SAND detector Phase II

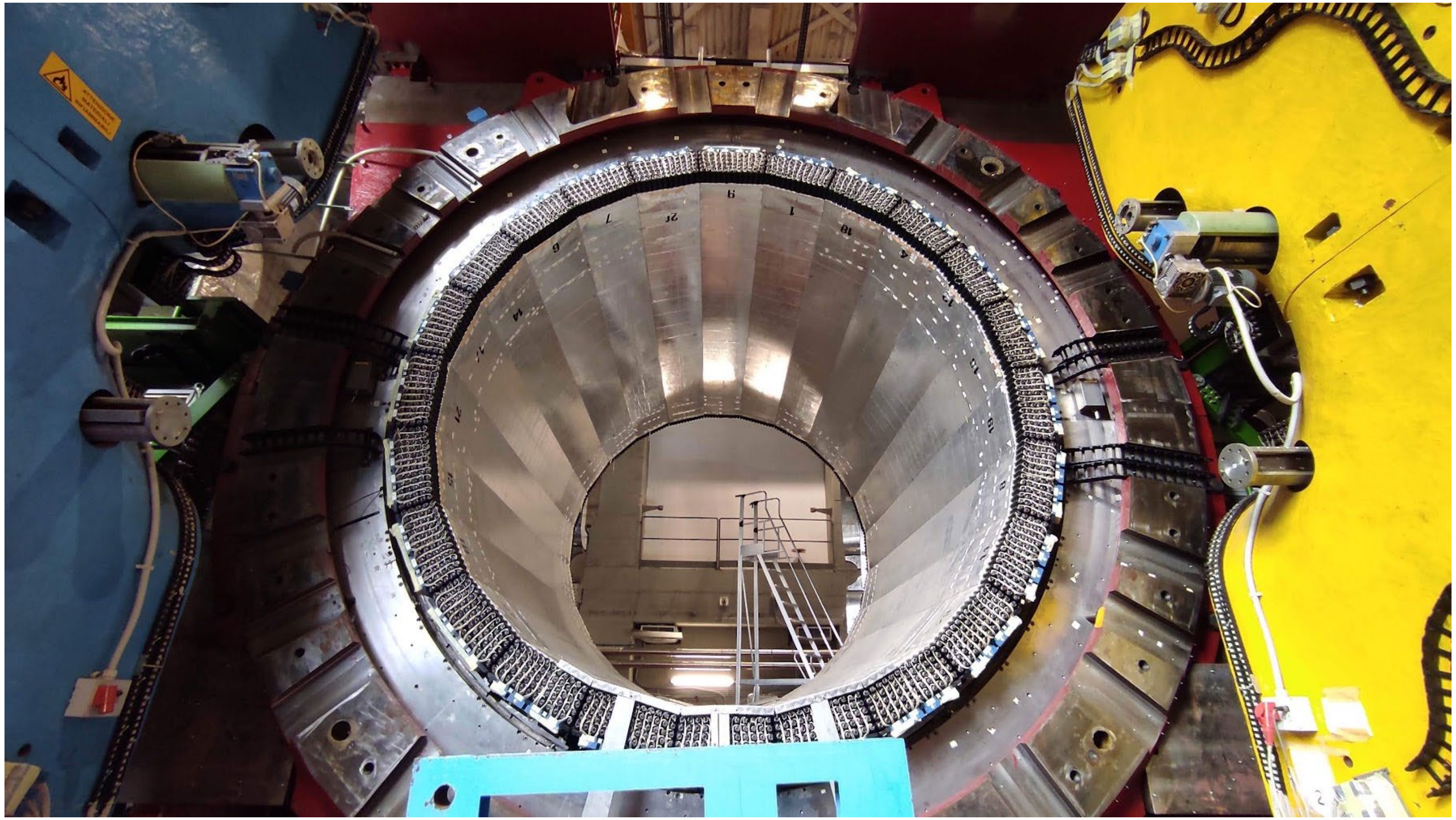
Alessandro Montanari
on behalf of SAND Consortium

Phase II ND Workshop

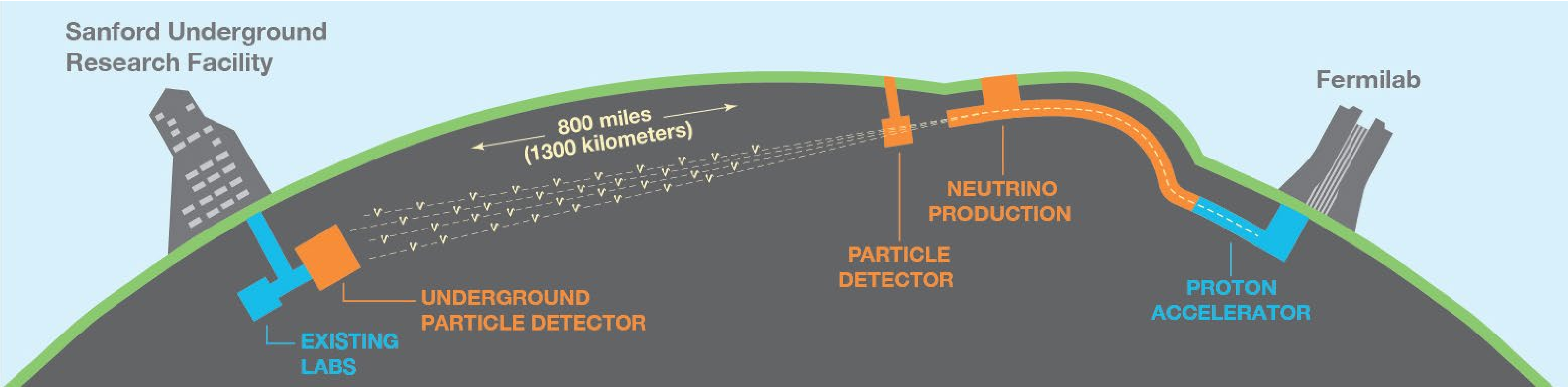
Imperial College, London, 20-22 June 2023

Outline

- Introduction
- ECAL/Magnet
- (Tracker I → II)
- GRAIN I → II



DUNE at work

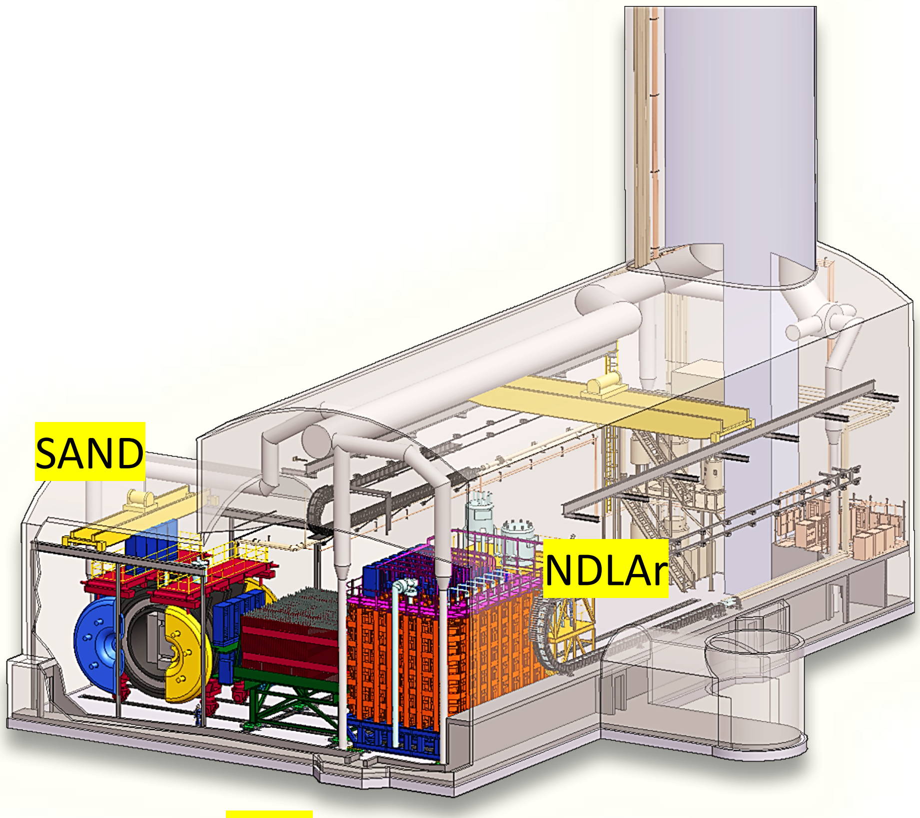


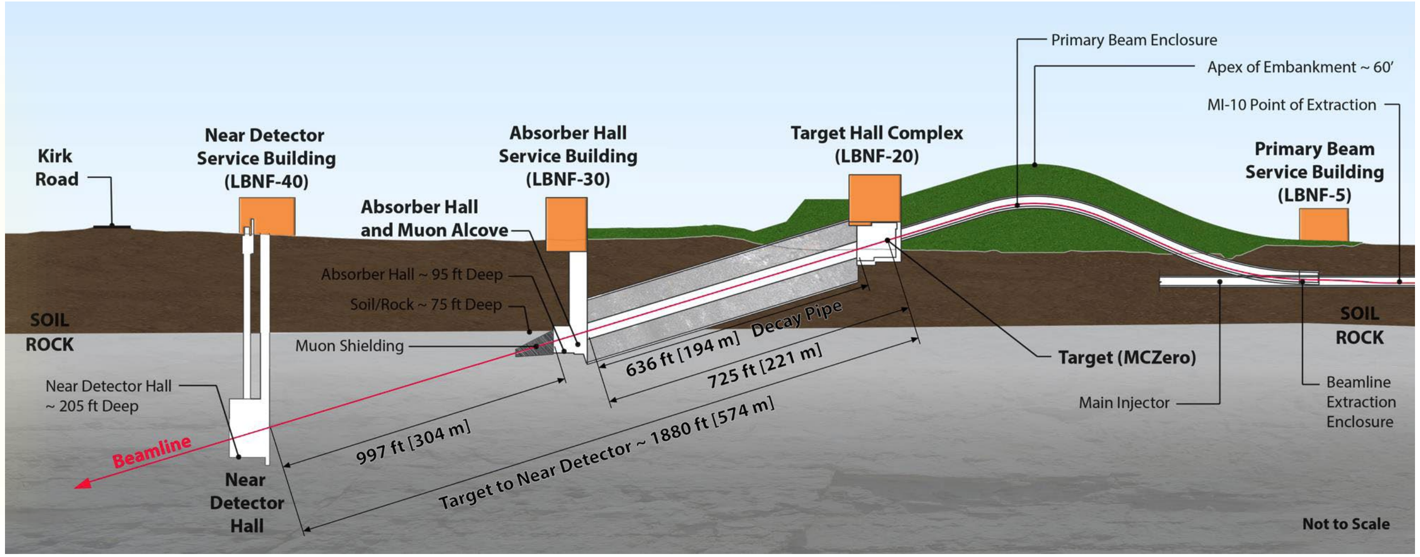
- Using the same type of target in ND and FD helps reducing systematics

$$\frac{dN^{FD}_{\nu_e}}{dN^{ND}_{\nu_\mu}} = \frac{\int \Phi^{ND}_{\nu_\mu}(E_\nu) P_{\nu_\mu \to \nu_x}(E_\nu) F(E_\nu) \sigma^{Ar}_{\nu_e}(E_\nu) R^{Ar}_{\nu_e}(E_\nu, E_{rec}) \epsilon^{FD}_{\nu_e}(E_\nu, E_{rec}) dE_\nu}{\int \Phi^{ND}_{\nu_\mu}(E_\nu) \sigma^{Ar}_{\nu_\mu}(E_\nu) R^{Ar}_{\nu_\mu}(E_\nu, E_{rec}) \epsilon^{ND}_{\nu_m u}(E_\nu, E_{rec}) dE_\nu}$$

