A novel imaging detector for liquid scintillator experiments

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on behalf of the DUNE Collaboration

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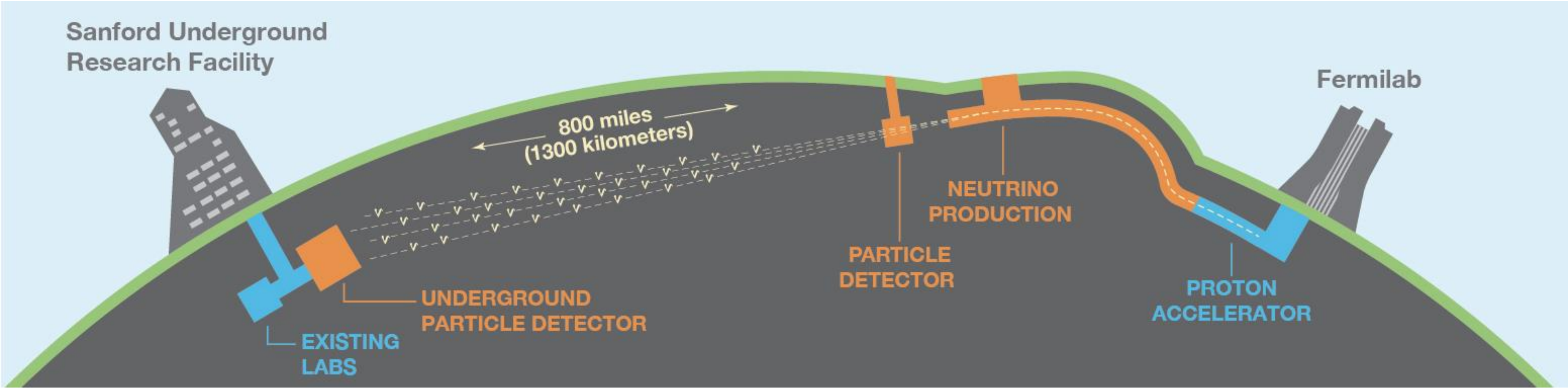
DUNE

The DUNE Experiment

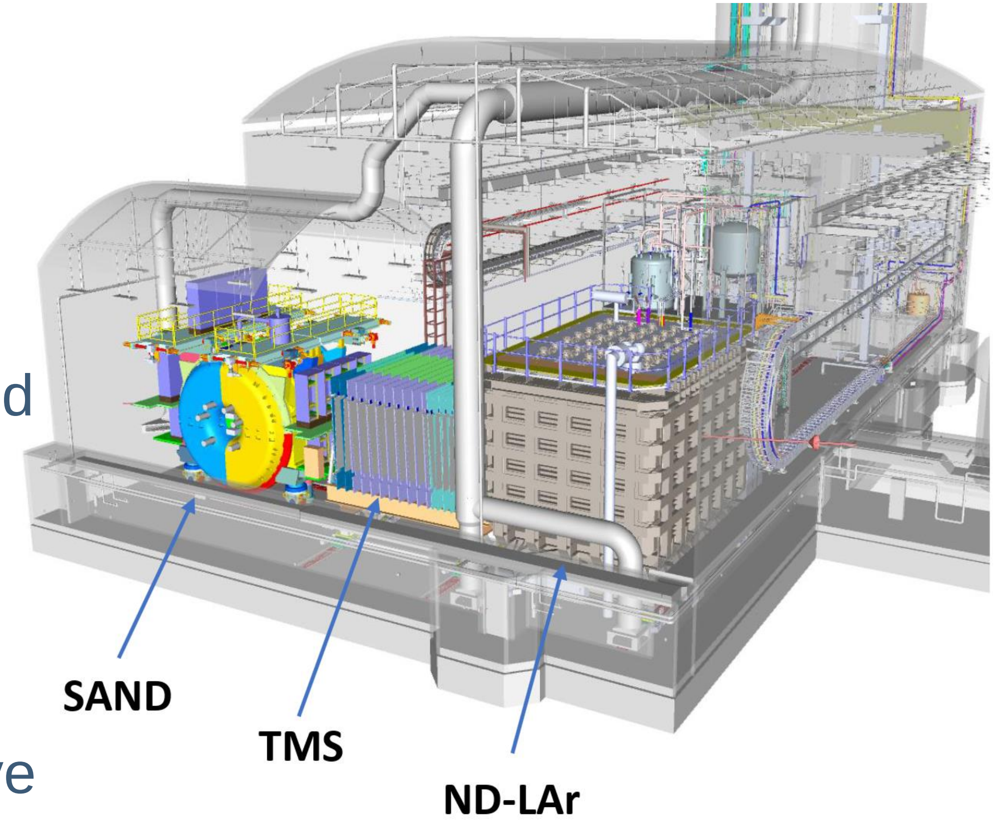
The Deep Underground Neutrino Experiment is a new generation long-baseline neutrino oscillation experiment.

