Liquid Argon cryogenics for the Neutrino Platform

Operational Experience with the Proto-DUNE NP02 and NP04 large volume liquid argon cryostats and their cryogenic systems at CERN

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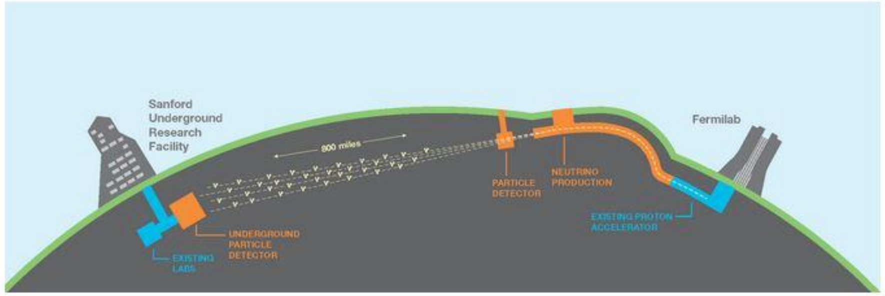
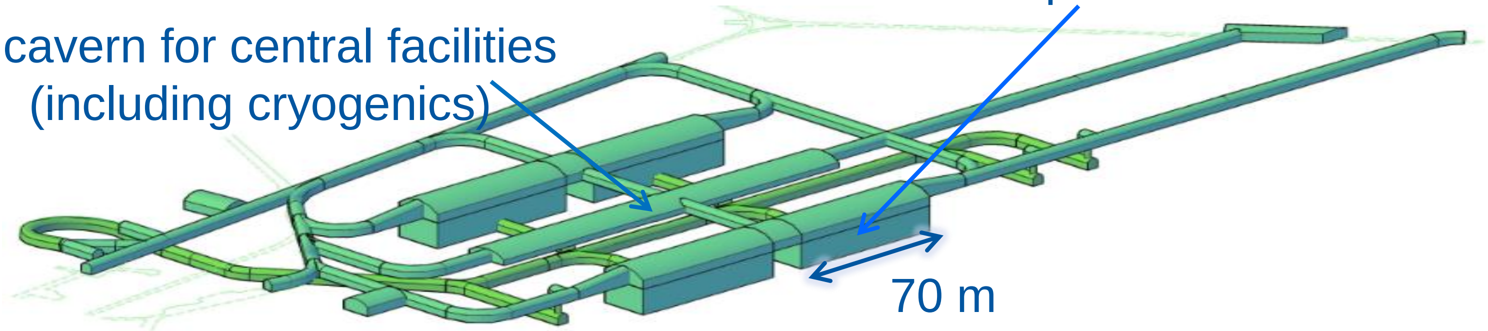
Content

Introduction

An international collaboration (DUNE) has been set-up to perform a comprehensive investigation on neutrino oscillations. Idea: Shoot a neutrino beam from Fermi Lab to Sandford Lab, covering a distance of 1300 km and detect neutrinos with a liquid argon based detector with a total argon mass of 70 kTon. The detectors will be placed in caverns at 1.5 km below the surface.





