GRAIN: a novel liquid argon detector for imaging of neutrino interactions in the DUNE near detector

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UNIVERSITÀ DEL SALENTO
L'Ateneo tra i due mari

INFN
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SEZIONE DI LECCE

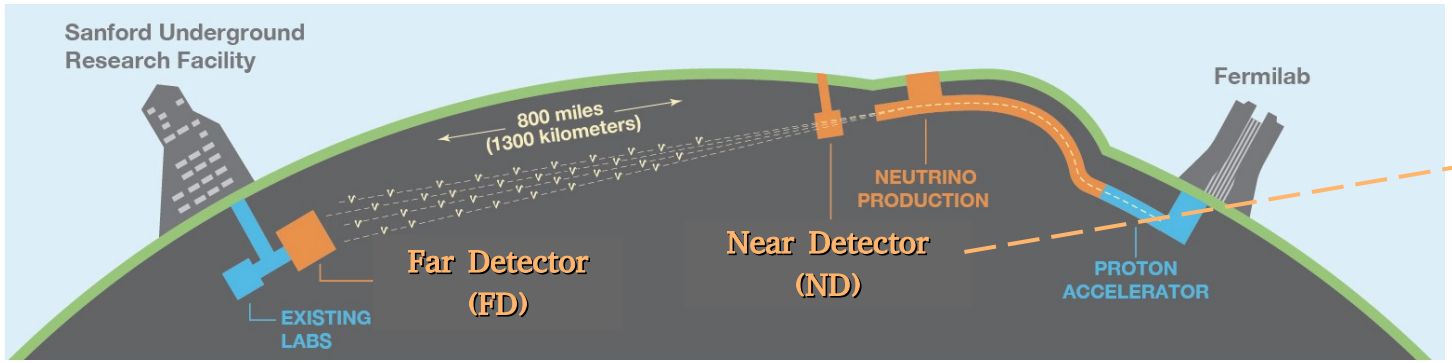
DUNE

The DUNE experiment and the Near Detector

The Deep Underground Neutrino Experiment (DUNE) is a new generation long-baseline neutrino oscillation experiment

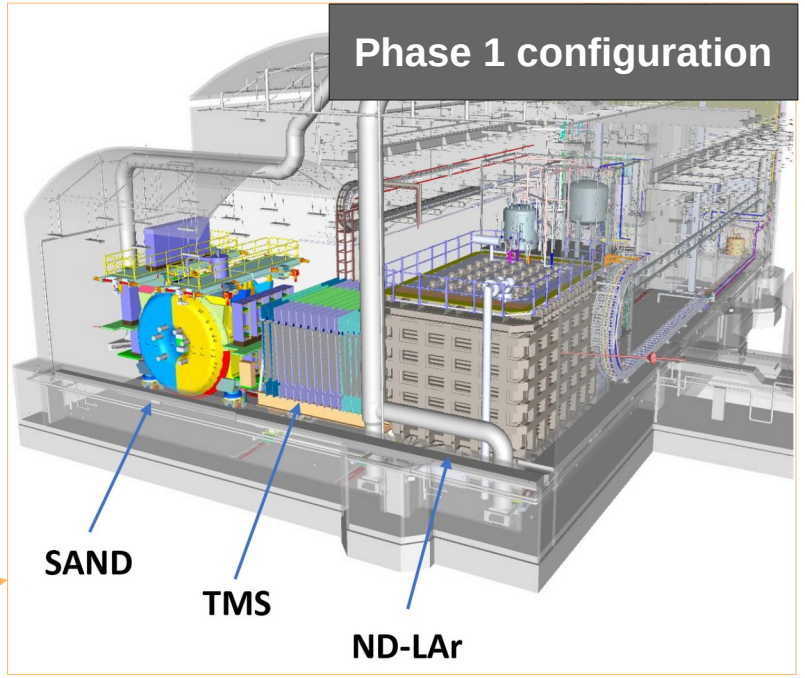
Main goals:

- High precision measurements of the neutrino oscillation parameters
- Supernova and solar neutrinos detection
- Beyond the Standard Model Searches
- Study of CP violation



- High-power proton beam of 1.2 MW upgradable to 2.4 MW
- High-power, wide-band neutrino beam (~GeV energy range)
- Near detector at 575 m from the ν source
- Far detector in South Dakota (~1300 km) and 1.5 km deep underground

