Appearance of tau neutrinos in the near detectors due to the oscillations involving sterile neutrinos

Lessons learned from MINOS+ studies

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Motivation

ν_τ appearance in the near detectors of long-baseline experiments:

- is not expected if there are only 3 neutrino flavours
- possible signature of sterile neutrinos
- access to θ_{34}

Probabilities at short-distances in the 3+1 model

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

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

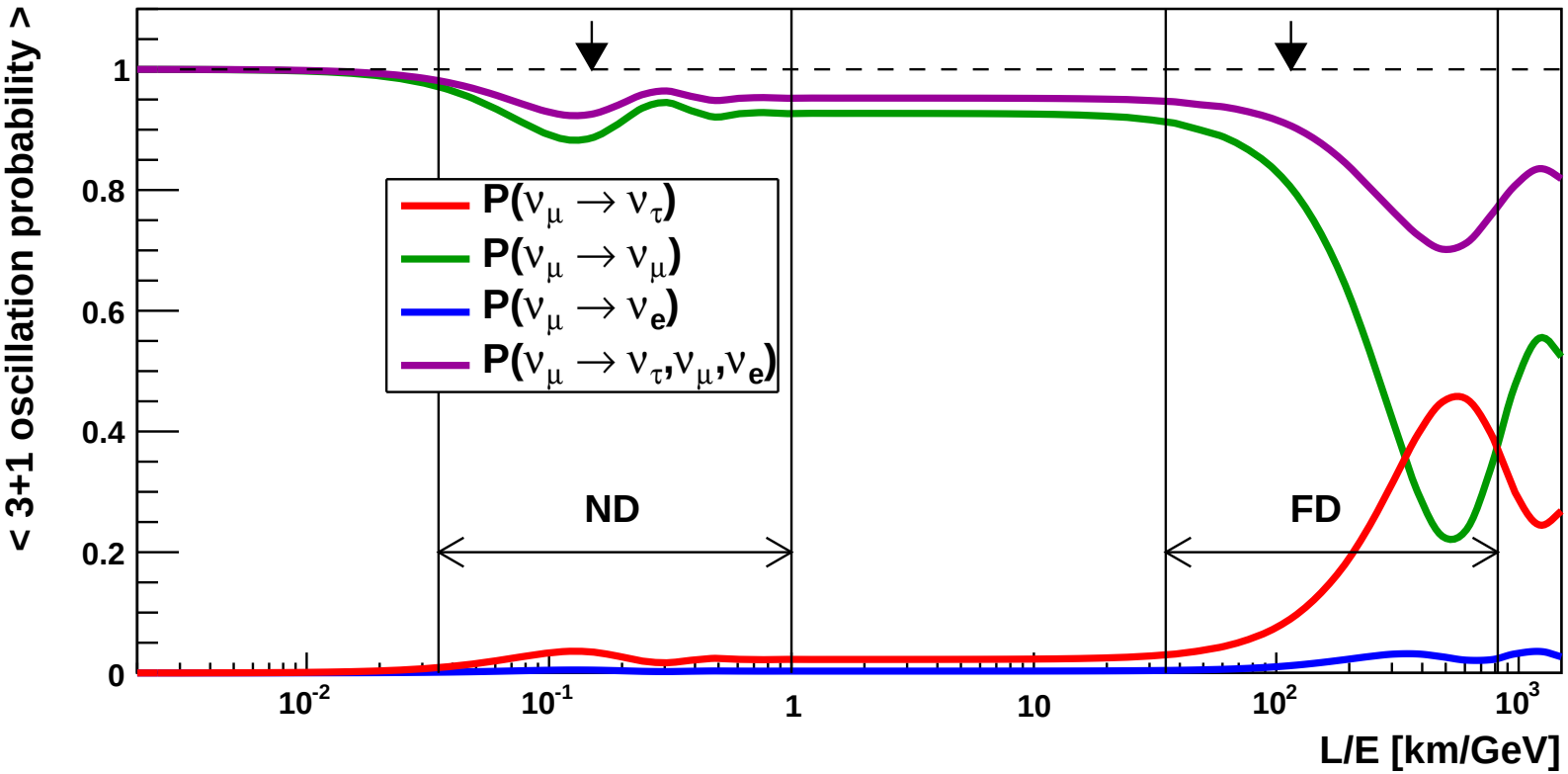
$$\mathrm{P}_{\nu_\mu \to \nu_\mu}(L, E) \simeq 1 - 4|U_{\mu 4}|^2(1 - |U_{\mu 4}|^2) \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