Near Detector Complex Phase I

- High statistics constrains cross section and neutrino flux



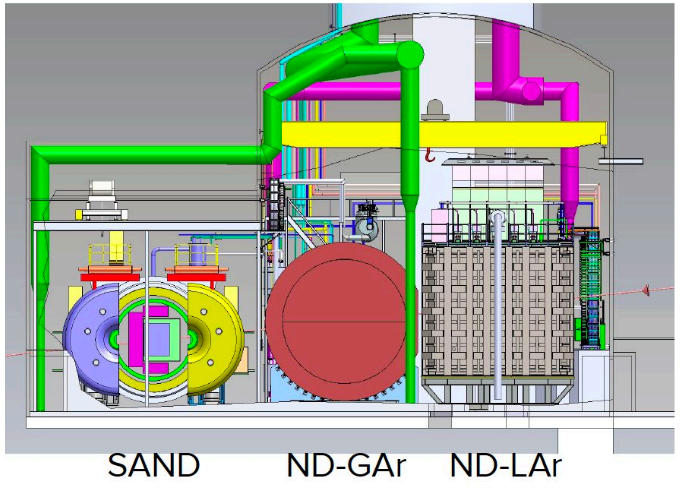


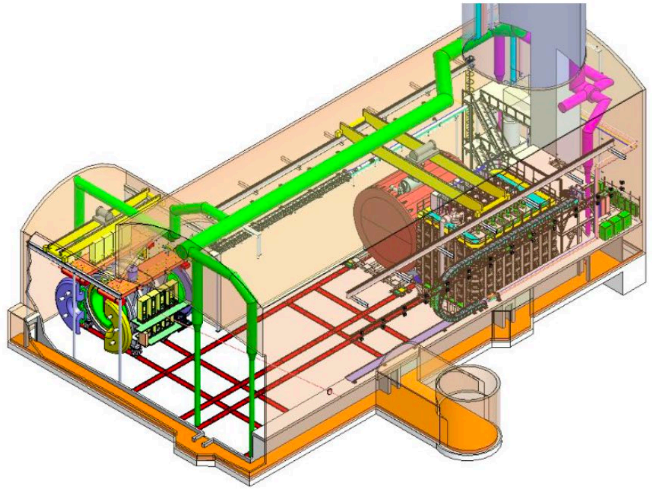
Near Detector Complex Phase II

Three main components:

- Liquid Argon detector (NDLAr)
- Downstream Tracker with gaseous Argon target in magnetic field (NDGar)
- System for on Axis Neutrino Detection (SAND), in magnetic field

NDGar and NDLAr can move off-axis (PRISM concept)





SAND features

SAND is a multipurpose detector with:

- Superconductive Solenoid **Magnet**
- High performant **ECAL**
- Light **Tracker** (see R.Petti talk)
- active **LAr target**

Requirements:

- **Monitor beam** changes on a weekly basis
- Indipendent measurement of the **flux** and **flavour content** of neutrino beam on event-by-event basis
- **Remove degeneracies** when other detectors are off-axis
- **Add robusteness** to ND complex to keep systematics and background under control
- Could contribute to **oscillation analysis** and **other physics** measurements thanks to high statistics

SAND Electromagnetic Calorimeter - ECAL

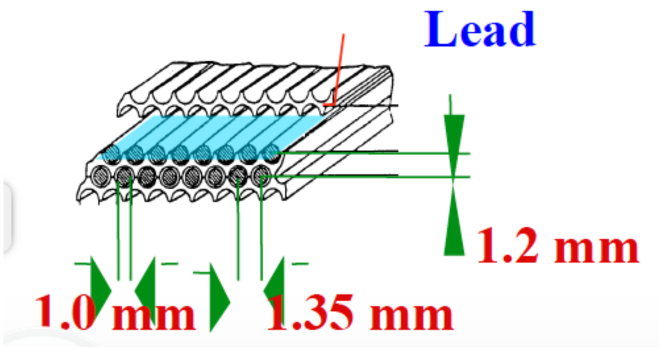
Lead/Scintillating fiber calorimeter of KLOE experiment (operated from 1999 till 2018):

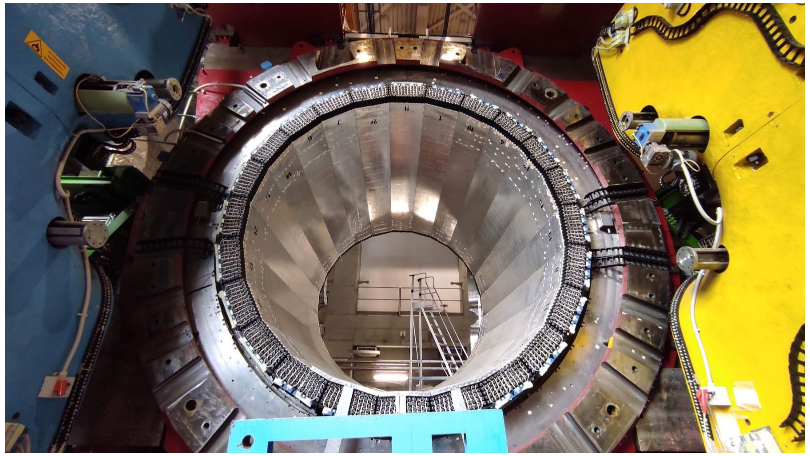
- 24 barrel modules + 2x32 endcaps modules

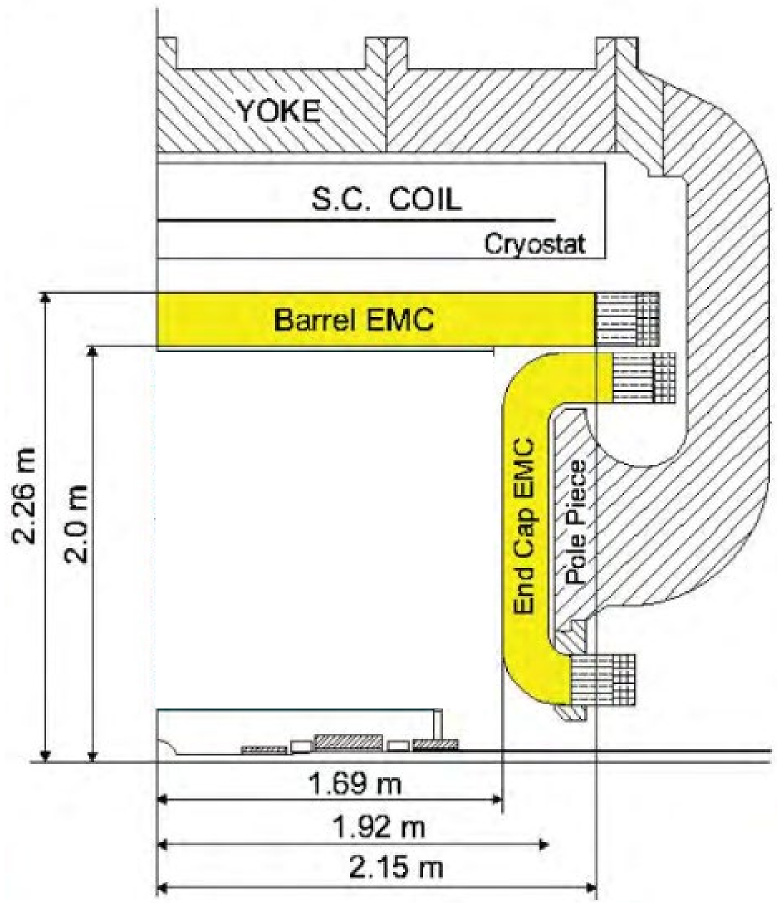
- Resolution:

$\sigma_E/E \cong 5.6\% / \sqrt{E(GeV)}$

$\sigma_t \cong 58\ ps / \sqrt{E(GeV)} \oplus 135\ ps$

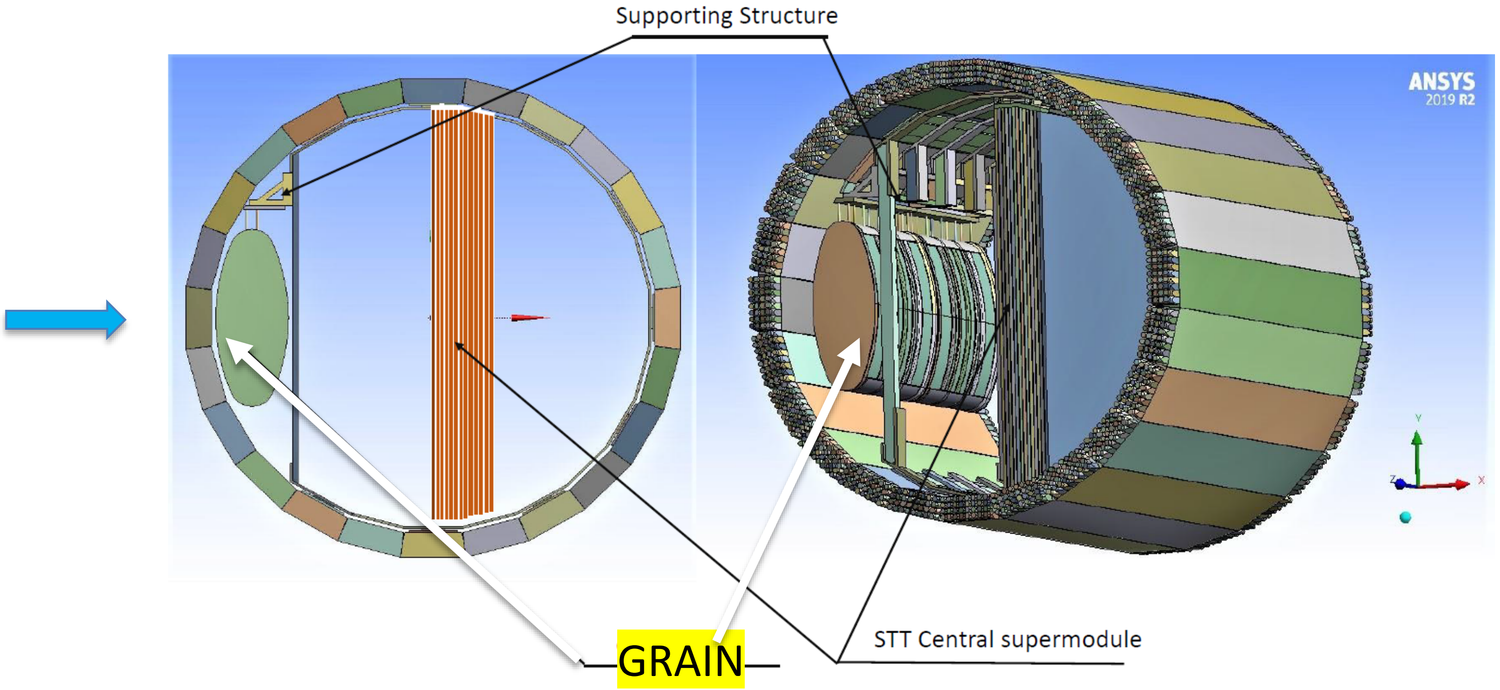


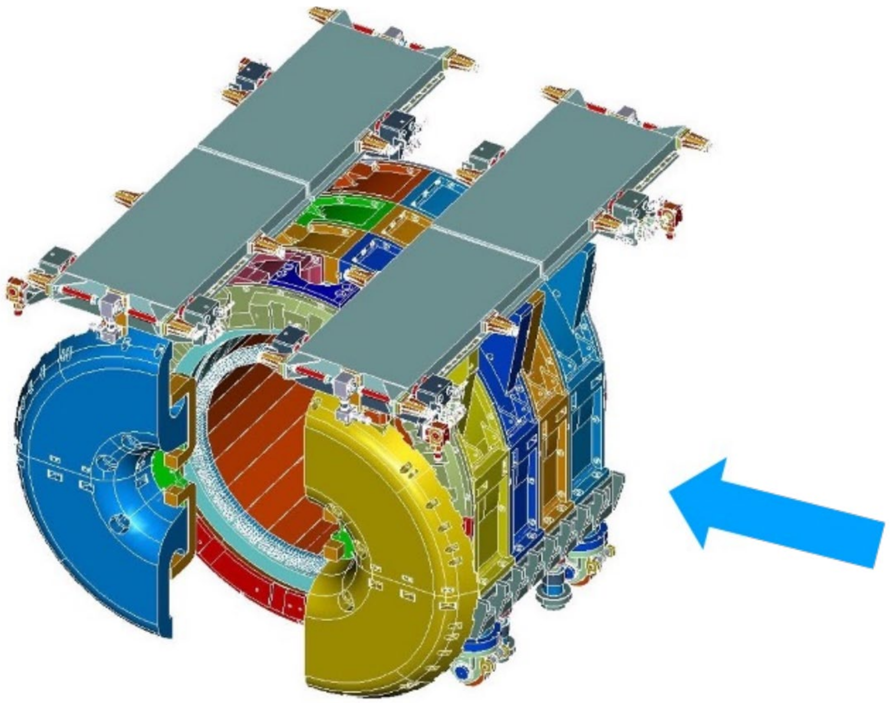




GRAIN (GRanular Argon for Interaction of Neutrinos)

