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Imaging systems for the liquid Argon target of SAND at the DUNE Near Detector Complex

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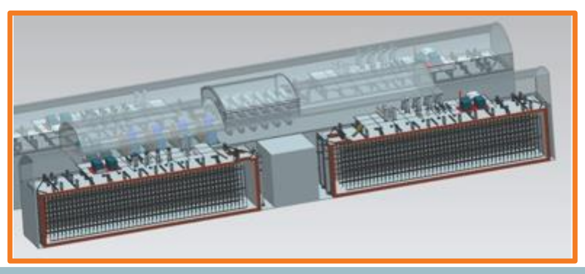
DUNE experiment

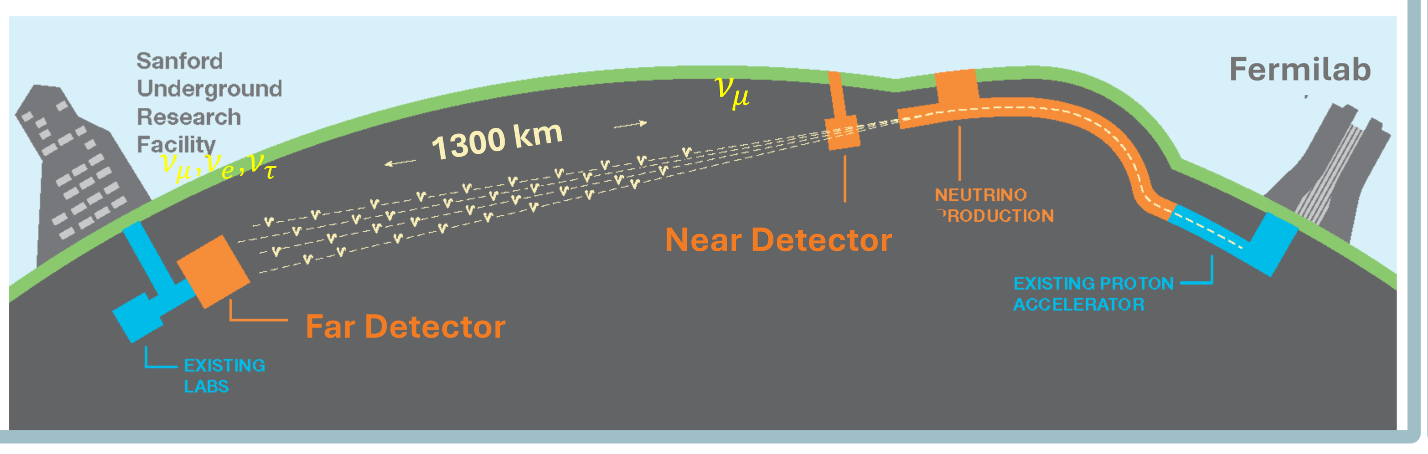
DUNE is a new-generation Long-Baseline neutrino oscillation experiment.

Physics goals:

- High precision measurements of the neutrino oscillation parameters
- Supernova and solar neutrinos detection
- Beyond the Standard Model searches

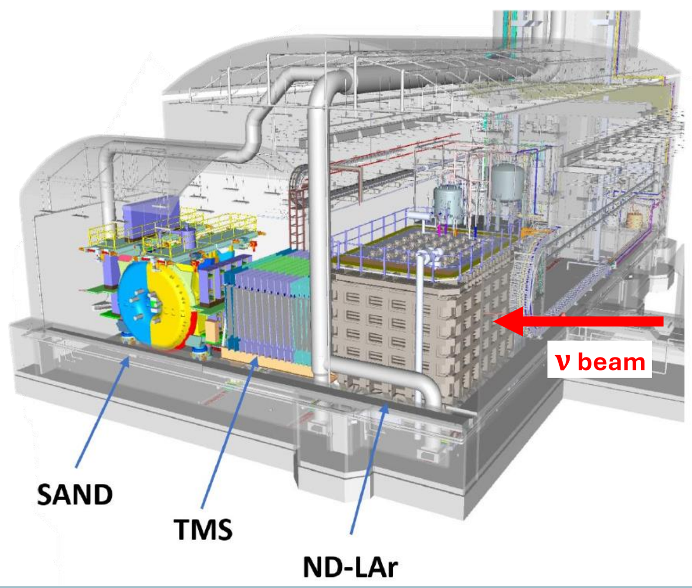
Far Detector at SURF: 4 LArTPC modules of 17 kton mass each





DUNE Near Detector Complex

The Near Detector complex is located 574 m downstream the of the proton target.