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

Sensitivities

- Sensitivities in the Δm^2_{41} vs $\sin^2 2\theta_{\mu\tau}$ plane, based on full MINOS+ Monte Carlo simulation and reconstruction
- $\sin^2 2\theta_{\mu\tau} = \cos^4 \theta_{14} \sin^2 2\theta_{24} \sin^2 \theta_{34}$

Probabilities in the 3+1 model

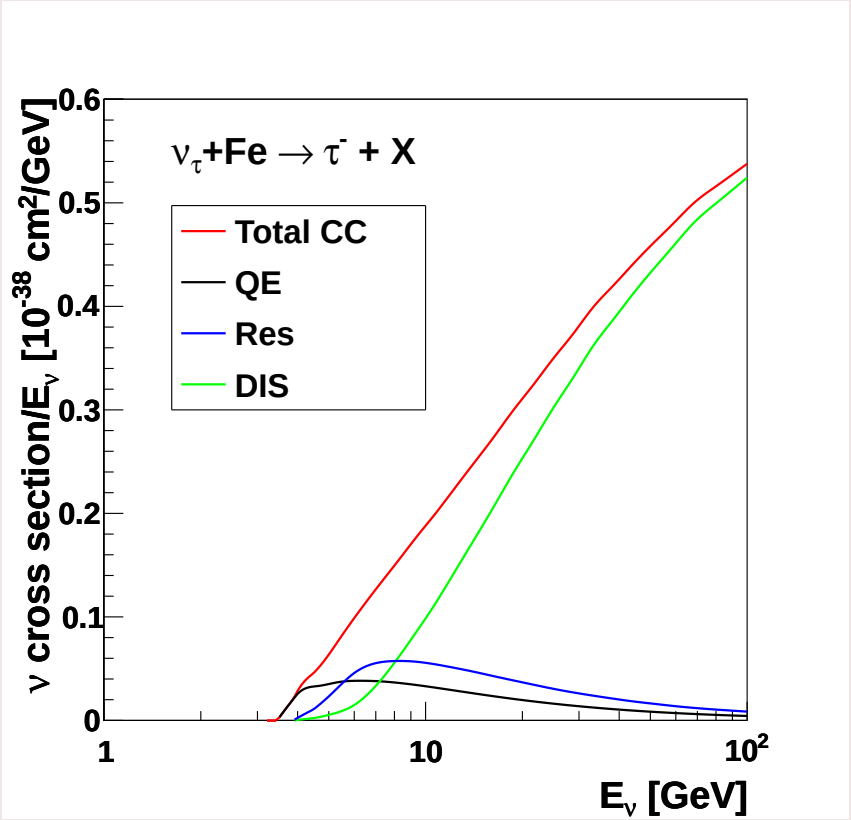


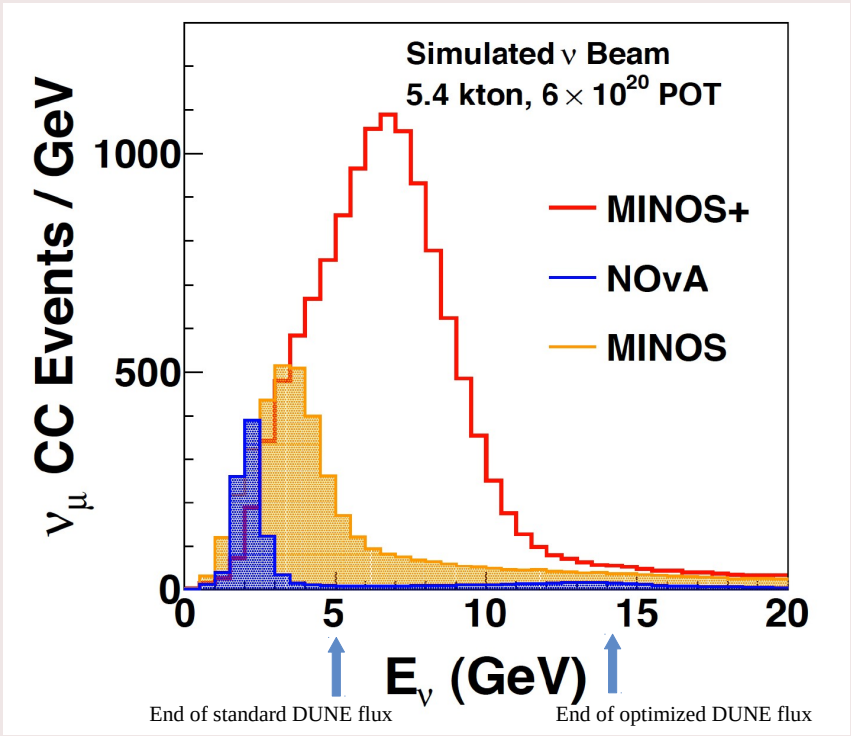
$\Delta m^2_{41} = \mathbf{10}\ \mathrm{eV}^2$, $\theta_{14} = 0.2$, $\theta_{24} = 0.2$, $\theta_{34} = 0.6$ and $\delta_i = 0$.

