DEEP UNDERGROUND NEUTRINO EXPERIMENT

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Cryogenic Instrumentation at ProtoDUNE

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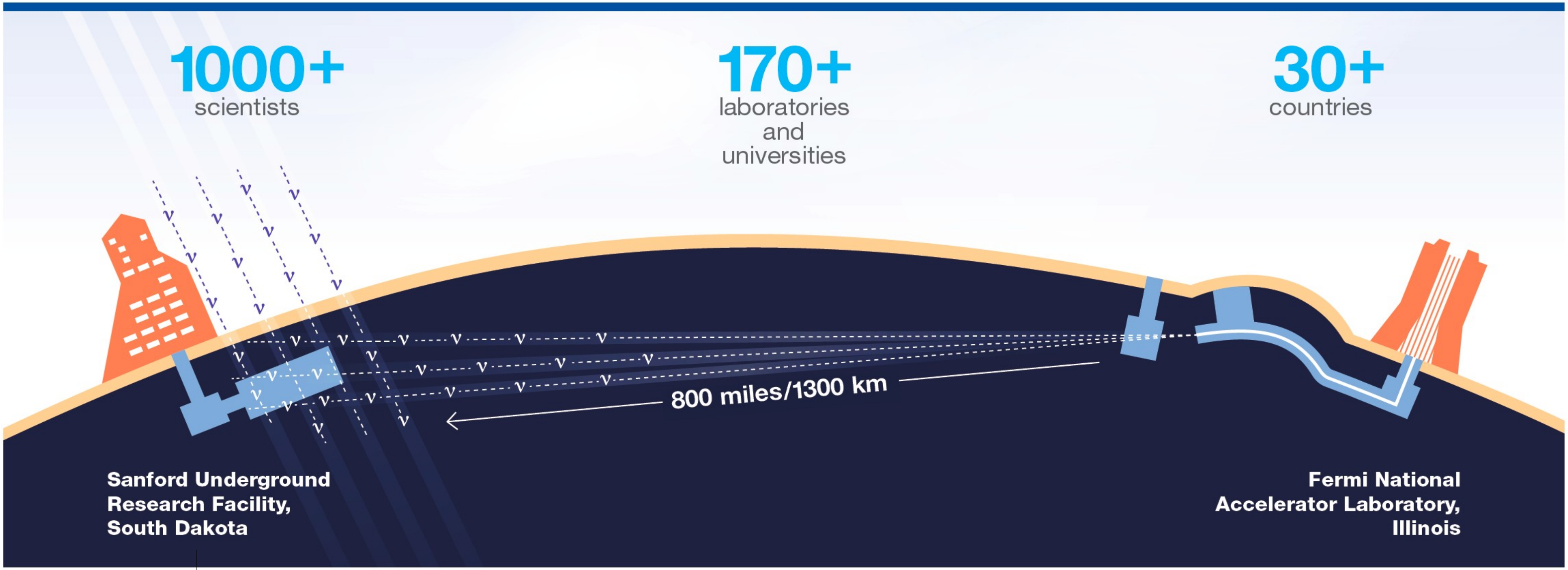
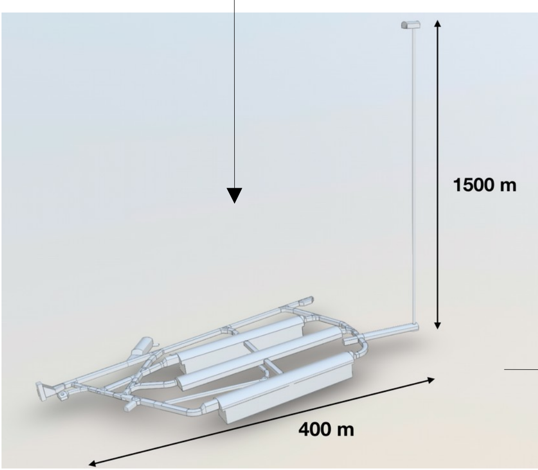
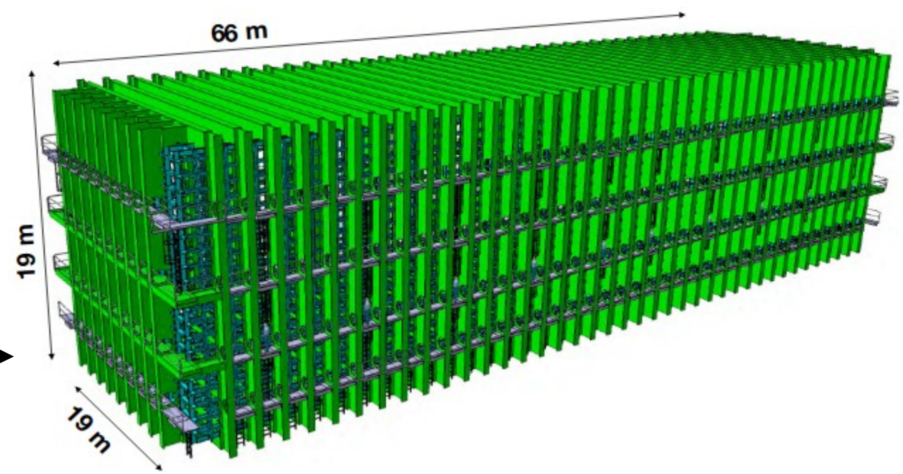
For the DUNE Collaboration

