Neutrino Oscillation Prospects with a Dual-Baseline Beam from BNL to SNOLAB and DUNE

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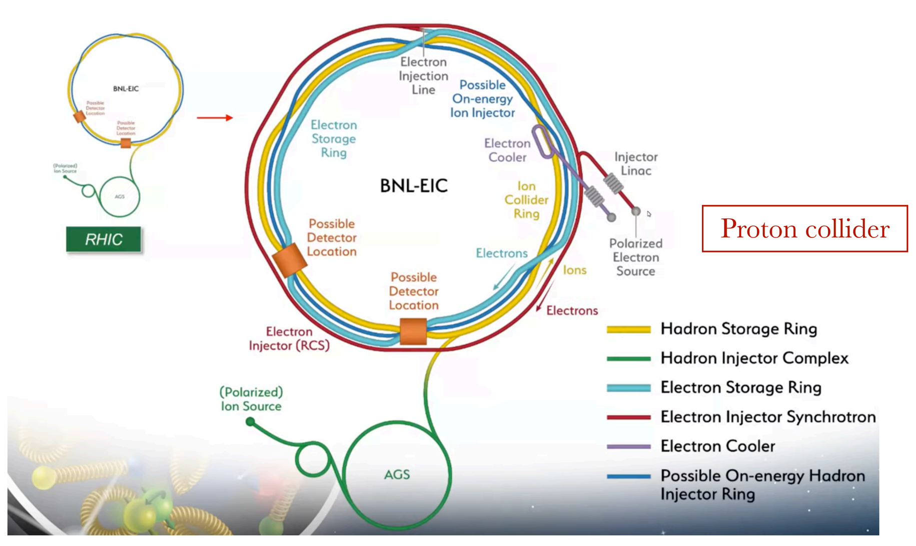
Abstract

In this project, we propose a long-baseline neutrino oscillation experiment utilizing a high-energy neutrino beam generated at Brookhaven National Laboratory (BNL), based on the proton beam from the proposed Electron-Ion Collider (EIC). The EIC proton beam is expected to have energies ranging from 40 to 400 GeV, with a luminosity of $10^{33}\ cm^{-2}\ s^{-1}$ offering a higher POT available for the neutrino generation.

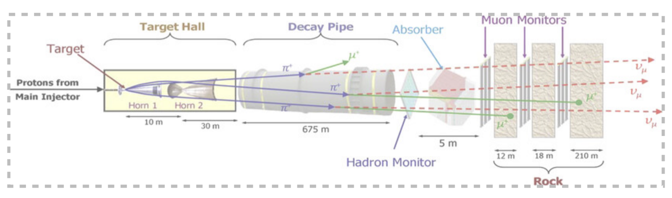
A conventional pion-decay beamline would be employed to produce a forward-directed neutrino beam. We propose two detector sites for the experiment: the DUNE far detector in South Dakota, covering a baseline of 2900 km, and a second detector at SNOLAB in Ontario, with a baseline of 900 km. This dual-baseline configuration enhances sensitivity to matter effects and provides a complementary perspective to the existing Fermilab–DUNE baseline studies.

Our initial work includes conceptual flux estimation and an evaluation of oscillation sensitivity, laying the groundwork for assessing the feasibility and scientific potential of this alternative neutrino source.