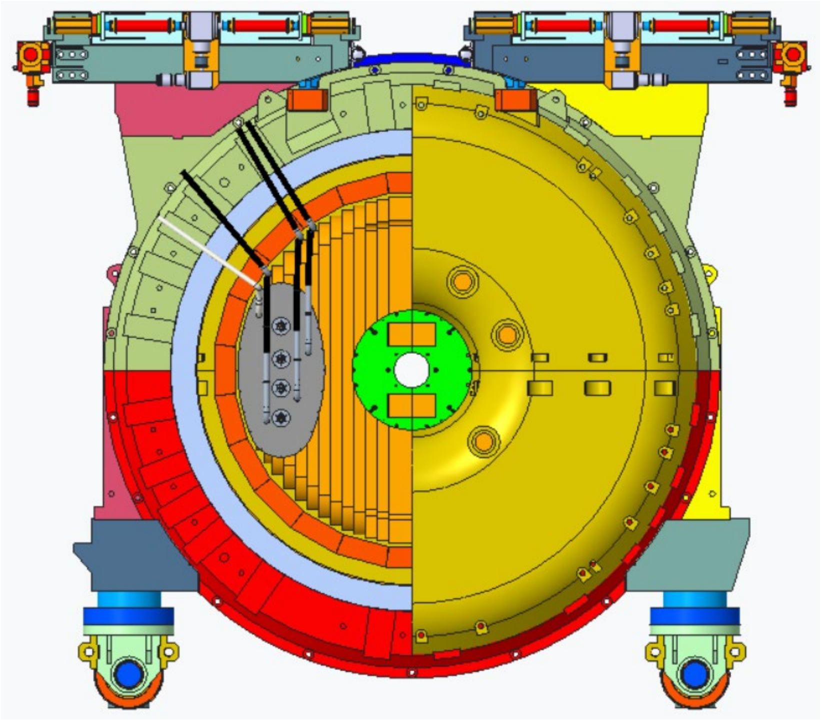
- 1 t Liquid Argon
- active target
- placed upstream
- inside magnetized volume of SAND

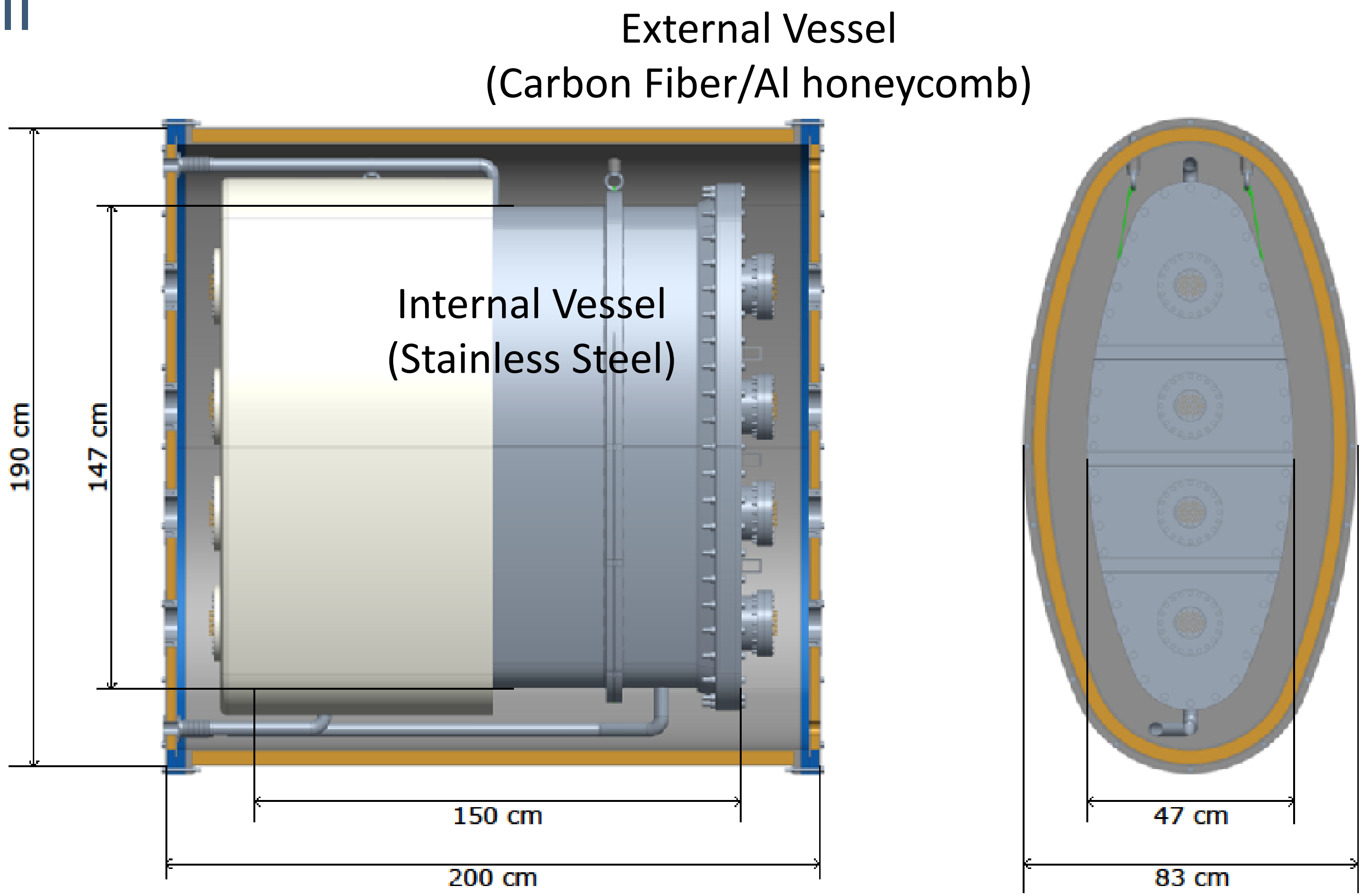




GRAIN cryostat

- It will not change in Phase II



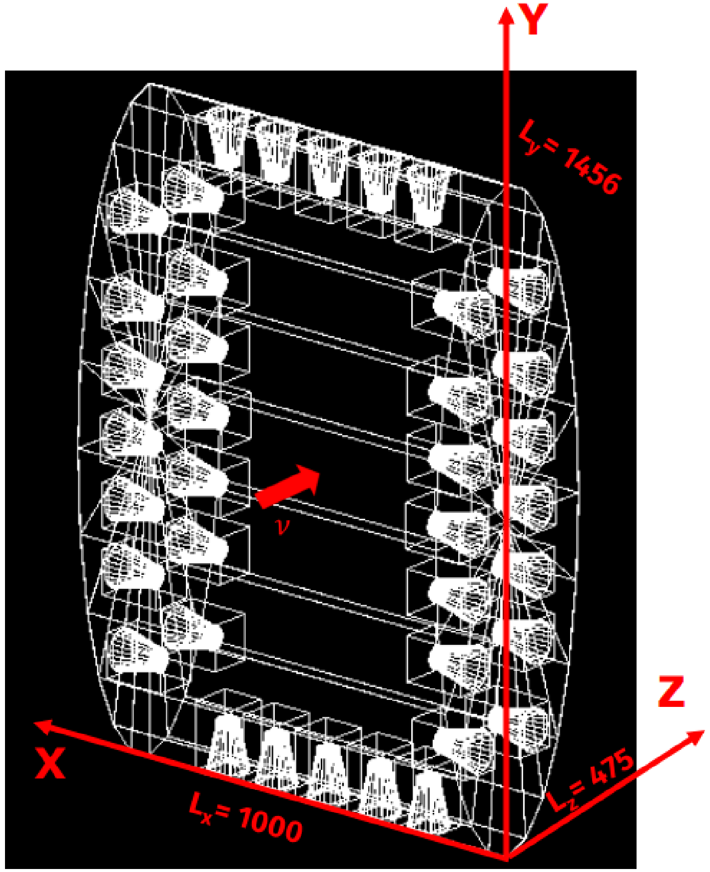


GRAIN: imaging with scintillation ligth

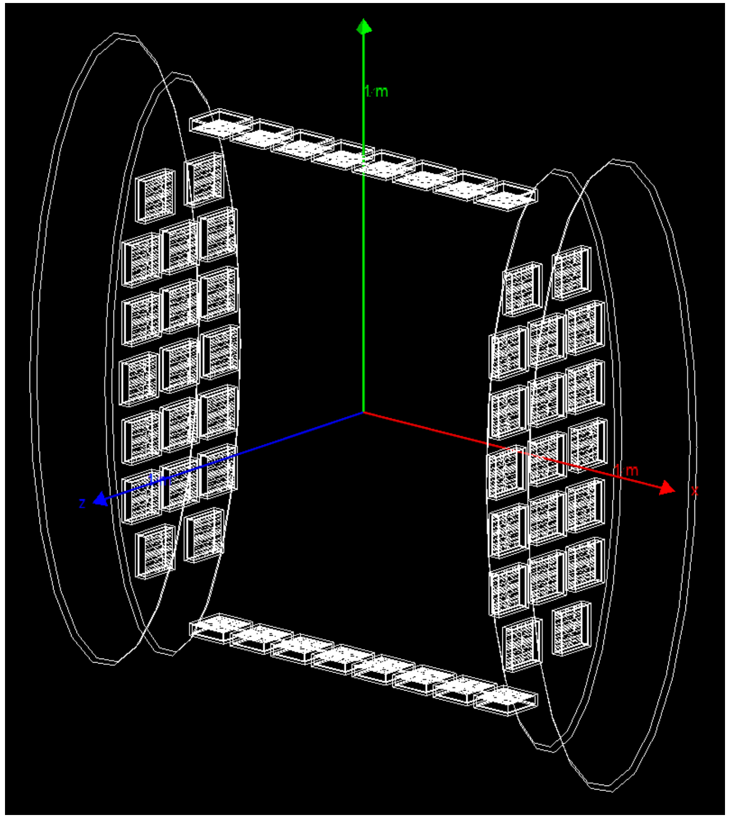
- We are developing an **Innovative technique** to exploit Argon scintillation light to reconstruct charged particle tracks like in an imaging device (ionization not used)

