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DEEP UNDERGROUND NEUTRINO EXPERIMENT

Tau Neutrino Physics at DUNE

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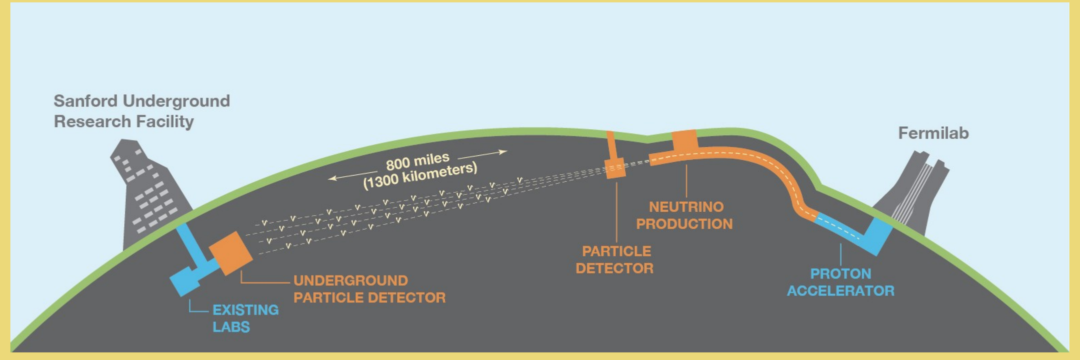
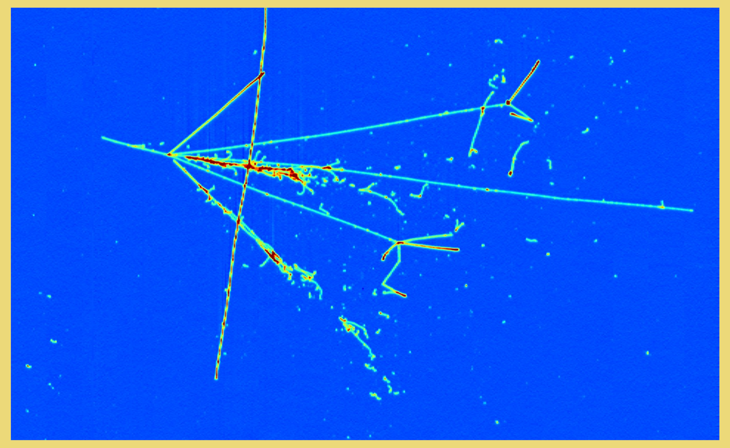
1) DUNE

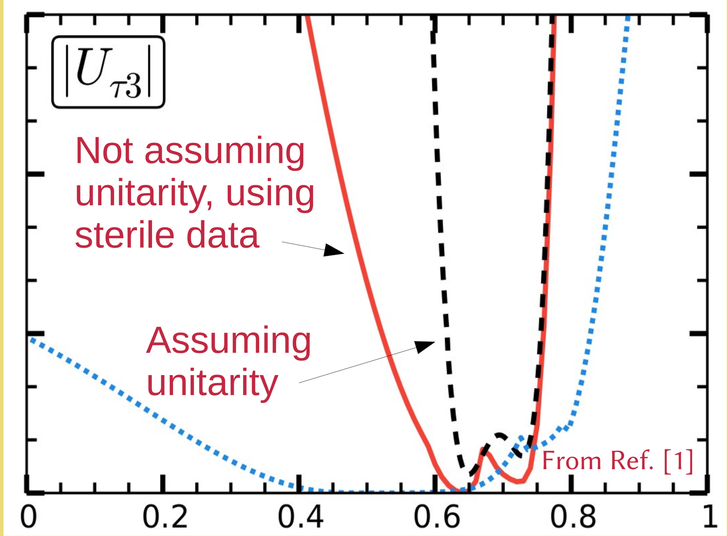


- DUNE is a long-baseline neutrino experiment currently under construction
- Will constrain the three flavor paradigm
  - Measure δ_{CP} and mass ordering by studying $\nu_\mu \to \nu_e$ oscillations

