Introduction to GRAIN detector

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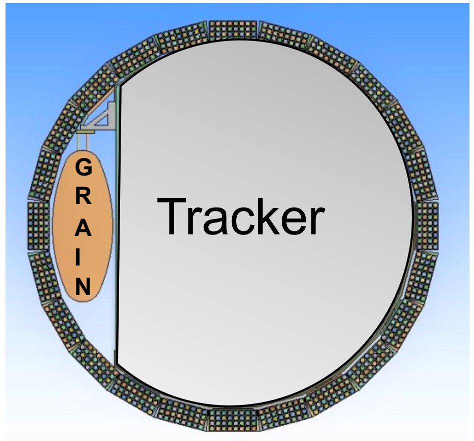
University of Genova and INFN Genova

DUNE CSN1 Review

July, 11th 2024

Why GRAIN in SAND?



- DUNE ND complex needs to constrain systematic uncertainties
- SAND is the unique detector permanently on axis

GOALS of SAND

- monitor for beam parameter changes on a weekly basis
- perform cross-section studies on different nuclear targets
- ν_μ , ν_e , $\bar{\nu}_\mu$, $\bar{\nu}_e$ on-axis sample

for a robust LBL analysis in combination with ND-LAr+TMS

Interactions on ECAL

Interactions on Tracker

Interactions on GRAIN

Events in GRAIN

Target	CP optimized FHC (1.2MW, 2y)				CP optimized RHC (1.2MW, 2y)			
	ν_μ CC	$\bar{\nu}_\mu$ CC	ν_e CC	$\bar{\nu}_e$ CC	ν_μ CC	$\bar{\nu}_\mu$ CC	ν_e CC	$\bar{\nu}_e$ CC
CH_2	13,010,337	624,330	192,118	31,902	2,035,973	4,870,562	91,004	69,278
H	1,222,576	111,574	18,396	5,557	194,216	906,130	8,712	12,434
C	1,547,011	67,294	22,799	3,458	241,710	520,287	10,800	7,460
Ar	3,114,331	121,506	46,384	6,503	480,862	936,489	21,932	13,867
Pb	62,127,600	2,507,940	923,012	130,680	10,375,400	18,222,200	437,284	265,304

0.1 neutrino interactions per spill

A good sample for:

- inclusive/exclusive CC sample with a magnetic spectrometer **← ND-LAr+ TMS**
- cross-section constraints / tuning nuclear model
- a comparison with hydrogen interactions

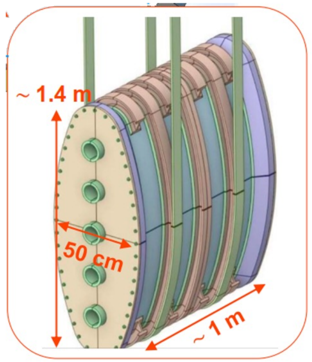
SAND multi-target

$$N_X(E_{rec}) = \int_{E_\nu} dE_\nu\, \Phi(E_\nu)\, P_{osc}(E_\nu)\, \sigma_X(E_\nu)\, R_{phys}(E_\nu, E_{vis})\, R_{det}(E_{vis}, E_{rec})$$

at NEAR $\qquad P_{osc} \sim 1$

SAND LAr interactions

GRAIN requirements



As a **passive** target:

- thin volume (minimum number of X_0)
- thin cryostat

Impose limits on cryostat **size** and **material**

There is the needs of R&D for imaging

As an **active** target:

- contribute to the neutrino energy reconstruction, for **recovering the energy** lost in LAr
- identify the **interaction vertex** and **tracks** of contained particles (protons, pions)
- matching with back-propagated tracks from the tracker.
- select interactions in terms of exclusive final state particles

  widens phase space (large angles w.r.t. beam axis, lower momentum + short particles not exiting).

- exploting the high resolution O(200 ps) **timing information**
  - SAND is the unique fast detector in the ND complex

GRAIN: Mechanics

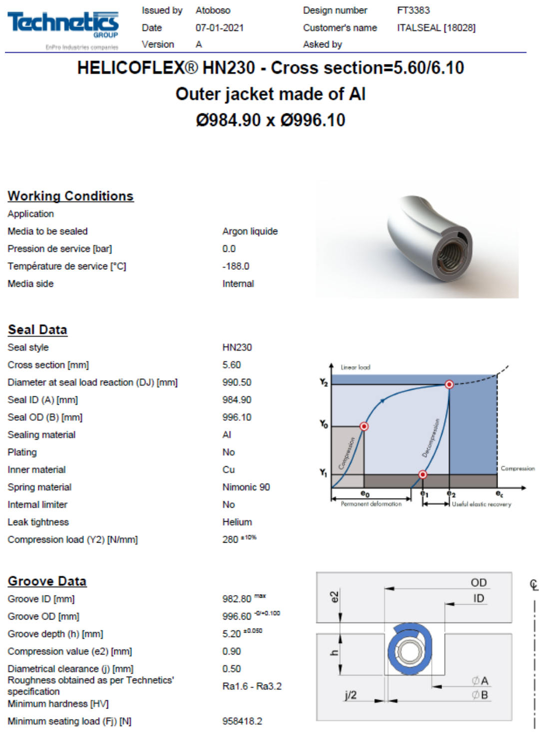
CSN1 review of SAND – Jul 11, 2024

Gianluigi Piazza

Inner vessel

Preliminary studies has been carried out, but the design has to be certified for EN13445 standards. An order for calculation has already been issued.

In the meantime, Technetics is conducting a study to validate the identified Helicoflex gasket in order to ensure a leak rate of 10^{-8} mbar·l/s



Technetics GROUP
EnPro Industries companies

Issued by	Atoboso	Design number	FT3383
Date	07-01-2021	Customer's name	ITALSEAL [18028]
Version	A	Asked by	

HELICOFLEX® HN230 - Cross section=5.60/6.10
Outer jacket made of Al
Ø984.90 x Ø996.10

Working Conditions

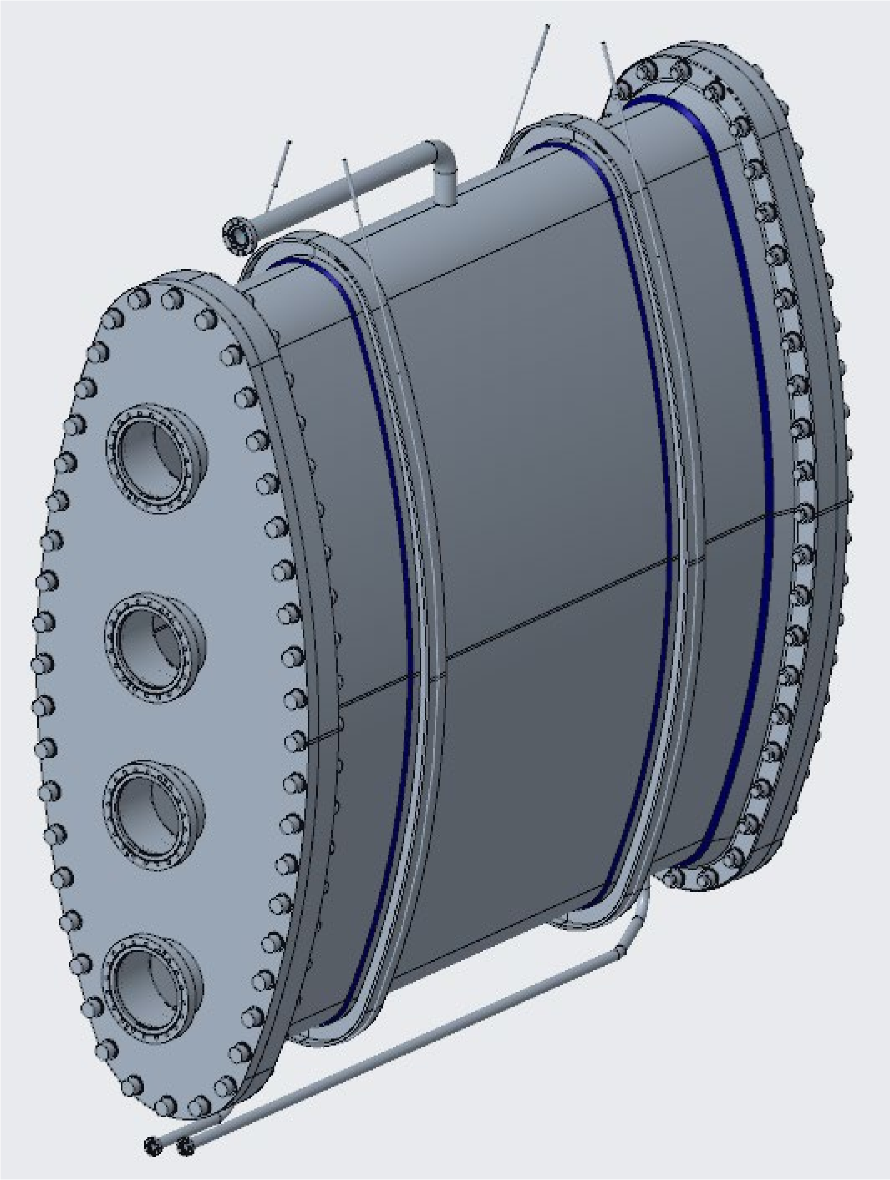
Application	
Media to be sealed	Argon liquide
Pression de service [bar]	0.0
Température de service [°C]	-188.0
Media side	Internal

Seal Data

Seal style	HN230
Cross section [mm]	5.60
Diameter at seal load reaction (DJ) [mm]	990.50
Seal ID (A) [mm]	984.90
Seal OD (B) [mm]	996.10
Sealing material	Al
Plating	No
Inner material	Cu
Spring material	Nimonic 90
Internal limiter	No
Leak tightness	Helium
Compression load (Y2) [N/mm]	280 $^{\pm 10\%}$

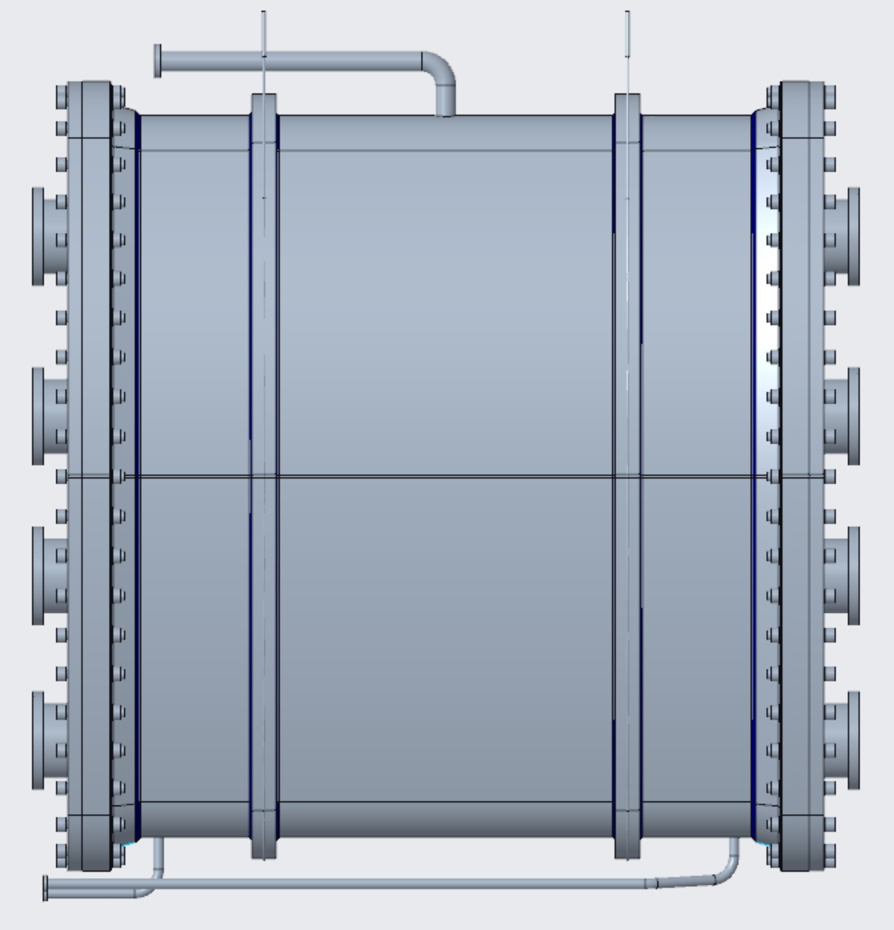
Groove Data

Groove ID [mm]	982.80 ^{max}
Groove OD [mm]	996.60 $^{-0/+0.100}$
Groove depth (h) [mm]	5.20 $^{\pm 0.050}$
Compression value (e2) [mm]	0.90
Diametrical clearance (j) [mm]	0.50
Roughness obtained as per Technetics' specification	Ra1.6 - Ra3.2
Minimum hardness [HV]	
Minimum seating load (Fj) [N]	958418.2



INFN DUNE

Internal vessel design

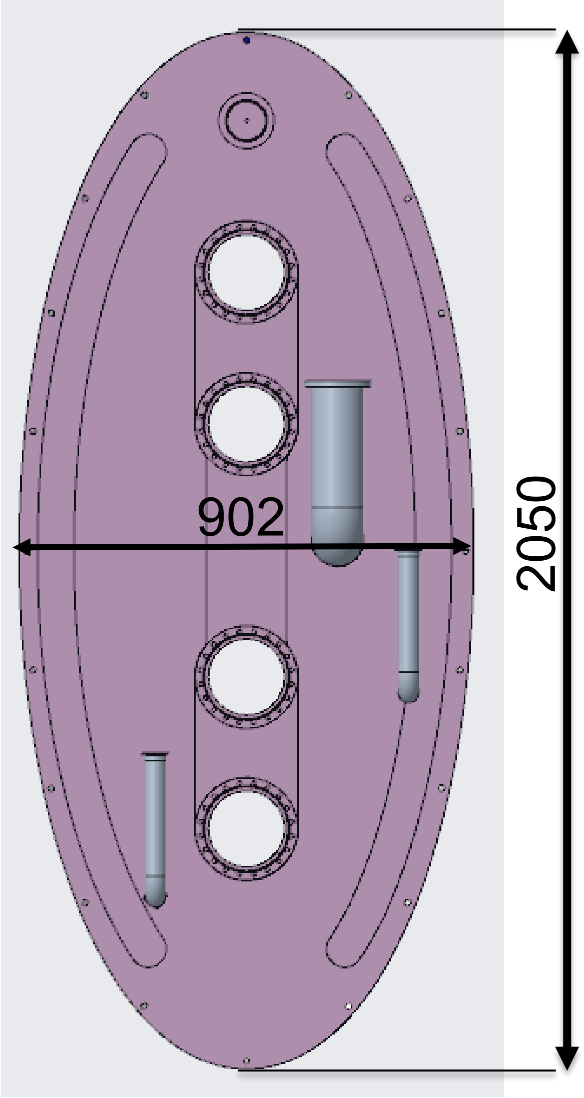


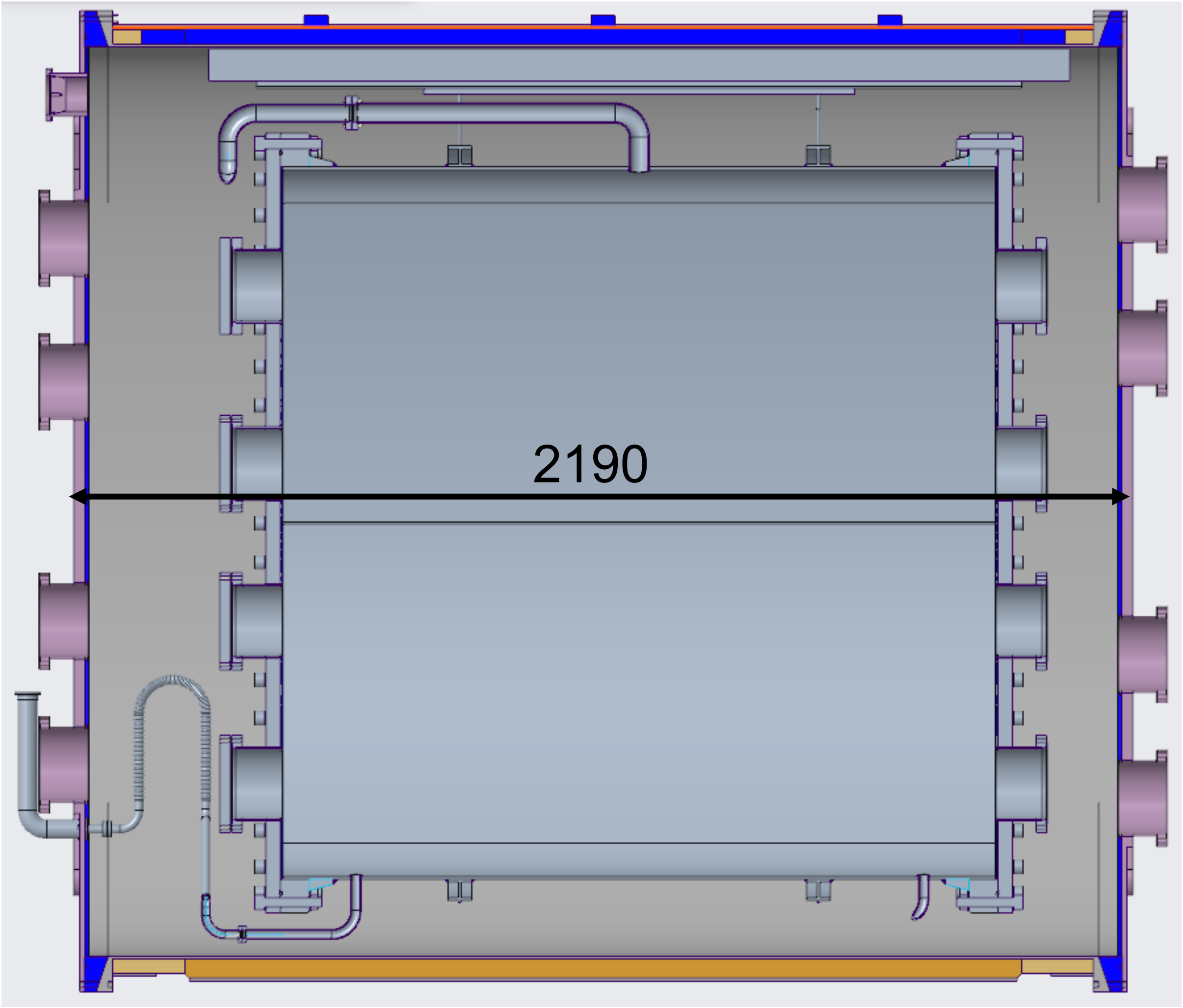
- Material: AISI 316 L
- Body wall thickness 6 mm
- Cover thickness 30 mm
- Internal pressure 1,5 bara

4 DN160 CF flanges per side, feedthrough to be defined.

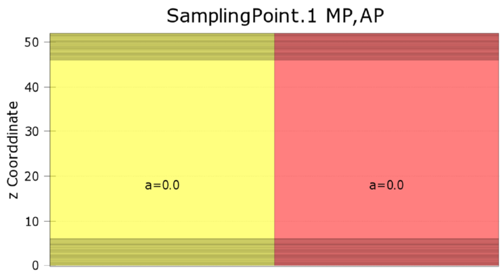
Suspension is provided by 2 stainless steel wire ropes with a thickness of 5 mm

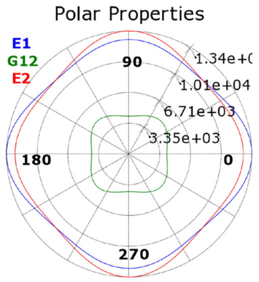
Vacuum tank



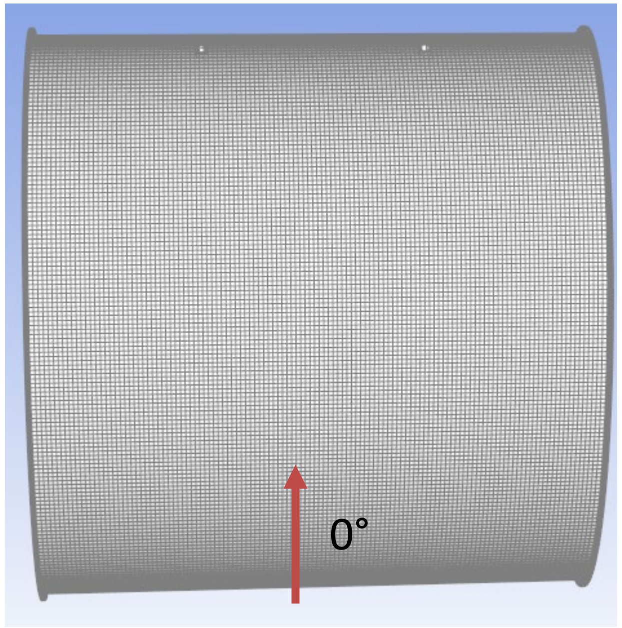


Vacuum tank

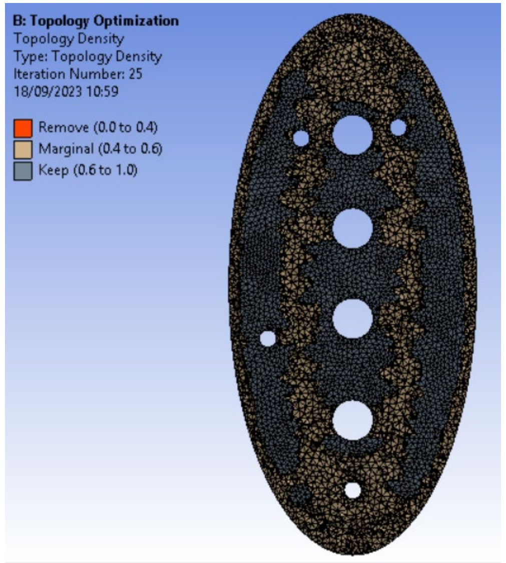


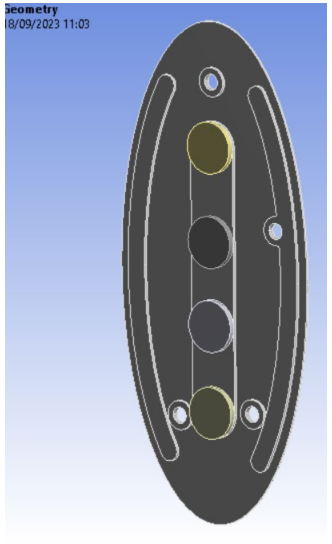


- Lay-up sequence main body:
  $[\ (45/0/45)_{10}\ ]$ + Core + $[\ (45/0/45)_{10}\ ]$
  Core thickness 40 mm



- Covers in aluminum alloy AA7075:
  Preliminary thickness optimization 12-24 mm

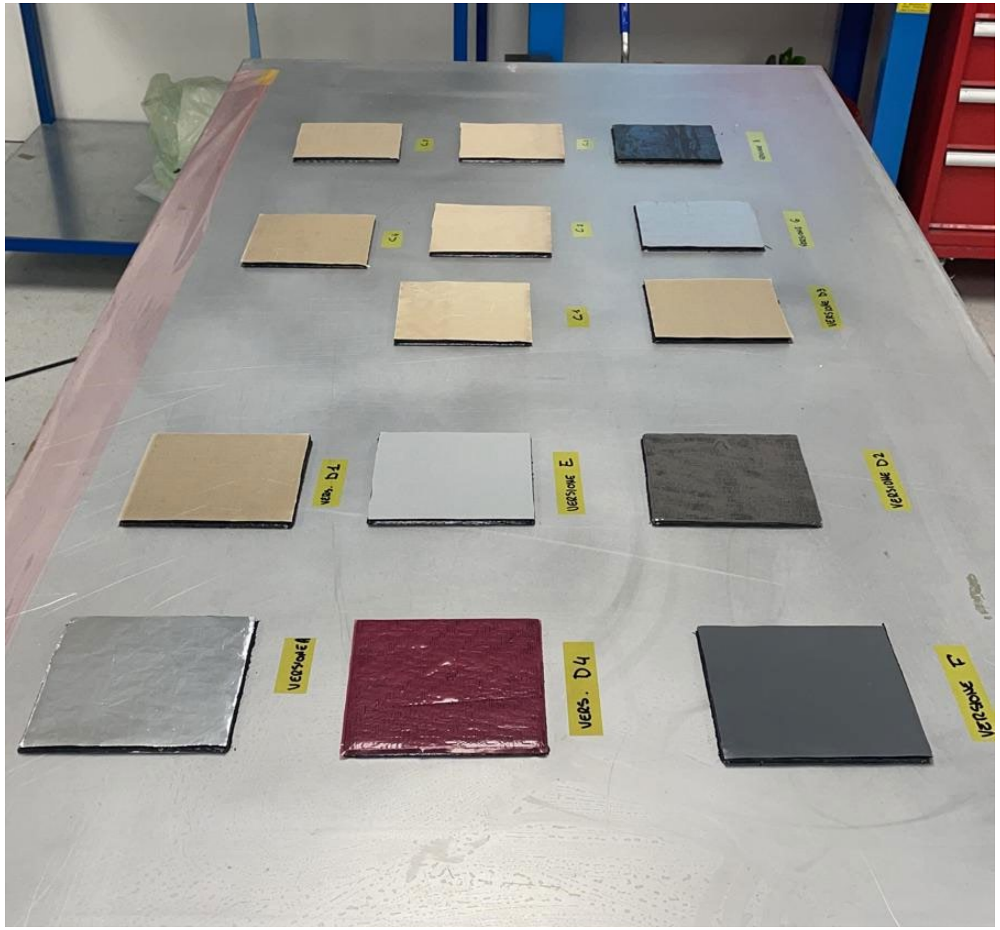




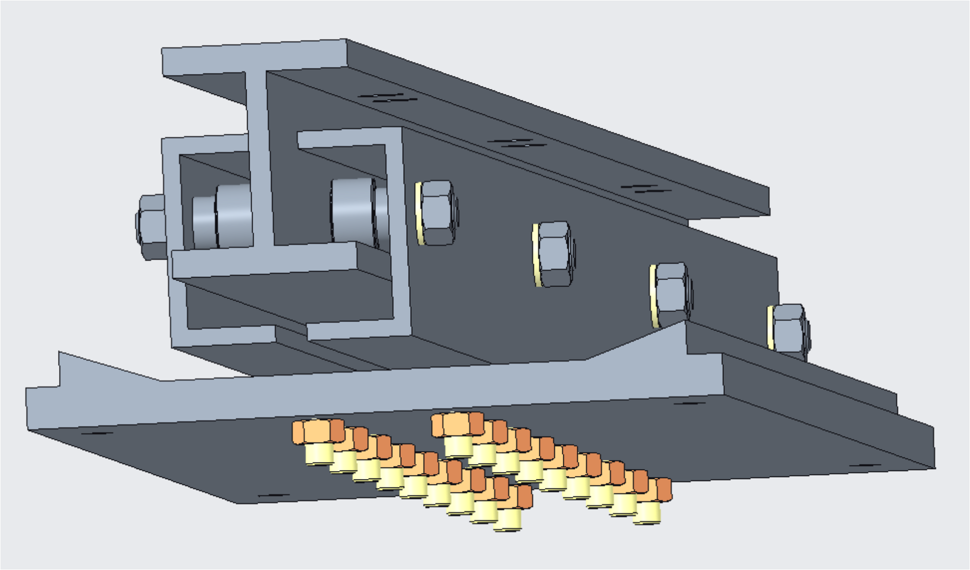
CFRP samples

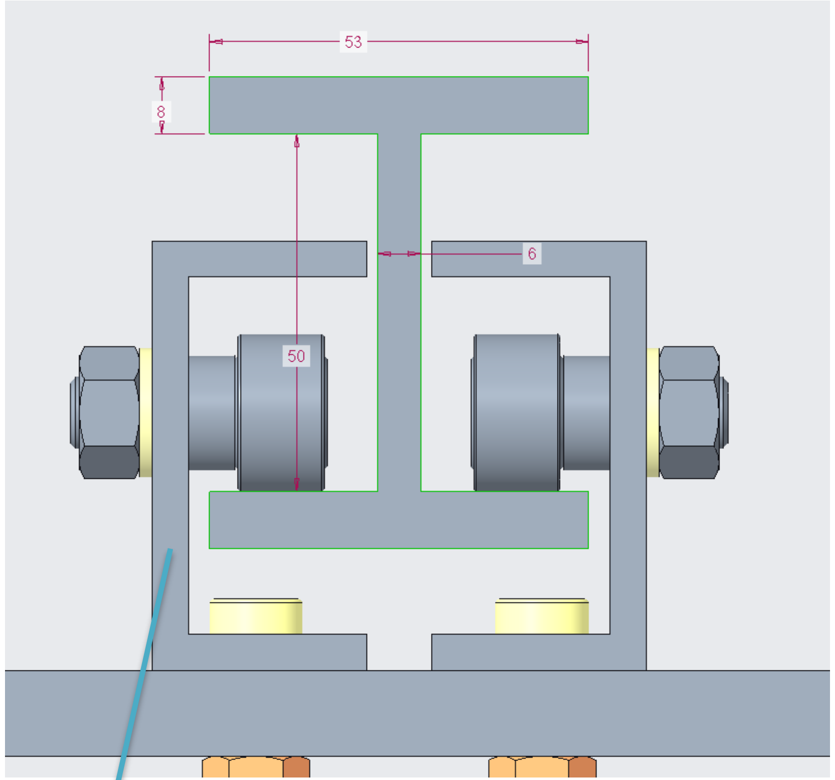
In order to understand feasibility of vacuum and to choose the best solution for the future mock-up, a campaign of outgassing test is currently underway in LNF.

