Intermediate BaseLine reactor neutrino experiments

unveil the neutrino mass hierarchy

Mehran Dehpour

Outline

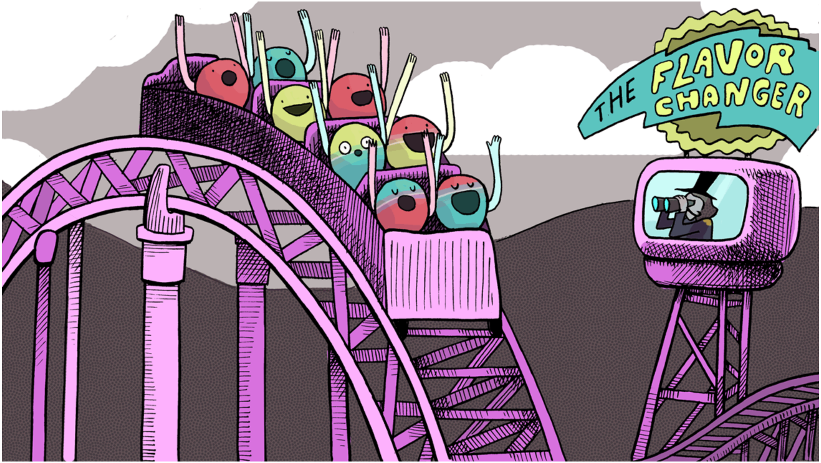
Bachelor of science in physics

Master of science in particle physics

Postmaster

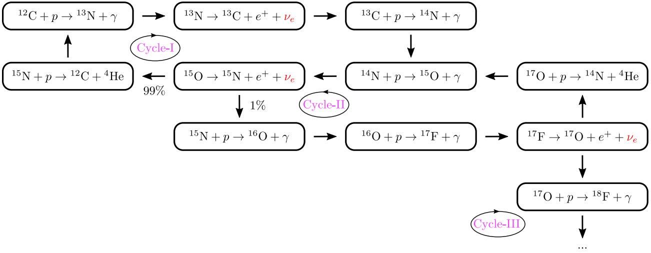
Introduction

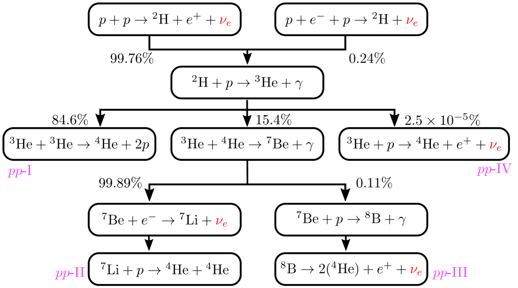
Neutrino oscillation



G. Bellini et al., Adv.High Energy Phys. 2014 (2014) 191960

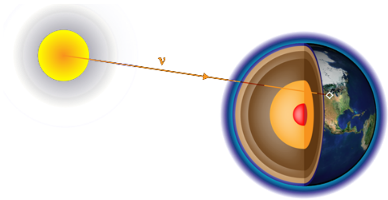
Solar neutrino production

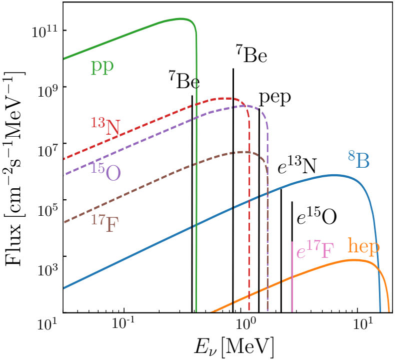




X. Xu et al., Prog.Part.Nucl.Phys. 131 (2023) 104043

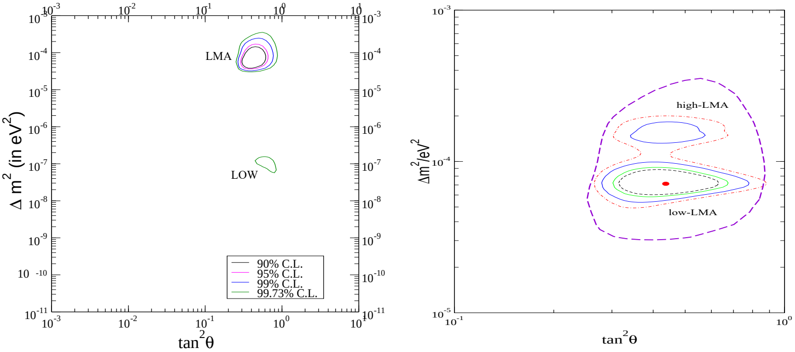
Solar neutrino flux