Three main components:

- **ND-LAR** : 67 ton modular LArTPC
- **TMS**: The Muon Spectrometer
- **SAND**: System for on Axis Neutrino Detection

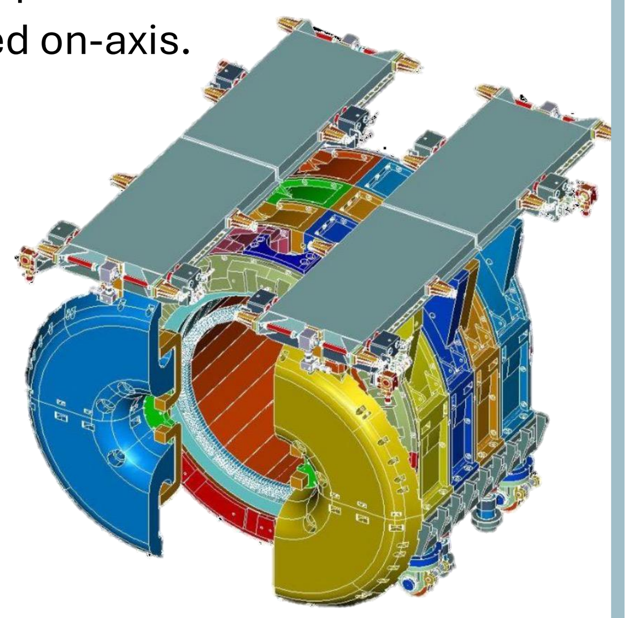
ND-Lar and TMS will be able to move off-axis to "scan" over the spectrum of ν energies to accurately determine the flux at the Far Detector.