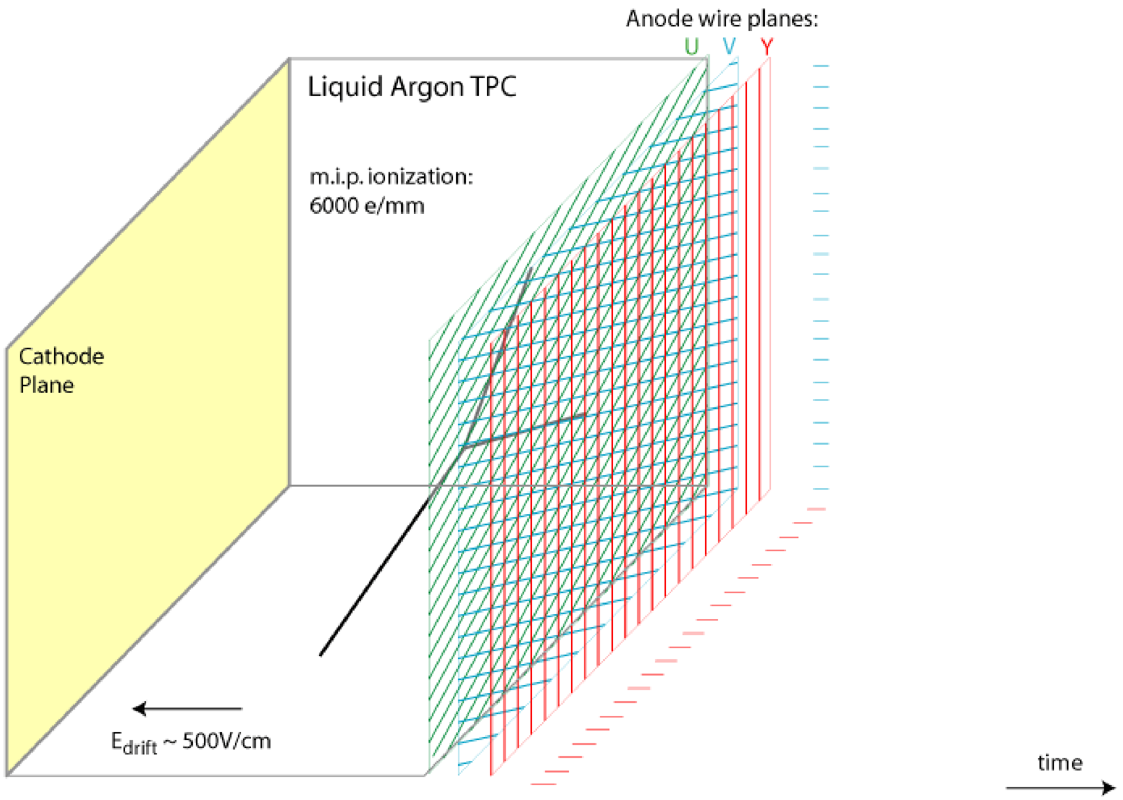
Detection principle

Neutrino has interaction with argon atoms creating secondary particle(s). These particles are liberating valence electrons along their travel through the detector;

Along the path through the detector about 6000 free electrons are created per mm;

These electrons are moving to the anode plane, while the much heavier positive ions move relatively slow in this field;

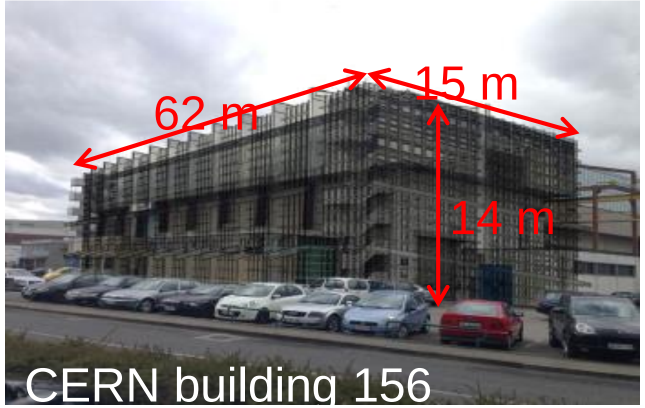
Together with the light detected by the photo multipliers, the track of the neutrino in the detector can be reconstructed.



Detection principle

For this operational principle to function:

1. Need of very pure argon to have a “long” free electron lifetime. “long” means milli-seconds, which corresponds to an oxygen equivalent purity in the parts per trillion level;
2. Need to be able to put a HV field of 300 kV over the sensitive argon volume;
3. The temperature gradient over the liquid argon volume shall be below 1 K;
4. Need of relatively long liquid argon bath and relative large argon surface perpendicular to the neutrino beam (increase change of interaction);
5. Trigger and exclusion systems are vital seen the large number of cosmic particles arriving at the detector;



