Appearance of tau neutrinos in the MINOS+ Near Detector due to the oscillations involving sterile neutrinos

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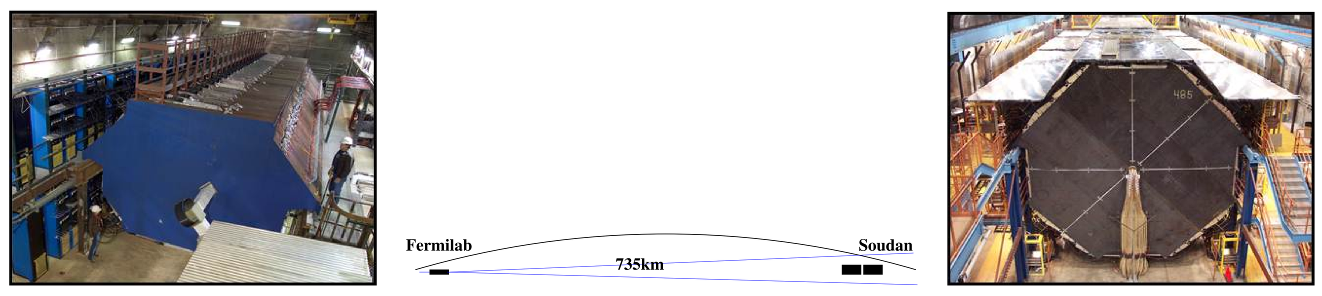
Introduction

- In the long-baseline experiments like MINOS+, standard oscillations are not expected in the detectors located close to the neutrino source.
- In the near detectors sterile neutrinos can reduce the flux of muon neutrinos and lead to the **anomalous production of tau neutrinos**.

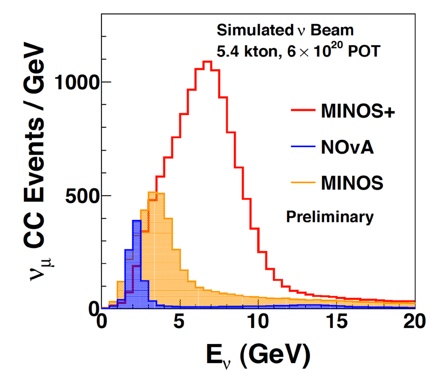
MINOS+



Near Detector
1 km from source

Far Detector
735 km from source

NuMI beam

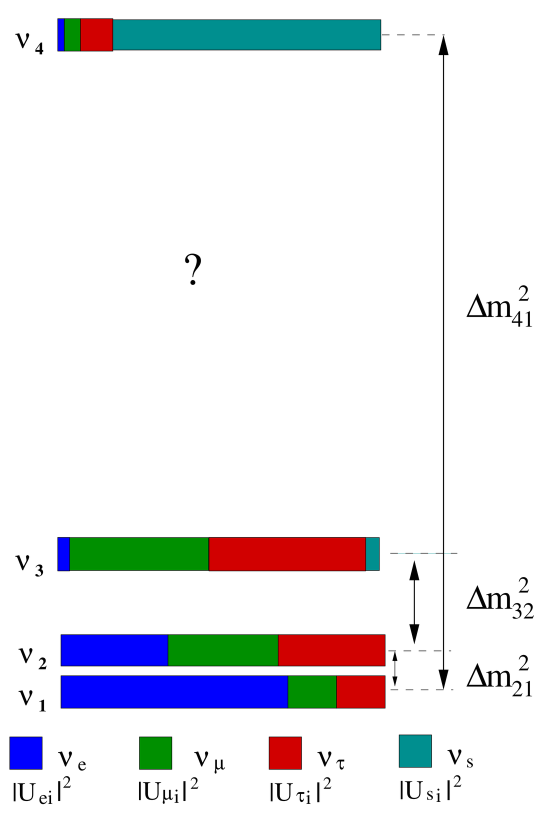


Most of the MINOS+ flux above τ production threshold.