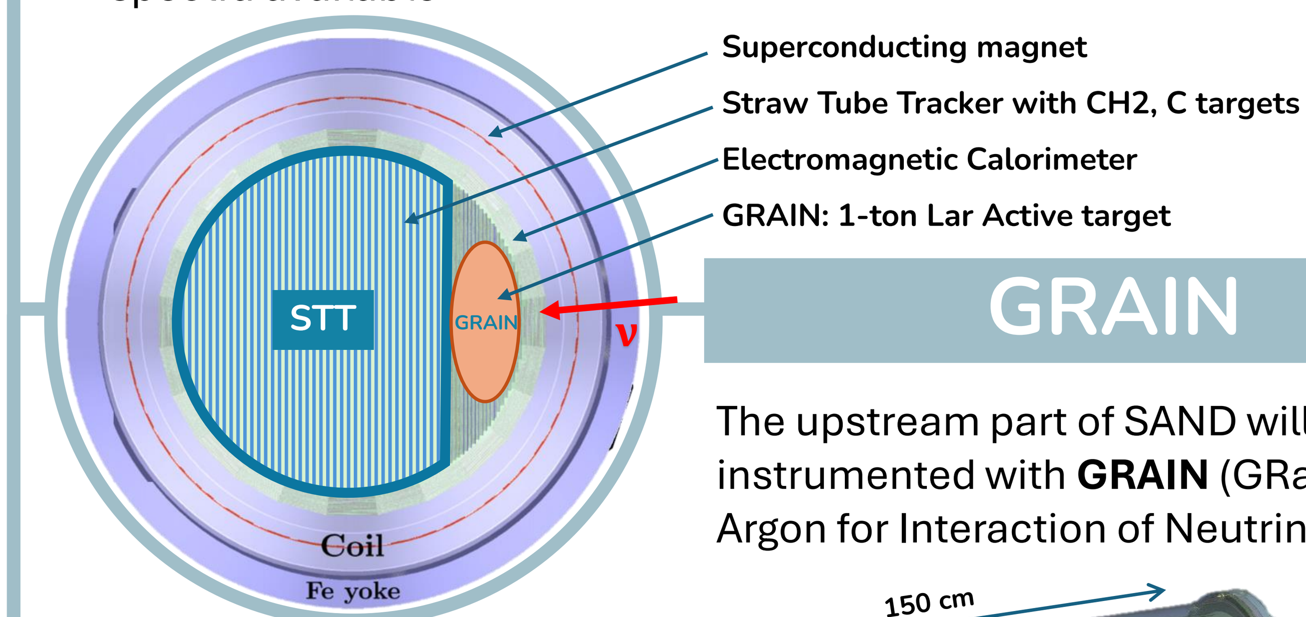
SAND

SAND is a multipurpose detector, capable of precision tracking and calorimetry, permanently located on-axis.

Primary goals:

- Monitoring the on-axis $\nu/\bar{\nu}$ spectra to detect beam variation on a weekly basis
- Constraint the nuclear effects in Argon measuring cross section of ν using a combination of different nuclear targets (C, H, Ca, Fe, Pb)
- Short baseline physics exploiting the high intensity and the broad energy spectra available



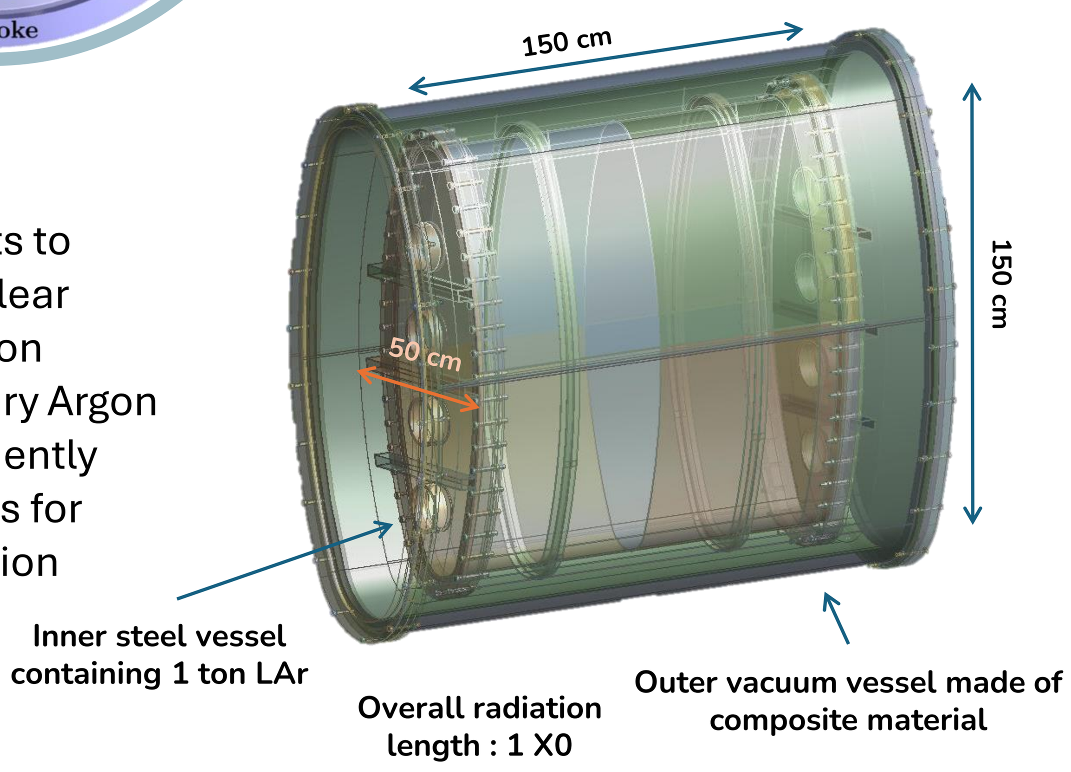


GRAIN

The upstream part of SAND will be instrumented with **GRAIN** (GRanular Argon for Interaction of Neutrinos).

