SUSY Inverse Seesaw gives Thermal Sneutrino Dark Matter

Hiroyuki Ishida (NCTS)

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Collaborators: Jung Chang (Chonnam Natl. U.)
Kingman Cheung (NTHU)
Chih-Ting Lu (NTHU)
Martin Spinrath (NTHU)
Yue-Lin Sming Tsai (AS)

Refs: 1707.04374, 1806.04468

Motivation

Why do we need to extend the SM?

- Neutrino masses
- Gauge hierarchy problem
- DM candidate
- Gauge coupling unification

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MSSM+type-I seesaw mechanism

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How small Majorana mass is possible?

Motivation

There are lots of alternative ideas

- Inverse seesaw (ISS) mechanism

[Mohapatra (1986); Mohapatra and Valle (1986)]

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By using another gauge singlet

$$-\mathcal{L} \supset y_\nu \bar{L} H \nu_R + M_N \overline{\nu_R^C} \nu_R + M_S SS + \mu \nu_R S + \mathrm{h.c}$$

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Neutrino mass matrix

$$M_\nu = \begin{pmatrix} 0 & y_\nu v_{\mathrm{EW}} & 0 \\ y_\nu^T v_{\mathrm{EW}} & M_N & \mu \\ 0 & \mu & M_S \end{pmatrix} \Rightarrow m_\nu = -\frac{y_\nu v_{\mathrm{EW}} M_S y_\nu^T v_{\mathrm{EW}}}{\mu^2}$$

Small M_S (Lepton # violation) leads tiny m_ν

Motivation

Assumption in most of works

technically naturalness

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when $M_S \to 0$ lepton # sym. is recovered

smallness of M_S is technically natural

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benefit of inverse seesaw

$$m_\nu = \left(\frac{y_\nu}{1}\right)^2 \left(\frac{v_{\rm EW}}{10^2{\rm GeV}}\right)^2 \left(\frac{\rm TeV}{\mu}\right)^2 \left(\frac{M_S}{10{\rm eV}}\right)$$

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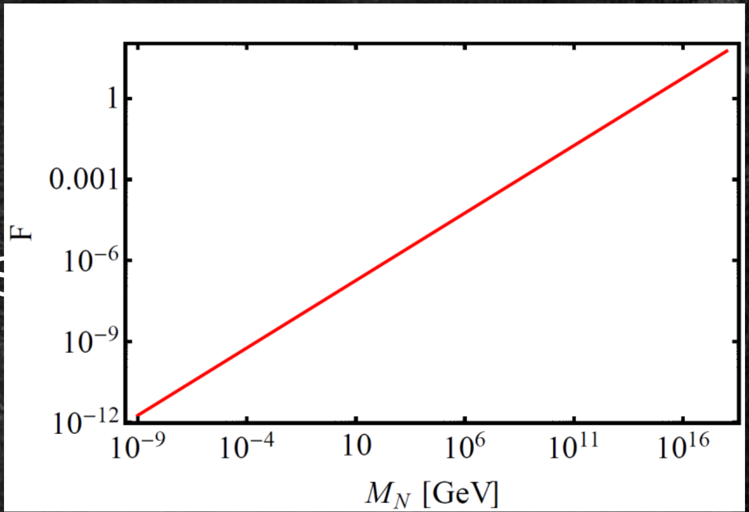

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extension at TeV scale with O(1) Yukawa

Rich phenomenology at collider!

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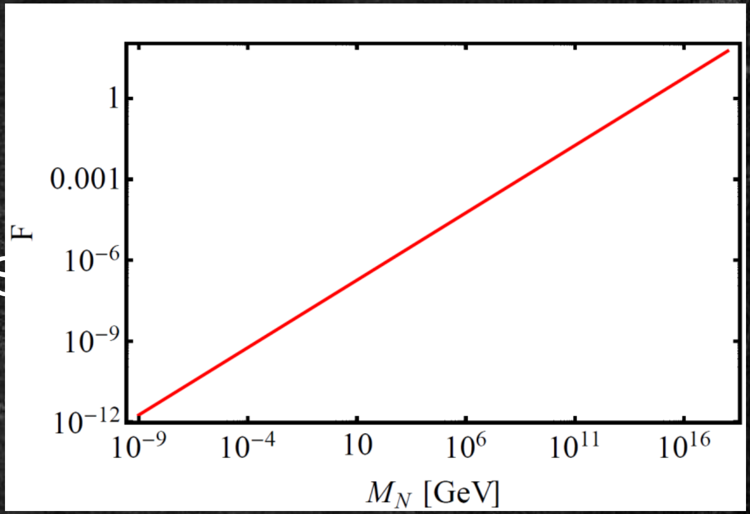

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Dynamical origin of M_S?