Different samples with different coatings (aluminum foil, various resins) have been prepared by Refraschini company and are ready to test.



Sliding system





IPE beam like:

h=66 mm
b=53 mm
tf=8 mm
tw=6 mm
L=1800 mm

Montanstahl can produce laser welded customised profiles in 316L
1500 € for 3000 mm ca

C beam IPA hot rolled, dimensions: 60x30x5 mm, 1600 mm long

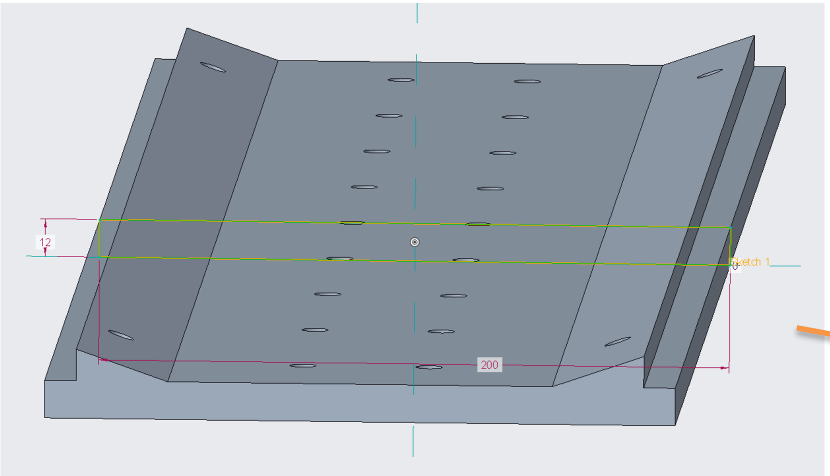
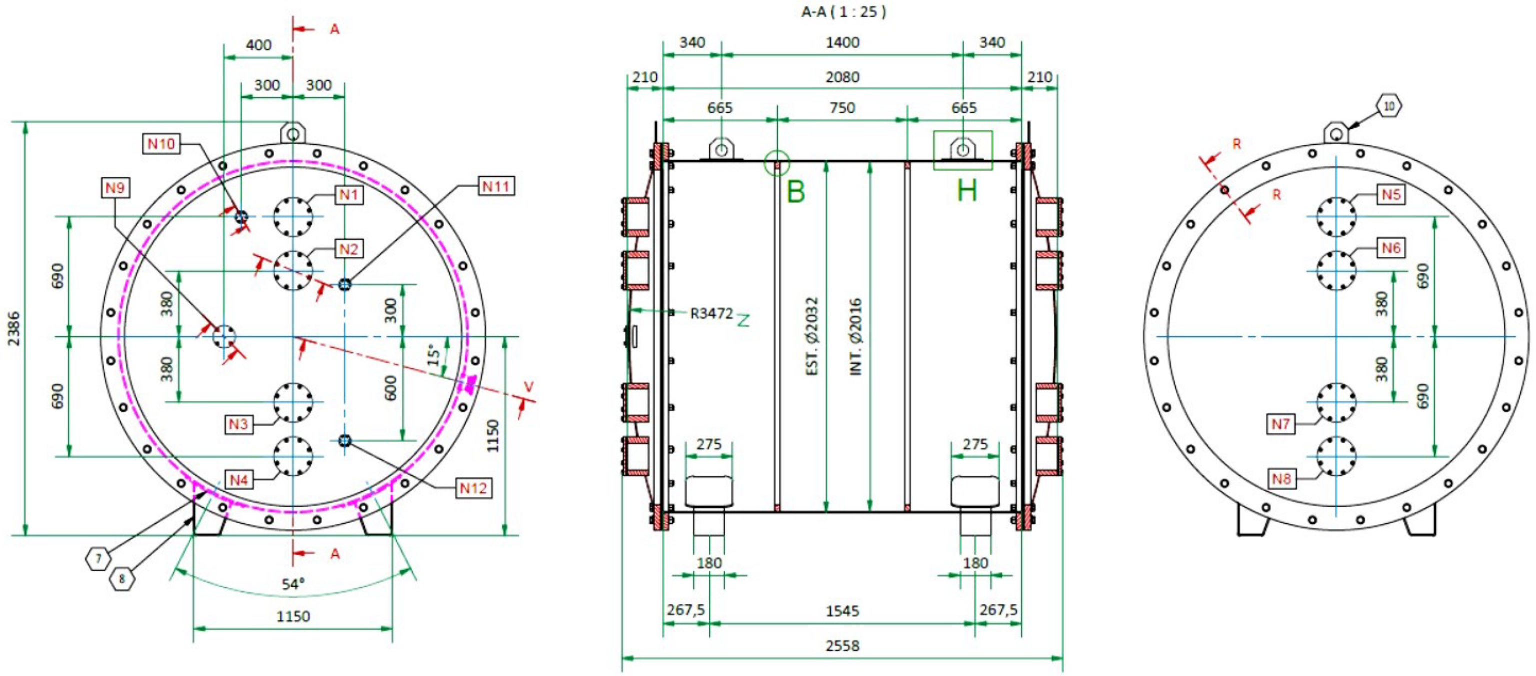


Plate 200x12x900 mm

first vacuum tank for LNL facility test

To test cryogenics in LNL,
it has been decided to use a temporary stainless steel vacuum tank

Almost all details have been discussed with the company CryoService
that is starting to manufacture. It will be ready in 6 months

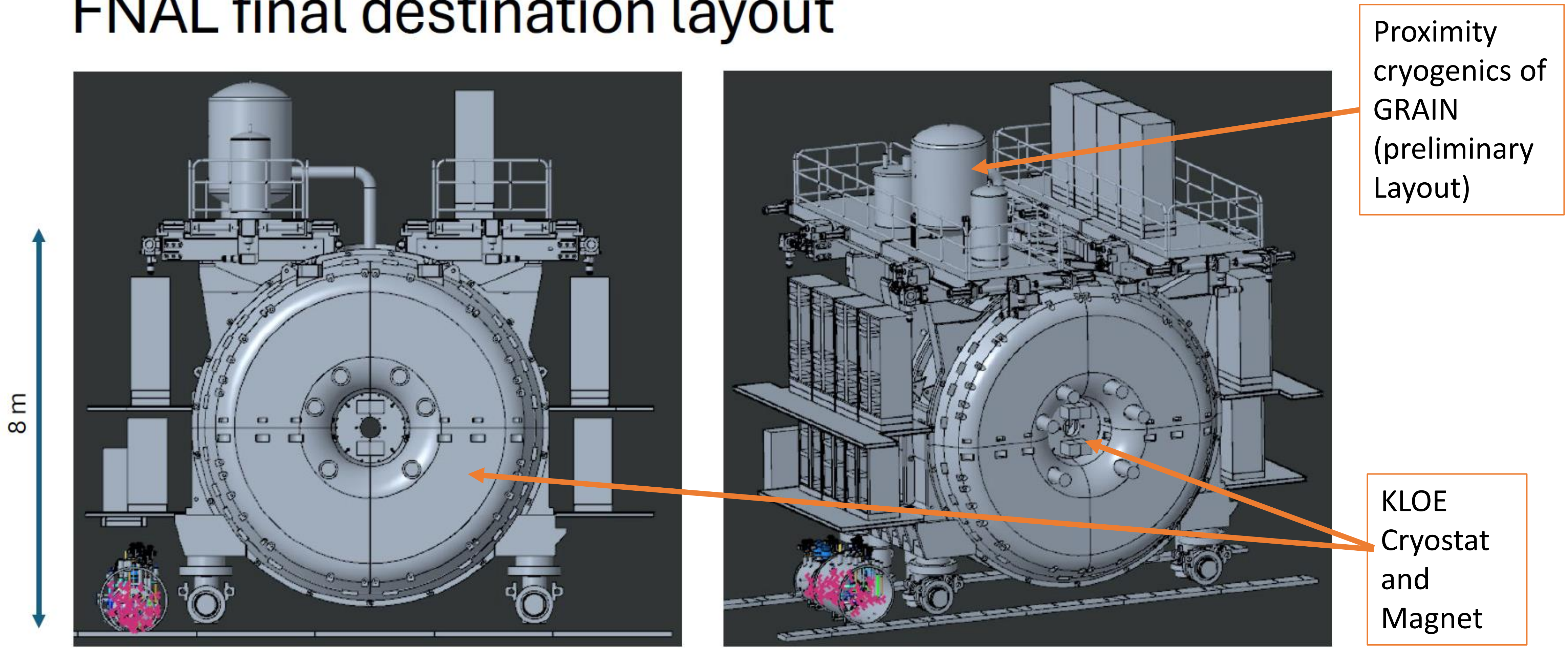


CRYOGENICS FOR GRAIN

CSN1 Review of SAND
July 11th-12th 2024

R.Pengo, G.Piazza & the cryogenic service of LNL

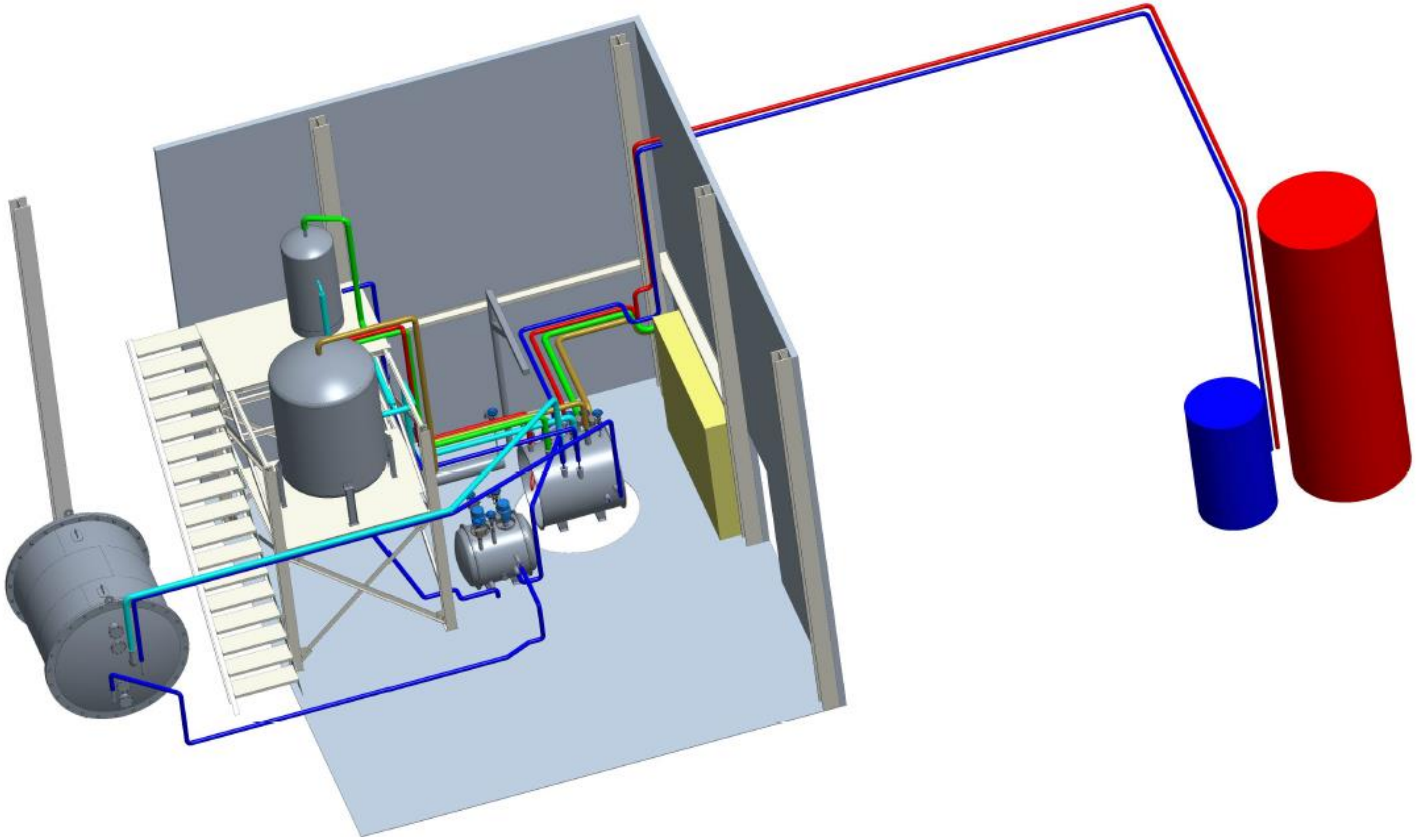
FNAL final destination layout



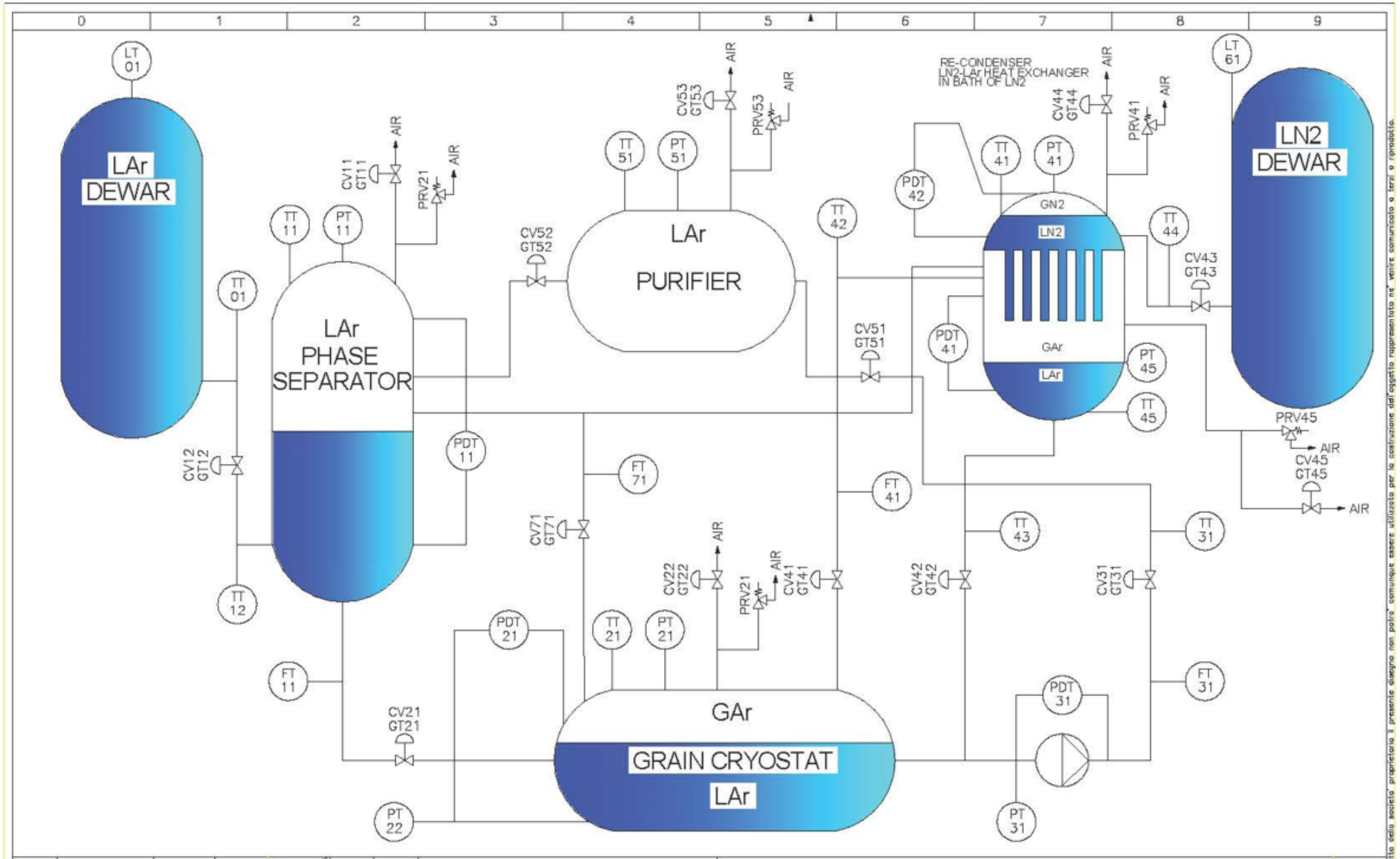
Refurbishment of LNL lab

- Existing LN2 tank outside
- Four new transfer lines (vacuum insulated) are being installed:
    - IN/OUT for LN2/GN2
    - IN/OUT for LAr/GAr

LNL preliminary layout



SIMPLIFIED P&ID



Name	Date	Draw.N.	Plant
Drawing by		CAE	Comm. COMMESSA
Controlled		File Name NOME-FILE	Description
Approved		Date DATA	

REV | CHANGE | DATE | SIGNAT. — Sheet 60, Next 86, TOT.

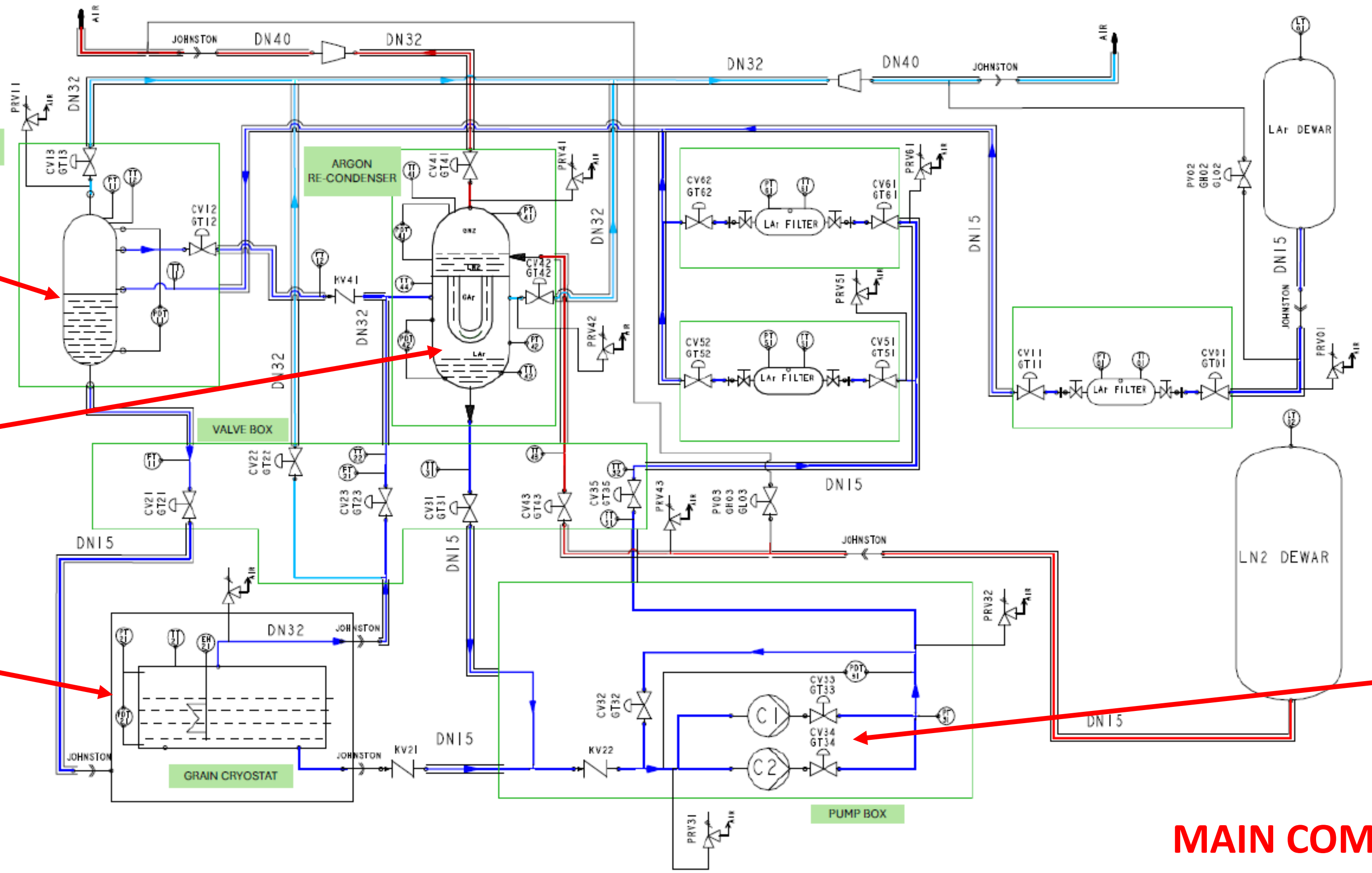
TT: Temperature Transmitter
PT: Pressure Transmitter
PDT: Differential Pressure Transmitter
FT: Mass Flow Transmitter
CV: Control Vave
PV: Valve ON/OFF
PRV: Pressure Relief Valve

GRAIN Piping & Instrumentation Diagram

Phase Separator (PS)

