Status of the Neutrino Platform Project

Johan Bremer for the NP project

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Agenda

- Introduction Neutrino Platform (NP)
- Introduction neutrinos
- DUNE Experiment
- Developments: Membrane Cryostat
- NP installations at Fermilab
- NP02 and NP04 at CERN
- Conclusion

Introduction Neutrino Platform (NP)

Neutrino Platform

The CERN Neutrino Platform (NP) is CERN’s undertaking to foster and contribute to fundamental research in neutrino physics at particle accelerators worldwide, as recommended by the 2013 European Strategy for Particle Physics. It includes the provision of a facility at CERN (E.g. proto-DUNE) to allow the global community of neutrino experts to develop and prototype the next generation of neutrino detectors, and also the installation of Icarus and the Short Baseline Near Detector at Fermilab and the DUNE detector (Lead, South Dakota, USA).

These are all large argon volume TPC detectors.

The TE department contributes to this research via the involvement of the CRG group. The material budget covering the CRG activities is covered by the NP, while the department participates with an average of about 1.7 FTE over the duration of the NP activities (this participations varies depending on the activities developed by the platform, manpower can also be supplied by NP budget).

Requirement to neutrino oscillation experiment (seen by non-expert)

- Neutrinos are non-charged particles. How to measure their energy, momentum etc.? Let's neutrinos interact with argon atoms and free electrons will be created (secondary particles): now we have measurable particles
- How to measure these electrons: put high voltage over argon volume (500 V/cm, E.g. 300 kV over detector) and accelerate these electrons to detection planes (TPC). Electrons shall be "free" for a sufficiently long time (10^s ms): extremely pure argon is needed
- Neutrinos are only weakly interacting with matter: use high intensity beam and large volumes of liquid argon (dense liquid) to increase number of interactions
- Cosmic particles could also interact with the argon bath: put detector in underground cavern for shielding
- Cosmic neutrinos will still enter the argon detector volume: use the signal from the accelerator where the neutrinos are created as trigger for the detector system.

neutrinos:

- 10^{11} neutrinos pass the surface of the earth per cm^2 per second. Only 0.001% of these neutrinos has an interaction when they pass through the earth
- Three different families of neutrinos have been identified (ϑ_μ, ϑ_τ, ϑ_e). Are they oscillating between families? Do other families exist…

DUNE experiment

DUNE experiment

Over 20 years a worldwide collaboration has been working on the development (and now implementation) of a particle beam driven long baseline neutrino oscillation experiment. Several propositions have been studied (for example Laguna, cavern in Finland with beam from CERN, and LBNE in South Dakota with beam from Fermilab).

Experiment: create a neutrino beam in an accelerator complex and measure the (muon) neutrinos directly after their creation, and after the particles have travelled a distance of about 1300 km (study of neutrino oscillations).

To increase the number of interactions (esspecially for the far detector) between the neutrinos and the detection matter, large volume detectors using a dense material had to be developed. Water and liquid argon were both studied since suitable detection media.

In January 2015 the international DUNE collaboration is founded: development of a neutrino experiment at Lead (South Dakota, US) in a former gold mine (caverns to be excavated 1.5 km underground), based on liquid argon as detection medium (liquid argon TPC) and a neutrino beam facility at Fermilab (PIP2 proton beam). In total 4 liquid argon detectors are foreseen with a volume of about 13.500 m^3 each (total of 70 kT of liquid argon, or about 1000 road trucks per cryostat).

DUNE experiment

The implementation of extremely large volumes of cryogenic liquids in underground caverns asks for a development of cryostats and cryogenic systems which can assure the correct operational conditions of such a detector:

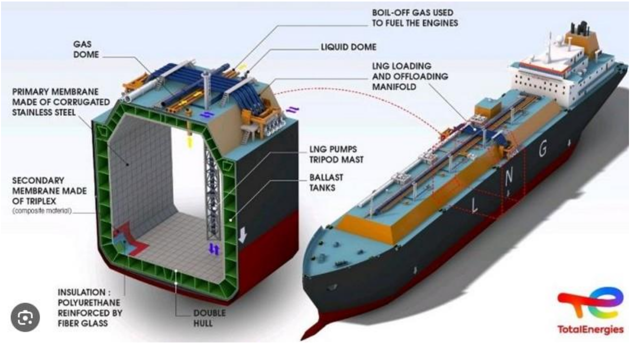
- Assure that the large volume of liquid argon stays, under all conditions, contained in cryostats
- Assure a low temperature gradient (< 1 K) and high temperature stability over the sensitive volume
- Assure stable pressure conditions (< 1 mbar)
- Assure O_2 equivalent pollution level in argon bath to an equivalent of a 30 ms electron free lifetime (< 10 ppt O_2 equivalent)

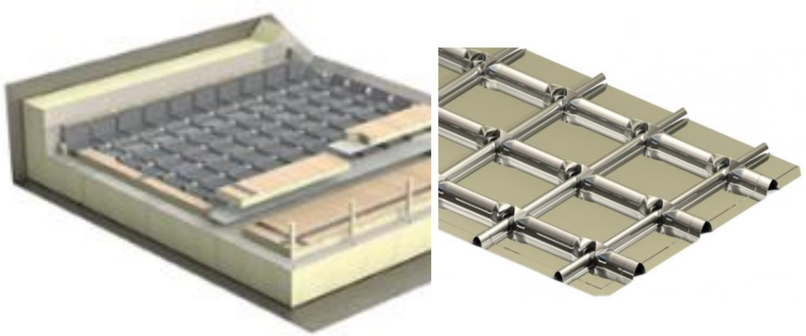
The NP has taken the responsibility for the development and design of the cryostat and the proximity cryogenic systems fulfilling the demands of the DUNE requirements, and for the design and installation of the ICARUS and SBND experiments at Fermilab and the proto-DUNES test area at CERN.