Model with one sterile neutrino

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

- Sterile neutrinos are necessary in some extentions of the Standard Model that provide neutrino mass generation mechanism.
- Most of the experimental data well described by the standard oscillation model with 3 neutrino flavours. Therefore the mixing between active and sterile states must be small: $|U_{\alpha 4}|^2 \ll 1$.



Oscillation probabilities at short baselines in the model with one sterile neutrino

$$P_{\nu_\mu \to \nu_\tau}(L,E) \simeq 4|U_{\mu 4}|^2 |U_{\tau 4}|^2 \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

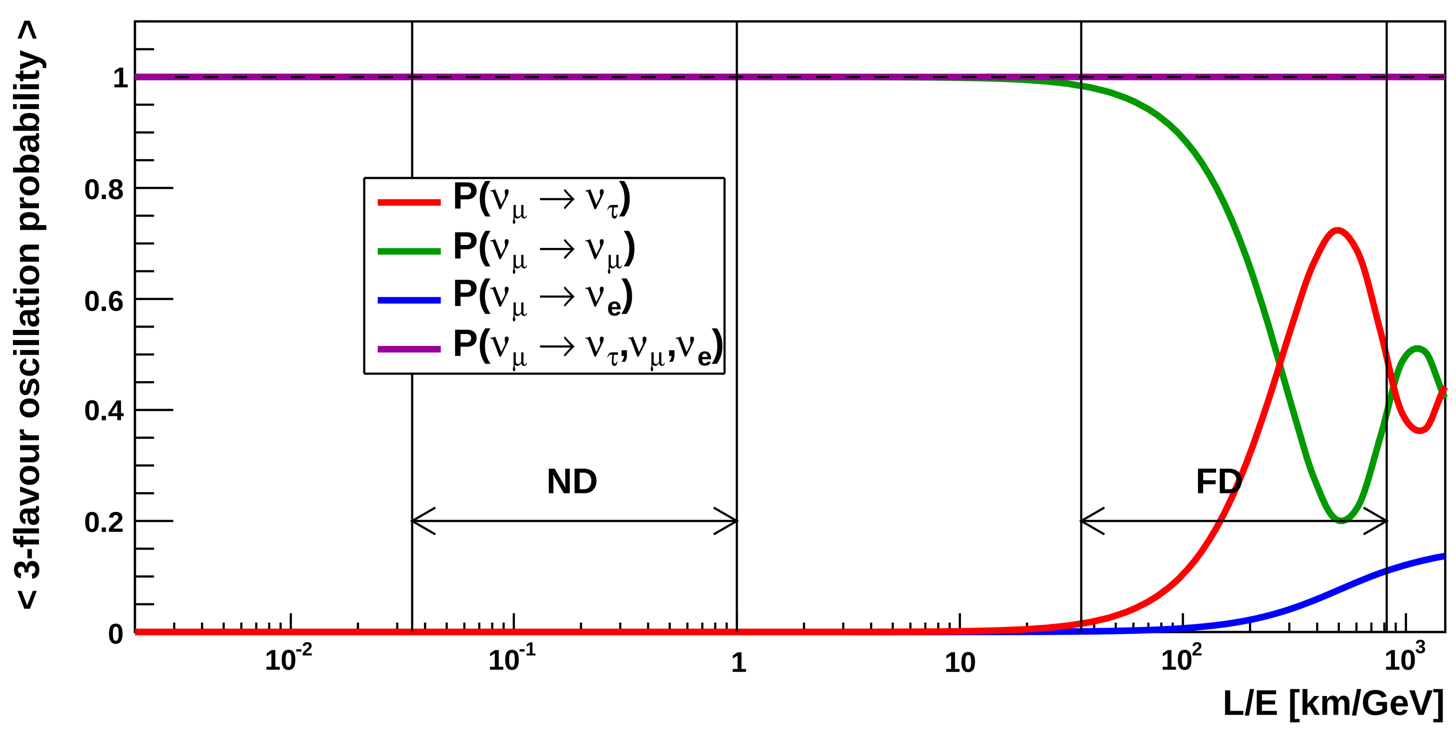
$$= \sin^2 2\theta_{\mu\tau} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$P_{\nu_\mu \to \nu_\mu}(L,E) \simeq 1 - 4|U_{\mu 4}|^2 (1 - |U_{\mu 4}|^2) \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$= 1 - \sin^2 2\theta_{\mu\mu} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