Objectives:

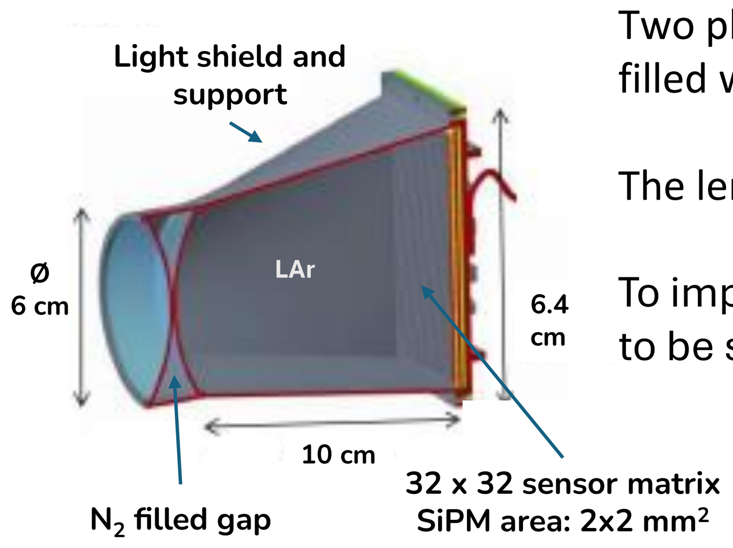
- Cross section measurements to constrain nuclear effects on Argon
- complementary Argon target permanently located on axis for cross-calibration



GRAIN will be equipped with an **imaging system to collect the scintillation light** and perform a fast reconstruction of the events without collecting the ionization charge.

Two imaging systems are currently being developed for GRAIN, both based on Silicon Photomultiplier (SiPM) matrices, coupled either to **UV cryogenic lenses** or **Coded Aperture masks**.