Development example: Membrane Cryostat

Membrane cryostat for DUNE

Design large volume (13.500 m^3) liquid argon detectors cryostats to be placed in underground caverns





GTT MARK III thermal insulation and primary membrane

First test station (B182): 17 m^3

- No vacuum: System is always in same condition, situation cannot get worse (but high heat load: 7.5 W/m^2)
- External detectors need to be installed: cryostat needs external support system cannot directly be mounted against cavern wall;
- Welding procedures / leak check to be adapted to the use of ultrapure argon
- Purging of insulation volume with gaseous nitrogen (no humidity entering in insulation)

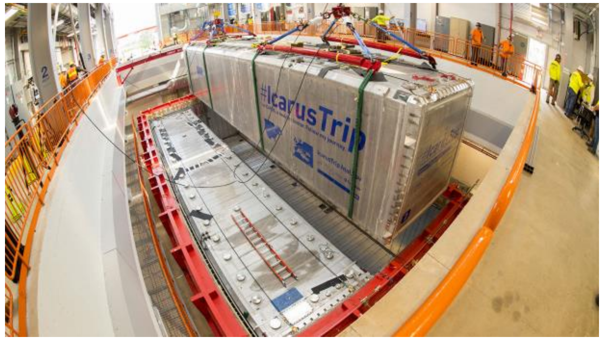
First test in B182 made clear: many more improvements needed, work by NP in collaboration with GTT

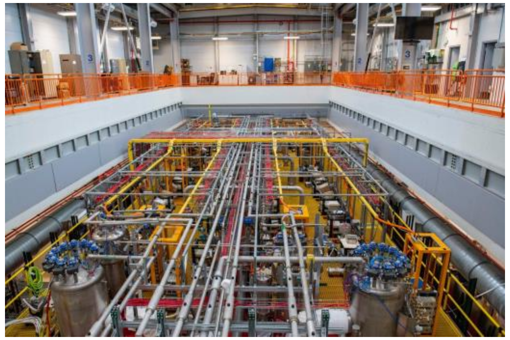
Other development examples: liquid argon purification system, small temperature gradients over detector (15 m high) over cooldown and standard operational period, pre-argon loss alarms,..

