Tau neutrino physics in the DUNE experiment

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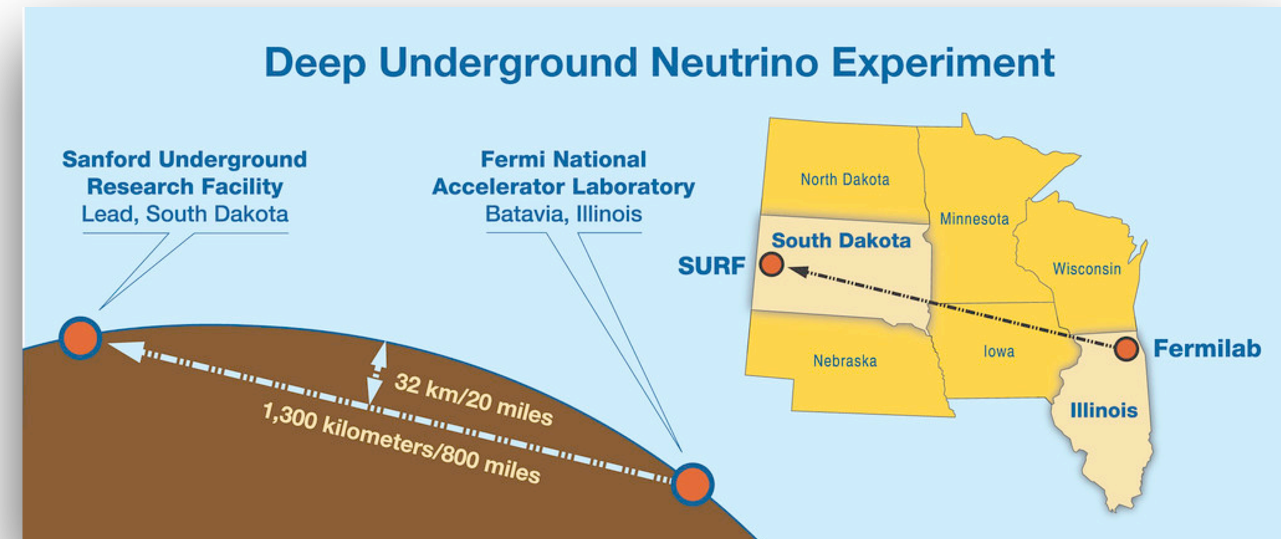
- Unprecedented sensitivity to ν_μ—>ν_τ oscillations (~30 beam events / 10kTon / year). DONUT 9 candidates (2008), OPERA 10 candidates (2018)

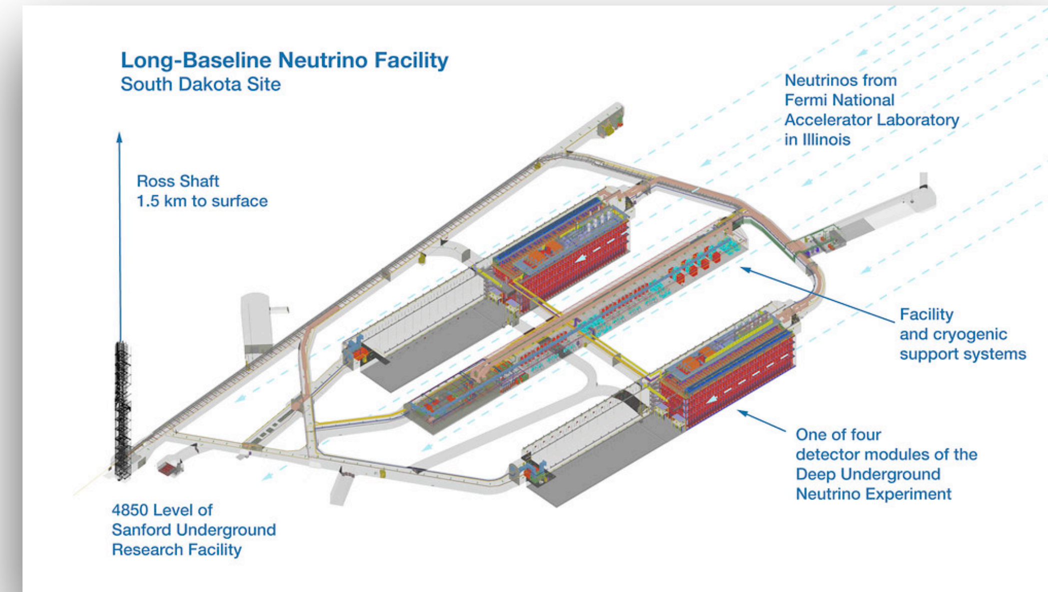
- Only large scale neutrino experiment with this sensitivity