- High precision measurements of the neutrino oscillation parameters: δ_{CP}, mass ordering, θ_{23}
- Supernova and solar neutrinos detection
- Beyond the Standard Model Searches



The ND Complex

- ND-LAr (segmented LAr TPC similar to the FD)
- TMS (magnetized muon spectrometer)
- SAND (on axis magnetized spectrometer)



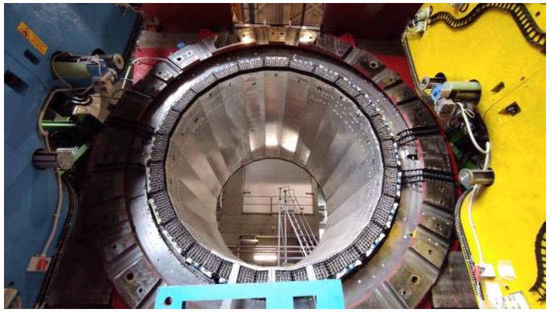
- ND-LAr and TMS will move in order to “scan” over the spectrum of ν energies

SAND

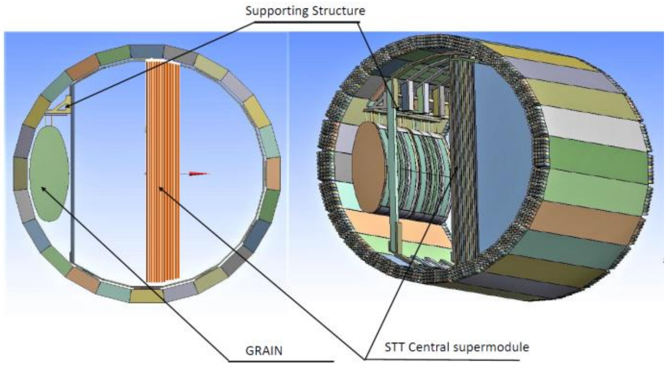
The System for on-Axis Neutrino Detection

- Superconducting magnet (0.6 T)
- Electromagnetic calorimeter

From KLOE (LNF)



- Target Tracker with CH_2, C targets
- GRAIN : 1 t LAr Active target



- *Its physics goals include*
- **Monitoring** of the on axis $\nu/\bar{\nu}$ spectra to detect **beam** variations on a weekly basis
- Perform neutrino **cross-section studies** on different nuclear targets
- ν_μ, ν_e on-axis flux measurement for a robust analysis in combination with other ND detectors

GRAIN

*Uses an **innovative technique**, replacing the TPC:*

- Argon scintillation light is captured by an **imaging device**
- Charge is not collected (too slow for the ND)