- Challenges for the imaging device:
  - Single Photon cryogenic sensor → **Silicon PhotoMultiplier** 32x32 matrices
  - Optics for 128 nm Ligth Wavelength → **Lens** and **Coded Aperture Masks**
  - Low Power electronics for O(50 k) channels → **ASIC** (1024 channels)

GRAIN imaging cameras



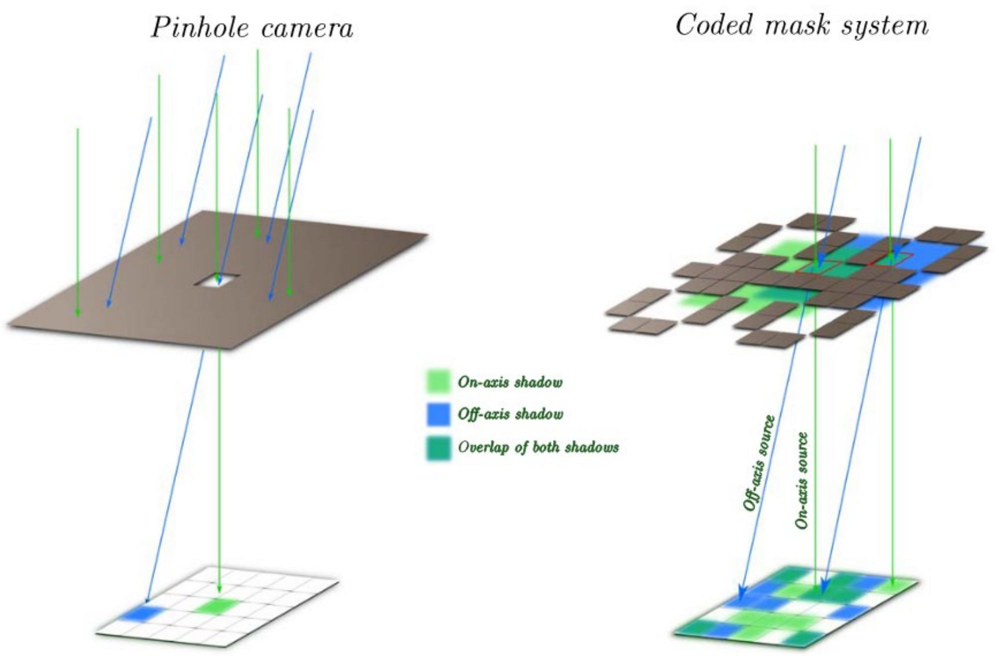
LENS:
- Good far view
- Ligth concentration

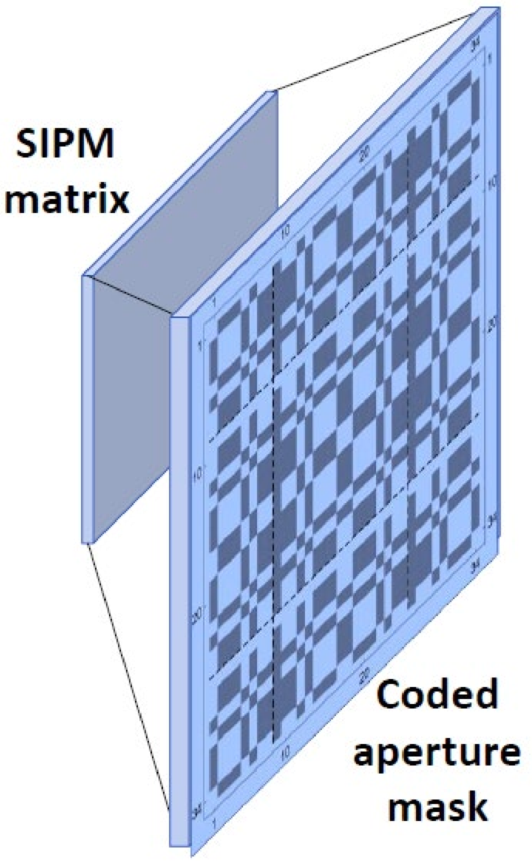


MASKS:
- Good near view
- Few photons on sensor

Coded Aperture Masks

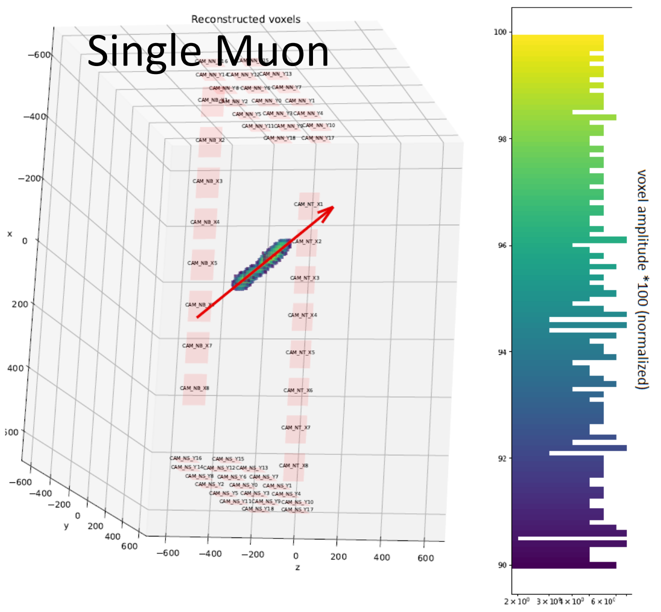
- Principle of pin hole camera
- Light pattern on sensor need interpretation

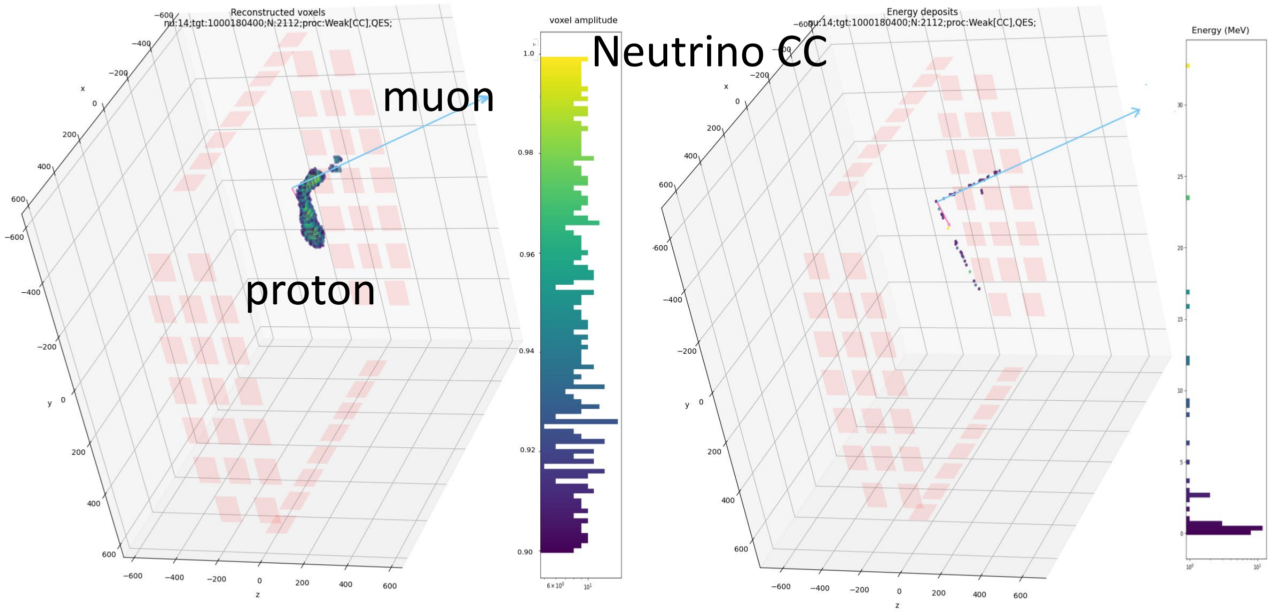




3D reconstruction algorithm

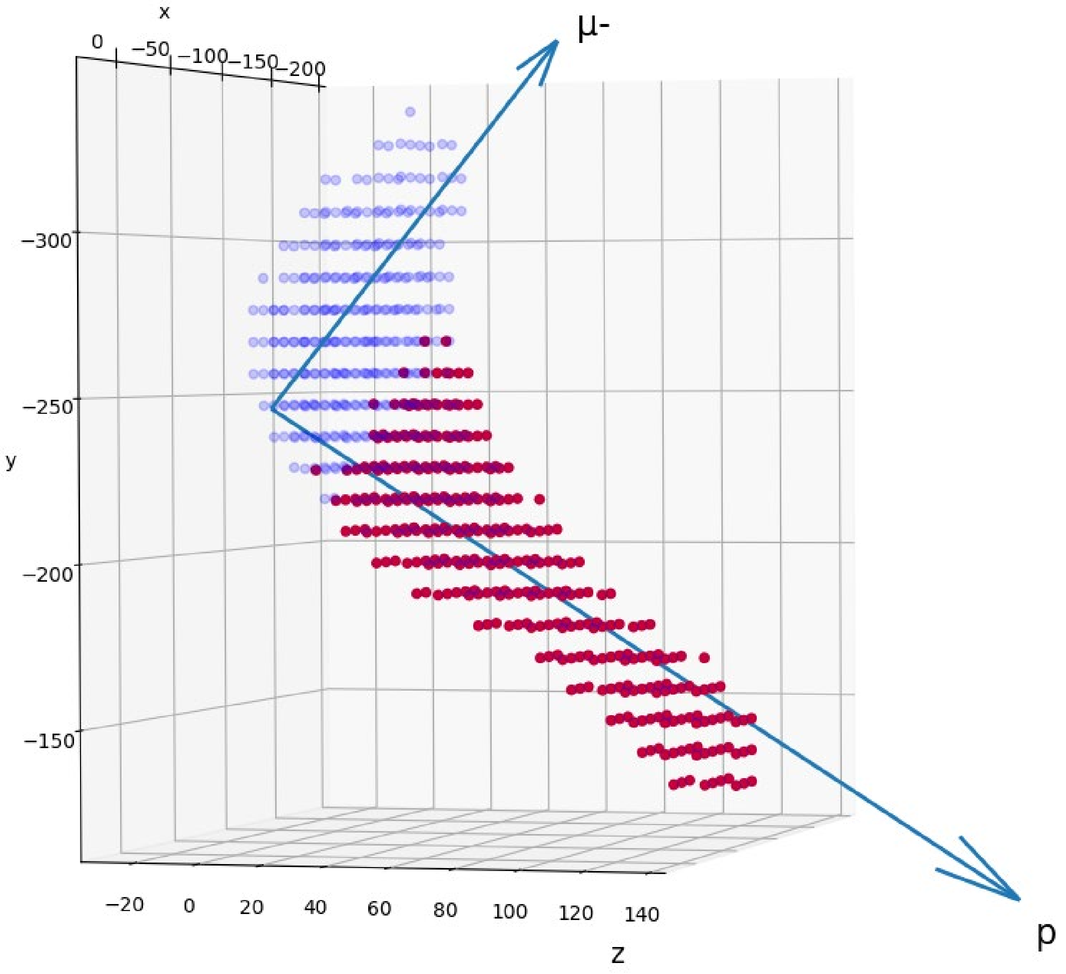
- LAr volume is divided in voxels and, through an iterative combinatorial procedure, each voxels is assigned a number of source photons compatible with the pattern observed on the sensor.
- **Few millimiters** resolution on single track
- Improvements on algorithm still possible





(a) (b)