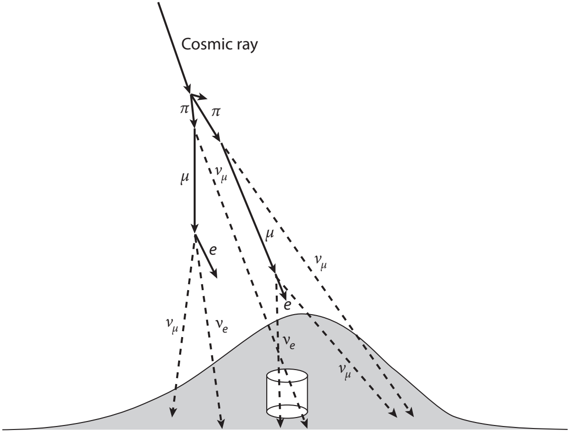
X. Xu et al., Prog.Part.Nucl.Phys. 131 (2023) 104043

SNO



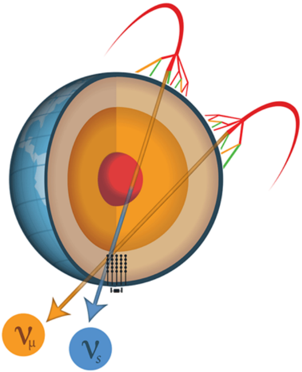
A. Bandyopadhyay, S. Choubey, R. Gandhi, S Goswami, D.P Roy, Phys.Lett.B 559 (2003) 121-130

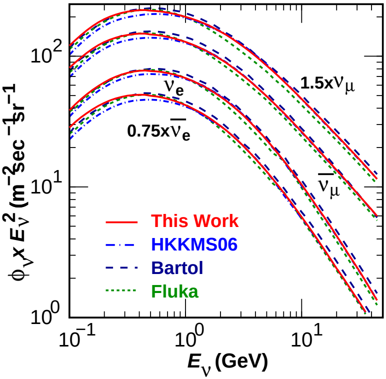
Atmospheric neutrino production



T. Kajita, Ann.Rev.Nucl.Part.Sci. 64 (2014) 343-362

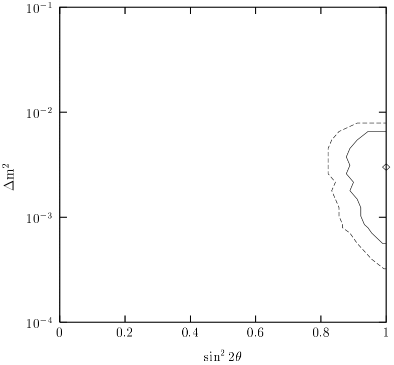
Atmospheric neutrino flux

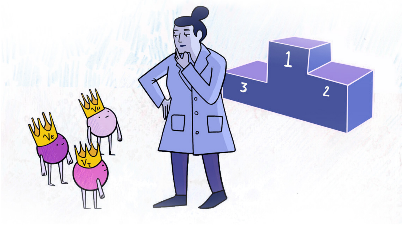




M. Honda et al., Phys.Rev.D 83 (2011) 123001

Super-Kamiokande

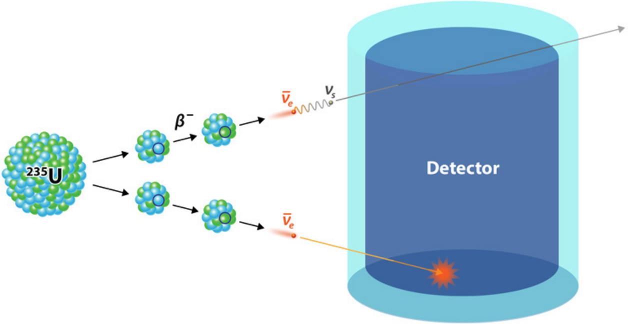




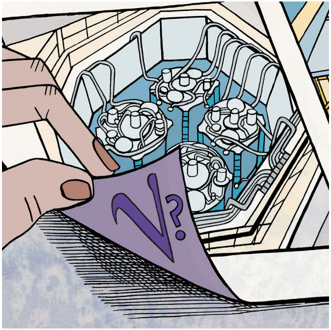
S. Choubey et al., Astropart.Phys. 14 (2000) 67-78