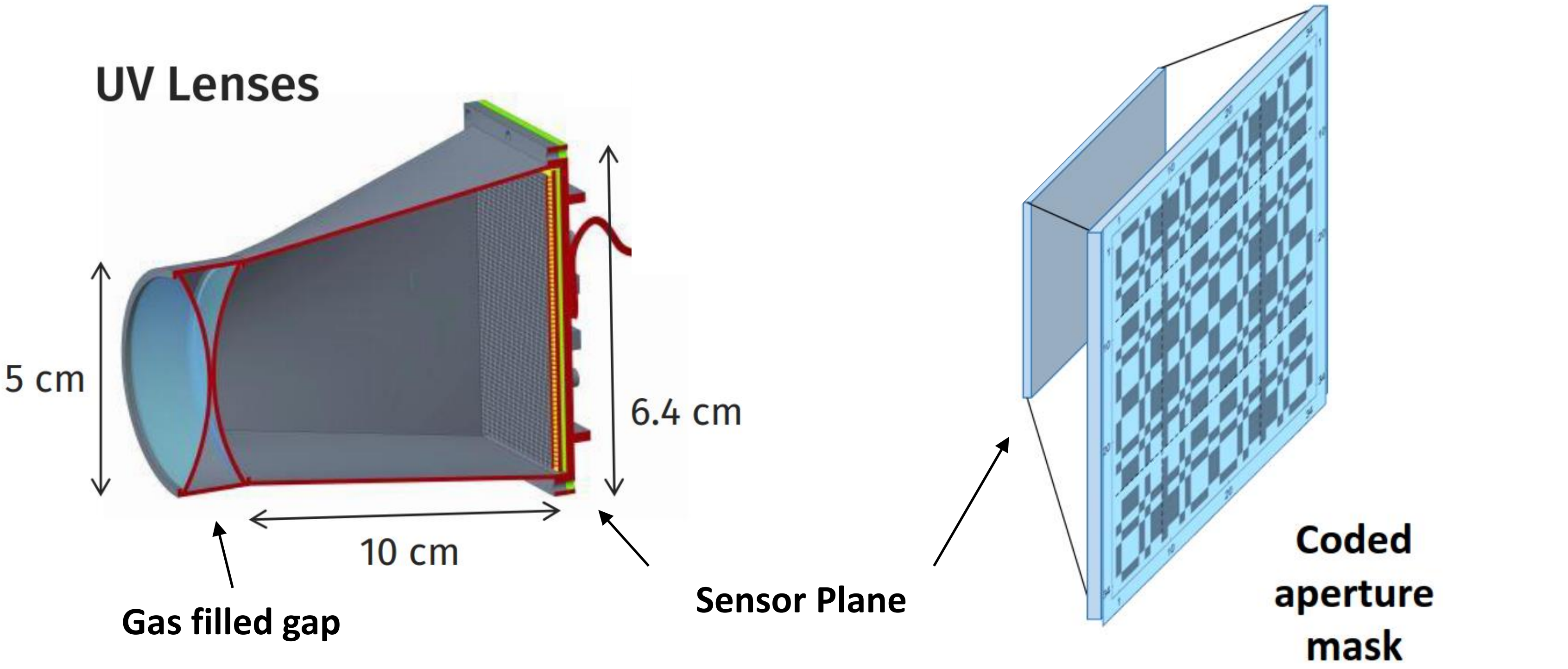
*To build a **camera**, we need:*

- An optical system
- A sensor plane
- A readout chip

Optical System

*Working with LAr scintillation **λ** and **n** is not easy, two options:*

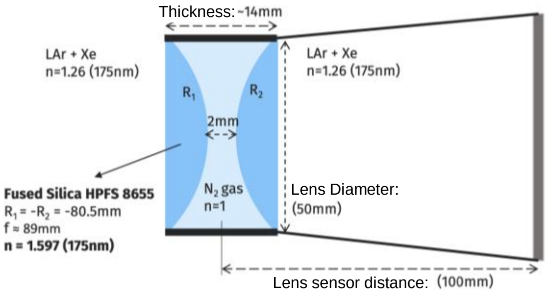
- **UV gas filled** lenses
- **Coded Aperture** masks

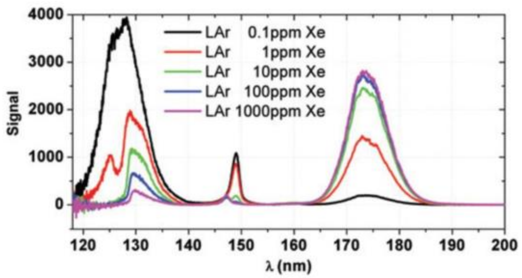


Gas Lens Cameras

*LAr scintillation **λ** and **n** are challenging*:

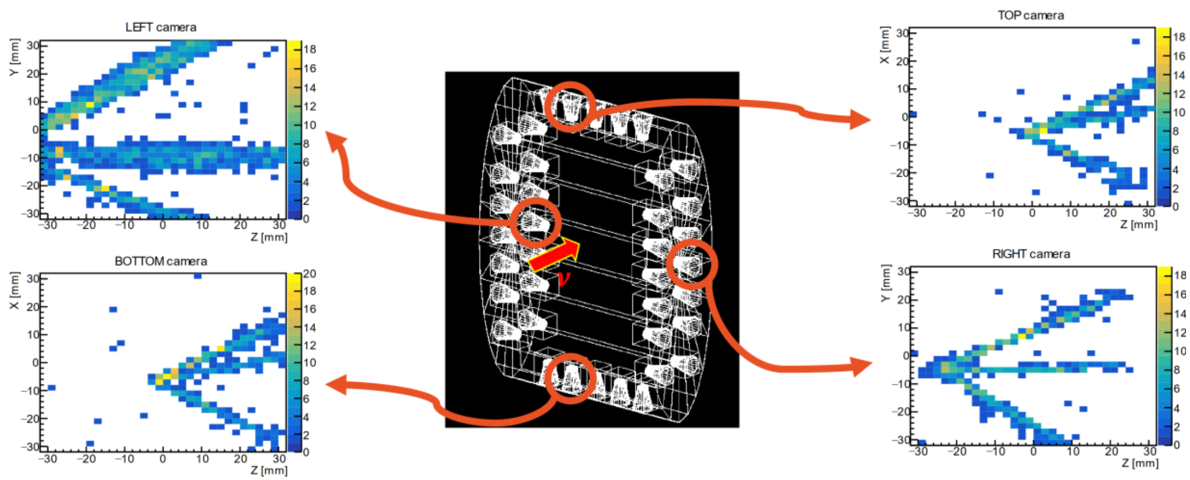
- Use **inverted** lens with gas filled gap (N_2) with n = 1
- Use **Xe doping** to raise λ for better transmission through the lens





Wavelength shift with Xe

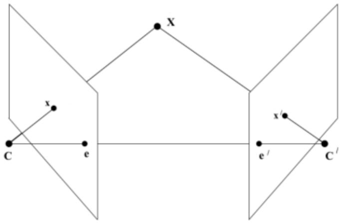
[A. Neumeier et al 2015 EPL 109 12001]



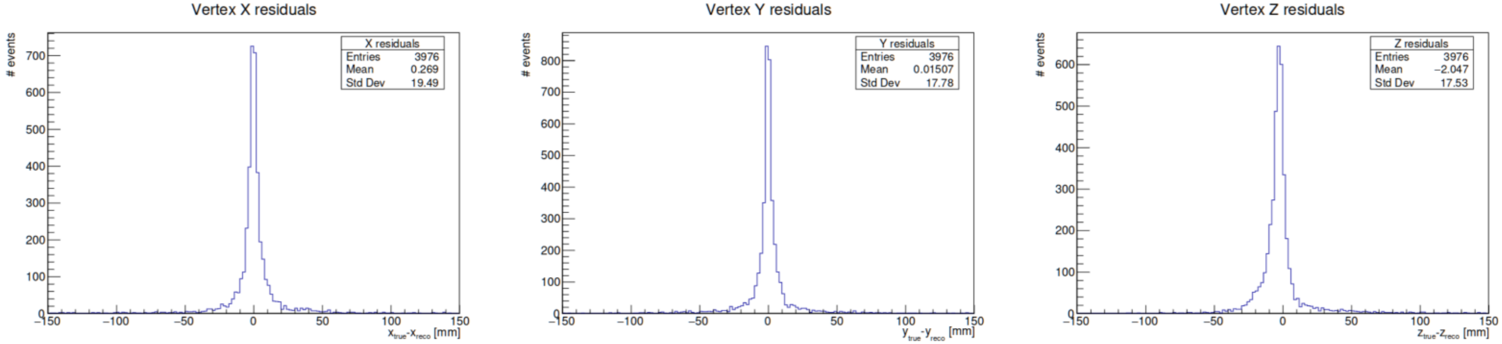
Example event views

Image Reconstruction (lenses)

