Sensitivity study for long-baseline neutrino oscillation experiments to sterile neutrinos

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Introduction

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- Neutrino oscillation can be explained by a mixing between the mass states; this require new mass generation mechanism.
- One of the possibilities adding two or more right-handed neutrinos (Singlet under $SU(2)_L$ with mass term $m_N \bar{\nu}_R \nu_R^c$).
- After spontaneous electro-weak symmetry breaking: 3 light states with masses $m_\nu \propto \frac{Y_V}{m_N}$, 2 or more heavy sterile neutrino with masses $\propto m_N$.
- Mixing: $\nu_i = \sum_\alpha U_{i\alpha} \nu_\alpha$.

Previous Mixing limits in the 1 - 30 MeV mass range

- Mixing with the electron and muon ($|U_{4e}|^2$ and $|U_{4\mu}|^2$) constrained up to $10^{-5} - 10^{-7}$.[1 2 3] However, Mixing with the tau still can be large $|U_{4\tau}|^2 = 0.01 - 0.1$.[4]

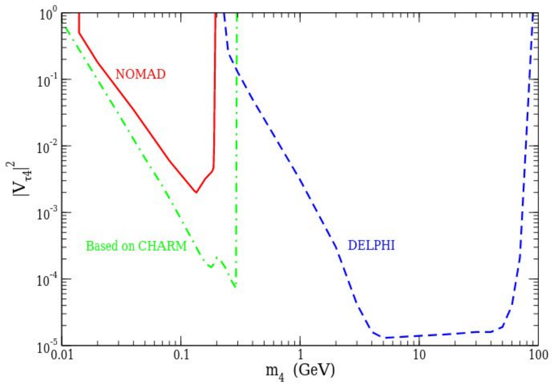
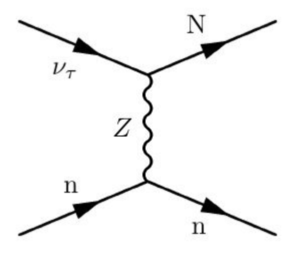


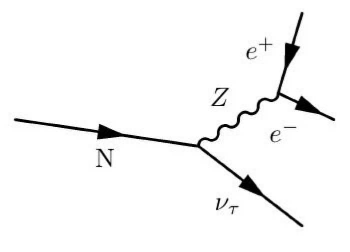
Figure 1: Bounds on $|U_{4\tau}|^2$ versus m_N given by (CHARM)[5] and (NOMAD)[6] at 90% C.L., and by (DELPHI)[7] at 95% C.L.

Methodology

Methodology

- In long-baseline neutrino oscillation:Neutrinos with muon flavor oscillate to tau flavor along the way.
- Due to the large mixing with the tau: a sterile neutrino produced after tau neutrino interact with the earth.
- The sterile neutrino decays inside the far detector into electron-positron pair and a tau neutrino.

