

Probing the pseudo-Dirac scenario using Solar neutrinos at JUNO

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Neutrino Masses

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SM SSB via Higgs vev

$$\mathcal{L}_\nu \supset -\frac{Y_{\alpha i} v}{\sqrt{2}} \overline{\nu}^\alpha_R N_R^i + \frac{1}{2} (N_R^i)^c M_{ij} N_R^j + h.c$$

Neutrino Masses

Let's rewrite it a bit neater...

$$\mathcal{L}_\nu \supset -\frac{1}{2}\bar{\Psi}^c M\Psi$$

$$\Psi = \begin{pmatrix} \nu_L \\ N_R^c \end{pmatrix} \quad M = \begin{pmatrix} 0_3 & \frac{Y^T v}{\sqrt{2}} \\ \frac{Y v}{\sqrt{2}} & M_R \end{pmatrix}$$

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In See-Saw scenarios, take:

$$M_R \gg Y v$$

But what about...

$$M_R \ll Y v$$

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Global symmetries should be broken by quantum gravity...

$$M_R \equiv 0 \quad \longrightarrow \quad 0 < M_R \ll 1$$

The Pseudo-Dirac Scenario

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The Pseudo-Dirac Scenario

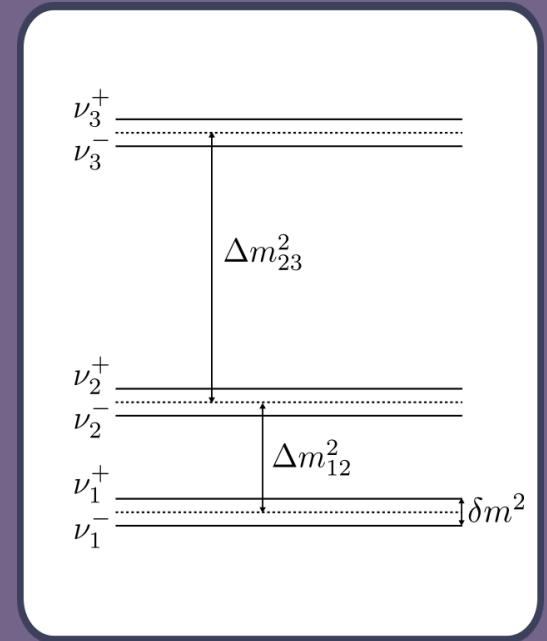
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Testing the Pseudo-Dirac Nature

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What about oscillations?

$$L_{osc} = \frac{4\pi E_\nu}{\delta m_k^2} \approx 25 \times 10^5 \text{ km} \left(\frac{E_\nu}{100 \text{ keV}} \right) \left(\frac{10^{-10} \text{ eV}^2}{\delta m_k^2} \right)$$

Solar oscillations with PD neutrinos

Solar neutrinos are a great probe:

$$E_{pp} \leq 420\text{keV}$$

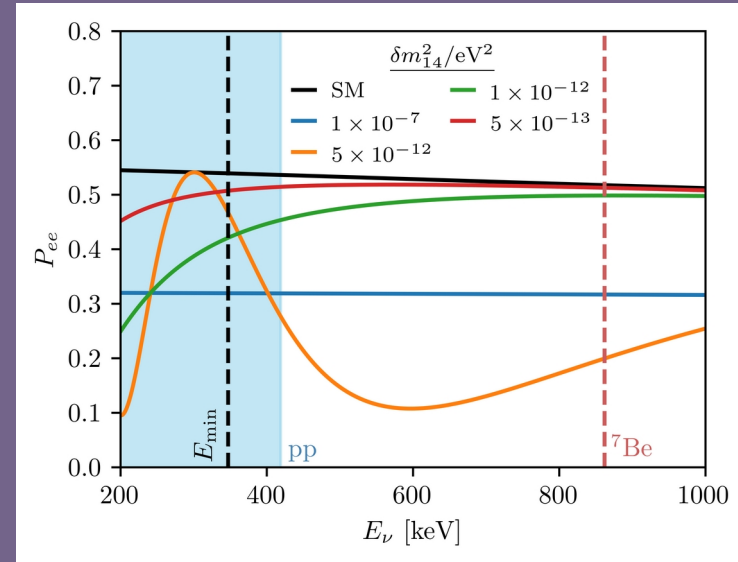
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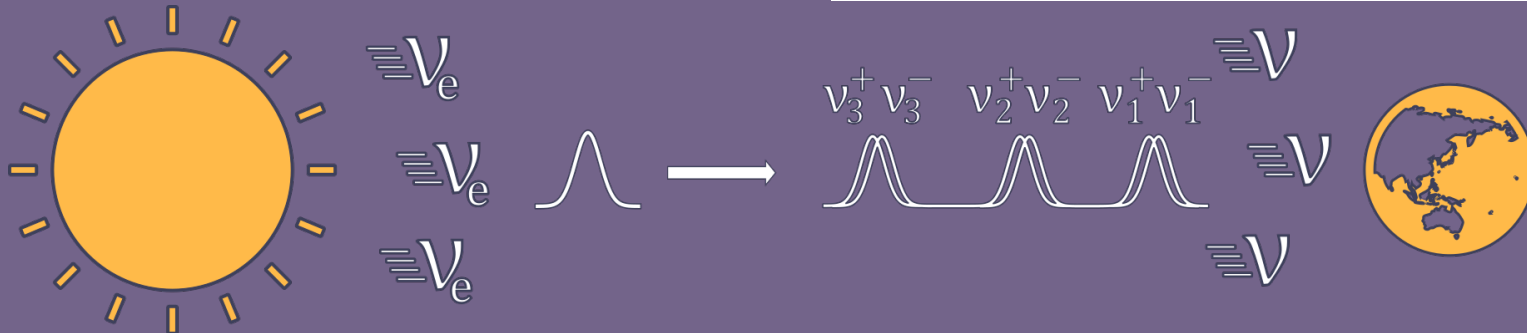
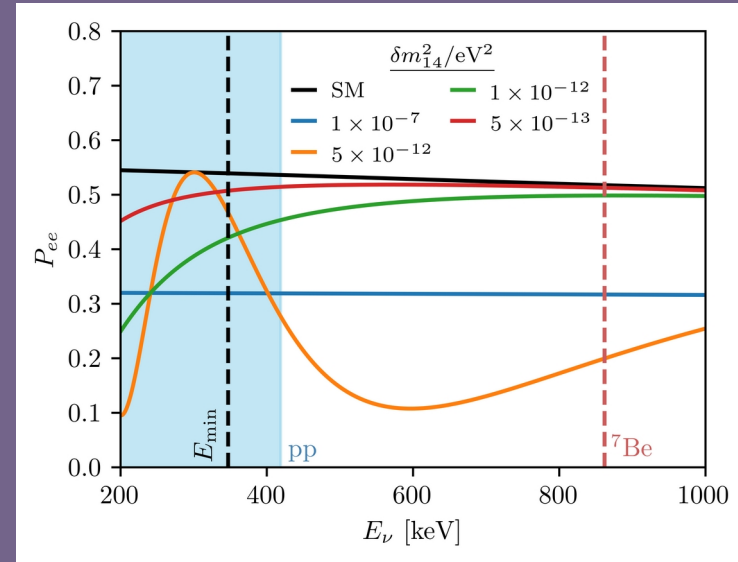


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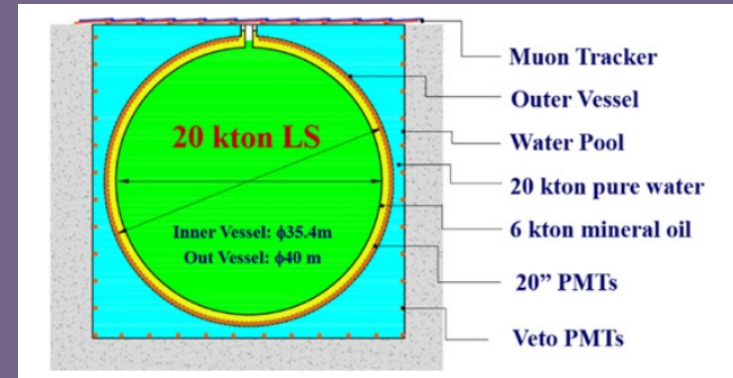
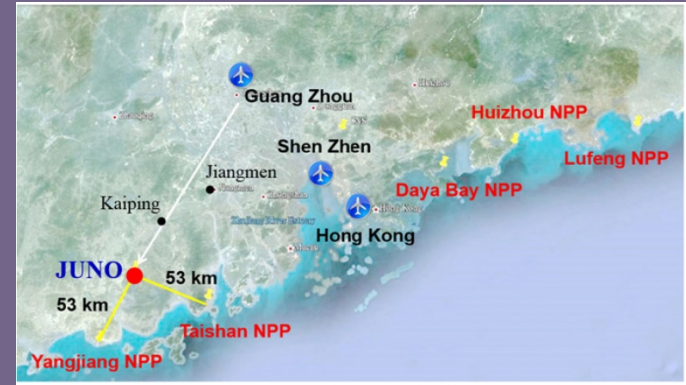
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The JUNO Experiment

