Sterile Neutrino Decay at Borexino

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CNP Day Presentation
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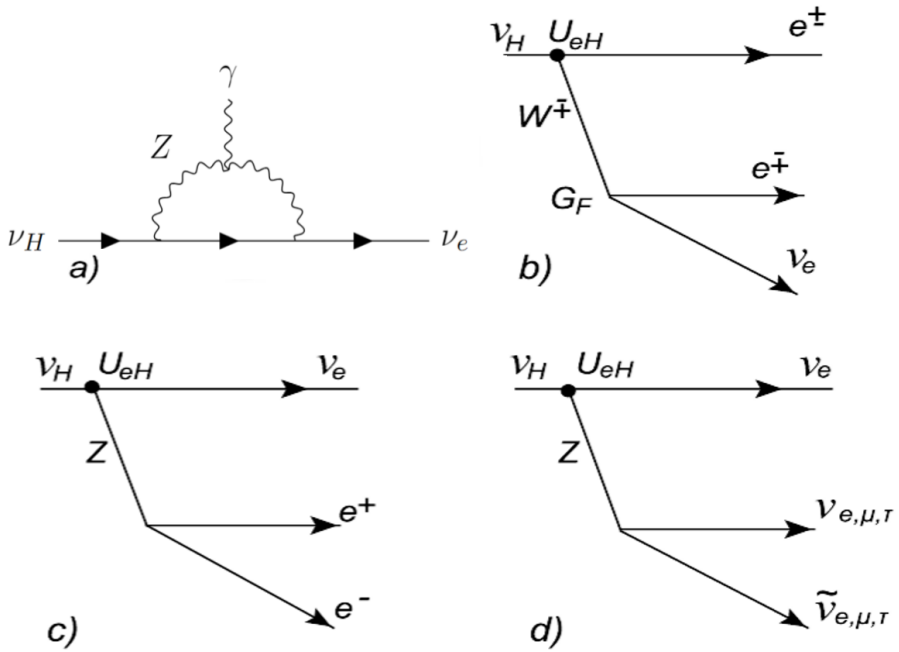
Outline

- What would happen if you have a MeV scale neutral heavy lepton that couples to the weak interaction?
- Current experimental limit for such decay.
- Closed-form kinematics calculation.
- How does this contribute to observable events (Borexino)?

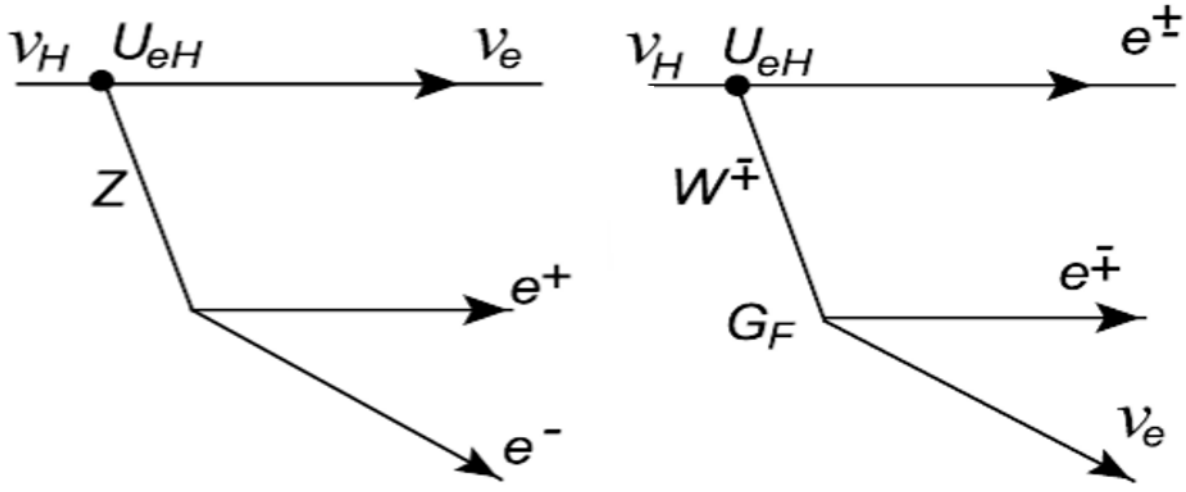
Heavy Sterile Neutrino (MeV) Decay



Different channels that the heavy sterile neutrino can decay to up to the order of 1-loop(Bellini et al. 2013)[1]: $\nu_H \to \nu_e + \gamma$, $\nu_H \to \nu_e + e^- + e^+$, and $\nu_H \to \nu_e \nu_i \tilde{\nu}_i$(Invisible)