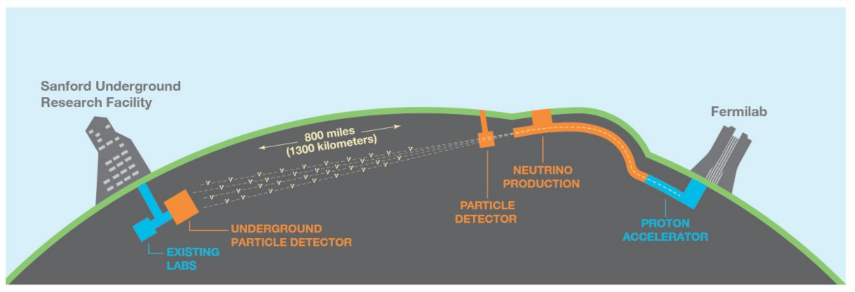




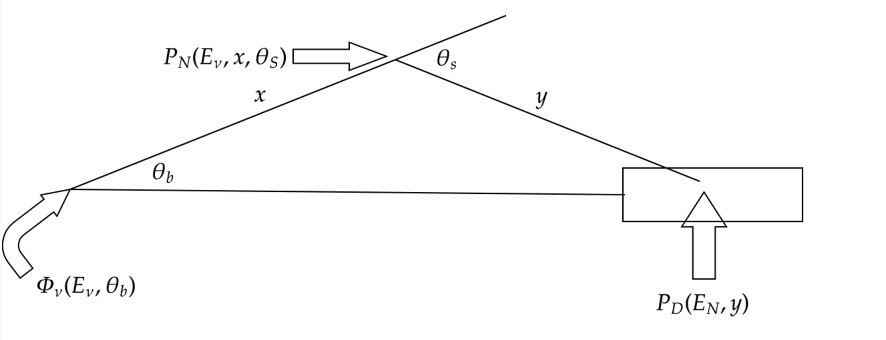
DUNE decay event rate

DUNE overview

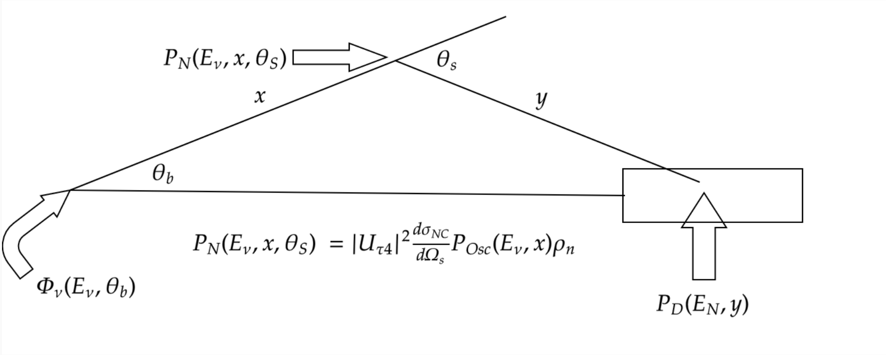
- 1.47 $\times 10^{21}$ proton on target (POT) per year.
- State-of-the-art Liquid Argon Time-Projection Chamber (LArTPC) technology in the far detector (four modules each one is 12m high, 14.5m wide, and 58m long).[8]