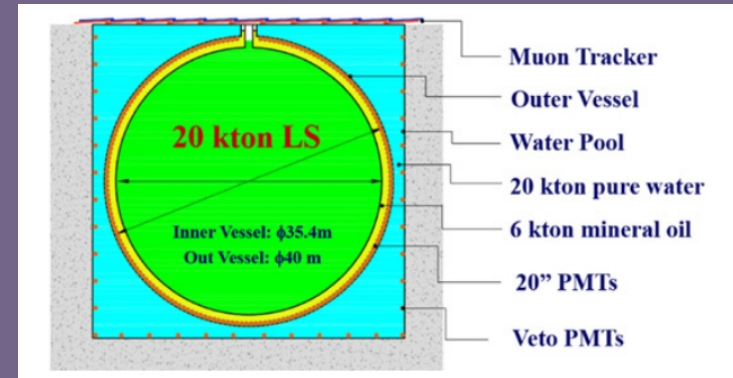
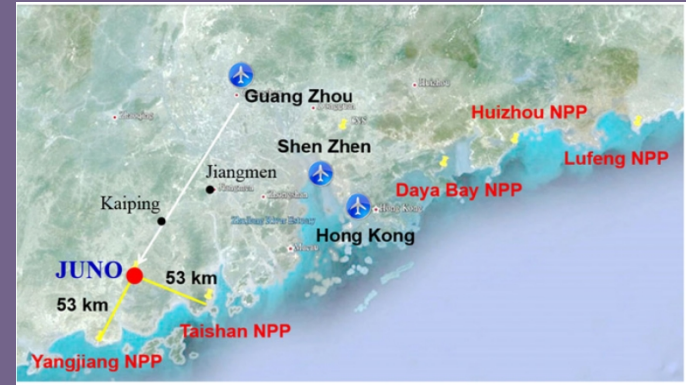
- Jiangmen Underground Neutrino Observatory (JUNO)
- Liquid scintillator detector



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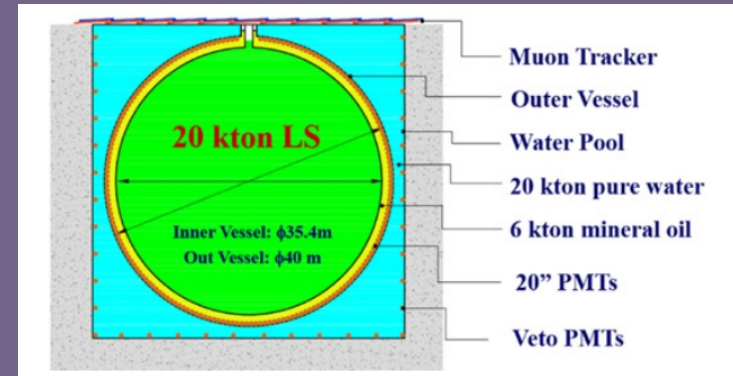
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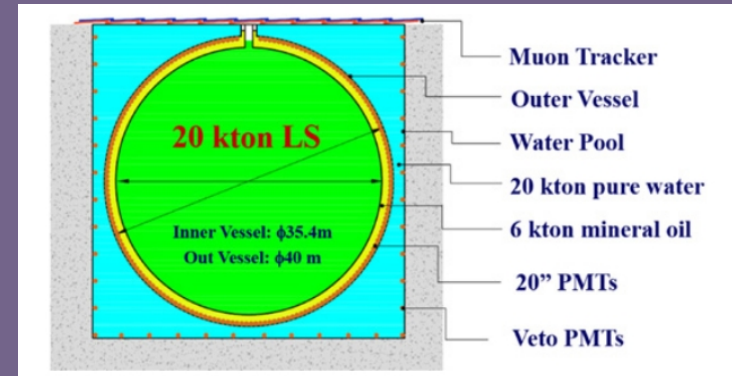
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- Primary goal is to determine the neutrino mass hierarchy



