Light right-handed neutrino WIMP motivated by Atomki anomalies

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contents

- Atomki anomalies
- Introduction
- Radiative neutrino mass in a gauged $U(1)_{B-L}$ model
- Revisit in light of 16 MeV vector boson
- Summary

§ Atomki anomalies

§ Atomki anomalies

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Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

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(Received 7 April 2015; published 26 January 2016)

Electron-positron angular correlations were measured for the isovector magnetic dipole 17.6 MeV ($J^\pi = 1^+$, $T = 1$) state → ground state ($J^\pi = 0^+$, $T = 0$) and the isoscalar magnetic dipole 18.15 MeV ($J^\pi = 1^+$, $T = 0$) state → ground state transitions in ^{8}Be. Significant enhancement relative to the internal pair creation was observed at large angles in the angular correlation for the isoscalar transition with a confidence level of $> 5\sigma$. This observation could possibly be due to nuclear reaction interference effects or might indicate that, in an intermediate step, a neutral isoscalar particle with a mass of $16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV$/c^2$ and $J^\pi = 1^+$ was created.

§ Atomki an

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Diagram from [Ajzenberg-Selove (1988)]

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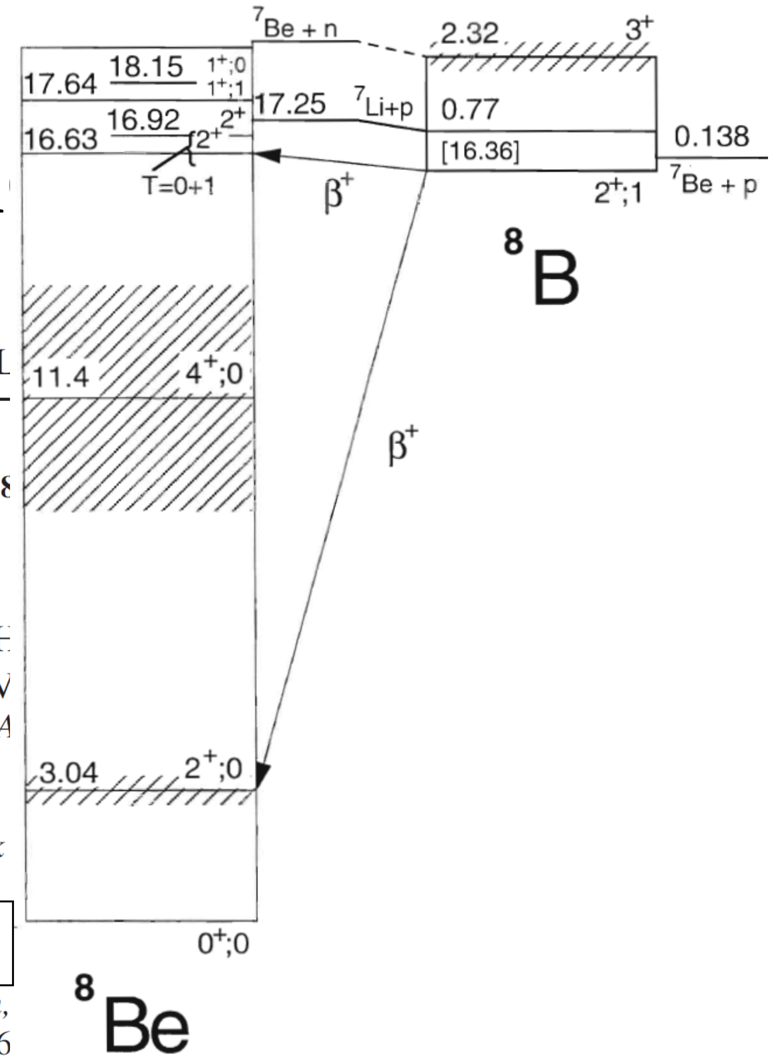