- Track fits 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



- **Excellent resolution** from simulation



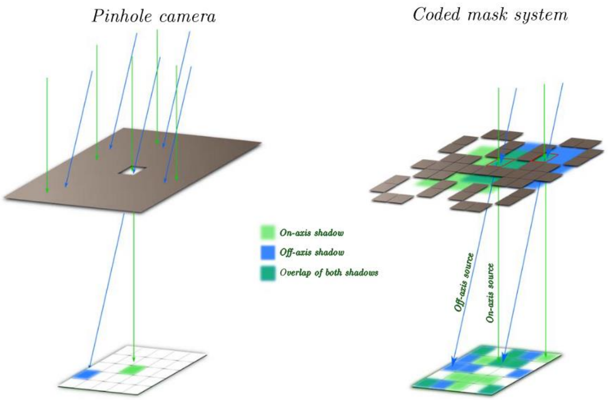
- Limited depth of field compared to the camera size

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

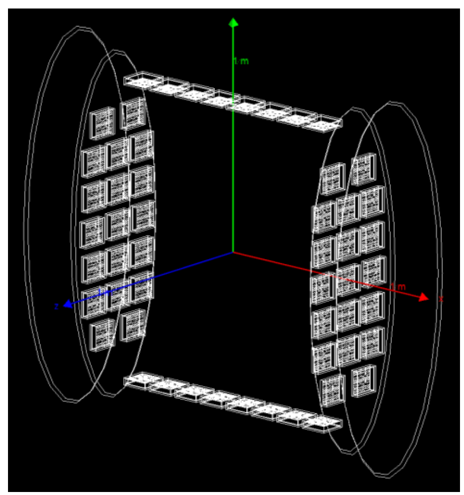
Coded Aperture Cameras

*Coded Aperture masks avoid issues with **λ** and **n***

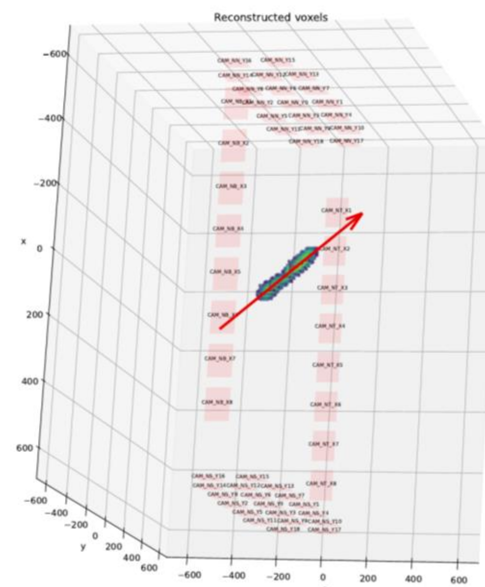
- Extension of the pinhole camera
- Good depth of field, compact
- Worse contrast than lenses



Concept



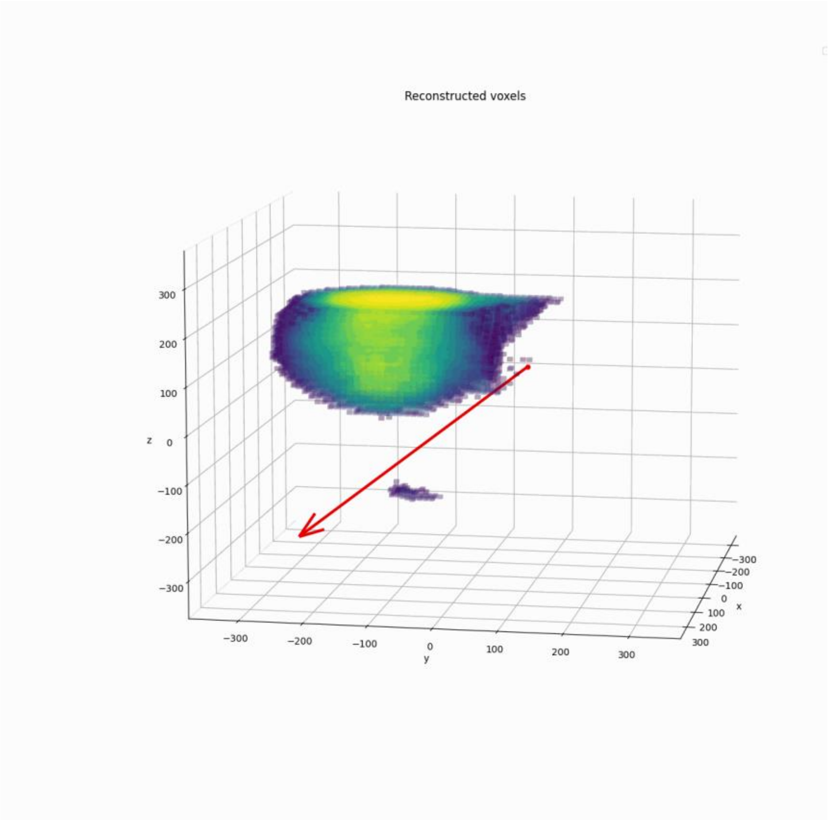
Example detector layout



Reconstructed Track

Image Reconstruction (CAM)