NP installations at Fermilab

Facilities designed and constructed by NP

NP01 / ICARUS at Fermilab / SBFD



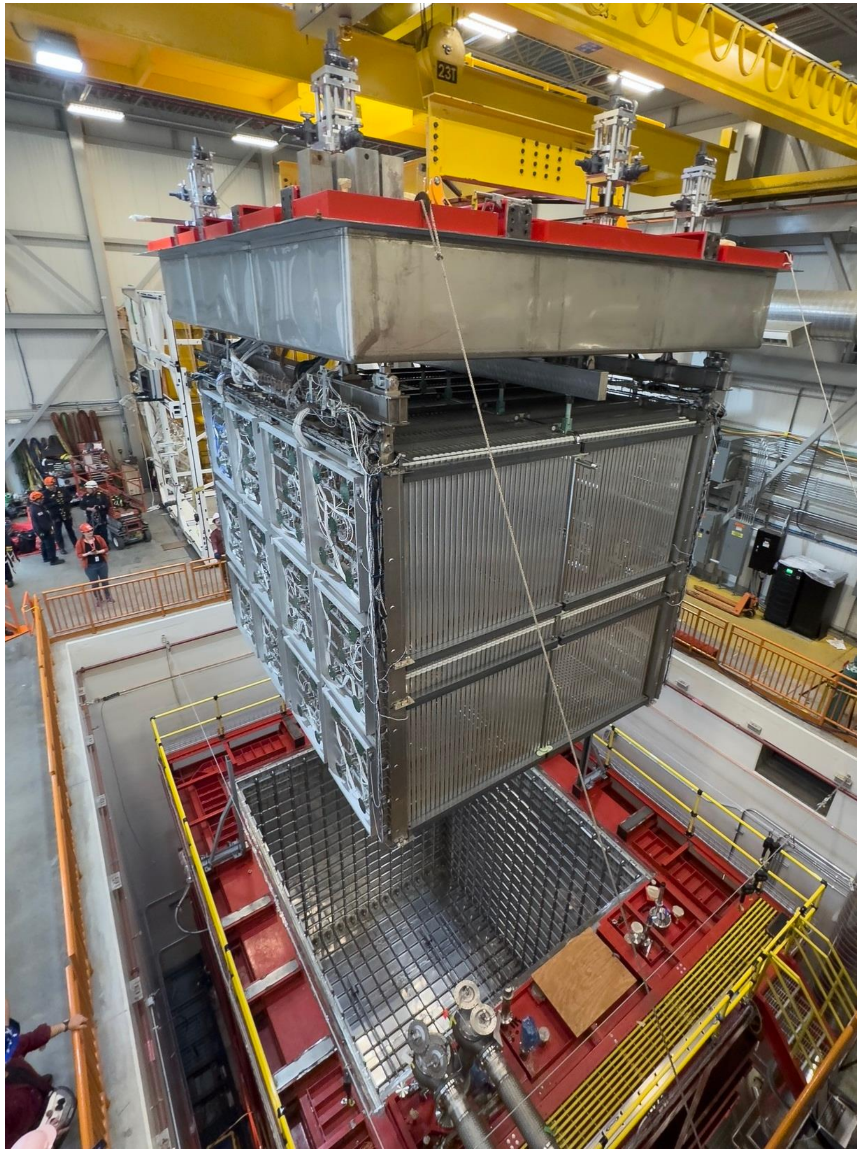


- Icarus detector had been in operation in Gran Sasso with a neutrino beam from CERN
- Icarus detector transported from Gran Sasso to CERN in original liquid argon cold vessels;
- Liquid argon cold vessels have been exchanged for upgraded model at CERN by EN/MME (20mx4mx4m)
- Detector system transported to Fermilab and installed in NP cryostat enclosure;
- New cryogenic system completely designed, specified, produced, transported, installed and commissioned by CRG
- Cryogenic control system specified by C`RG, implemented by Fermilab

- System in continuous operation for 4 years, temperature gradient < 0.1 K, pressure stability < 2 mbar, free electron lifetime 8 ms (about 40 ppt)

Facilities designed and constructed by NP

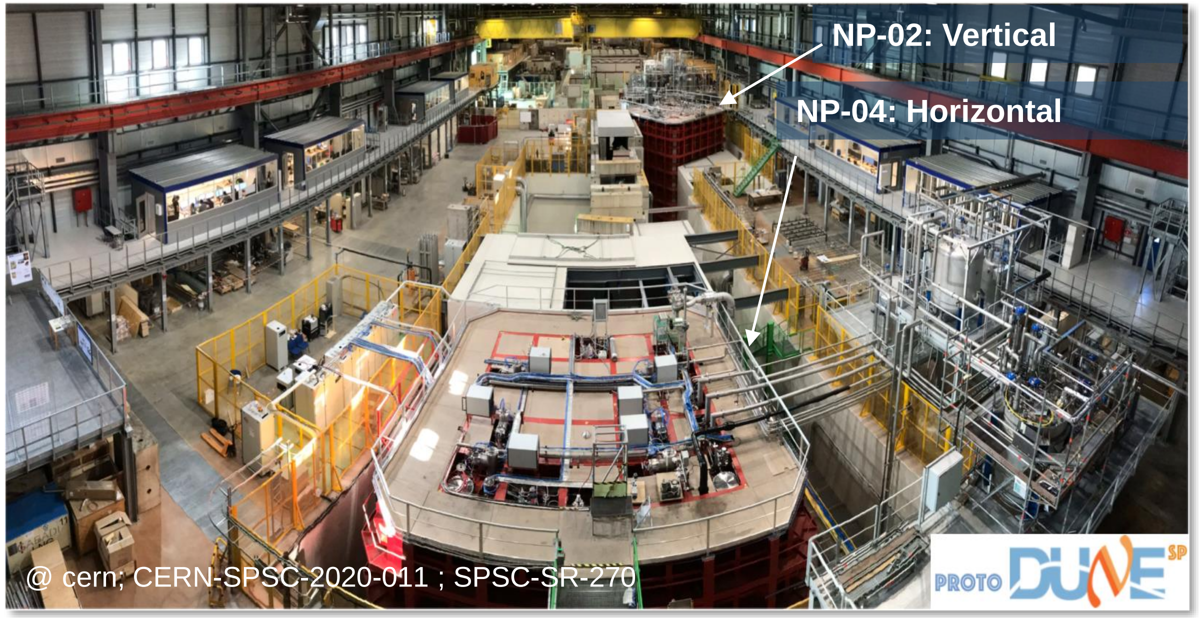
NP03 / SBND at Fermilab



Complete cryostat and cryogenic system delivered by NP to Fermilab just before COVID……..
Detector has been introduced end 2023, cooldown started 2024, now stable for about 4 months: System well within the specifications, but…..some problems with the detector read-out.

NP02 and NP04 at CERN

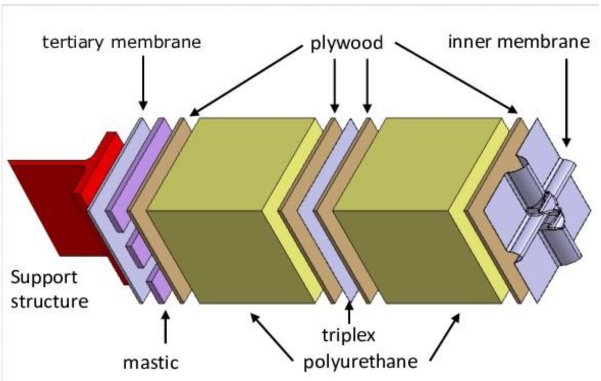
Facilities designed and constructed by NP