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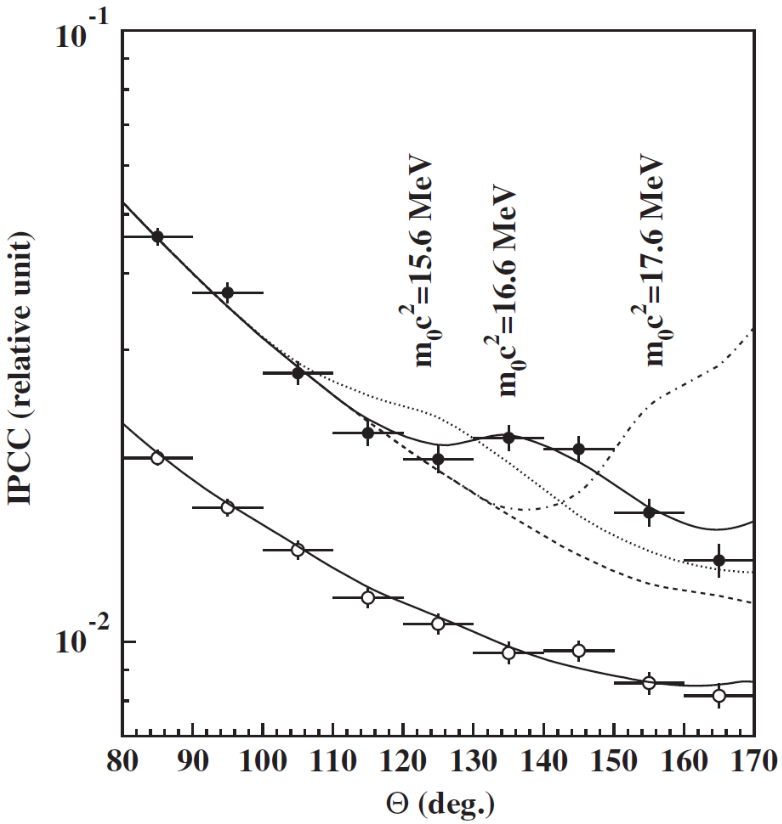
§ Atomki anomalies

[Krasznahorkay et al (2016)]

- A light vector boson



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our knowledge, no nuclear physics related description of such deviation can be made. The deviation between the experimental and theoretical angular correlations is significant and can be described by assuming the creation and subsequent decay of a $J^\pi = 1^+$ boson with mass $m_0c^2 = 16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV. The branching ratio of the e^+e^- decay of such a boson to the γ decay of the 18.15 MeV level of ^{8}Be is found to be 5.8×10^{-6} for the best fit.

Such a boson might be a good candidate for the relatively light $U(1)_d$ gauge boson [4], or the light mediator of the secluded WIMP dark matter scenario [5] or the dark Z (Z_d) suggested for explaining the muon anomalous magnetic moment [7].

4. Experimental angular e^+e^- pair correlations measured

§§ Needs and constraints

Constraints on couplings [Feng et al (1608.03591)]

- constraints from e.g., the neutral π decay, beam dump experiments, e-ν scatterings.

$$|\varepsilon_n| = |\varepsilon_X| = (2 - 10) \times 10^{-3},$$

$$|\varepsilon_p| = |\varepsilon_X - \varepsilon c_W| \lesssim 1.2 \times 10^{-3}$$