- Physics perspectives (de Gouvêa *et al.*) **10.1103/PhysRevD.100.016004** :
  - 3 flavour phenomenology
  - PMNS unitarity test
  - Sterile neutrino
  - Non-standard neutral current interactions

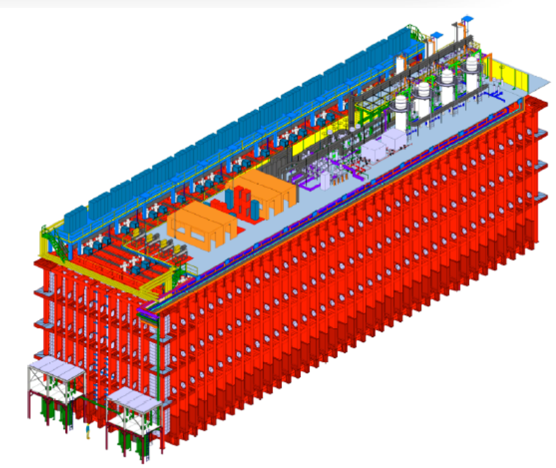
- Cross section measurement

- Future long-baseline (1285 km) beam neutrino experiment between Fermilab and Sanford. Start by the end of the decade.





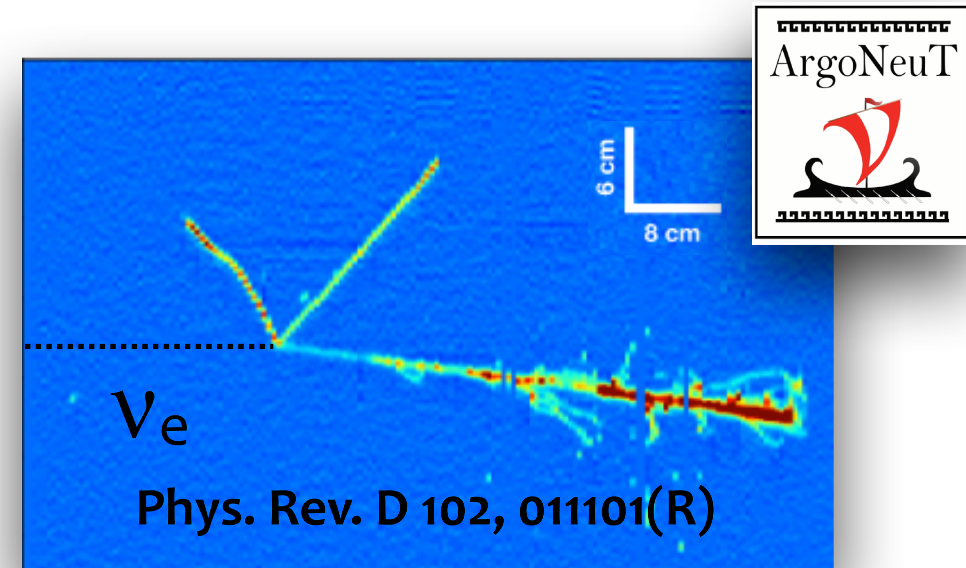
- Characteristics:
  - 1.2 MW beam (upgradable to 2.4 MW)
  - Near detector hall (Fermilab)
  - four 10 kTons (fiducial mass) modules at far detector site

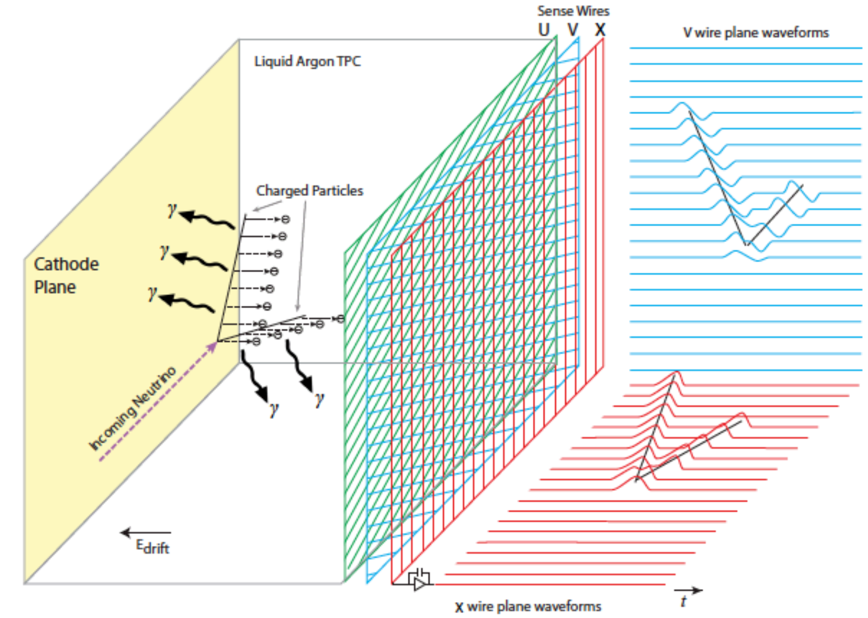


DUNE (II)