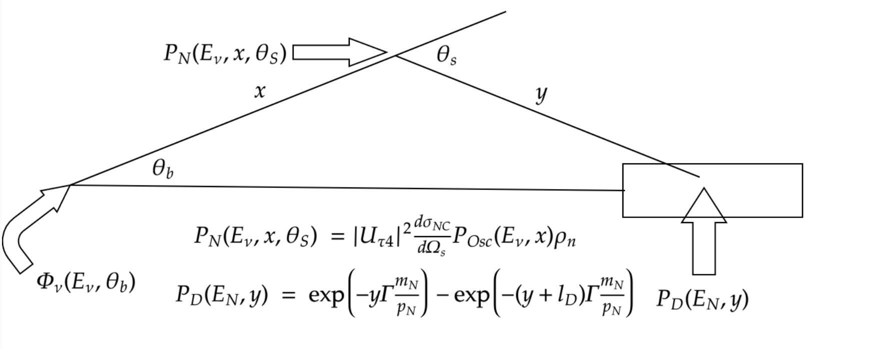
Decay event rate in the far detector



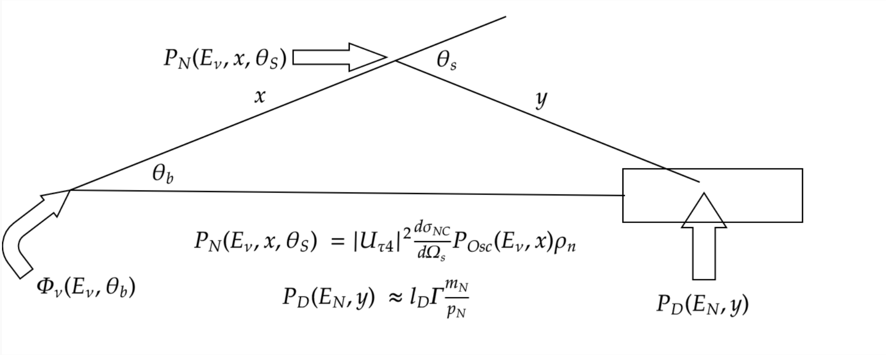
Production probability



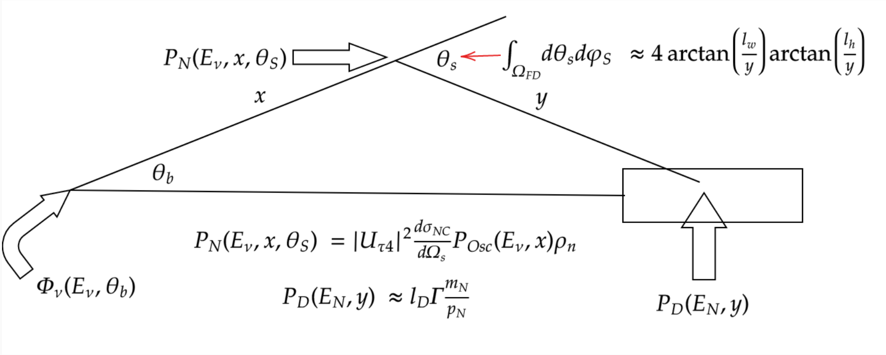
Decay probability



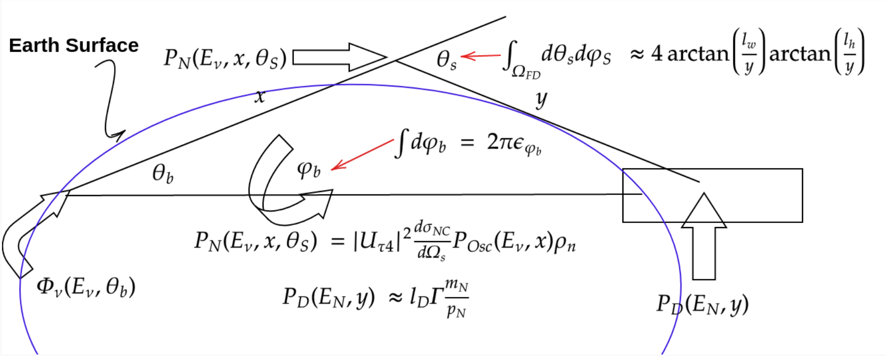
Decay probability



Scattering angle integral



Azimuth angle ϕ_b integral

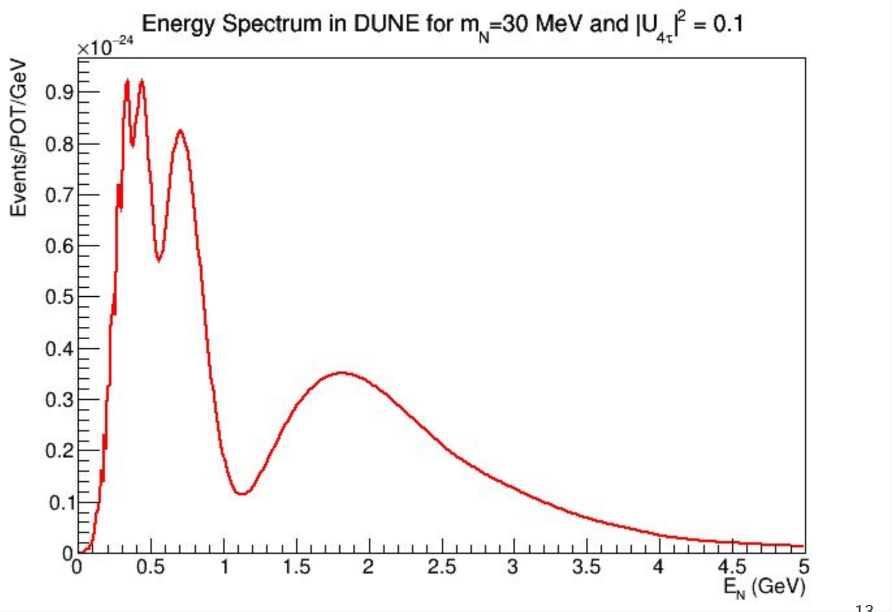


Decay event rate

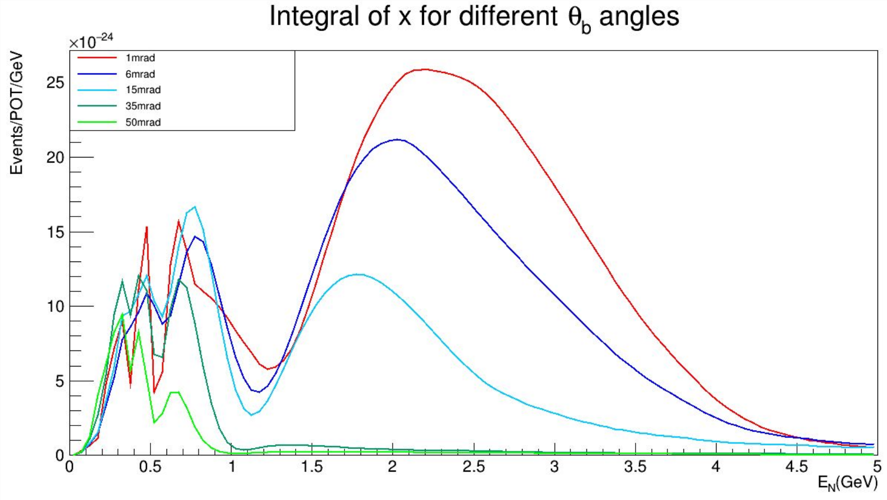
Finally, the expected event rate inside the far detector is given by

$$\begin{aligned}\frac{dN}{dE_N} =& 4 Br_e {U_{\tau 4}}^2 \Gamma \frac{m_N}{m_n E_N - m_N^2/2} \rho_n \mathrm{L}_{\mathrm{ND}}^2 l_D \int d\theta_b \sin\theta_b \int_0^{x_{max}} dx \\ & \times \epsilon_\phi(x, \theta_b) \arctan\left(\frac{l_w}{y}\right) \arctan\left(\frac{l_h}{y}\right) P_{\nu_\mu \to \nu_\tau}(x, E_\nu) \\ & \times \Phi_{\mathrm{ND}}(E_\nu) \frac{d\sigma_{\mathrm{NC}}}{dE_N}(E_\nu) \sin\theta_s E_\nu^2,\end{aligned} \tag{1}$$