Introduction



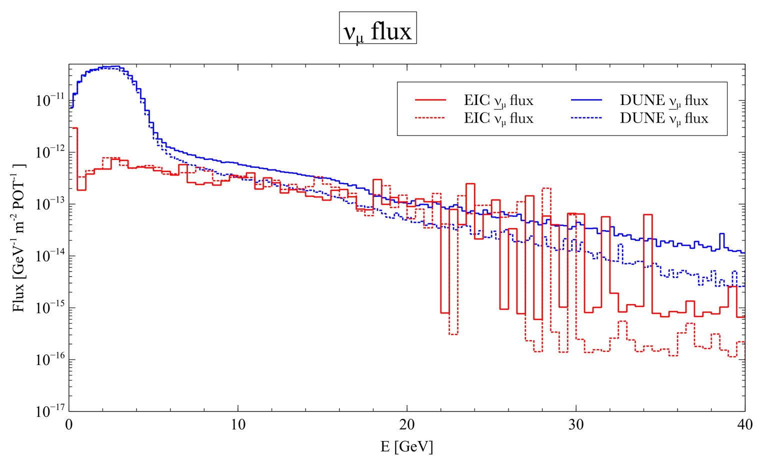
Proton collider

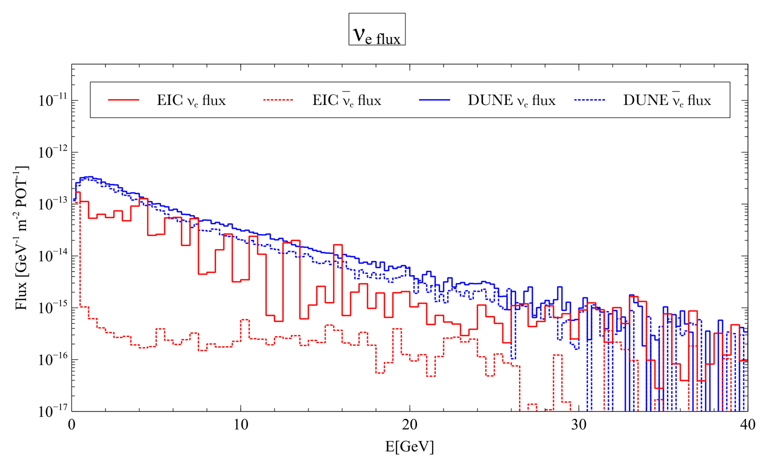


Can produce ν's with energy upto 100GeV

Objective:
Propose a long-baseline neutrino oscillation experiment using a high-energy neutrino beam from Brookhaven National Laboratory (BNL), based on the proton beam from the Electron-Ion Collider (EIC).

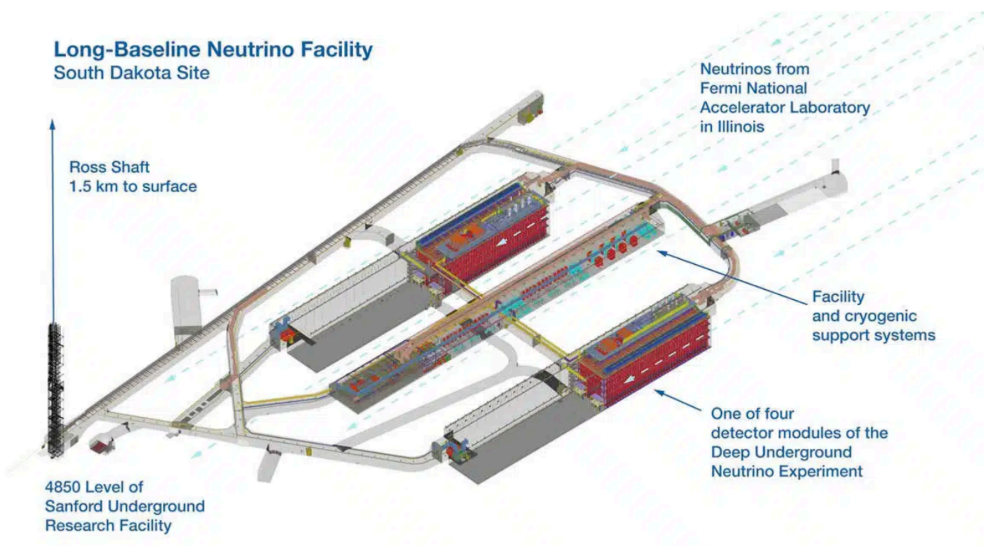
Neutrino Beam Generation:
Utilize a conventional pion-decay beamline to produce a forward-directed **muon neutrino** beam.