Gas Lens optical system

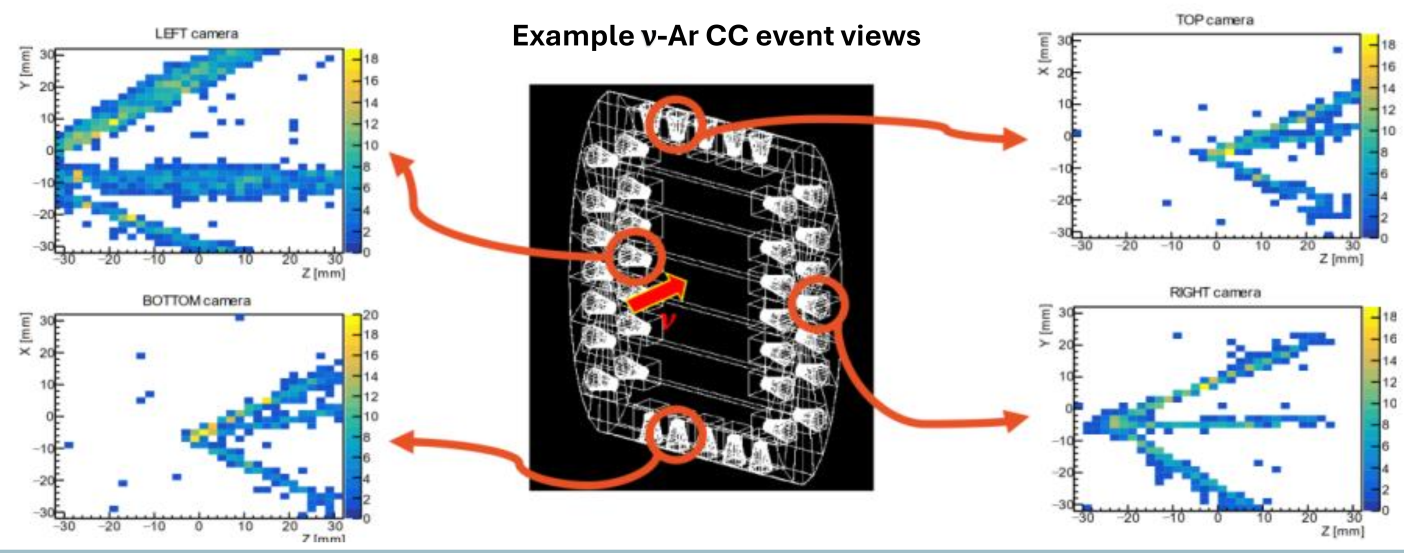


Two plane-convex lenses made of UV-grade fused silica with an inner concave gap filled with N_2 and refractive index = 1 .

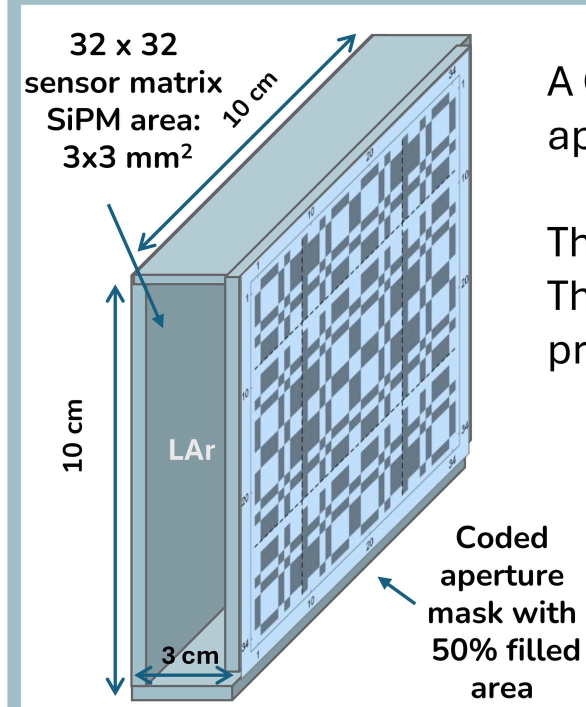
The lens design is optimized for a depth of field between 40 and 120 cm.

To improve the transmission through the lenses, LAr scintillation light will have to be shifted using Xenon doping.

For a 3D reconstruction, multiple camera views are combined using projective geometry.



Coded Aperture Mask optical system



A Coded aperture masks is a thin sheet of opaque material, with a pattern of apertures.

The image formed on the sensor is the superimposition of multiple pinhole images. The original image of the photon source can be obtained with a deconvolution process where the kernel is derived from the mask pattern [1].

- Compact design allowing for a large fiducial volume
- Robust and easy to build
- No Xenon doping needed

We developed a **reconstruction algorithm** alternative to deconvolution techniques that performs better with low light yields [2].

- Directly reconstructs in 3D the initial photon source distribution in a segmented volume (voxels).
- Includes the physical description of the detection process
- Maximizes the Likelihood that an initial distribution density can produce the observed data

