How to explain neutrino masses (and consequently oscillations)?

A natural extension is one with 3 new right-handed neutrinos (sterile):

\[-\frac{1}{2} \begin{pmatrix} \bar{\nu}_L & \nu^c_R \end{pmatrix} \begin{pmatrix} 0 & m_D^T \\ m_D & m_R \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix} \]

- Light neutrinos
  \[m_\nu \sim \frac{m_D^2}{m_R} \lesssim 0.1 \text{ eV}\]
- Heavy neutrinos
  \[M_N \sim m_R\]

Three new heavy neutrinos at an unknown scale (eV → GUT)!

How to detect heavy neutrinos?

- \(N_I\) couple to \(W\) and \(Z\) with a strength
  \[U_{\alpha I}^2 \equiv |\Theta_{\alpha I}|^2 \sim \mathcal{O}\left(\frac{m_\nu}{M_N}\right)\]

- Can be produced e.g. in colliders or in meson decays (arXiv:1502.00477).

- For \(0.1 < M_N < 100 \text{ GeV}/c^2\), we have
  \[U_{\alpha I}^2 \sim 10^{-10} - 10^{-8}\]

90% limits from current experiments on the mixing of heavy neutrinos to electron and muon.
Detection in T2K:
Heavy neutrinos are produced alongside standard neutrino beam. They propagate and can decay in T2K near detector ND280 → detection of 2 particles with opposite charges.

Analysis and results:
- **Remaining background after selection:** less than 2 evts (from active $\nu$ int.)
- Bayesian approach, marginalization with a Markov Chain Monte Carlo.

T2K preliminary
T2K put the most stringent limits in the high mass region.