Deep Underground Neutrino Experiment (DUNE)







17 ktons argon mass.

Expected to run for 10 year periods.

→ Cryogenic instrumentation is needed

But before DUNE we have...

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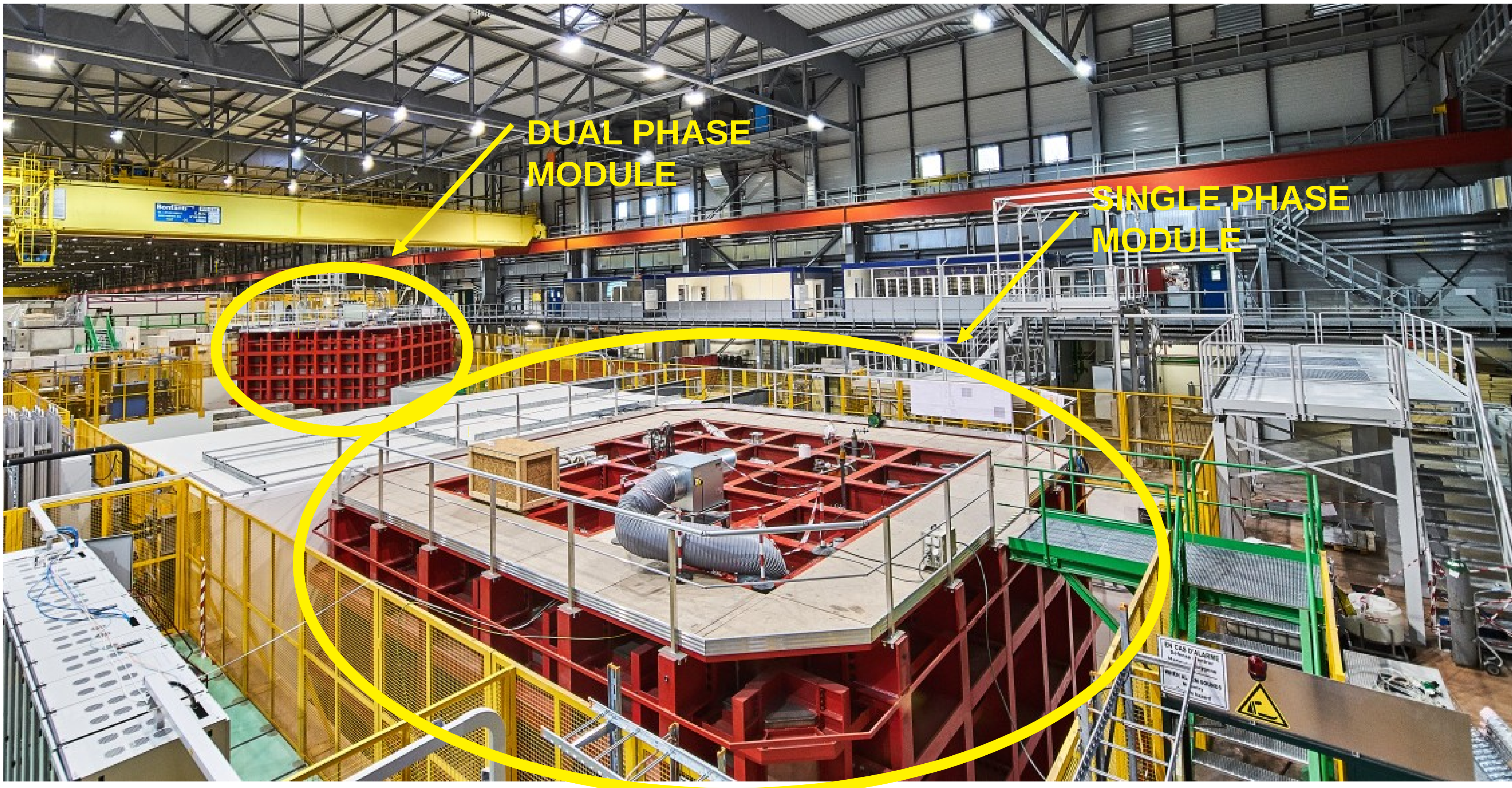
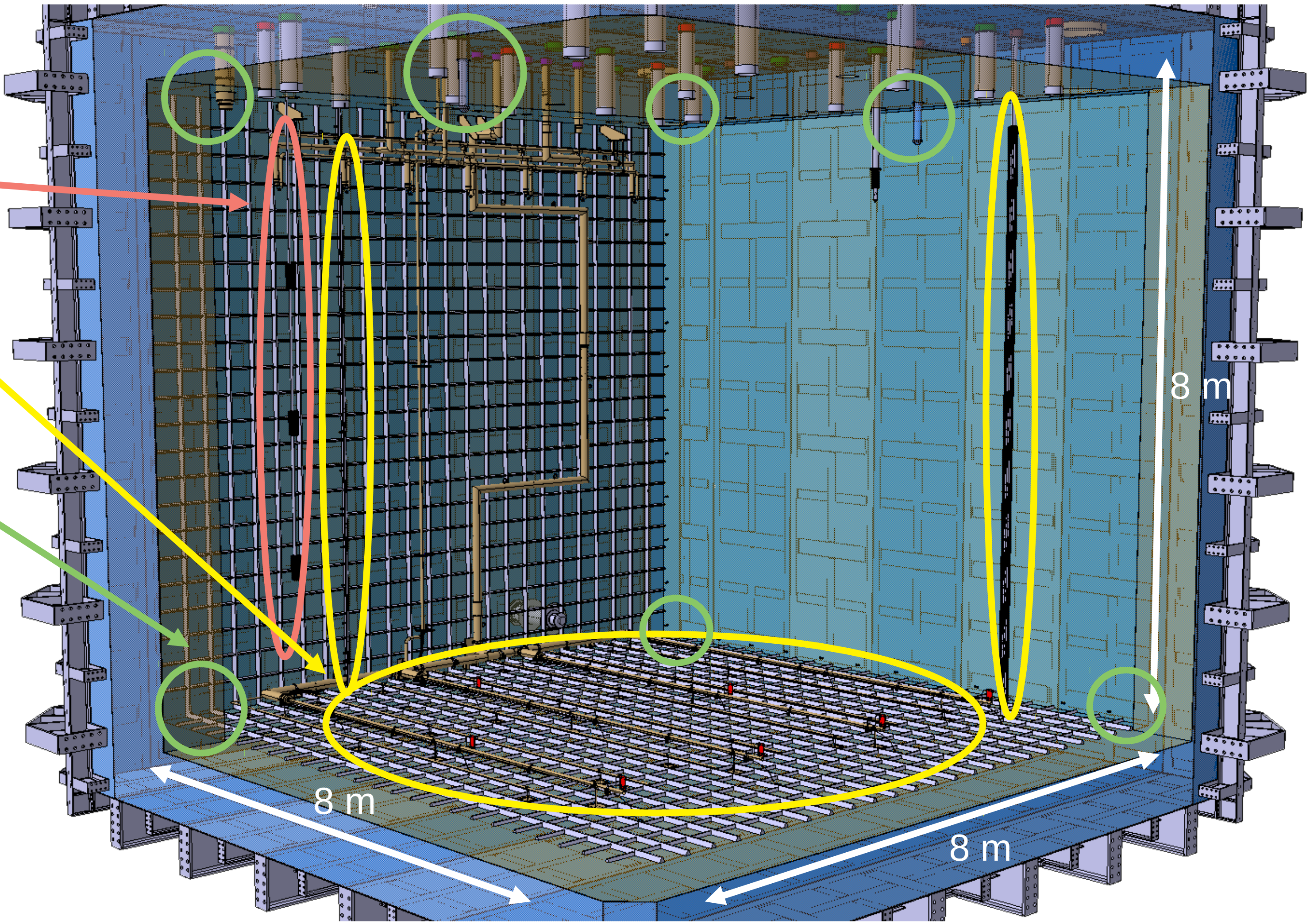


