Learning from Tau Neutrino Appearance at Long Baselines

NuTau2021 Workshop, 29th September 2021

Kevin Kelly

$$\frac{1}{\sqrt{2}}\left(|\mathrm{FNAL}\rangle + |\mathrm{CERN}\rangle\right)$$

[1904.07265] (with de Gouvêa, Pasquini, Stenico)
[2008.01088] (with Ellis & Li)

Outline

- Tau-neutrino Appearance at Long Baselines
- What can we learn from it?
  - “Standard” three-neutrino mixing
  - Additional physics beyond three neutrinos

Long-Baseline Oscillations

Long-Baseline, Three-Neutrino Oscillations

Assuming we're in the regime where the atmospheric mass-splitting dominates the solar one, the muon-neutrino to tau-neutrino oscillation probability can be *very* well approximated by

$$P(\nu_\mu \to \nu_\tau) = 4|U_{\mu 3}|^2|U_{\tau 3}|^2 \sin^2\left(\frac{\Delta m^2_{31} L}{4E_\nu}\right) + \text{subleading}$$

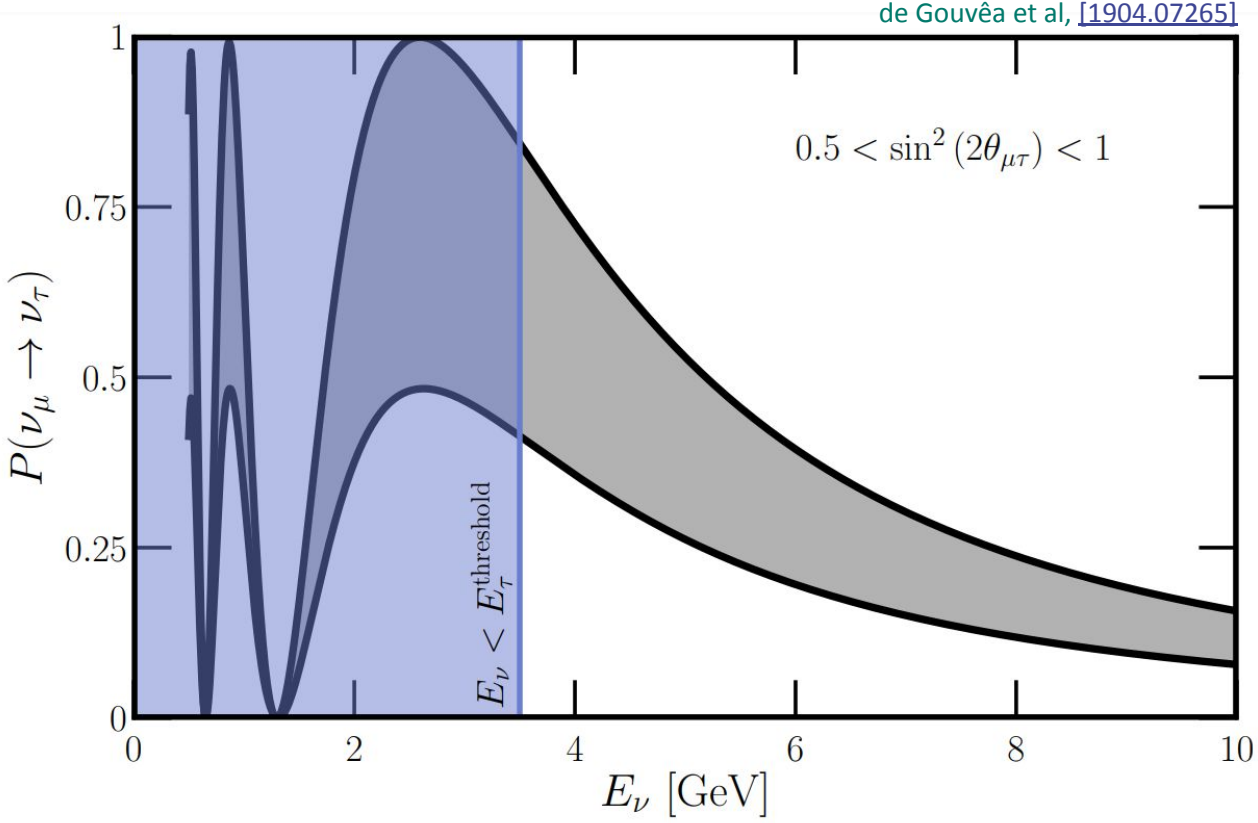
"Mixing angle" associated with tau-neutrino appearance, predicted to be large in the three-neutrino mixing paradigm

