Studies of ν_τ appearance in the DUNE Near Detector Complex

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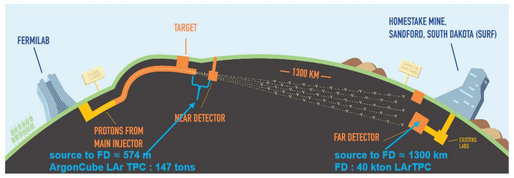
U.S. DEPARTMENT OF ENERGY | Office of Science

DUNE Experiment



- LBL experiment with a baseline of 1300 km (Fermilab to South Dakota)
- Uses a ν_μ beam provided by the LBNF Facility (with a small ν_e contamination).

DUNE PRIMARY PHYSICS GOALS :

- Measurements of the charge parity (CP) phase.
- Determination of the neutrino mass ordering(the sign of $\Delta m^2_{31} \equiv m^2_3 - m^2_1$)
- Measurement of the mixing angle θ_{23} and the determination of the octant in which it lies.
- Search for Physics Beyond the Standard Model

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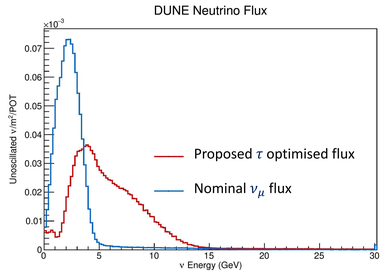
Objectives of the analysis

- Short baseline $\nu_\mu \rightarrow \nu_\tau$ oscillations could be evidence for a sterile neutrino :

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

$$\sin^2(2\theta_{\mu\tau}) = 4\left|U_{\mu 4}\right|^2 |U_{\tau 4}|^2 = \cos^4\theta_{14}\sin^2(2\theta_{24})\sin^2(2\theta_{34})$$

- **Objective**: Study the evetual ν_τ interactions in the DUNE ND Complex (574 m from neutrino source) driven by sterile neutrino mixing.
- Neutrino interactions were simulated using GENIE.



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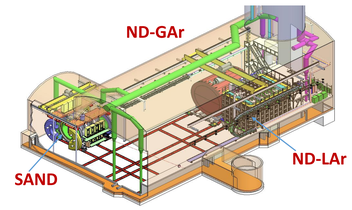
DUNE Near Detectors

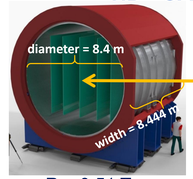
DUNE Near Detector complex



The great resolution of the **DUNE ND Complex,** intense neutrino flux from LBNF and the short baseline of 574 makes the DUNE ND ideal for a **sterile neutrino search**.

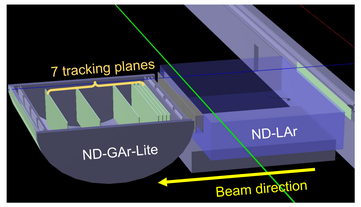
Early phase of DUNE proposed detectors

ND - GAr-Lite



Scintillator tracking planes

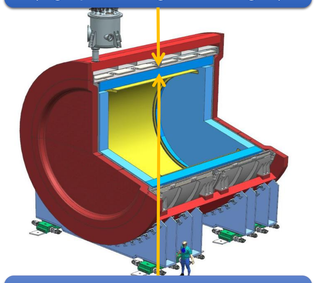
→ **B** = 0.51 T



Full scope DUNE Experiment

ND - GAr

HPgTPC
(high-pressure gaseous argon)



ECAL
(electromagnetic calorimeter)

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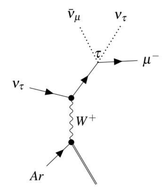
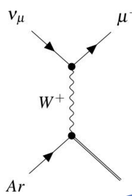
τ decay modes

Decay mode	Branching ratio (%)
$\pi^- \pi^0 \nu_\tau$	25.49
$e^- \bar{\nu}_e \nu_\tau$	17.82
$\mu^- \bar{\nu}_\mu \nu_\tau$	17.39
$\pi^- \nu_\tau$	10.82
$\pi^- 2\pi^0 \nu_\tau$	9.26



ν_τ CC ($\tau \rightarrow \mu^-$)



ν_μ CC

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Muon momentum resolution

- Several τ decay channels were considered for the analysis with a particular focus on the muon case.
- Only a small fraction of the muon will be contained in the ND-LAr so the ND-GAr(-Lite) is needed to measure their momentum.

Energy (GeV)	ND GAr-Lite		ND GAr	
Resolution	Momentum	Angular	Momentum	Angular
0 - 8	2.186 %	0.452147 °	2.657 %	0.439295 °
8 - 14	4.465 %	0.213239 °	5.256 %	0.268346 °
14 - 18	6.283 %	0.194204 °	6.397 %	0.250816 °
18 - 25	7.894 %	0.178582 °	6.814 %	0.235035 °

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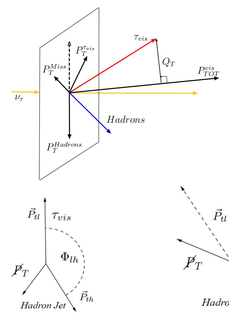
ν_τ signal and background separation

The signal and background separation is based on kinematic differences. A total of 18 variables was used.