Model (NCTS model)

Symmetry : $\mathcal{G}_{\rm SM} \times Z_6$

Superfield	$\hat{Q}_i$	$\hat{U}^c_i$	$\hat{E}^c_i$	$\hat{L}_i$	$\hat{D}^c_i$	$\hat{H}_u$	$\hat{H}_d$	$\hat{N}^c_\alpha$	$\hat{S}_\alpha$	$\hat{X}$
Z_3 charge	1	1	1	0	0	1	2	2	1	1
Z_2 charge	1	1	1	1	1	0	0	1	1	0

$(\alpha = 1\,, 2)$

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forbid R-parity violating terms

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New super potential in addition to MSSM

$$\mathcal{W}_\nu = Y_\nu\, \hat{L}\hat{H}_u\hat{N}^c + \mu_{\rm NS}\, \hat{N}^c\hat{S} + \frac{\lambda}{2}\,\hat{X}\,\hat{S}^2 + \frac{\kappa}{3}\,\hat{X}^3$$

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related to neutrino

$$-\mathcal{L}_\nu = (Y_\nu)_{i\alpha}L_i N_\alpha^c H_u + (\mu_{\rm NS})_{\alpha\beta}N_\alpha^c S_\beta + \frac{1}{2}\lambda_{\alpha\beta}S_\alpha S_\beta X + {\rm H.c.}$$

Model

Phenomenological constraints?

-LFV

1. Non-SUSY : $\mathrm{Br}(\mu \to e + \gamma) \simeq \mathcal{O}(10^{-20})$

2. SUSY : depends on sparticle mixing

-0νββ decay

1. Non-SUSY : $m_{\mathrm{eff}} \simeq 8 \times 10^{-9}\mathrm{meV}\left(\frac{\mu_{NS}}{\mathrm{TeV}}\right)$

2. SUSY : no contribution due to "R-parity" conservation

DM estimation

Boundary conditions

$$m_0^2 = \frac{1}{9} m_{\tilde{Q}}^2 = \frac{1}{9} m_{\tilde{D}}^2 = \frac{1}{9} m_{\tilde{U}}^2 = m_{\tilde{L}}^2 = m_{\tilde{E}}^2 = m_{\tilde{N}}^2 = m_{\tilde{S}}^2 = m_{H_u}^2 = m_{H_d}^2 = b_{NS} \ ,$$

$$M_{1/2} = \frac{1}{3} M_3 = M_2 = M_1 \ ,$$

$$A_i = A_0 Y_i,\ A_\lambda = A_0 \lambda,\ A_\kappa = \kappa A_0 \ ,$$

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-Put arbitrary factor to make colored particles heavy enough

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-Put arbitrary factor to make colored particles heavy enough

-m_0 and $M_{1/2}$ are fixed at high scale

-v_X a and **κ** are fixed at low scale

not to worry about running effect

DM estimation

Sneutrino mass matrix

$$m^2_{\tilde{\nu}^R} \approx m^2_{\tilde{\nu}^I} \approx \begin{pmatrix} m_0^2 + \frac{1}{2}M_Z^2 \cos(2\beta) & 0 & 0 \\ 0 & m_0^2 + \mu_{NS}^2 & m_0^2 \\ 0 & m_0^2 & m_0^2 + \mu_{NS}^2 \end{pmatrix}$$