Arrows $\rightarrow$ position of MINOS+ maximum flux. In the near detector region also position of DUNE maximum flux.

ν_τ appearance in MINOS+

- Most of the MINOS+ flux above τ production threshold





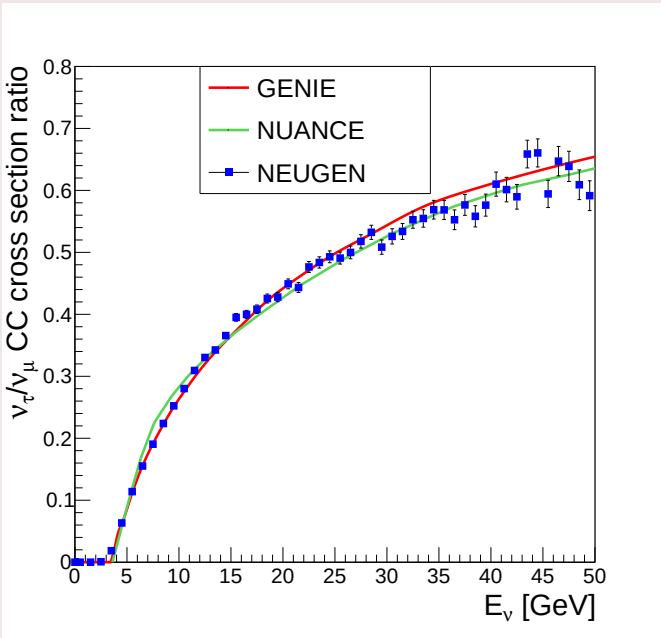
- High statistics of events collected in the Near Detector.
- Low spatial resolution of the detector (layers: 2.45 cm of steel and 1 cm of plastic scintillator)

Selection

CC $\nu_\tau, \tau \rightarrow \mu\nu_\tau\nu_\mu$

- Channel with smallest systematics
- Selection similar to ν_μ disappearance analysis

Additional systematics:
ν_τ cross section

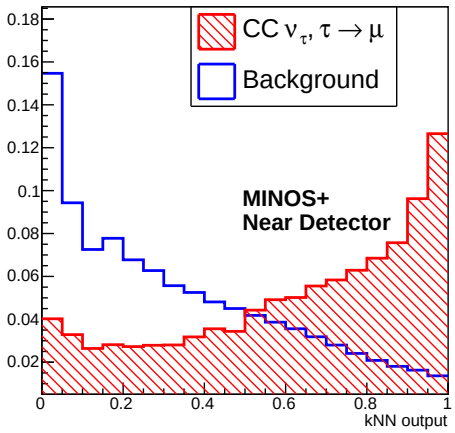


GENIE 2.8.6

Selection

- Preselection
- Removal of NC background
- kNN (k-nearest neighbour) selection of quasi-elastic-like ν_τ interactions.