Phase 1 configuration



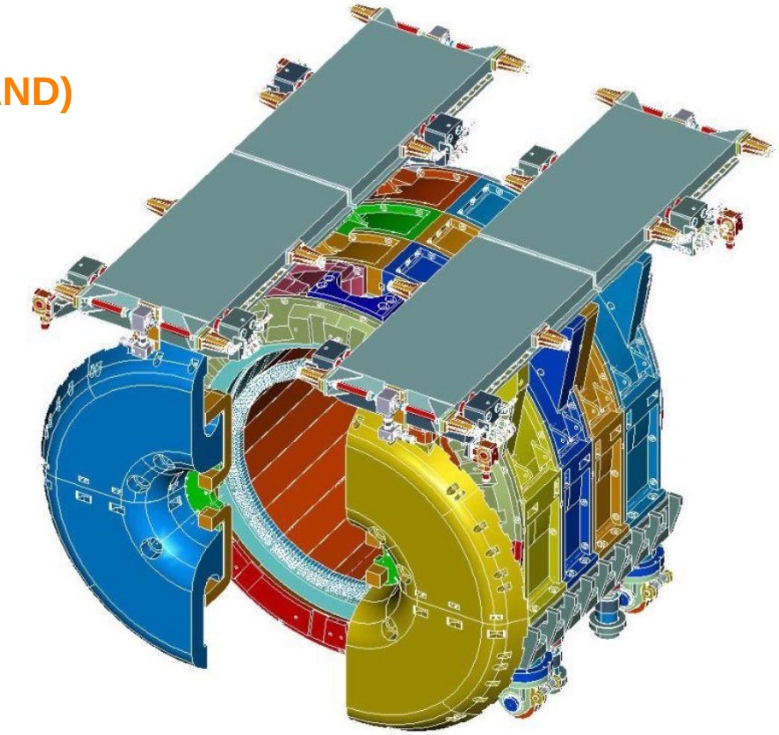
- ND-LAr (segmented LAr TPC similar to the FD)
- TMS (magnetized muon spectrometer, to be substituted by the ND-GAr in the phase 2)
- ND-LAr and TMS will move in order to "scan" over the spectrum of ν energies
- SAND (on axis magnetized spectrometer)

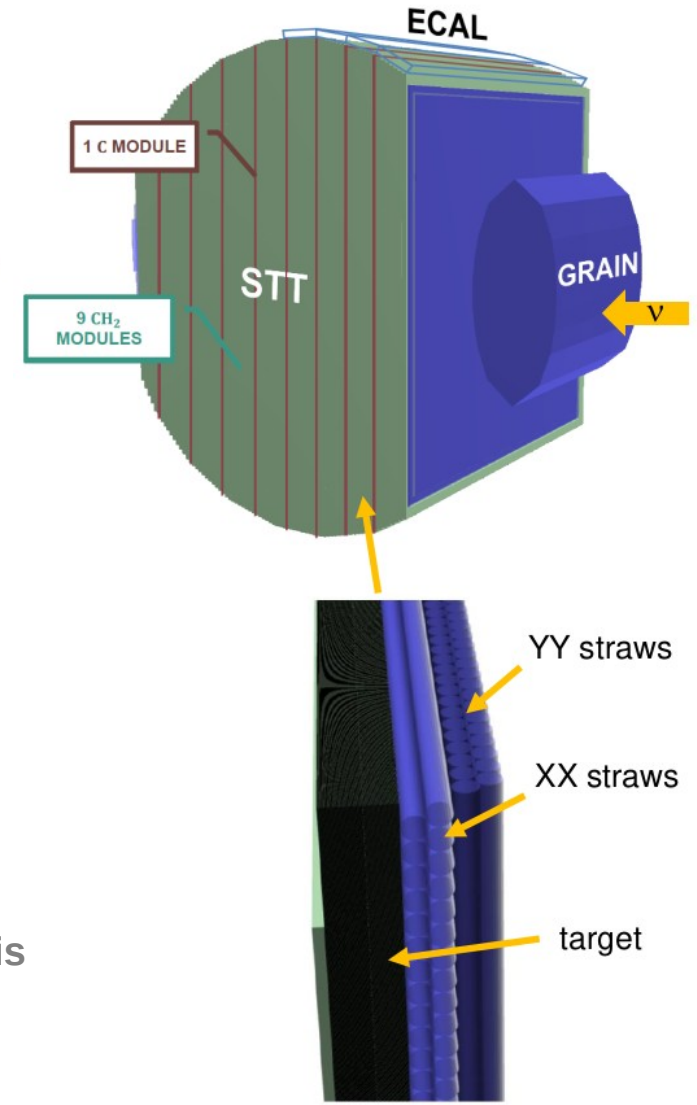
The SAND detector

The System for on-Axis Neutrino Detection (SAND)

