Induced Magnetic Fields in LBNF Horns and DUNE-PRISM Off-Axis Neutrinos

UNIVERSITY OF MINNESOTA

Yuri Bae, for the DUNE Collaboration

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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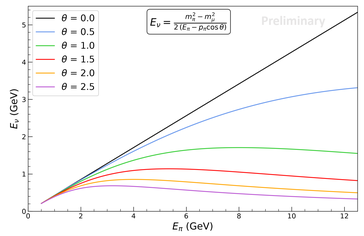
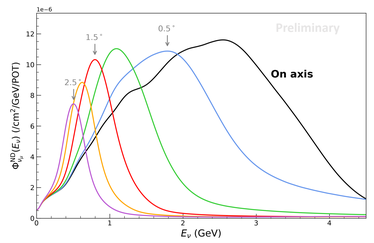
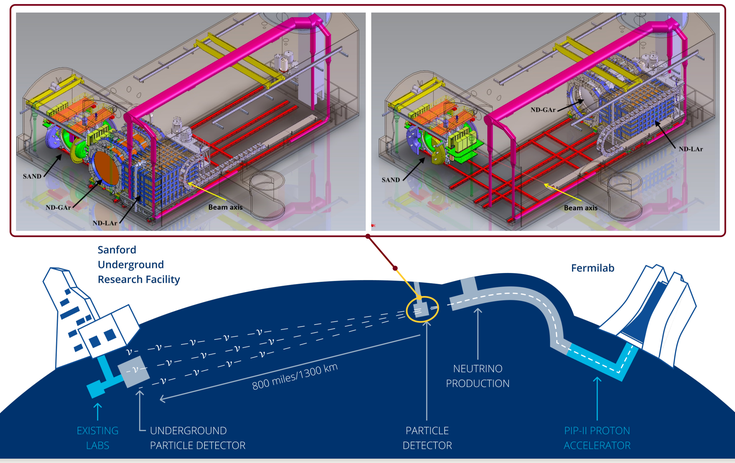
DUNE-PRISM: Off-Axis Strategy

- **DUNE** is a **next-generation**, **accelerator-based neutrino experiment** that will send an intense neutrino beam from Fermilab in Illinois to SURF in South Dakota.
- **PRISM** (Precision Reaction Independent Spectrum Measurement) program features a novel near detector concept where **the near detector (ND) moves transversely off-axis** to measure **varying neutrino energy spectra**.
- ND off-axis spectra can be **linearly combined** to predict the oscillated far detector (FD) spectrum.

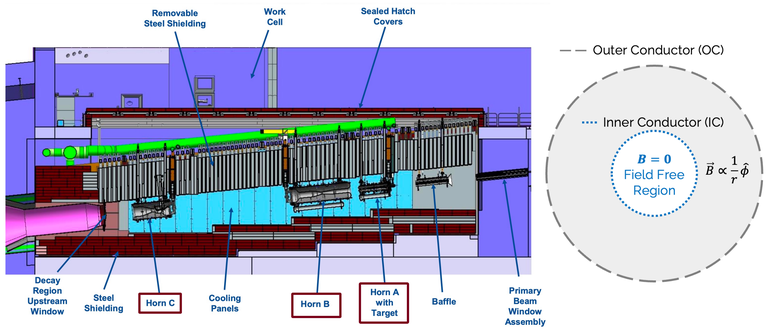






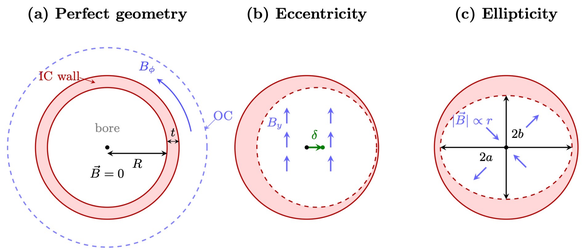
LBNF Magnetic Focusing Horns

- **LBNF** (Long-Baseline Neutrino Facility) beamline utilizes three magnetic horns, each consisting of coaxial inner and outer conductors.
- The region **inside the inner conductor** is ideally **field-free**.
- The region **between the conductors** serves as the **focusing** region.