GRAIN combined with Tracker



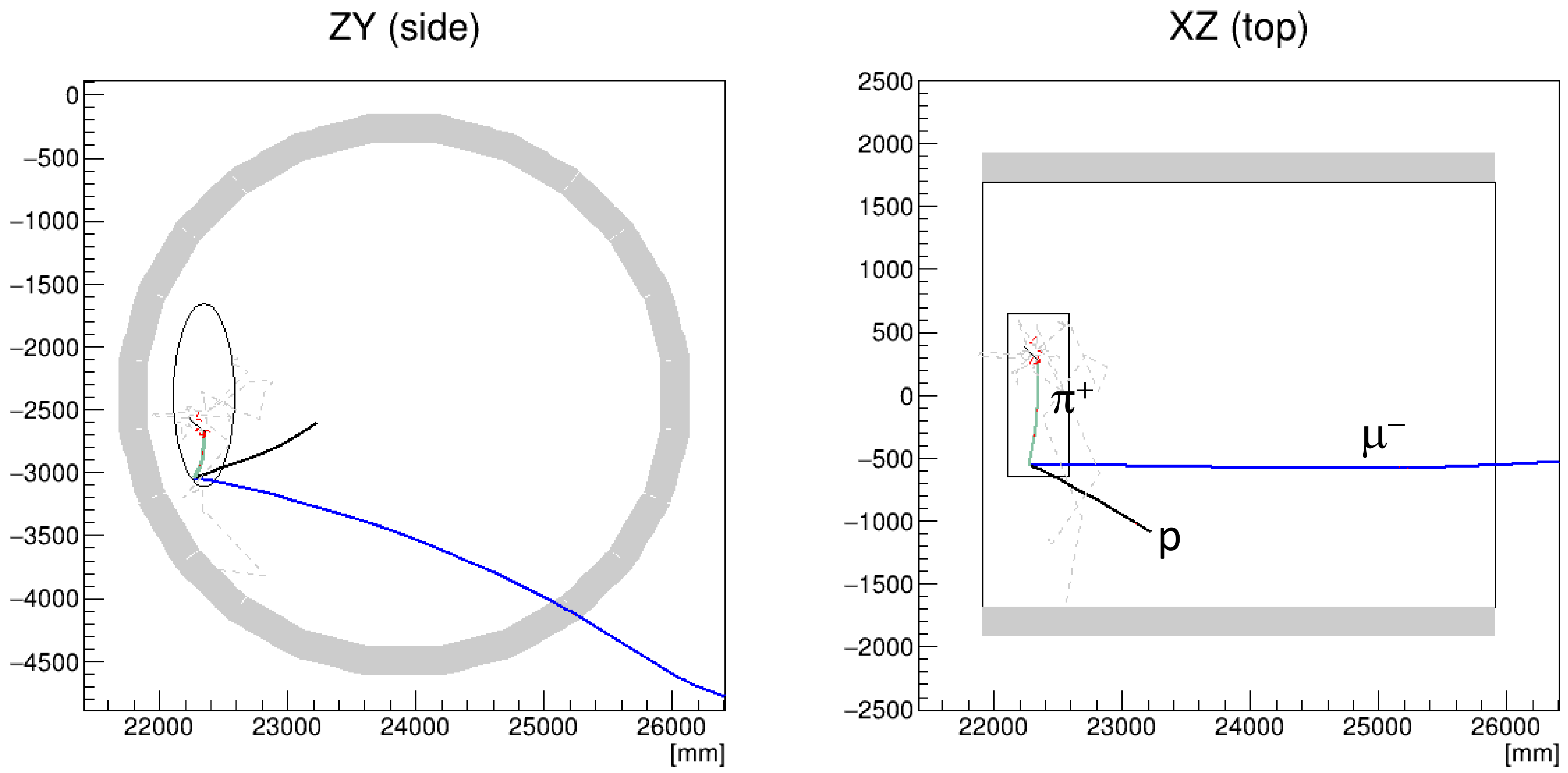
- Assuming that muon track is measured by SAND tracker:

  Resolution **on vertex O(1 cm)**

ECAL+Tracker energy can be corrected by energy measurement of the proton stopped inside GRAIN

GRAIN event

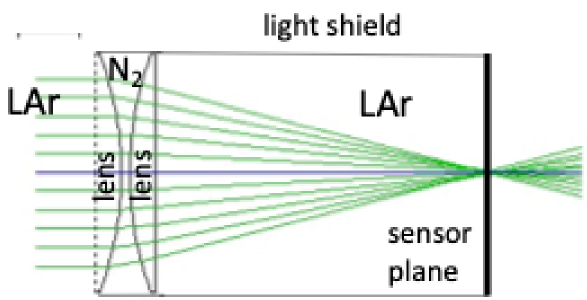
- $\nu_\mu \rightarrow X + \pi^+ + p + \mu^-$ (neutrino energy 2.5 geV)



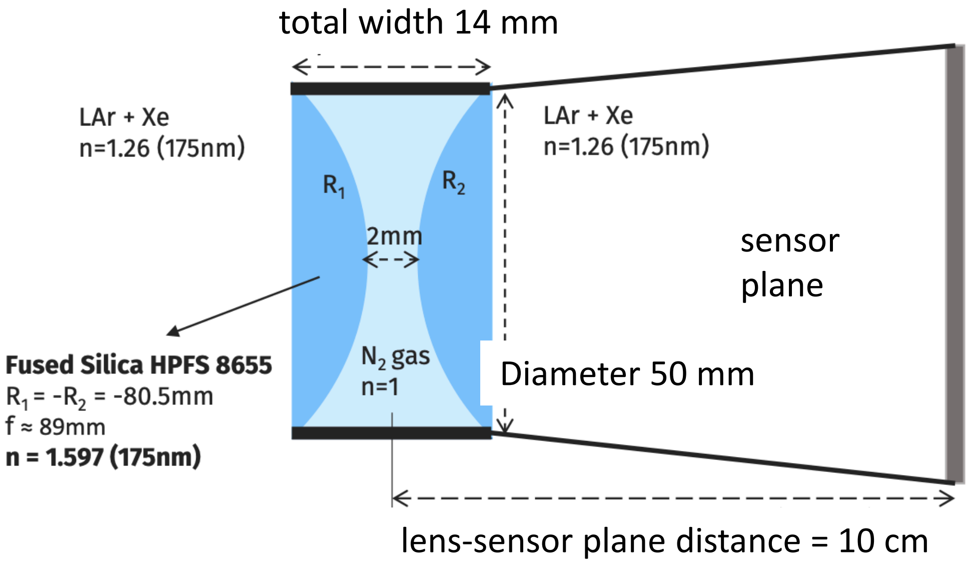
Lens based optical readout for GRAIN

Since the glass refractive index might be close to the LAr refractive index the focusing effect can be done by placing N_2 gas between the lens surfaces

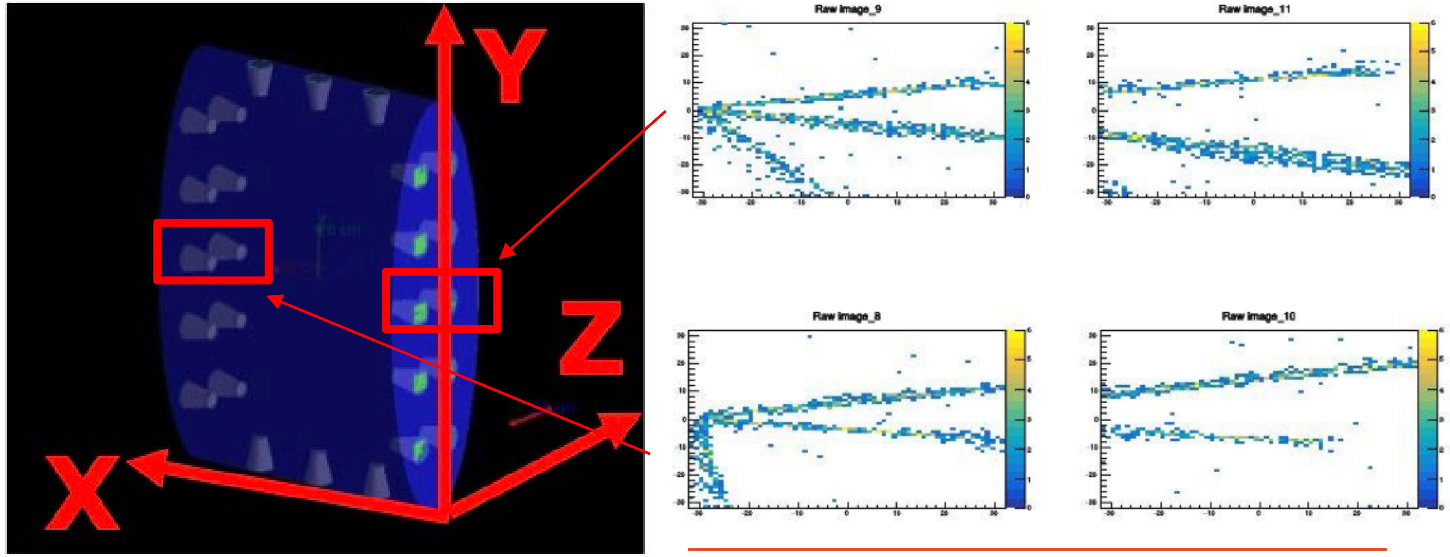
The lens material must show high transmittance → we use Xe doped LAr (>99% at 178 nm)



first prototype

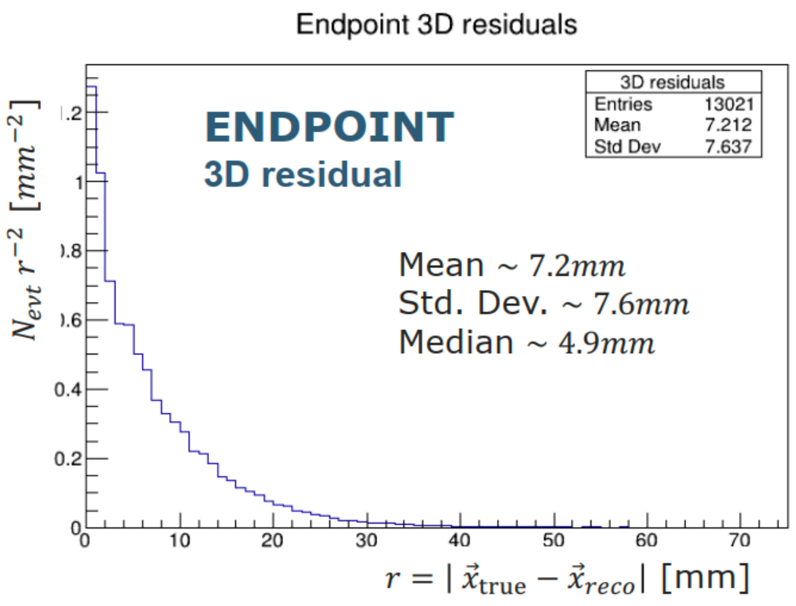


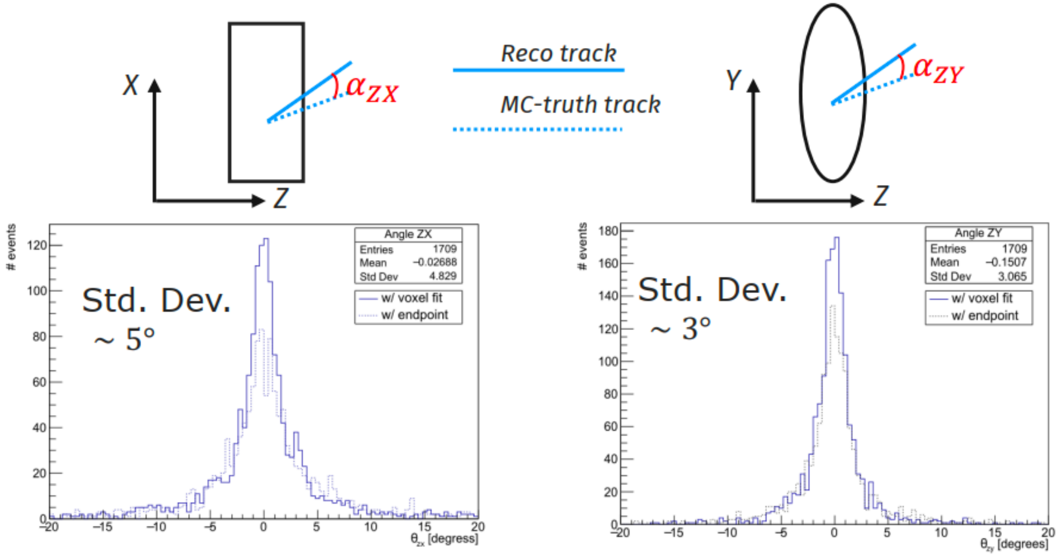
Simulations performed with 38 sensors in GRAIN for a n event at center



Track reconstruction with lenses

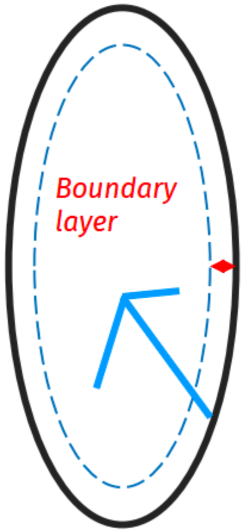
- 3D track reconstruction: track endpoint, track direction, matching with downstream tracker.