- Superconducting magnet (0.6 T)
- Electromagnetic calorimeter
- Straw Tube Tracker with CH_2, C targets
- GRAIN : 1 t LAr Active target

From the KLOE experiment at Frascati National Laboratories (Italy)





Its physics goals include

- **Monitoring** of the on-axis $\nu/\overline{\nu}$ spectra to **detect beam variations** on a weekly basis
- **ν_μ, ν_e on-axis flux measurement**
- Perform neutrino **cross-section studies** on different nuclear targets

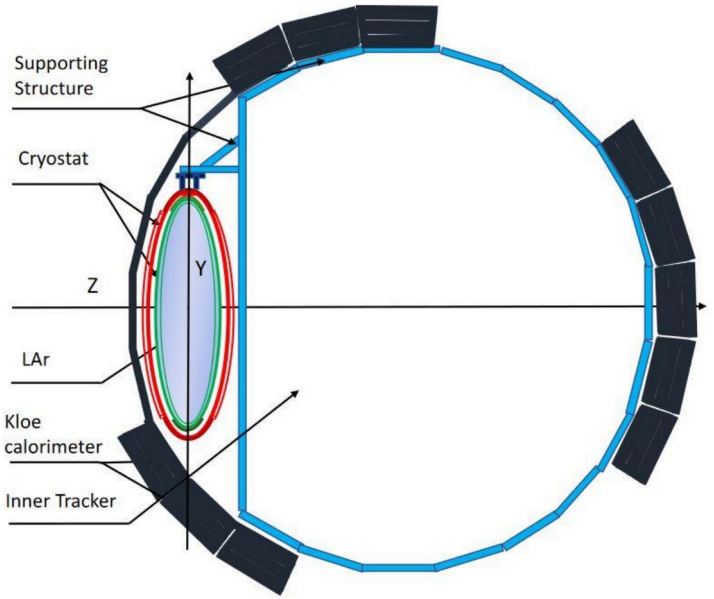
The GRAIN detector

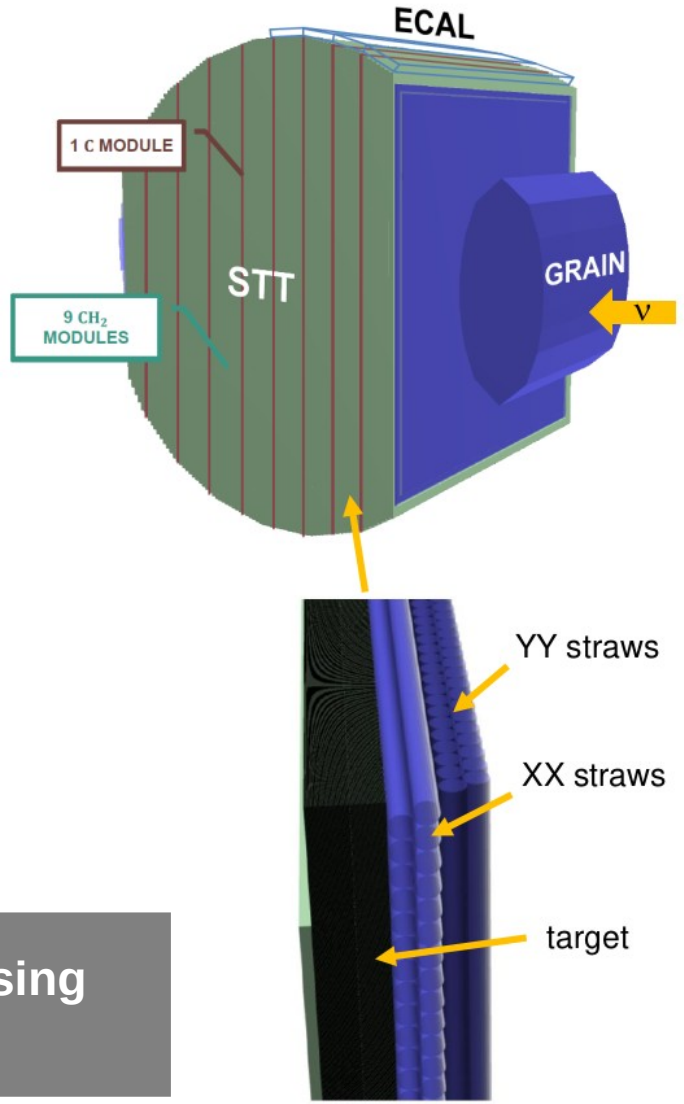
GRAIN: GRanular Argon for Interactions of Neutrinos