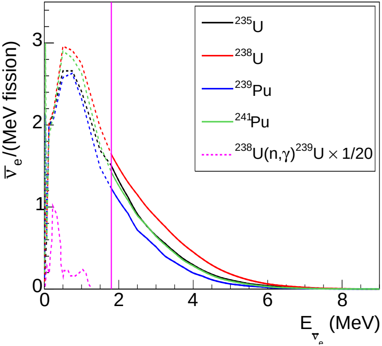
Reactor neutrino experiments

Reactor neutrino production



Reactor neutrino flux

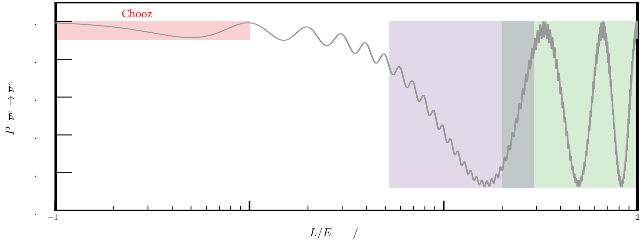




S. Kim et al., Adv.High Energy Phys. 2013 (2013) 453816

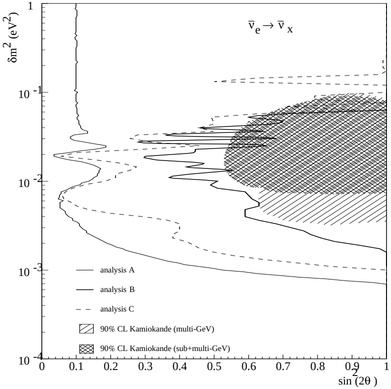
Survival probability of $\overline{\nu}_e$

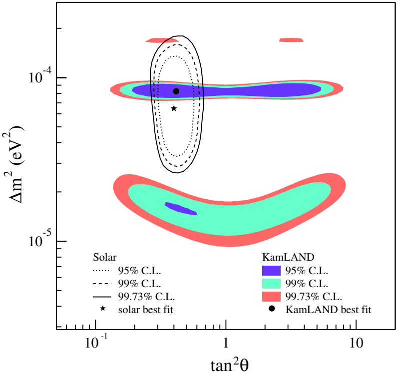
$$P^{\mathrm{NH}/\mathrm{IH}}_{\overline{\nu}_e\to\overline{\nu}_e} = 1 - \frac{1}{2} \sin^2 2\theta_{13} \left[1 - \cos\left(\frac{\Delta m^2_{\mathrm{atm}} L}{2E_\nu}\right)\right]$$
$$- \frac{1}{2}\cos^4\theta_{13}\sin^2 2\theta_{12}\left[1-\cos\left(\frac{\Delta m^2_{\mathrm{sol}} L}{2E_\nu}\right)\right]$$
$$+ 2\sin^2\theta_{13}\cos^2\theta_{13}\sin^2/\cos^2\theta_{12}\left[\cos\left(\frac{\Delta m^2_{\mathrm{atm}} L}{2E_\nu} - \frac{\Delta m^2_{\mathrm{sol}} L}{2E_\nu}\right) - \cos\left(\frac{\Delta m^2_{\mathrm{atm}} L}{2E_\nu}\right)\right]$$



S. Choubey et al., Phys.Rev.D 68 (2003) 113006

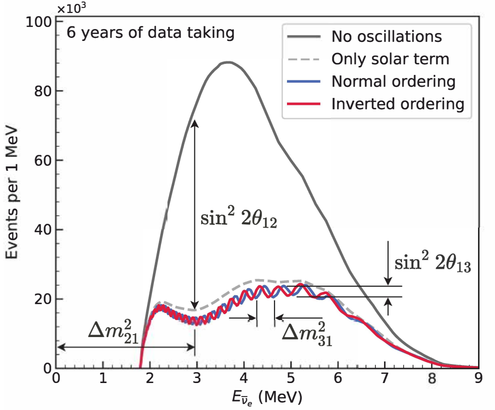
Chooz and KamLAND





M. Apollonio et al., Eur.Phys.J.C 27 (2003) 331-374, K. Inoue, New J.Phys. 6 (2004) 147

JUNO



M. He, Nucl.Part.Phys.Proc. 265-266 (2015) 111-113, A. Abusleme et al., Chin.Phys.C 46 (2022) 12, 123001

Accelerator neutrino experiments

Conclusion

- We have four main types of neutrino experiments in which neutrinos are produced in solar, atmosphere, reactor, and accelerator
- Currently, due to global fits, we are not sure about neutrino mass hierarchy, octant of θ_{23}, and δ_{CP} yet
- These will be determined in future accelerator neutrino experiments
- Also, the neutrino mass hierarchy can solved in the Intermediate BaseLine reactor neutrino experiment which the first such experiment, JUNO, will start data taking this year

Thanks for your attention!

