Non-Unitarity of the neutrino mixing matrix

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Link to the LoI

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Mixing matrix

Neutral heavy leptons are a common feature of many extensions of the SM and play and important role in models for neutrino mass generation. The seesaw mechanism is perhaps the most representative example.

$$U_{\alpha i}^{n\times n} = \begin{pmatrix} N & S \\ V & T \end{pmatrix}$$

$$NN^{\dagger} + SS^{\dagger} = I,$$

- S Antusch, O Fischer, JHEP 10(2014) 094
- S Parke, M Ross-Lonergan, Physical Review, **D93** 113009 (2016)
- E Fernandez-Martinez, J Hernandez-Garcia, and J Lopez-Pavon, JHEP 08(2016) 033
- C S Fong, H Minakata, H Nunokawa, JHEP 02(2017) 114
- M Blennow, P Coloma, E Fernandez-Martinez, J Hernandez-Garcia, J Lopez-Pavon, JHEP 02(2019) 015
- S A Ellis, K Kelly, S W Li arXiv:2008.01088
- and others...

Mixing matrix

$$N = N^{NP}\, U^{3\times 3} = \begin{pmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} U^{3\times 3}$$

$$\begin{aligned} \alpha_{11} &= c_{1\,n}\, c_{1n-1} c_{1\,n-2} \cdots c_{14}, \\ \alpha_{22} &= c_{2\,n}\, c_{2n-1} c_{2\,n-2} \cdots c_{24}, \\ \alpha_{33} &= c_{3\,n}\, c_{3n-1} c_{3\,n-2} \cdots c_{34}, \end{aligned}$$

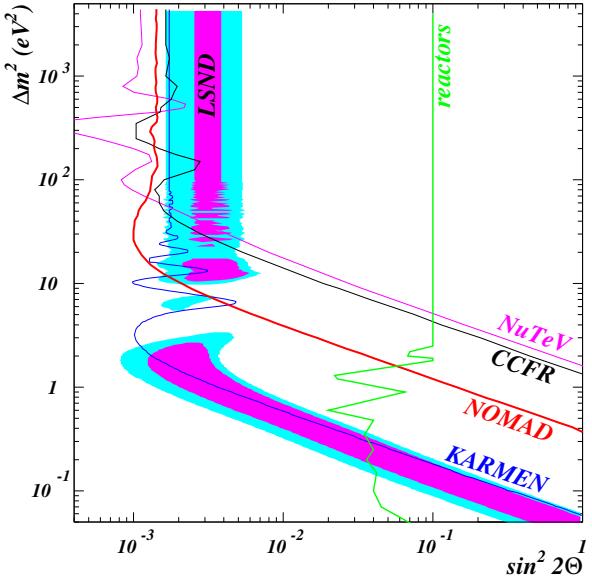
Escrihuela, Forero, OGM, Tortola, Valle **PRD 93** 053009 (2015)

Mixing matrix

$$NN^\dagger = \begin{pmatrix} \alpha_{11}^2 & \alpha_{11}\alpha_{21}^* & \alpha_{11}\alpha_{31}^* \\ \alpha_{11}\alpha_{21} & \alpha_{22}^2 + |\alpha_{21}|^2 & \alpha_{22}\alpha_{32}^* + \alpha_{21}\alpha_{31}^* \\ \alpha_{11}\alpha_{31} & \alpha_{22}\alpha_{32} + \alpha_{31}\alpha_{21}^* & \alpha_{33}^2 + |\alpha_{31}|^2 + |\alpha_{32}|^2 \end{pmatrix}$$

Zero distance effect

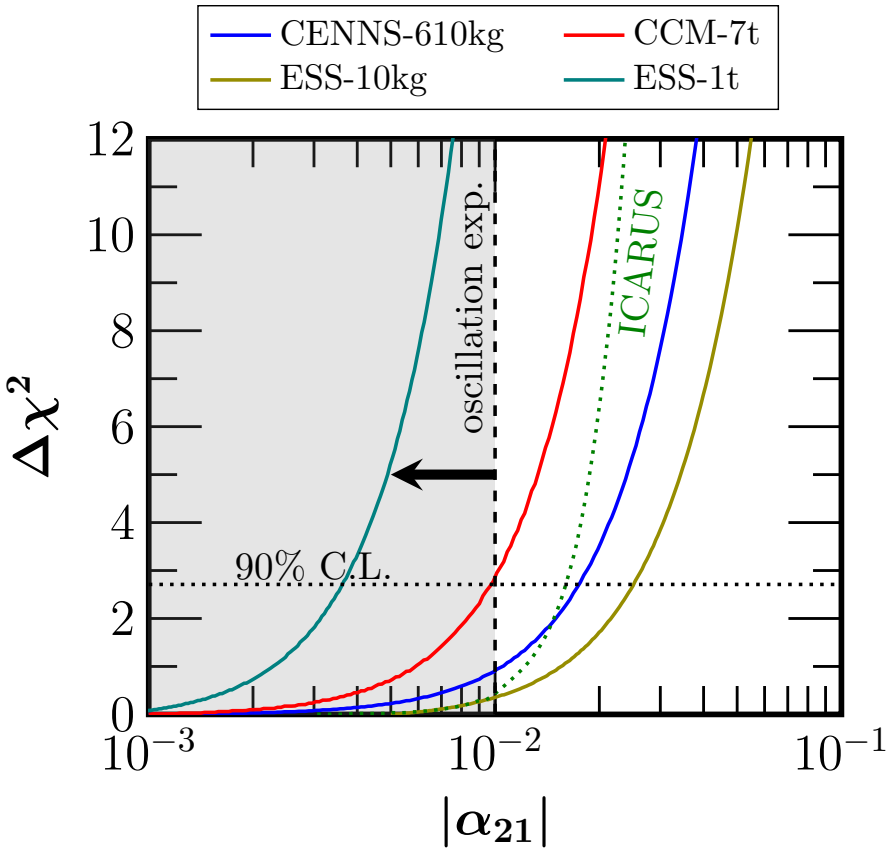
$$P_{\mu e} = \alpha_{11}^2 |\alpha_{21}|^2 = \frac{1}{2}\left[\sin^2(2\theta_{\mu e})\right]_{\text{eff}}$$