- Maximum Likelyhood – Expectation Maximization algorithm
- Iterative algorithm converges towards the correct solution
- Self normalizing, preserves amplitude
- Computationally expensive, needs GPUs and lots of RAM



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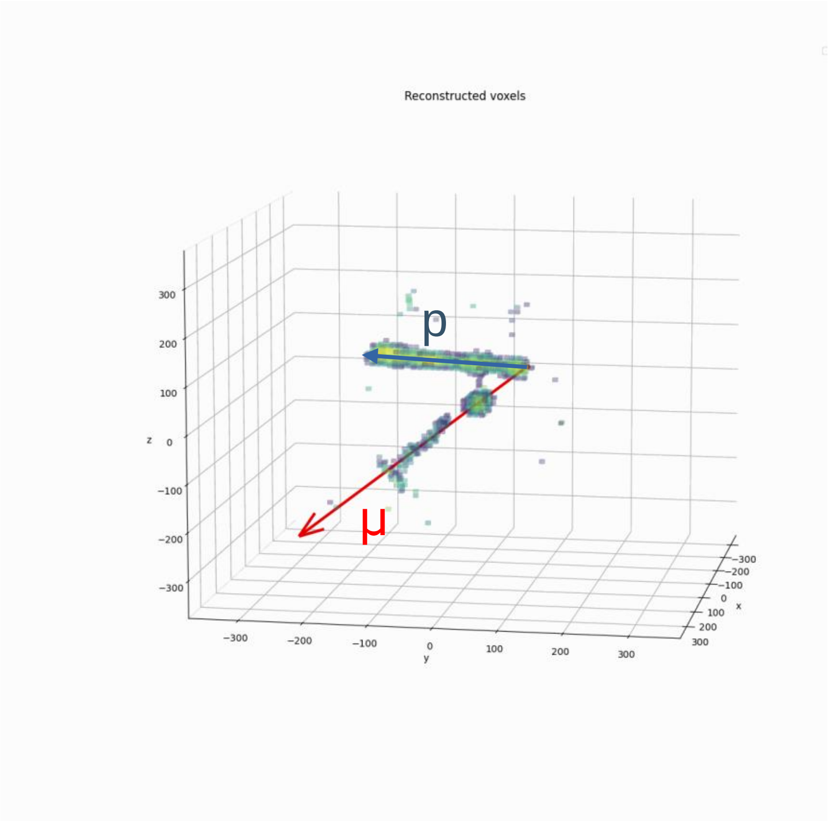
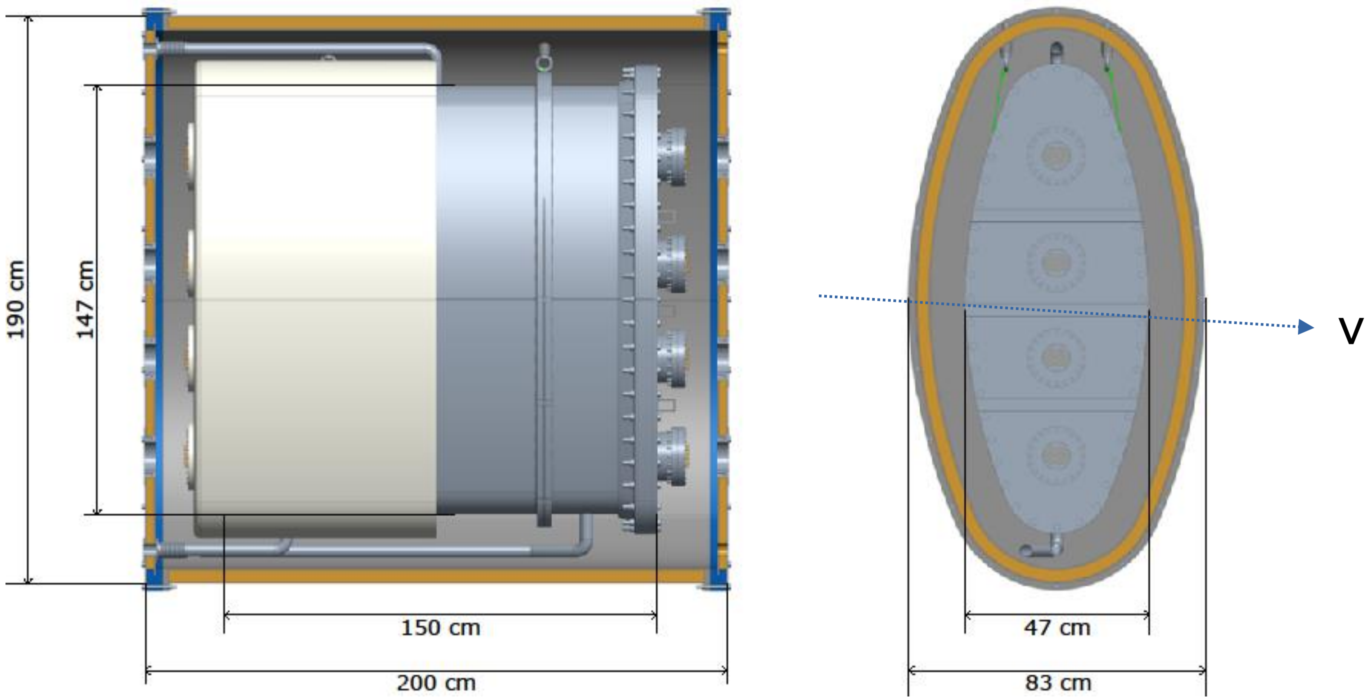