$$\sin^2 2\theta_{\mu\tau} \equiv 4|U_{\mu 3}|^2|U_{\tau 3}|^2$$

At the same baselines where muon-neutrino to electron-neutrino appearance is being studied (relatively small probability), the tau-neutrino appearance probability is large!

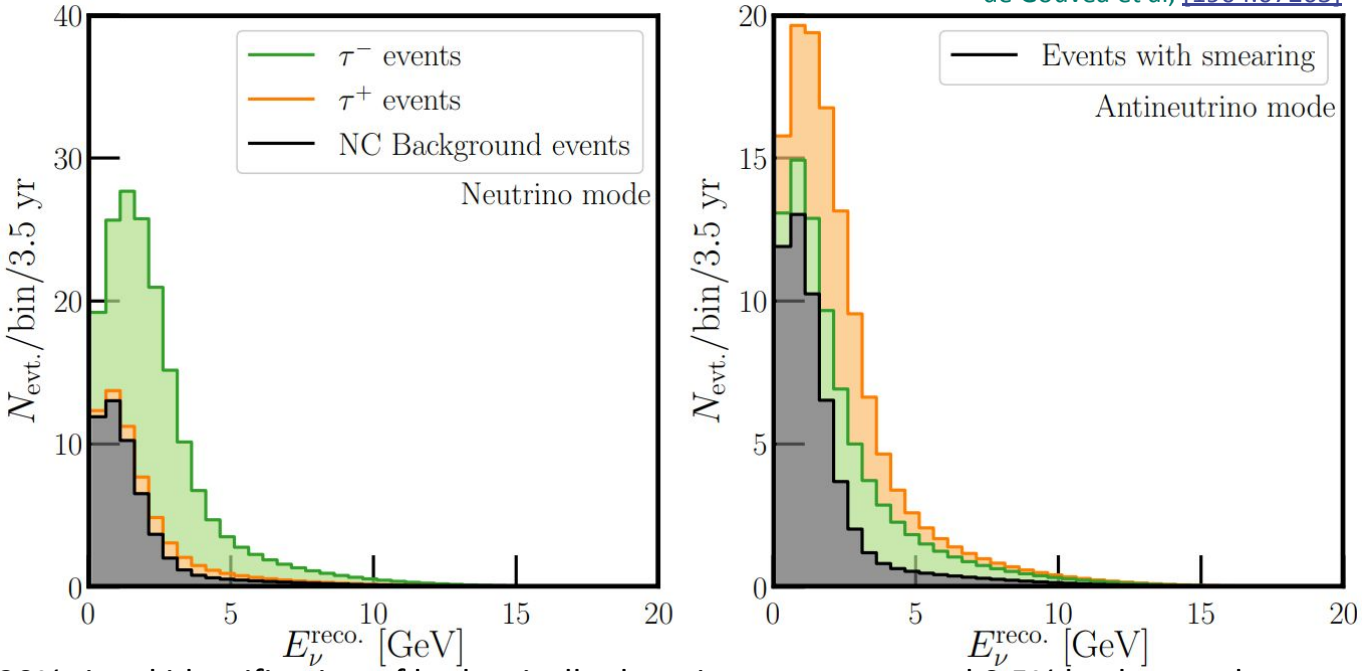
Appearance Probability at DUNE

de Gouvêa et al, [1904.07265]