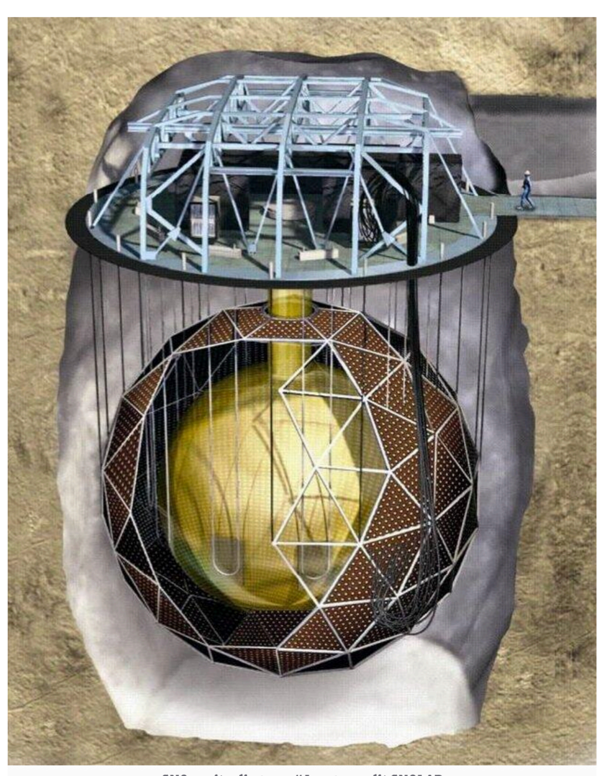


Detector Configuration:

- **DUNE Far Detector** at **SURF**, South Dakota
  - Baseline: **~2,900 km**
  - Strength: Enhanced sensitivity to **matter effects** and long-baseline oscillation features.
- **WbLS Detector** at **SNOLAB**, Ontario, Canada
  - Baseline: **~900 km**
  - Strength: High-statistics measurements with **reduced matter effects**, near the first oscillation maximum.