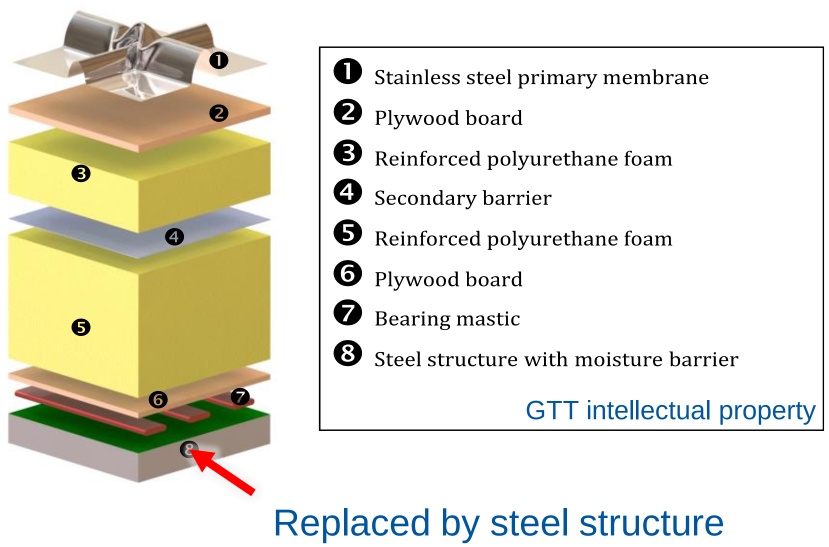
Cryostat Principle

Cryostat and Cryogenics collaborators were demanded

- To develop, prototype and build cryostats conform to the physics demands, and which also guarantee the highest safety level for use in the underground caverns;
- To develop, prototype and construct a cryogenic system, which guarantees stable conditions in the large liquid argon baths, and an argon purity level in ppt oxygen equivalent level

Seen the detector size and the underground installation: a non-vacuum insulated cryostat option (membrane cryostat) would be preferable:

1. No degradation possible by “vacuum rupture”, and no continuous vacuum pumping needed;
2. However: heat-load of about 7.5 W/m^2, higher than in case of vacuum insulated cryostats;
3. However: cryostat cold volume shall not go into an under pressure;
4. Qualified technique used for liquid natural gas (111 K) transport by ship and land storage.



Prototyping

Can the membrane cryostat principle fulfill the demands?

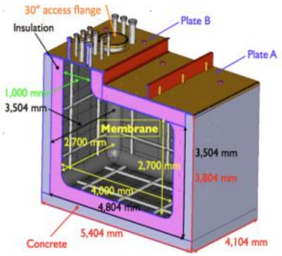
- Can a detector be mounted in such a structure?
- Is heat load through insulation indeed < 7.5 W/m^2?
- What will be the long term temperature / pressure stability in cryostat volume?
- Can demanded purity levels be reached (> 3 ms of free electron life time)?
- Can the safety levels for use in the underground areas be guaranteed?

Prototyping!

1 x 1 x 3
17 m^3

26 T
Program finished
(CERN)

35 T



35 T
Program finished
(Fermilab)

Proto Dune
SP

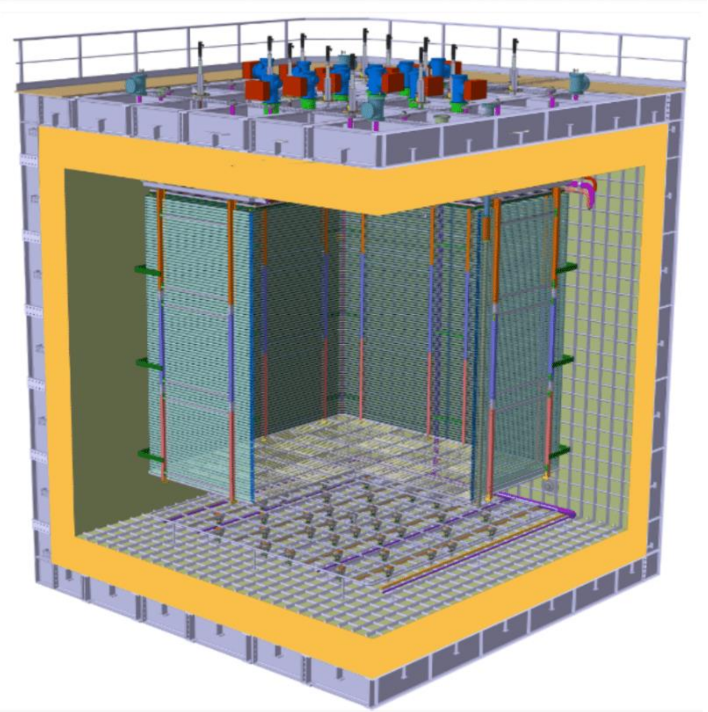
740 T
Cool-down in June 2018
(NP04, CERN)