- Far Detector
  - 1300 km baseline
  - Liquid argon time projection chamber (LArTPC) technology for high resolution neutrino interaction imaging
  - 4x17 kton LArTPC modules
- Near Detector
  - 574 m baseline
  - Multiple detector systems
  - 147 ton LArTPC component

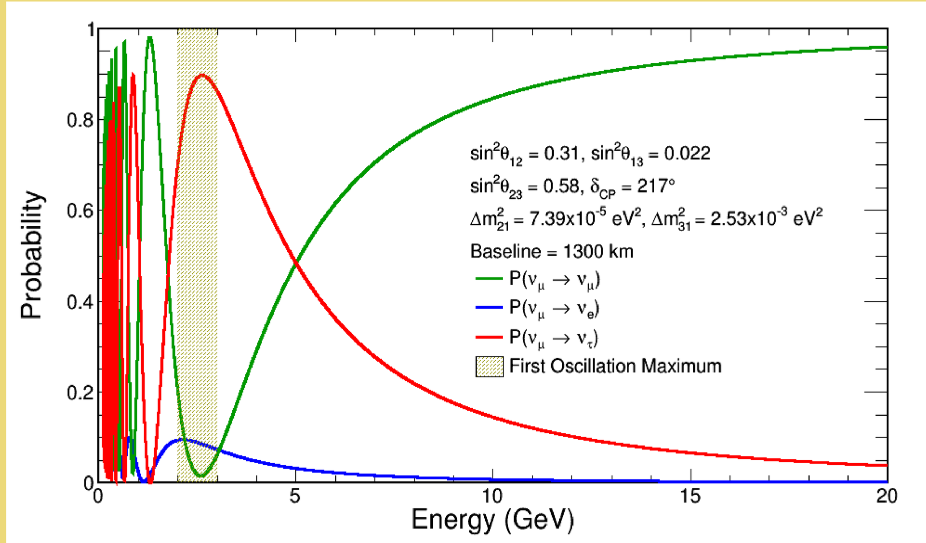


2) Why Tau Neutrinos?



- Current generation of neutrino experiments provides nearly complete description of three flavor paradigm
- Almost all knowledge of tau neutrino sector is taken from
  - Lepton universality for cross sections
  - PMNS unitarity for oscillations
- Critital that these assumptions are tested

- At atmospheric maximum, almost all muon neutrinos oscillate to tau neutrinos
- Excellent opportunity to probe:
  - Unitarity by measuring all three oscillation modes
  - Standard model cross section assumptions

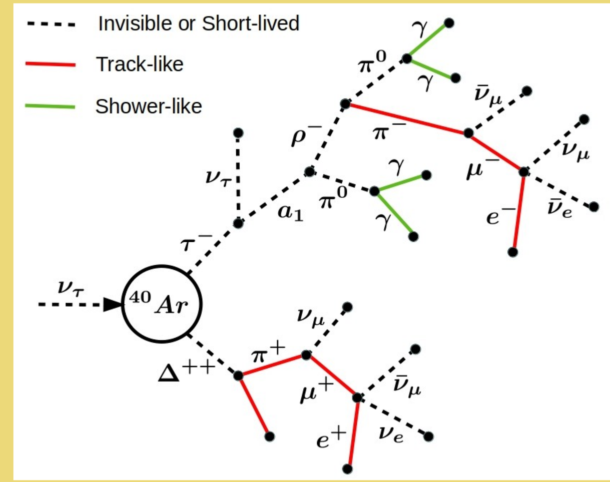


3) Tau Neutrino Challenges

τ^- Decay Mode	Branching Ratio
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
$e^-\bar{\nu}_e\nu_\tau$	17.8%
$\pi^-\nu_\tau$	10.8%
$\pi^-\pi^0\nu_\tau$	25.5%
$\pi^-2\pi^0\nu_\tau$	9.3%
$2\pi^-\pi^0\nu_\tau$	9.3%
$2\pi^-\pi^+\pi^0\nu_\tau$	4.6%