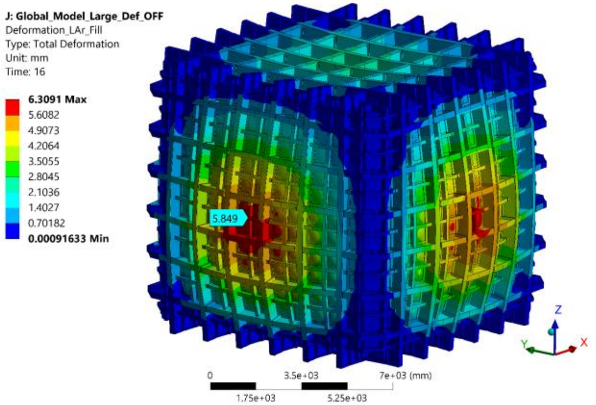


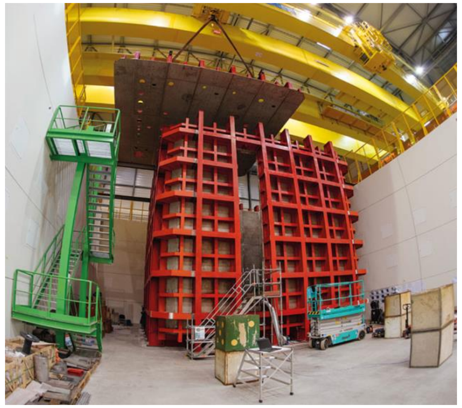
NP02 and NP04 proto-DUNE installations at CERN:

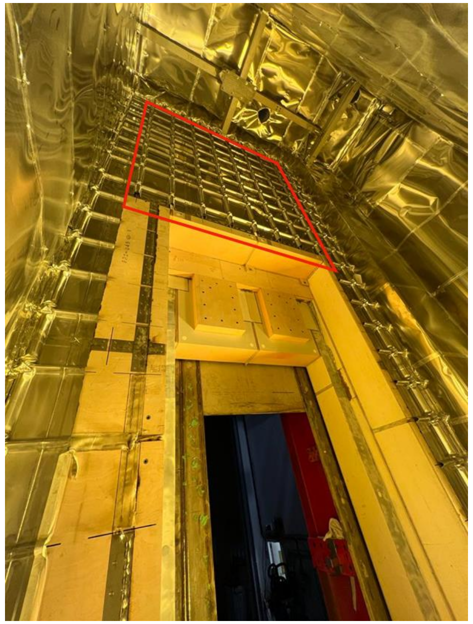
- Test of Membrane Cryostat Principle
- Test of Cryogenic Principle
- Test of Liquid Argon Purification Principle
- Test of Detector Principles (installation of detector, cabling, cool-down, operational results (cosmic and with beam);

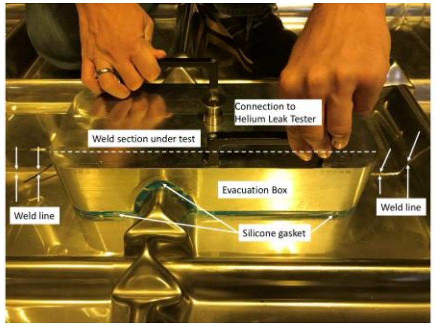
NP02 and NP04 proto-DUNE membrane Cryostat principle

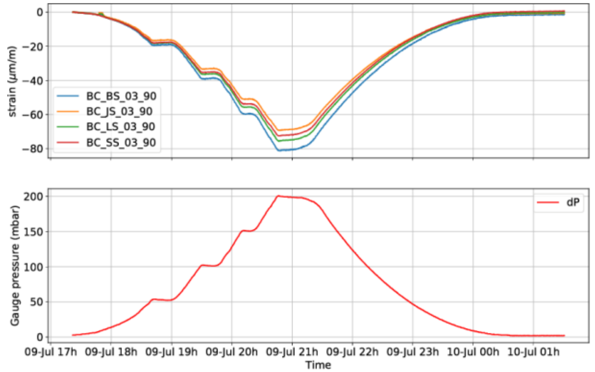










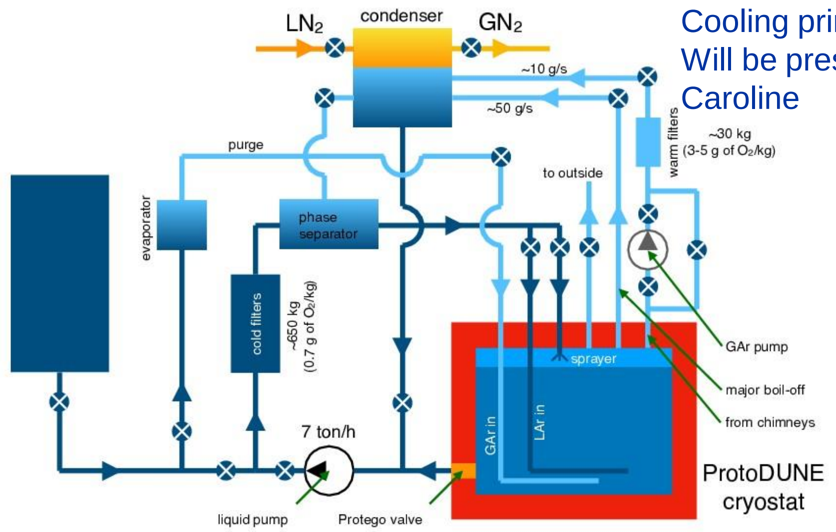


In filled cryostat: no condensation on the outside

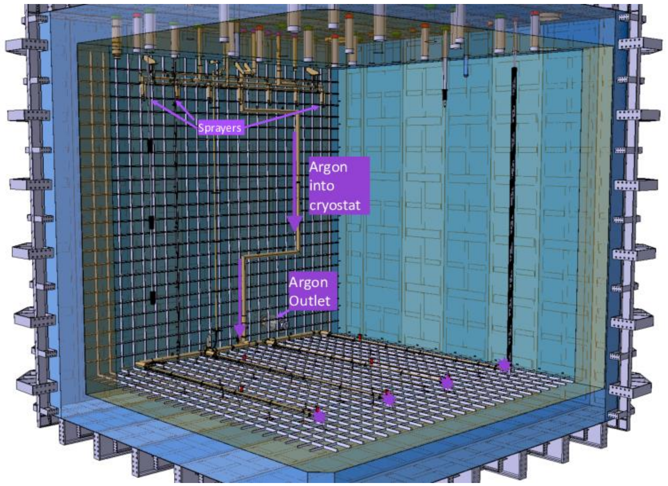
Measured heat load through cryostat surface 8 W/m^2