-RG corrections to them is small enough

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-Physical states

$$\tilde{\nu}_{1,2} \approx \frac{1}{\sqrt{2}}\left(\tilde{N}_1^c \mp \tilde{S}_1\right) \text{ and } \tilde{\nu}_3 \approx \tilde{L}_1$$

$$m^2_{\tilde{\nu}_1} \approx \mu^2_{NS}$$

-Mass difference

$$m^2_{\tilde{\nu}_1^R} - m^2_{\tilde{\nu}_1^I} \approx \frac{1}{2}\lambda\, v_X\left(\sqrt{2}\, A_0 - 2\sqrt{2}\mu_{NS} + \kappa\, v_X\right)$$

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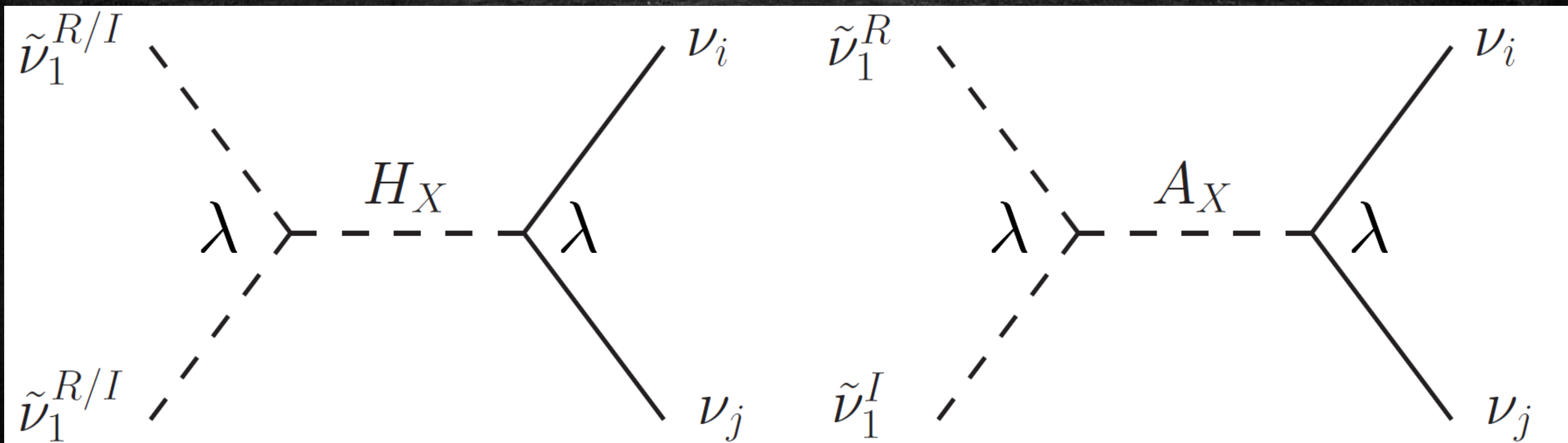
DM estimation

Dominant (co-)annihilation channels



H-funnel A-funnel

DM estimation

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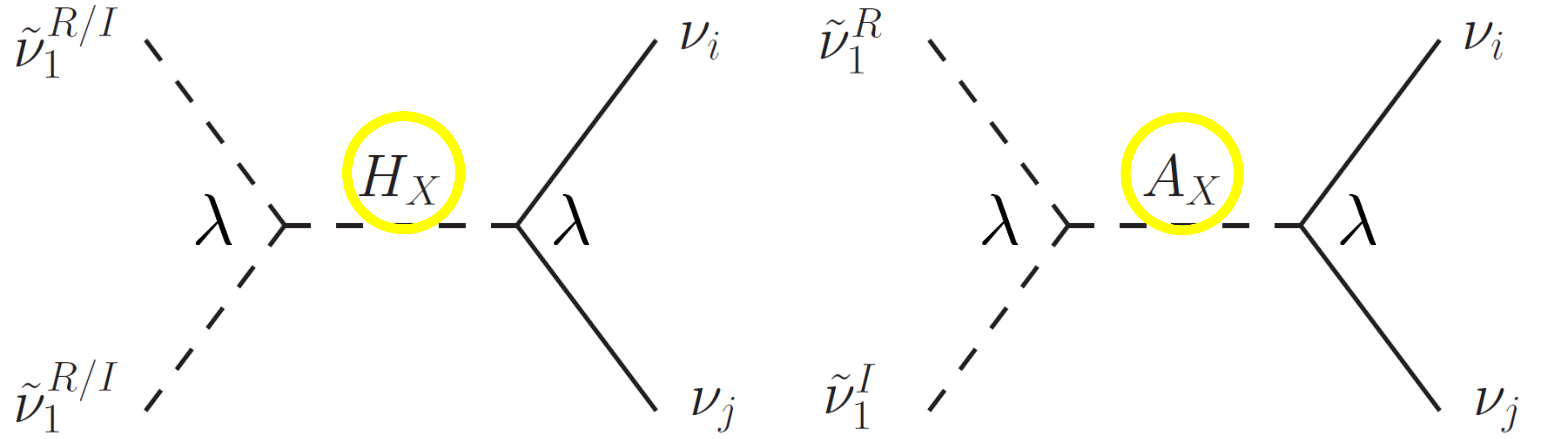