$$|\varepsilon_e| = (0.2 - 1.4) \times 10^{-3}$$

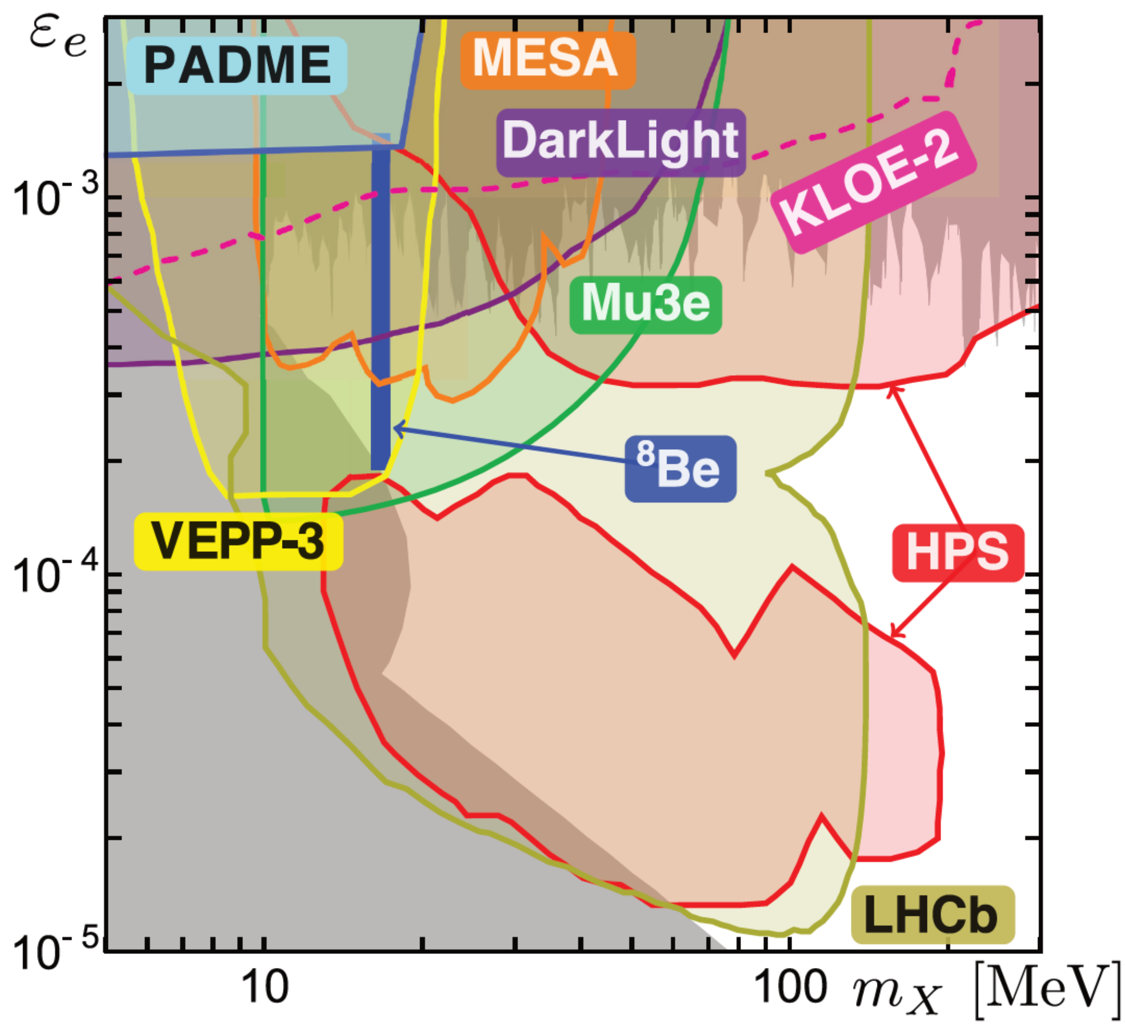
$$\sqrt{|\varepsilon_e \varepsilon_\nu|} \lesssim 3 \times 10^{-4}.$$

- Gauge kinetic mixing
- While a naive $U(1)_{B\text{-}L}$ model predicts $\varepsilon_n = -\varepsilon_\nu$, with additional vector-like leptons it avoids the constraints.

§ § Needs and constraints

Near future double checks [Feng et al (1608.03591)]