GRAIN Vessel Design

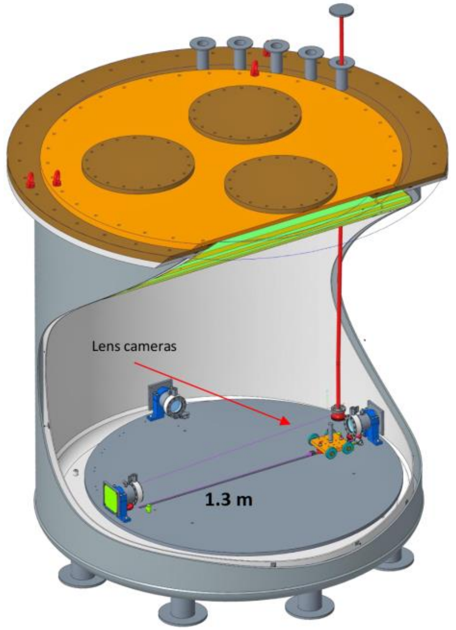
- Elliptical to minimize thickness along beam axis
- Steel (6mm) inner LAr vessel (~700 litres, 1 ton)
- Carbon Fibre + Al honeycomb outer Vacuum vessel

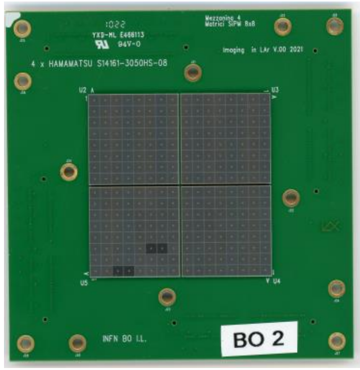


Status of hardware development

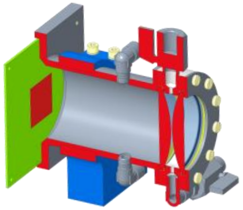
Two facilities are being equipped for GRAIN related R&D

- **Artic** in Genoa, for studies of sensor performance, starting soon





256 ch SiPM matrix



PCB with 8 x 32ch ALCOR cryo ASICs

- Integration facility in LNL, for cryo-vacuum integration studies, will host a prototype inner vessel and services, in design

Outlook

- GRAIN will be the first detector to image LAr scintillation
- Cryo demonstrator with 3 x 256 pixel cameras almost ready
- Prototype inner vessel design finalized
- Cameras and ASIC with 1024 pixels under development
- On track to be ready for first beams in ND

Backup

Image Reconstruction (lenses)