H-funnel A-funnel

Origin of #L violation mediates between dark and visible sectors!

DM estimation

Features of our analysis

-Three exceptions of thermal relic calculation

[Griest and Seckel (1991)]

1. Co-annihilation

2. Annihilation into forbidden channel
   (near threshold)

3. Annihilation near pole (resonance)

DM estimation

Features of our analysis

-Three exceptions of thermal relic calculation

[Griest and Seckel (1991)]

1. Co-annihilation

2. Annihilation into forbidden channel (near threshold)

3. Annihilation near pole (resonance)

We have to take into account 1 and 3!

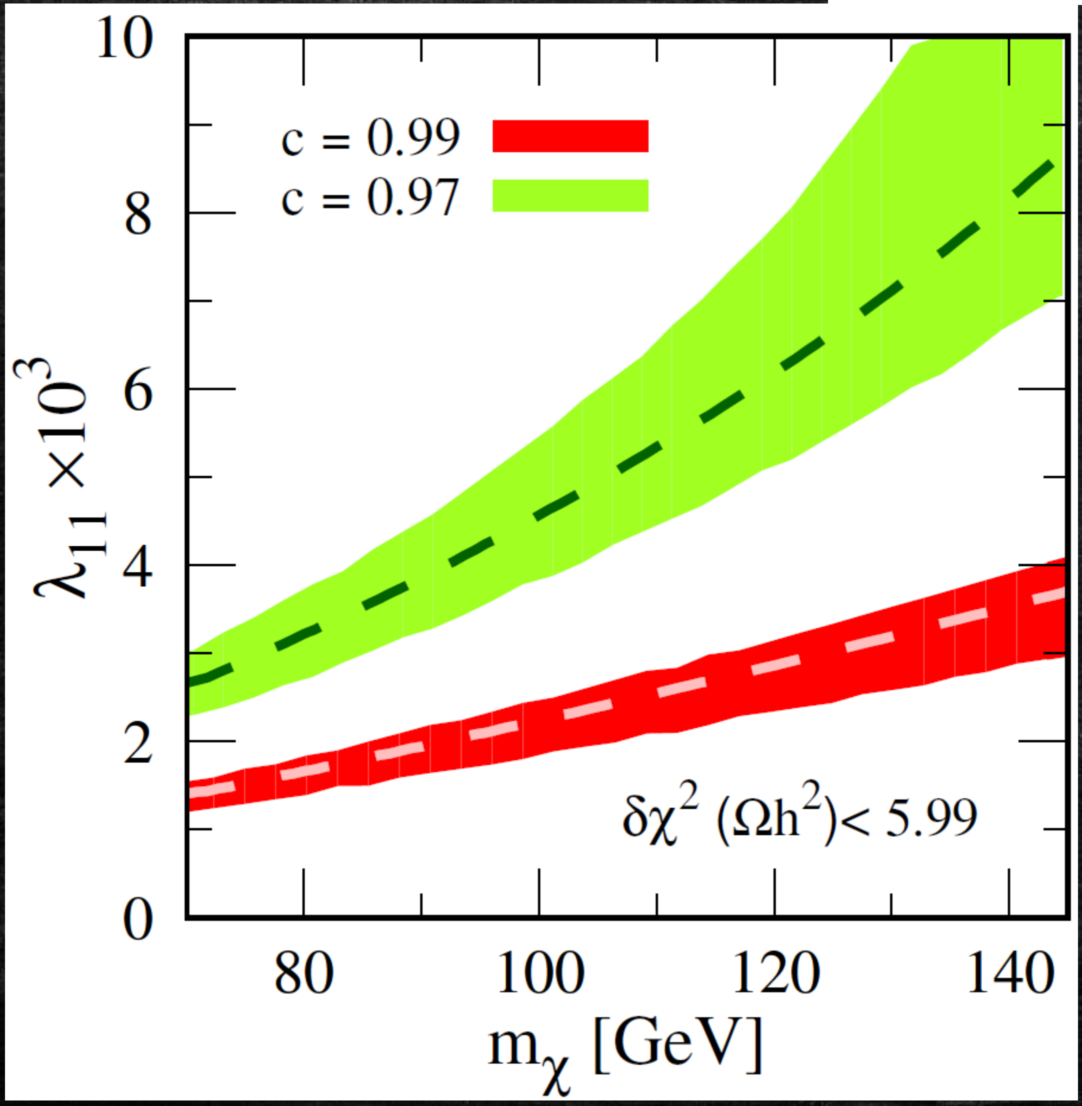
$$m_{\tilde{\nu}_1^R} \simeq m_{\tilde{\nu}_1^I} \,,\; m_{\tilde{\nu}_1^R} + m_{\tilde{\nu}_1^I} \simeq m_{A_X}$$