Proto Dune
DP

740 T
Cool-down in December 2018
(NP02, CERN)

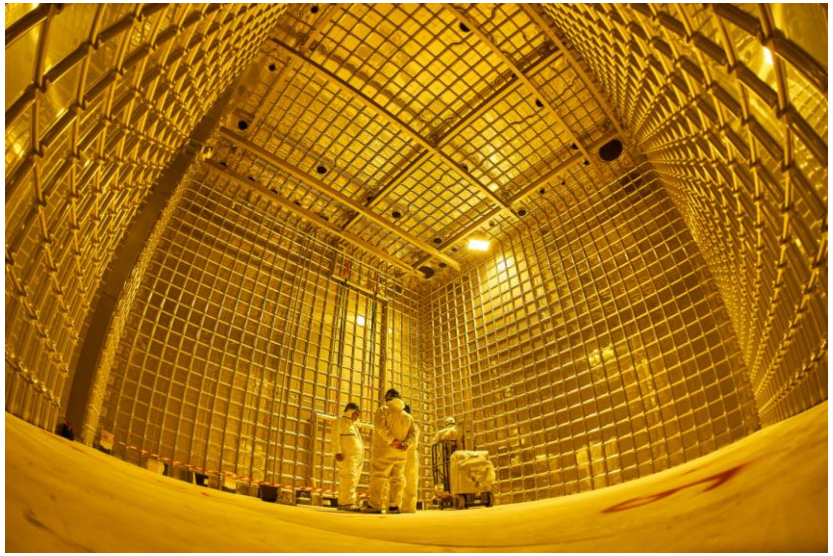
Proto-DUNE

At CERN a special building and its infrastructure have been put in place to test the two Proto-DUNE cryostats. These cryostats have an internal argon volume of 8 x 8 x 8 m^3 (external 10 x 10 x 10 m^3) and are equipped with prototype detectors and cryogenic system. These prototypes shall also be used to check the mounting principle of such a system (structural, how to leak check successfully, how to install detectors,…)



cryostat on the design table

The experimental area



NP04 cryostat before detector integration

Demands to cryogenic system

Cryogenic system requirements:

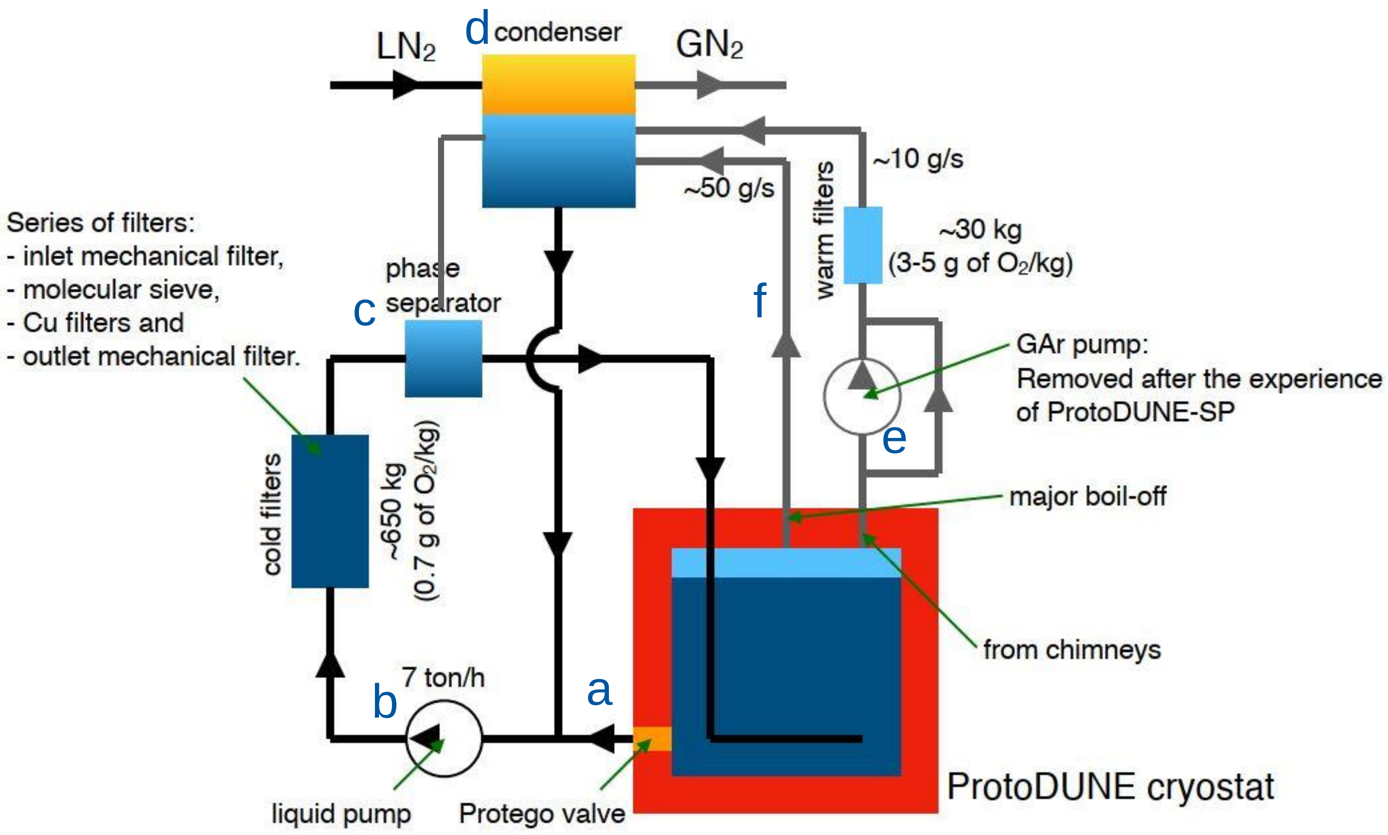
1. Keep liquid argon in cryostat (8 x 8 x 8 m^3) in stable conditions, without any boiling within the sensitive detector volume (6 x 6 x 6 m^3);
2. Guarantee a max temperature gradient of 0.5 K between any two points in the liquid argon bath;
3. Guarantee a continuous operation of the cryogenic system, over a long period (years);
4. Guarantee a purity level of the liquid argon bath at the100's ppt oxygen equivalent;