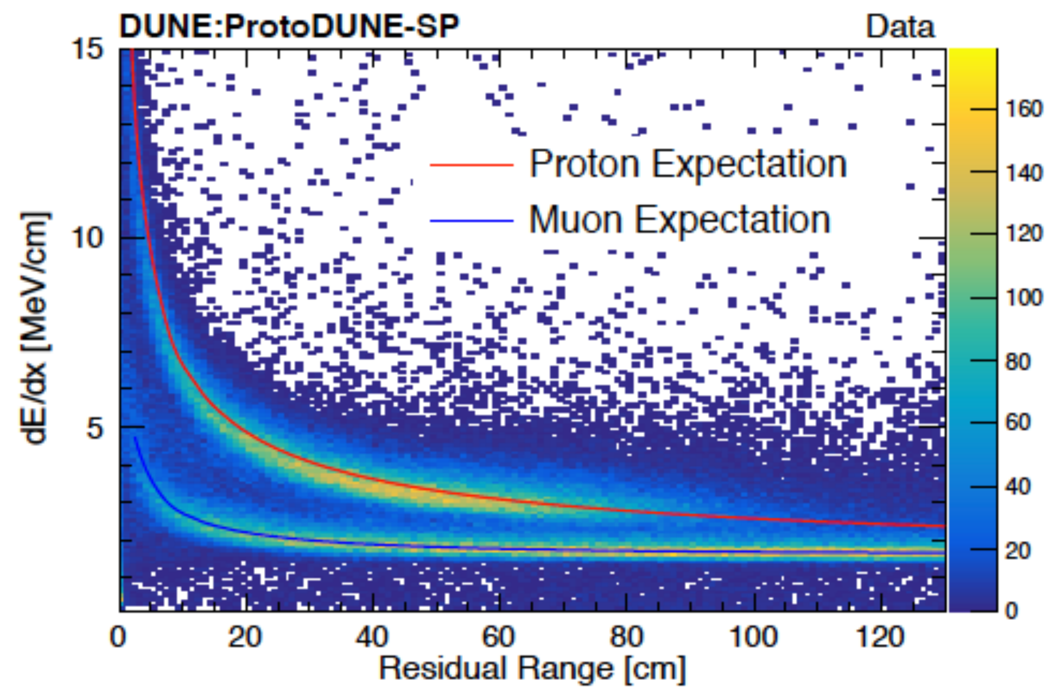
- Tuned to study subleading ν_μ—>ν_e oscillations (~10%) sensitive to last unconstrained PMNS parameter δ_{CP}, related to possible CP violation
- Rich program
  - Neutrino oscillations (mass hierarchy, octant of θ_{23}, CP violation study)
  - Neutrino astrophysics (supernovae, solar)
  - BSM studies
- >1000 physicists, >30 countries, >200 research institutions

- Far detector chosen technology:
  - Excellent spatial resolution
  - Excellent calorimetric response





- Step to large scaling at CERN
  - Excellent spatial resolution
  - Excellent calorimetric and dE/dx responses