- Mu3e (2018~)
- LHCb (2021~)
- …

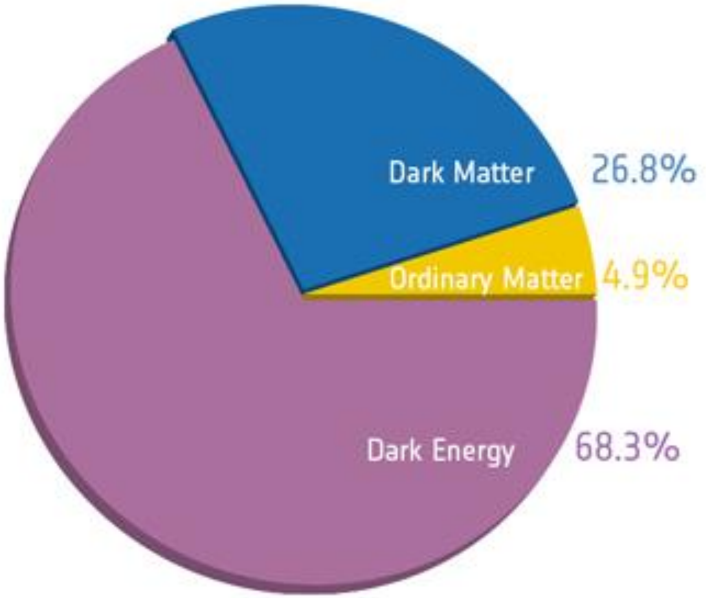


§ Introduction

- Atomki anomalies (done)
- Dark matter
- Massive neutrinos

§ § Dark matter

- What is dark matter?



[ESA]

§ § Massive neutrino

- How neutrinos can be massive

1. RH neutrino and tiny Yukawas; Dirac neutrino
2. RH Majorana neutrino and Yukawas; seesaw mechanism
3. RH Majorana neutrino and “no” Yukawa; radiative seesaw
4. Triplet Higgs field
5. ...

§ § Massive neutrino

- How neutrinos can be massive

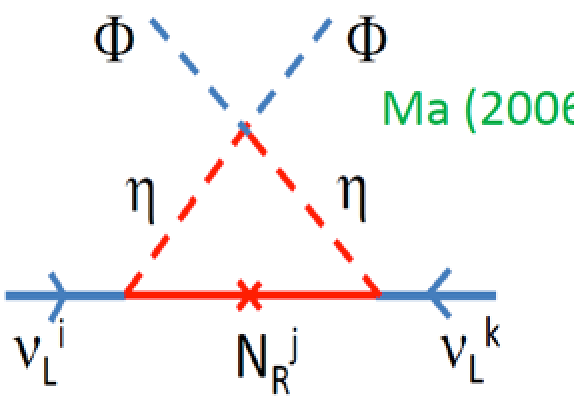
1. RH neutrino and tiny Yukawas; Dirac neutrino
2. RH Majorana neutrino and Yukawas; seesaw mechanism
3. RH Majorana neutrino and “no” Yukawa; radiative seesaw
4. Triplet Higgs field
5. ...

Z_2 parity

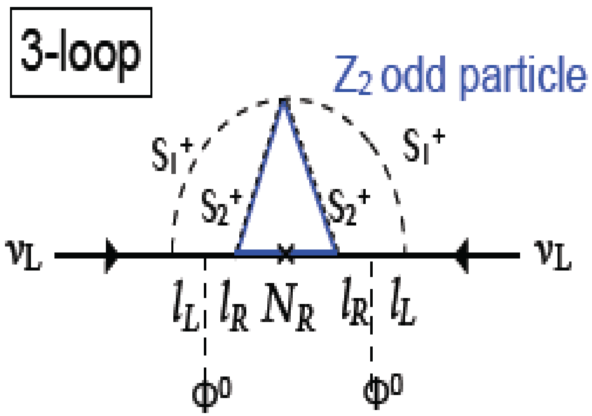
Dark matter stability

Examples of radiative seesaw models

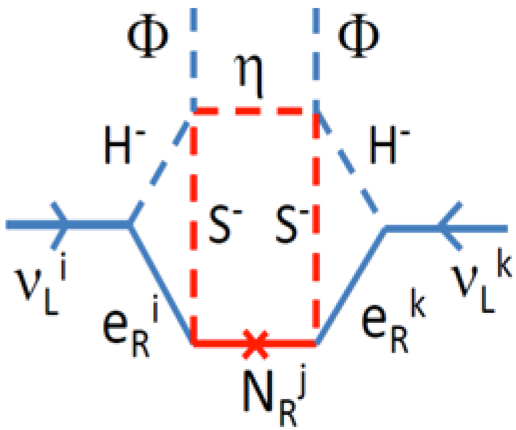
- New ingredient : discrete Z_2 parity
- The Z_2 parity guarantees the absence of Dirac mass, and provides a dark matter candidate as the bonus.