  4 input variables

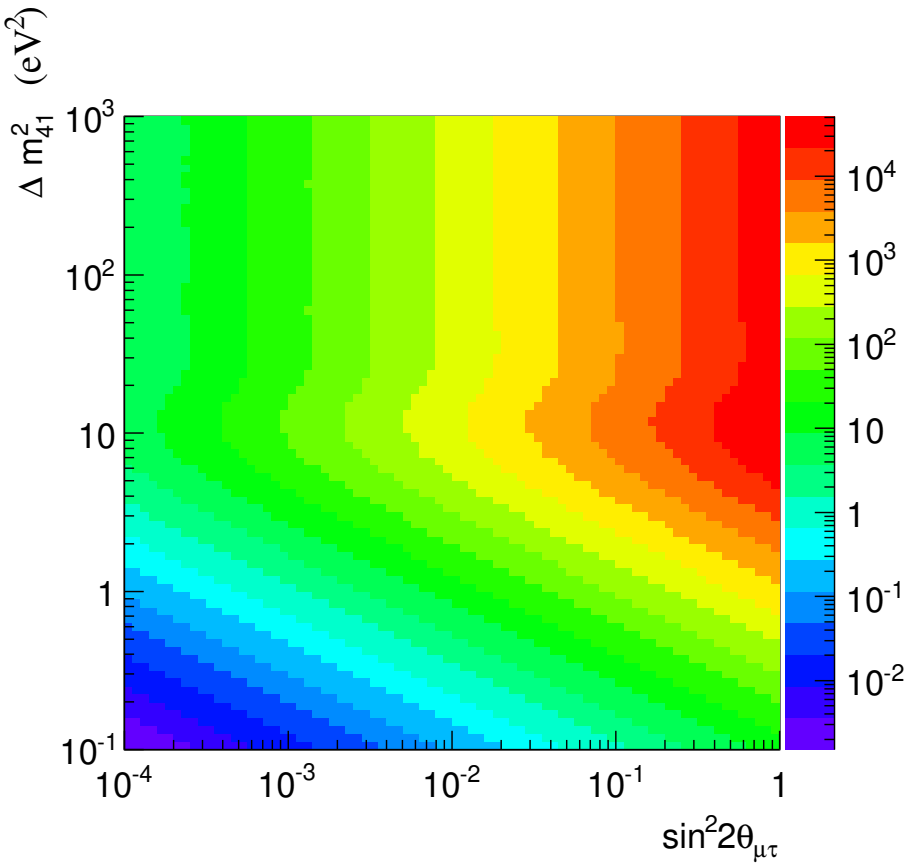


kNN from: https://root.cern/manual/tmva/

Distributions for equal number of signal nad background events.