Event Rates

de Gouvêa et al, [1904.07265]



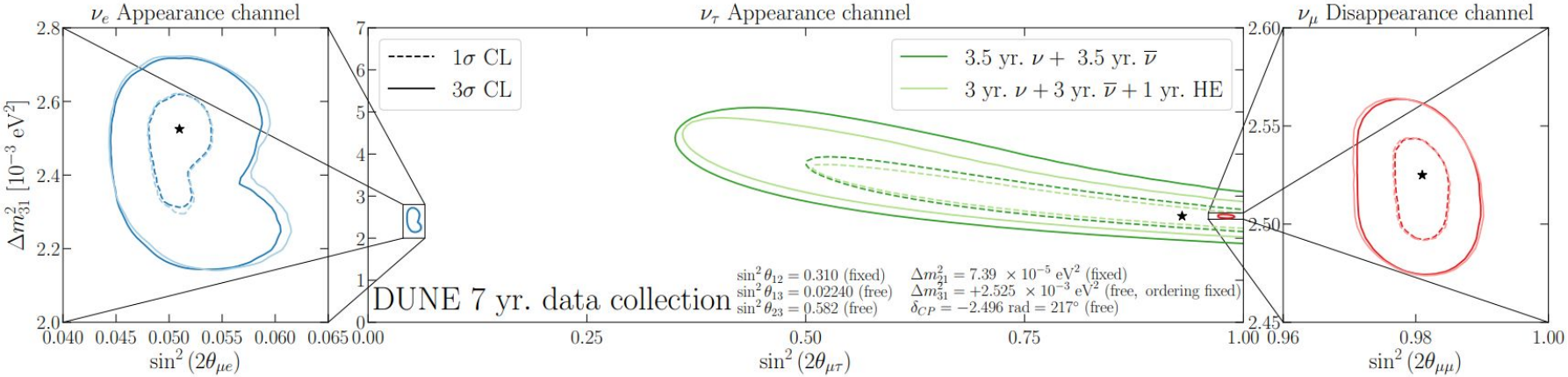
Considers 30% signal identification of hadronically-decaying tau events and 0.5% background contamination of neutral current events.

We also considered the “high-energy” beam tune -- results in higher event rate, but still just measuring the tail of the oscillation probability.

Extracting Three-Neutrino Physics

Three-Neutrino Measurements

de Gouvêa et al, [1904.07265]