Ma (2006)



Krauss et al (2003)



Aoki et al (2009)

§ Radiative neutrino mass in a gauged U(1)B-L model

[Kanemura, OS and Shimomura (2011)]

- Gauge symmetry

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

- Particle content

	Q^i	d_R^i	u_R^i	L^i	e_R^i	Φ	η	S	N_R^α
$SU(3)_C$	3	3	3	1	1	1	1	1	1
$SU(2)_W$	2	1	1	2	1	2	2	1	1
$U(1)_Y$	$1/6$	$-1/3$	$+2/3$	$1/2$	-1	$1/2$	$1/2$	0	0
$U(1)_{B-L}$	$1/3$	$1/3$	$1/3$	-1	-1	0	0	$+2$	-1
Z_2	$+$	$+$	$+$	$+$	$+$	$+$	$-$	$+$	$-$

§ Radiative neutrino mass in a gauged U(1)B-L model

[Kanemura, OS and Shimomura (2011)]

- Interactions

$$\mathcal{L}_{\rm int} = \mathcal{L}_{\rm Yukawa}^{\rm SM} + \mathcal{L}_N - V(\Phi, \eta, S), \tag{2}$$

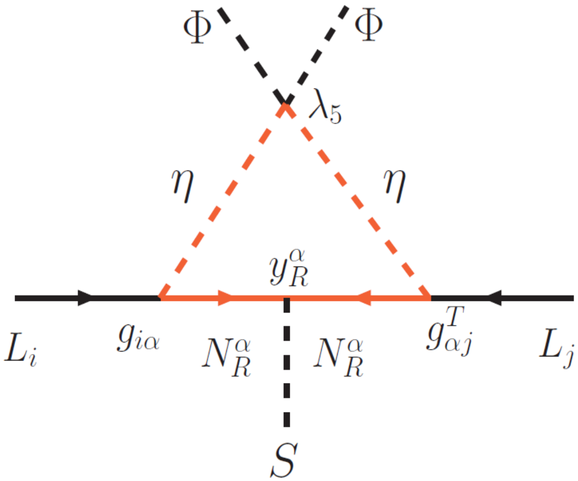
where $\mathcal{L}_{\rm Yukawa}^{\rm SM}$ is the SM Yukawa interaction, and

$$\mathcal{L}_N = \sum_{\alpha=1}^{3} \left(\sum_{i=1}^{3} g_{i\alpha} \overline{L}^i \tilde{\eta} N_R^\alpha - \frac{y_R^\alpha}{2} \overline{N}_R^\alpha S N_R^\alpha + \text{h.c.} \right), \tag{3}$$

§ § Neutrino masses

- Neutrino mass

$$m_{\nu_L}^{ij} \simeq \frac{\lambda_5}{8\pi^2}\left(\sum_{\alpha=1}^{3} g_{i\alpha} y_R^\alpha g_{\alpha j}^T\right)\left(\frac{v}{m_{\phi'}}\right)^2 v_S$$



- RH neutrino mass

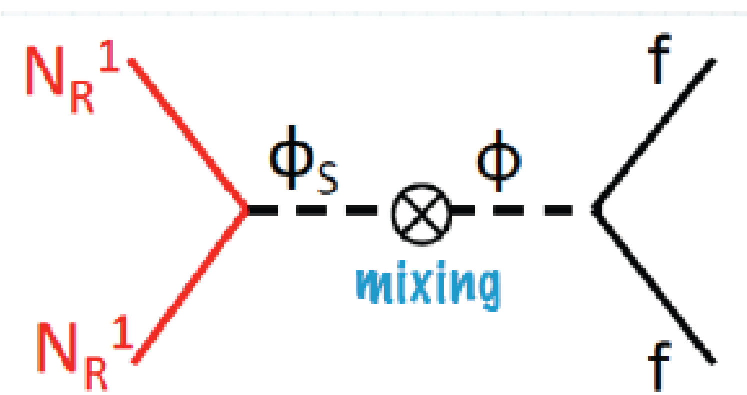
$$m_{N_R^\alpha} = -y_R^\alpha \frac{v_S}{\sqrt{2}}$$