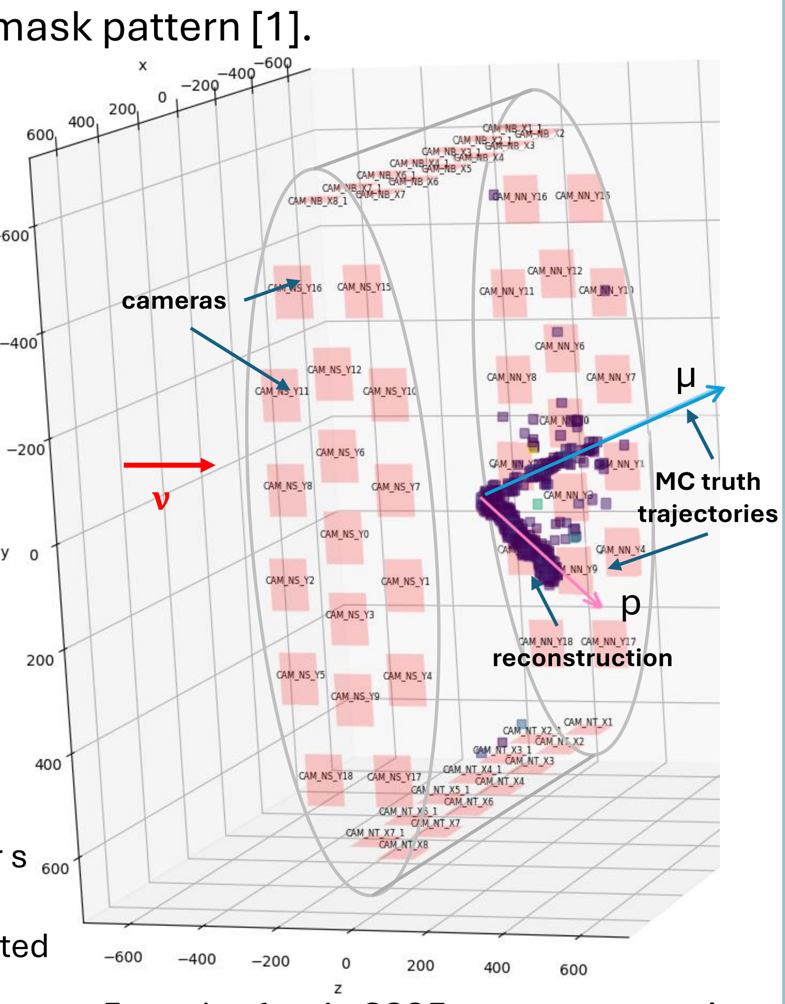
$$\lambda_j^{k+1} = \frac{\lambda_j^k}{\sum_s p(j,s)} \cdot \sum_s \frac{H_s \cdot p(j,s)}{\sum_j p(j,s) \cdot \lambda_j^k}$$

H_s: number of detected photons by sensor s

λ_j unknown photon emission in voxel j

$p(j,s)$: probability of a photon that originated in voxel j is detected by sensor s

k : iteration number



Example of ν_μ-Ar CCQE event reconstruction

Tracking performances

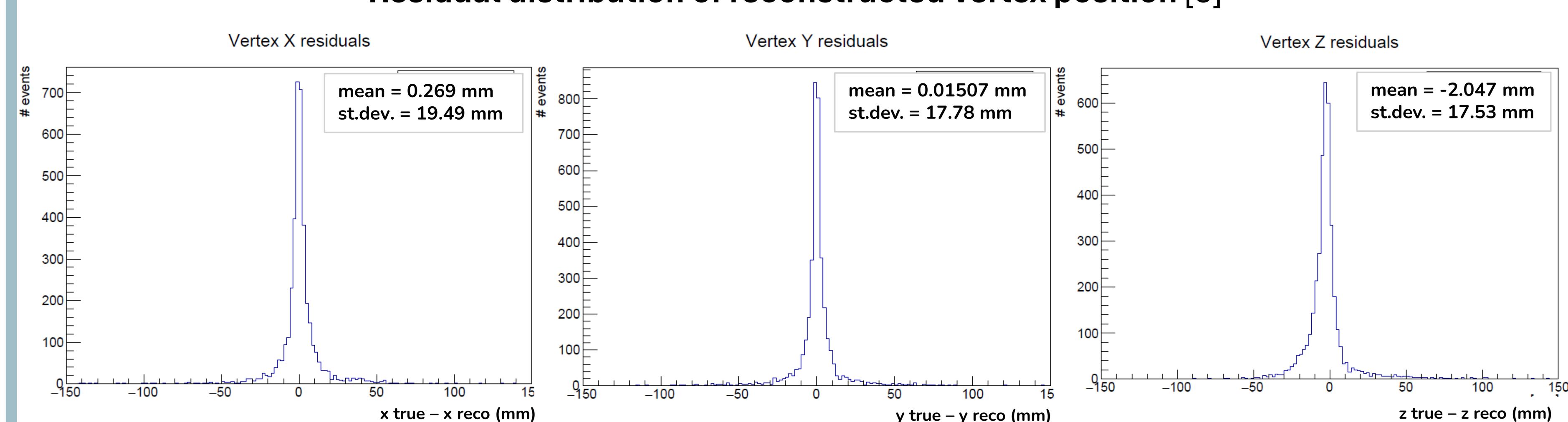
In preliminary simulation studies both system show good spatial resolution for interaction vertices and tracks location.