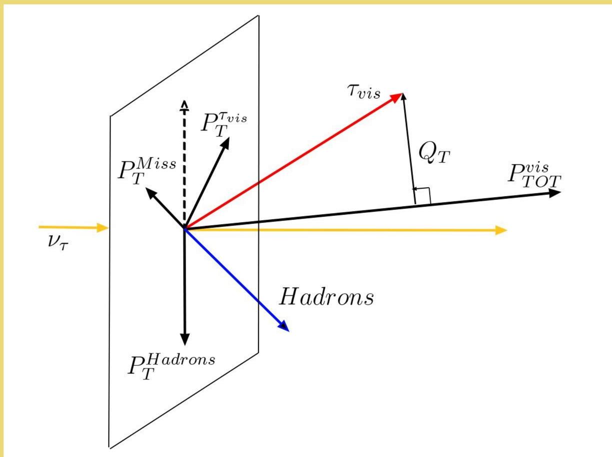
- Kinematically forbidden at typical beam energies
  - Even above threshold, still suppressed
- Tau leptons have many decay modes
  - Mimic ν_e CC, ν_μ CC, or NC events depending on decay

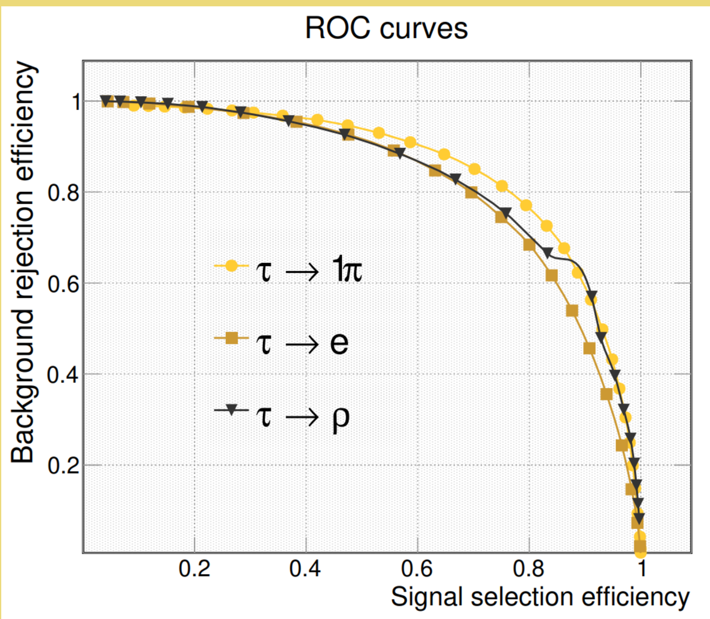
- Outgoing neutrino → missing energy
  - Worse for leptonic decay modes
- Hadronic decay modes can be complicated
  - Difficult to separate hadronic systems from tau decay and nucleus