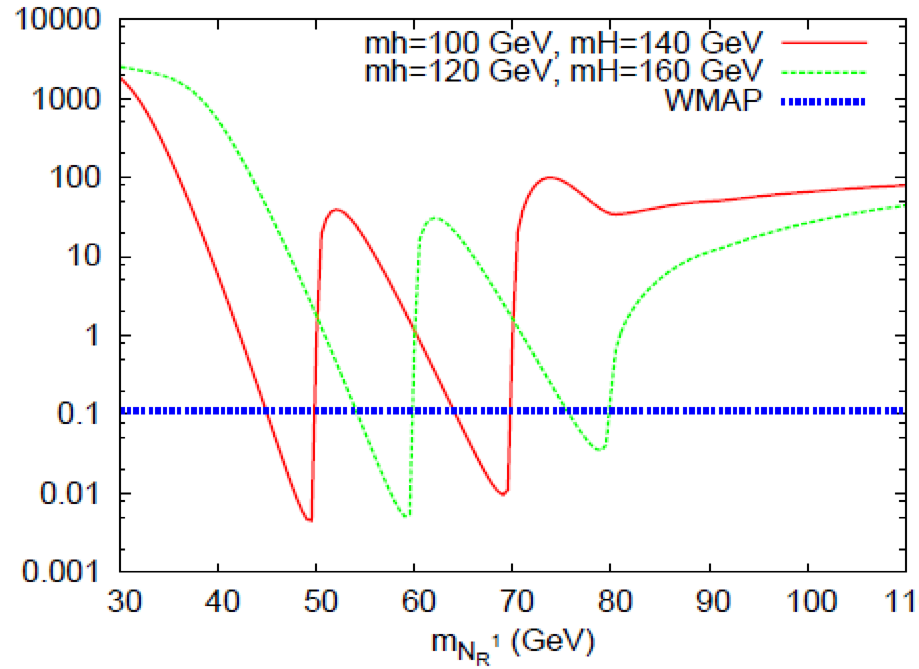
- The LEP bound for a heavy Z'

$$v_S \gtrsim 3\text{-}3.5 \text{ TeV}$$

§ § Dark matter

- Dark matter relic abundance





§ Revisit in light of 16 MeV vector boson

[OS and Shimomura (2016)]

§§ Radiative neutrino mass in a gauged U(1)$_{B-L}$ model

- Additional interactions: gauge kinetic mixing
- The anomalies tell the mass and couplings of the vector boson.
- The scale of U(1)$_{B-L}$ breaking

$$v_s = 13.78 \left(\frac{2 \times 10^{-3}}{|\varepsilon_X|} \right) \text{ GeV},$$

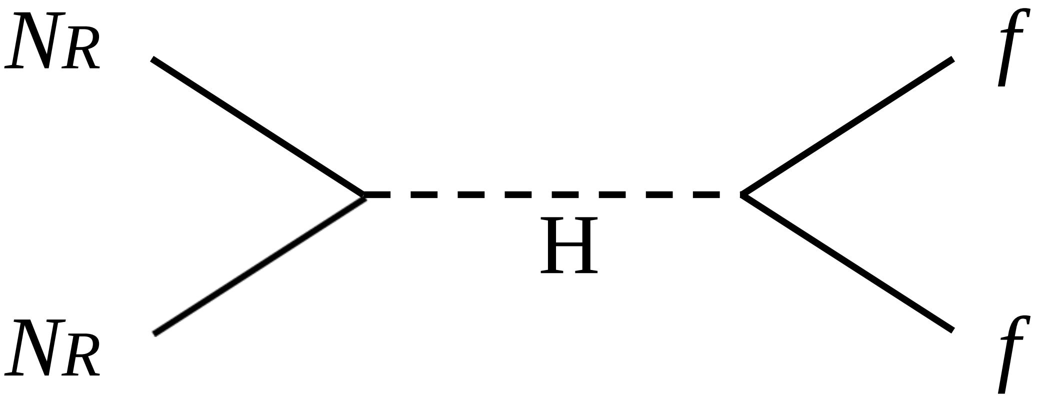
- Mass spectrum

$$m_H = 6.16 \left(\frac{\lambda_s}{0.1} \right)^{1/2} \left(\frac{2 \times 10^{-3}}{|\varepsilon_X|} \right) \text{ GeV},$$

$$m_N = 3.08 \left(\frac{Y_R}{0.316} \right) \left(\frac{2 \times 10^{-3}}{|\varepsilon_X|} \right) \text{ GeV},$$