No argon leak to insulation space

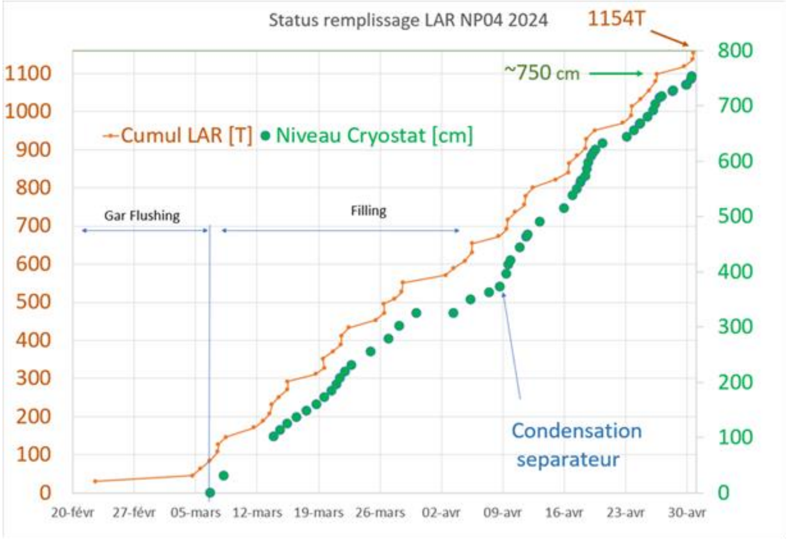
NP02 and NP04 proto-DUNE Cryogenic principle

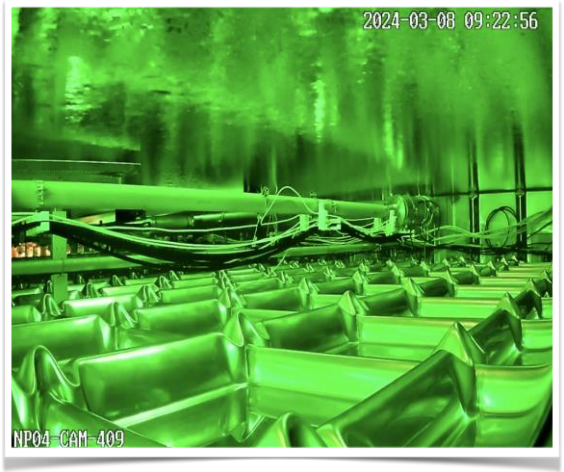


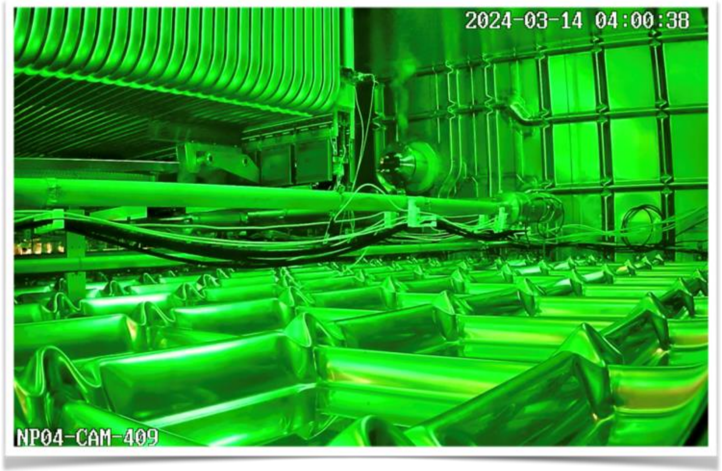
Cooling principle:
Will be presented by Caroline



- Before cooldown: no under-pressure possible: piston purge purification
- During filling: liquid from bottom, pulverized liquid argon from top: diminish gradients and pollution
- In operation warmer liquid returned to bottom and cooling at the top of cryostat: breaking the stratification