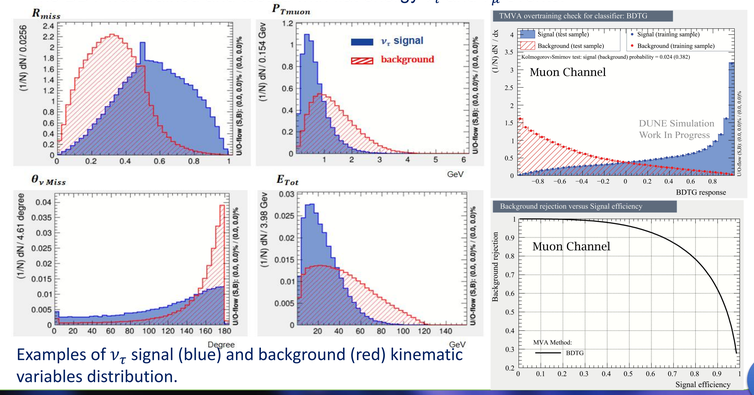
Background interaction products in the transverse plane

ν_τ CC interaction products in the transverse plane

6 variables providing highest signal/bg separation

Ranking	Kinematic varialbles
1	R_{miss}=$\frac{P_{TMiss}}{P_{TMiss} + P_{Tmuon}}$
2	P_{Tmuon}: transverse lepton momentum
3	$\theta_{\nu\,Miss}$: angle between beam direction and missing transverse momentum
4	E_{Tot}: total visible energy
5	$\Phi_{muon\,hadron}$: angle between transverse muon and hadron momentum
6	P_{Tot}: total transverse momentum

- A Boosted Decision Tree classifier was used with the kinematic variables for the signal and background separation.
- The BDT was trained and tested with flat energy ν_τ and ν_μ events.



Examples of ν_τ signal (blue) and background (red) kinematic variables distribution.

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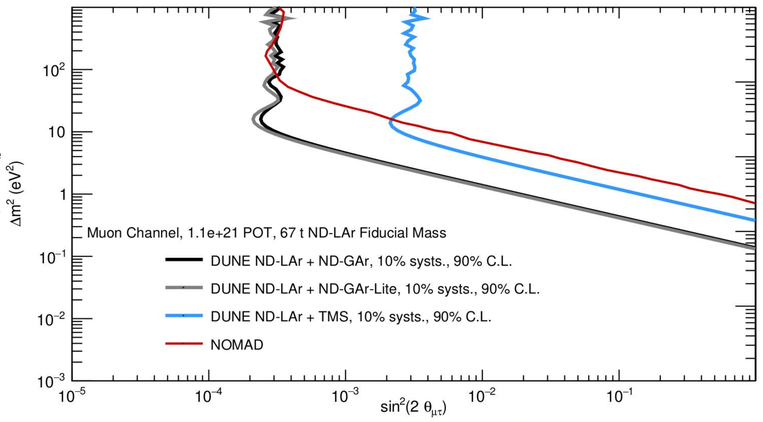
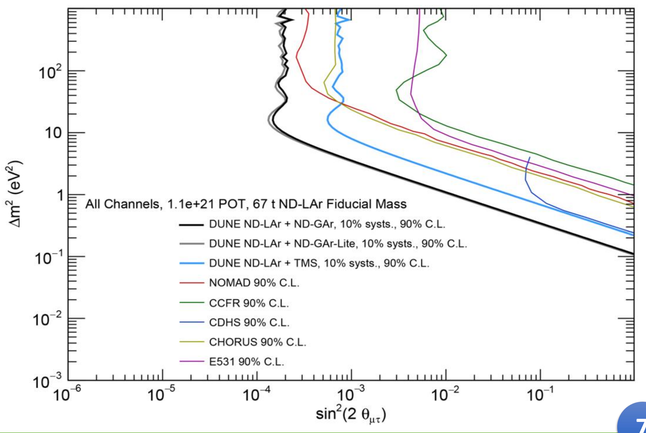
Sensitivity to ν_τ appearance

- Runtime: 1 year
- Flux: τ optimised flux
- ND-LAr fiducial mass : 67 t
- Systematic uncertainty : 10%
- High BDTG cuts applied to both ND GAr (BDTG score > 0.9965) and ND GAr-Lite (BDTG score > 0.9969) corresponding to regions with almost no backgrounds.
- The electron and rho decay channel were added to the analysis (represented in the plot on the right) in which particles from interactions were supposed to be contained in ND LAr.

Muon Channel Only



Muon + Electron + Rho decay channels



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Conclusion

- DUNE's near detectors are sensitive to short-baseline ν_τ appearance for sterile neutrino searches.
- ND-GAr and ND-GAr Lite are key due to their muon resolution.
- A high-energy beam configuration could potentially give DUNE leading sensitivity to anomalous short-baseline ν_τ appearance.
- Next steps:
  - Include SAND detector.
  - Investigate other tau decay channels.

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