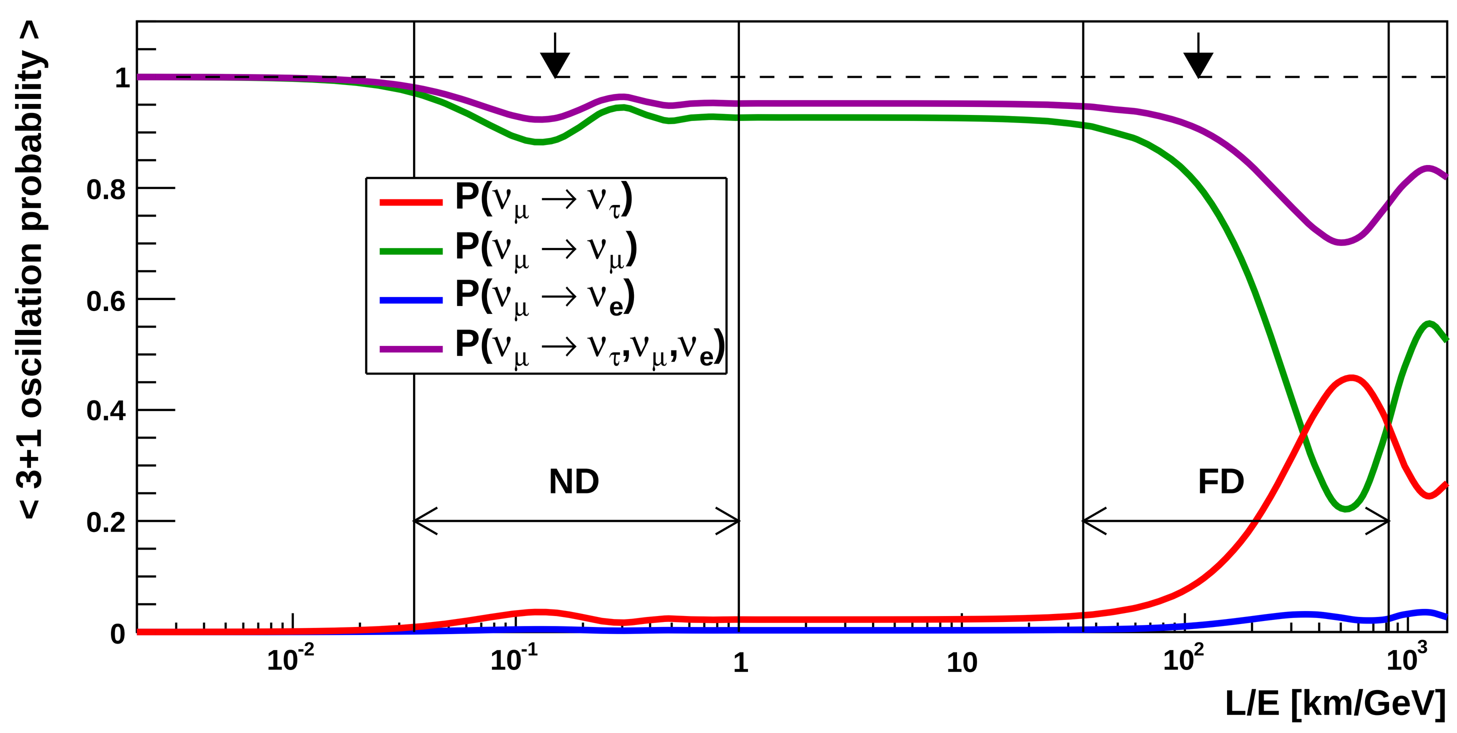
For $\theta_{14} = 0$ $\sin^2 2\theta_{\mu\tau} = \sin^2 2\theta_{24} \sin^2 \theta_{34}$, $\sin^2 2\theta_{\mu\mu} = \sin^2 2\theta_{24}$

Standard oscillations



Vertical lines mark the L/E regions for Near and Far MINOS+ detectors.