10.1088/1748-0221/15/12/P12004

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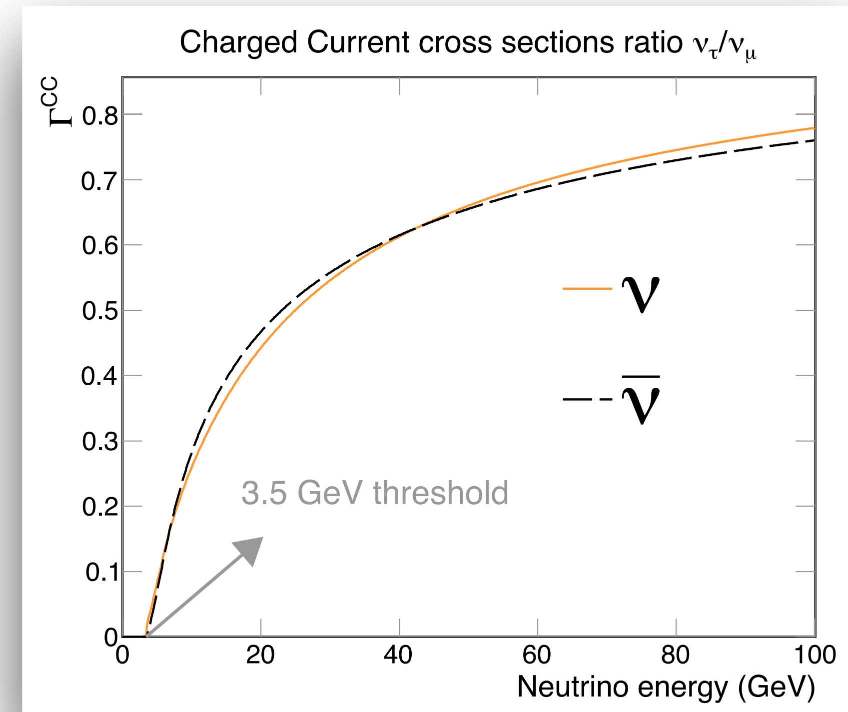
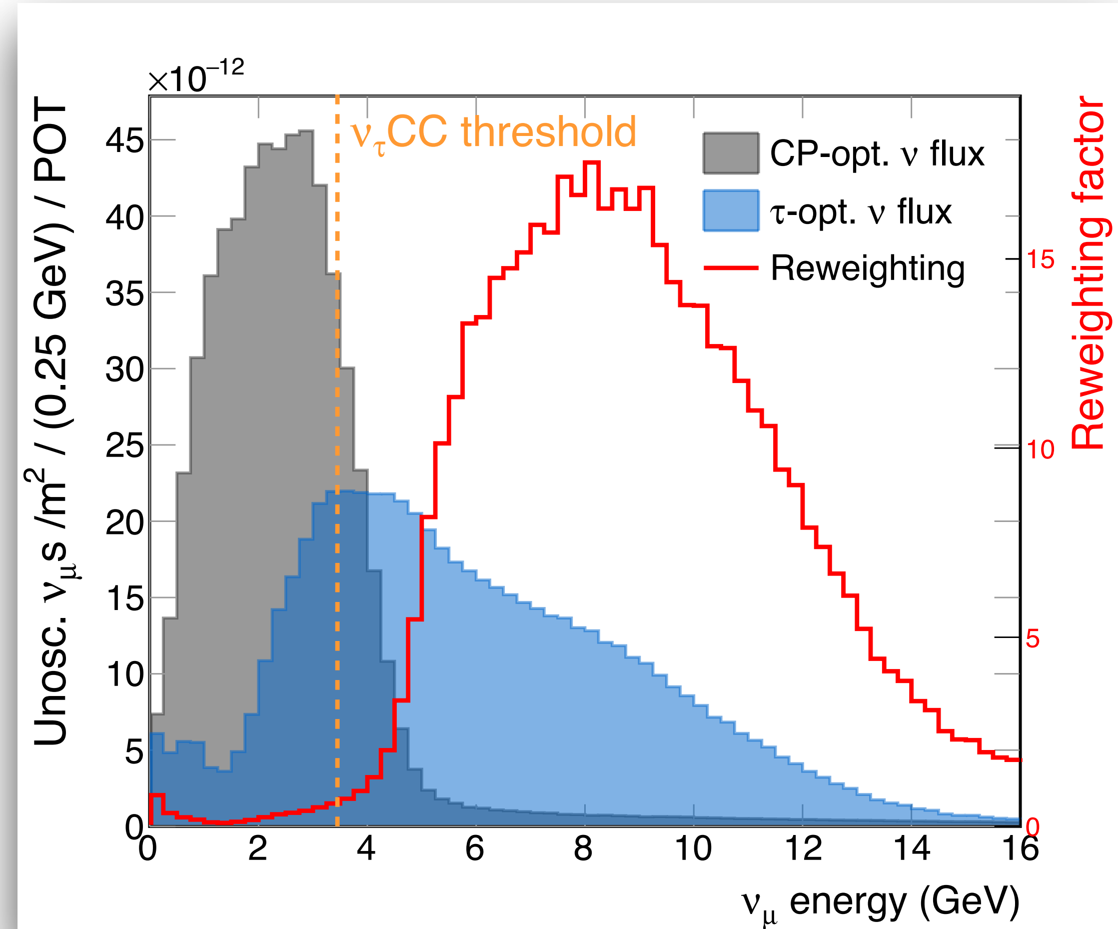
DUNE