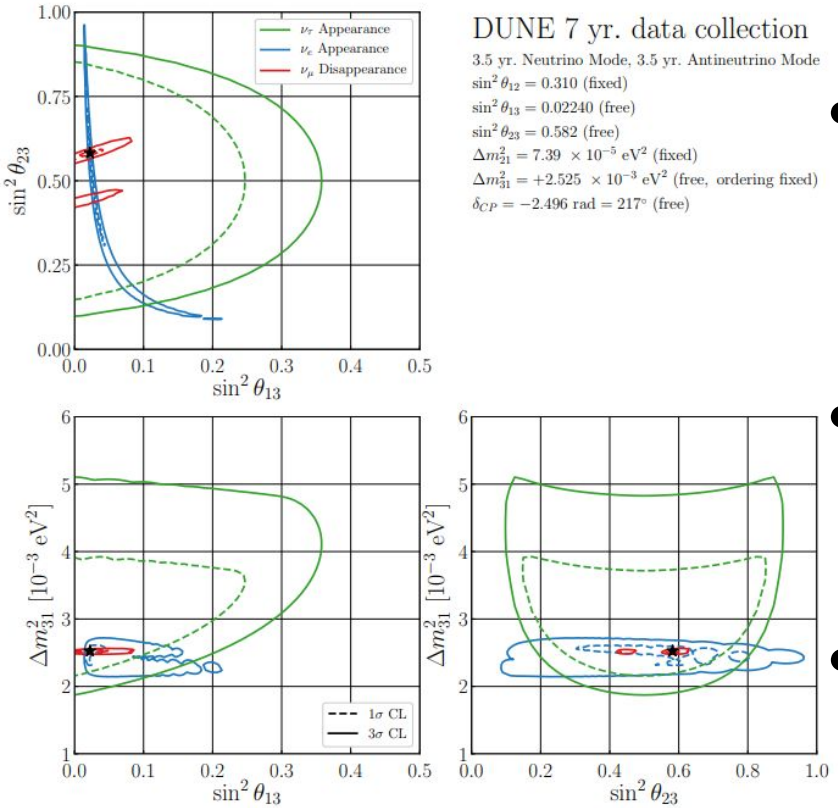


Within the three-neutrino picture, effective mixing angles are related, but we can determine the measurement capability of each of the three channels at DUNE. Consistency check -- do the mixing angles sum properly?

$$\sin^2 2\theta_{\mu e} \equiv 4|U_{\mu 3}|^2|U_{e3}|^2, \qquad \sin^2 2\theta_{\mu\mu} \equiv 4|U_{\mu 3}|^2(1-|U_{\mu 3}|^2)$$

$$\sin^2 2\theta_{\mu e} + \sin^2 2\theta_{\mu\tau} = \sin^2 2\theta_{\mu\mu}$$

Independent Mixing/Mass Splitting Measurements



- Separating out oscillation channels in the analysis, attempting to independently measure the mixing angles (and CP violation, not shown), as well as the atmospheric mass-squared splitting.
- Unsurprisingly, the tau channel (green) is weaker than the combined muon disappearance (red) and electron appearance (blue) channels.
- Still, this can serve as a consistency check.

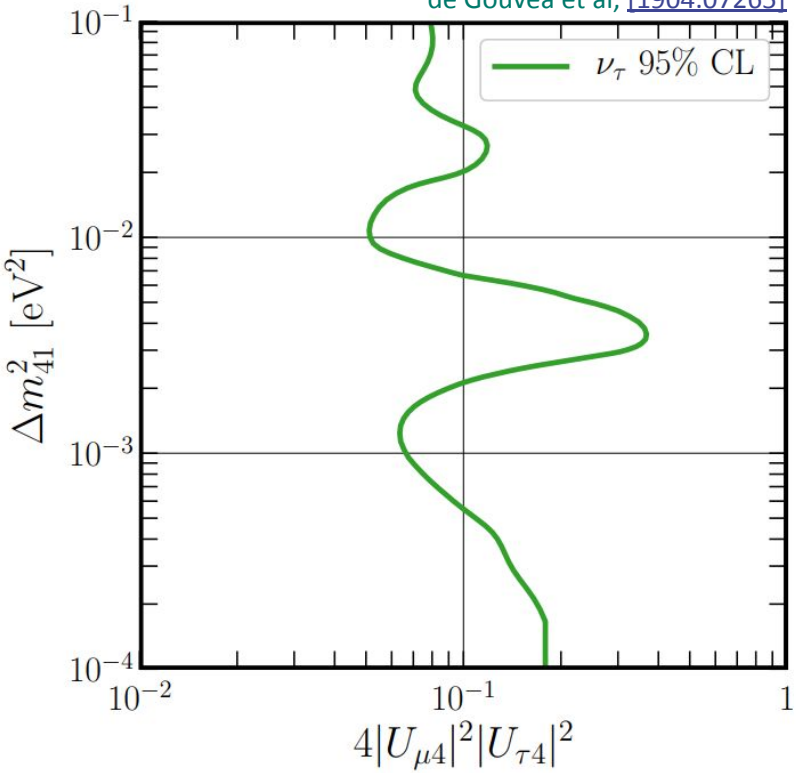
de Gouvêa et al, [1904.07265]

Some Physics Beyond Three Neutrinos

Light Sterile Neutrino

In the 3+1 Sterile Neutrino scenario, tau neutrino appearance has sensitivity to one of the three new mixing angles that electron neutrino appearance/muon neutrino disappearance don't (except through matter effects).