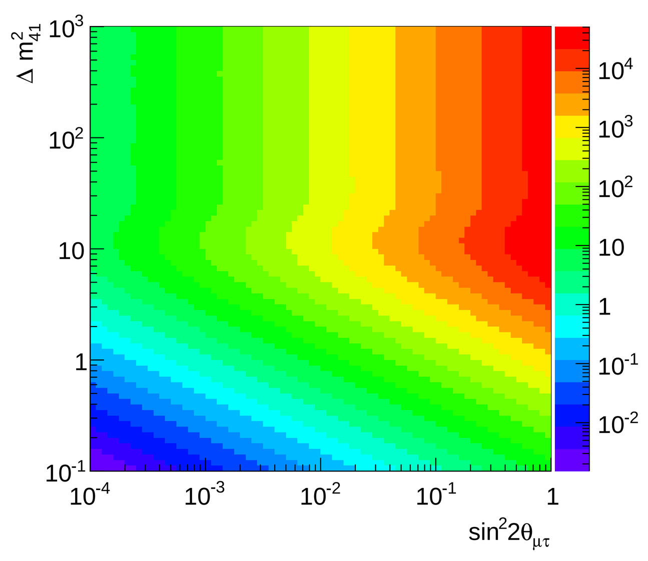
Oscillations with one sterile neutrino



Example for $\Delta m^2_{41} = 10$ eV^2, $\theta_{14} = 0.2$, $\theta_{24} = 0.2$, $\theta_{34} = 0.6$ and $\delta_i = 0$. Black arrows indicate L/E value corresponding to the maximum rate of events in the Near and Far MINOS+ detectors.

$\tau \to \mu\nu_\tau\nu_\mu$ selection

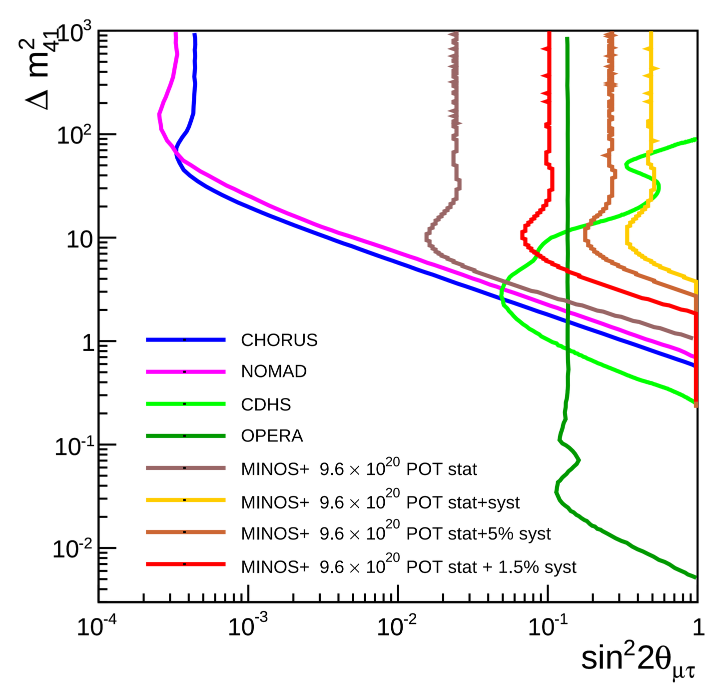
- High statistics of events collected in the Near Detector allows to select τ decay channel with the smallest systematics.
- Presented sensitivities are for τ decaying into muons: $\tau \to \mu\nu_\tau\nu_\mu$
- Dominant, large background from $CC\nu_\mu$ interactions.



