

Heavy Neutrino Decay

Detection Sensitivity and Decay Width

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Summary

1 Introduction

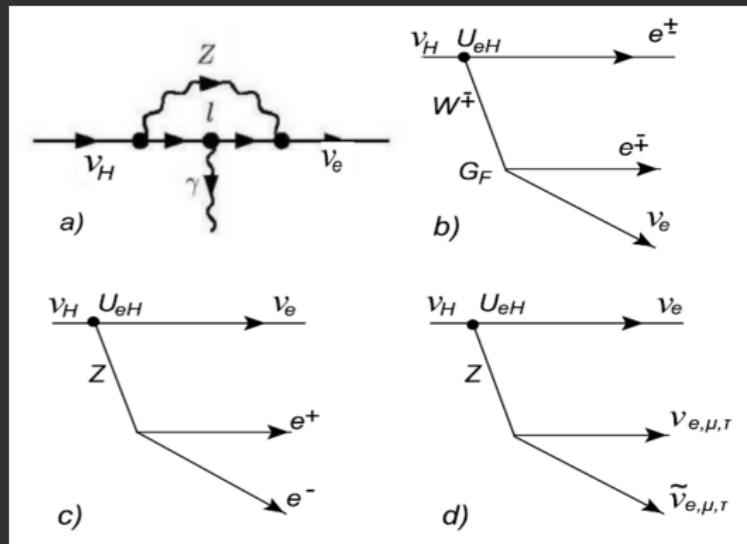
2 Closed-Form Calculations

3 Discussions of Borexino's Bound

4 Future Experimental Bounds

Introduction

Heavy Neutrino (MeV)



$$\nu_H \rightarrow \nu_e + \gamma$$

$$\nu_H \rightarrow \nu_e + e^+ + e^-$$

$$\nu_H \rightarrow \nu_e \nu_i \tilde{\nu}_i \text{ (Invisible)}$$

Experimental Limits for Heavy Neutrino

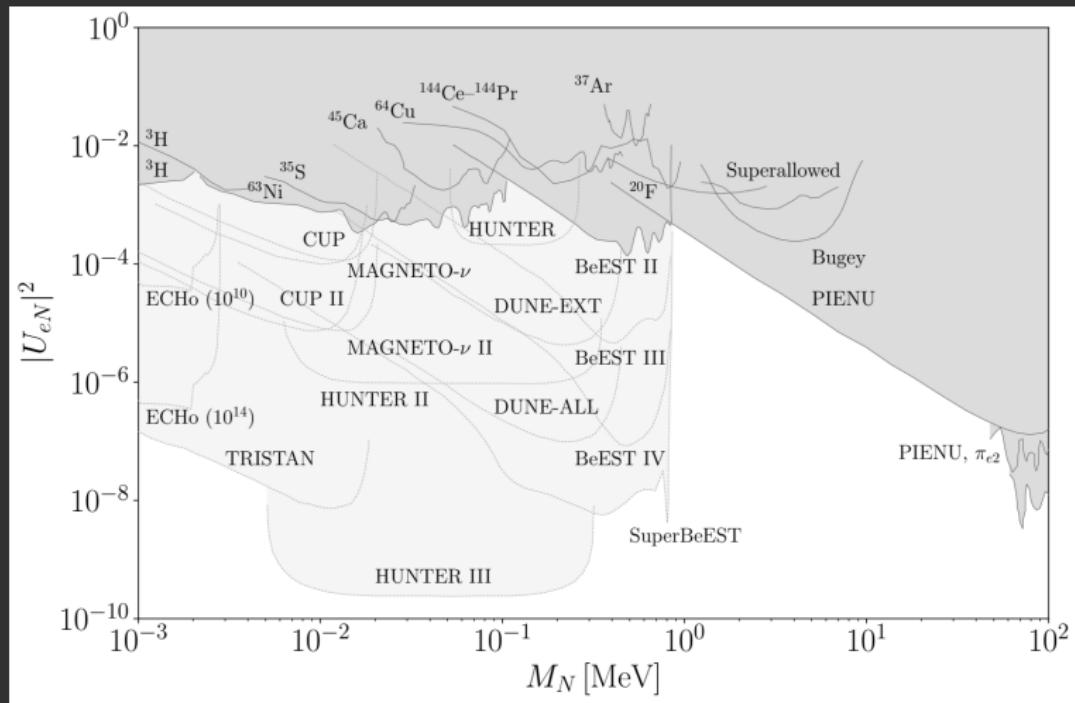


Figure: Current and future limits in mass-mixing parameter space

Closed-Form Calculations

What Channels Can This Neutrino Be Involved?