GAr Re-liquefier

GRAIN Cryostat



Online LAr Purifiers/Filters

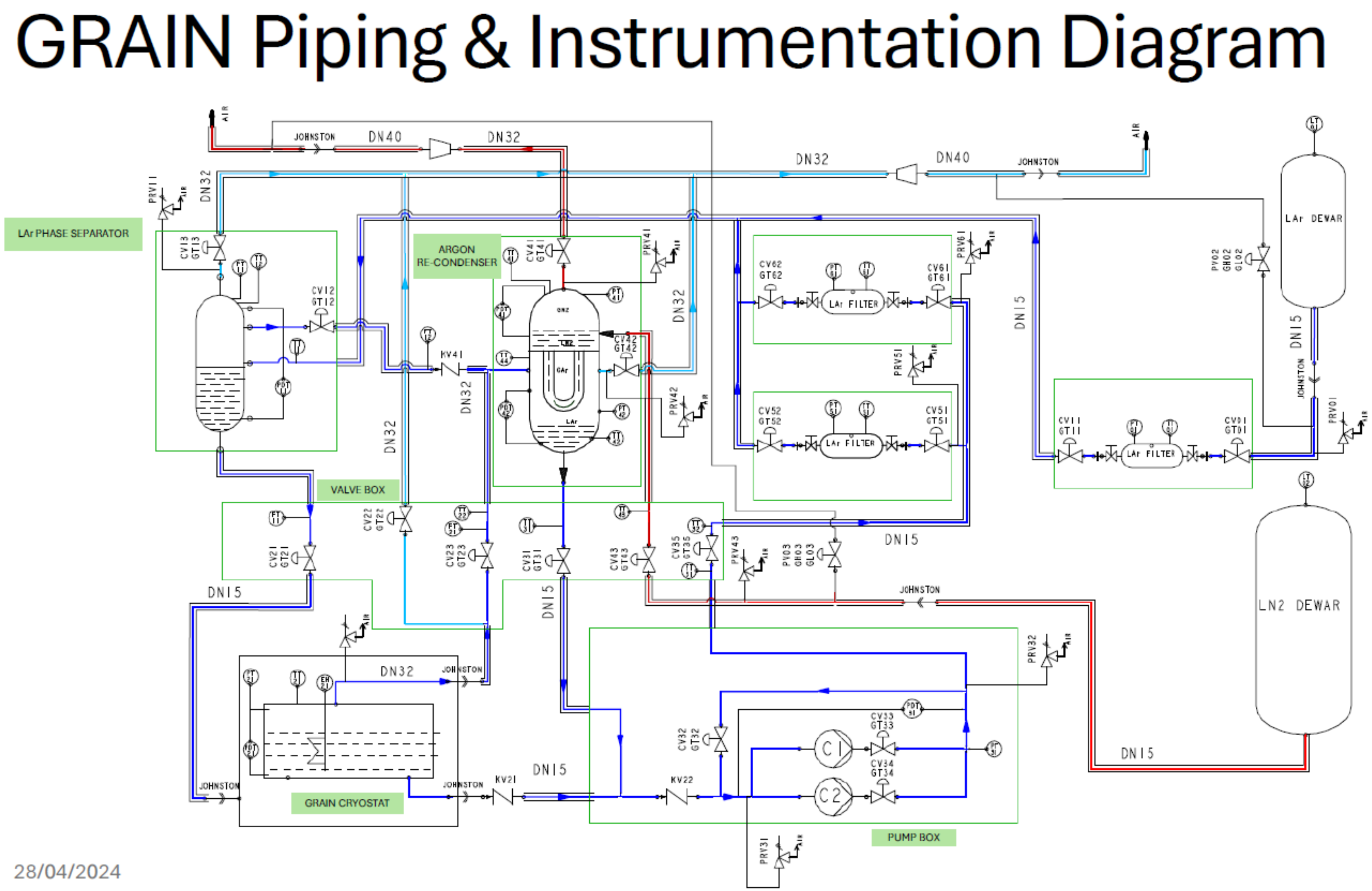
Filling LAr Purifiers/Filters

Centrifugal LAr pumps

MAIN COMPONENTS

28/04/2024

Normal operation



1) *Centrifugal pump* is circulating the LAr:

- through the purifier
- to the phase separator (PS)

2) The GAr boil-off of both the cryostat and of the PS enter the *re-liquefier*, where it is liquefied with the *aid of LN2* at the pressure corresponding to LAr (ca. 2.8 bar)

Cryogenic specifications

- Recirculation of LAr will be provided by *centrifugal pumps*: one at LNL, two at FNAL (one redundant)
- *Maximum heat* load 1500 Watt (800 liters LN2 for 24 hours of operation)
- *Mass flow* of LAr max. 20 g/s (one GRAIN volume in 20-24 hours)
- Maximum head (Delta P) necessary: 0.5 bar (3.5 m) at LNL and 1.1 bar (8 m) at FNAL
- Two filters needed (*copper spheres*): one dismountable/replaceable for regeneration
- Control system according to *UNICOS CERN* (WINCC OA) (see scheme)

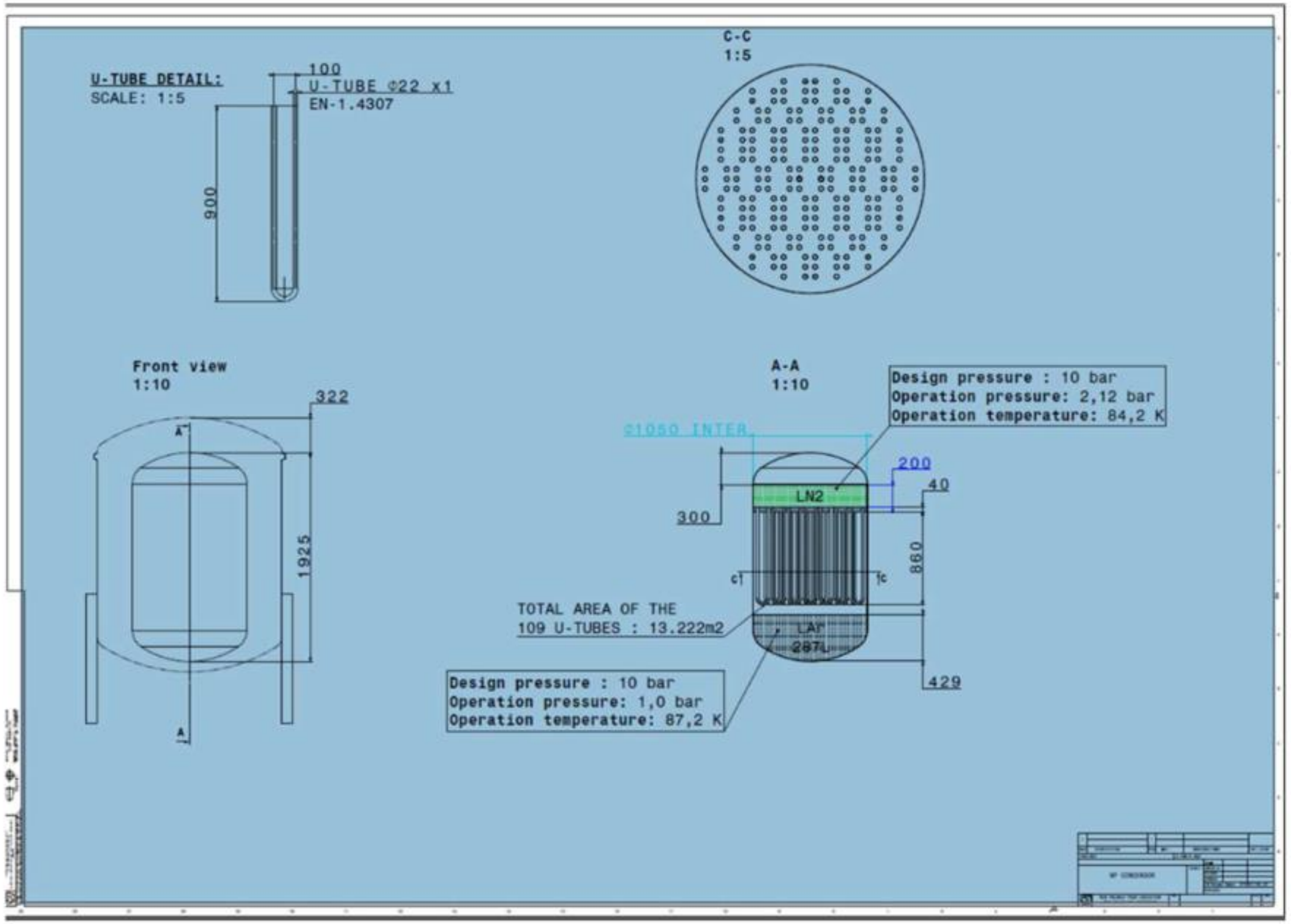
Cryogenic specifications (status)

- Recirculation will be provided by centrifugal pumps (one at LNL/two at FNAL, one redundant)
- Maximum heat load 1500 Watt (800 liters LN2 for 24 hours of operation)=> To Be Confirmed
- Mass flow of LAr max. 20 g/s (one GRAIN volume in 20-24 hours)
- Maximum head (Delta P) necessary: 0.5 bar (3.5 m) at LNL and 1.1 bar (8 m) at FNAL=> contacts with Barber&Nichols ongoing
- Two filters needed (copper spheres): one dismountable/replaceable for regeneration => C. Montanari
- Control system according to UNICOS CERN (WINCC OA), the same for LNL and FNAL =>(see detailed scheme prepared by LNL cryogenic service, order placed)

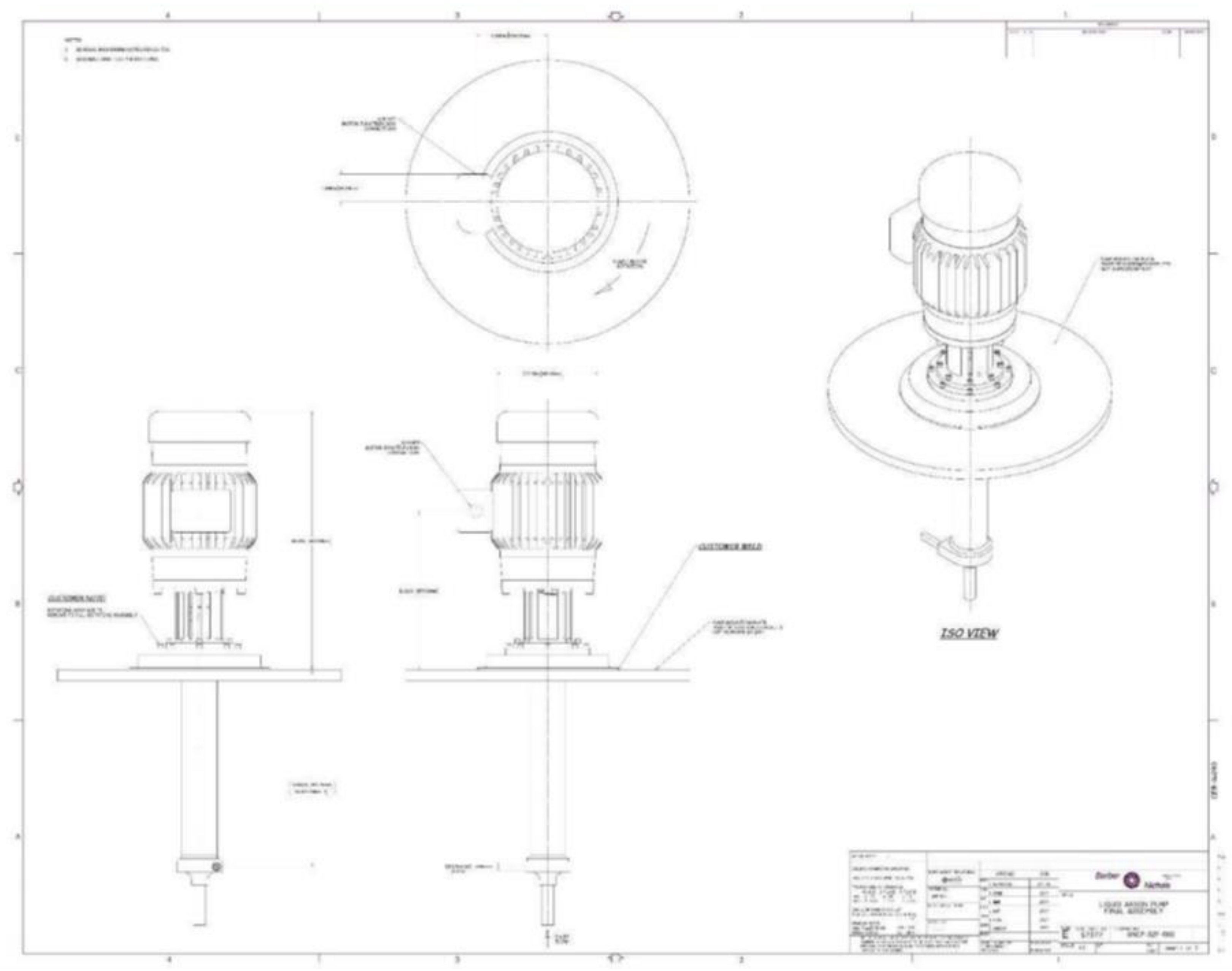
Summary of the design status of the cryogenic components

- Inner vessel (SS): designed completed
- Vacuum tank for the test facility (SS): designed completed (see G.Piazza talk)
- Vacuum tank for FNAL in Carbon fiber reinforced polymers (CFRP): design advanced
- Centrifugal pumps for LNL (head 3.5 m): design available (B&N)
- Centrifugal pumps for FNAL (head 8 m): new design to be agreed with B&N
- Phase separator: design available
- Re-condenser: design available
- Filters/purifiers: specifications available
- Control system: design ready and order placed for hardware
- Functional logics: to be prepared (UNICOS)

Re-condenser



This U-tube heat exchanger is dimensioned for 1500 W.
The boil off is produced by the static heat load, detectors heat load and feedthroughs.
The GAr formed has to be re-condensed and sent for gravity to the recirculation pump

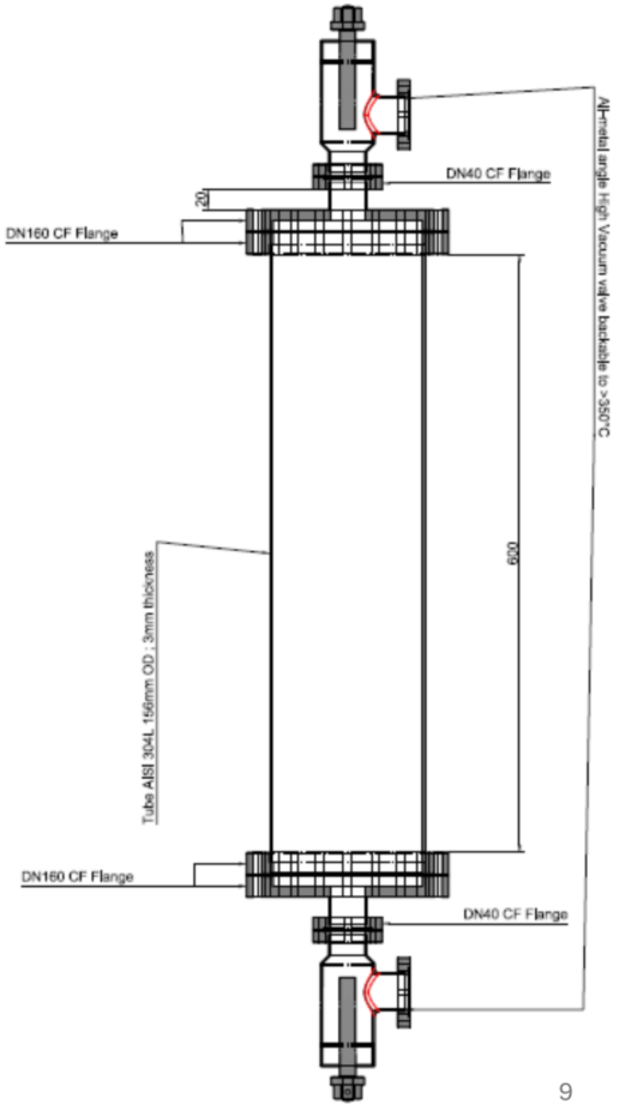

CUSTOMER WELD
ISO VIEW
LIQUID ARGON PUMP
FINAL ASSEMBLY

Purification filters

Made of molecular sieve (sintered disk) and small spheres of Al_2O_3 coated with Cu
One purifier for the filling and two in parallel for the recirculation

The filters have not been sized and designed yet.

In order to dismount and regenerate the filters there will be placed a CF flange and a manual shut-off valve on both sides;
in this way the filter can be removed and installed, preventing air from entering.



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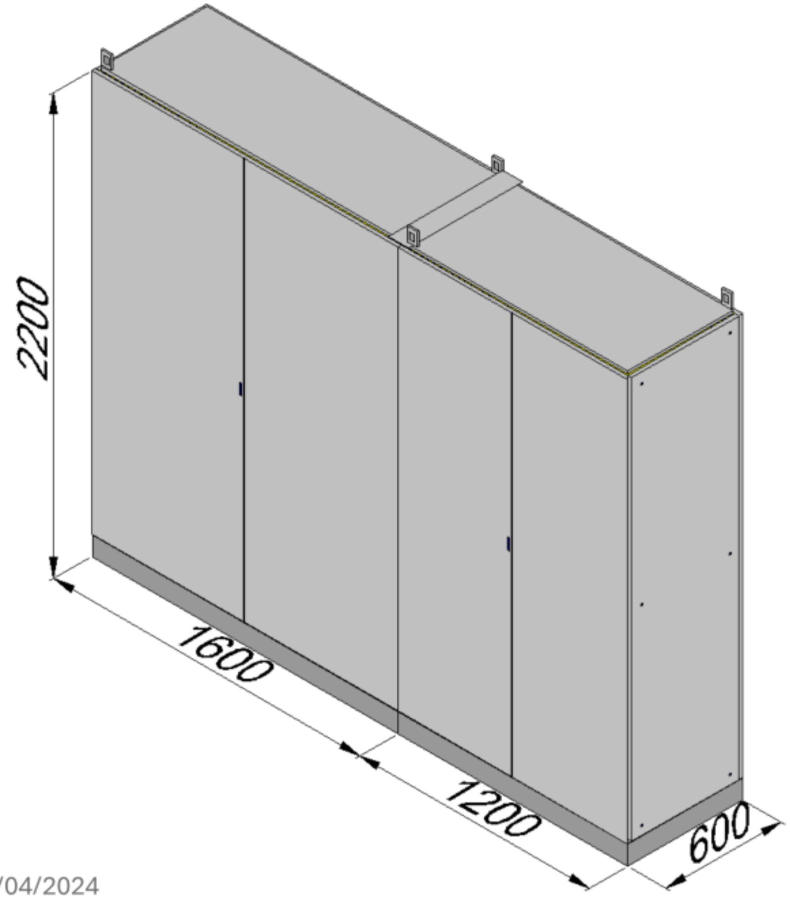
Electric control panel



The project has been completed with the help of LNL cryogenic division staff, and all the material has been delivered to LNL.

Analog Input: 52
Analog Output: 21
Digital Input: 14
Digital Output: 9

Plus some spares

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Optics and reconstruction with lenses

Alessio Caminata – Alice Campani for the Grain WG

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July 11th, 2024

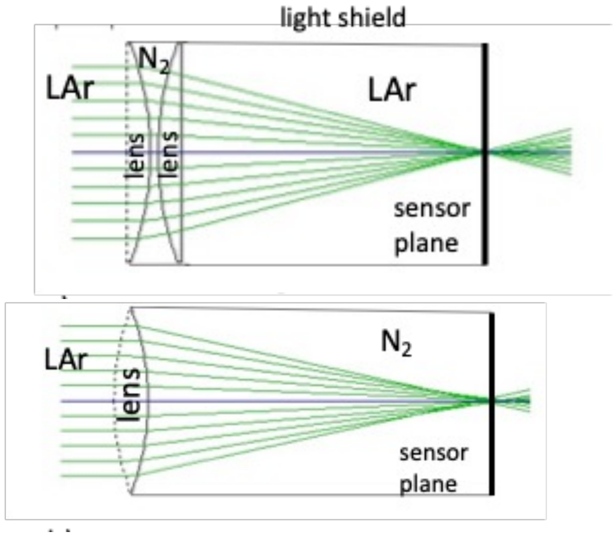
Università di Genova
INFN Istituto Nazionale di Fisica Nucleare
DUNE

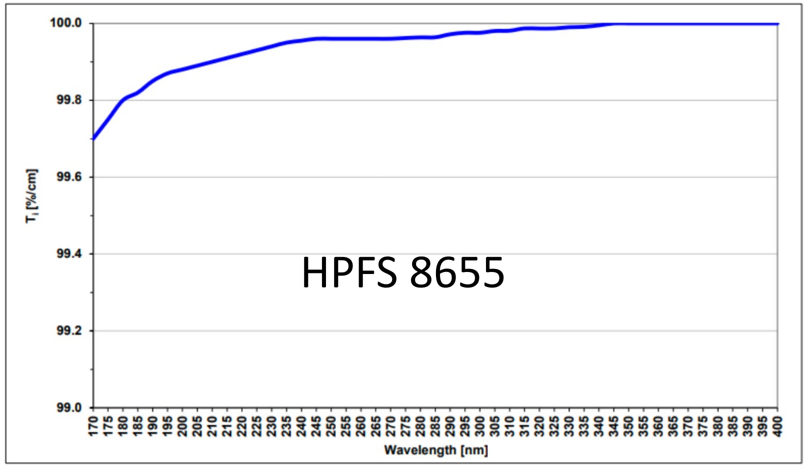
Materials and design

- Materials
  - Fused silica HPFS 8655 need of xenon doping of Argon
  - Alternative option: usage of MgF2 – no need for xenon doping

Both successfully tested in LN_2

- Design
  - Type A: Two plane-convex lenses → gas between the two lenses
  - Type B: Single bi-convex lens → gas between the lens and the sensor
- SiPMs:
  - Matrix with 32x32 SiPMs with different sizes:
  - (1mm, 2mm -> baseline, 3mm)

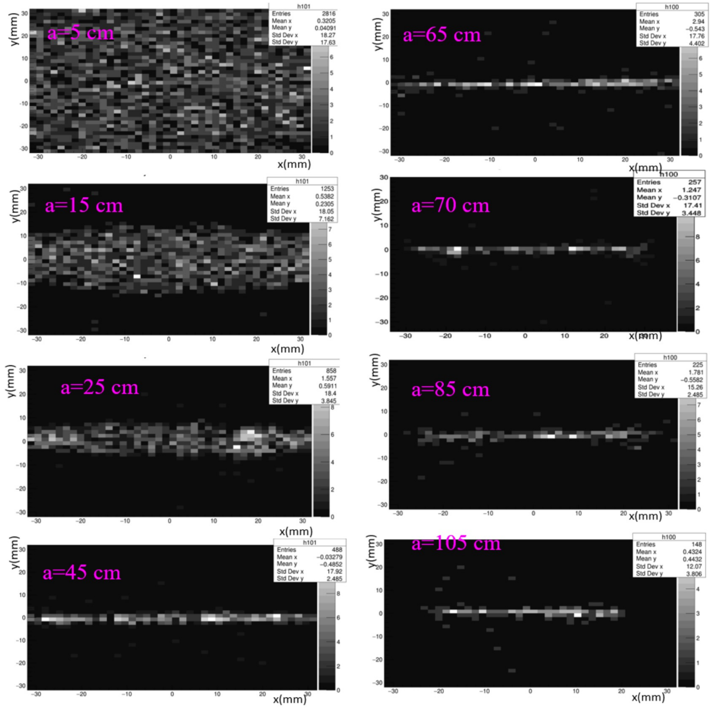




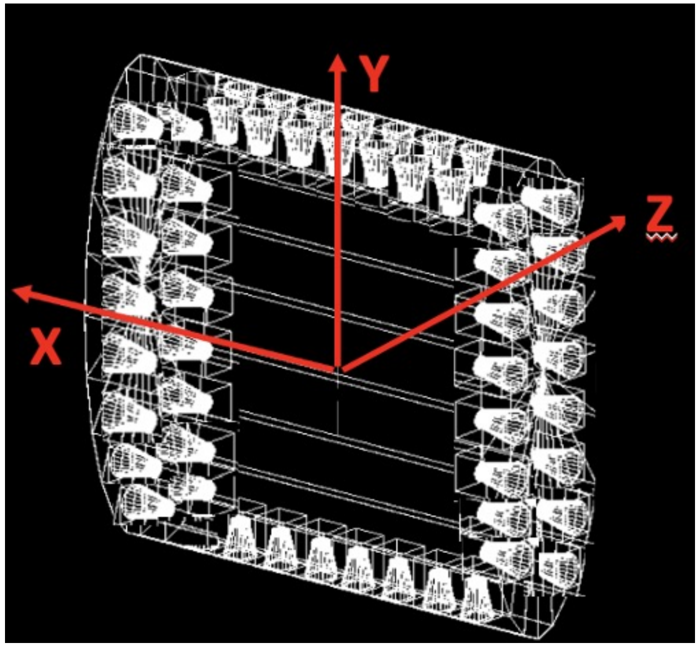
UniGe INFN DUNE

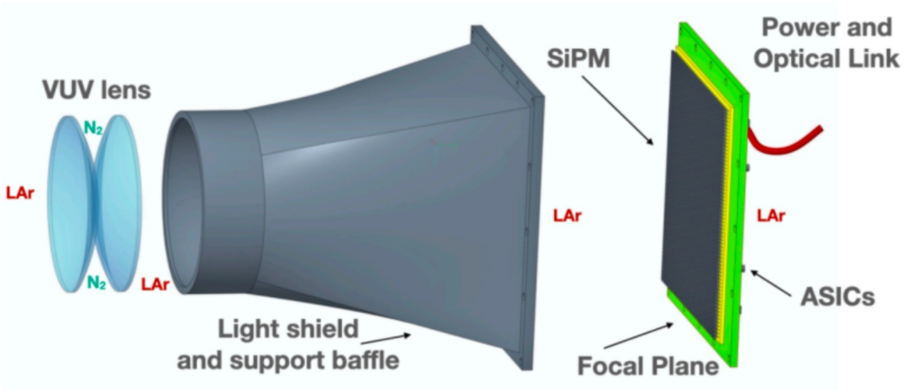
Example of the simulation results

- Geant4-based simulation framework implemented
- Capability to simulate both single interactions and spills