Cryogenic instrumentation

Monitoring and understanding the cryostat and the detector during the different parts of the experiment. Ensuring its long time reliability.

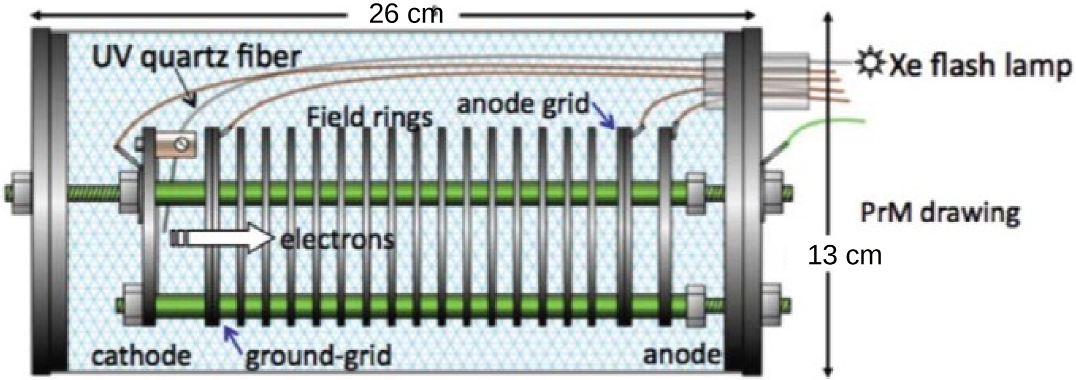
Different devices:

- Purity monitors
- Temperature sensors
- Cameras
- Gas analysers
- Level meters
- Pressure Sensors



Purity Monitors (PrM)