NOMAD Coll. PLB **570** (2003) 19

Zero distance effect in future shorte baseline experiments

- SBN FNAL program and DUNE ND
- Coherent elastic neutrino-nucleus scattering



OGM, Papoulias, Sanders, Tortola, Valle, arxiv:2008.02759

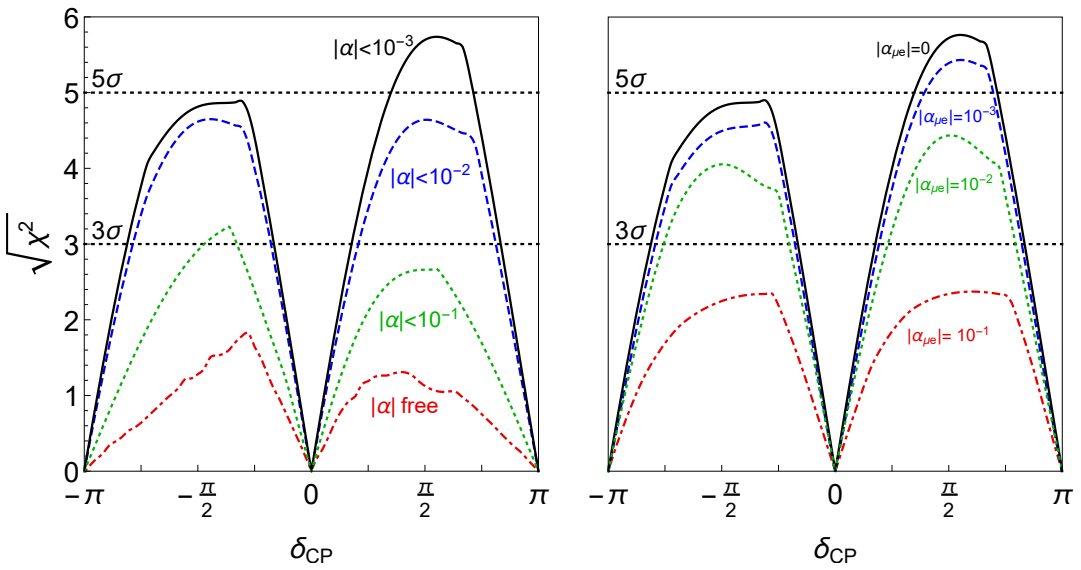
Oscillation probabilities

$$P_{\mu e} = (\alpha_{11}\alpha_{22})^2 P_{\mu e}^{3\times 3} + \alpha_{11}^2\alpha_{22}|\alpha_{21}|P_{\mu e}^{I} + \alpha_{11}^2|\alpha_{21}|^2,$$

$$\begin{aligned} P_{\mu e}^{I} &= -2\left[\sin(2\theta_{13})\sin\theta_{23}\sin\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right)\sin\left(\frac{\Delta m_{31}^2 L}{4E_\nu} + \phi + \delta_{CP}\right)\right] \\ &- \cos\theta_{13}\cos\theta_{23}\sin(2\theta_{12})\sin\left(\frac{\Delta m_{21}^2 L}{2E_\nu}\right)\sin(\phi), \end{aligned}$$

with $-\delta_{CP} = \phi_{12} - \phi_{13} + \phi_{23}$ and $\phi = \mathrm{I}_{\mathrm{NP}} = \phi_{12} - \mathrm{Arg}(\alpha_{21})$.

Oscillation probabilities



DUNE Coll. arXiv:2008.12769

- Non-unitarity is theoretically well-motivated
- Different neutrino experiments can complement each other to get the parameters better constraint