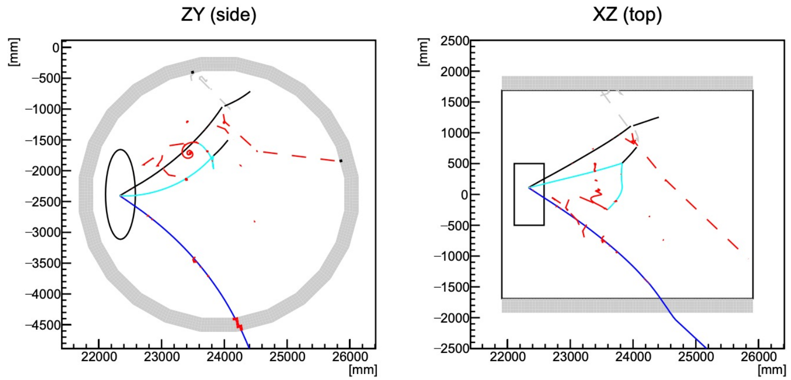


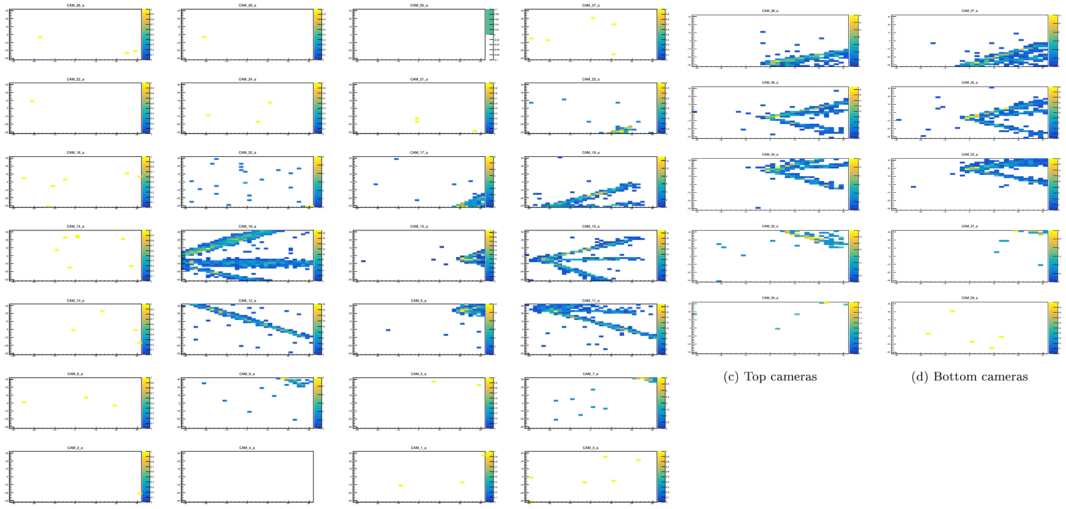
1 GeV muon parallel
to the lens central plane





Grain performance
reco and track containment

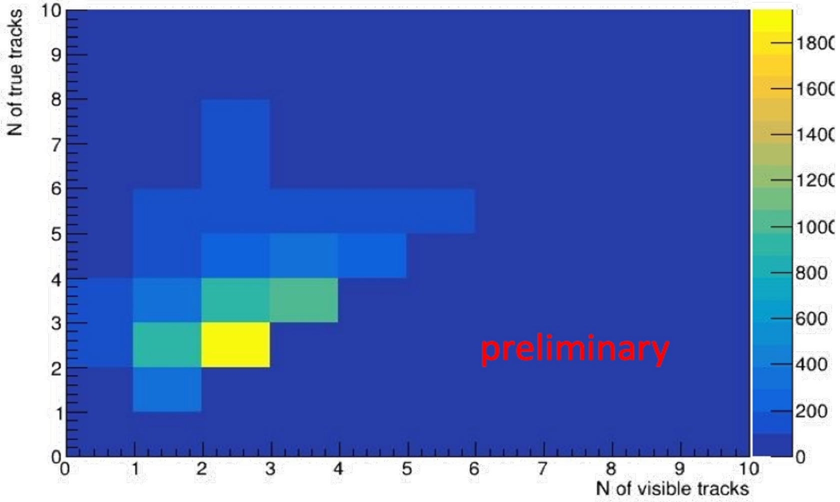




(a) Left cameras (b) Right cameras (c) Top cameras (d) Bottom cameras

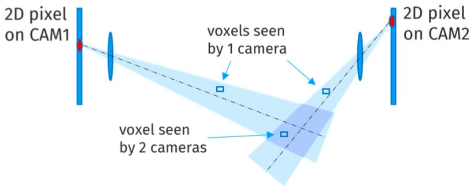
True \ Reco	Contained	Not contained
Not contained	247 (∼ 3%)	8269 (∼ 97%)
Contained	3301 (∼ 74%)	1186 (∼ 26%)

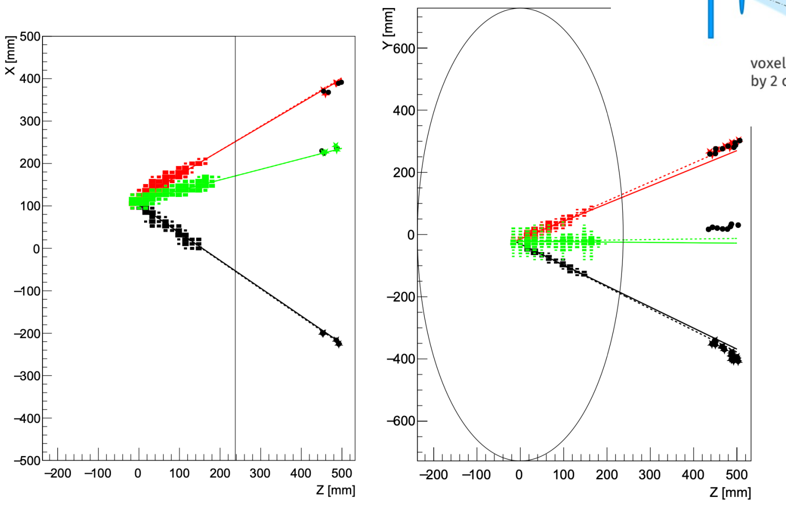
15k ν_μ CC sample and 5 cm FV cut from the cryostat walls
GRAIN+STT info used here



GRAIN performance -track reconstruction

- Track reconstruction in 2 steps:
- 2D analysis of the camera images and fit of the tracks
- 3D matching of the different tracks based on projective geometry or voxelization

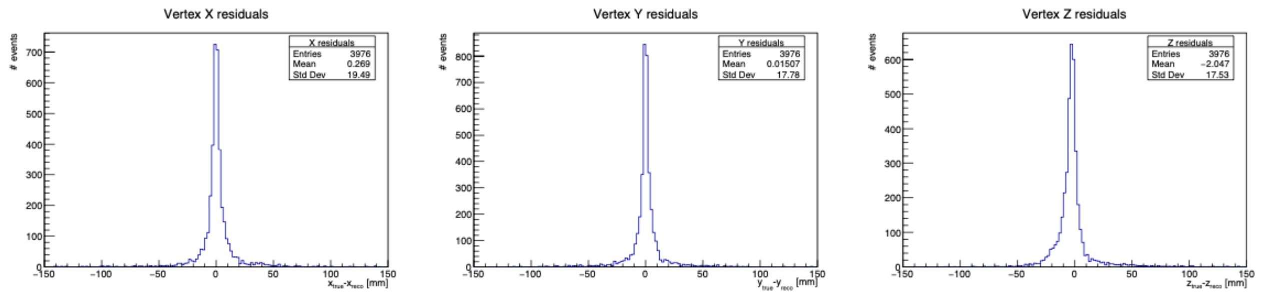




(a) ZX (top)

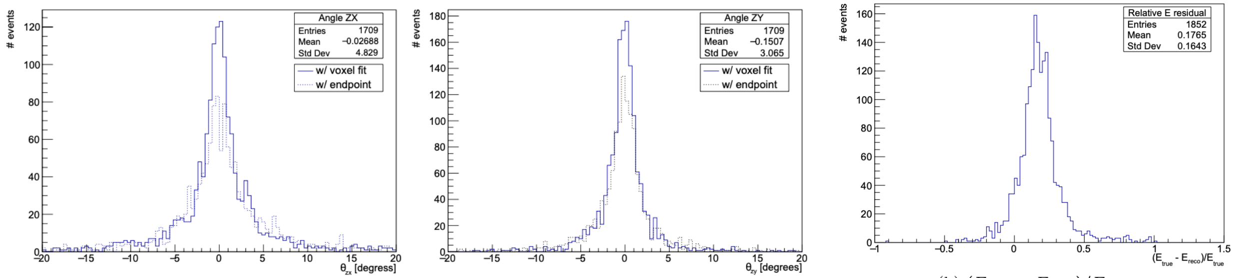
(b) ZY (side)

- Vertex detection performance



(a) (b) (c)

- Angular resolution, energy resolution



(a) Angle ZX

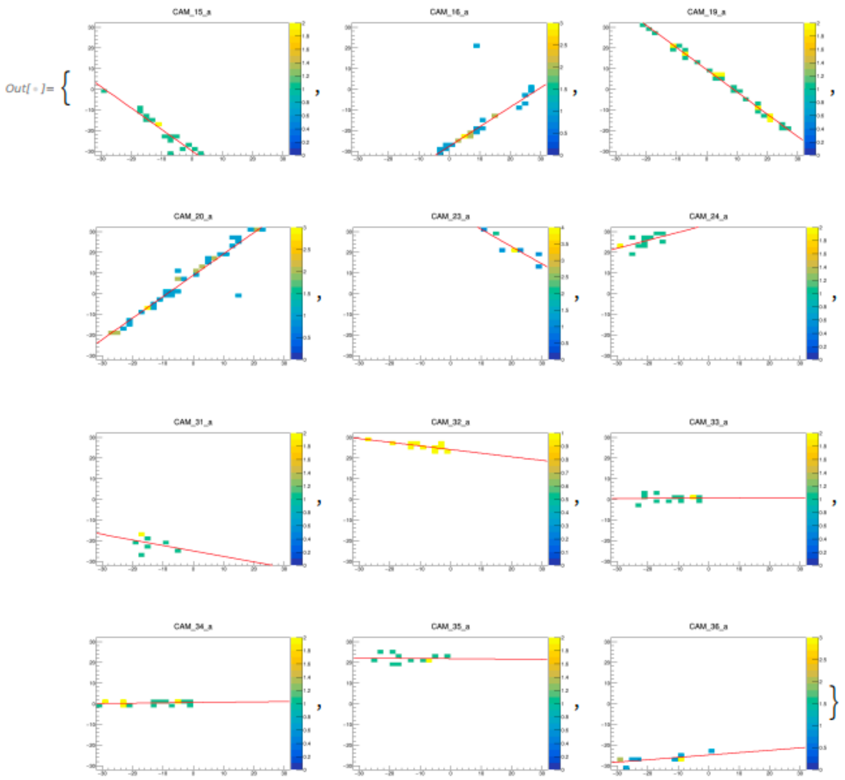
(b) Angle ZY

(b) $(E_{reco} - E_{true})/E_{true}$

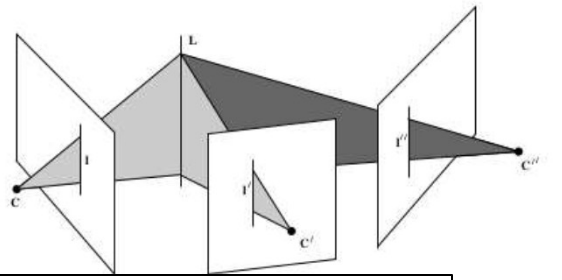
More details here

Projective geometry

- Algorithm for track reconstruction under development by Lecce group



- Single track: tested
- Test with 2 tracks from neutrino interaction: in progress



Global Multiple View Reconstruction of a Track

- The track is detected/seen by N cameras
- There are $M = \frac{N!}{2!(N-2)!}$ possible double-view reconstructions for the track
- We perform M reconstructions
- We take the mean value of the M possible reconstructions for each line parameter (director cosines (l, m, n))

$$l = \frac{\sum_{i<j}^{N} l_{ij}}{M} \quad m = \frac{\sum_{i<j}^{N} m_{ij}}{M} \quad n = \frac{\sum_{i<j}^{N} n_{ij}}{M} \qquad (21)$$

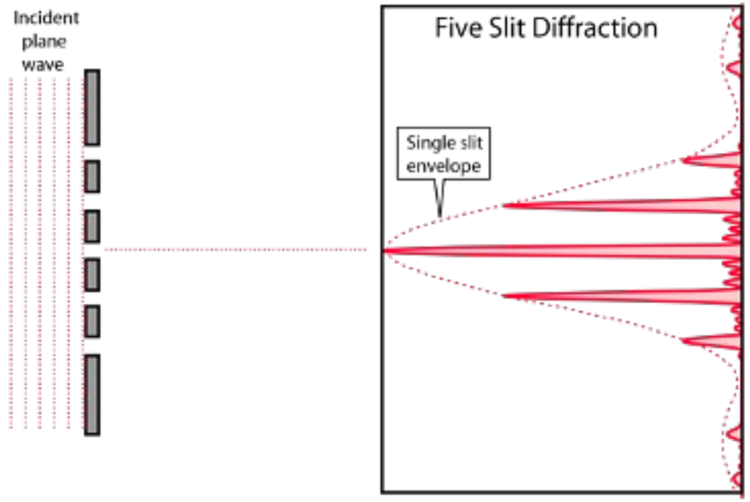
i, j camera indices

- Analysis of intercepts of the M reconstructions

LArRI:

A new setup to measure **L**iquid **Ar**gon **R**efractive **I**ndex

- LAr: most widely used scintillator, excellent properties at low cost
- Xe-doping shifts s. peak to λ_s=175 nm: increased uniformity, simplified detection
- **Main goal**: direct measurement of LAr refractive index crucial for imaging systems
- Further goals:
  - Characterize optical properties of LAr
    - Measure dispersion relation
    - Measure the attenuation length
  - Extend to other liquified noble gases

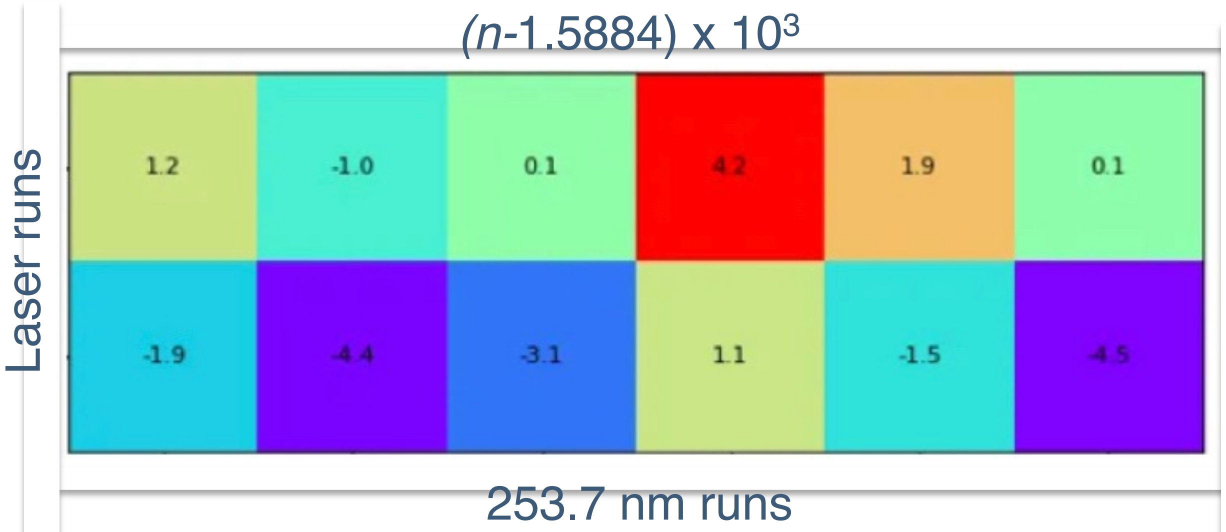


- A diffraction grating is used and when immersed in liquid the diffraction peaks position depends on $\lambda_L = \lambda_0/n$
- We need a light source:
  - Peak @λ_s, coherent and monochromatic

Key idea: compare the diffraction patterns produced by light in LAr and vacuum

LArRI: results and next steps

- Consistency check measurements:
  - Same medium (vacuum), 2 wavelengths
  - Scans @402.9 nm vs scans @253.7 nm
  - Results shown as deviations x 10^3



- Compatibility of few parts per thousand!

- Preliminary results in liquid argon:
  - Refractive index @402.9 nm nLAr = 1.24(1)
  - Refractive index @253.7 nm nLAr = 1.24(1)
  - Refractive index @184.9 nm nLAr = 1.29(5)
- Conclusions:
  - System fully operational in vacuum and liquid
  - Analysis strategy validated
- Steps moving forward:
  - Evaluation of the systematics
  - Improve measurements @185 nm
  - Take runs in LAr to achieve the target

Optics and reconstruction with Coded Aperture masks

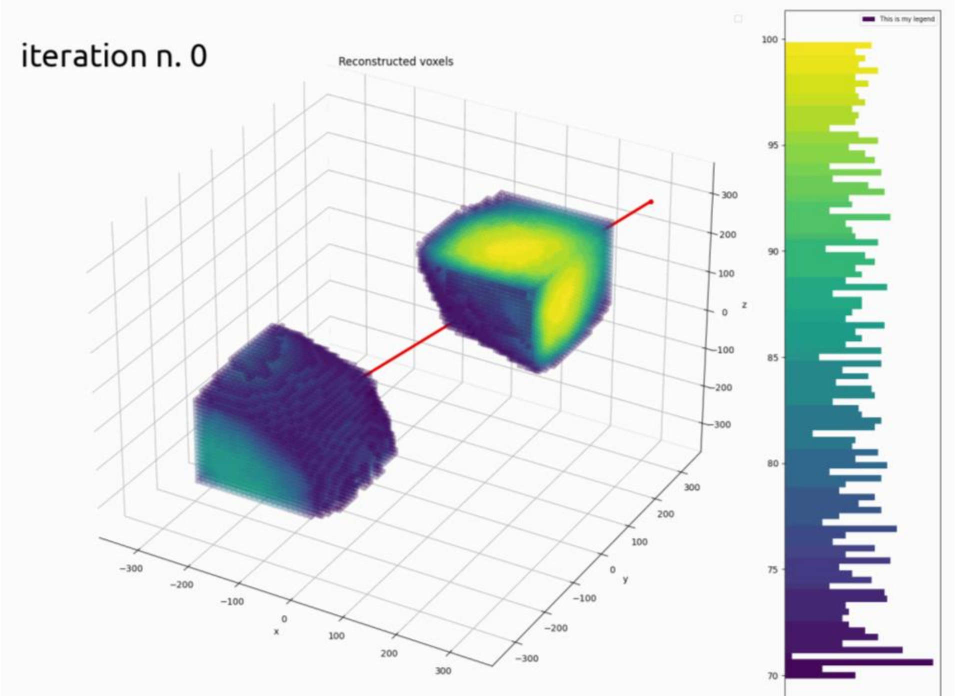
Valentina Cicero

CSN1 Review of SAND

11/07/2024

GRAIN Reconstruction algorithm

- Directly reconstructs in 3D dimensions the initial photon source distribution in a segmented volume (voxels)
- Combines information of multiple cameras at once



- **Maximum Likelihood Expectation Maximization** (MLEM) algorithm:
  - iteratively converges to the photon source distribution that maximizes the likelihood of detecting the observed images
- Implemented for execution on (multiple) GPUs

GRAIN Reconstruction algorithm

- Photon counting is described by a Poissonian pdf:

$$f(H_s|[\lambda_s]) = e^{-[\lambda_s]}\frac{[\lambda_s]^{H_s}}{H_s\,!}$$

$$[\lambda_s] = \sum_j \lambda_j\, p(j,s)$$

H_s number of detected photons by sensor *s*

$[\lambda_s]$ detected photons expectation value

λ_j unknown photon emission in voxel ***j***

p(j,s) probability of a photon that originated in voxel *j* is detected by pixel *s*

- Likelihood for all sensors:

$$\prod_s e^{-[\lambda_s]}\frac{[\lambda_s]^{H_s}}{H_s\,!}$$

maximization

Reconstruction algorithm:

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

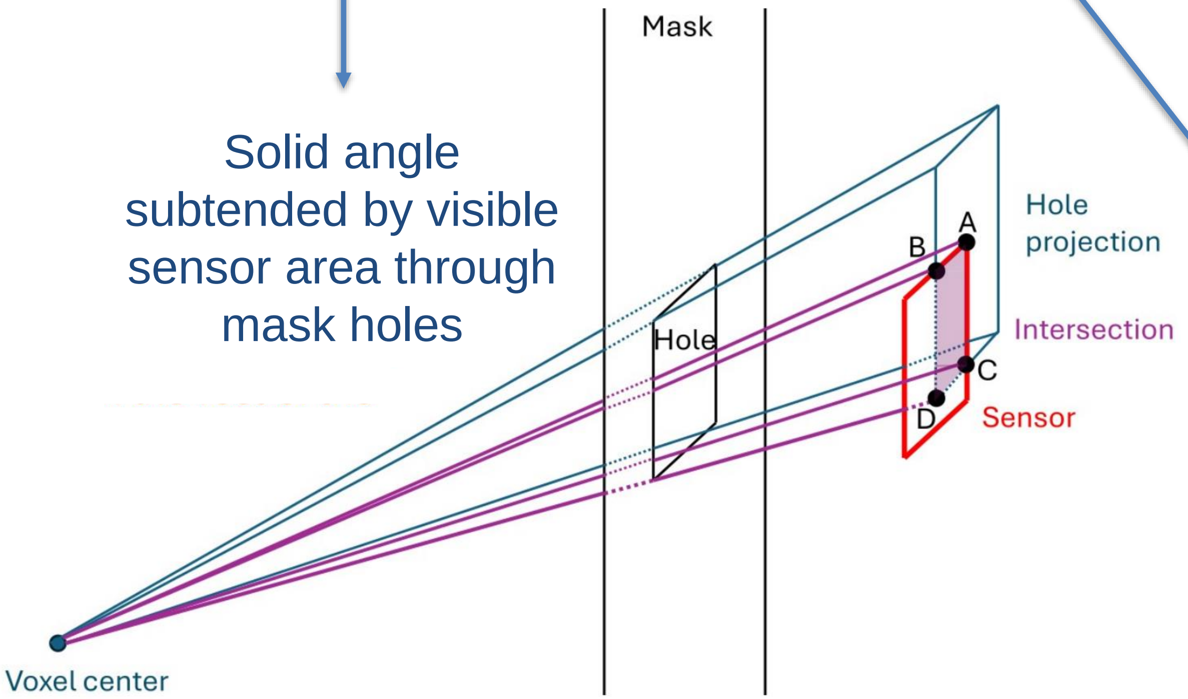
k iteration number

GRAIN reconstruction algorithm

The algorithm key element is the accurate computation of **p(j,s)**

$$p\,(j,s) = P\,geometry\,(j,s) * P\,LAr\,(j,s) * P\,sensor\,(s)$$

Solid angle subtended by visible sensor area through mask holes

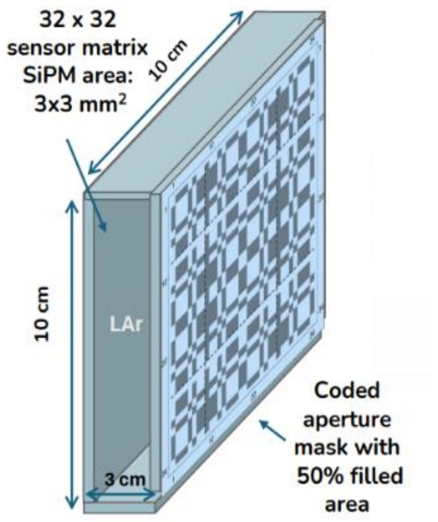


Sensor Photon Detection Efficiency

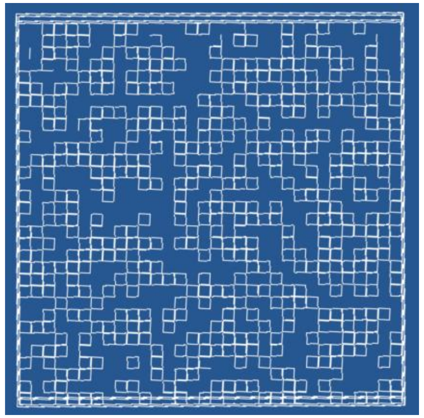
Photon absorption in LAr
Depends on distance between voxel and sensor

GRAIN CA imaging system

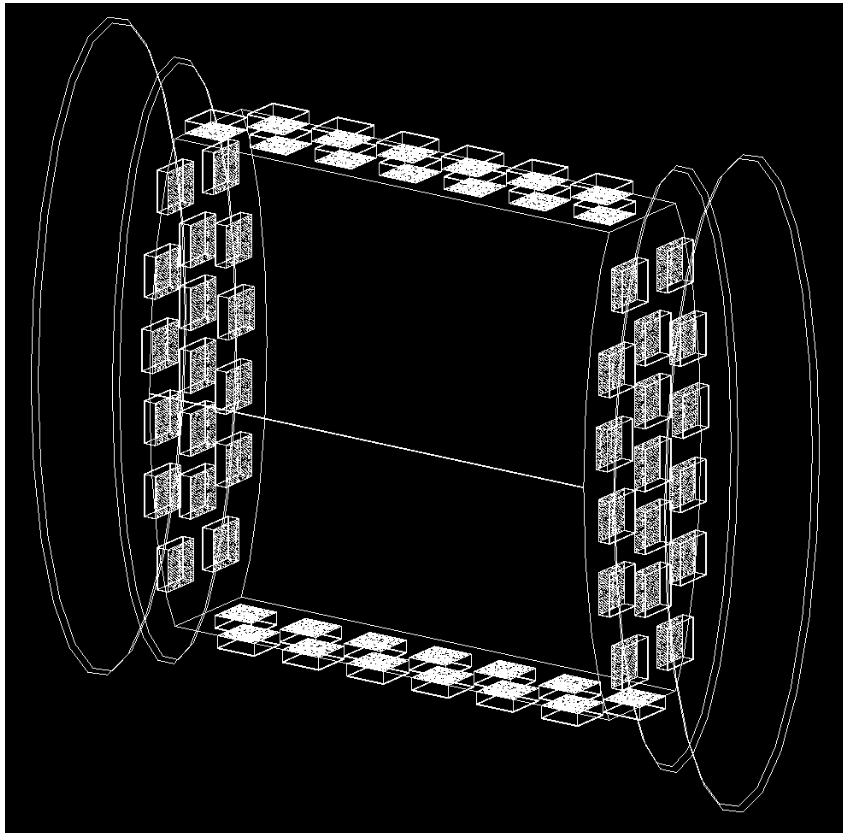
- **Sensor matrix:**
  - 32 x 32 Silicon Photomultipliers (SiPM)
  - SiPM active area: 3x3 mm^2
- 60 cameras in GRAIN
- covering elliptic sides + bottom and top rows
- **Coded aperture mask**:
  - Random uniform pattern of holes
  - Holes aligned to SiPMs, area: 3x3 mm^2
  - Distance from sensors: 3 cm