Gas-lens system

Simulated sample:

4k ν_μ - Ar Charged Current events in GRAIN with 2+ tracks, neutrino energy spectrum of DUNE beam

Residual distribution of reconstructed vertex position [3]



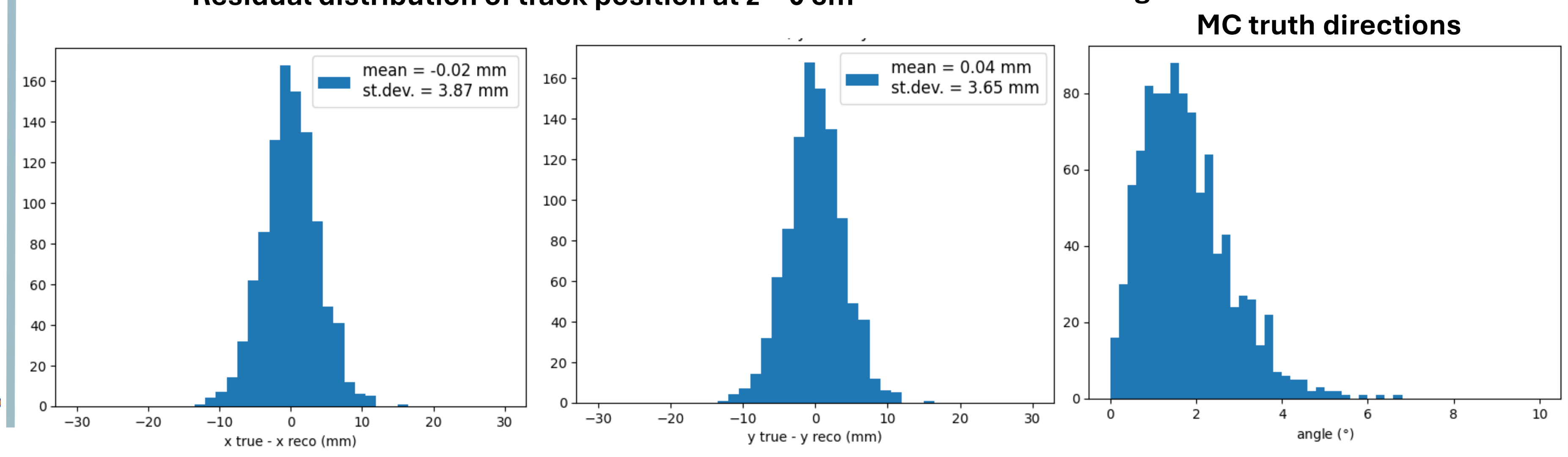
Coded Aperture system

Simulated sample:

1k muons crossing GRAIN along the neutrino beam direction, E = 1.0 ± 0.3 GeV

Residual distribution of track position at z = 0 cm

Angle between reconstructed and MC truth directions



References

1. M. Andreotti et Al., "Coded masks for imaging of neutrino events", *European Physical Journal C (2021) 81:1011*
2. V. Cicero, "*Study of the tracking performance of a liquid Argon detector based on a novel optical imaging concept*", *PhD Thesis, University of Bologna (2023)*
3. M. Vicenzi, "*A Grain of SAND for DUNE: Development of simulations and reconstruction algorithms for the liquid Argon target of the SAND detector in DUNE*", *PhD Thesis, University of Genova (2023).*