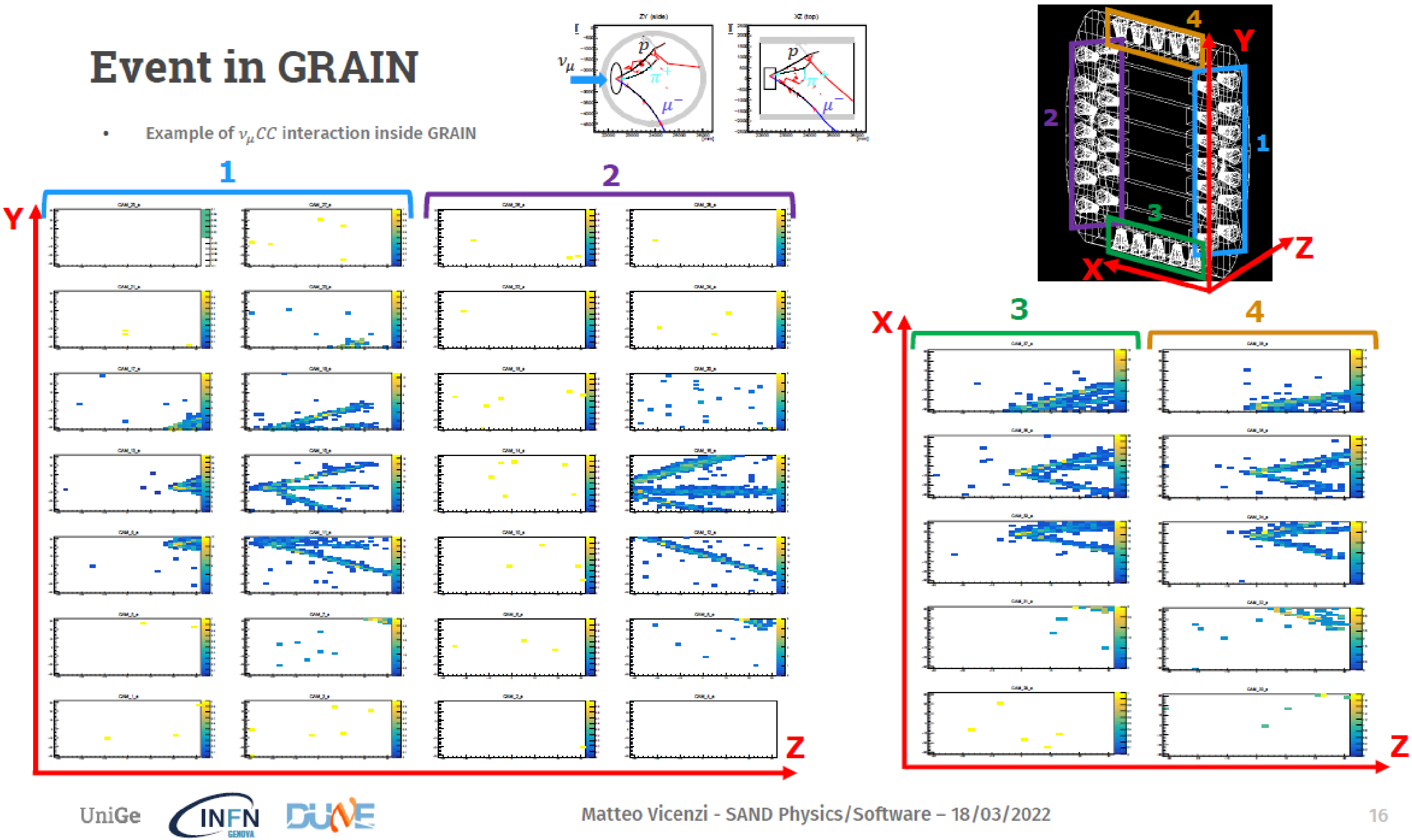


Image Reconstruction (CAM)

[Willingale, Sims, and Turner. “Advanced deconvolution techniques for coded aperture imaging” NIM 221.1 (1984). doi: https://doi.org/10.1016/0167-5087(84)90180-7]