τ optimized neutrino beam opportunity

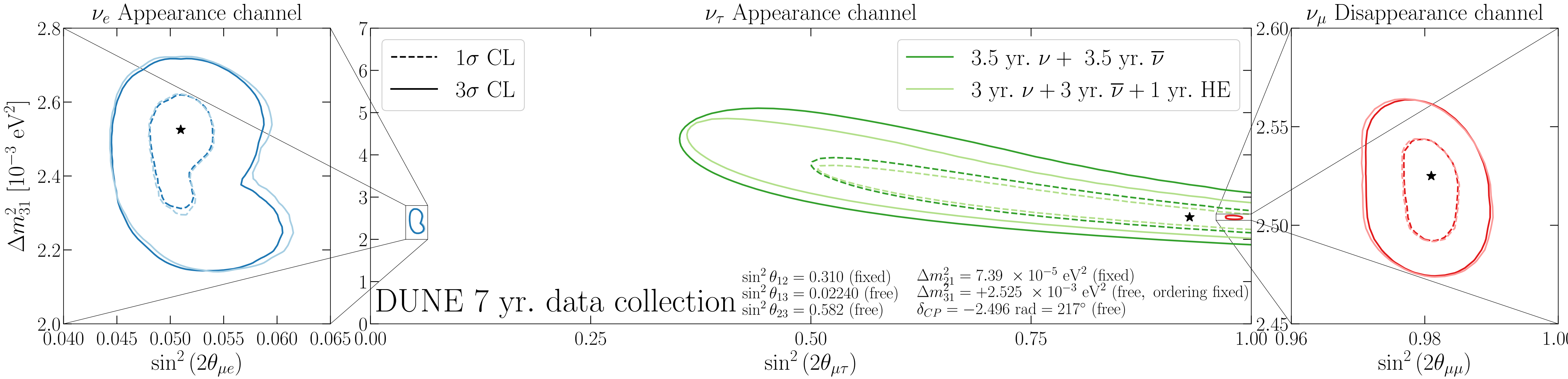
- Alternative beam design to run with a higher energy neutrinos:
  - Kinematic suppression
  - CC 3.45 GeV threshold





- τ neutrino statistics boosted by a factor 6 !

Physics opportunitites - PMNS non-unitarity



$$\sin^2 2\theta_{\mu e} = 4|U_{\mu 3}|^2|U_{e3}|^2$$

$$\sin^2 2\theta_{\mu\mu} = 4|U_{\mu 3}|^2\left(1-|U_{\mu 3}|^2\right)$$

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

- Most knowledge on $|U_{\tau 3}|$ comes from unitarity
- Poor ν_τ appearance, no ν_τ disappearance
- DUNE will help constraining 3rd column unitarity at ~5%

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left(y^2 x + \frac{m_\tau^2 y}{2E_\nu M}\right)F_1$$
$$+\left[\left(1-\frac{m_\tau^2}{4E_\nu^2}\right)-\left(1+\frac{Mx}{2E_\nu}y\right)\right]F_2$$
$$\pm\left[xy\left(1-\frac{y}{2}\right)-\frac{m_\tau^2 y}{4E_\nu M}\right]F_3$$
$$+\frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5.$$

- F4 and F5 not accessible with ν_e and ν_μ

- Expect ~170 ν_τ CC / 10kTon / year with τ optimized beam

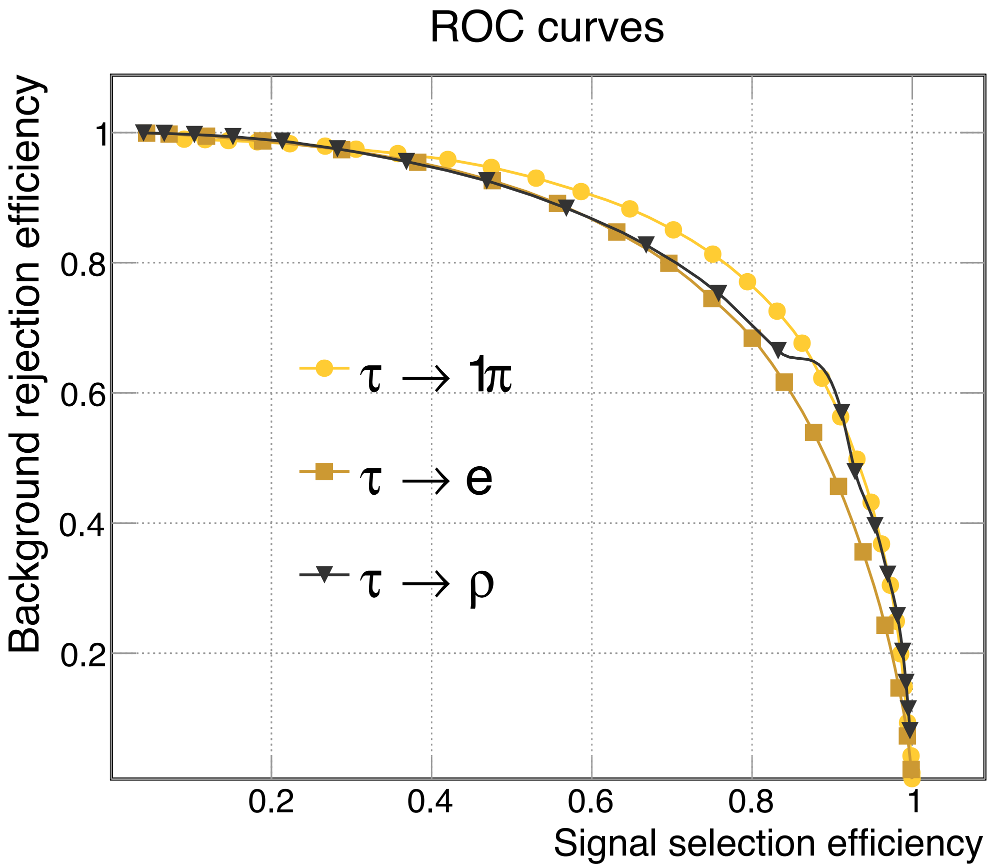
- No direct reconstruction of the τ lepton feasible for DUNE