The liquid argon delivered to the experiments was accepted on the following conditions:

1. O_2 < 2 ppm
2. N_2 < 2 ppm
3. H_2O < 1 ppm

and argon will be continuously purified with the use of Molecular Sieve (H_2O) and active Cu pellets (O_2) at liquid argon temperatures.

Proposed cryogenic system



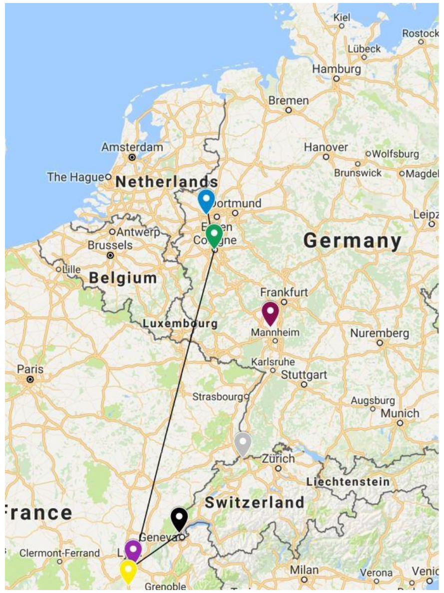
Thanks to F. Resnati

a) Cryostat safety valve, closes liquid outlet in case predefined events take place
b) Liquid argon circulation pump: used to purify in liquid phase;
c) Phase separation of argon coming from purification system. Liquid returned to cryostat, at slightly higher temperature;

d) Gaseous argon condensed by nitrogen evaporation via heat exchanger, and brought to inlet circulation pump (purity!);
e) Signal chimney warm gas flow, caused by argon vaporization in the cryostat
f) Argon cold gas evaporating from the cryostat

Cryostat filling

- Piston purge of cryostat volume since cryostat cannot be pumped: enter argon gas at the bottom of the cryostat and vent the gas at top. Enter gas corresponding with a gas displacement in the cryostat of 1 m/h: no turbulences and no back diffusion. Stop if purity level of gas in cryostat is < 1 ppm O_2 equivalent;
- Cool-down of detector by spraying vaporized argon from the top of cryostat. Pressure in cryostat is regulated to 50 mbar rel. Maximum allowed temperature gradient over detector volume defined as 30 K. Very light detector structure. Cool-down performed within 4 days;
- Filling of cryostat: 800 tons to be delivered per cryostat, 20 to 40 tons per day. Argon coming from Dortmund (Germany) area, delivered per train and truck. Total time to fill one cryostat takes about 5 full weeks.