Backup slides

The two-flavor neutrino oscillation

$$U = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

$$P_{\nu_\alpha \to \nu_\beta}(L, E_\nu) = \frac{1}{2}\sin^2 2\theta \left[1 - \cos\left(\frac{\Delta m^2 L}{2E_\nu}\right)\right]$$

MSW effect on two-flavor neturino oscillation

$$\Delta m_{\mathrm{M}}^2 \equiv \sqrt{(\Delta m^2 \cos 2\theta - 2EV_{\mathrm{CC}})^2 + (\Delta m^2 \sin 2\theta)^2}$$

$$\tan 2\theta_{\mathrm{M}} \equiv \frac{\tan 2\theta}{1 - \frac{2EV_{\mathrm{CC}}}{\Delta m^2 \cos 2\theta}}$$

$$V_{\mathrm{CC}} \equiv \sqrt{2} G_{\mathrm{F}} N_e$$

The three-flavor neutrino oscillation

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$c_{ij} \equiv \cos\theta ij, \;\; s_{ij} \equiv \sin\theta_{ij}$$

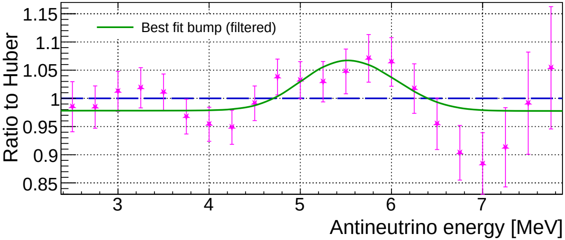
$$P_{\nu_\alpha \to \nu_\beta}(L, E_\nu) = \sum_{j,k} U^*_{\alpha j} U_{\beta j} U_{\alpha k} U^*_{\beta k} \exp\left(-i\frac{\Delta m^2_{jk}}{2E_\nu}L\right)$$

$$\Delta m^2_{\mathrm{sol}} \equiv \Delta m^2_{12}, \;\; \Delta m^2_{\mathrm{atm}} \equiv \Delta m^2_{13}$$

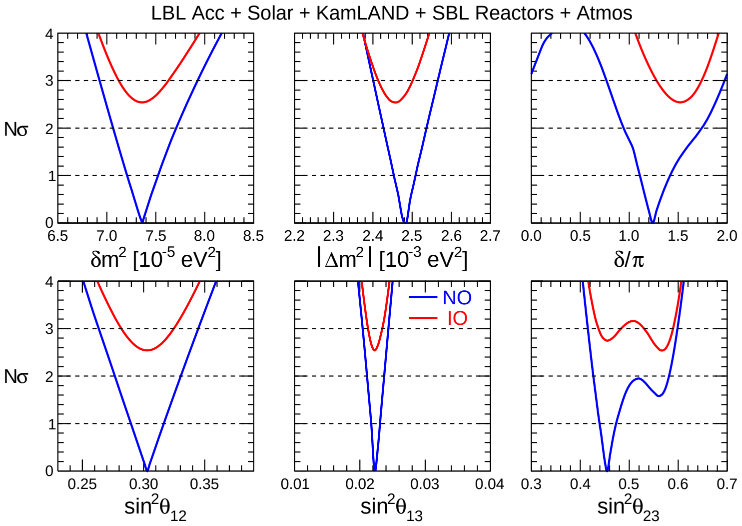
CP violation

$$
\begin{aligned}
A_{\alpha\beta}^{\mathrm{CP}} &= P_{\nu_\alpha \to \nu_\beta} - P_{\bar{\nu}_\alpha \to \bar{\nu}_\beta} \\
&= 4 \sum_{k>j} \Im \left[U_{\alpha k}^{*} U_{\beta k} U_{\alpha j} U_{\beta j}^{*} \right] \sin \frac{\Delta m_{kj}^{2} L}{2 E_\nu}
\end{aligned}
$$

Reactor Antineutrino deficit and 5 MeV bump Anomalies



Current global fit



F. Capozzi et al., Phys.Rev.D 104 (2021) 8, 083031