- Follow the pioneering work of the NOMAD collaboration (90's):
  - 1 τ decay mode = 1 dedicated analysis
  - Transverse plane known for beam events
  - Large transverse missing momentum associated to leptonic decay modes of the τ (*Albright & Shrock, 1978*)

- Promising decay modes
  - τ—>e: final state electron + large BR (better than τ—>μ)
  - τ—>ρ—>$\pi_0\pi$: large BR + invariant masses of ρ and π_0
  - τ—>3π: large hadronic activity

- Simulation driven likelihood analysis on three τ decay modes, each with its associated backgrounds

- ~40% signal selection efficiency with >95% background rejection for each



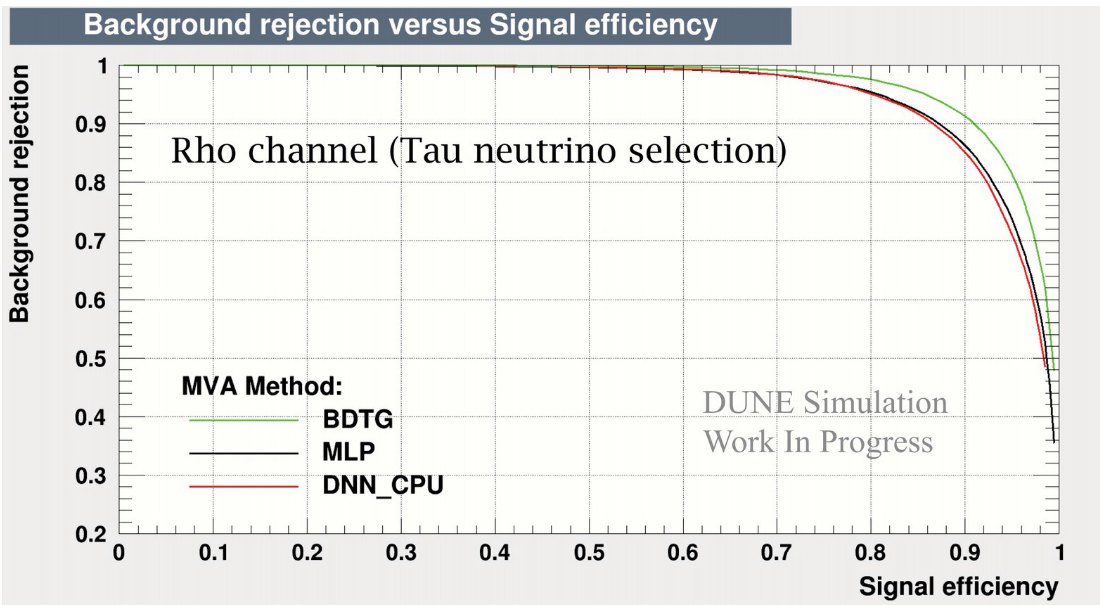
	Standard LBNF ν beam	τ optimized beam
3 channels combined		
ν_τ	44.0 ± 0.3	284.2 ± 1.6
Backgrounds	202.9 ± 2.1	375.4 ± 4.1
Significance	3.0 ± 0.0	13.2 ± 0.1