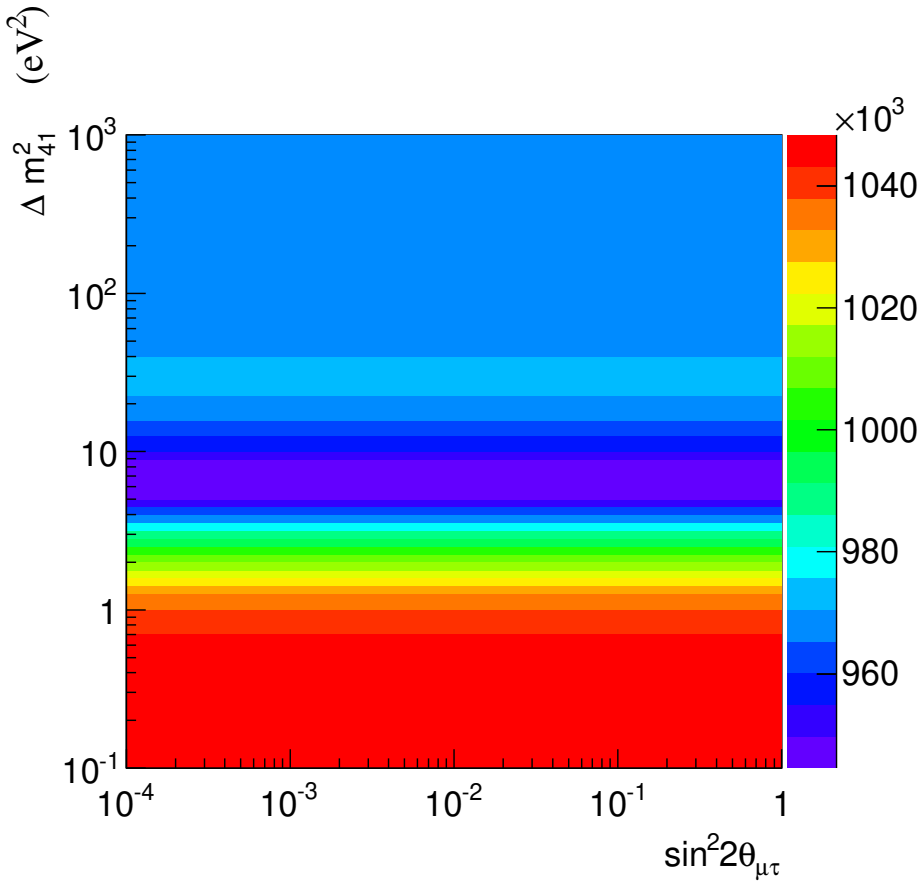
Mean signal efficiency: $\sim$ 20%

Signal CC $\nu_\tau, \tau \rightarrow \mu\nu_\tau\nu_\mu$

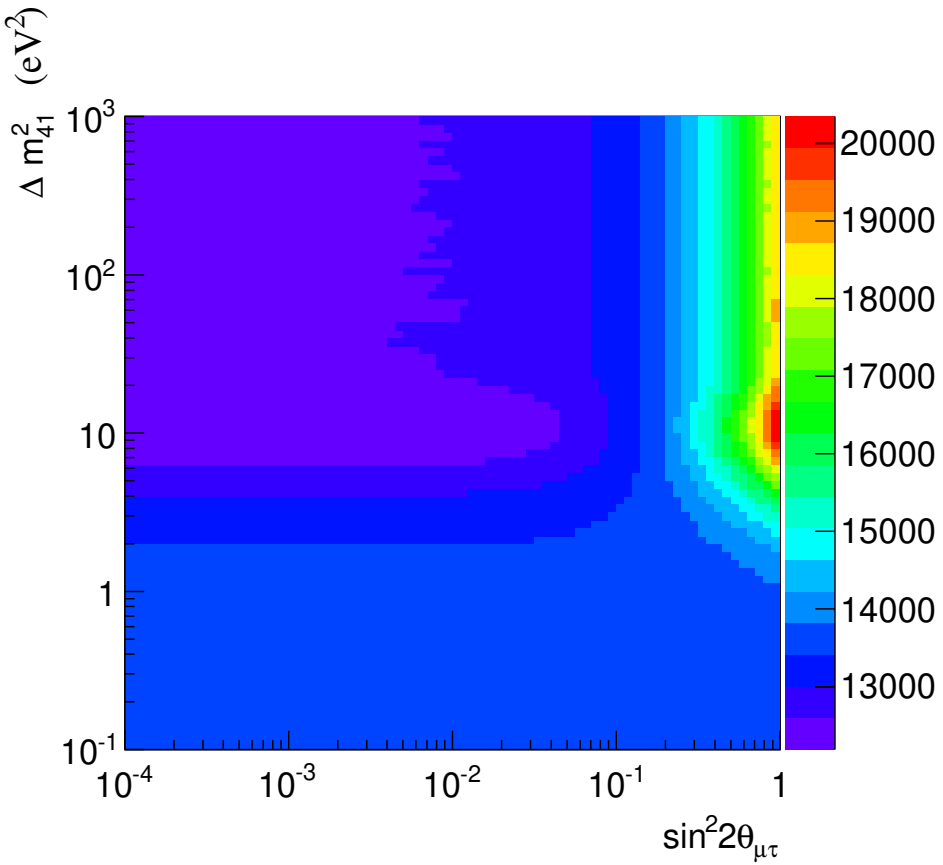


Expected numbers of selected CC $\nu_\tau, \tau \rightarrow \mu\nu_\tau\nu_\mu$ interactions for 3×10^{20} POT