DM estimation

Results in A_X-funnel scenario

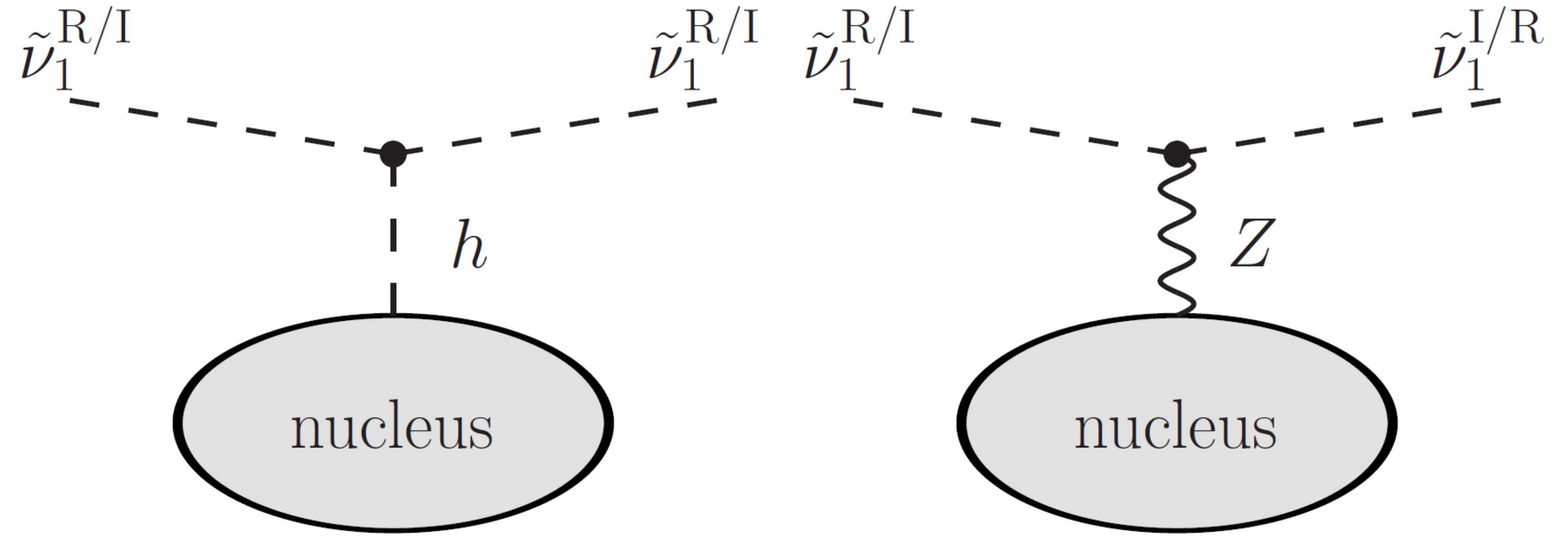
DM estimation

Results in A_X-funnel scenario $m_{\tilde{\nu}_1^R} + m_{\tilde{\nu}_1^I} = c\, m_{A_X}$