Raw Image

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

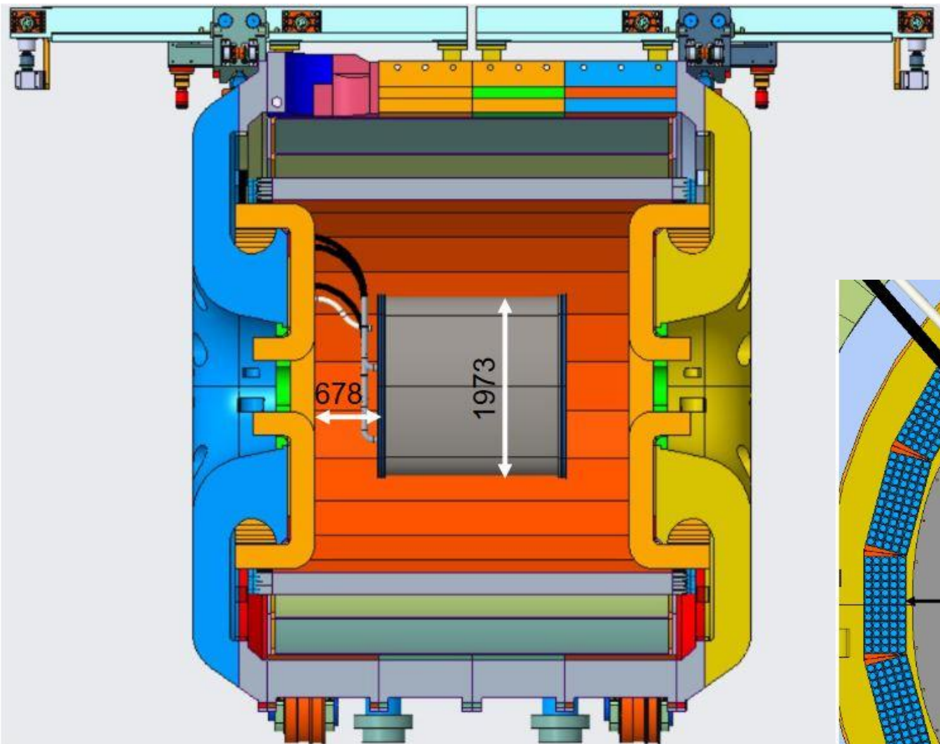
Voxel Amplitudes

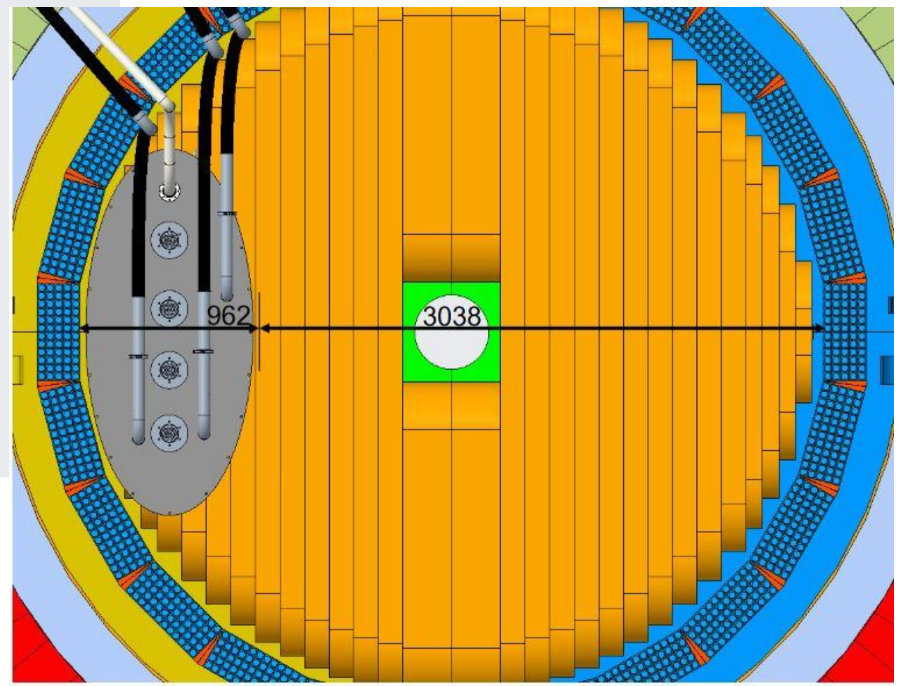
System Matrix

Expectation

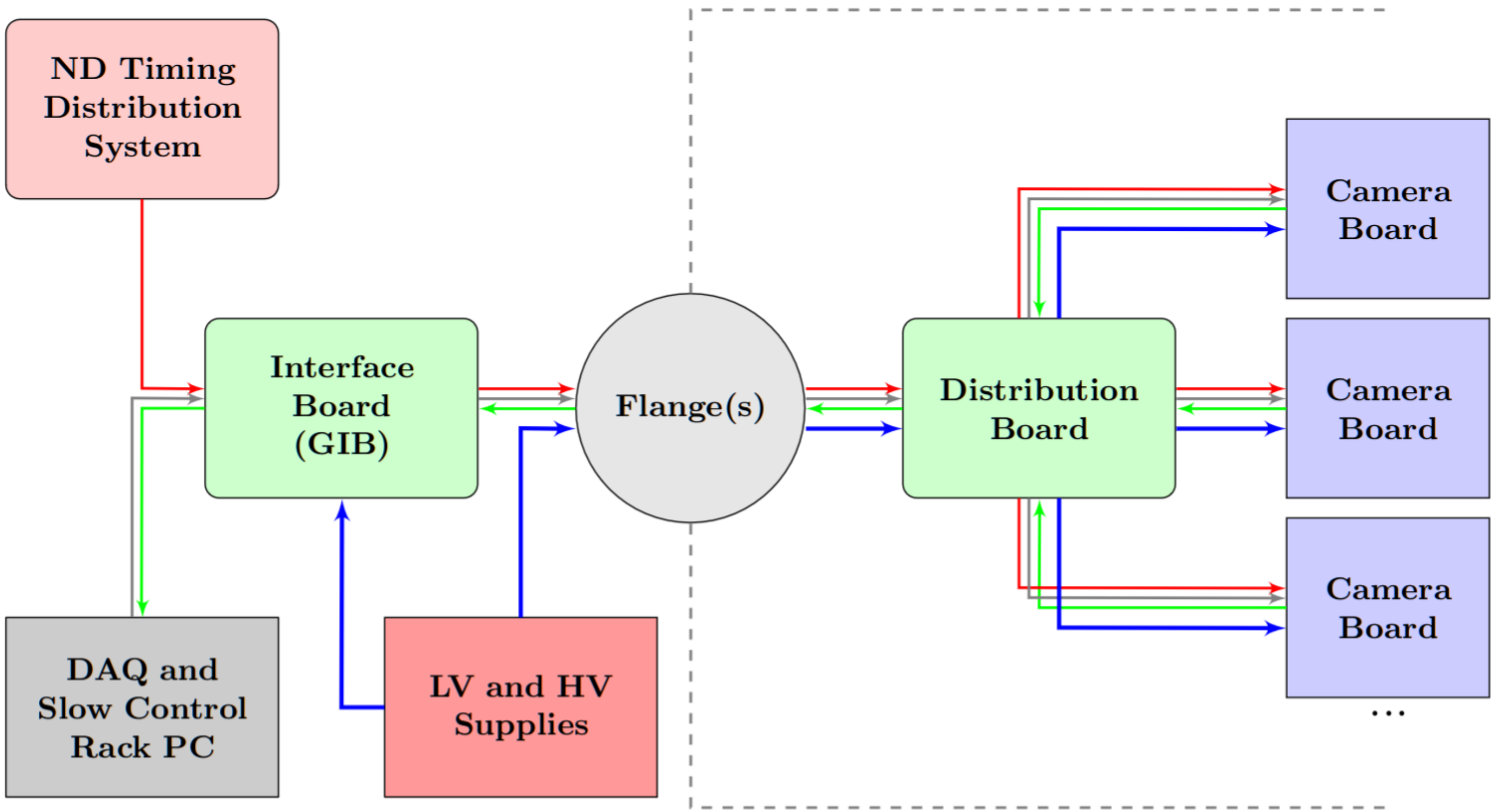
$p(j,s)$, the probability that light emitted by voxel j gets to sensor s

GRAIN integration





DAQ Plans



ND Timing Distribution System
Interface Board (GIB)
Flange(s)
Distribution Board
Camera Board
Camera Board
Camera Board
...
DAQ and Slow Control Rack PC
LV and HV Supplies