Main backgrounds



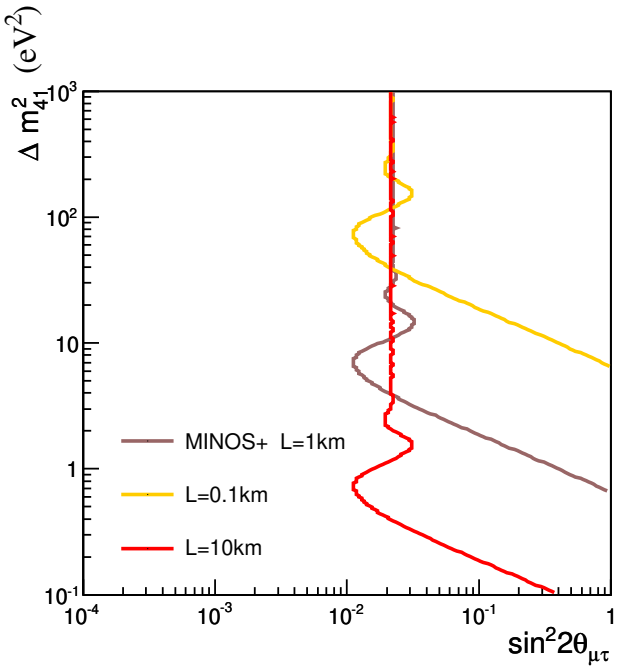
CC ν_μ



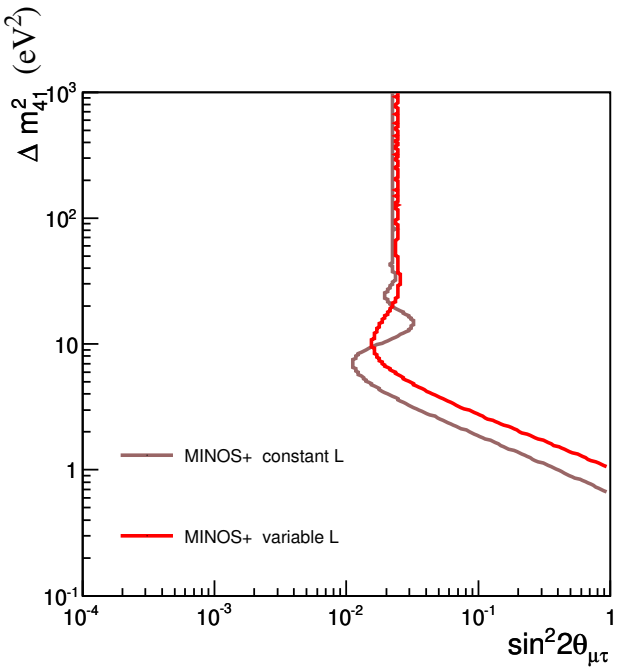
NC

Expected numbers of CC ν_μ and NC events.

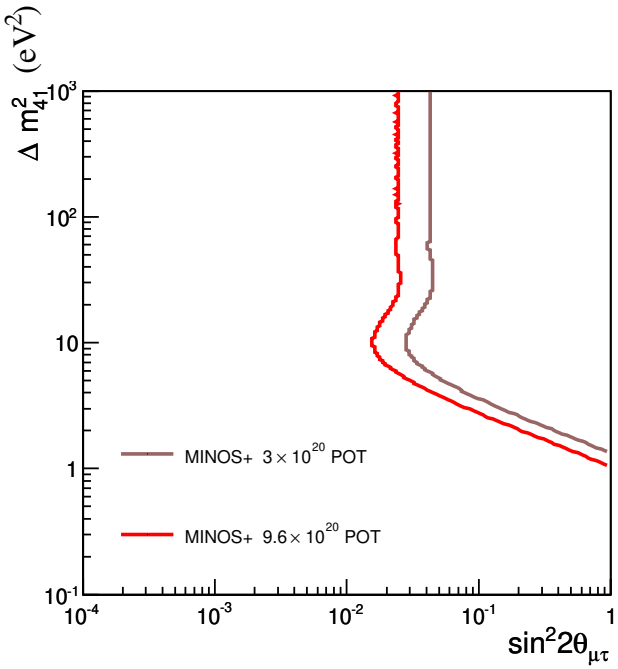
MINOS+ statistics only sensitivities



For tau appearance studies longer baselines are preferred.