DM properties

Direct detection



-Z exchange is more suppressed

DM properties

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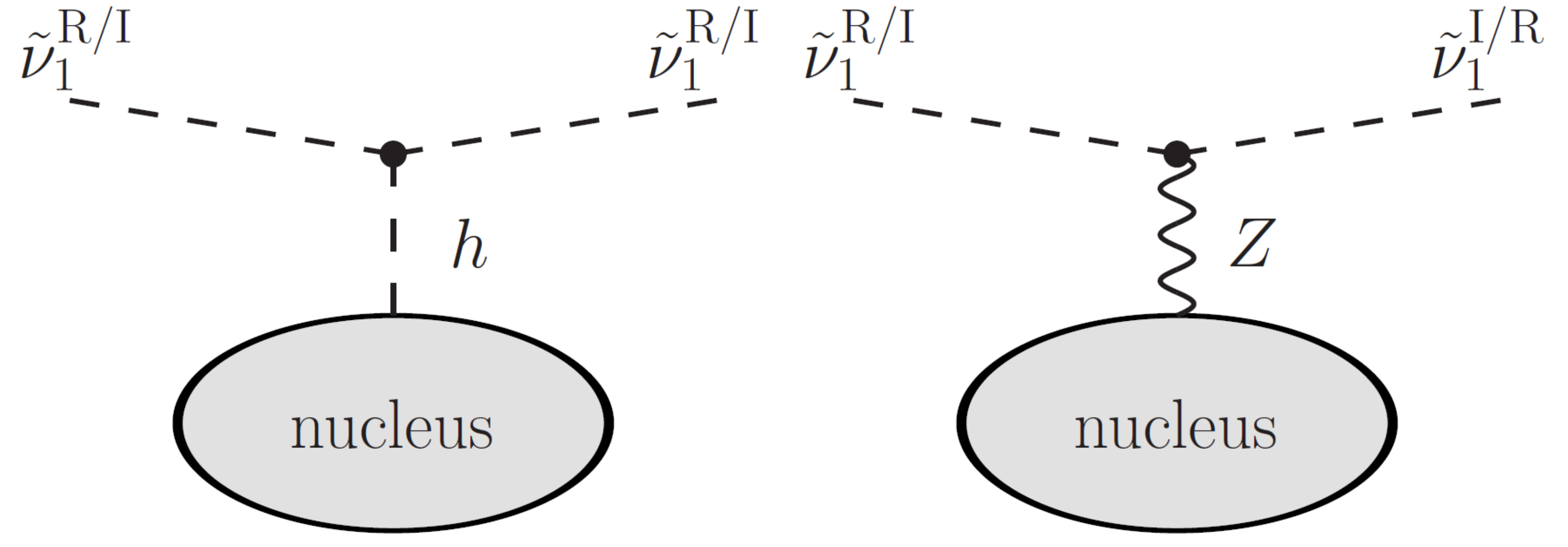
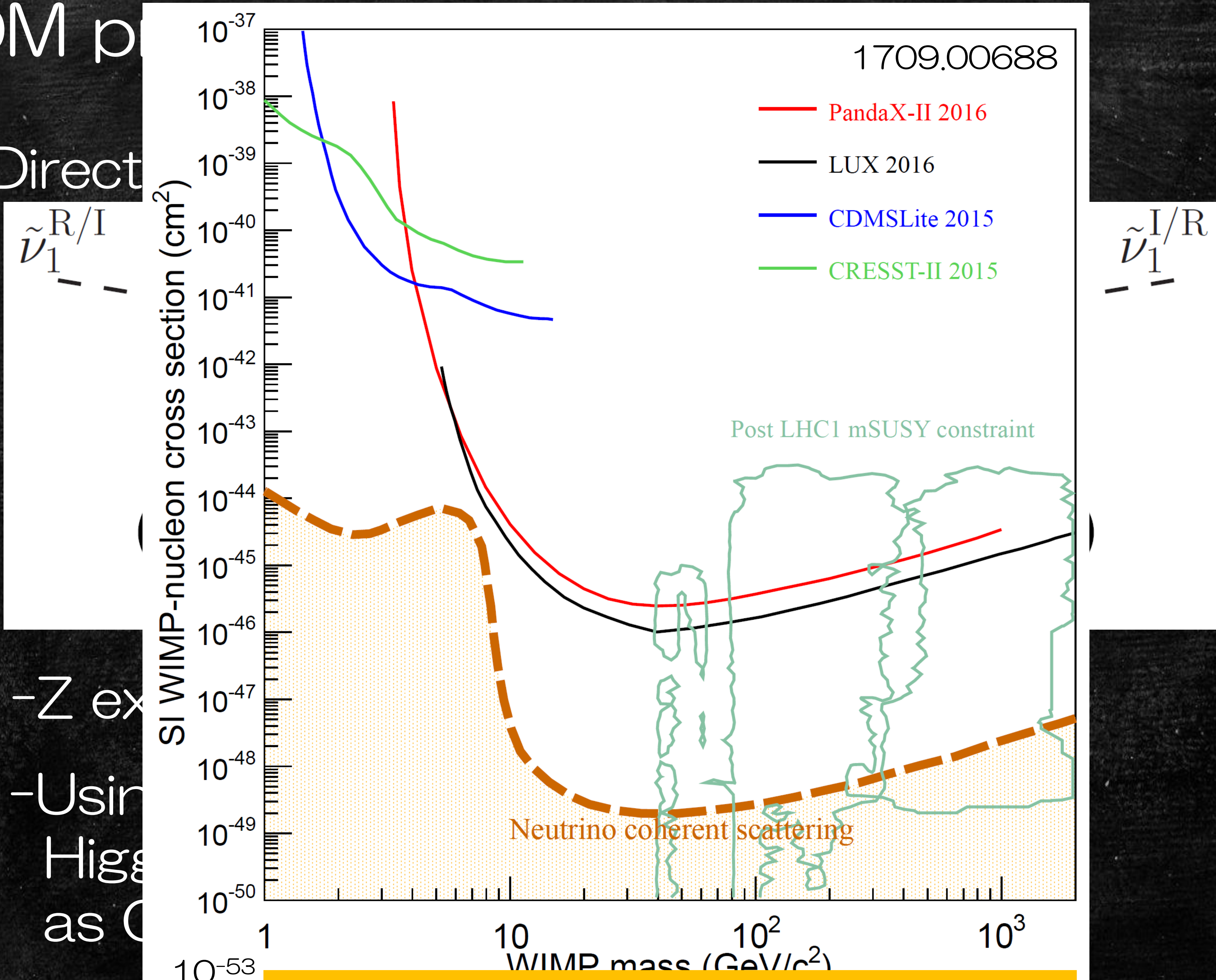