[1] Bellini et al. (2013). "New limits on heavy sterile neutrino mixing in ^8B decay obtained with the Borexino detector"

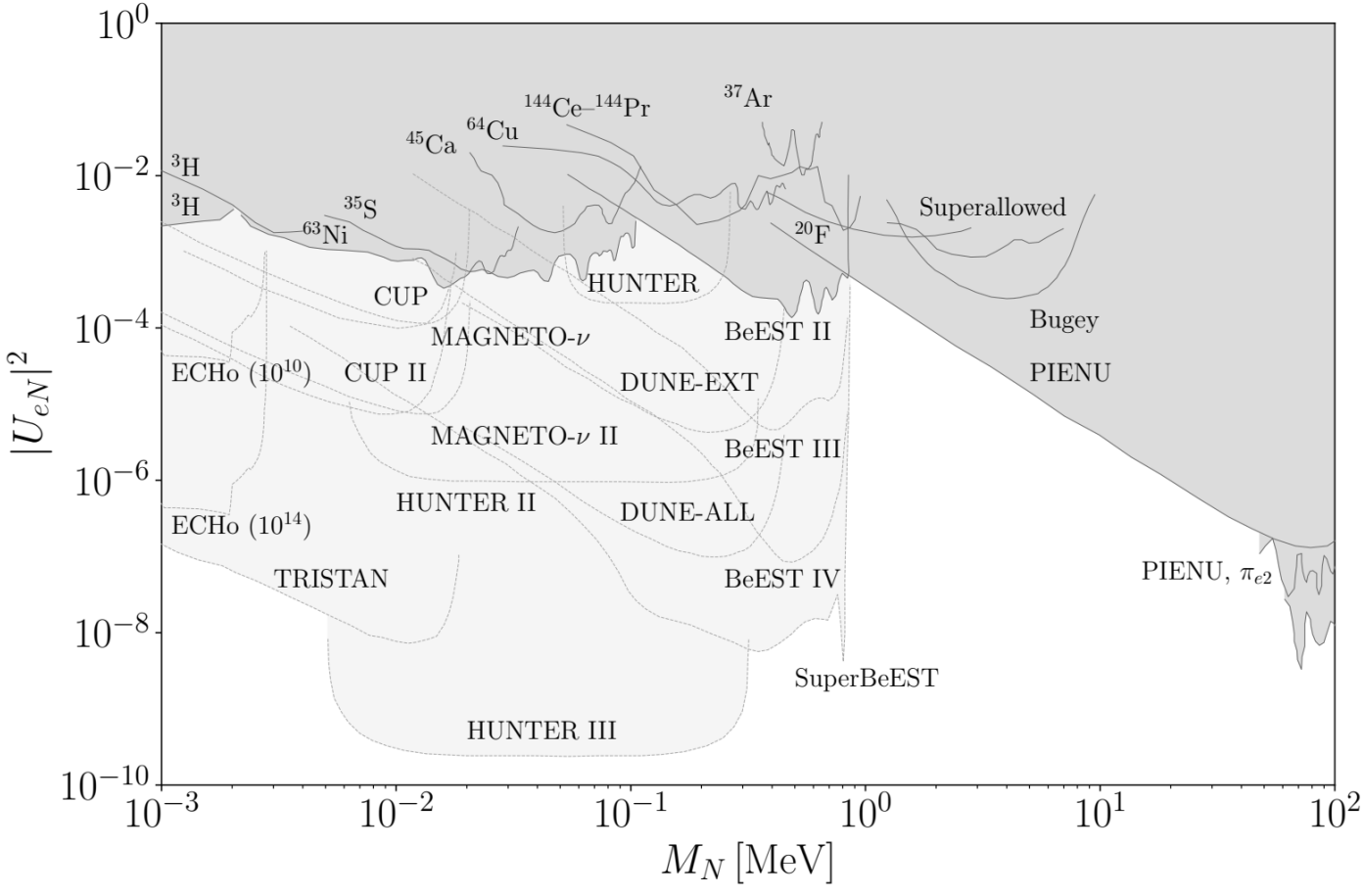
The Relevant Channels for Our Detection on Earth



The relevant graphs.