MATCHING with STT

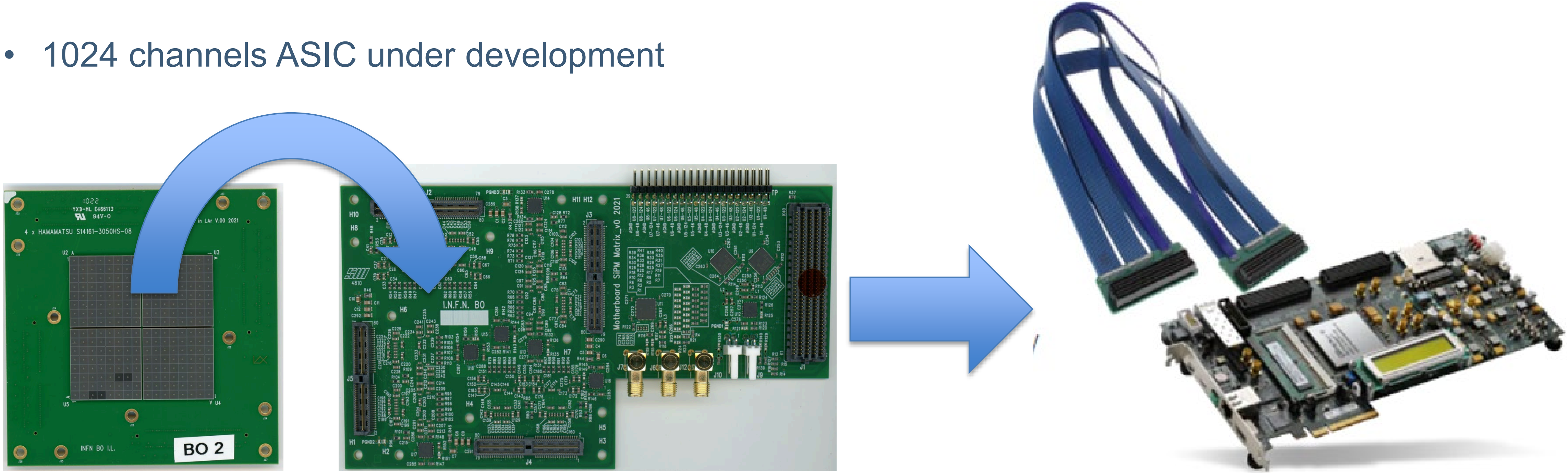
TRUE \ RECO	Contained	Not contained
Entering STT	3%	97%
Not ent. STT	74%	26%



Demonstrator

- SiPM 16x16 matrix (256 channels)
- Frontent based on 8 ALCOR (32 ch ASIC)
- Readout and control through XilinX FPGA

- 1024 channels ASIC under development



GRAIN: phase II

1) Improve SiPM Photon Detection Efficiency

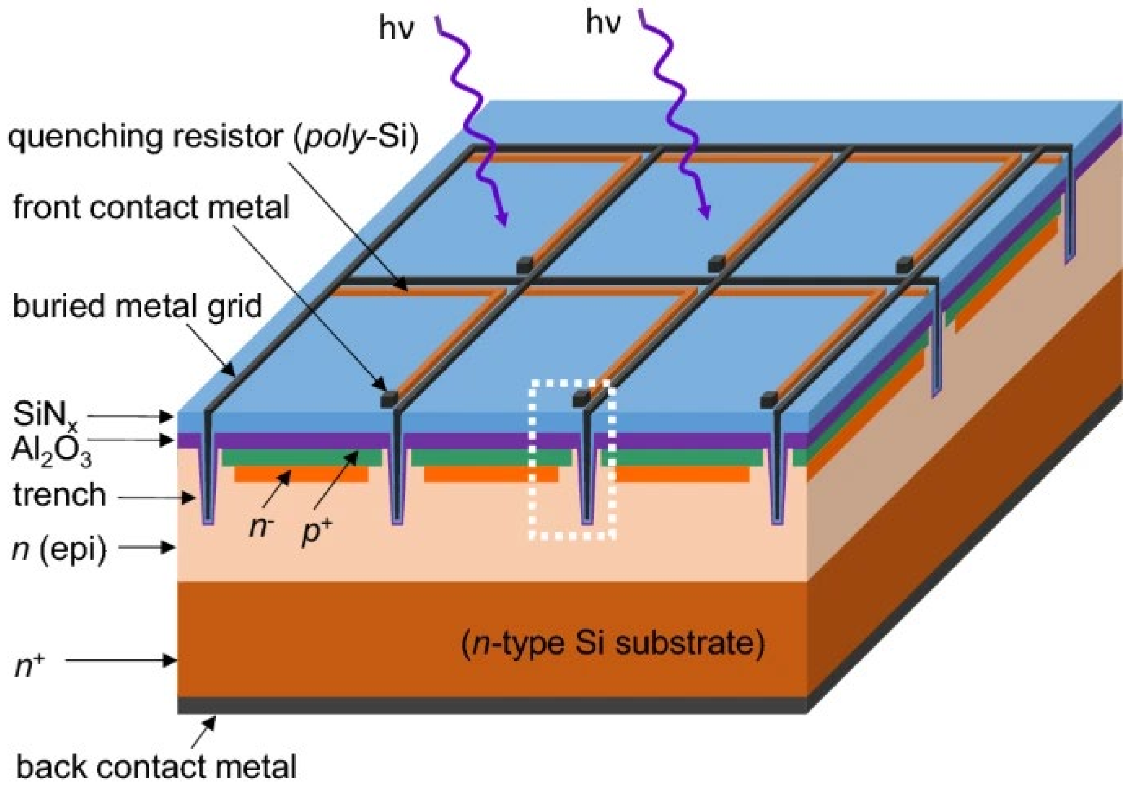
→ we have a joint project with FBK-Trento to develop **Back Side Illuminated** SiPMs

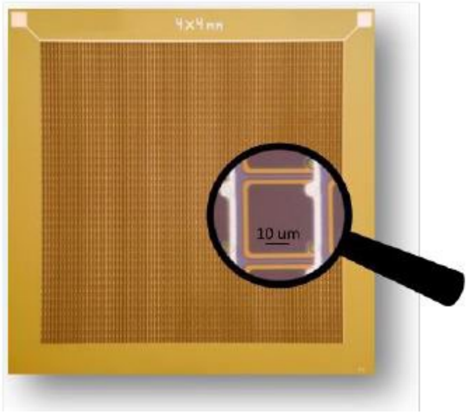
2) Readout both **Ionization Charges** and **Scintillation Light**

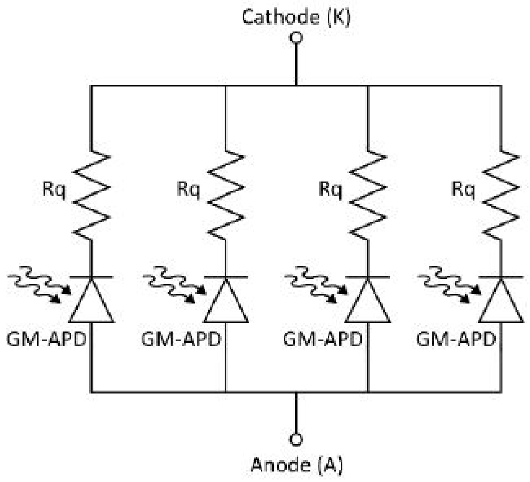
→ Just an idea, needs some work to demonstrate feasibility

The Standard SiPM

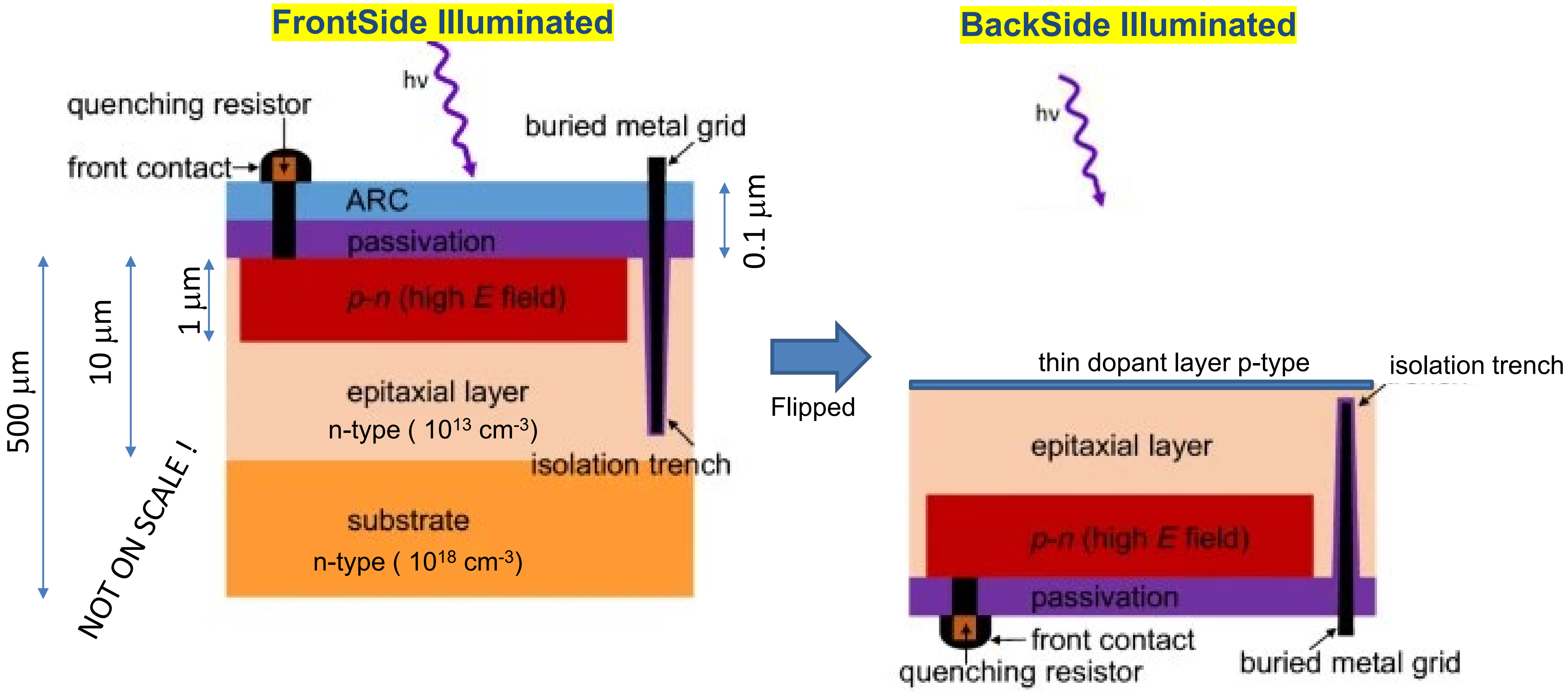
A set of Geiger avalache photodiodes (SPAD) connected in parallel:
the analog output is «linearly» proportional to number of impinging photons