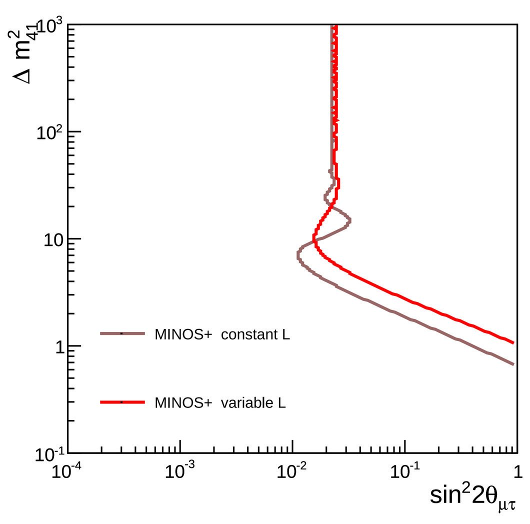
Expected numbers of selected CC $\nu_\tau, \tau \to \mu\nu_\tau\nu_\mu$ interactions for 3×10^{20} POT.

MINOS+ sensitivities

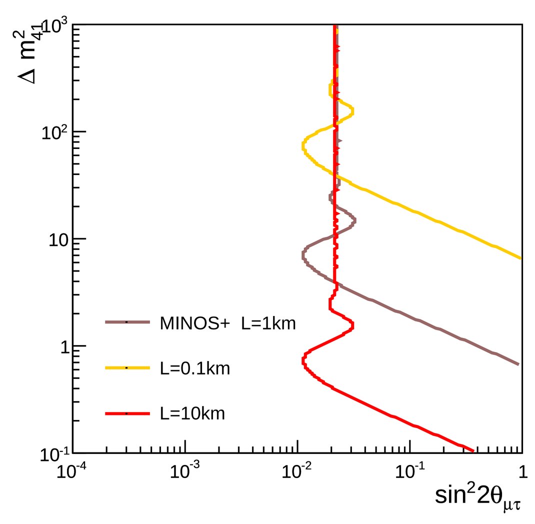
- Sensitivities obtained with full MINOS+ simulation and reconstruction
- Comparison of statistics-only sensitivities, sensitivities with conservative and reduced systematics.



Discussion



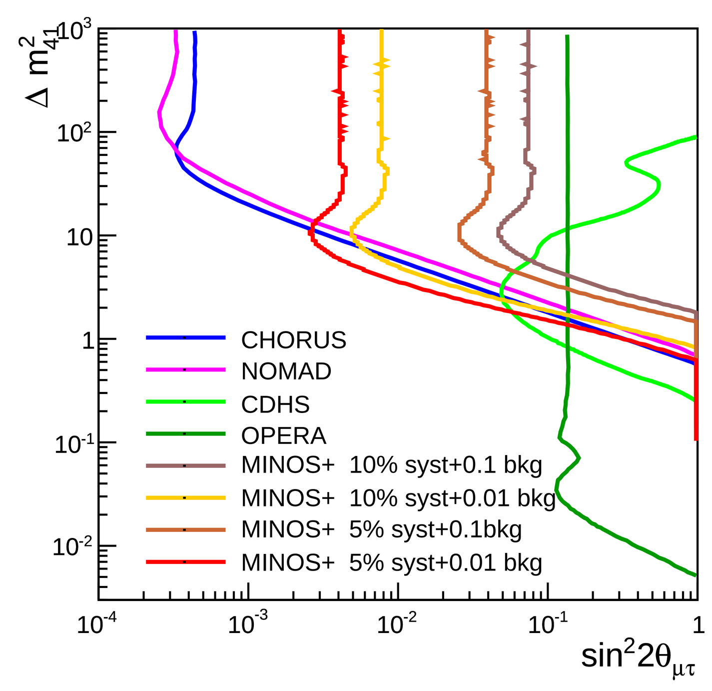
Sensitivities for assumed constant baseline 1 km and for the fully simulated baseline.
90% CL sensitivity contours.



In the τ appearance search longer baselines of near detectors are preferred.
90% CL sensitivity contours.

Expectations for future

- Prerequisite for τ appearance search in the near detectors: neutrino flux above τ production threshold. This condition is fulfilled by MINOS+, NOvA (small part of flux), DUNE (small part of flux).
- NOvA L/E ratio smaller than for MINOS+, better sig/bkg ratio.
- DUNE L/E ratio similar to MINOS+, better sig/bkg ratio.



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