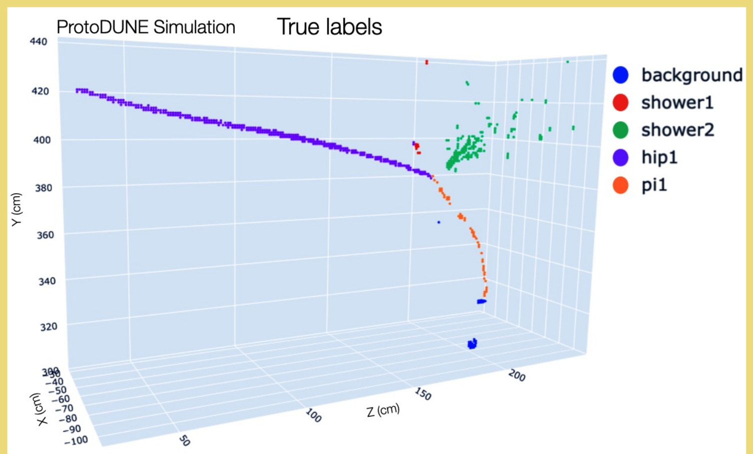
4) Selection

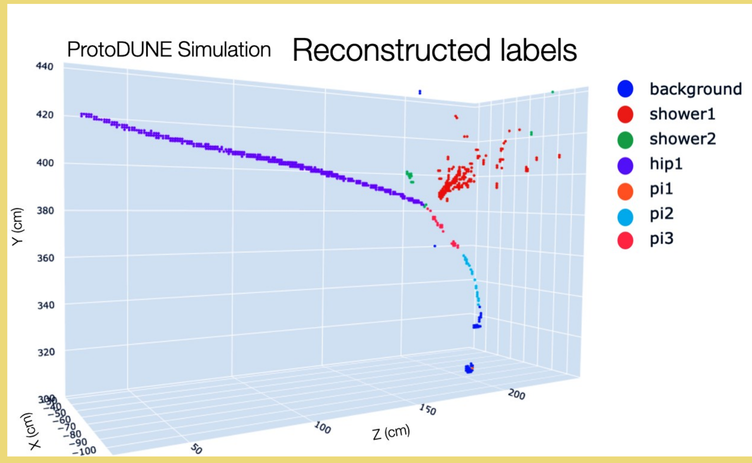
- Truth-level study of atmospheric tau neutrinos suggested excellent hadronic ν_τ/NC discrimination using simple kinematic cuts [2]
  - Optimistic assumption: near perfect e/γ and μ/π discrimination in LArTPC
  - Suggests 30% signal efficiency and 0.5% NC background efficiency possible
  - Use as a first estimate of sensitivity



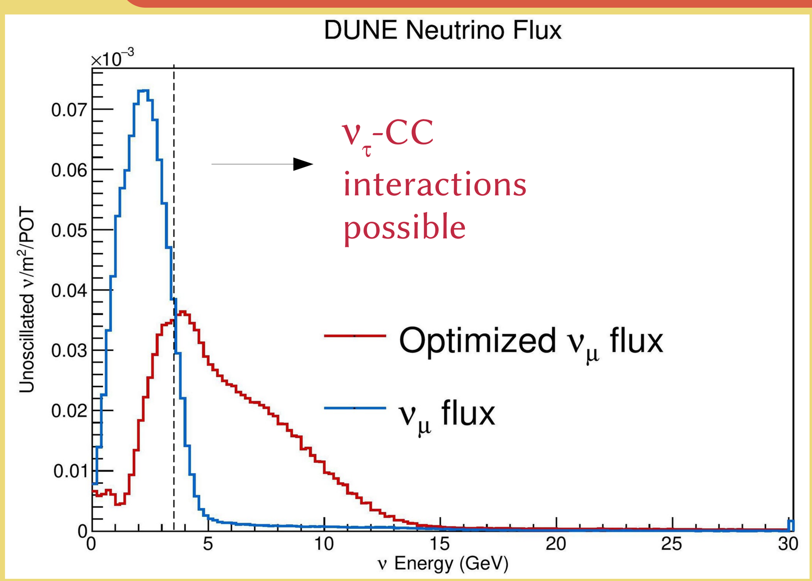


- More realistic reconstruction relies on the transverse plane kinematic approach suggested in Ref. [3]
- Can be applied to hadronic decays if the tau-lepton products can be identified
  - First attempt in Ref. [4] applied approach to $\tau \to \rho$ decays
- Investigating machine learning approaches for improved particle ID and reconstruction