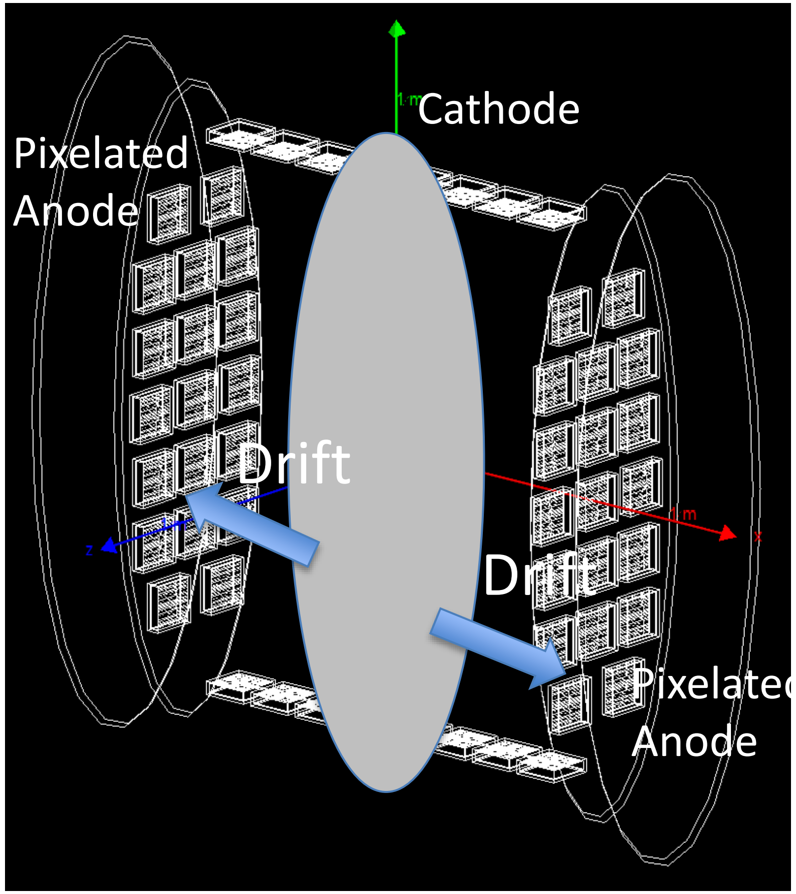
Back Side Illuminated SiPM



In BSI entrance window is clear: better Fill Factor, more possibilities for Anti Reflecting Coating: Improvements in VUV Particle Detection Efficiency is expected

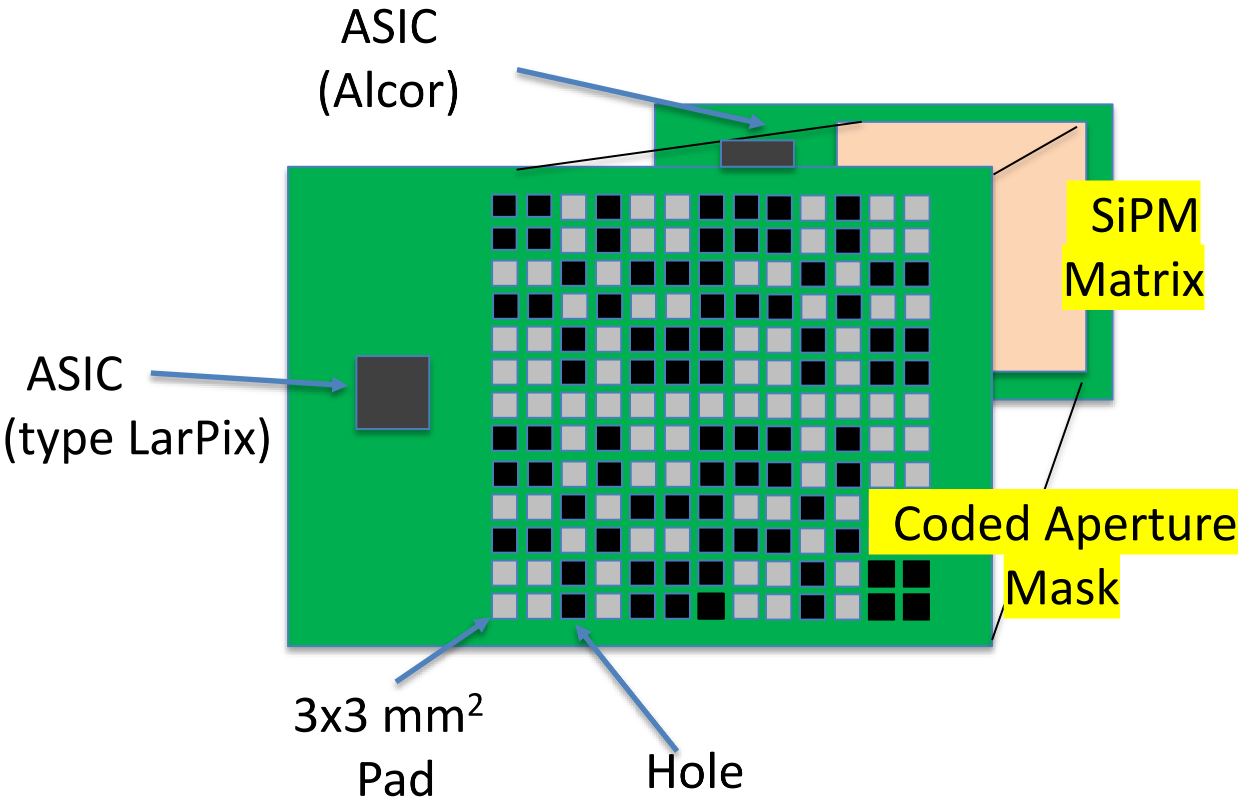
GRAIN: TPC + Scintillation Ligth Imaging

- Coded Aperture Masks are pixelated and form the anode.
- A Cathode grid is added in the middle to form a TPC with horizontal drift.
- Standard mask on top and bottom
- Combined reconstruction of tracks by scintillation light and charge readout allows to solve superimposed events
- Charge identification thanks to magnetic field



Dual purpose Camera

- Holes in a FR4 (or else) form the Coded Aperture Mask
- 3x3 mm^2 metallic pads are placed in the mask positions free from holes (50% surface)
- Dedicated ASICs read the charge and SiPM response to light



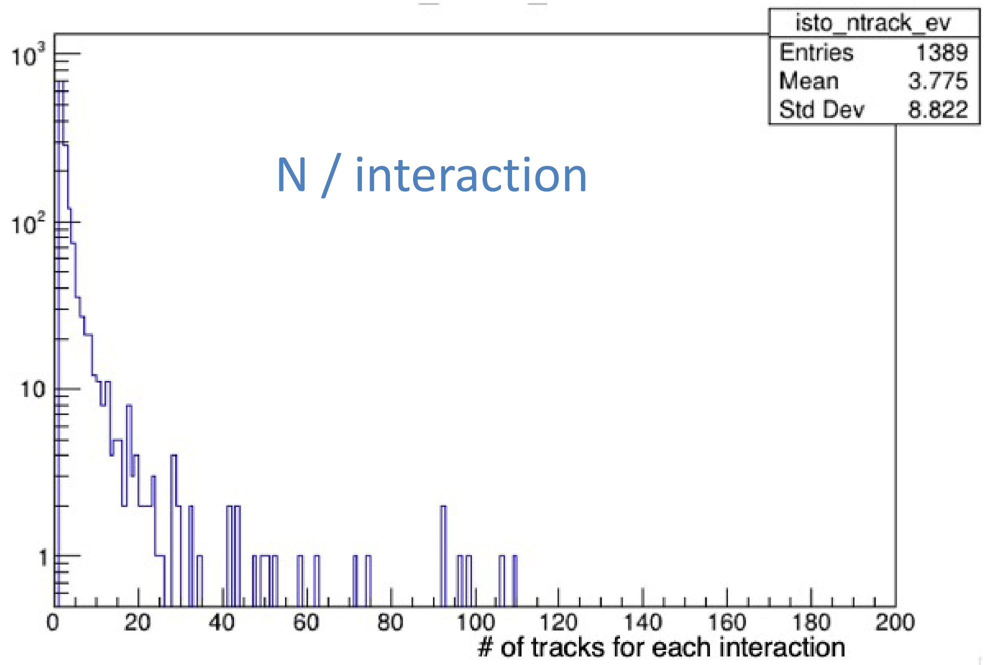
Conclusions

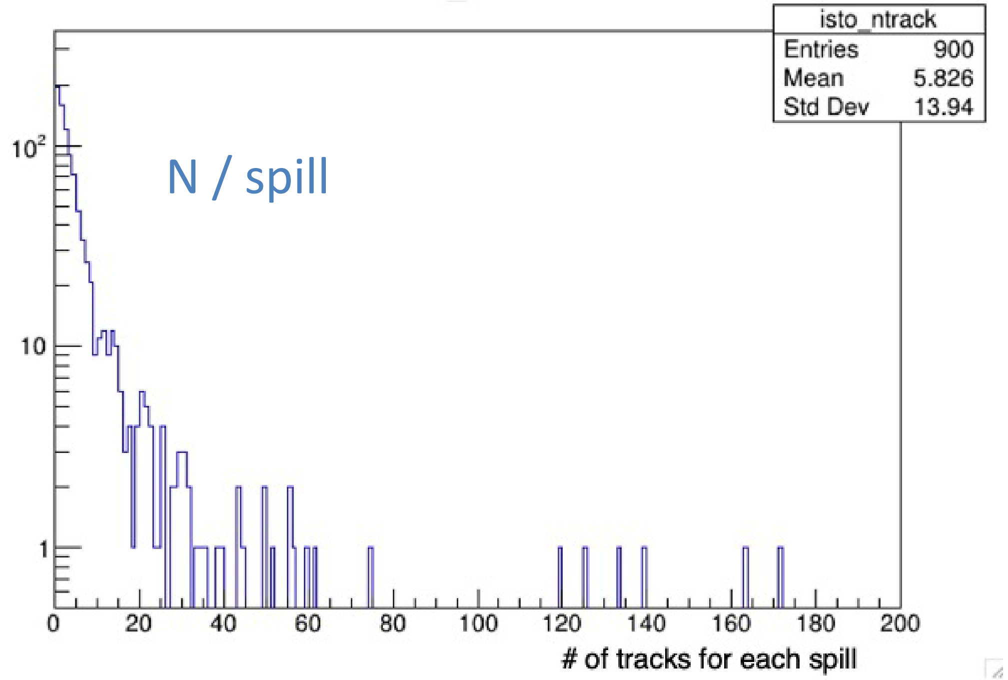
- SAND for phase I will be made by a consolidated Superconductive Magnet and a performant ECAL (from KLOE)
- The Tracker (STT) and the active Argon target (GRAIN) will be completely new
- GRAIN with optical readout will be an innovative detector already for phase I (with track resolution O(cm))
- New ideas for phase II to improve track resolution down to O(mm).