- Z exchange is more suppressed
- Using $Y_\nu \sim 10^{-6}$ and M_{SUSY}=1 TeV, Higgs exchange cross section is given as $O(10^{-29})$ pb

DM pr

Direct

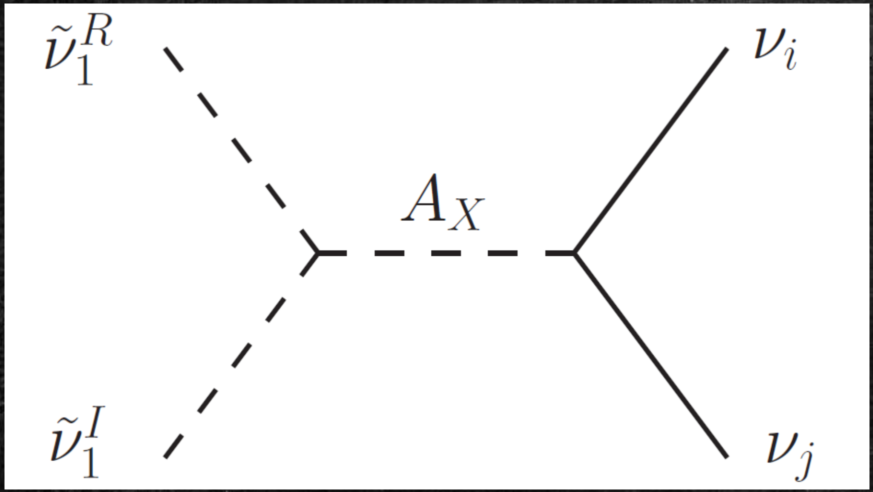


-Z ex

-Usin
Higg
as C

DM properties

Indirect detection



-If DM annihilate into two active neutrinos or one active and one heavy neutrino, we could see line signal of active **ν** at IceCube

-Since annihilation cross section into two active neutrinos $O(10^{-41})\,\mathrm{cm}^3\,\mathrm{s}^{-1}$, this signal seems not to be so promising

DM properties

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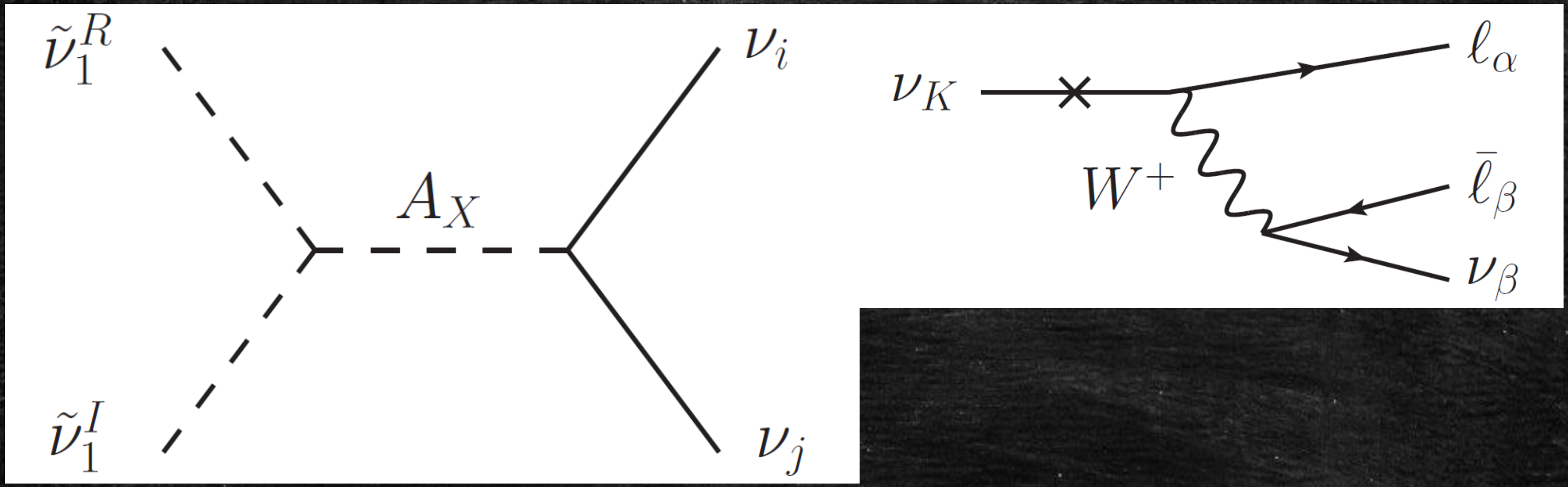

-Since heavy ν can decay into SM leptons, cascade decay could become important

-Cross section decaying into 2 heavy neutrinos is a few order of magnitude smaller, we could see signal in future

Conclusions

- SUSY inverse seesaw model

-Majorana mass term is dynamically induced

-Low scale seesaw mechanism can be realized

-Thermal relic sneutrino DM is possible
thanks to existing the origin of #L violation

-Our extensions to MSSM is really hidden,

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-Our extensions to MSSM is really hidden,
in other words,
our model can be easily excluded
by any other signals of DM!

Thank you
for your attention