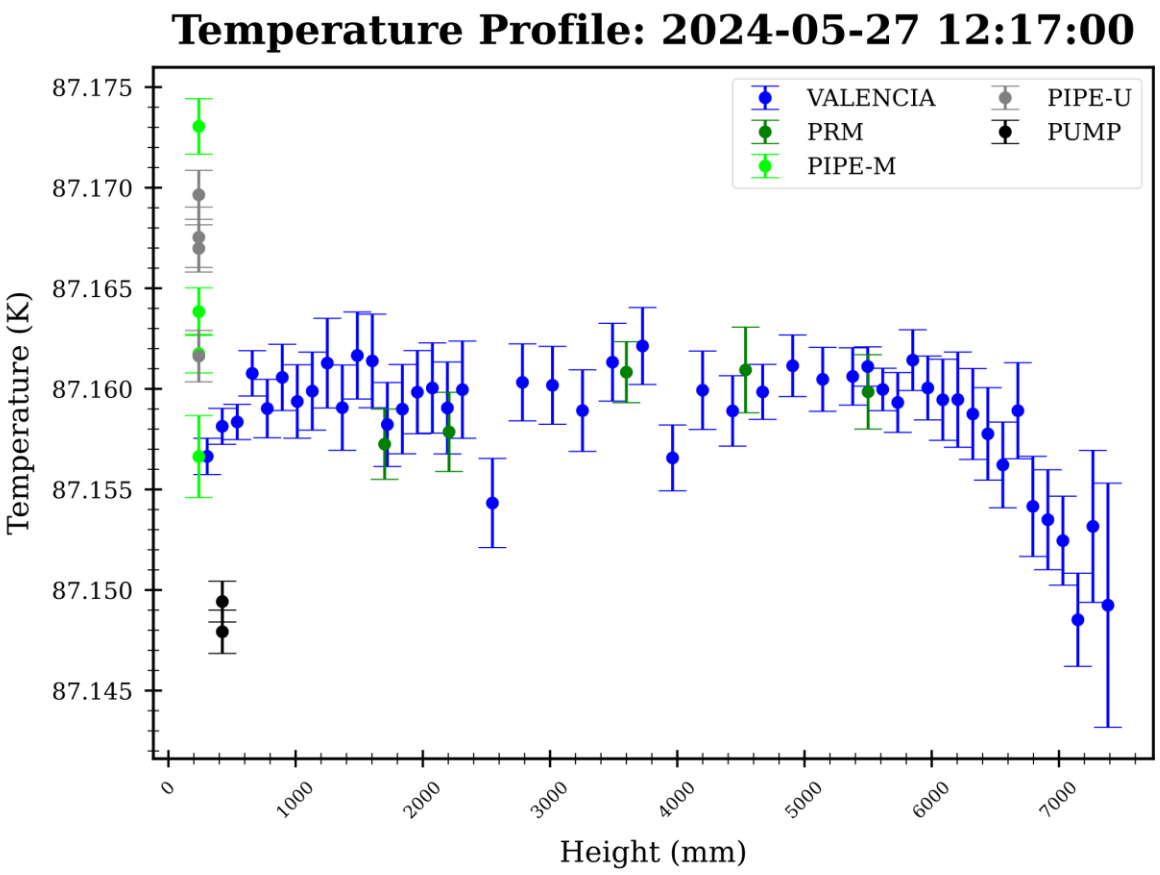


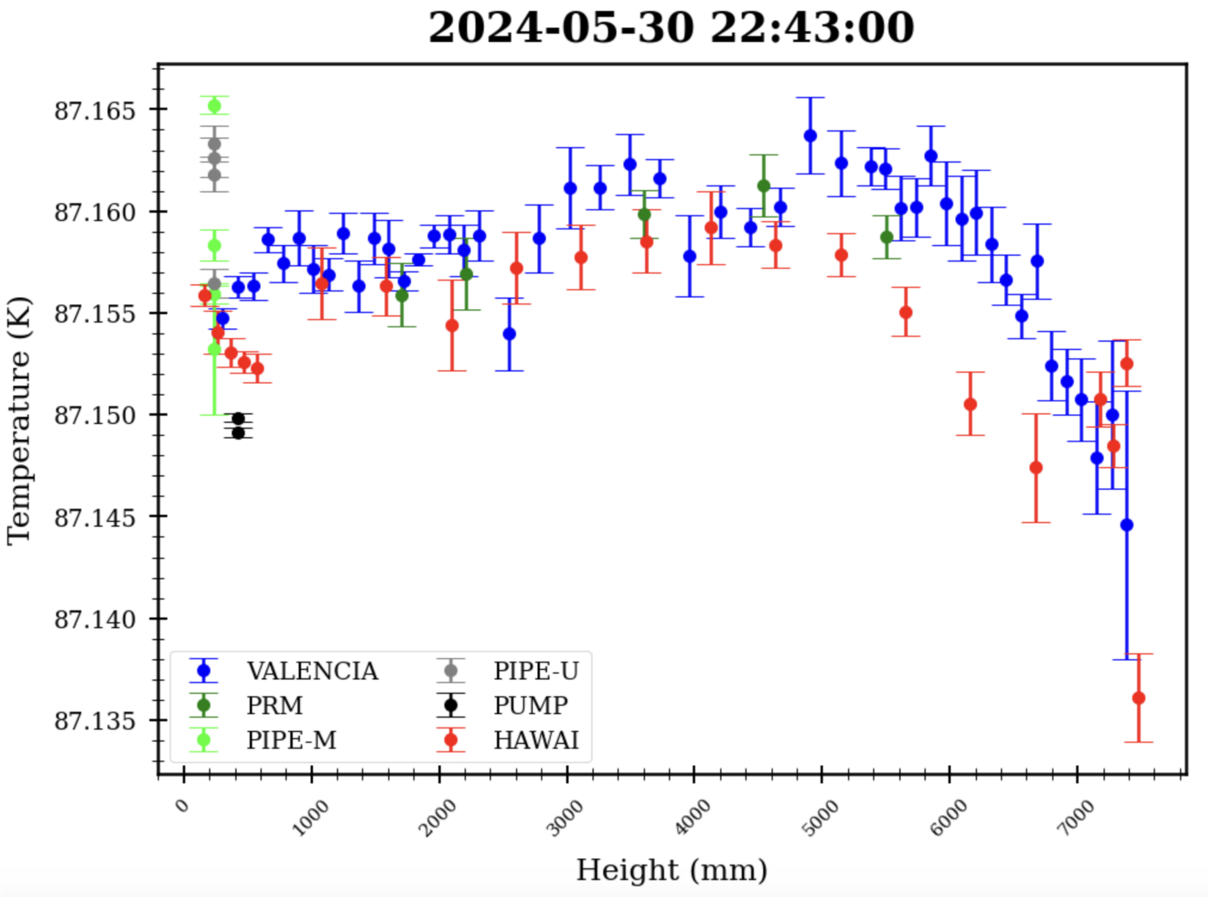




NP04 during filling

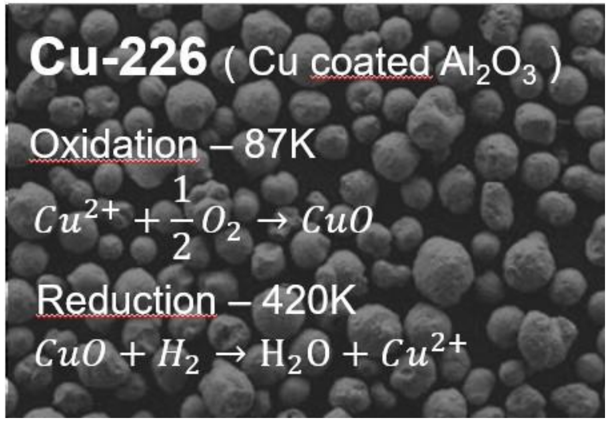
NP02 and NP04 proto-DUNE Cryogenic principle



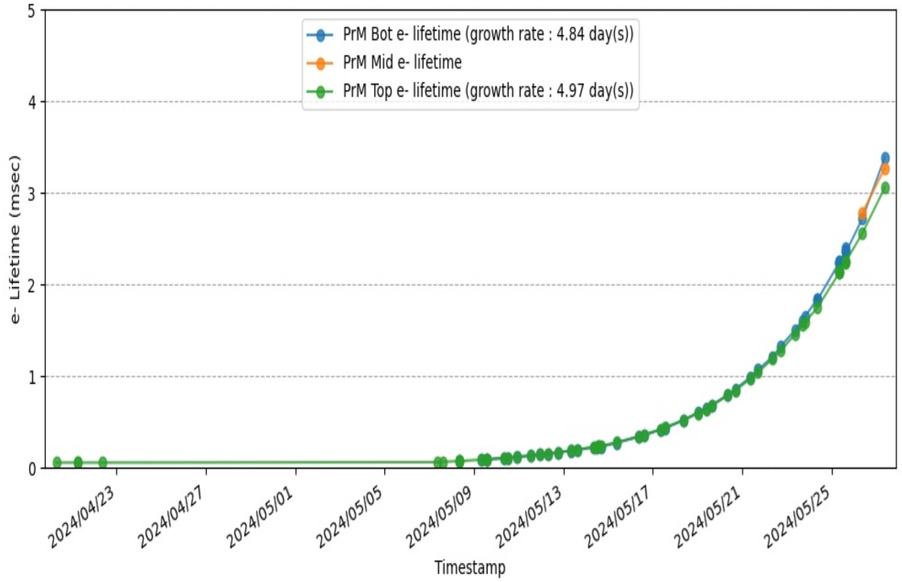