Schematic diagram of DUNE FD

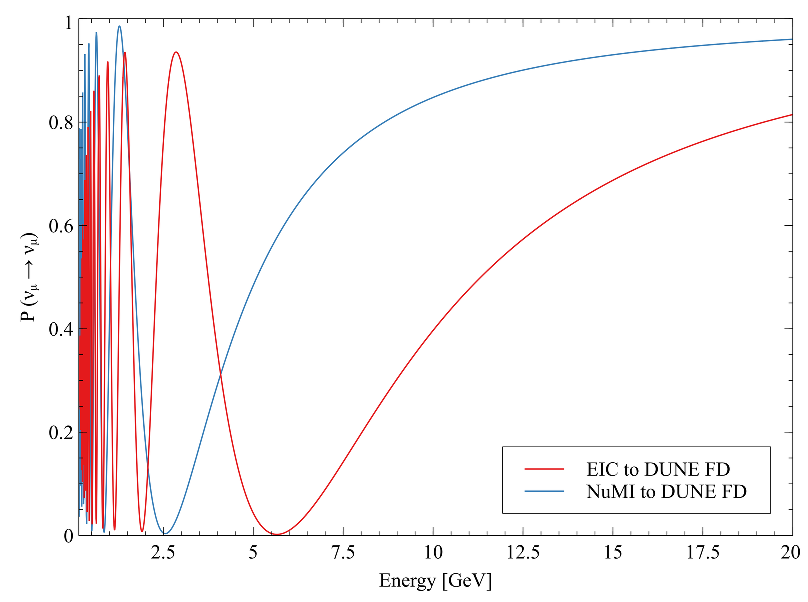


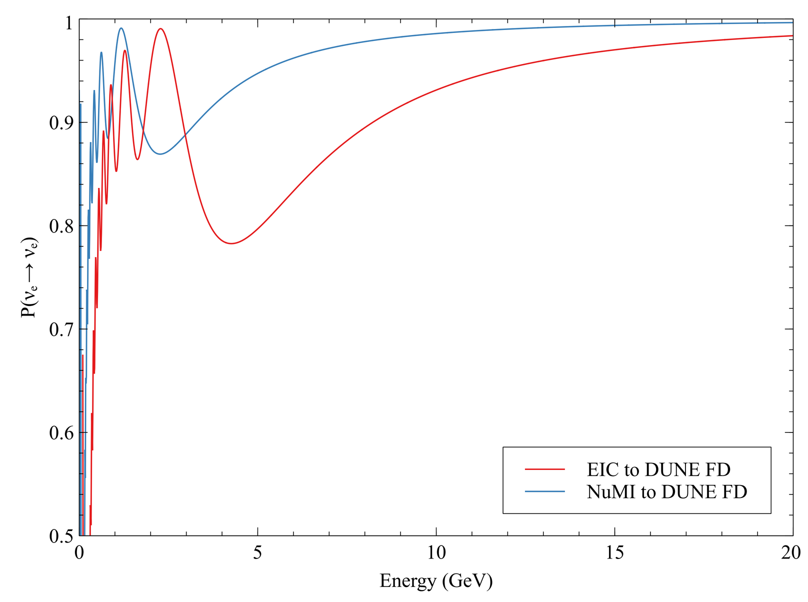
SNO cavity diagram // Image credit SNOLAB

Physics Goals:

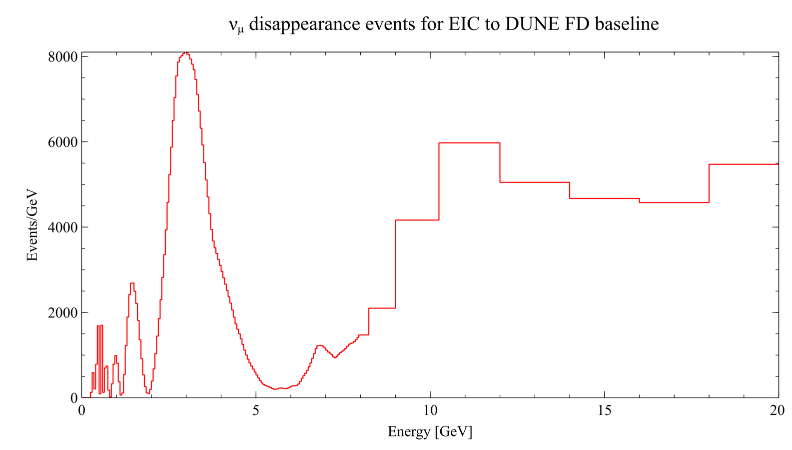
- The 2900 km long baseline will significantly enhance the sensitivity to matter effect allowing us to probe mass hierarchy and measurement of the CP-violating phase
- The shorter baseline from EIC to SNOlab will have more statistics allowing us to cross-validate the results
- Simultaneous measurements at two distinct baselines using the same beam configuration help reduce beam-related and detector-related systematic uncertainties. Shared systematics such as flux normalization and cross-section uncertainties can be better constrained by comparing observed spectra at both sites