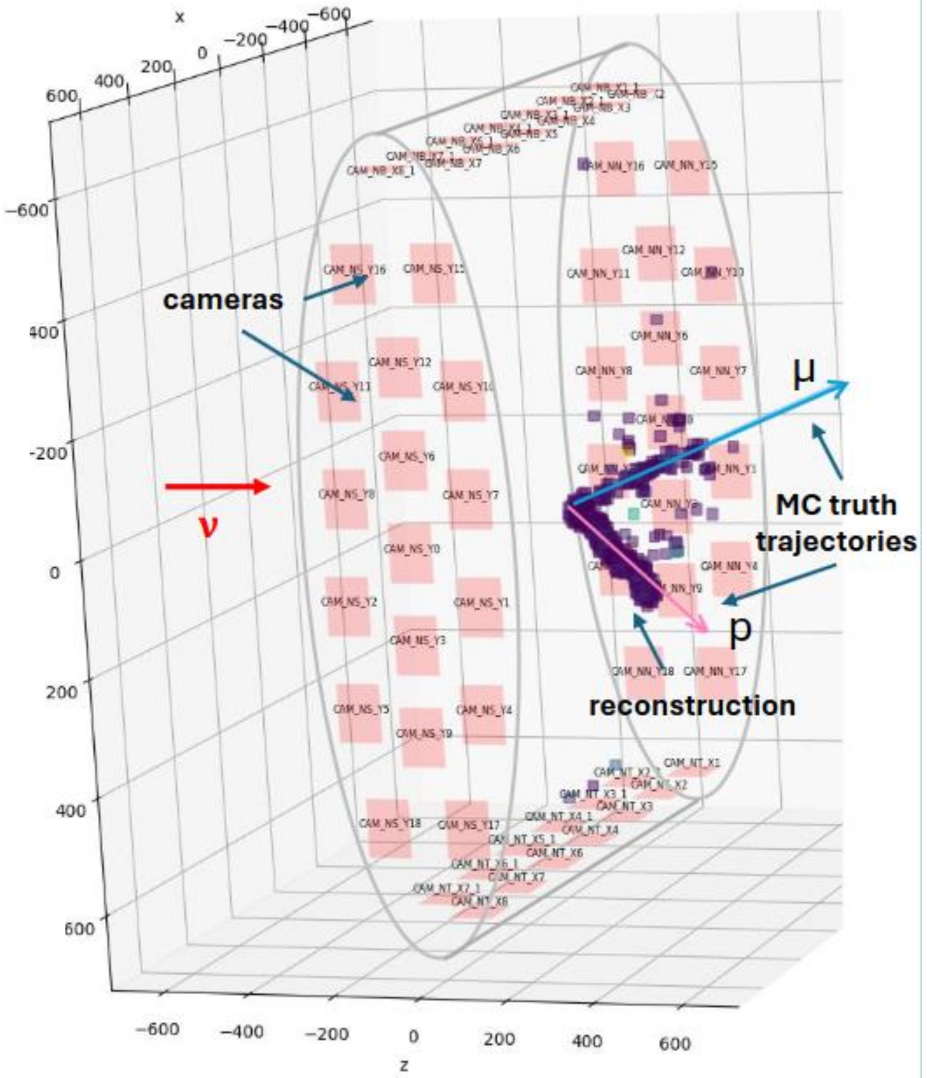
Mask pattern



Camera design was optimized with simulations in simplified geometry



Example of reconstructed neutrino event

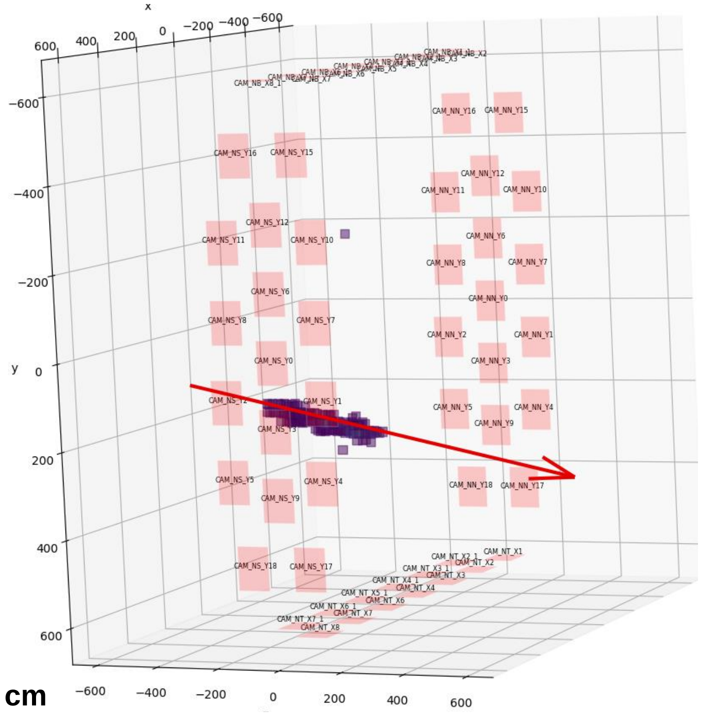


***ν* – Ar Charged Current Quasi-Elastic scattering**

Reconstruction:

- 12 mm voxel size
- 200 algorithm iterations
- Shown voxels with estimated photon emission ~> 5% of max value

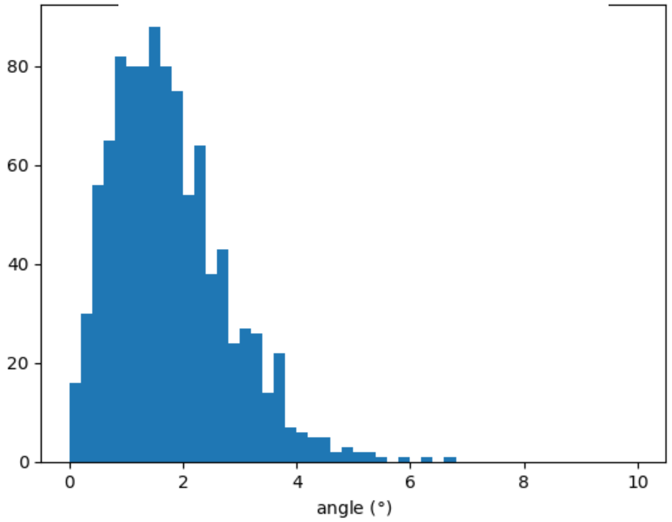
Muon reconstruction in GRAIN



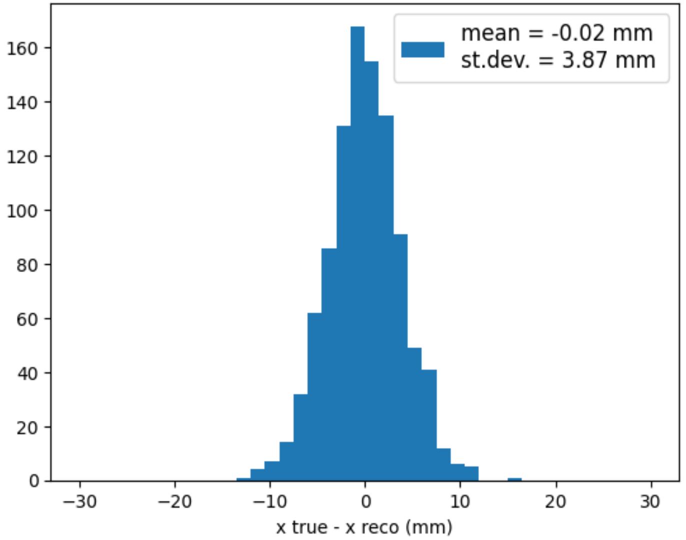
Simulated sample:
- 1k muons crossing GRAIN along z
- Origin position: ([-30, + 30], [-30, + 30], -50) cm
- Direction: θ = [160, 180], φ = [0, 360]
- Energy = (1 ± 0.3) GeV

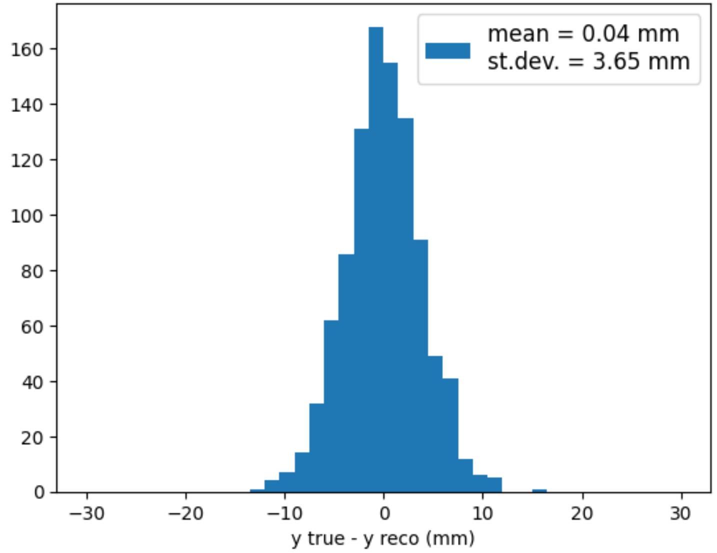
Reconstruction:
- Voxels size = 18 mm
- Iterations = 200
- Reconstruction time: ~ 3.5 min / event

Angle between MC and reconstructed track direction



Track position residuals at z = 0 cm



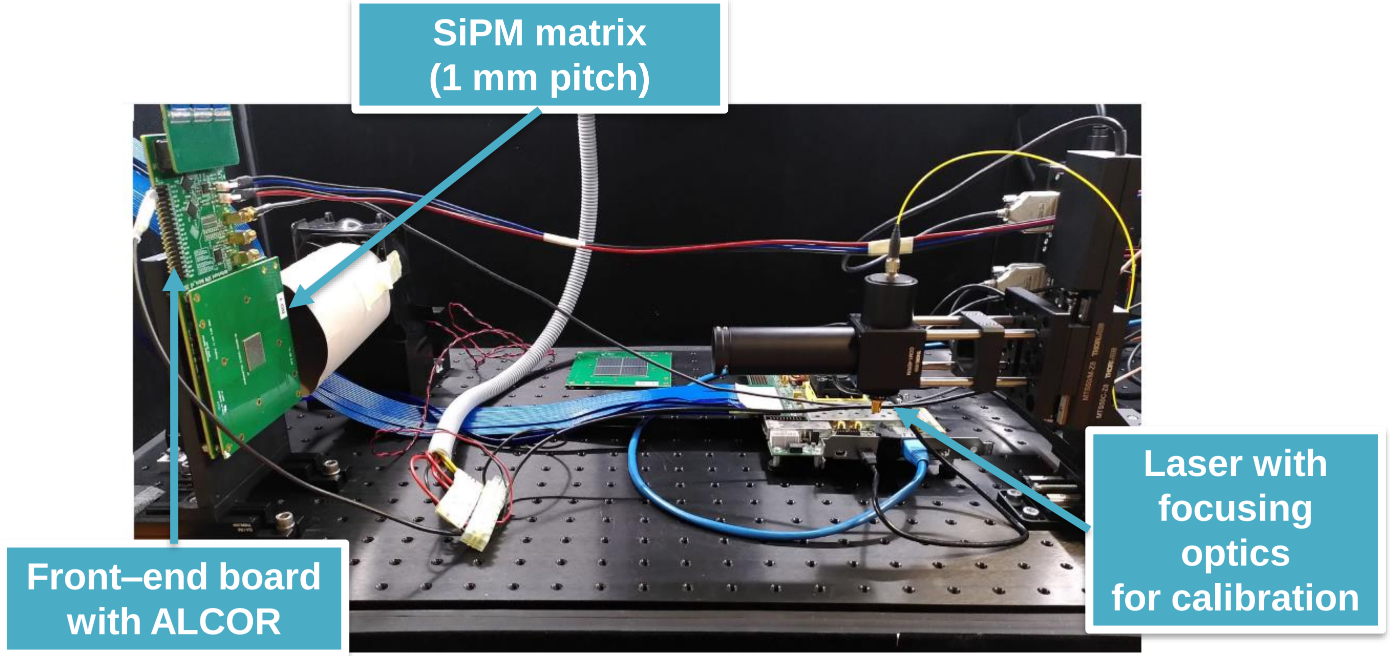


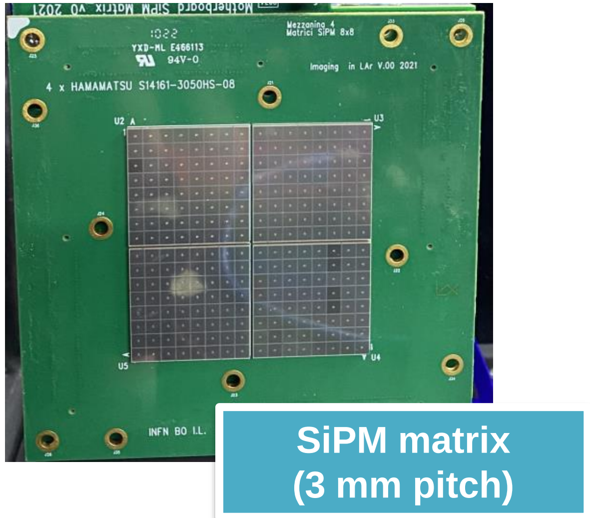
Camera prototype

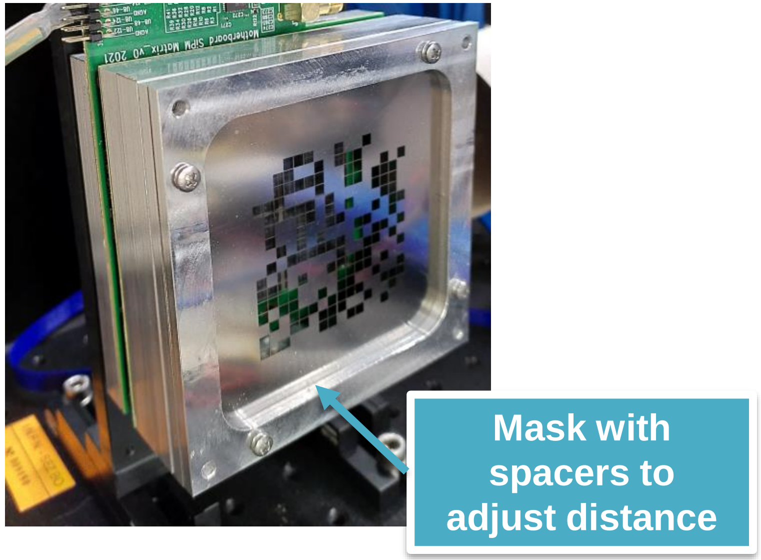
- Built 2 camera prototypes:
  - 16 x 16 SiPM matrix
  - SiPM area 3x3 mm^2
  - Mask: stainless steel sheet 120 um thick, laser cut

- Front end electronics with 8 ALCOR ASIC
- DAQ with a Xilinx FPGA board

- to be tested in LAr at ARTIC facility at Genoa with cosmic rays



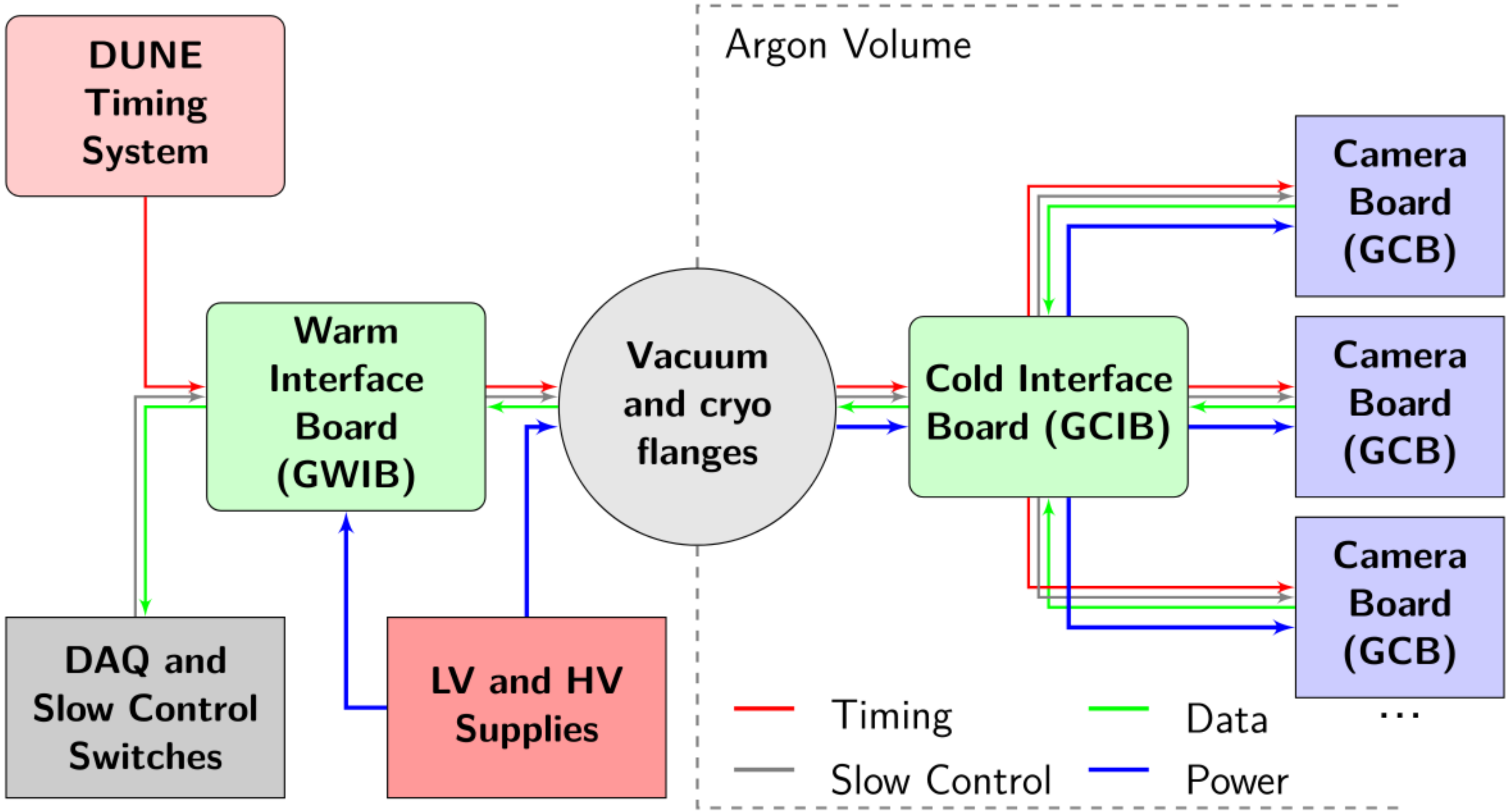




GRAIN readout overview and integration

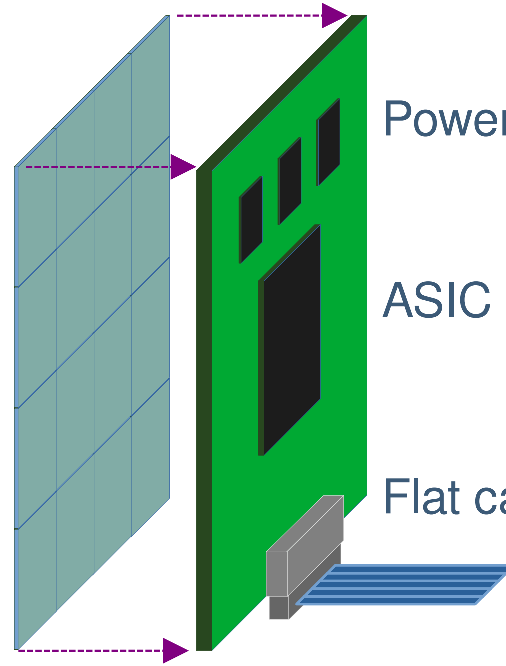
Nicolò Tosi – INFN Bologna

GRAIN Readout Scheme



GRAIN Camera Board

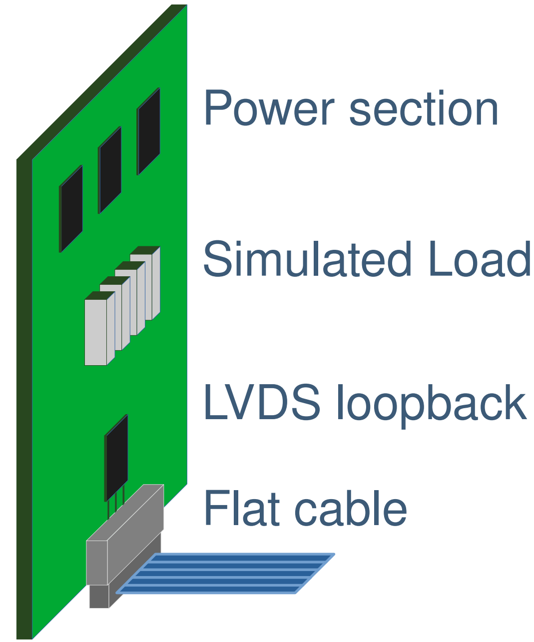
- On the front side:
  - VUV or WLS coated SiPM Matrices
- On the rear side:
  - One ASIC
  - A few LDO regulators
  - Connection



GRAIN Mock Up Camera Board

A test board for thermal and electrical tests

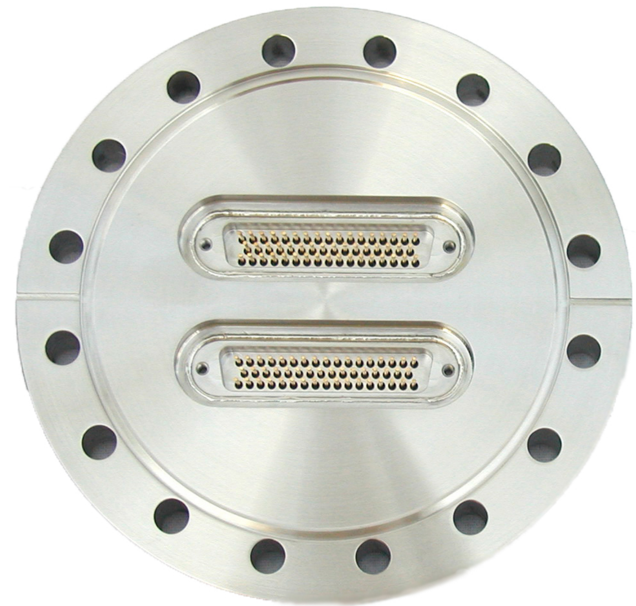
- Validate commercial LDOs
- Validate full I/O solution
- Study bubble formation and mitigation
  - ASIC simulated with equivalent power Resistors



Cold Interface Board and Flanges

A study is now in progress on the optimization of I/O considering:

- Availability of commercial feedthrough flanges with high density connectors (Sub-D or similar) vs custom flanges

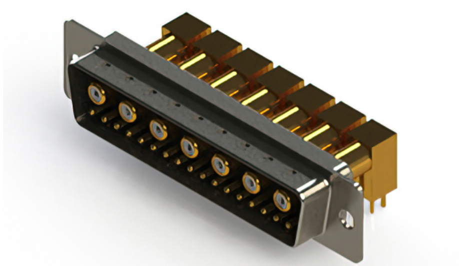


Example CF with 2x Sub-D 50 pin (Allectra GmbH)

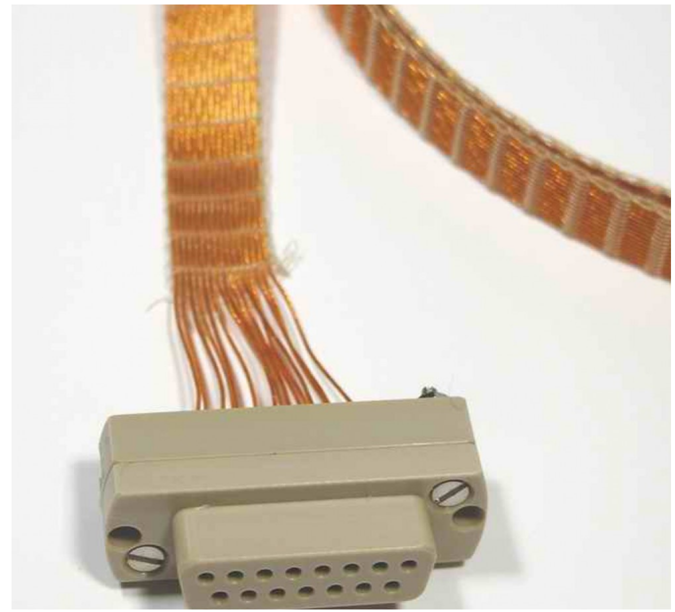
Cold Interface Board and Flanges

A study is now in progress on the optimization of I/O considering:

- Choice of cables and connectors as a compromise of signal integrity (for at least clk and data lines at 300+ MHz) vs cost



Example Sub-D with combined coax & pins

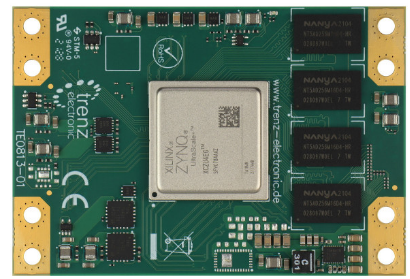


Example Sub-D with standard pins, Peek connector and polyimide cable

GRAIN Warm Interface Board

This board hosts an FPGA (and a CPU) to interface the ASIC with:

- The DUNE Timing System (dedicated fiber)
- DUNE-DAQ (10 GbE)
- DCS (1 GbE)