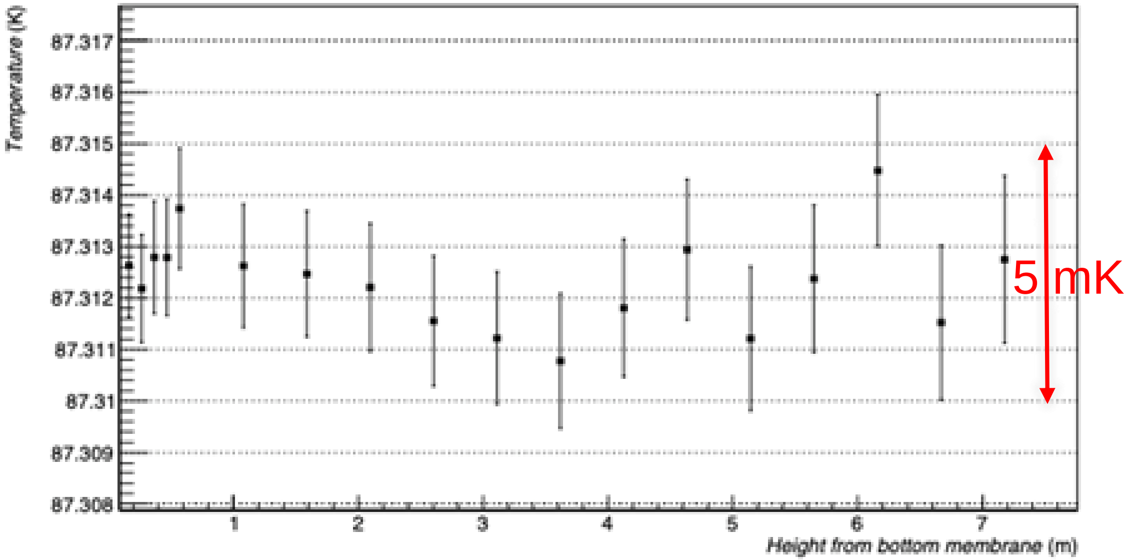


Thanks to D. Duchesneau

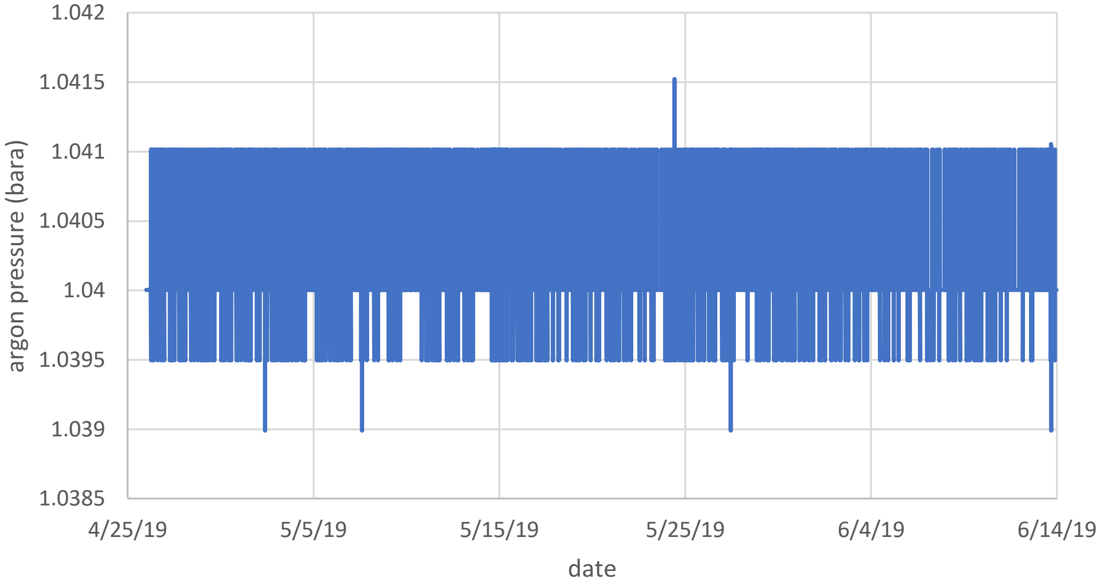
Stability

- When filling, liquid is passed through purification system, to guarantee that only “pure” argon enters the cryostat;
- After filling stabilizing the argon in the cryostat, regulating the absolute argon gas layer pressure pressure, while circulating for purification. After several weeks of stable operation:

Thanks to F. Resnati

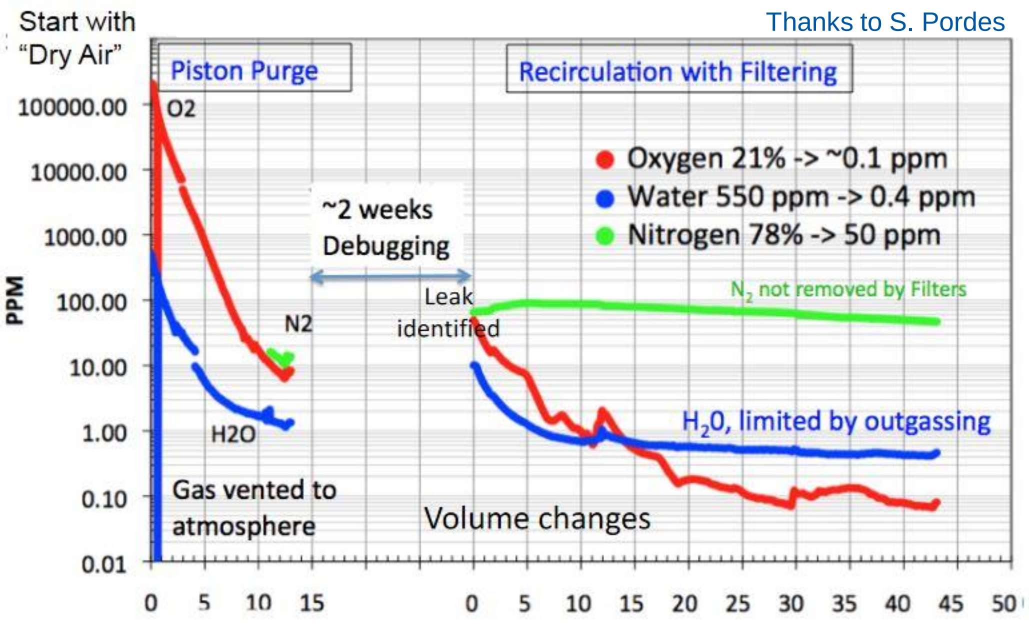


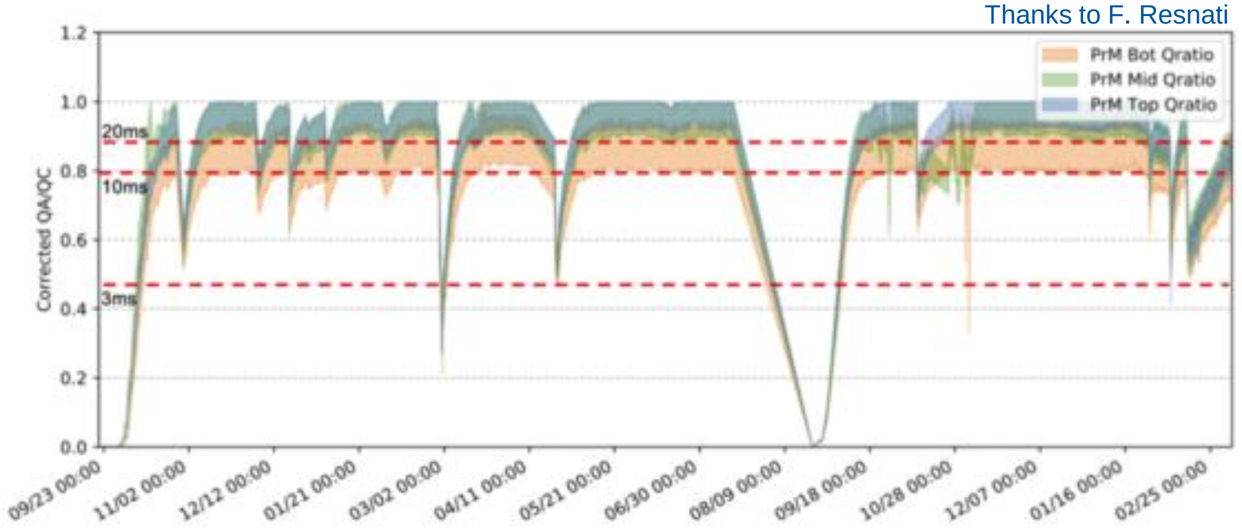
T gradient (in height) over cryostat volume