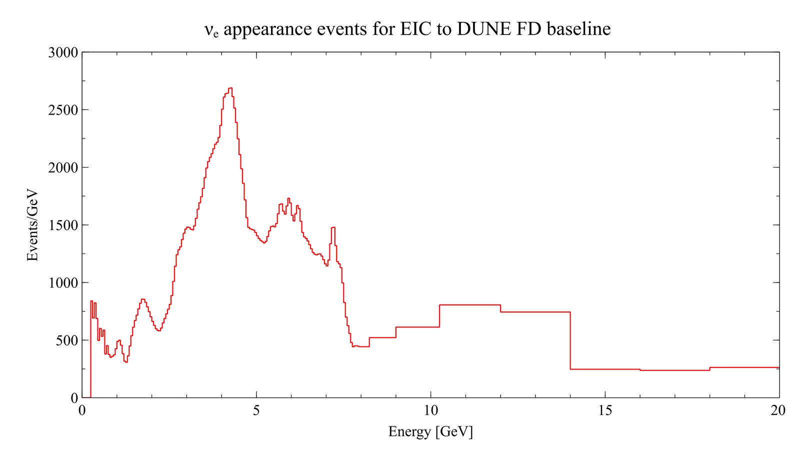
Results

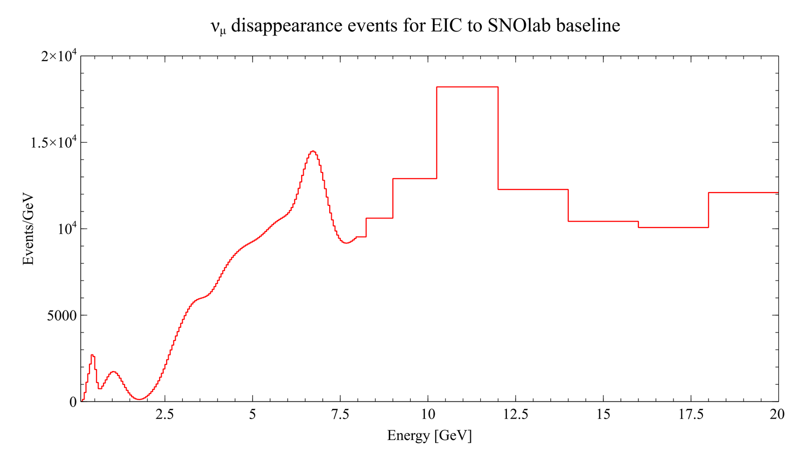


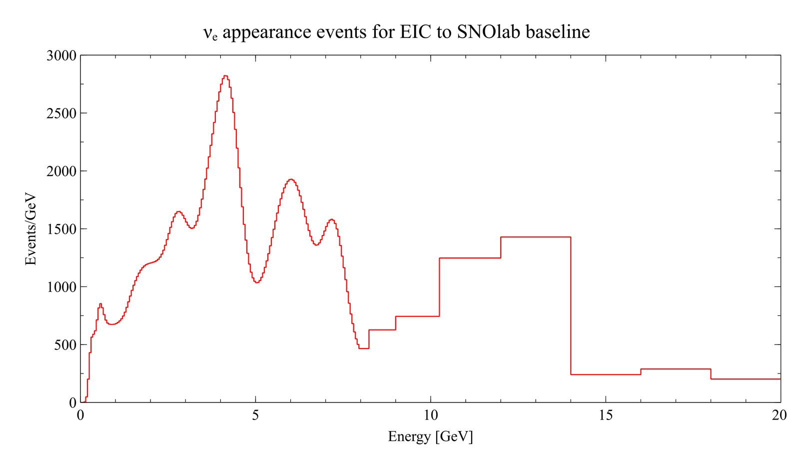


- For two different baselines, the first oscillation maximum occurs at different neutrino energies, allowing the DUNE far detector to study neutrino events from the NuMI and EIC beams separately