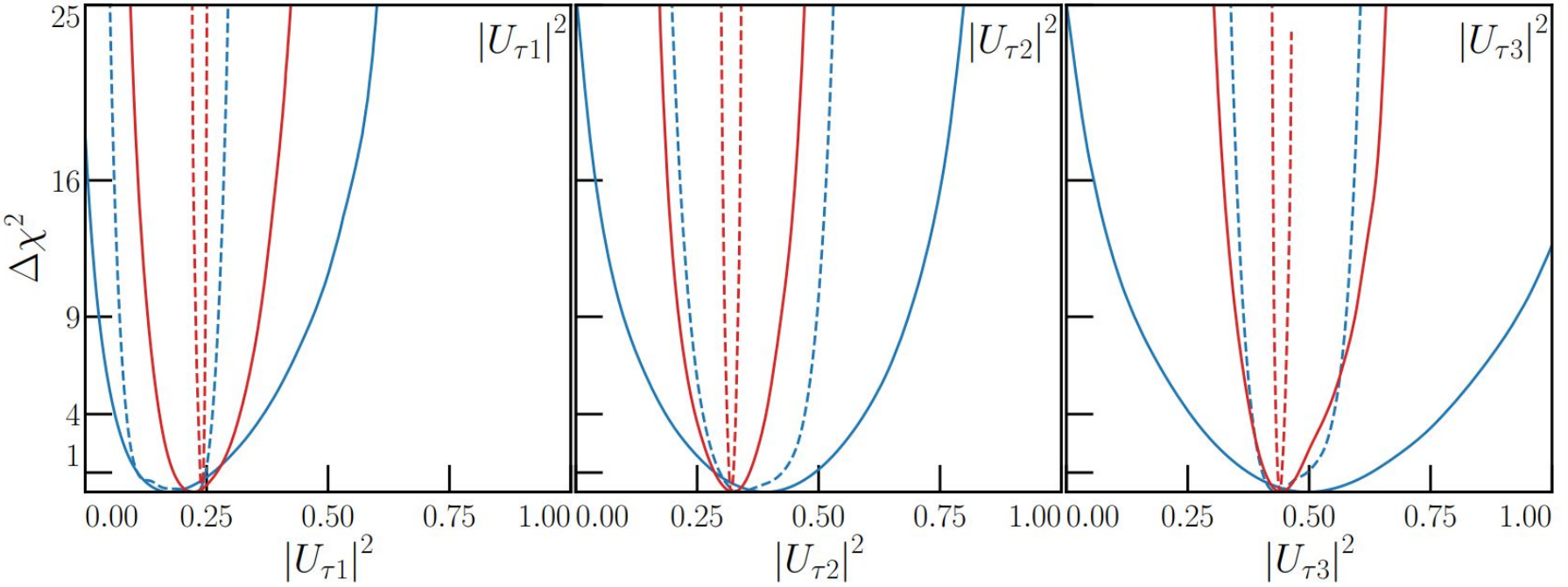
de Gouvêa et al, [1904.07265]



*See Miriama's talk for this type of search at the DUNE Near Detector (larger mass splittings)

Leptonic Unitarity

Ellis et al, [2008.01088]



Dashed: unitarity assumed.
Blue: Current data
Red: Future (+DUNE, IceCube Gen2)

- Unsurprisingly, the tau row of the Leptonic Mixing Matrix is the least understood. If we abandon the assumption of unitarity, we need direct measurements of tau neutrinos -- DUNE, and similarly, IceCube Gen2, have a lot to offer with tau neutrino appearance.

*More on this topic from Julia this afternoon.

Conclusions

- With upcoming experiments, the future of tau-neutrino appearance is bright!
- While this information serves more as a “consistency check” on three-neutrino physics, it still has much to offer in well-motivated extensions beyond three neutrinos.