Dirac

- Both Charged Current and Neutral Current Channels [1]

Majorana

- Both Charged Current and Neutral Current Channels

A Combined CC and NC Channel Calculation (Dirac)

With the correct Fierz Transformation, the CC contribution should cancel with the NC contribution

$$\mathcal{H} = \frac{G_F}{\sqrt{2}} [\bar{u}_{\nu_e} \gamma_\mu (1 - \gamma_5) u_{\nu_H}] \{ \bar{u}_e \gamma^m u [(g_V + 1) - (g_A + 1)\gamma_5] v_e \}$$

where

$$\begin{aligned} g_V &= -\frac{1}{2} + 2 \sin^2 \hat{\theta}_W(0) = -0.0397 \\ g_A &= -\frac{1}{2} \end{aligned}$$

More Than A Factorial Difference From CC Channel

For $\nu_H(p, s) \rightarrow \nu_e(l) + e^+(k) + e^-(q)$, and $a = p + m_{\nu_H} s$

- $\frac{1}{2} \sum_{\text{spin}} |M|^2 =$
$$32 \left[(X - 2Y)(l \cdot q)(a \cdot k) + (X + 2Y)(l \cdot k)(a \cdot q) - Z m_e^2 (l \cdot a) \right]$$
- $I = \int \frac{d^3 k}{2k^0} \int \frac{d^3 q}{2q^0} \delta^4(k + q + l - p) = \frac{\pi}{2} \sqrt{1 - \frac{4m_e^2}{Q^2}}$
- CC contribution does not contain this term [2]

Expected Decay Width

$$\Gamma_0 = \frac{G_F^2 m_{\nu_H}^5}{192\pi^3}, \quad \frac{d^2\Gamma}{dl^0 d\cos\theta} = \Gamma_0 |U_{s1}|^2 \frac{d^2\bar{\Gamma}}{dl^0 d\cos\theta}$$

$$\begin{aligned} \frac{d^2\bar{\Gamma}}{dl^0 d\cos\theta} &= 4(1-Q^2)^2 \sqrt{1 - \frac{4m_e^2}{Q^2}} \frac{1}{Q^2} \left\{ \right. \\ &\quad \left[X \left(Q^2 + 2Q^4 - 2m_e^2(Q^2 - 1) \right) - 6ZQ^2m_e^2 \right] \\ &\quad \left. - |\vec{s}| \cos\theta \left[X \left(Q^2 - 2Q^4 + 2m_e^2(1 + Q^2) \right) - 6ZQ^2m_e^2 \right] \right\} \end{aligned}$$

where $X = [(g_V + 1)^2 + (g_A + 1)^2]$, $Y = [(g_V + 1)(g_A + 1)]$, and $Z = [(g_V + 1)^2 - (g_A + 1)^2]$.

Discussions of Borexino's Bound

Borexino Solar Neutrino Experiment



Borexino

- Detects solar neutrinos by scattering them with electrons
- 278 tons of purified organic liquid scintillator
- Selects 100 tons fiducial volume to suppress external radiation background
- Energy of an event is quantified by photo-multipliers with a resolution of 5%

Discrepancies

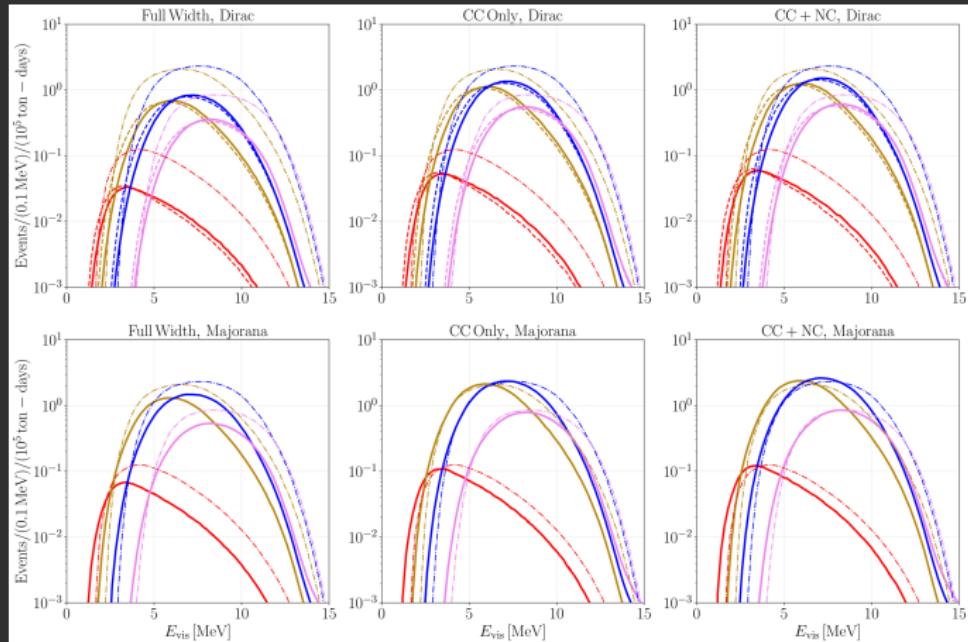


Figure: Solid lines are from our Monte-Carlo simulation; dash-dot lines are Borexino's plot [1]