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

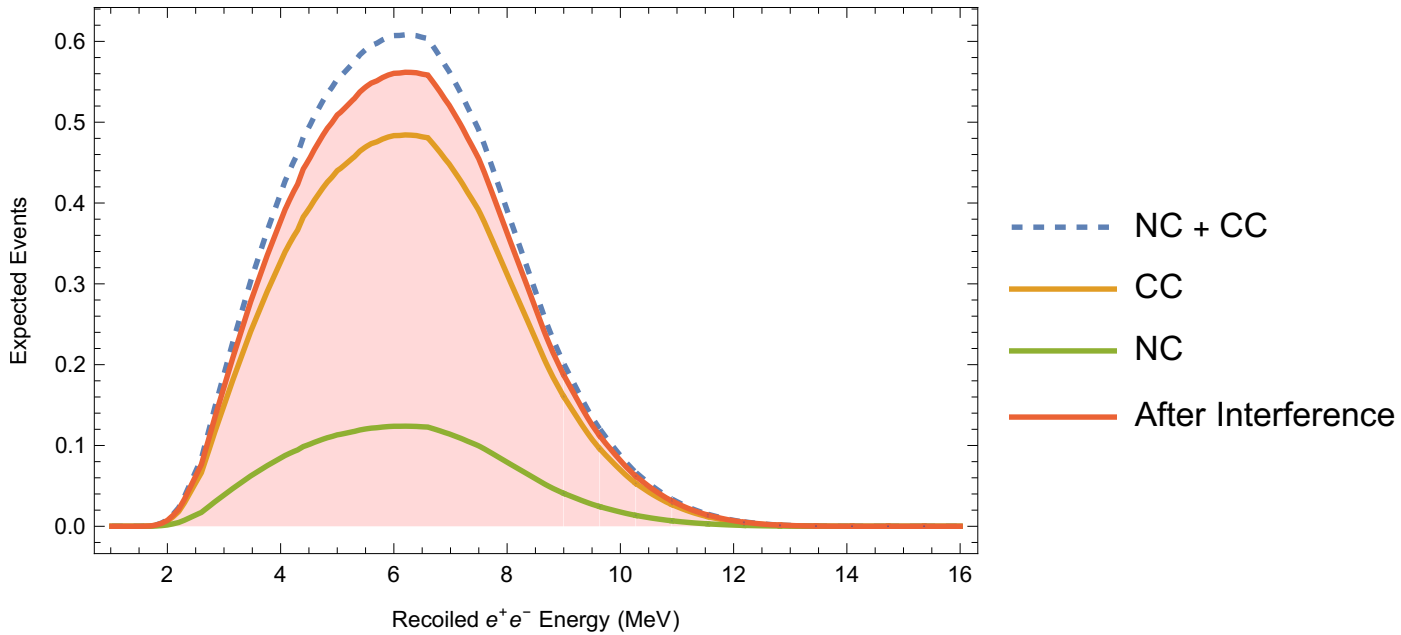
Experiment Limit



Current and future limits in mass-mixing parameter space.

Interference Between Charged Current (CC) Channel and Neutral Current (NC) Channel

- Since the product is $\nu_e + e^- + e^+$, the contribution is from the interference of the CC and NC channels.



This is a comparison between the CC channel, NC channel, their interfered channel (in shade), and their incoherently summed channel (dashed).