§ § DM relic density revisited

- Annihilation

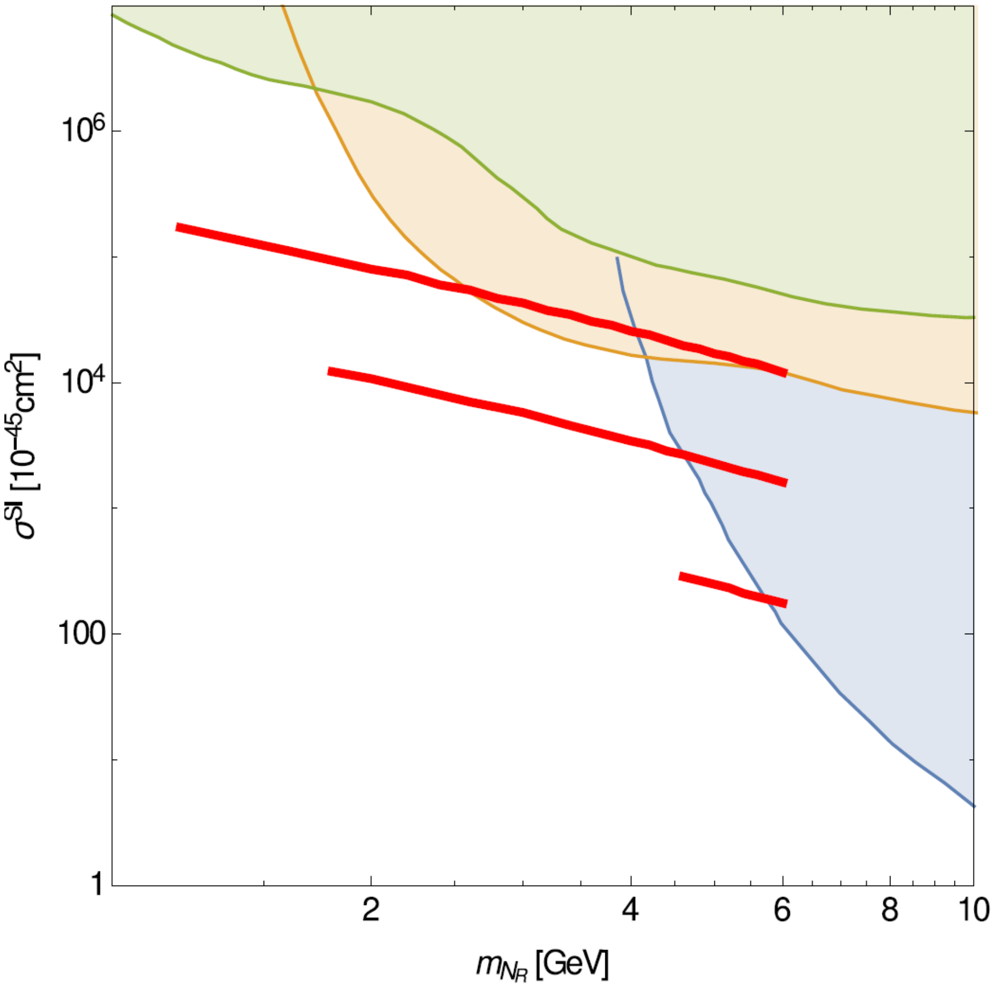


- Thermal relic abundance

$$\Omega\, h^2(m_{N_R}, m_H, \sin\alpha) \cong 0.1$$

§ § DM direct detection

- Cross section with a nucleon for thermal DM



sinα=

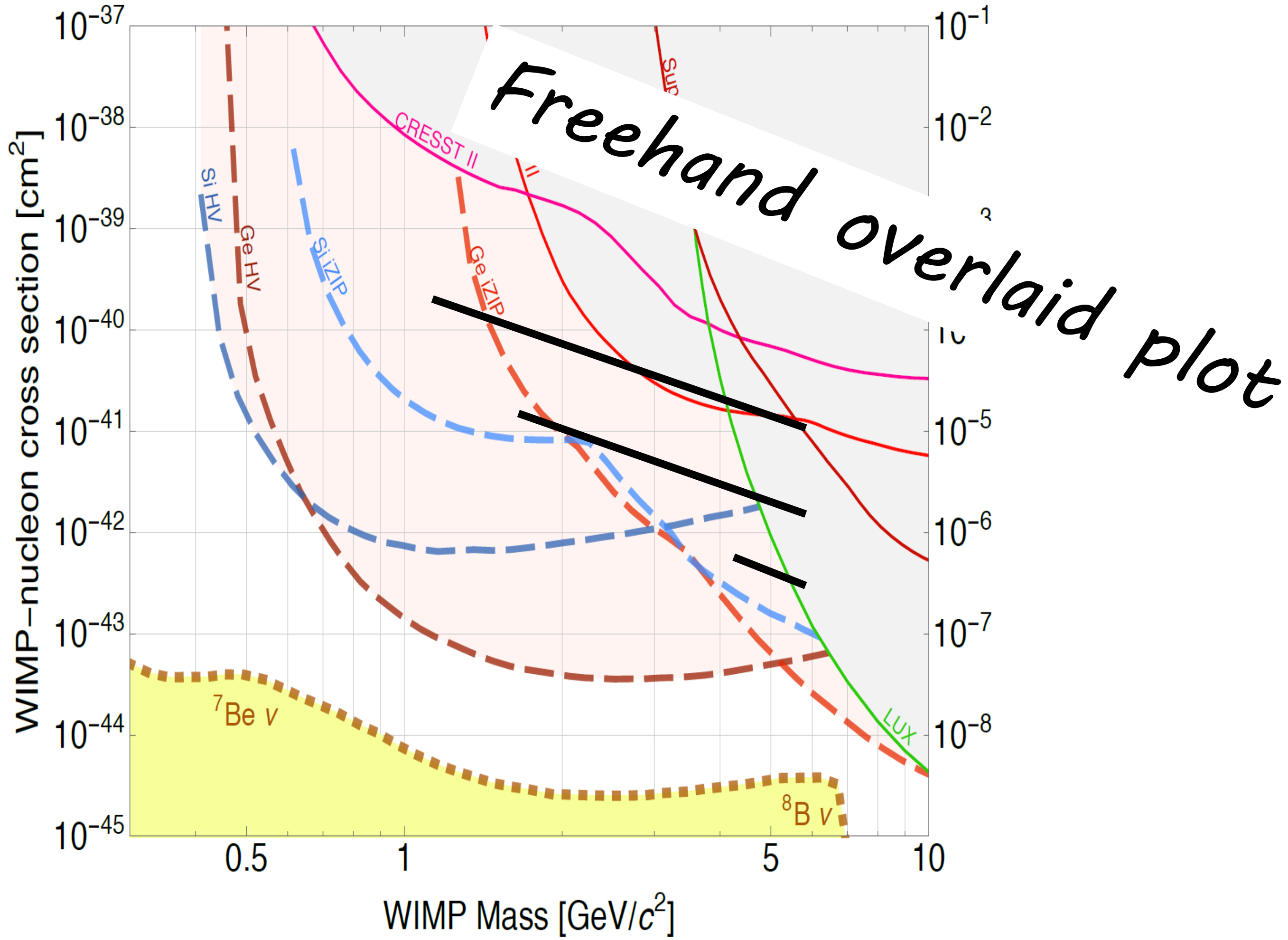
0.0003

0.0001

0.00003

§ § DM direct detection

- v.s. superCDMS projection [1610.00006]



§ Summary

- Radiative model of neutrino mass
- $U(1)_{B-L}$
- Atomki anomalies→ 16 MeV vector boson

- A few GeV mass RH neutrino dark matter
- Prediction: The superCDMS can detect DM.