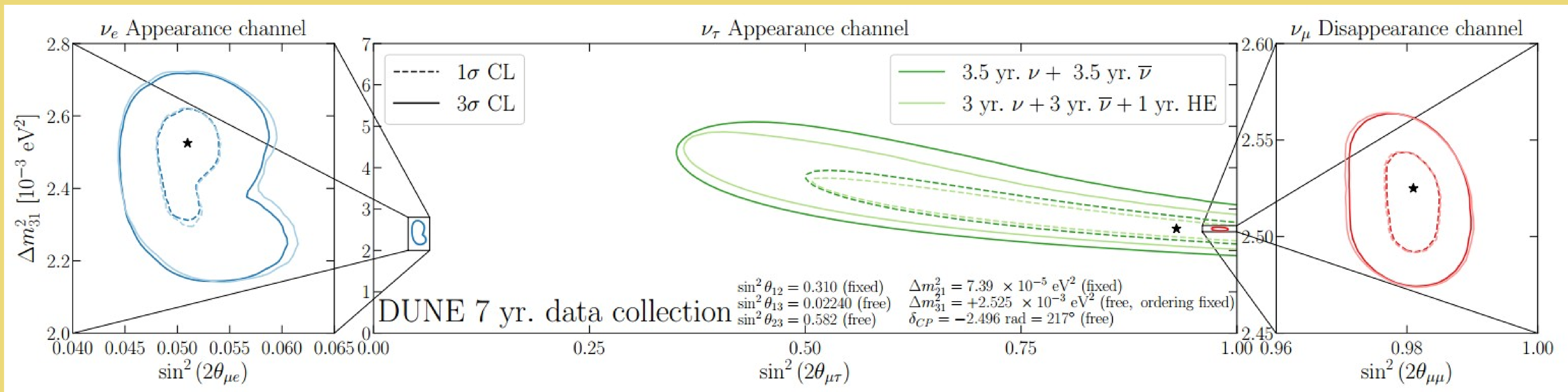




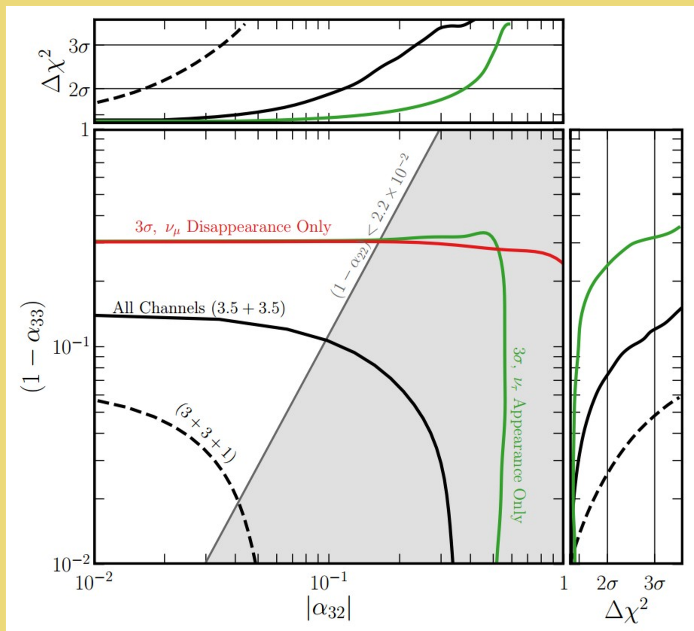
5) Long-Baseline Oscillations



- Default beam configuration peaks ~2 GeV to maximize sensitivity to CP violation
  - High energy tail is above kinematic threshold
  - Expected counts/year (1.2 MW beam)
    - ~130 ν_τ in neutrino mode
    - ~30 $\bar{\nu}_\tau$ in antineutrino mode
- Tau optimized configuration
  - Higher energy
  - Possible configuration after CP program
  - ~800 ν_τ per year