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The JUNO Experiment

- Jiangmen Underground Neutrino Observatory (JUNO)
- Liquid scintillator detector
- 20 kt fiducial volume (Borexino ~ 1kt)
- Primary goal is to determine the neutrino mass hierarchy
- Will be able to detect Solar neutrinos




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Poster


- Come see my poster to see our results!
- Feel free to ask me any questions


JUNO as a Probe of the Pseudo-Dirac Nature using Solar Neutrinos



Durham University

Jack Franklin
2304.05418





The Pseudo-Dirac Scenario

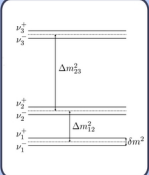
The neutrino mass Lagrangian term:

$$\mathcal{L}_\nu = -\frac{1}{2}\bar{\psi}^T M \psi,$$

with

$$\psi = \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}, \quad M = \begin{pmatrix} 0 & Y\nu/\sqrt{2} \\ Y\nu/\sqrt{2} & M_R \end{pmatrix}.$$

is usually encountered in Seesaw models with large Lepton Number Violation (LNV), $M_R \gg Y\nu$. However, we could equally be in a universe where $M_R \ll Y\nu$. This is the pseudo-Dirac scenario.



Pseudo-Dirac Neutrino Oscillations

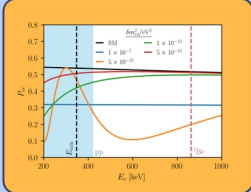
We can define the flavour states:

$$\nu_e = \frac{U_{e1}^T}{\sqrt{2}}(\nu_1^e + \nu_2^e)$$

We evolve the neutrino states with the Hamiltonian:

$$H = \frac{1}{2E_\nu} [H_{free} + A]$$

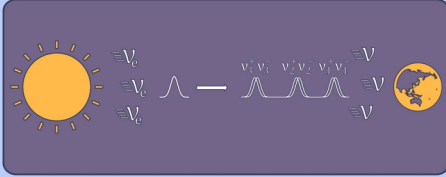
Where A is the matter potential in the Sun.

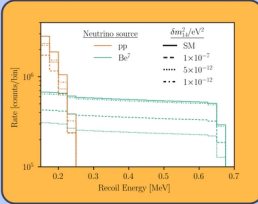


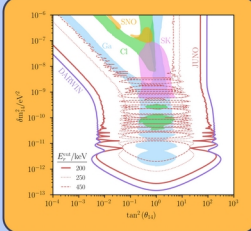
Solar Neutrinos at JUNO

- JUNO will detect pp and ⁷Be neutrinos at rates well above the expected background.
- Pseudo-Dirac neutrino oscillations would impact the number of events and spectral shape of detected neutrinos at JUNO.
- Test statistic used to estimate the sensitivity of JUNO to the pseudo-Dirac scenario:

$$\chi^2 = \sum_I \left(\frac{\sum_a \alpha_a N_{theory}^a + \sum_b (\alpha_b - 1) N^{I,b} - N_{bench}^I}{N_{bench}^I \sum_b \alpha_b N_b^I} \right)^2 + \sum_a \left(\frac{\alpha_a - 1}{\sigma_a} \right)^2 + \sum_b \left(\frac{\alpha_b - 1}{\sigma_b} \right)^2$$