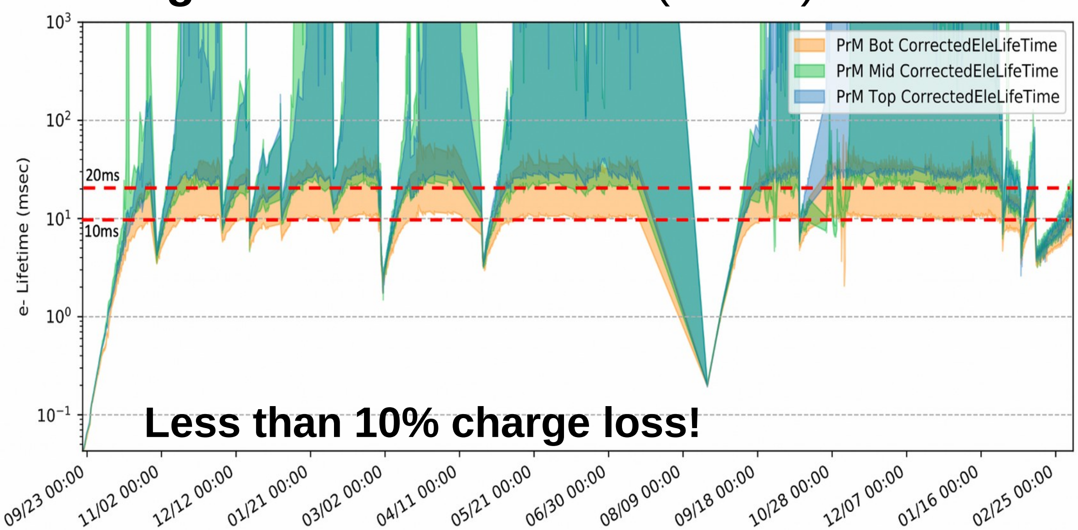
A miniature TPC to measure e⁻ lifetime



M. Adamowskiet al., JINST 9, P07005 (2014)

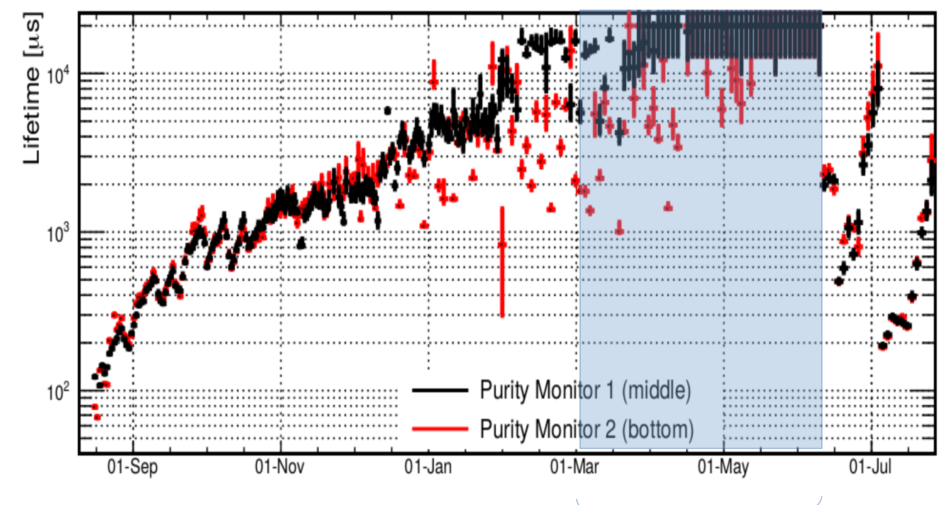
$$Q_{anode} = Q_{cathode} * e^{-t_{drift}/\tau}$$ ← e⁻ lifetime

Single Phase: three PrM (25 cm)

