$ guarantee stability of dark matter.

We consider that the Ψ^1 is lightest U(1)$_{DM}$ particle case.

3.Neutrino mass and dark matter

LFV constraint



$$BR(\mu \to e\gamma) = \frac{3\alpha_{\rm em}}{64\pi G_F^2}\left|\frac{1}{M_{\eta^\pm}^2} f_{\mu i} F_2\left(\frac{(M_\Psi)_i^2}{M_{\eta^\pm}^2}\right)(f^\dagger)_{ie}\right|^2,$$

$$F_2(a) \equiv \frac{1-6a+3a^2+2a^3-6a^2\ln(a)}{6(1-a)^4}.$$

Experimental upper bound:

$BR(\mu \to e, \gamma) < 2.4 \times 10^{-12}$ J. Adam et al.(2011)

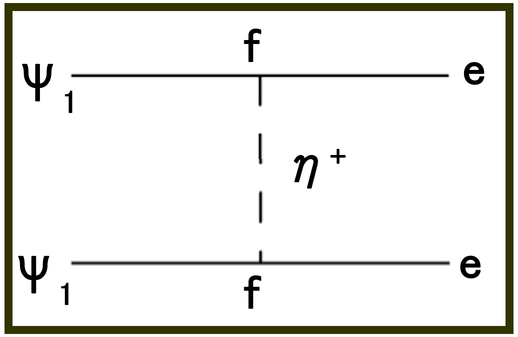
For our parameter set, it is evaluated as

$BR(\mu \to e, \gamma) = 5.1 \times 10^{-13}$

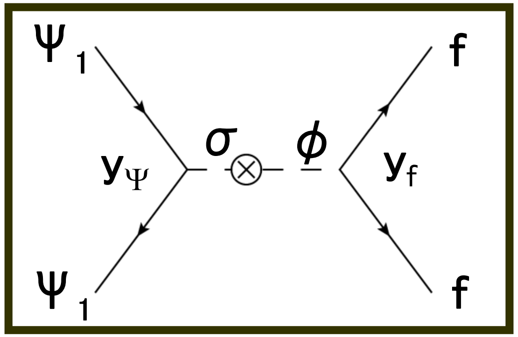
Our parameter set safety current experimental upper bound but could be within future experimental reach.

3.Neutrino mass and dark matter

Relic abundance of Ψ1



LΨη coupling is small due to LFV constraint

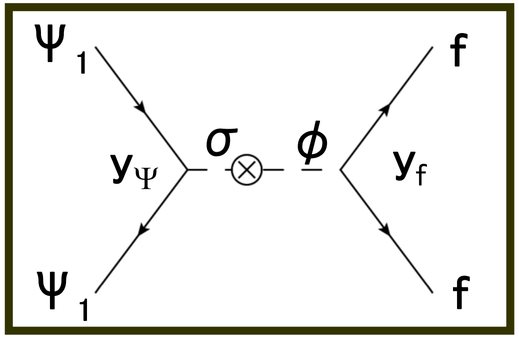


ΨΨσ coupling ∼O(0.01)
but resonance can be used.

Mixing between B-L Higgs σ and SM Higgs Φ is essentially important.

3.Neutrino mass and dark matter

Relic abundance of Ψ^1



$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_r^0 \\ \sigma_r^0 \end{pmatrix}$$