- **1-ton LAr target**
- Cryostat made of C-composite materials and Aluminum
- Overall radiation length of ~ **1 X_0** (cryostat+LAr)

GRAIN will be used as active target

- To study **ν–Ar interactions**, in synergy with STT and ECAL
- To perform **imaging on prompt VUV scintillation light** (readout by arrays of Silicon Photo-Multipliers)





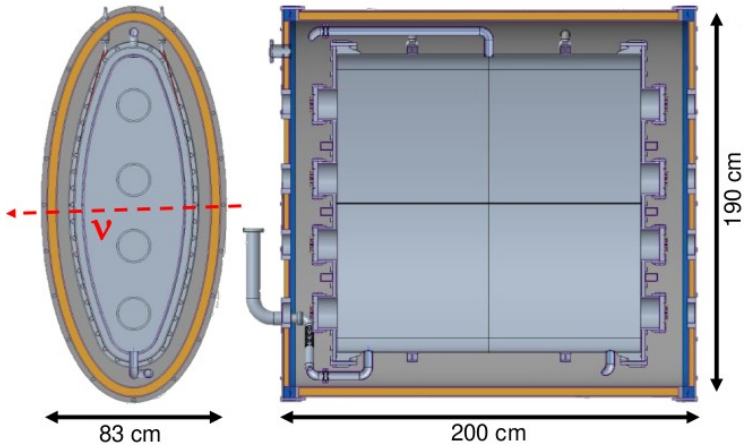
Reconstruct particle tracks using only scintillation light

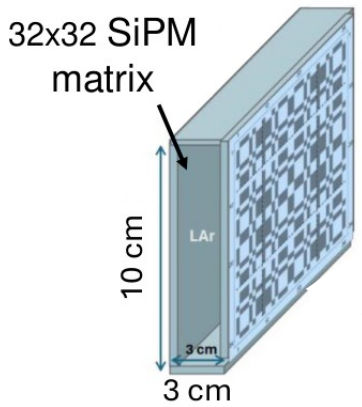
The GRAIN detector

Reconstruct particle tracks using only scintillation light

Requirements

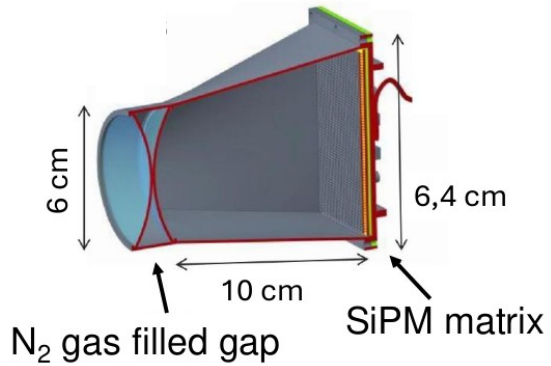
- **Segmented sensors** on the inner cryostat walls
- Spatial resolution **< 1 cm**
- Time resolution **< 1 ns**
- **Light sensors** operating in the VUV range (127 nm)
- Sensors and **electronics** operating in LAr (87 K)





Two options under study for the readout

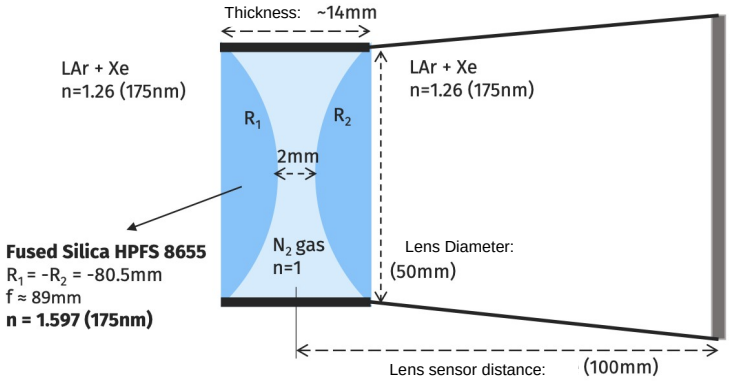
- **Coded aperture masks**
- **UV gas filled lenses**