Closed Form Calculation

- Using Fierz Transformation,

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

$$\downarrow$$

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

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

Expected Decay Width

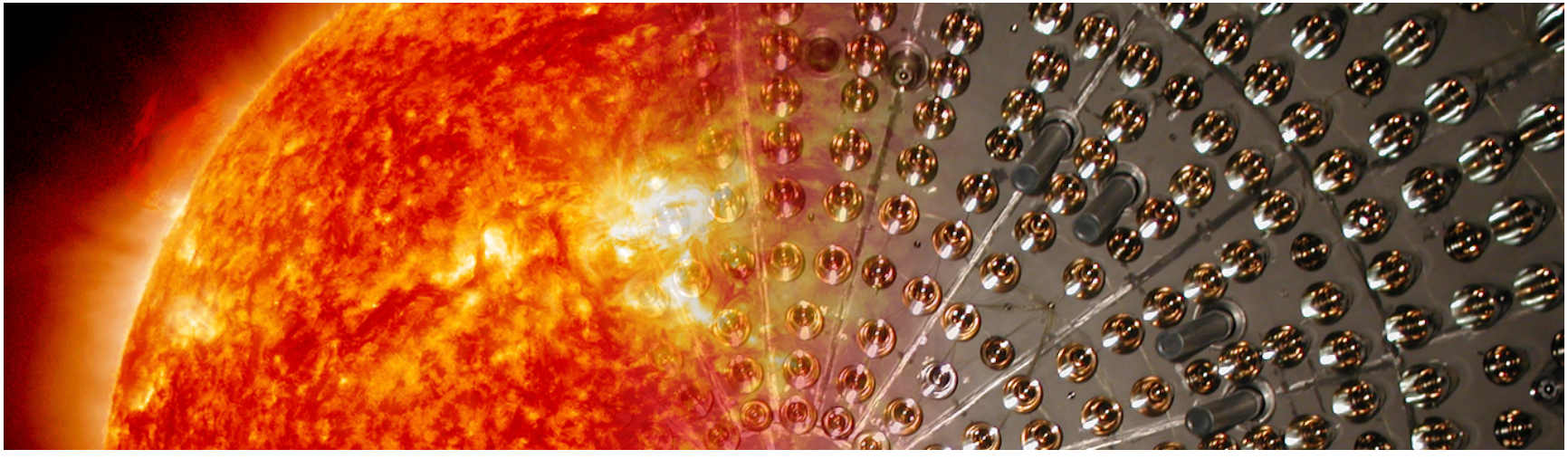
$$\Gamma_0 = \frac{G_F^2 m_{\nu_H}^5}{192\pi^3}, \qquad \frac{d^2\Gamma}{dl^0 d\cos\theta} = \Gamma_0 |U_{s1}|^2 \frac{d^2\overline{\Gamma}}{dl^0 d\cos\theta}$$

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

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

Are the Current Experiments Sensitive to Such Event?

We can start by analyzing Borexino's bounds on this process.