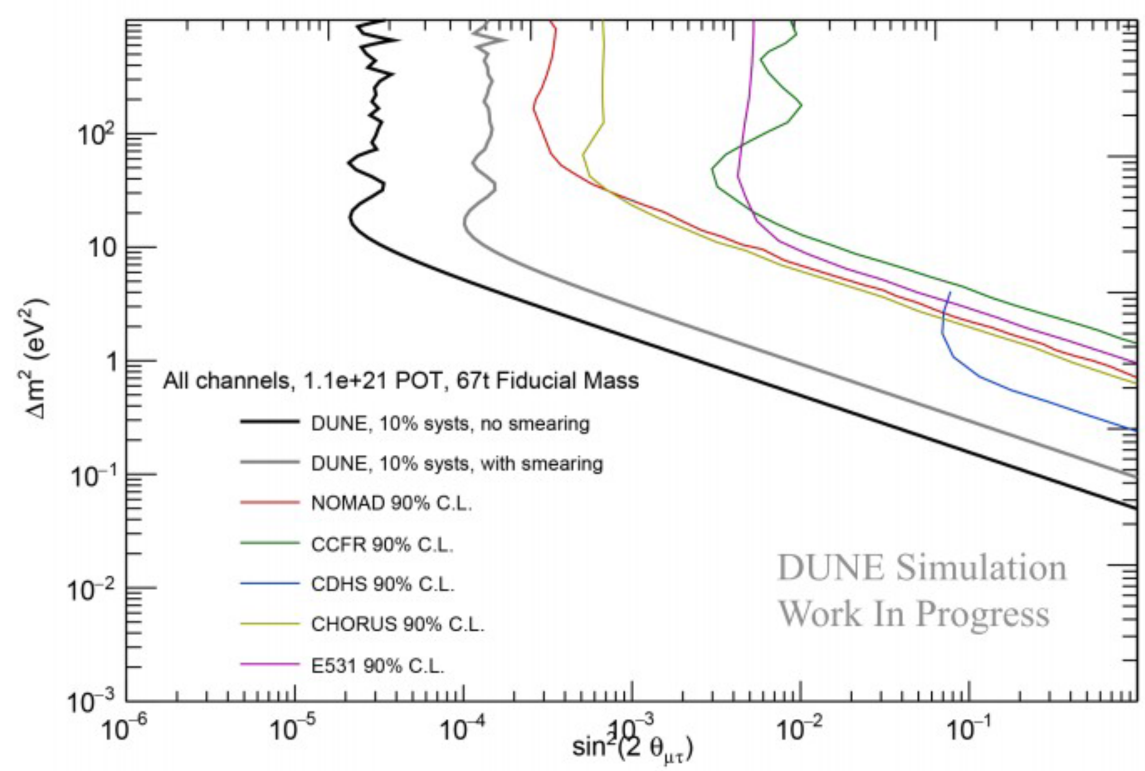
- Asimov significance (3.5 years staged normalization) shows gigantic help of the alternative τ optimized neutrino beam

Short baseline ν_μ—>ν_τ appearance analysis

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2(2\theta_{\mu\tau})\sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

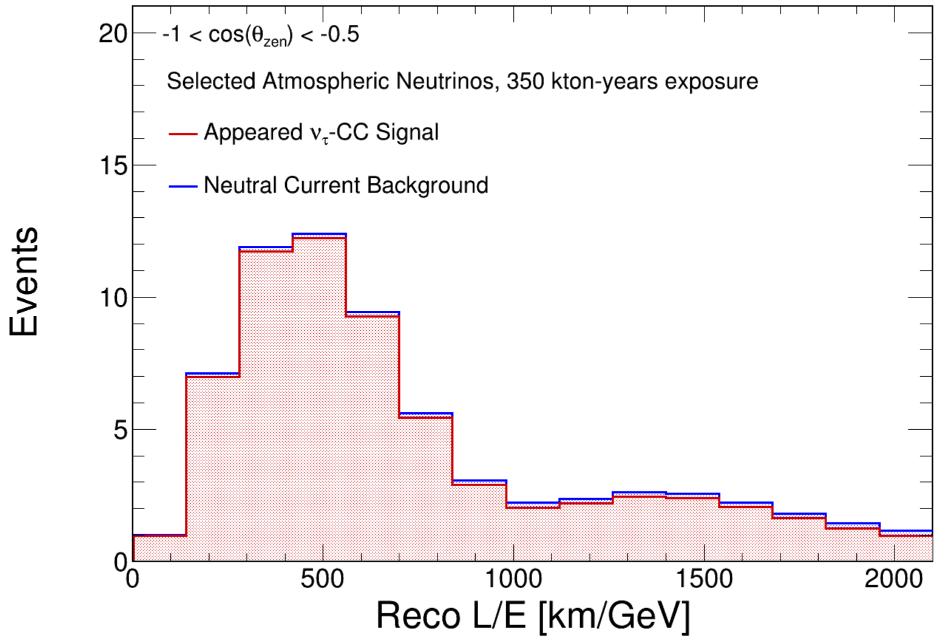
- Sterile scenario with $\Delta m^2 \sim eV^2$: ν_τ appearance !
- Work ongoing on several τ decay modes (leptonic and ρ)