Okada and Seto (2010)
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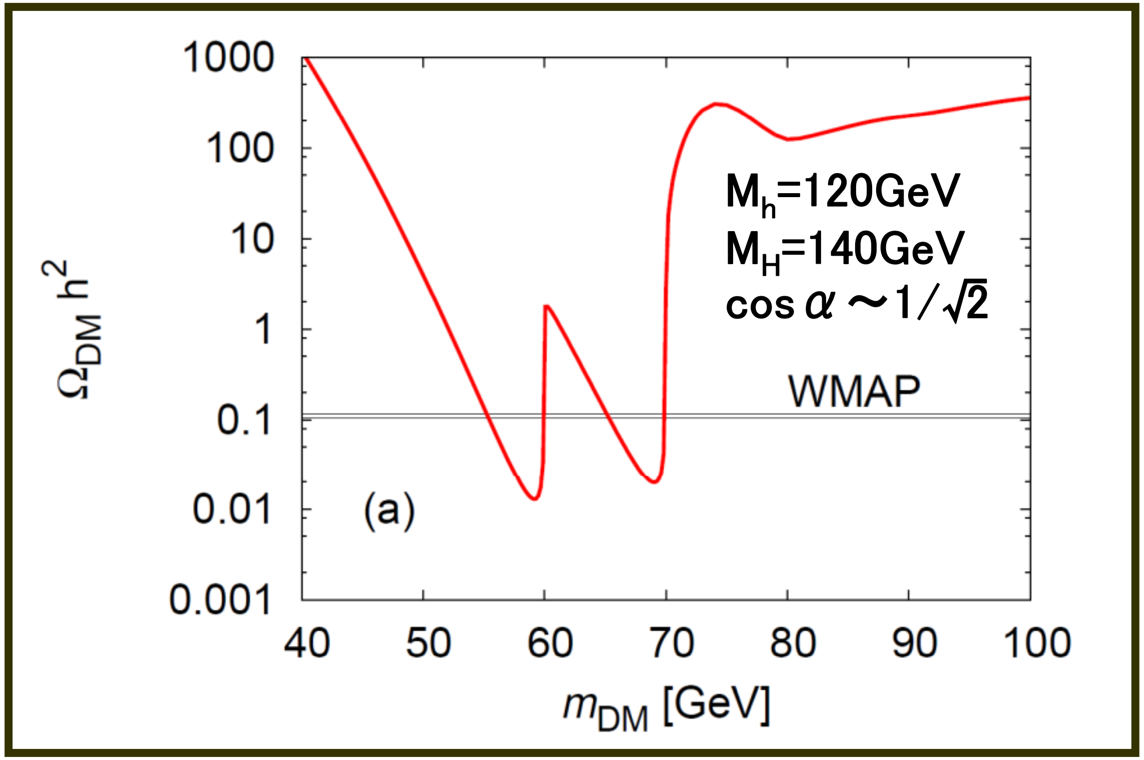
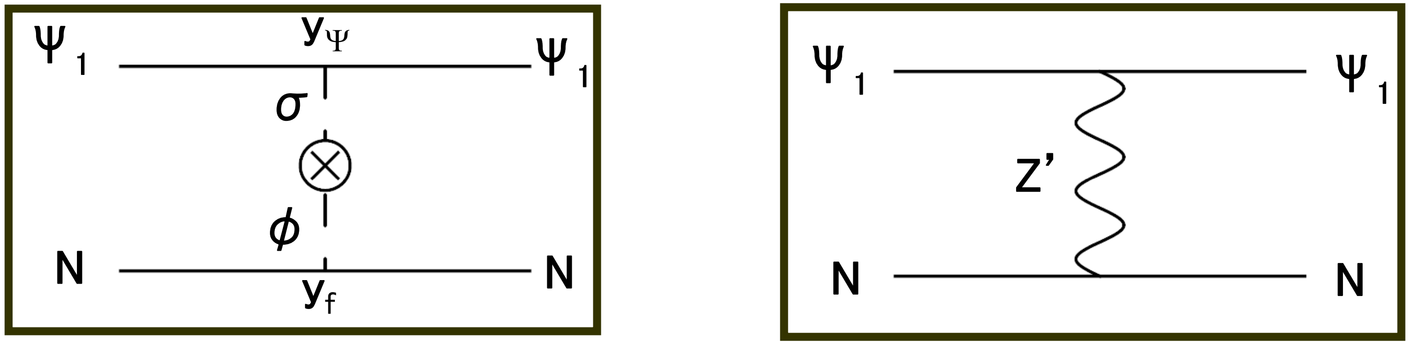


Ψ^1 is consistent with WMAP data at the $M_{\Psi 1}$ = 57.0 GeV .

3.Neutrino mass and dark matter

Direct detection of Ψ1



$$\sigma(\Psi_1 N \to \Psi_1 N) \simeq \frac{8 g_{\mathrm{B-L}}^2 m_{\Psi_1}^2 \sin^2\alpha \cos^2\alpha}{v^2 m_{Z'}^2} \left(\frac{1}{m_{h^0}^2} - \frac{1}{m_{H^0}^2} \right)^2 \frac{m_N^2 m_{\Psi_1}^2}{\pi \left(m_{\Psi_1} + m_N\right)^2} f_N^2 + \left(\frac{g_{\mathrm{B-L}}}{m_{Z'}} \right)^4 \frac{m_{\Psi_1}^2 m_N^2}{4\pi (m_{\Psi_1} + m_N)^2},$$

Experimental bound (XENON100):

$\sigma(\Psi_1 N \to \Psi_1 N)$ $=8 \times 10^{-45} \mathrm{cm}^2$ E. Aprile et al. (2011)

For our parameter set, it is evaluated as

$\sigma(\Psi_1 N \to \Psi_1 N)$ $=2.7 \times 10^{-45} \mathrm{cm}^2$

Our parameter set safety current experimental bound

but could be within future experimental reach.

BR($Z' \to XX$)								
$q\overline{q}$	$\ell^-\ell^+$	$\nu_L\overline{\nu_L}$	$\nu_R\overline{\nu_R}$	$\Psi_1\overline{\Psi_1}$	$\Psi_2\overline{\Psi_2}$	$s_1^0(s_1^0)^*$	$s_2^0(s_2^0)^*$	$\eta^+\eta^-$
0.20	0.30	0.15	0.10	0.13	0.085	0.012	0.011	0.011