Expected decay events spectrum in DUNE

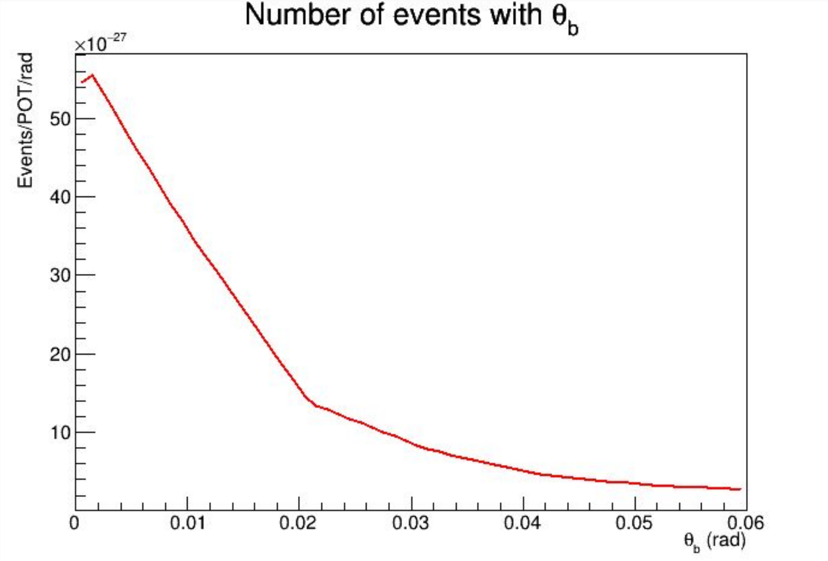


Off-axis beam angle dependence in DUNE



Off-axis beam angle dependence in DUNE

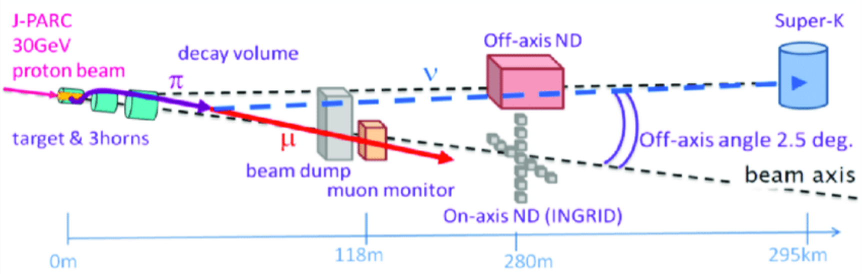
- Small off-axis beam angles contribution is important.



T2HK decay event rate

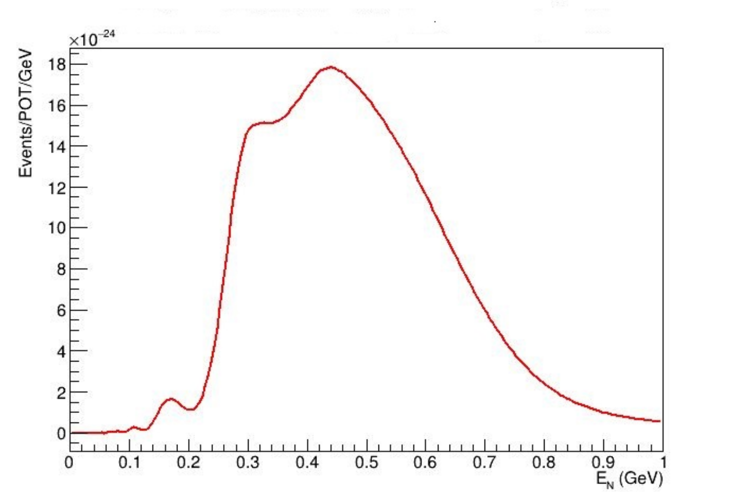
T2K overview

- Off-axis far detector.[9]



T2HK rough estimate

- Assuming uniform flux with the beam solid angle with $\theta_{bmax} = 20mrad$ around the far detector off-axis beam.
- Rough estimate for $m_N = 30$MeV and $|U_{4\tau}|^2 = 0.1$.



Conclusion

Conclusion

- We got around 10^{-24}decay event/POT at DUNE far detector for $m_N = 30MeV$ and $|U_{4\tau}|^2 = 0.1$ (Given $\approx 1.5 \times 10^{21}$POT/year; not competitive).
- Off-axis beam scatterings give a non negligible contribution up to around 40 mrad.
- Assuming uniform flux in T2HK we get around 10^{-23}decay event/POT, However, still need to consider more realistic geometry of the flux.
- Further steps; do a statistical analysis and evaluate the sensitivity.

Thank you!

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Total number of events with the sterile mass and the mixing