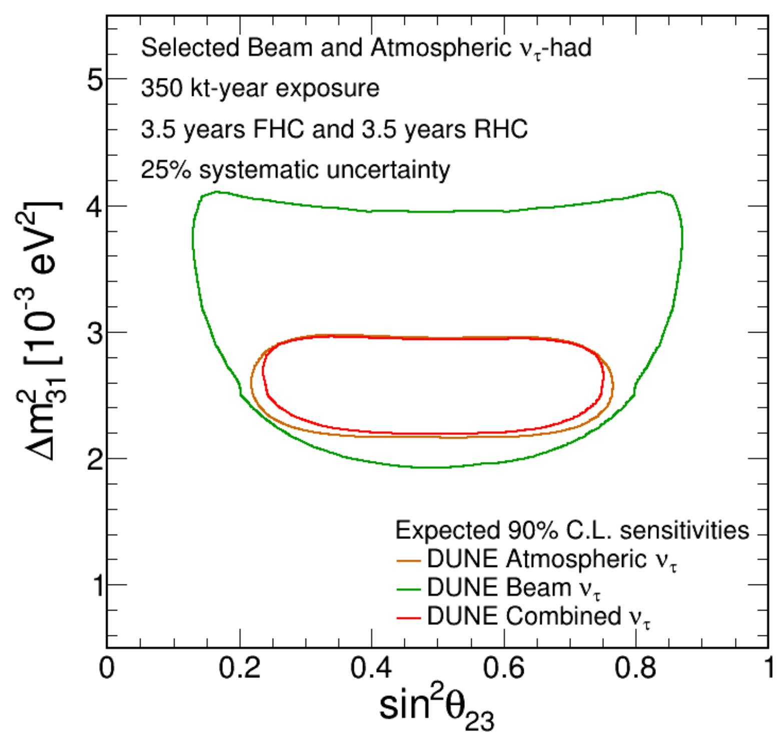
- Improve sensitivity wrt NOMAD

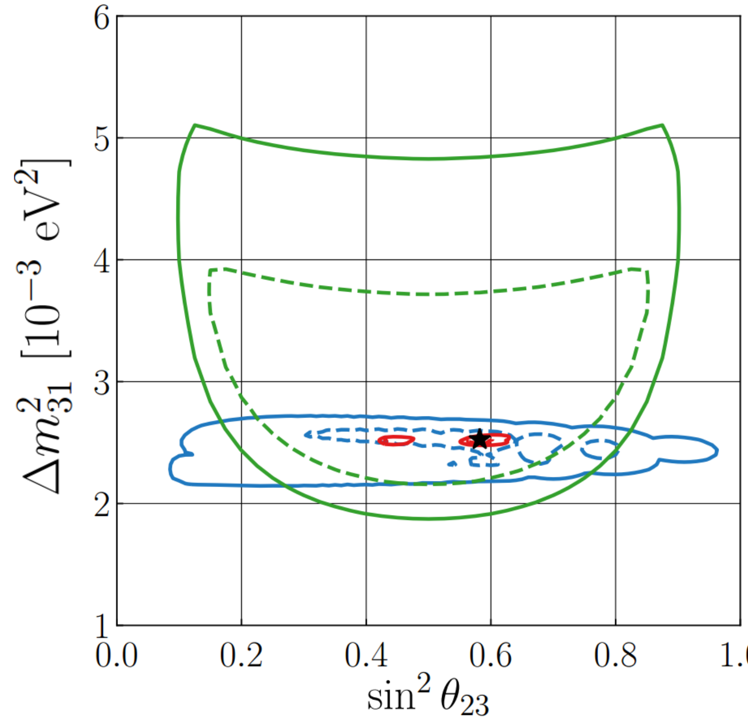
Atmospheric $\nu_\mu \longrightarrow \nu_\tau$



- Clear 1st oscillation maximum with atmospheric sample

- Better sensitivity than beam ν_τ





- DUNE (Deep Underground Neutrino Experiment) is a future long-baseline neutrino experiments tuned to probe possible CP violation in the neutrino sector via ν_μ—>ν_e oscillations.

- DUNE will have an opportunistic and unprecedented sensitivity to τ neutrino appearance (~30 beam events / 10 kTon / year).

- Phenomenological studies: PMNS unitarity, 3-flavour phenomenology, cross-section, sterile neutrinos.

- ν_τ search at the fast Monte Carlo level ongoing.

Thank you !

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DUNE near detector hall