Cryostat pressure stability over time

Purity level





Cryostat purity level at warm

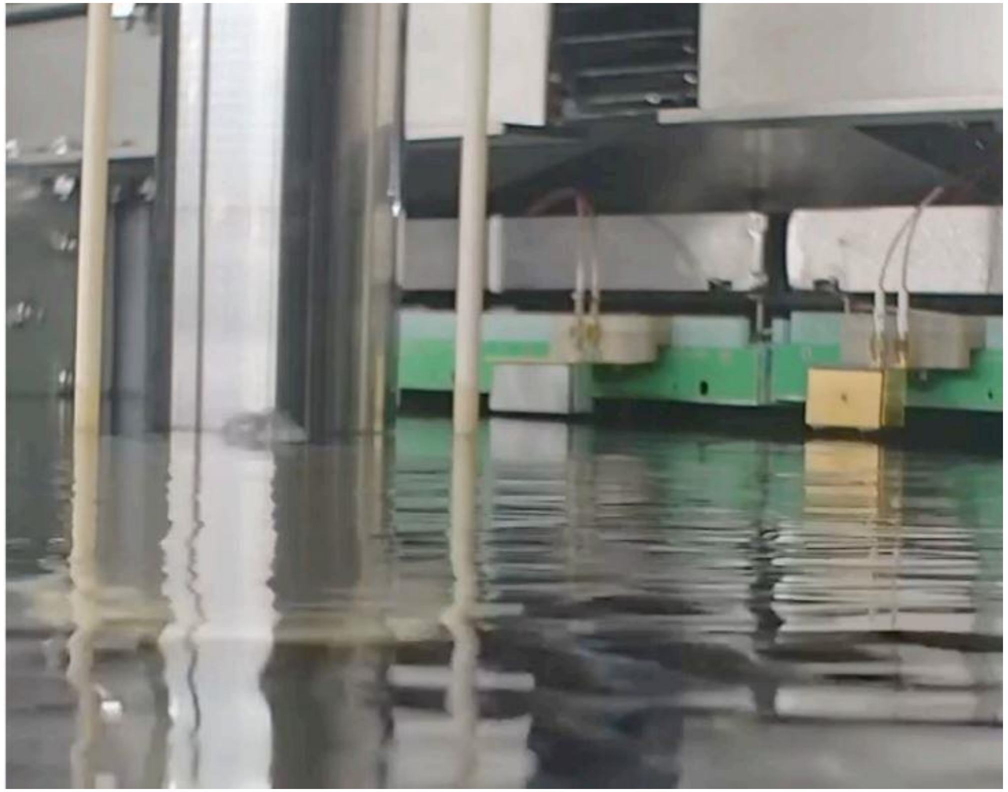
Cryostat purity level in liquid argon

- After end of data-taking period, circulation pump was used to push liquid to outside storage tank, from which it was recuperated by contractor;
- Cryostat is then warmed up by natural heat loads.

Return of experience and further studies

Points for which further study was needed:

- Some gas bubbling visible at top of liquid level, no effect on detector functioning, but…..
  - → HV feedthrough exchanged
- Sometimes mechanical blocking in liquid purifier inlet filter, caused by dust, but where is this coming from….
  - → mechanical filter added
- The liquid safety valve set-up at bottom of cryostat is not ideal: ice and condensation formation, improvement needed;
- Feed-through gas circulation pump broke-down (broken membrane). Can an another circulator be identified, is another circulator needed?
  - → pump removed + circuit modified to limit pressure drop; recirculation by pressure difference only



Conclusions

- The DUNE experiment will operate with four 17 kT cryostats in an underground area. Prototyping of the foreseen equipment has to be performed;
- Two larger volume liquid argon filled membrane cryostats (0.8 kT) have recently been operational at CERN for several years;
- The temperature gradients (in time and in volume) and purity levels within these two cryostats were well within the demanded limits;
- The results of the mentioned further studies have been successfully implemented in the second run of these cryostats which started by mid August 2021.
- Synergies with the CERN Neutrino Platform are considered for the design of the DarkSide-20k AAr (LNGS) where the acquired experience can be used.