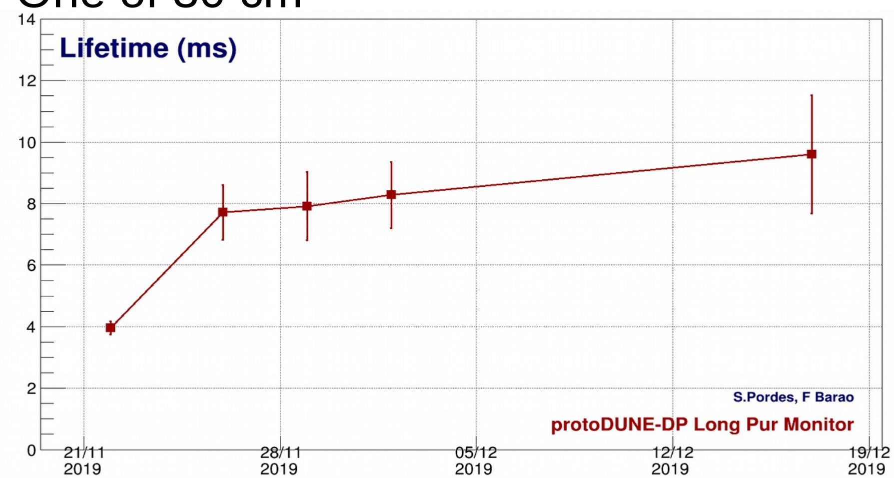


Dual Phase: three PrM

Two of 15 cm



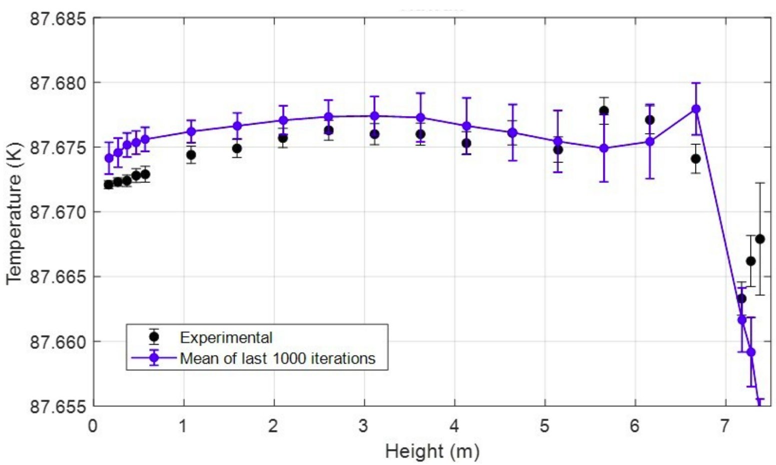
One of 30 cm



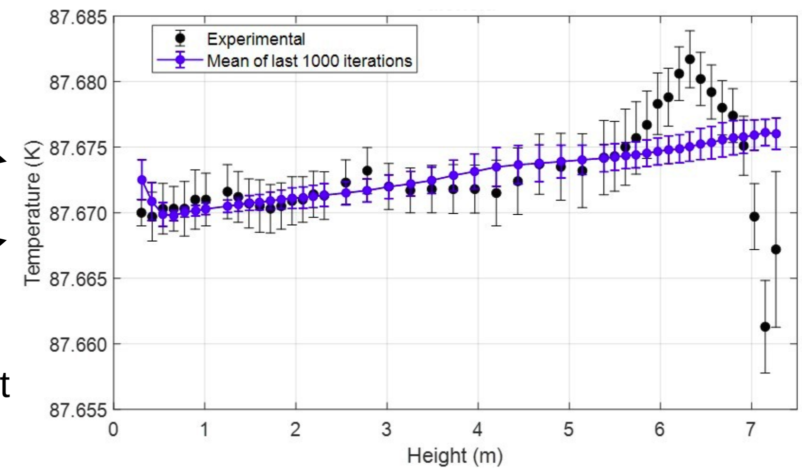
Temperature Monitors

Monitor cool-down and filling processes.

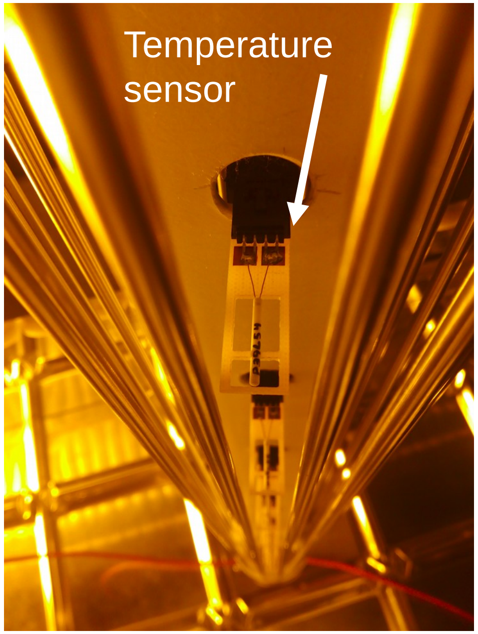
Precisely (mK) measure liquid argon temperature → fluid flow simulations → e⁻ lifetime prediction