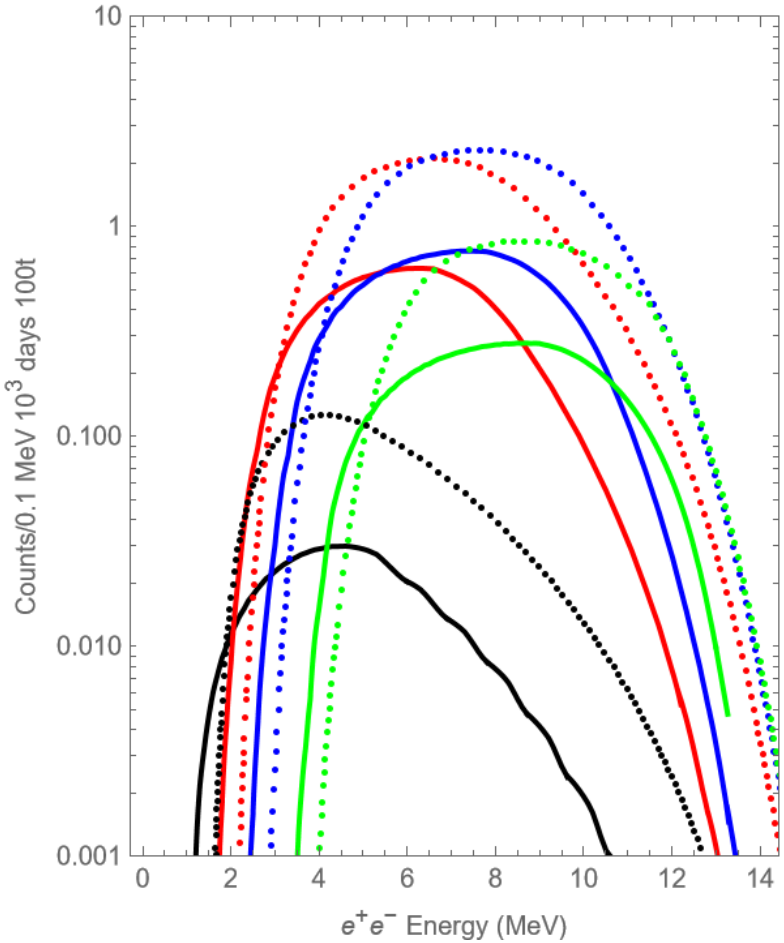


Sun-Borexino

Borexino

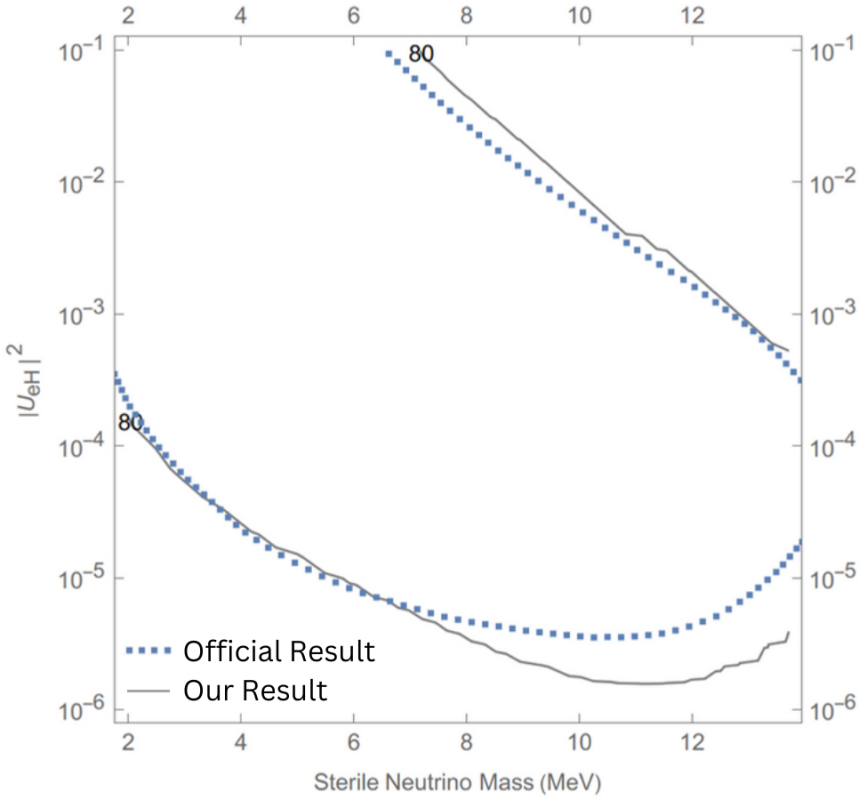
- Detects solar neutrinos by scattering them with electrons
- 278 tons of purified organic liquid scintillator (C_9H_{12})
- Selects 100 tons fiducial volume to suppress external radiation background
- Energy of an event is quantified by photo-multipliers with a resolution of $5\%/\sqrt{E[\mathrm{MeV}]}$

Discrepancies



Solid lines are from our closed-form calculation; dash lines are Borexino's plot (Bellini et al. 2013)

Re-analyze Borexino



This has a light more sensitivity due to our different event spectra.

Summary and the future work

- There is no clear evidence for such a sterile neutrino.
- Due to possible reasons, Borexino may have underestimated the sensitivity of sterile neutrino decay.
- I will be working on evaluating the experimental bounds on reactor neutrinos (IsoDAR@Yemilab)

References I

Bellini, G. et al. (2013). "New limits on heavy sterile neutrino mixing in B8 decay obtained with the Borexino detector". In: *Phys. Rev. D* 88.7, p. 072010. DOI: 10.1103/PhysRevD.88.072010. arXiv: 1311.5347 [hep-ex].