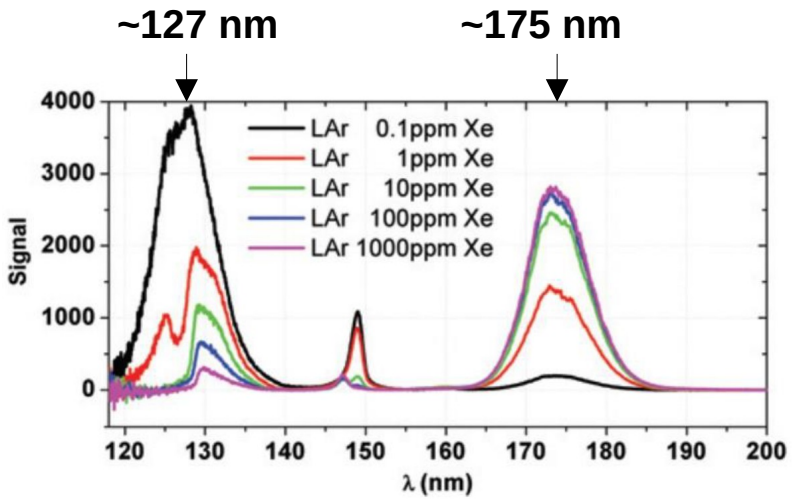


UV gas filled Lenses

Match between LAr and lenses (wavelength λ and refractive index n)

- Use inverted lenses with gas filled gap (N_2) with n=1
- Use Xe doping to raise λ for better transmission through the lens

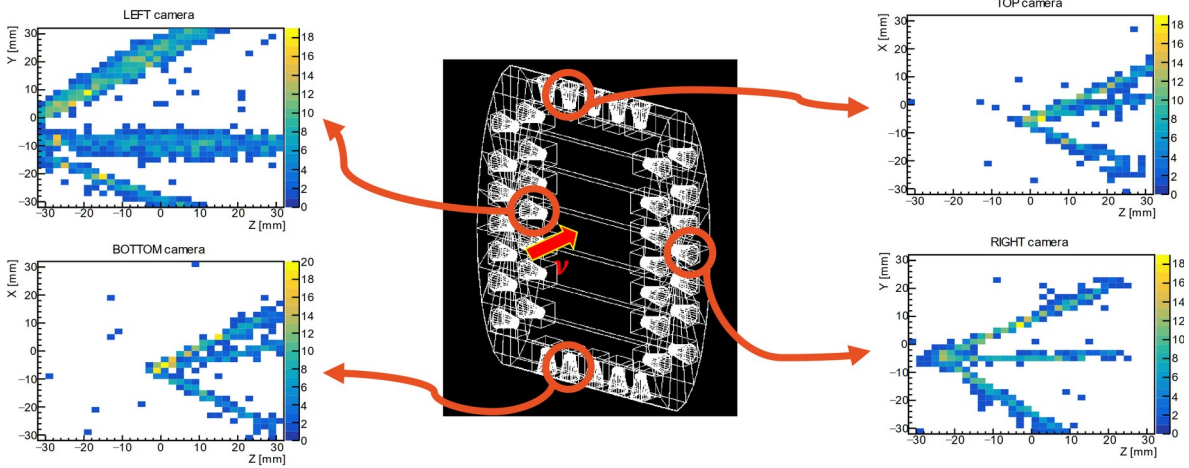




Wavelength shift with Xe

[A. Neumeier et al 2015 EPL 109 12001]