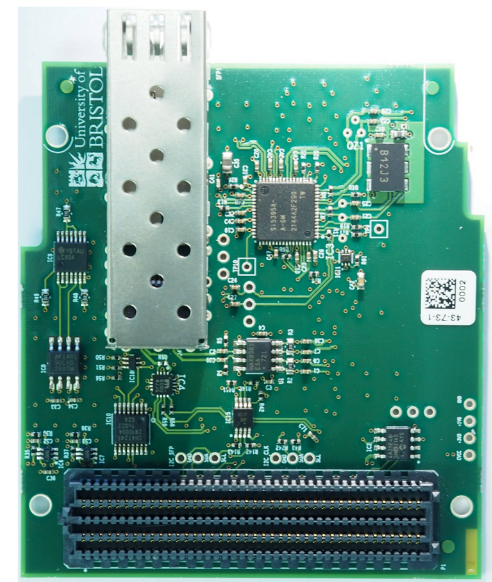


Each board (one per flange) will support up to 8 Camera Boards

Reduce PCB and FW development effort/risk and possibly exploit synergies with STT by using a commercial Zynq mezzanine with a custom base board

Timing system integration

- Bristol designed a reference Timing Endpoint
  - They provide an FMC mezzanine, FW and SW (uses Ipbus)
  - Acts as master or endpoint depending on loaded firmware
- We can plug these in our current VC707 DAQ boards
- Test integration of hardware and firmware and learn how to use software tools



Outlook

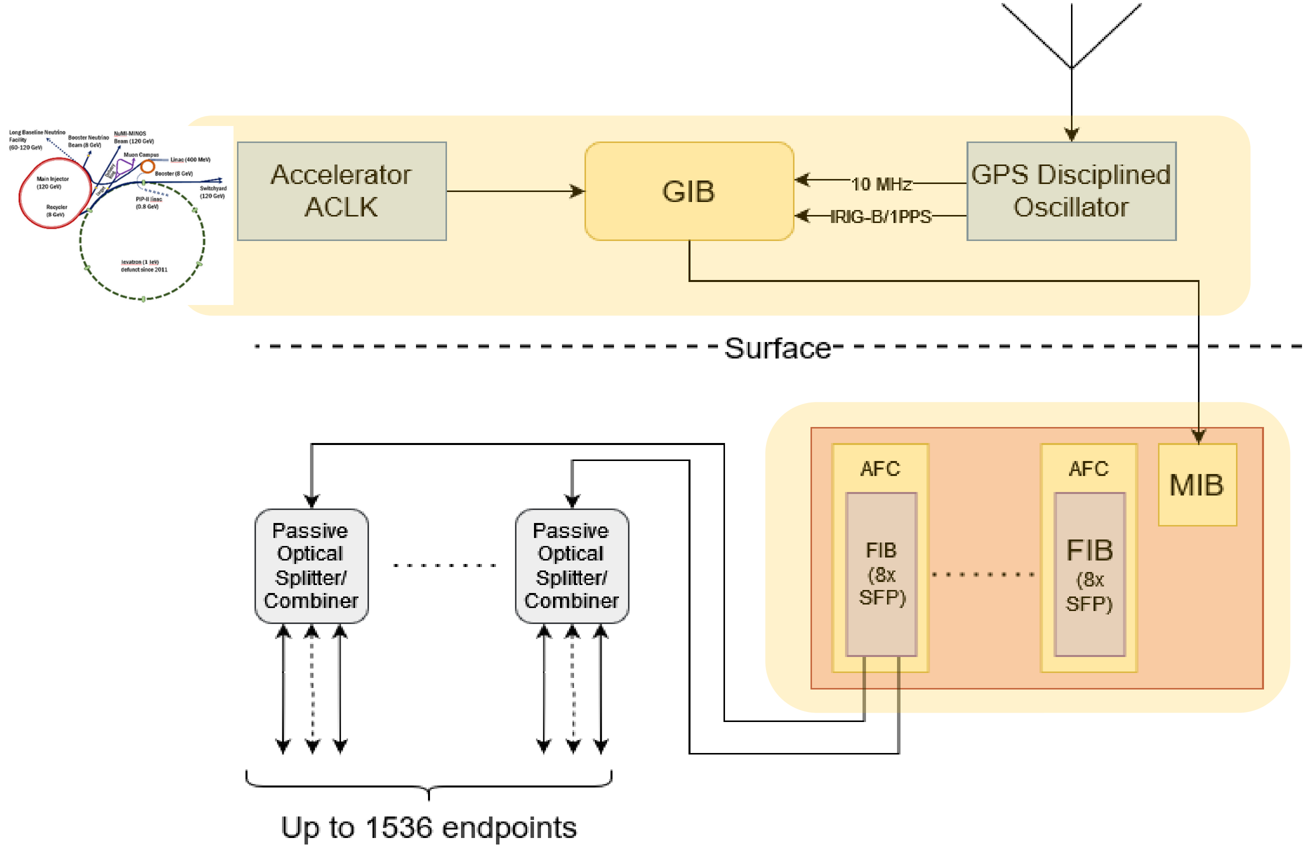
Activities that have started or will start in 2024:

- ASIC development
- DUNE Timing System integration testing
- D-Sub connector tests with flanges

Plans for 2025:

- Design mock-up camera boards and cold interface board
- Begin design of Warm Interface Board

ND Timing System Overview



The New ASIC for GRAIN

ASIC Specs, Architecture Validation and Project Timeline

INFN-LNF – Project Review
July 11th, 2024

Stefano Durando

Sofia Blua, Valerio Pagliarino, Angelo Rivetti

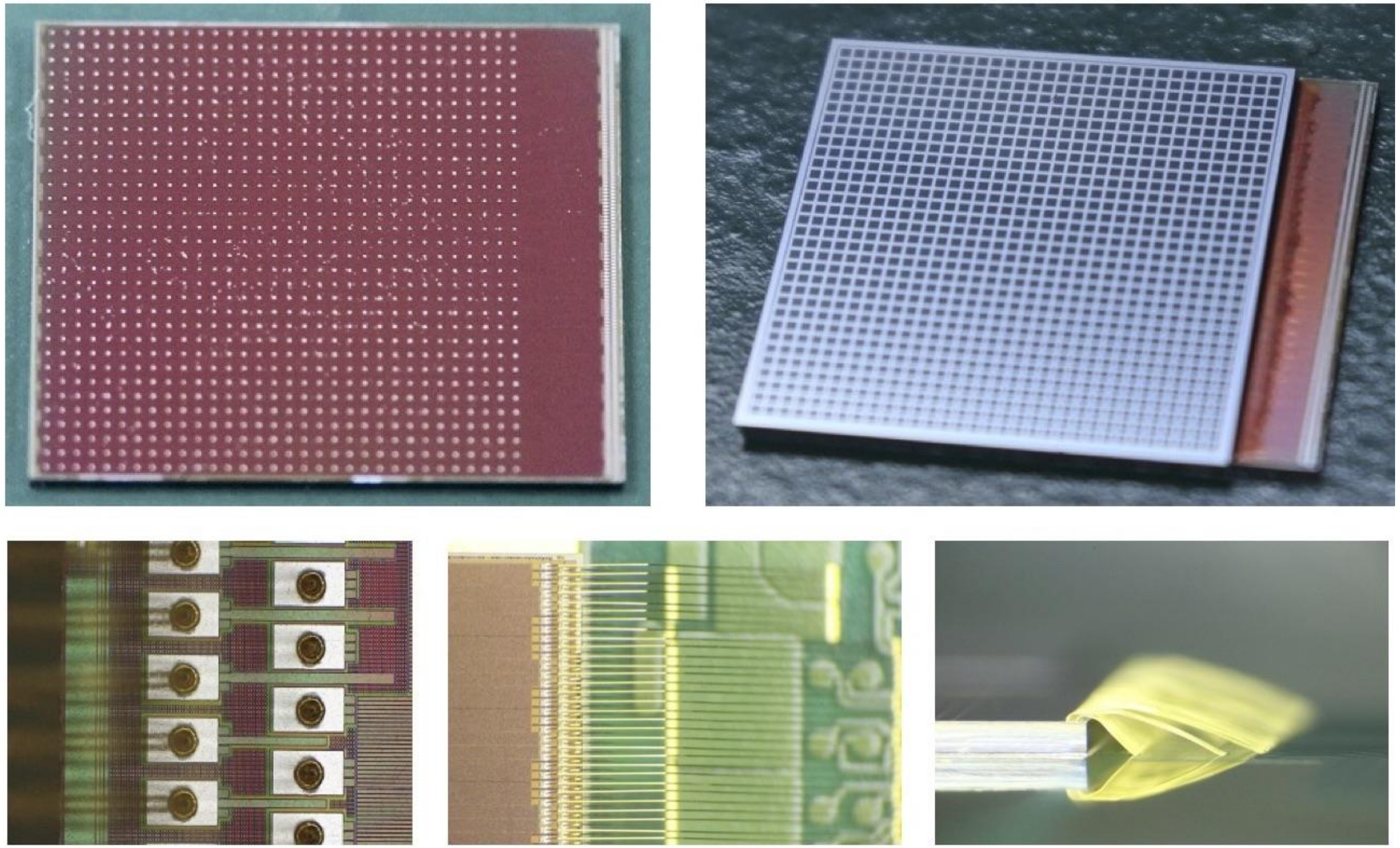
Parameter	Value
SiPM Size	2 x 2 mm^2 (140 pF) 3 x 3 mm^2 (500 pF)
# Channels/ASIC	1024
Operating Temperatures	300 K – 77 K
<Power Consumption>	5 W / cm^2 ◊
Duty Cycle	On $\geq$ 9.6 μs (50 μs) Off ◊◊ < 0.1 s
Measurements:	**Q – ToA - ToT**
Integrator Dynamic Range	> 100 PE
RMS_{ToA} (first PE)	100 $\div$ 150 ps / 1PE
RMS_{ToT}	≈ ns
Threshold	0.5 x 1PE
SNR	30

◊ Set by the cryogenic condition, still under study. ◊◊ Interspill = 1.2 ms - 9.6 μs

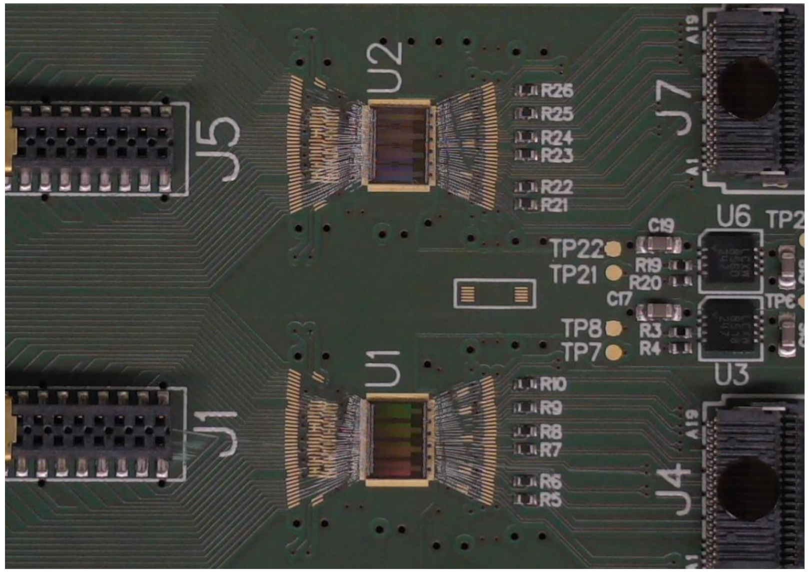
ALCOR Parent

- **Parent ASIC:** R&D with an external company
  - UMC 110 nm
  - 1024 Channels, reading out silicon pixels
  - The ASIC is bump-bonded to the pixels
  - Key IP blocks like the TAC based TDC (30 ps)
  - Basis for the following prototypes

- **ALCOR v1**
  A **L**ow power **C**hip for **O**ptical sensors **R**eadout

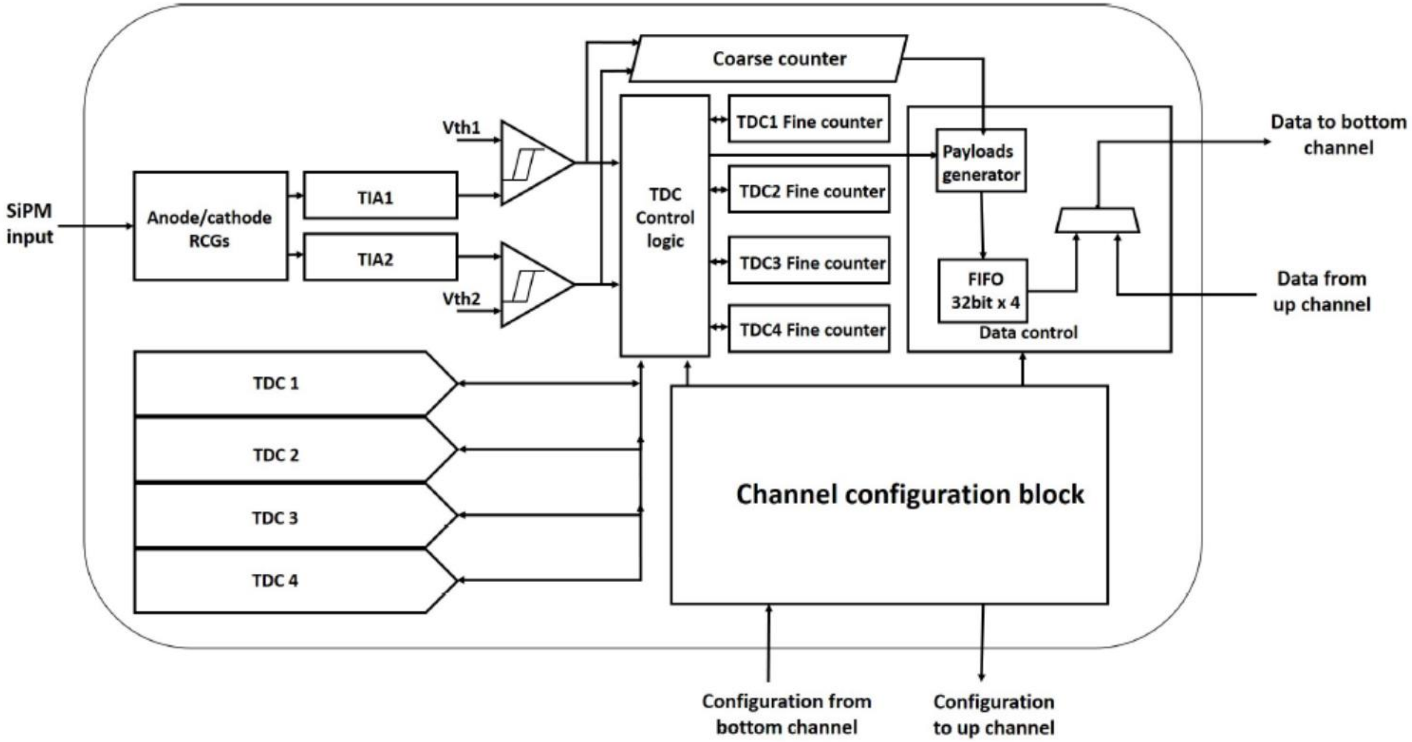


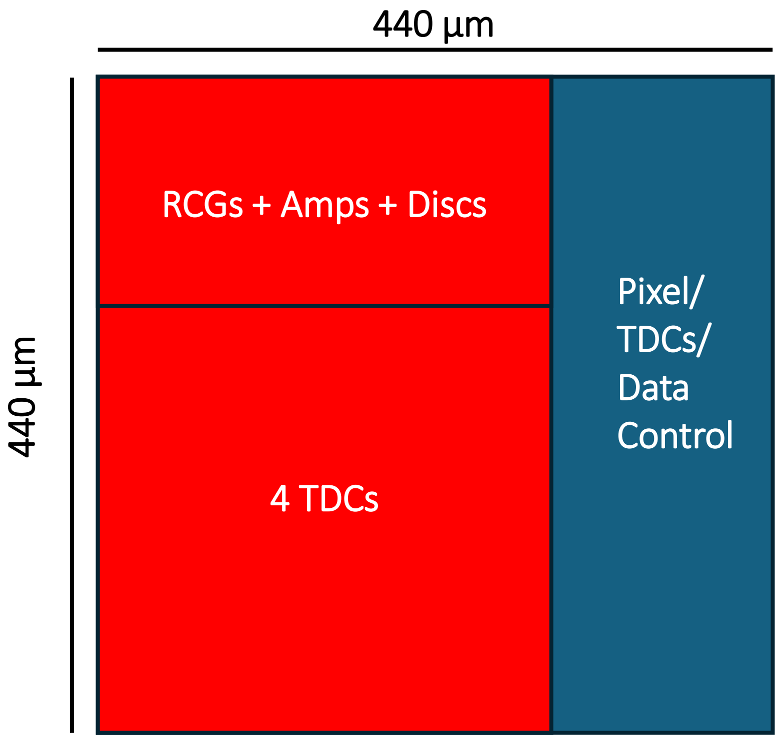
ALCOR's Parent: 1024 pixel channels were bump-bonded to the silicon pixels. The ASIC was wire-bonded on the board



2 ALCOR chips wire bonded on the dedicated board
Courtesy of Fabio Cossio (INFN)

ALCOR Pixel Scheme



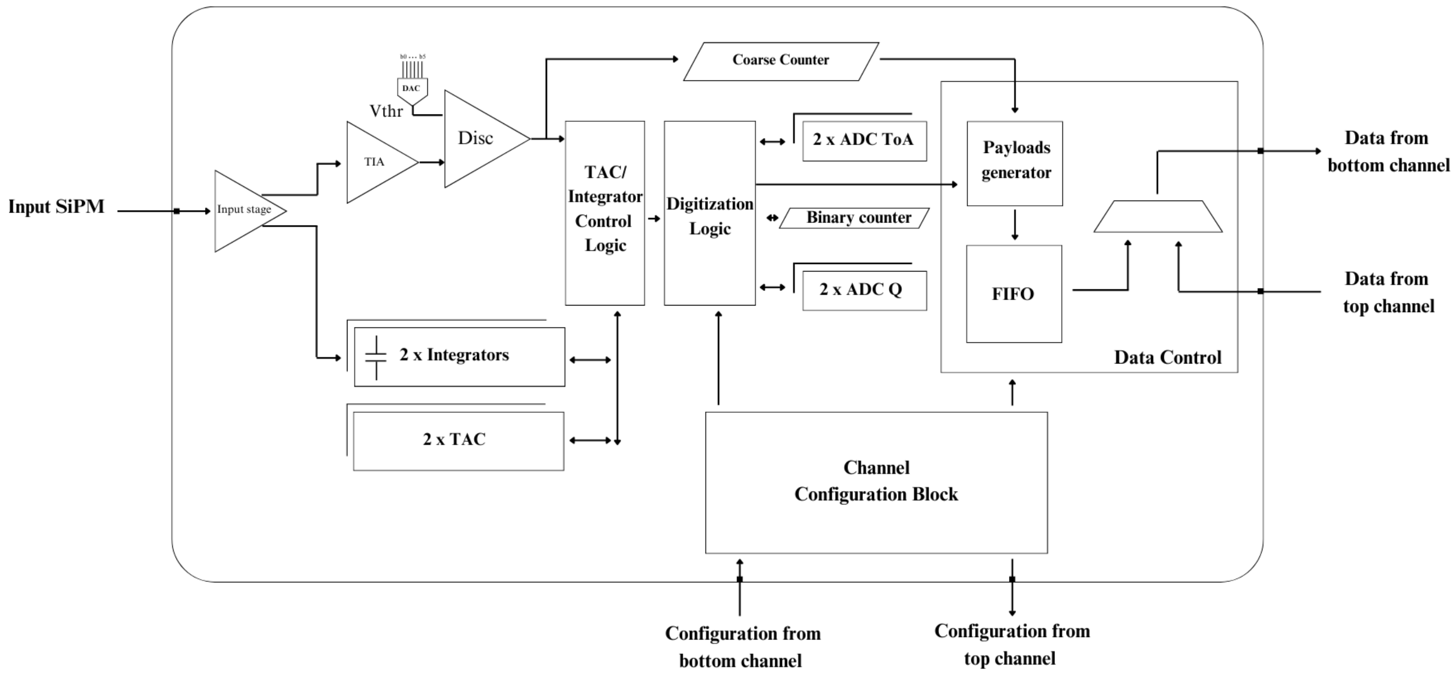


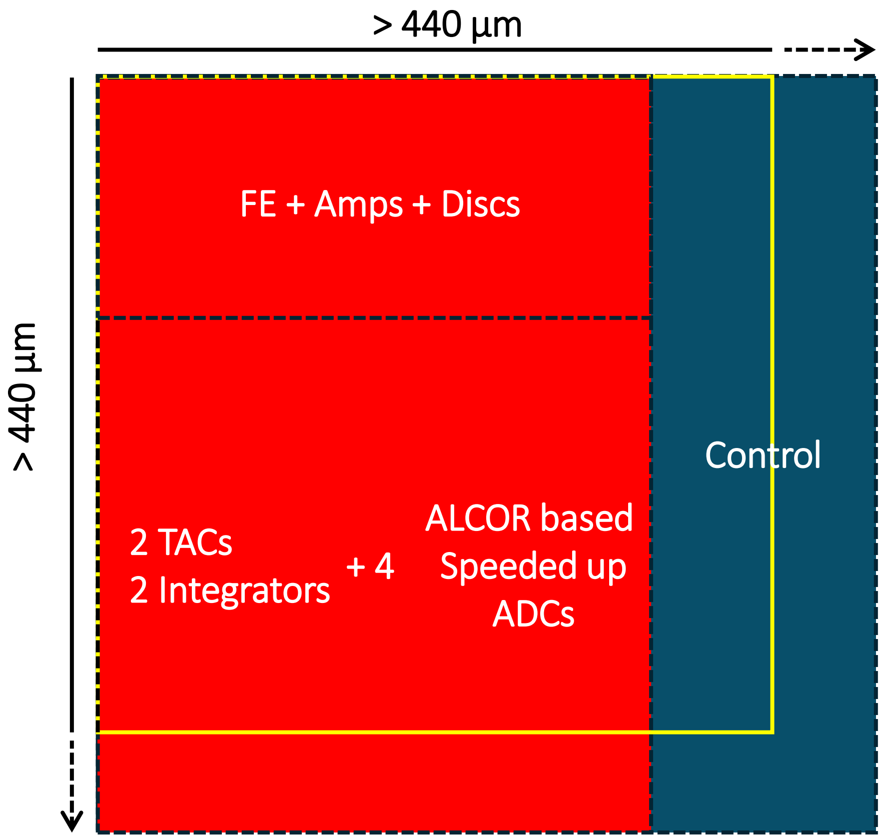
ALCOR v1 pixel

Dominated by the analog blocks (capacitors)

- 2 (Anode/Cathode) Regulated Common Gates (RCGs) Input stage
- 2 Independent Trans-Impedance Amplifiers (TIAs)
- 2 Leading Edge Discriminators (LE Discs)
- 4 TDCs = 4 x (TAC + Wilkinson ADC)
- Control Logic: pixel config, TDCs operation and data transmission

GRAIN ASIC Pixel Scheme





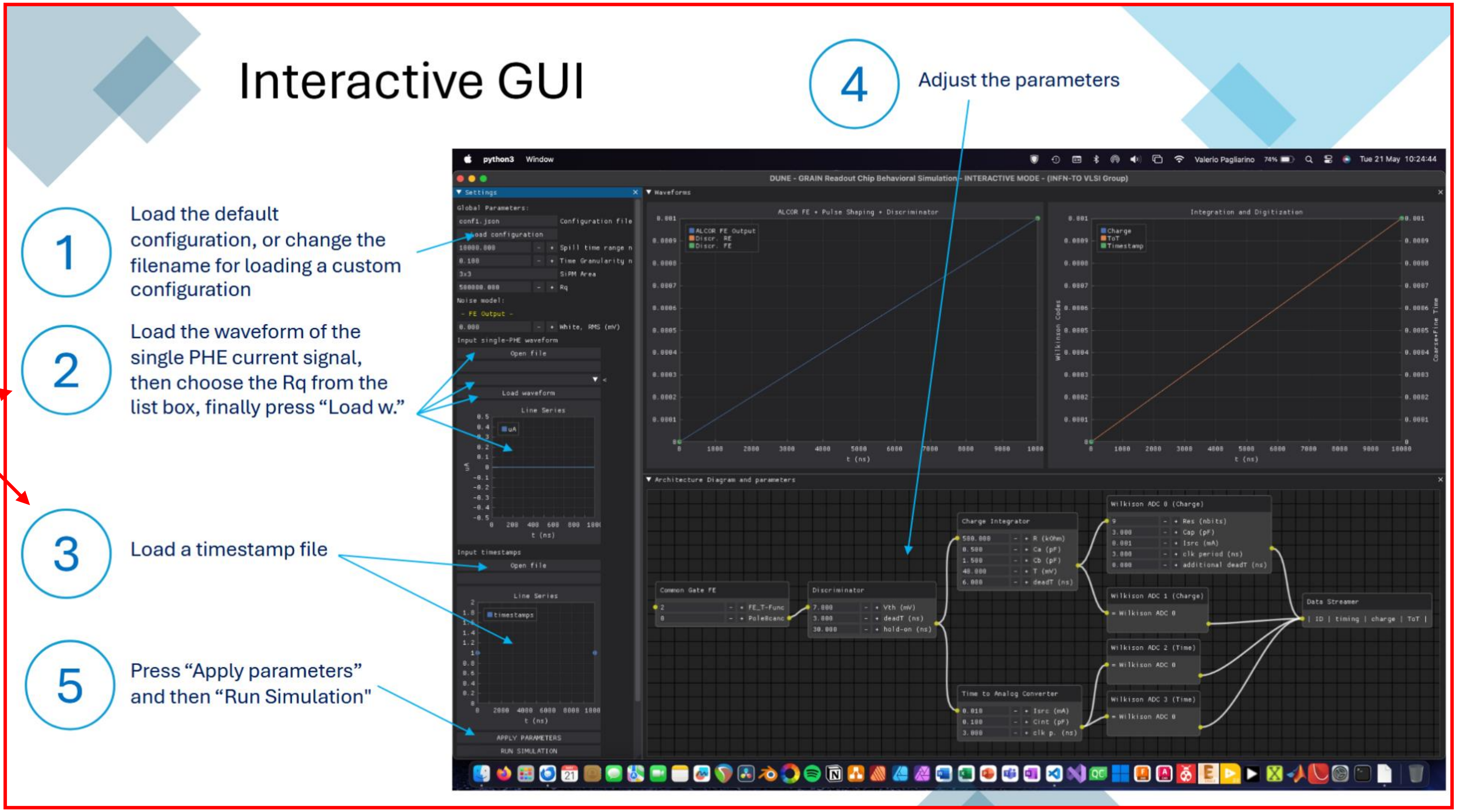
GRAIN ASIC pixel

Based on the ALCOR scheme, with minimum changes:

- Regulated Common Gate input stage
- Time branch:
  - TIA + LE Discriminators
  - 2 Time to Analog Converters (TACs)
- Charge branch
  - 2 Integrators
- 4 Analog to Digital Converters with speed increased up to 4/8 times
- Control: pixel config, ADCs/Integrators/TACs operation and data transmission

Architecture Validation

- **Ongoing validation of the architecture** by the collaboration for GRAIN detector's physics with:
    - Coded aperture masks
    - Lenses
- **Python software** designed in Torino by Sofia Blua and Valerio Pagliarino
    - Inputs: time domain reconstruction of a single spill SiPM event
    - Behavioural model: Ideal description of the pixel electronics' response
    - Output: numpy array (ASIC-like output)
- **First results suggest the proposed architecture meets the requirements**



Courtesy of Sofia Blua and Valerio Pagliarino

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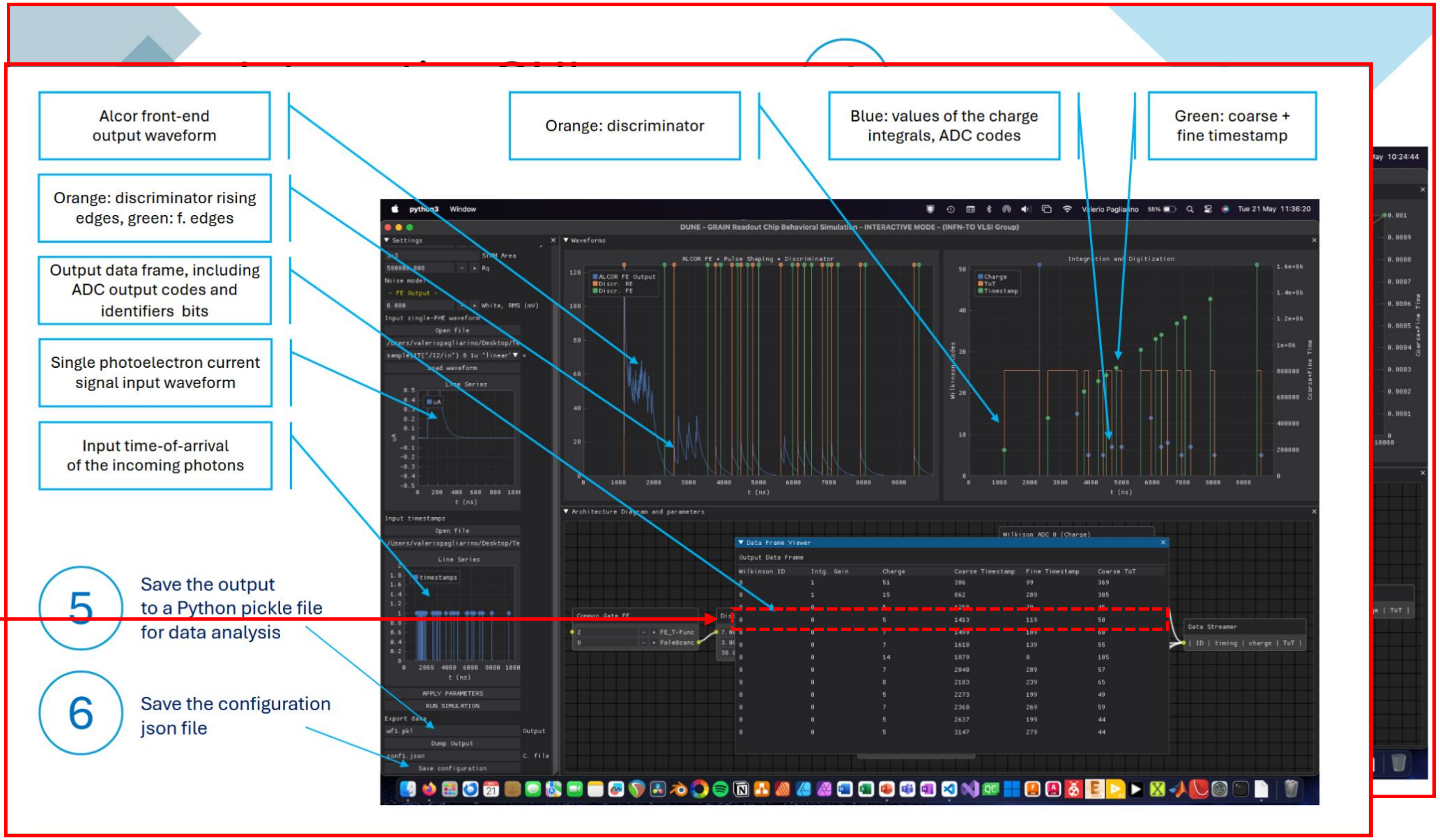
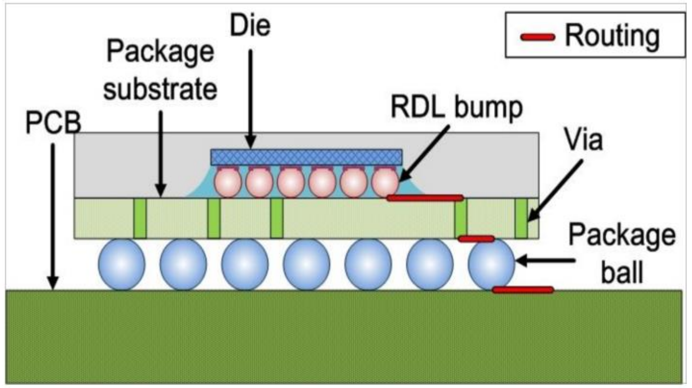


Courtesy of Sofia Blua and Valerio Pagliarino

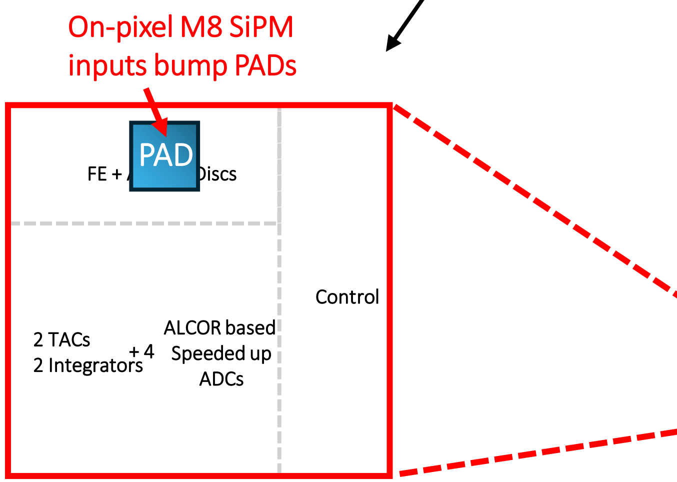
Flip-Chip BGA package

- The ASIC is bump-bonded to an interposer connected to the board with package balls
  - On-pixel PAD for SiPM
  - Inter-column supply and ground PADs for reduced IR drops
- Similar approach is followed for ALCOR v3 implementation for EIC

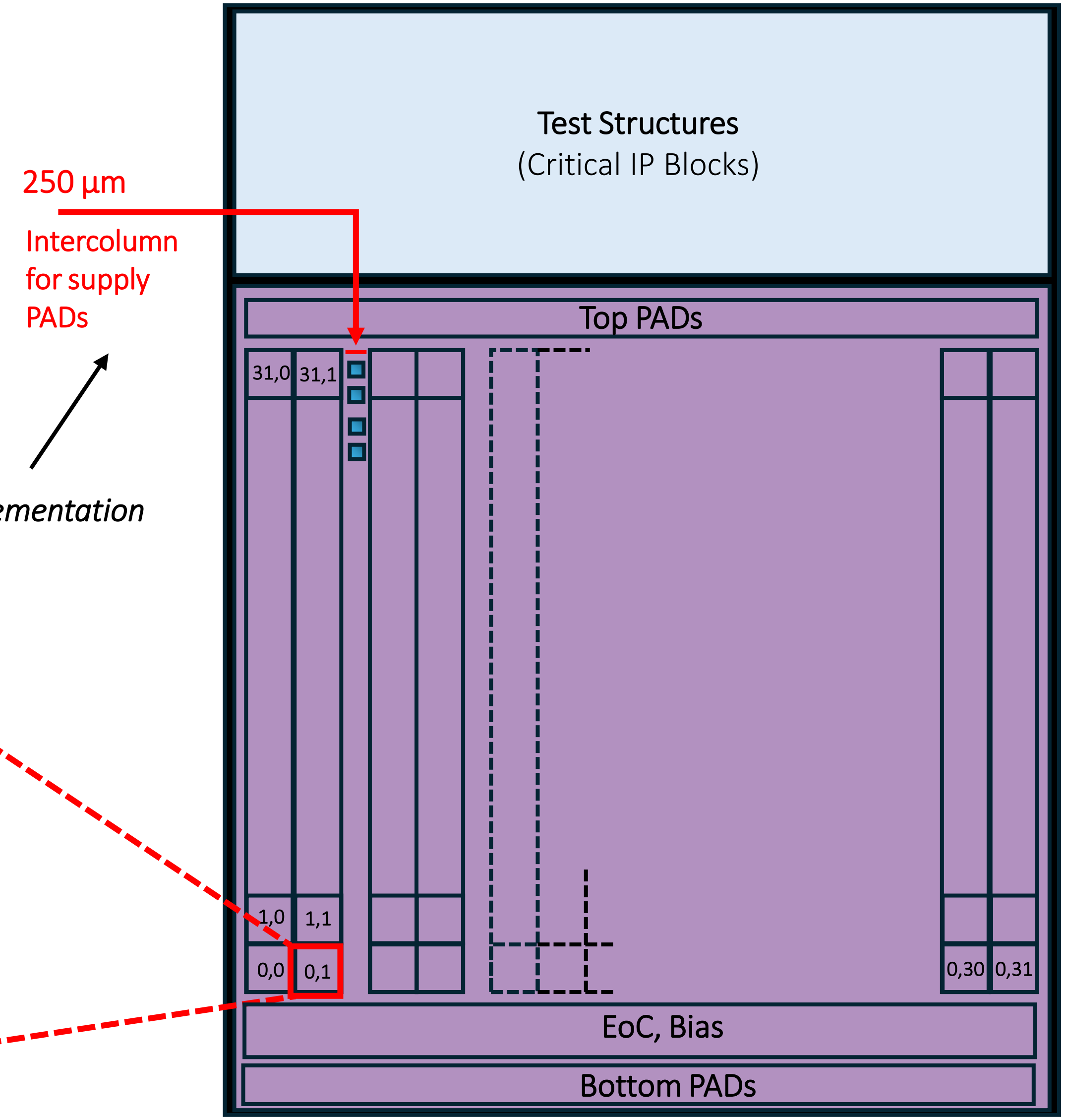


Flip-chip BGA working principle

Hsu, Hsin-Wu & Chen, Meng-Ling & Chen, Hung-Ming & Li, Hung-Chun & Chen, Shi-Hao. (2012). On effective flip-chip routing via pseudo single redistribution layer. 1597-1602. 10.1109/DATE.2012.6176727.



GRAIN ASIC : Pixel Channel



GRAIN ASIC

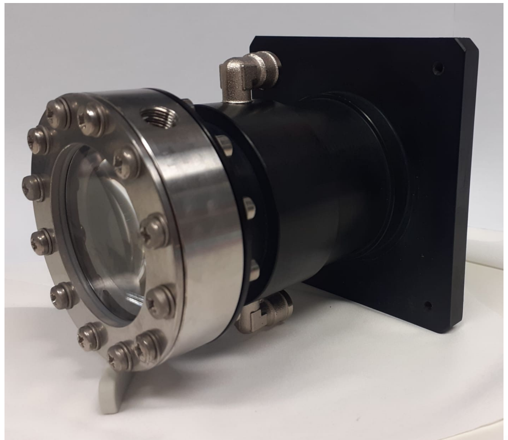
Tests in ARTIC

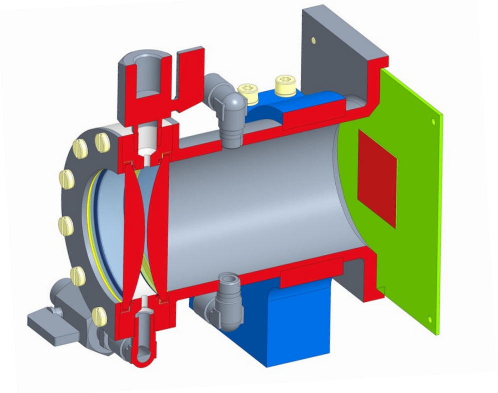
Lea Di Noto
University of Genova and INFN Sez.Genova

DUNE CSN1 Review

July, 11th 2024

The lens prototypes





Material: Corning® HPFS 8655 glass

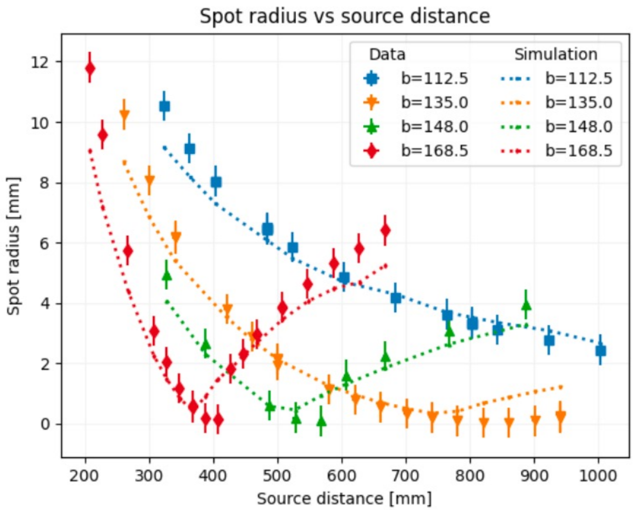
Focal lenght: 89 mm

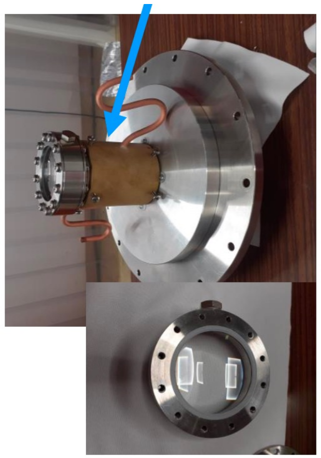
- 2 built prototypes:

    - **smaller diameter 50 mm** with optimized curvature
      thickness: 12 mm

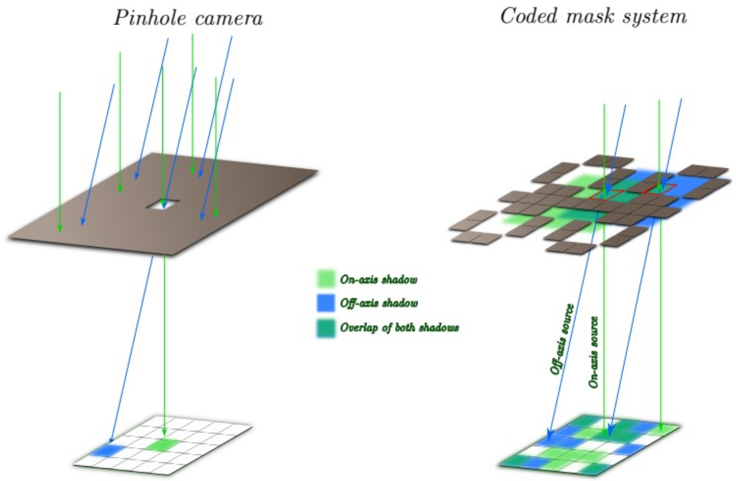
    - **bigger diameter 60 mm** optimized for higher distance
      (up to 1.2 m)
      thickness: 20 mm

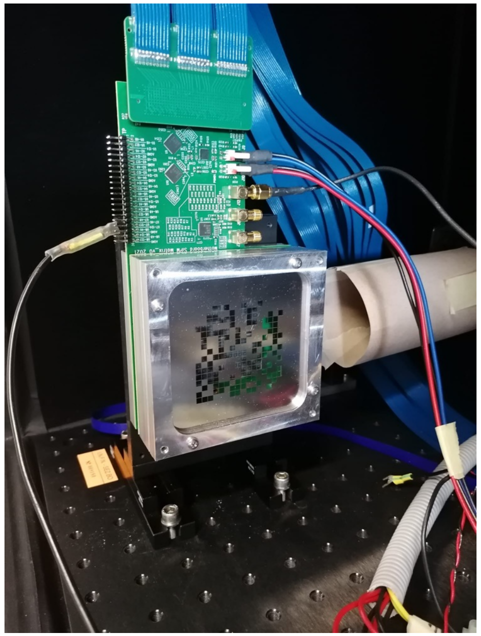
Tests in water in 2022-23





The coded mask prototype





Coded aperture mask techniques were developed as the evolution of a single pinhole camera

- matrix of multiple pinholes to improve light collection and reduce exposure time

Image formed on sensor is the superimposition of multiple pinhole images ….

Advantages:

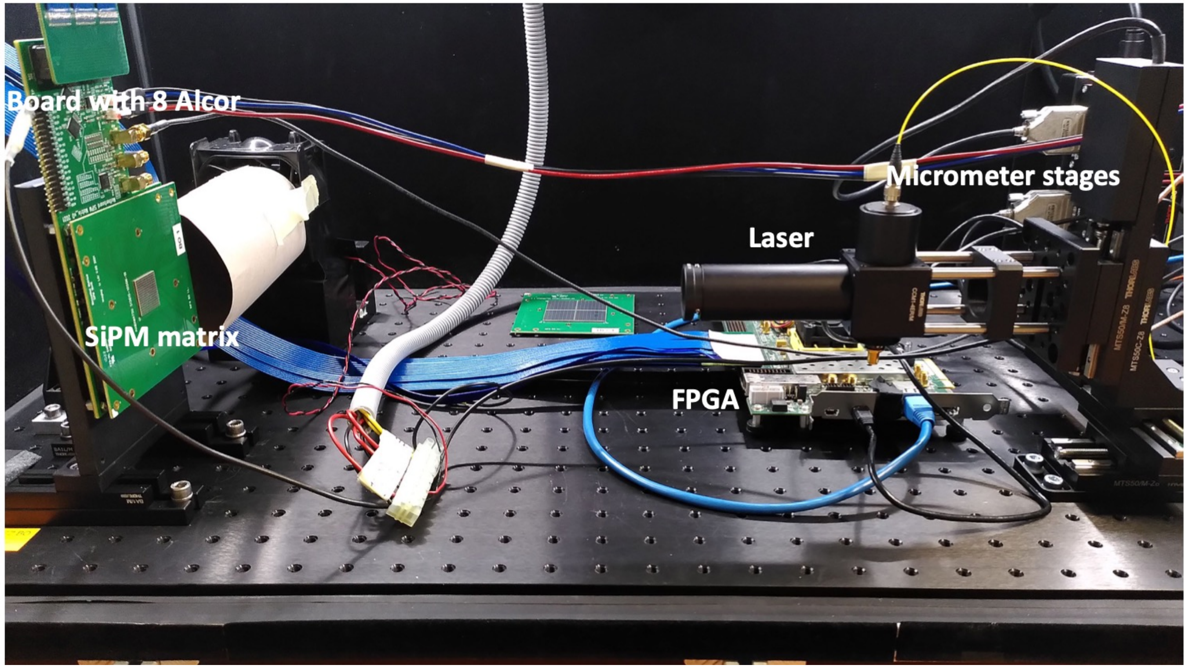
- Good light transmission (50%)
- Good depth of field
- Small required volume

First readout

Sensors:

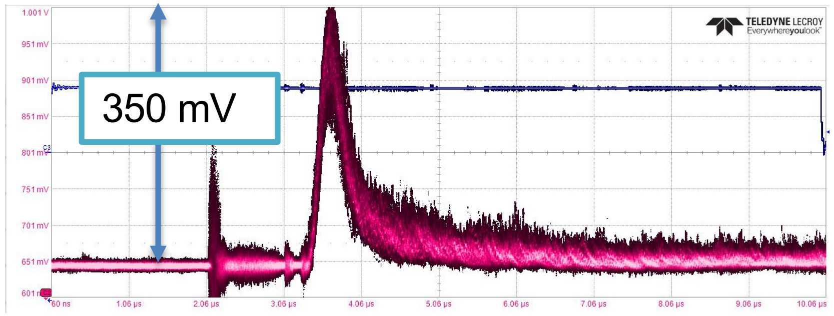
Matrix with 16x16 SiPM with different sizes:

- 1 mm available
- 3 mm available
- 2 mm in progress→ the baseline for lens



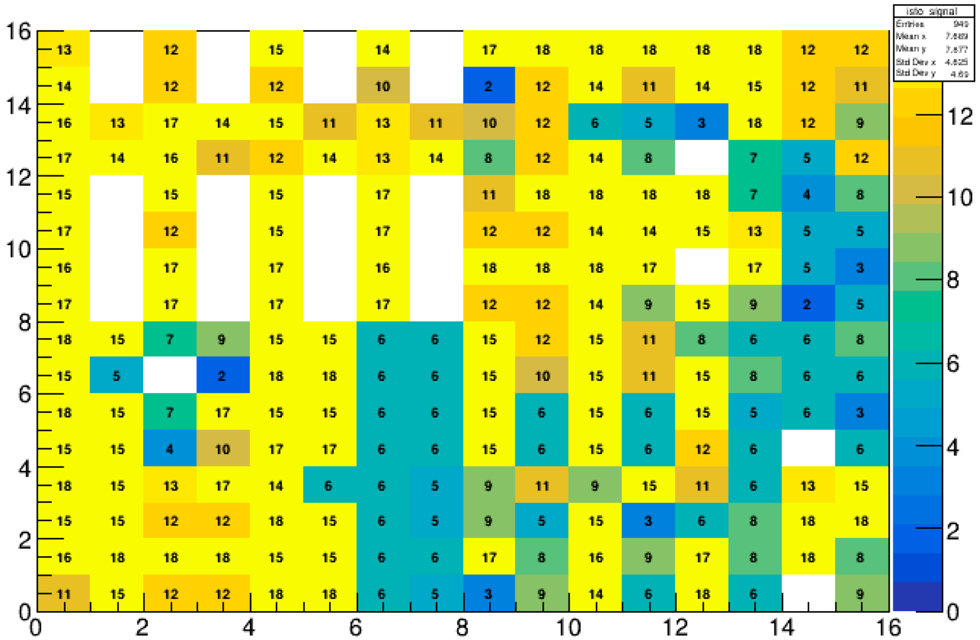
- The SiPM matrix is acquired by 8 Alcor chips:
  - For each channel, we can record:
    - Time of the over-threshold (TDC time)
    - TOT (Time over threshold)

First tests with SiPM matrix



Pulsed light signal on all channels

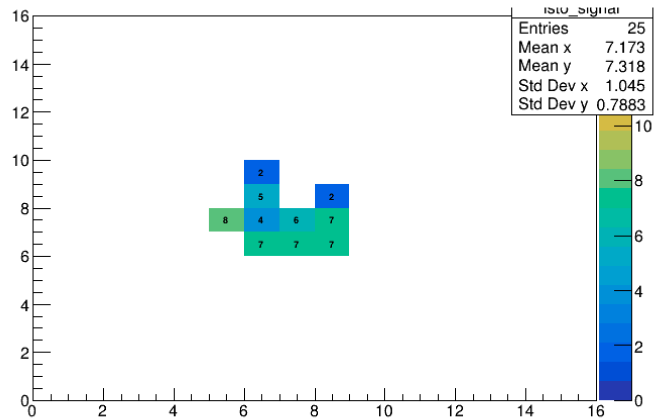
18 counts are expected for each channels



For each channel the number of signals with ToT > 200 ns and with the same period of the pulsed light is counted

- Few channels are broken (due to an ALCOR chip)
- Not same efficiency (the threshold have to be optimized)
- Not good reproducibility (to be improved)