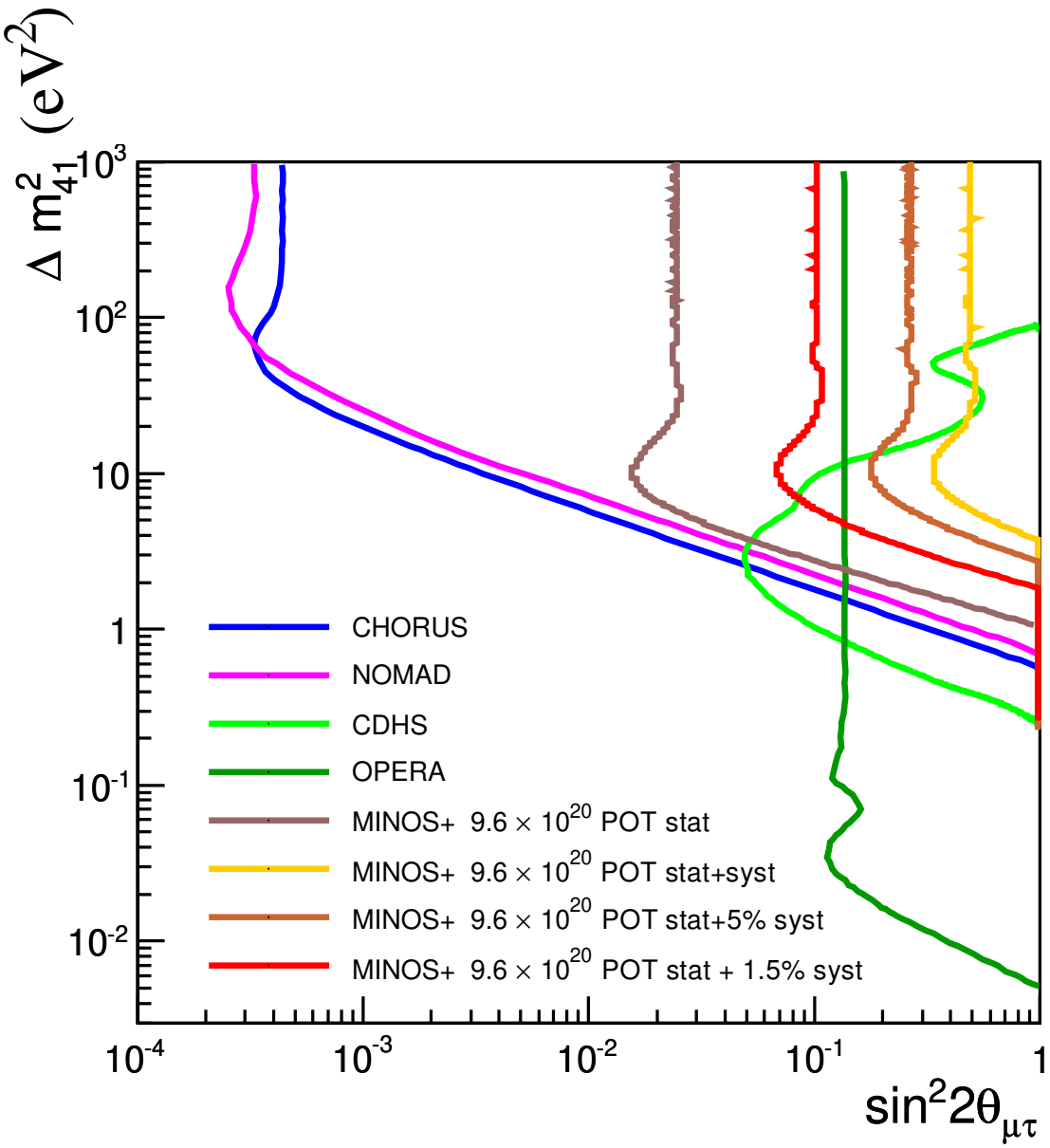
Sensitivities for constant (1km) and changing baseline.