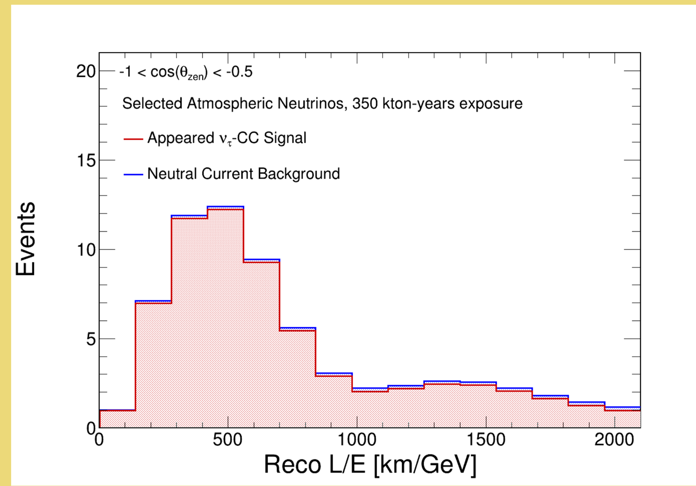


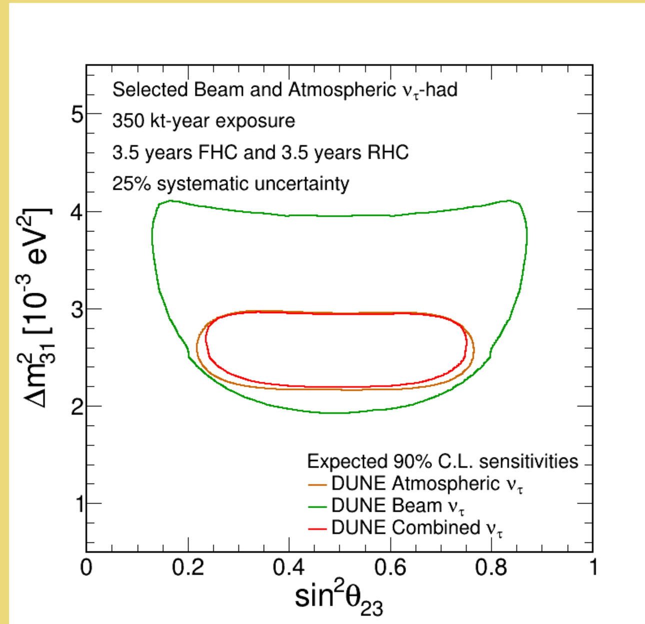
- Ref. [6] showed that DUNE can constrain normalization of 3rd PMNS column to ~5% in model independent way
  - If we assume non-unitarity is due to kinematically inaccessible sterile neutrinos, can set strong limits on α_{33}
- Tau optimized configuration is particularly useful for this



6) Atmospheric Oscillations

- Due to kinematic threshold, beam ν_τ are only detected above the atmospheric oscillation maximum
- Causes a degeneracy between Δm^2_{31} and $\sin^2\theta_{23}$
- Due to long baseline of atmospheric neutrinos, atmospheric maximum is above kinematic threshold
  - Complements beam neutrinos





- Expect ~1 ν_τ / kton-year
- Lower statistics, but clear signal at atmospheric maximum
  - Breaks degeneracy
- Interplay between atmospherics and beam important
  - Atmospherics have favorable L/E
  - Beam has defined direction and Near Detector for systematic uncertainty reduction

See posters:
#199 Studies of tau neutrinos appearing at the DUNE Near Detector Complex
#418 Tau Neutrino Cross Section at DUNE
for details about the tau neutrino program at DUNE

References

[1] S. Parke and M. Ross-Lonergan, Phys. Rev. D 93, 1103009 (2016)
[2] J. Conrad, A. de Gouvea, S. Shalgar, J. Spitz, Phys. Rev. D 82, 093012 (2010)
[3] C. Albright and R. Shrock, Phys. Lett. B 84, 123 (1979)
[4] T. Kosc, PhD thesis, Université de Lyon (2021)
[5] R. Mammen Abraham et al, arXiv:2202.05591
[6] A. de Gouvea, K. Kelly, G. Stenico, P. Pasquini, Phys. Rev. D 100, 016004 (2019)

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