Re-analyze Borexino

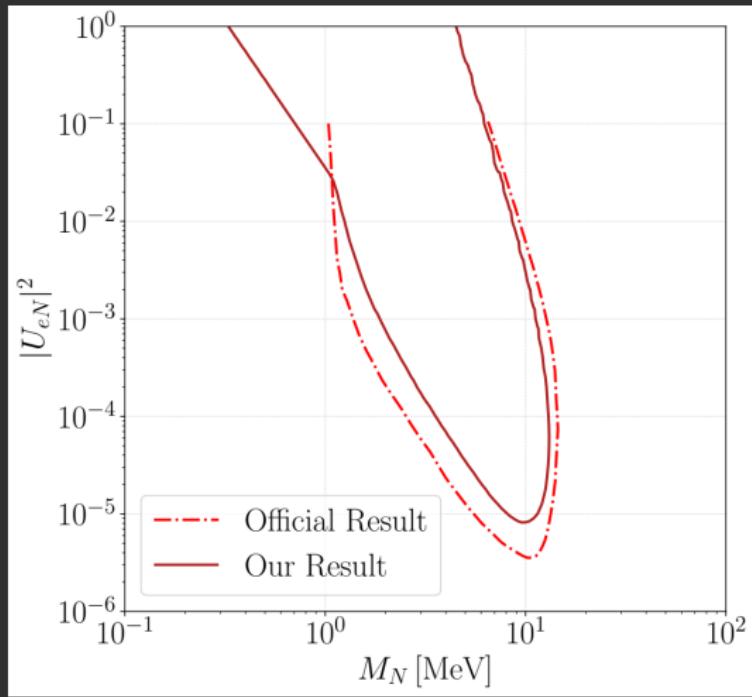


Figure: Our result is more pessimistic though we are able to constrain in the region $m_{\nu_H} \lesssim 1\text{MeV}$ because we have included the process $\bar{\nu}_H \rightarrow \nu_e + \gamma$

Future Experimental Bounds

Experimental Sensitivity

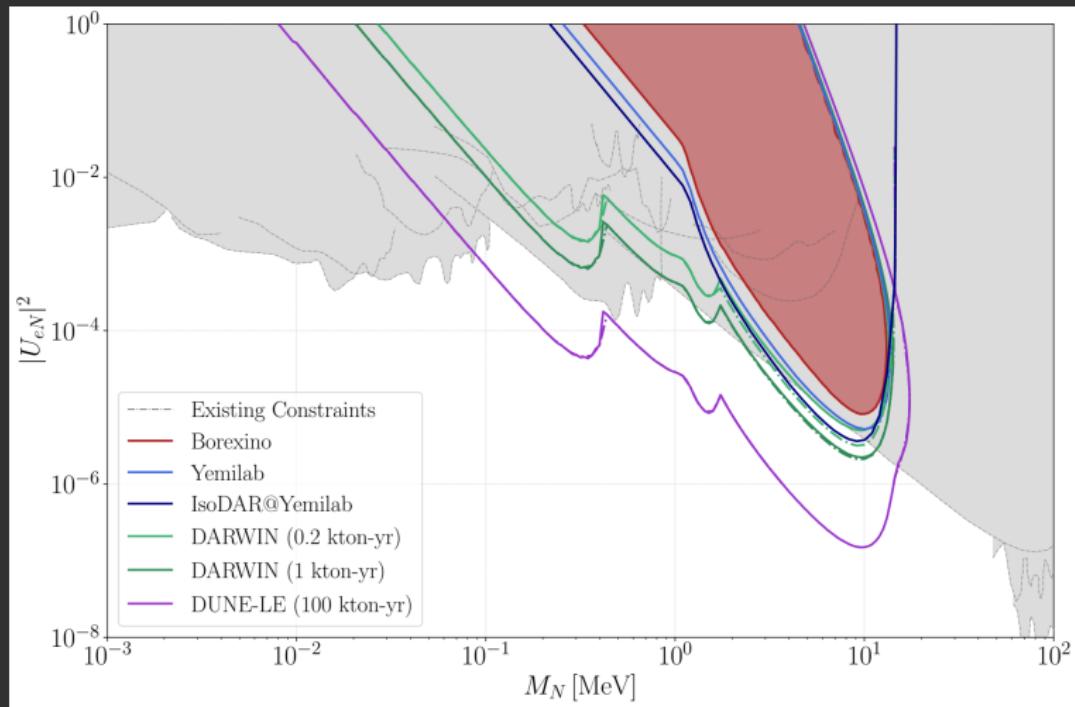


Figure: All constraints are 90% C.L.

Various Experimental Set-ups

- Yemilab: 12m height and diameter fiducial cut;
- IsoDAR@Yemilab: detect $\bar{\nu}_e$ decay from ${}^8\text{Li}$ at Yemilab;
- DARWIN: Liquid Xenon detector;
- DUNE: Neutrino Oscillation from Fermilab to Sanford Underground Research Facility

References

1. Bellini, G. *et al.* New limits on heavy sterile neutrino mixing in B8 decay obtained with the Borexino detector. *Phys. Rev. D* **88**, 072010. arXiv: 1311.5347 [hep-ex] (2013).
2. Shrock, R. E. General Theory of Weak Processes Involving Neutrinos. 2. Pure Leptonic Decays. *Phys. Rev. D* **24**, 1275 (1981).

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