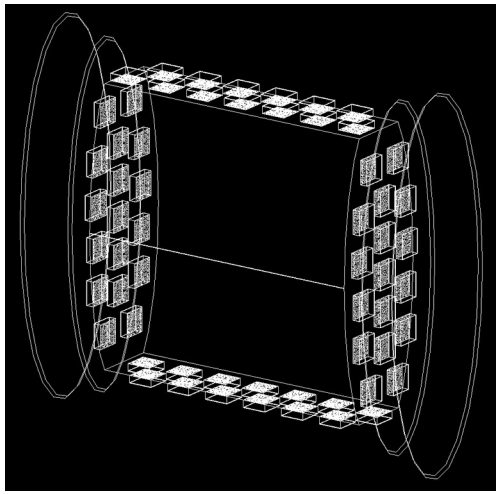
Example event view

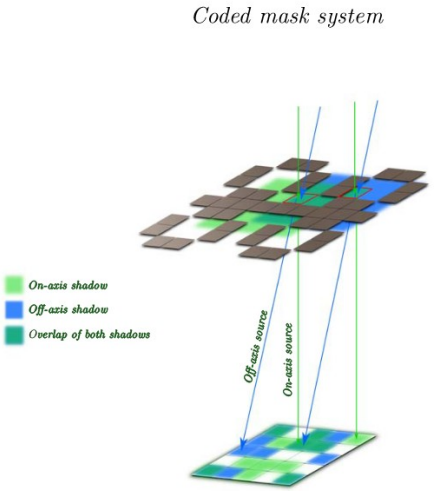


Coded Aperture Masks

Coded aperture masks

- **Xe doping not strictly necessary**
- Good depth of field, compact
- Worse contrast than lenses

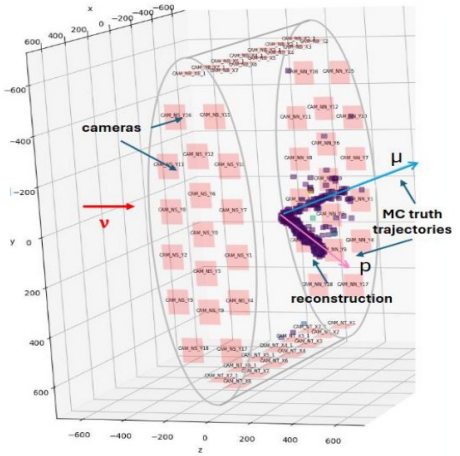




Matrices of holes with specific locations and sizes with the SiPM arrays on the focal plane

3D event reconstruction

- Iterative algorithm based on Maximum Likelihood - Expectation Maximization
- Directly **reconstructs in 3D** the initial photon source distribution in a segmented volume (voxels)
- Requires significant GPU resources

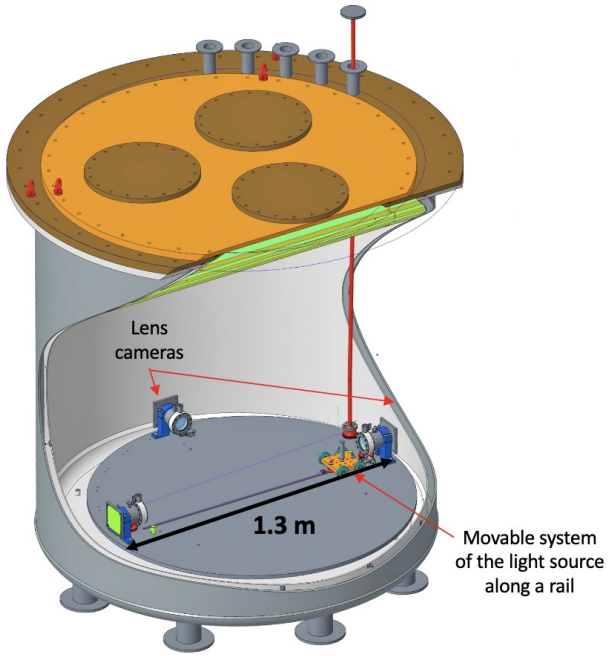


[*] Andreotti, M., et al. "Coded masks for imaging of neutrino events." The European Physical Journal C 81 (2021): 1-15.

Tests on prototypes

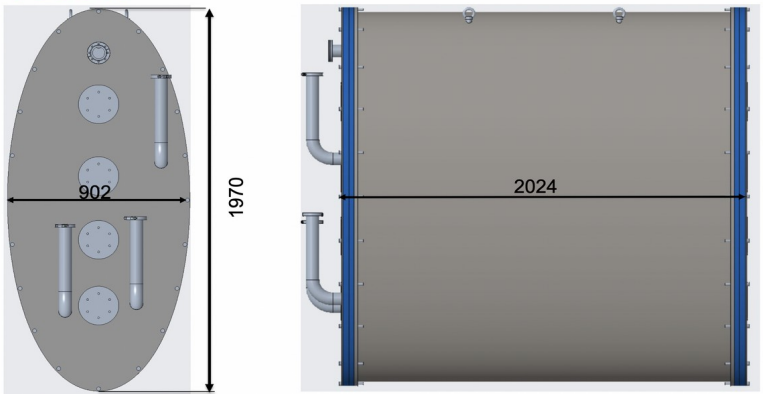
Cold tests at the ARTIC facility at the University and INFN - Genova