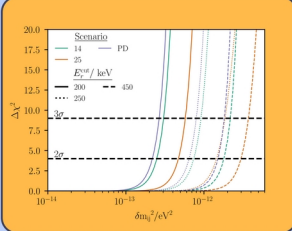






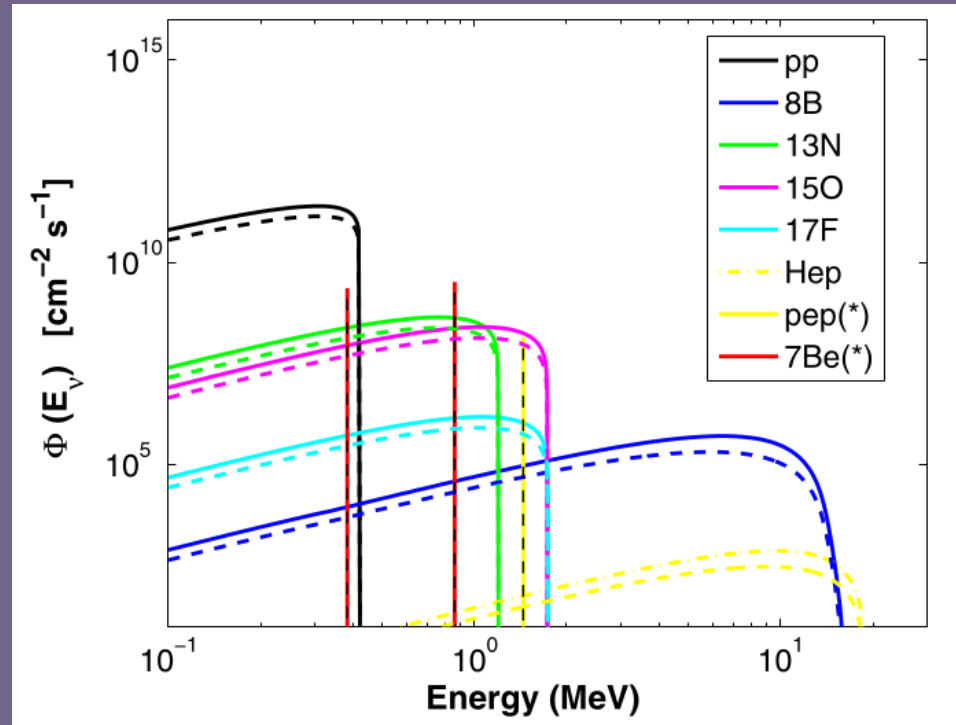
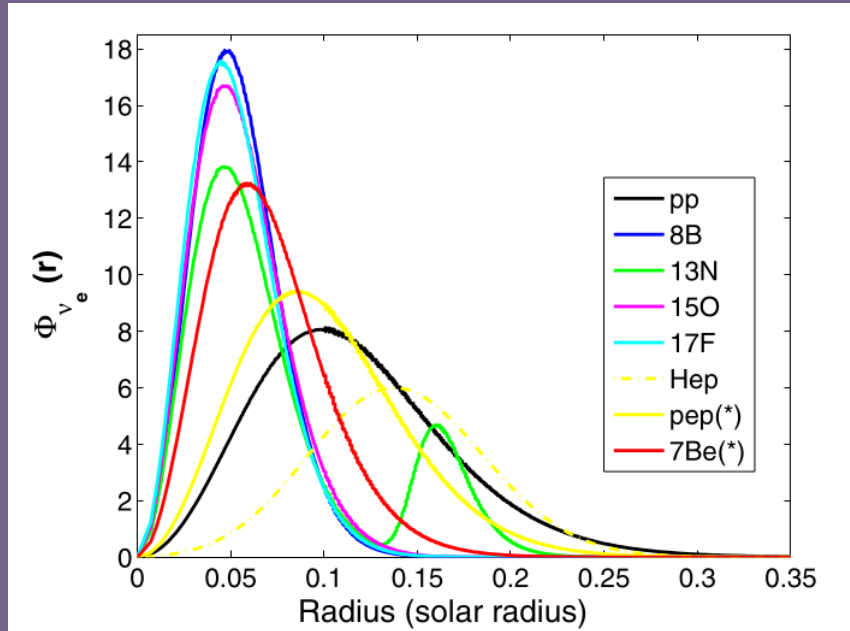
Results and Conclusions

- Assume 6 years of data taking
- Comparable sensitivity to future DARWIN experiment
- Sensitive to $\delta m^2 > 3.1 \times 10^{-13} \text{ eV}^2$ for 1-4 scenario and $\delta m^2 > 6 \times 10^{-13} \text{ eV}^2$ for 2-5 scenario
- 3σ exclusion of $\delta m^2 > 2.9 \times 10^{-12} \text{ eV}^2$ for pseudo-Dirac scenario
- Strongly dependent on control of backgrounds



Thank you

Solar neutrino fluxes



Source: Ilídio Lopes and Sylvaine Turck-Chièze 2013 ApJ 765 14

Chi-squared

$$\chi^2 = \sum_i \frac{\left(\sum_a \alpha_a N_{\text{theory}}^{i,a} + \sum_b (\alpha_b - 1) N^{i,b} - N_{\text{bench}}^i\right)^2}{N_{\text{bench}}^i + \sum_b N_b^i} + \sum_a \left(\frac{\alpha_a - 1}{\sigma_a}\right)^2 + \sum_b \left(\frac{\alpha_b - 1}{\sigma_b}\right)^2$$

Backgrounds at JUNO