Impact of increased statistics

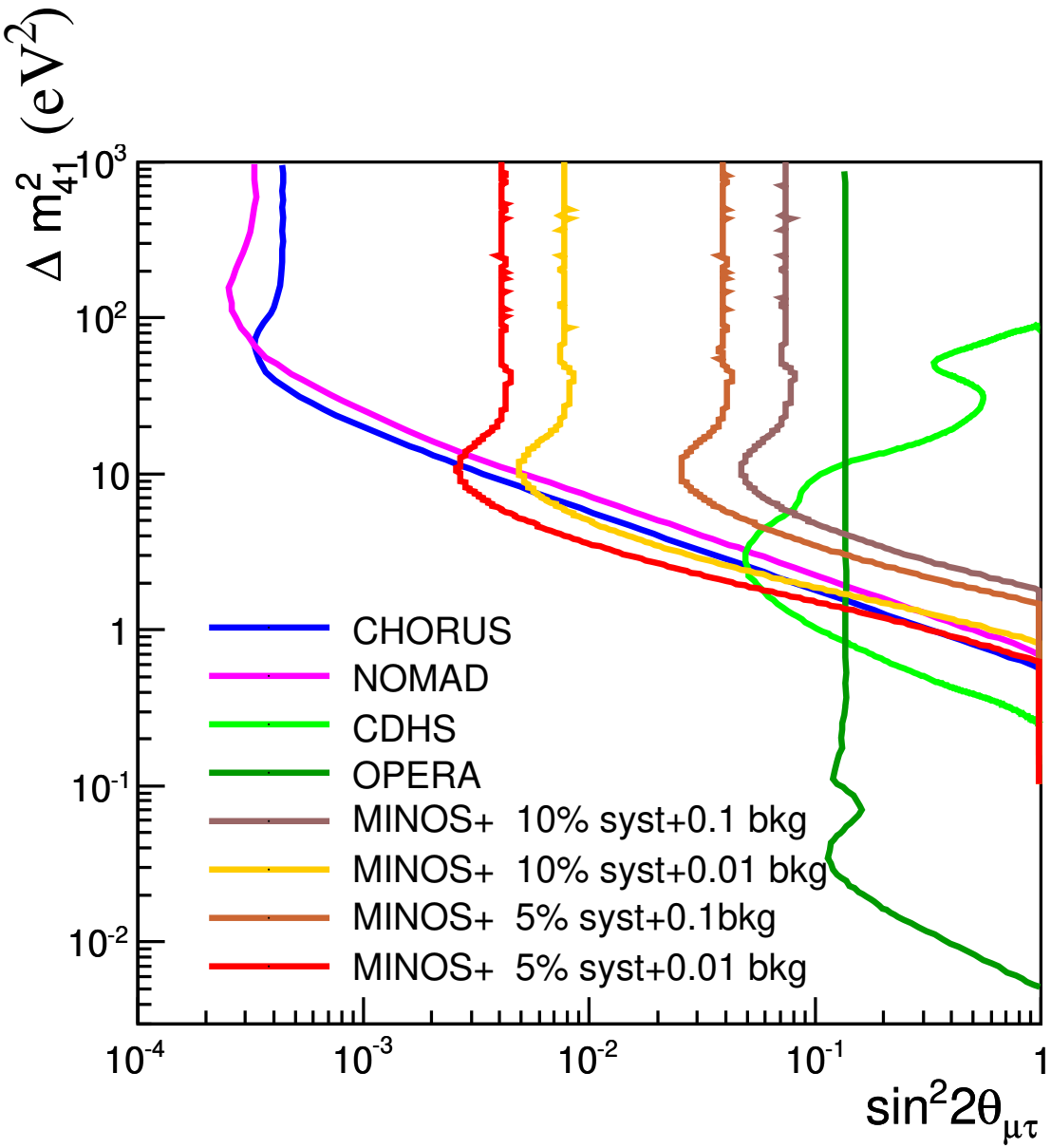
90% C.L. sensitivity contours

MINOS+ sensitivities



- Sensitivities obtained with full MINOS+ simulation and reconstruction
- Impact of reduced systematics

MINOS+ sensitivities



- Sensitivities obtained with full MINOS+ simulation and reconstruction
- Impact of improved signal/background ratio

Problems

- Large CC ν_μ background
- Proton from QE interactions usually not reconstructed
- No τ polarization in GENIE (2.8.6) and NEUGEN

All of these can be addressed in DUNE.

Summary

- MINOS+ ND sensitivities (Δm^2_{41} vs $\sin^2 2\theta_{\mu\tau}$) are based on full Monte Carlo simulation and reconstruction
- DUNE vs MINOS+
  - beams: similar neutrino energies (DUNE ν_τ optimized beam !)
  - similar L/E
  - total MINOS+ statistics corresponds to one-year of DUNE data taking
  - in DUNE significantly better signal/background ratio is expected
- $\Rightarrow$ DUNE should be able to access unknown area of ($\sin^2 2\theta_{\mu\tau}$,Δm^2_{41}) parameter space.