- Facility to **test the imaging of charged particle tracks** (and interaction vertexes), thanks to the scintillation light in liquid Ar
- Use of **lenses or coded masks** coupled with **SiPM matrices**
- Tests with **light source** and with **cosmic rays** (using a cosmic ray tagger)



GRAIN full scale prototype
Laboratori Nazionali di Legnaro (LNL)

Outer vessel



Summary and conclusion

- The **GRanular Argon for Interactions of Neutrinos (GRAIN)** will be one of the subdetectors of SAND, in the near detector site of the DUNE experiment
- **It will be the first detector to image LAr scintillation**
- GRAIN will be used as an **active target** to perform a 3D reconstruction of the tracks and to study ν-Ar interactions
- Many activities are ongoing to define the optimal design of GRAIN and to be ready for the first beam in the DUNE near detector

Thank you for the attention

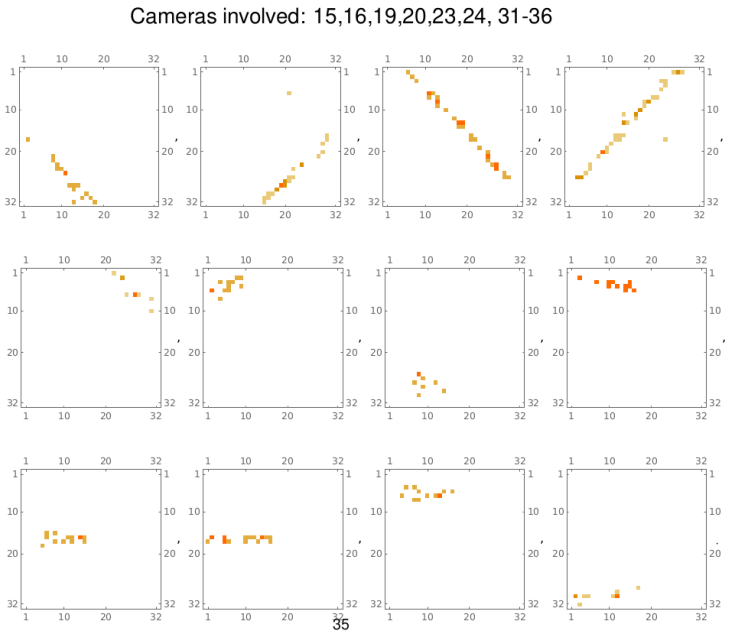
BACKUP

Image reconstruction with Lenses

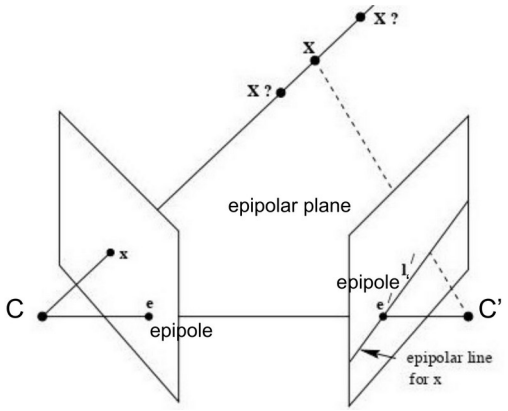
3D event reconstruction

- **Track fit** on individual views
- **Epipolar and Multiple-View Projective Geometry** methods applied to
  - Muon Track 3D reconstruction
  - Two tracks Vertex 3D reconstruction
  - Matching conditions for multiple 2D Views and Image Transfer

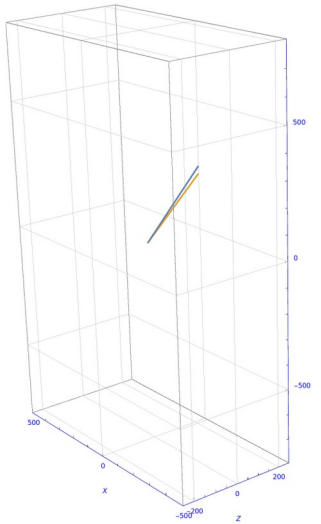
Multiple view track reconstruction



Epipolar reconstruction



Global track reconstruction



- **Excellent resolution** from simulation
- Limited depth of field compared to the camera size