Preliminary results NP04 temperature distribution / stability ongoing measurements

NP02 and NP04 proto-DUNE Purification principle



Purification principle:
Will be presented by Caroline



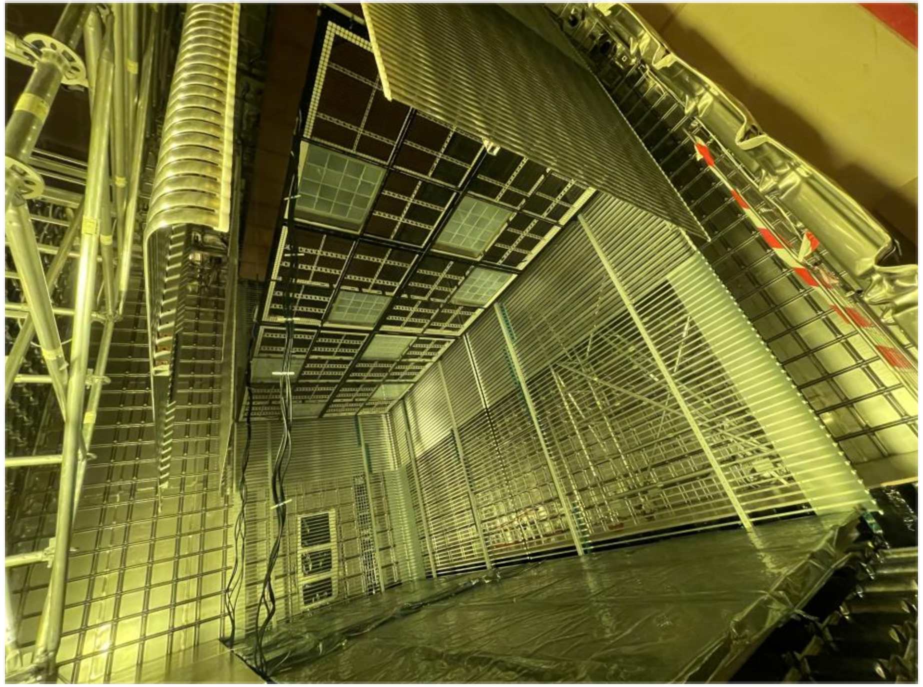
To arrive at a very low O_2 contamination level:

- No surface materials which can include pollutions (air, Cl, F_2, H_2O) are used in detector construction
- Vacuum purging of piping and piston purging of cryostat volume before cooldown. Outgassing of warm surfaces to be considered
- Warm gas from feedthroughs passes warm and cold purifier system before being returned to the cryostat
- Liquid argon is continuously (2kg/s) passing through cold purifier system

NP02 and NP04 proto-DUNE Detector principles

Horizontal Drift (in NP04)
- APA: three sets of wires winded around a SS frame
- Electronics in LAr including digitisation
- Drift of 3.5 m, CPA at -175 kV nominal voltage
- PDS embedded in the APA frames
- In cold test now, beam end of June

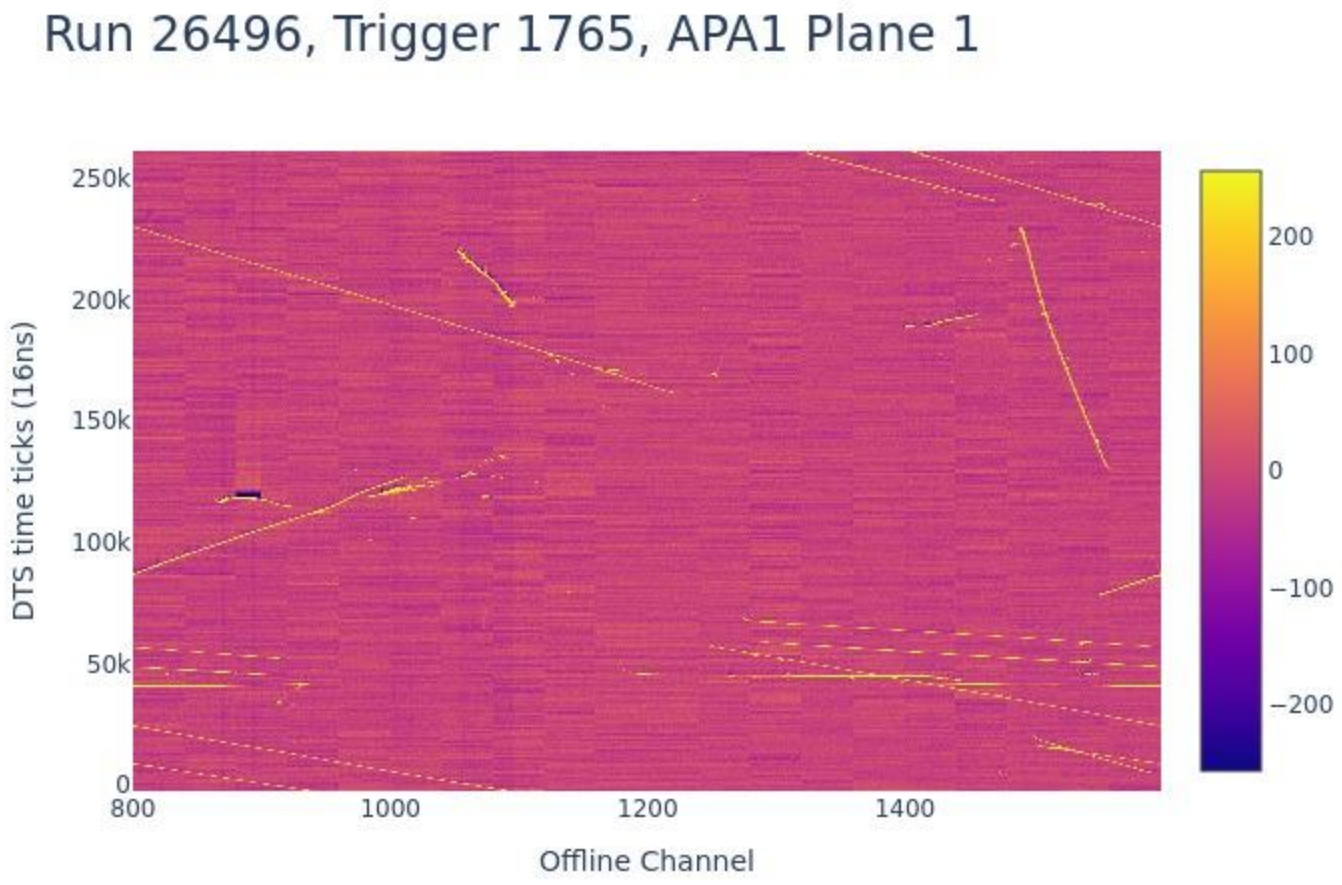
Vertical Drift (in NP02)
- CRP: perforated PCBs stuck with electrodes segmented
- Top CRPs readout with accessible electronics
- Bottom CRPs electronics in LAr including digitisation
- 6.5 m drift, -300 kV nominal
- PDS on the cryostat walls and on the cathode
- 2nd half 2024 transfer liquid NP04 to NP02 and start cold testing



Conclusions

- The NP had been charged with the development of e.g. the cryostat and cryogenic systems for DUNE, with the building of the cryostat and cryogenics infrastructure for the Fermilab based Short Baseline, and a test area at CERN to verify the functionality of these systems and to use them as a test area for detection principles to be applied in DUNE
- The SB at Fermilab installations are operational (FD for more than 4 years) well within the demanded cryogenic limits
- The results of the proto-DUNE area show that the cryostat and the cryogenic systems are fulfilling their requirements

Cryostat and Cryogenic principles are sufficiently aged to be implemented at DUNE
(see presentation by Caroline)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DTS time ticks (16ns)
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