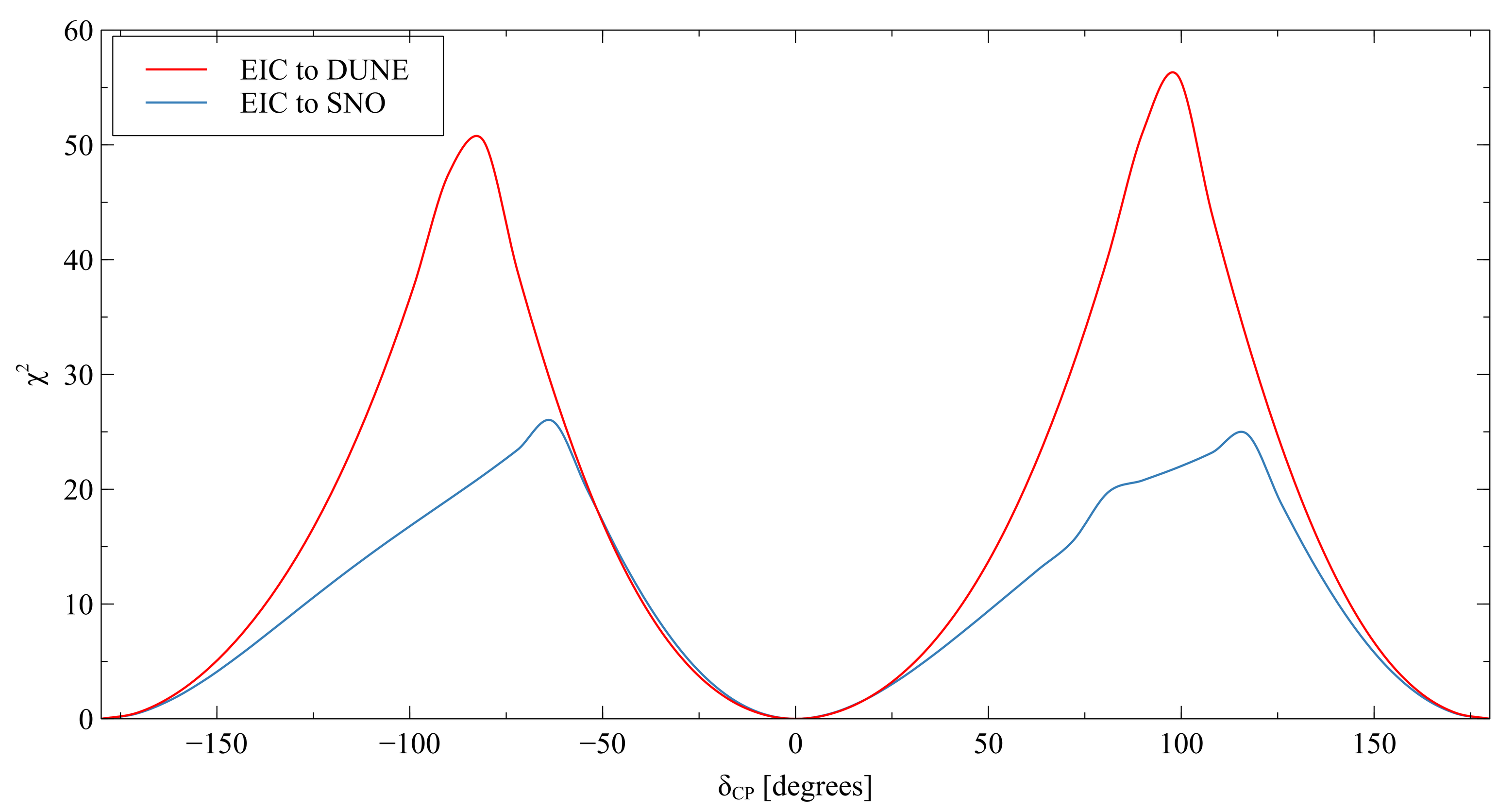








- Event samples were generated using an assumed 10^{23} **protons-on-target (POT)** from the EIC proton beam
- The EIC-based neutrino beam produces significant event rates at both **DUNE** and **SNOlab**, demonstrating strong baseline complementarity
- We have done a preliminary study of the chi square calculation for CP-violating phase (δ_{CP}) and this study can be extended to other oscillation parameters



Summary

This study explores the use of a high-energy neutrino beam from the proposed EIC at BNL to establish a dual-baseline neutrino oscillation experiment. By utilizing existing detectors at DUNE (2900 km) and SNOLAB (900 km), the setup offers enhanced sensitivity to CP violation and improved resolution of matter effects. The two-detector configuration helps reduce systematic uncertainties and complements existing U.S. neutrino programs. Overall, it presents a scalable and cost-effective approach for advancing precision neutrino physics.