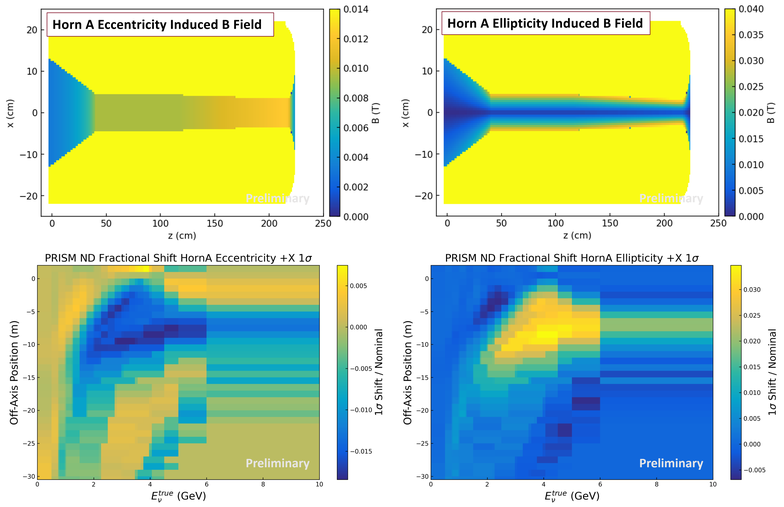


Inner Conductor Deformation

- Since off-axis fluxes are used to predict the far detector on-axis flux, any systematic uncertainty that affects off-axis fluxes but not the on-axis flux can **reduce DUNE's sensitivity** to oscillation parameters.
- Minor imperfections in horn geometry, such as **inner conductor deformation** (eccentricity and ellipticity), were identified as the most important systematic uncertainties for the PRISM linear combination analysis.
- This inner conductor deformation, which arises from non-zero manufacturing tolerances, can disrupt the ideal field-free configuration.



- ➢ **Eccentricity**: A transverse displacement of the inner surface induces a **constant dipole field** within the field-free region.
- ➢ **Ellipticity**: An elliptical deformation of the inner surface induces a **quadrupole field** within the field-free region.



- Neutrinos originating from hadrons deflected by the induced fields exhibit **distinct, localized gains or losses** in specific off-axis regions.
- A 0.035 mm **Horn A eccentricity** (manufacturing tolerance) results in a **~2% fractional shift** relative to the nominal flux, notably localized within the dominant energy range below 6 GeV.
- Following a similar trend, a 0.120 mm **Horn A ellipticity** results in a **~3% fractional shift** relative to the nominal flux below 6 GeV.
- The **on-axis flux** remains largely unaffected in both cases.

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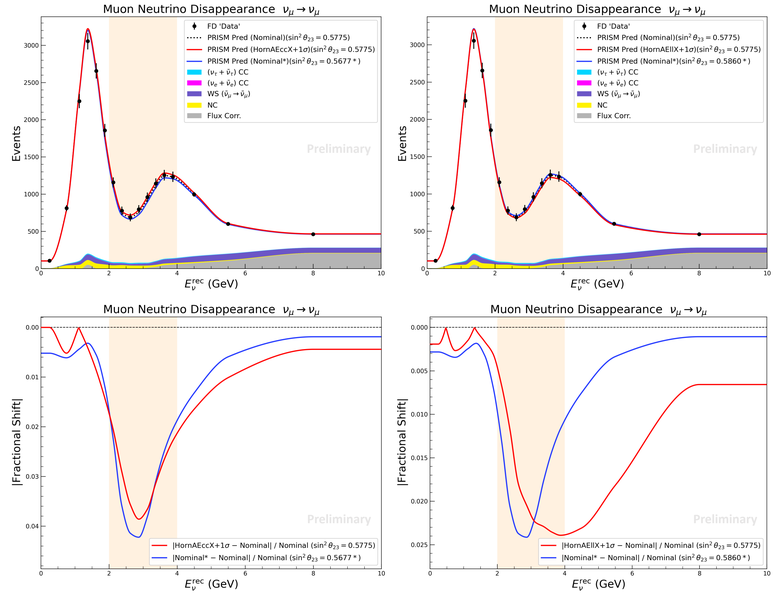
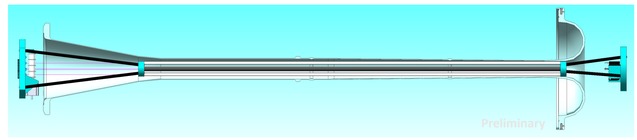
PRISM Oscillation Prediction



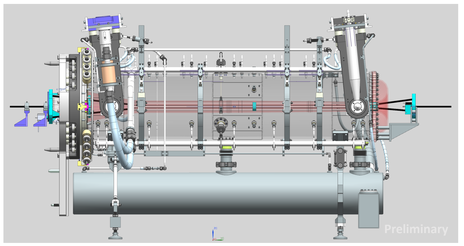
- This particular analysis predicts oscillated spectra at the far detector by performing a **linear combination of on- and off-axis** near detector fluxes.
- Deformation-induced magnetic fields introduce a subtle but critical **enhancement or reduction at the oscillation dip**. Since the dip is the key region for constraining oscillation parameters, this effect could lead to a **degradation in the sensitivity** to these parameters.

As-Built Horn A Field Mapping

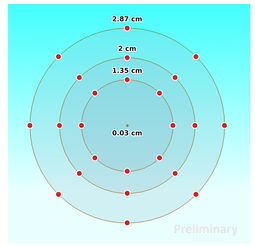
- Direct magnetic field map measurements for the inner conductor of the as-built Horn A are being planned to mitigate the systematic uncertainties.



Horn A Inner Conductor + Hall Probe Mechanical System 1



Horn A + Hall Probe Mechanical System 2



e.g. Measurement Points

References [1] DUNE Collaboration, "Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report," *Instruments* **5**, no.4, 31 (2021). [2] J. Lewis et al., "LBNF Beamline Technical Design Report" (2025).

Yuri Bae · University of Minnesota
bae00073@umn.edu