Backup

Rates in GRAIN

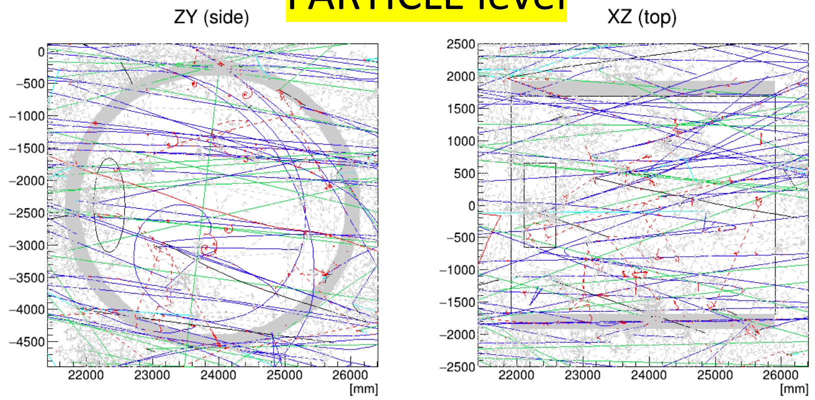
- Neutrino interactions:
  - in whole SAND: 80 / spill
  - in GRAIN : 0.1 / spill
- Neutrinos interactions with tracks (> 6MeV) in GRAIN: 1.5 / spill
- Number of tracks (> 6 MeV) in GRAIN:





Events in an entire spill

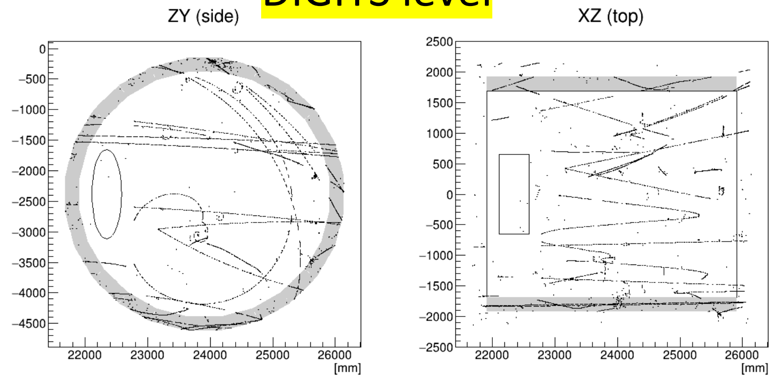
PARTICLE level



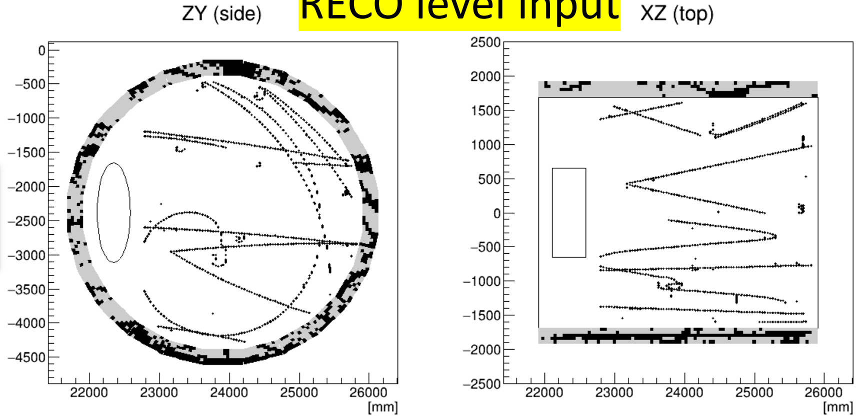
SAND + TMS + NDLAR (no rock-muon)

(not time-gated)

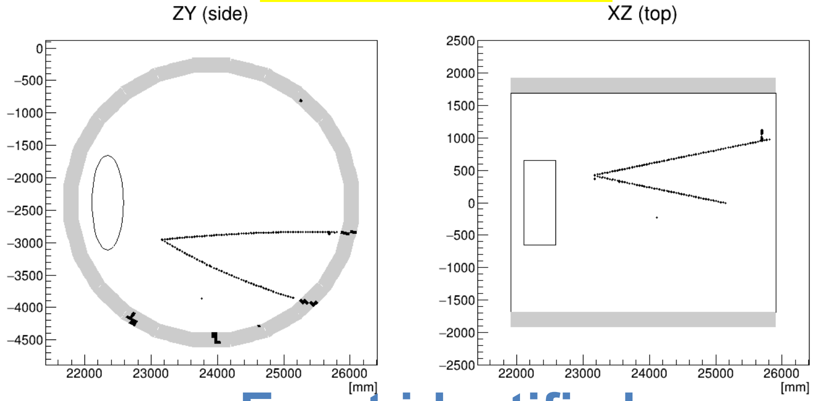
DIGITS level



RECO level input



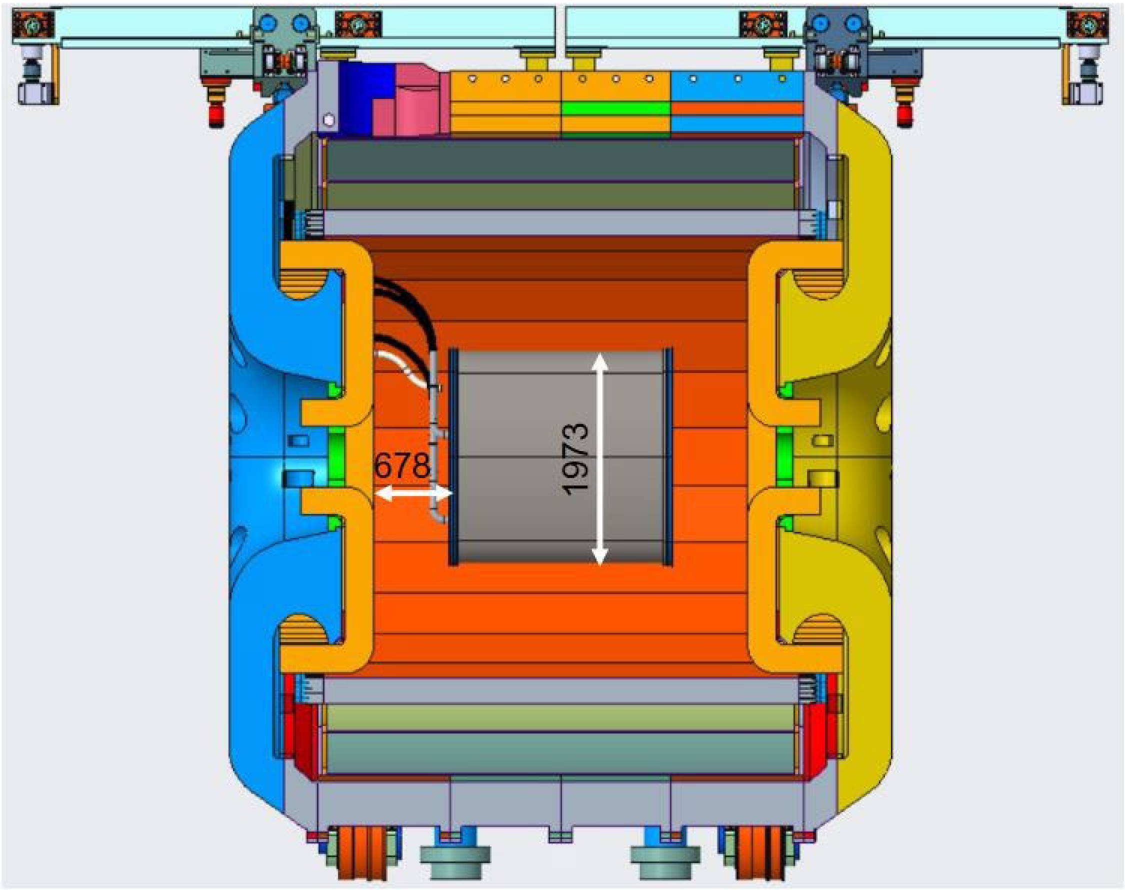
time-gated 100 ns

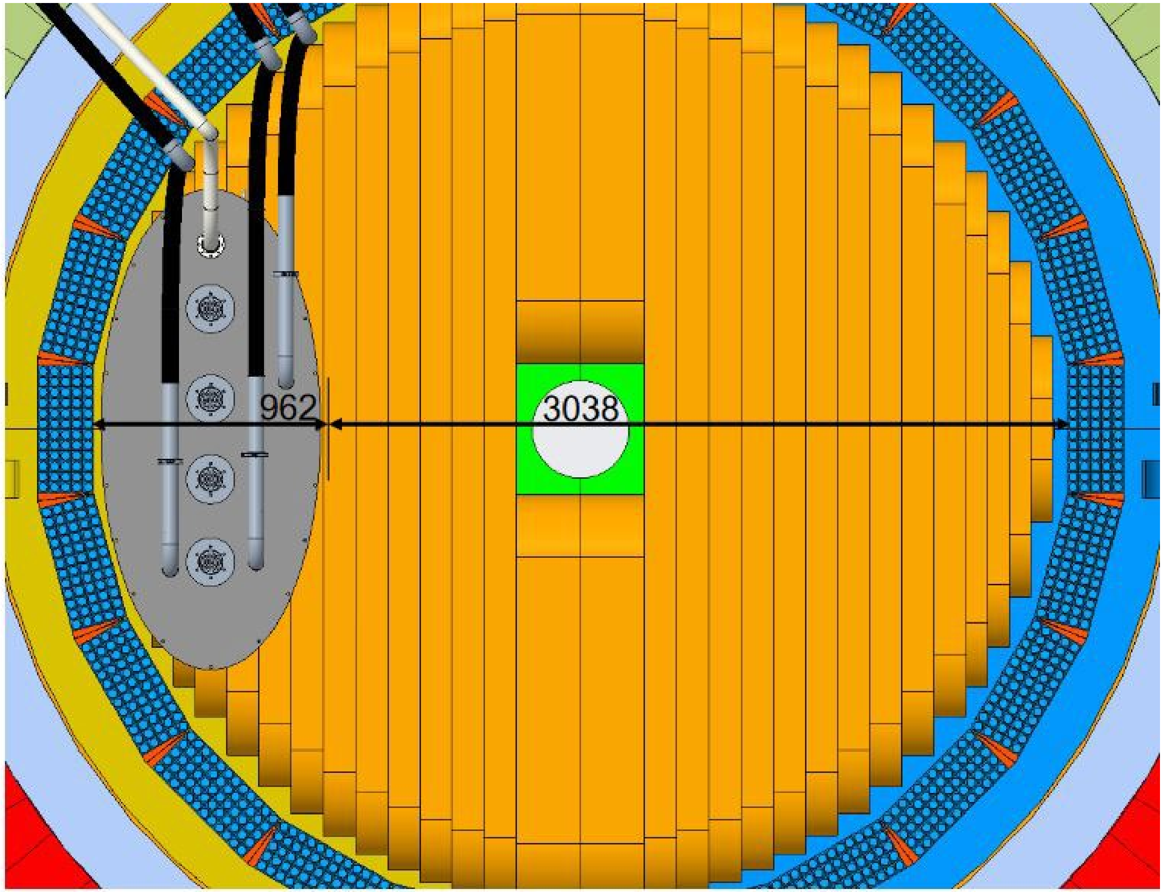


Event identified

GRAIN integration

- Dimensions (clearance included) increased wrt first draft design
  - Internal vessel volume is the same but some mechanical parts and tubes were missing





ASIC wire bonding

- 8 Alcor (32 ch) were succesfully wire bonded and are working fine
  - Thanks to INFN Torino group!!