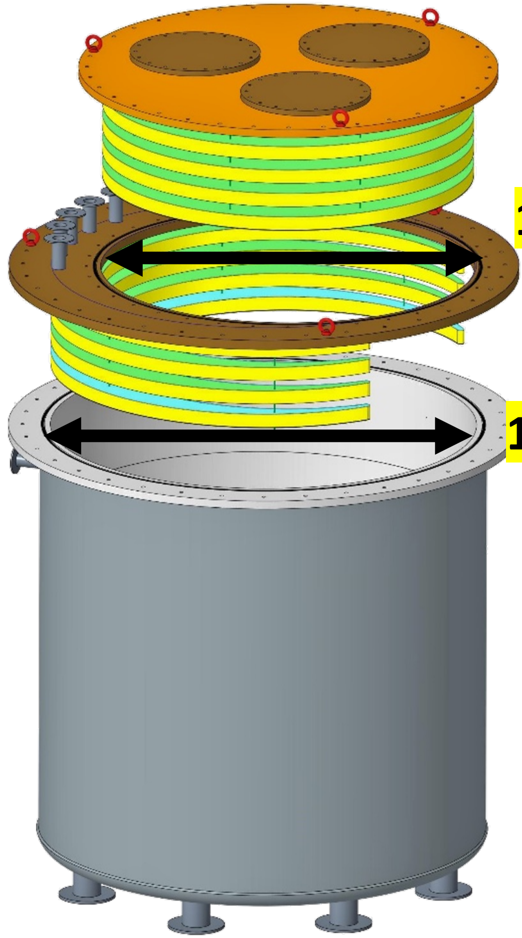
Pulsed light signal on few channels



ARTIC - Argon Test InfrastruCture

Thermal shields are hanging by the external top flanges

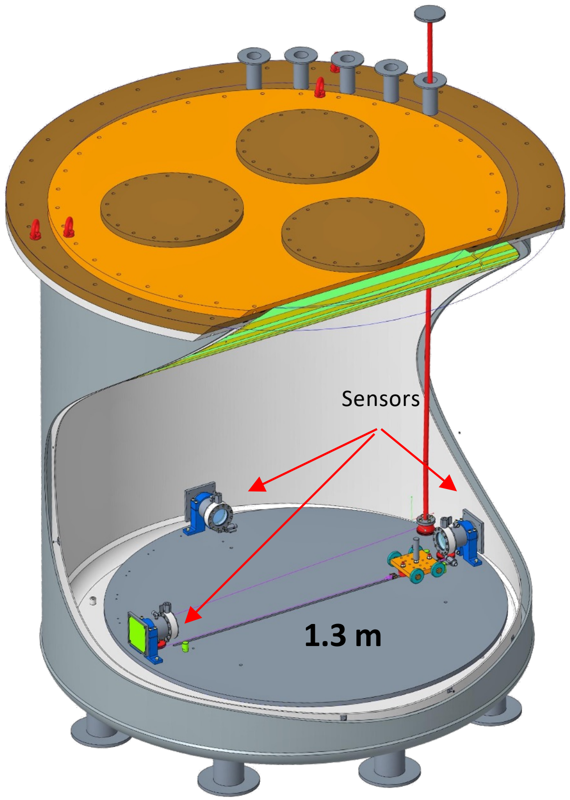
Installed since 2020



Evaporation rate

→ 0.7 l/h if the N2 level is at 10 cm

Tests for sensor optimization



- Cosmic ray detection in LAr (+Xe) triggered by an external cosmic ray system
- In ARTIC we have to install a LAr recirculation (+ Xe doping system) for collecting scintillation light (by end 2024)
- An external CRT will be mounted on the top and on the bottom
- We plan to use 2 - 3 cameras for reconstructing the muon tracks

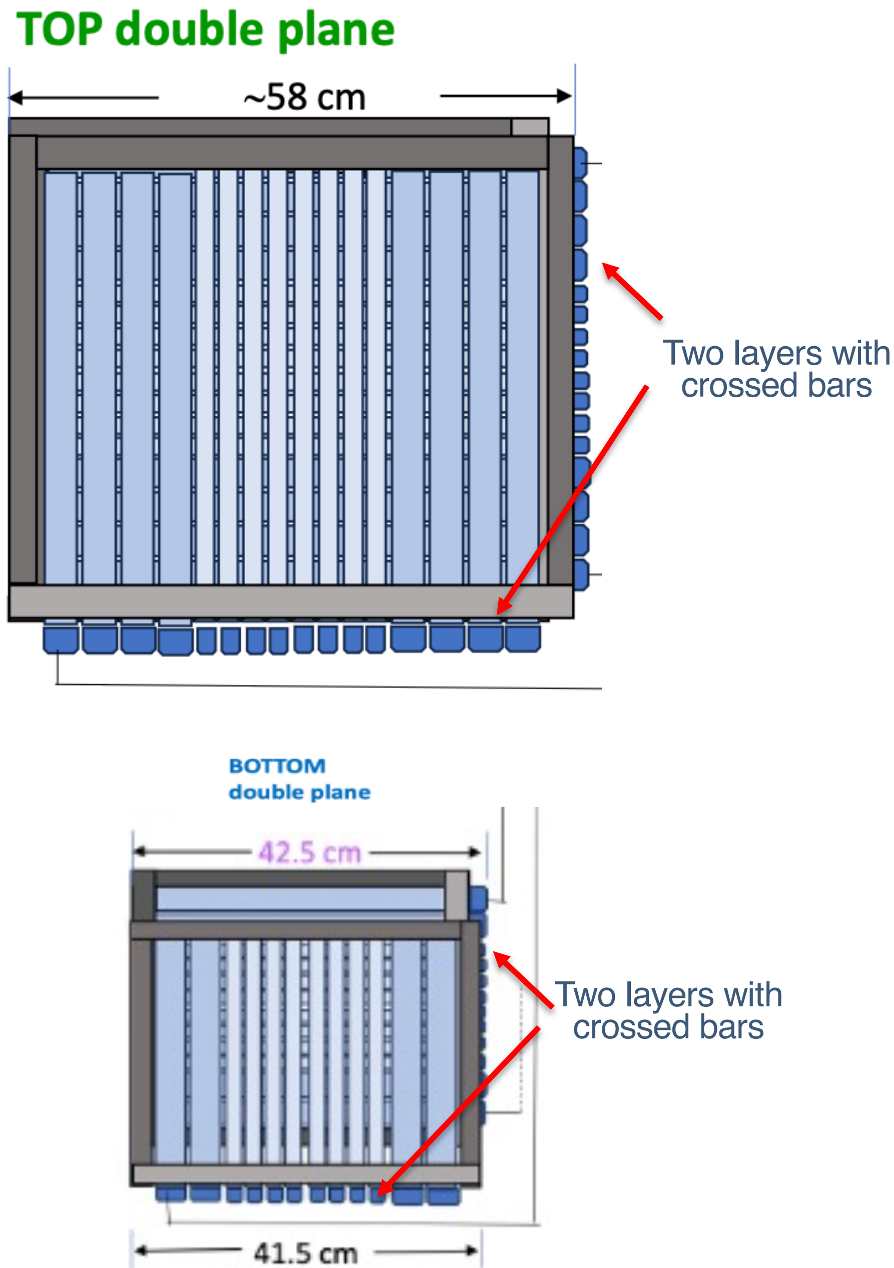
These tests:
- will validate the possibility to use the new detectors in GRAIN
- will allow us to design and test the final detectors and electronics
- will provide additional measurement of LAr properties

CRT for ARTIC

<u>CRT GOALS:</u>

- Trigger for the LAr acquisition (fourfold coincidence)
- Two-view tracking to help the LAr event reconstruction

<u>Trigger condition</u>: Fourfold coincidence

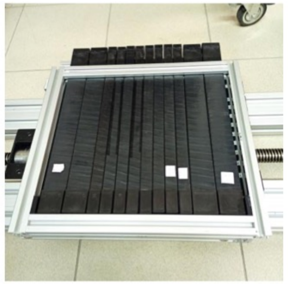


CRT for ARTIC is completed

The CRT is in the commissioning phase at LECCE

TOP tray

BOTTOM tray



It will installed at GENOVA soon

GRAIN: Project plan

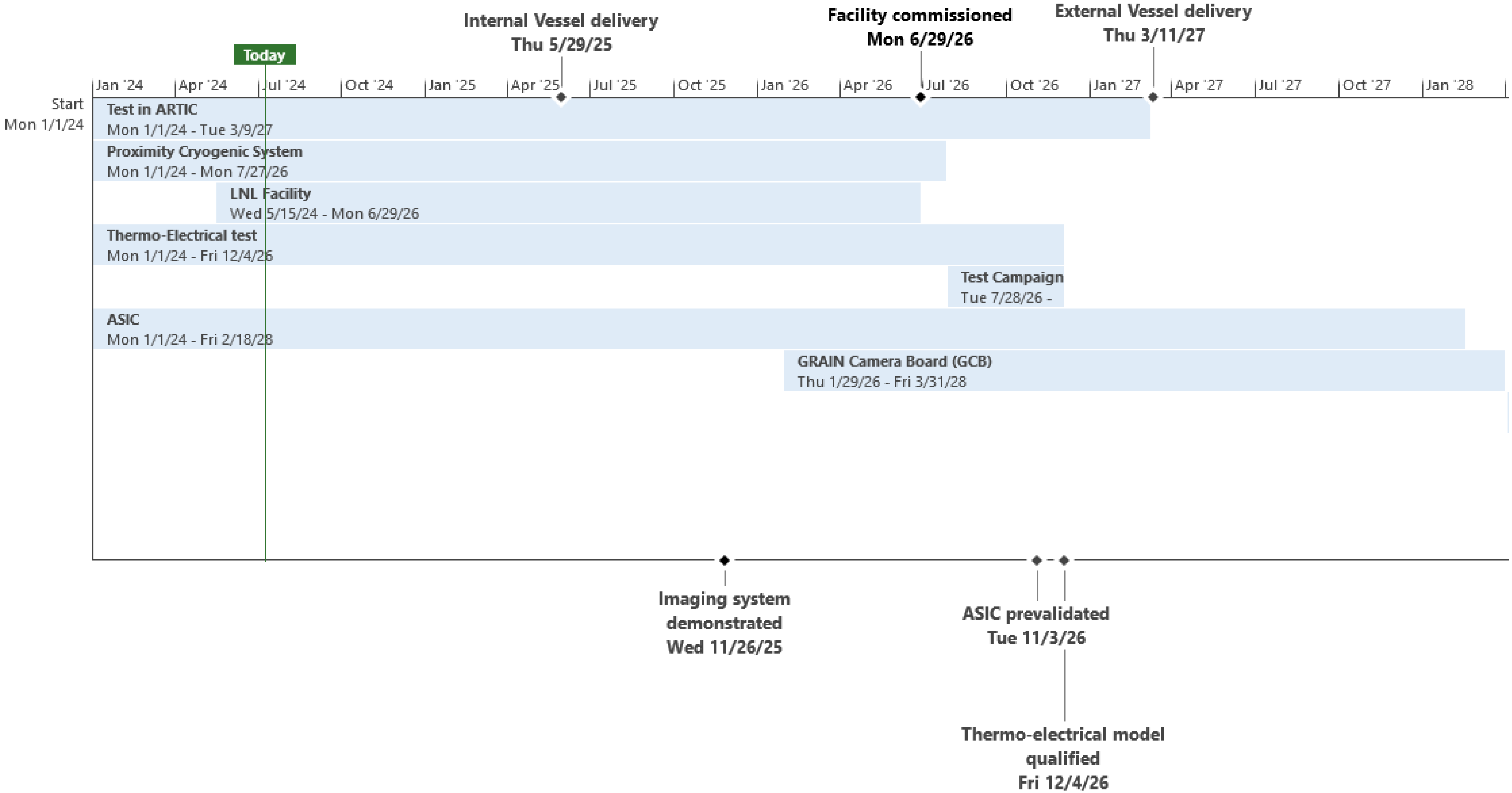
Alessandro Montanari
INFN Bologna

CSN1 review
Frascati, 11 Luglio 2024

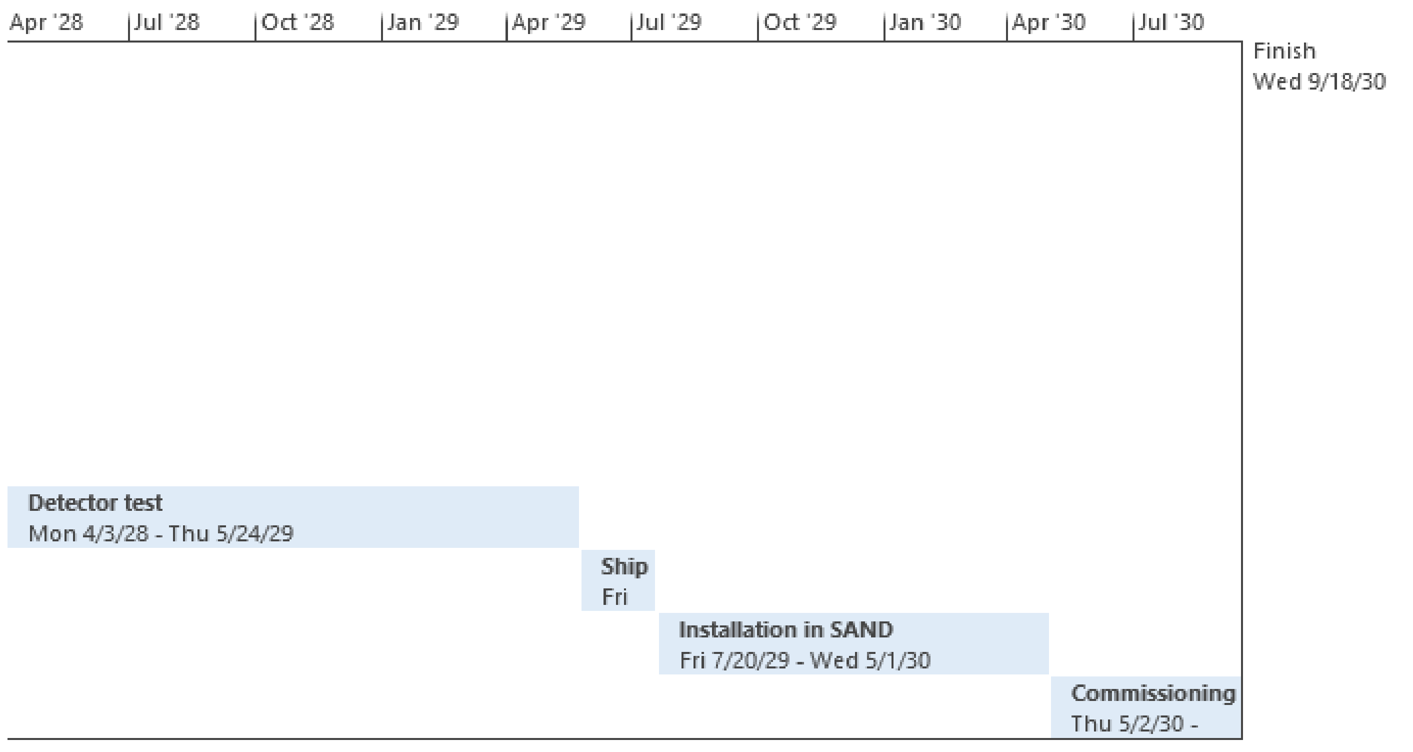
Test roadmap

- Test campaign through all the Project evolution:
  - Imaging technology:
    - Cameras with Masks or Lenses in ARTIC (LAr)
  - Thermo-electrical qualification:
    - At room temperature in Lab
    - At LAr temperature in LNL (when Internal vessel and cryogeny ready)
  - Full detector test:
    - Final configuration of all cameras with Cosmic rays in LNL

Timeline (2024-2027)

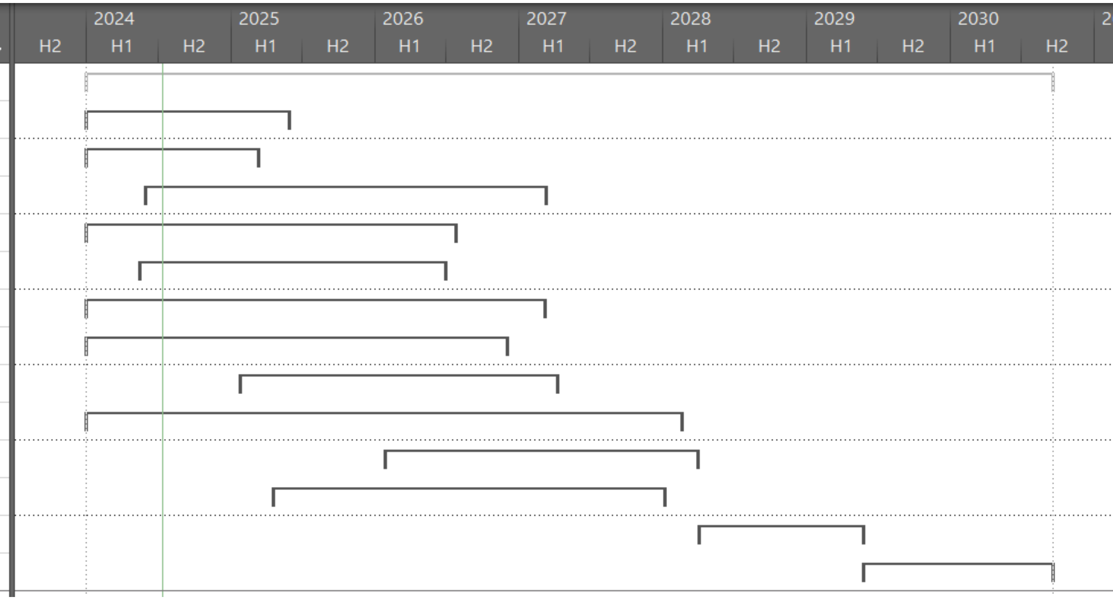


Timeline (2028-2030)



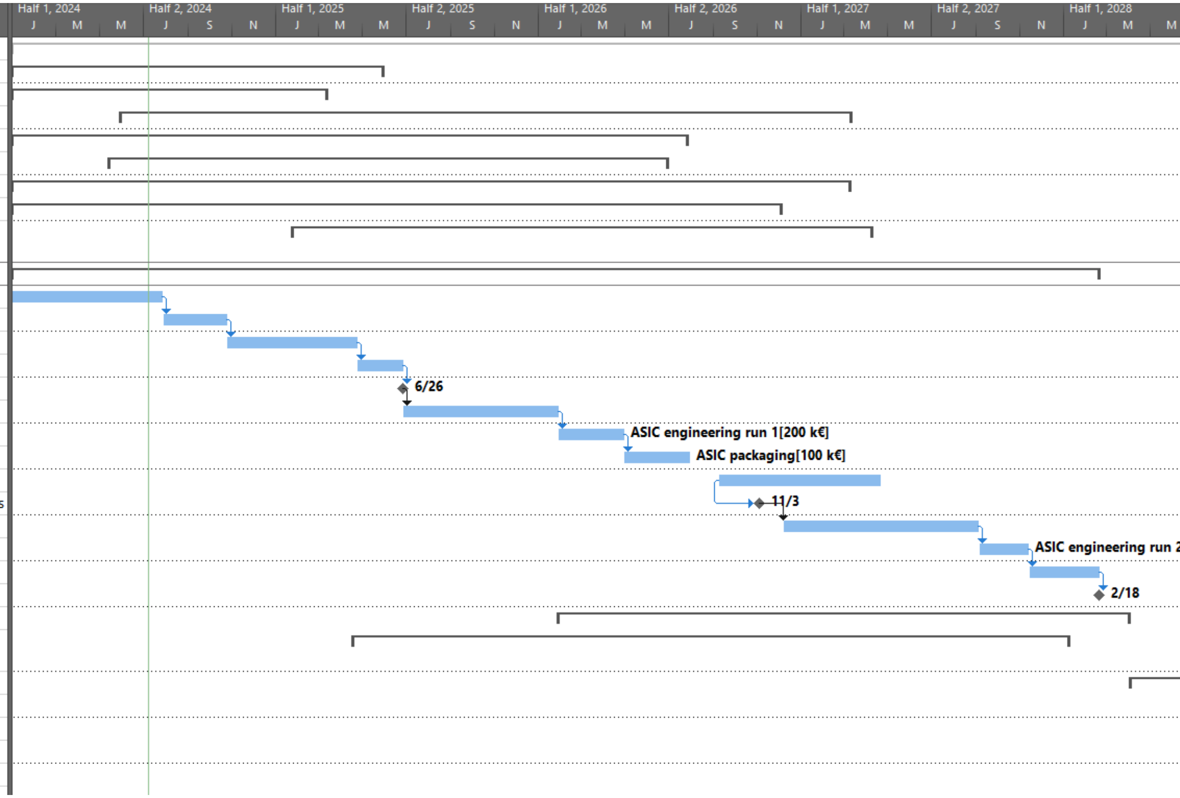
Timeline (overall view)

ID	Task Mode	Task Name	Duration
0		GRAIN	321.6 wks
1		Internal Vessel	69 wks
9		Vacuum Tank	58 wks
18		External Vessel	130.6 wks
25		Proximity Cryogenic System	124.6 wks
45		LNL Facility	101.2 wks
64		Test in ARTIC	152 wks
73		Thermo-Electrical test	140.6 wks
86		GRAIN Cold Interface Board (GCIB)	105.6 wks
91		ASIC	196.6 wks
106		GRAIN Camera Board (GCB)	103.6 wks
119		GRAIN Warm Interface Board (GWIB)	127.6 wks
129		Detector test	55 wks
136		Installation and commissioning	64 wks

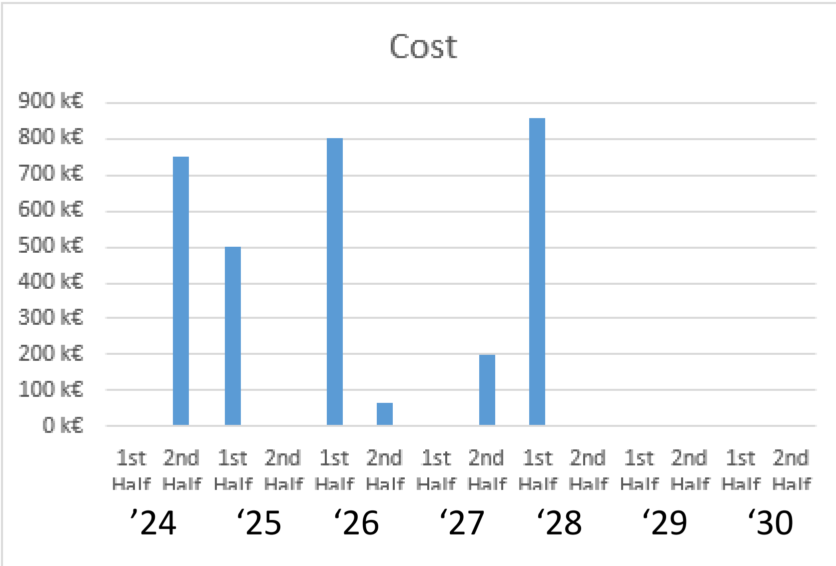


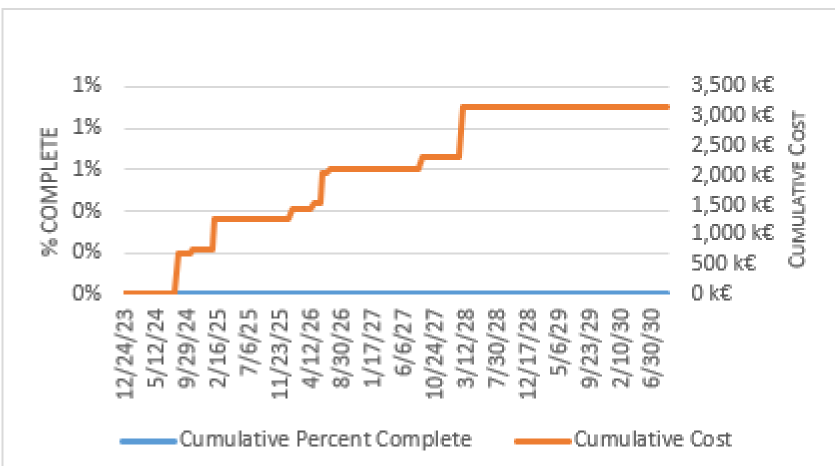
Critical Path

	Task Mode	Task Name	Duration	Work	Start	Finish	Predecessors
0		GRAIN	321.6 wks	0 wks	Mon 1/	Wed 9/1	
1		Internal Vessel	69 wks	0 wks	Mon 1/1	Thu 5/29/	
9		Vacuum Tank	58 wks	0 wks	Mon 1/1	Thu 3/13/	
18		External Vessel	130.6 wks	0 wks	Fri 5/31/	Thu 3/11/	
25		Proximity Cryogenic System	124.6 wks	0 wks	Mon 1/1	Mon 7/27	
45		LNL Facility	101.2 wks	0 wks	Wed 5/1	Mon 6/29	
64		Test in ARTIC	152 wks	0 wks	Mon 1/1	Tue 3/9/2	
73		Thermo-Electrical test	140.6 wks	0 wks	Mon 1/1	Fri 12/4/2	
86		GRAIN Cold Interface Board (GCIB)	105.6 wks	0 wks	Fri 1/24/25	Fri 4/9/27	
91		ASIC	196.6 wks	0 wks	Mon 1/1	Fri 2/18/2	
92		specs definition	30 wks	0 wks	Mon 1/1	Fri 7/26/2	
93		Channel design	10 wks	0 wks	Mon 7/2	Thu 10/24	92
94		Readout and integration desi	24 wks	0 wks	Fri 10/25	Thu 4/24/	93
95		Layout design	9 wks	0 wks	Fri 4/25/	Thu 6/26/	94
96		ASIC interface document reac	0 wks	0 wks	Thu 6/26	Thu 6/26/	95
97		Final verification	26 wks	0 wks	Fri 6/27/	Wed 1/28	96
98		Chip Production	13 wks	0 wks	Thu 1/29	Wed 4/29	97
99		Packaging	13 wks	0 wks	Thu 4/30	Wed 7/29	98
100		Test and validation	30 wks	0 wks	Wed 9/9	Tue 4/20/	113,88,124
101		ASIC prevalidated	0 wks	0 wks	Tue 11/3	Tue 11/3/	100SS+8 wks
102		Final design	34 wks	0 wks	Mon 12/	Fri 9/3/27	101,85
103		Final chip production	10 wks	0 wks	Mon 9/6	Fri 11/12/	102
104		Packaging	12 wks	0 wks	Mon 11/	Fri 2/18/2	103
105		ASIC completed	0 wks	0 wks	Fri 2/18/	Fri 2/18/2	104
106		GRAIN Camera Board (GCB)	103.6 wks	0 wks	Thu 1/29	Fri 3/31/2	
119		GRAIN Warm Interface Board (GWIB)	127.6 wks	0 wks	Fri 4/18/25	Fri 1/7/28	
129		Detector test	55 wks	0 wks	Mon 4/3	Thu 5/24/	
136		Installation and commissioning	64 wks	0 wks	Fri 5/25/	Wed 9/18	



Expenditure profile (preliminary)





Name	Remaining Cost
Internal Vessel	180 k€
Vacuum Tank	70 k€
External Vessel	500 k€
Proximity Cryogenic System	1,000 k€
LNL Facility	
Test in ARTIC	
Thermo-Electrical test	
GRAIN Cold Interface Board (GCIB)	
ASIC	500 k€
GRAIN Camera Board (GCB)	920 k€
GRAIN Warm Interface Board (GWIB)	
Detector test	[illegible]

MON 1/1/24 - WED 9/18/30

COST

3,170 k€