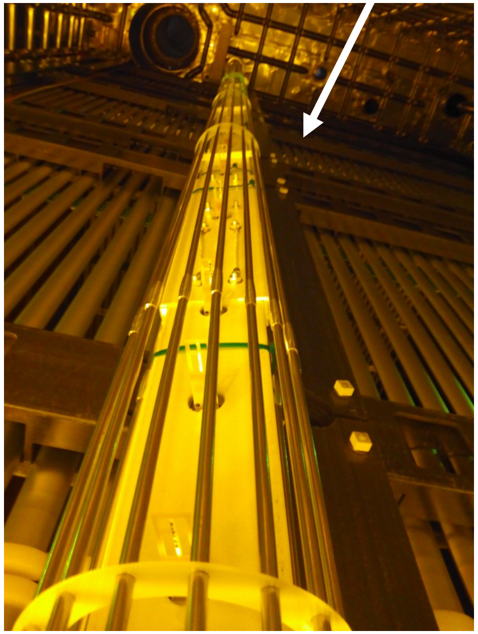


Data and simulations

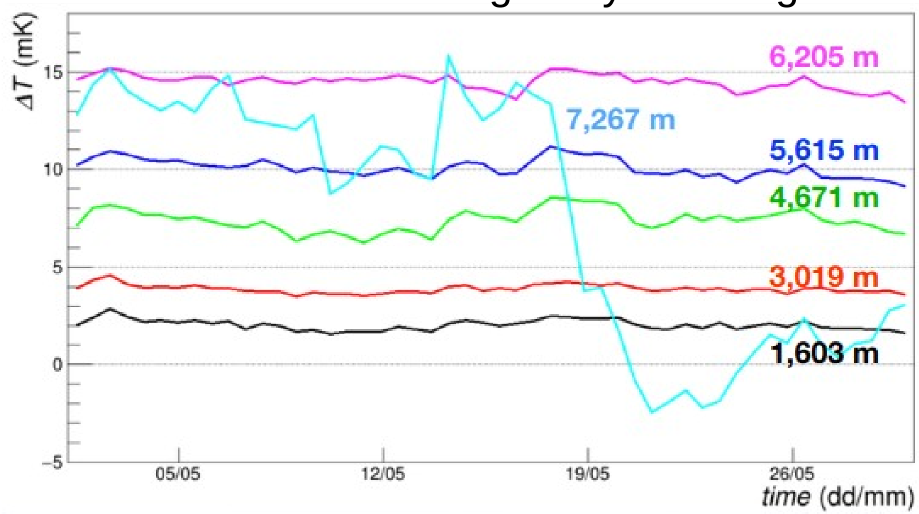


Two vertical arrays of high precision sensors. Different calibration procedures.



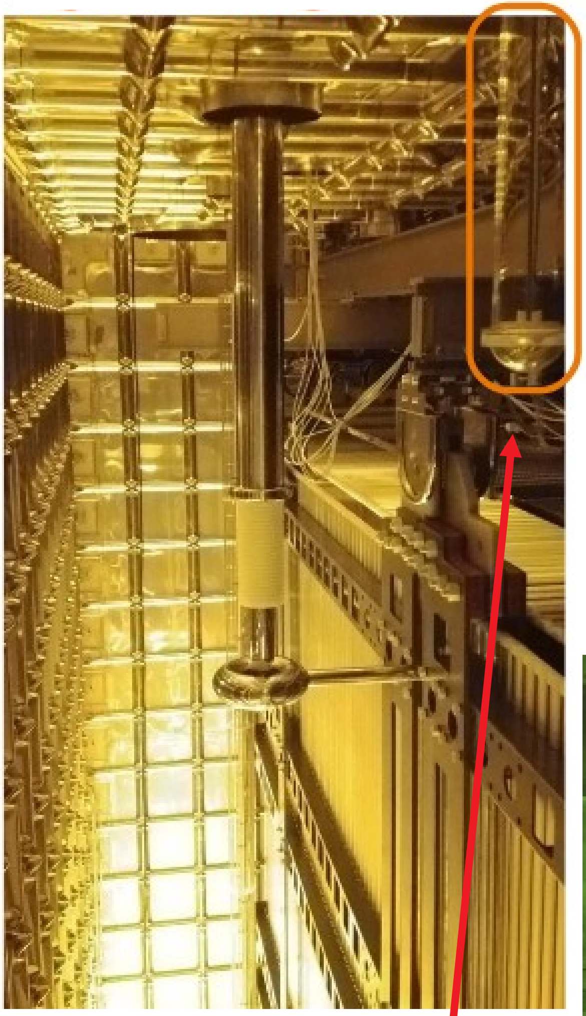


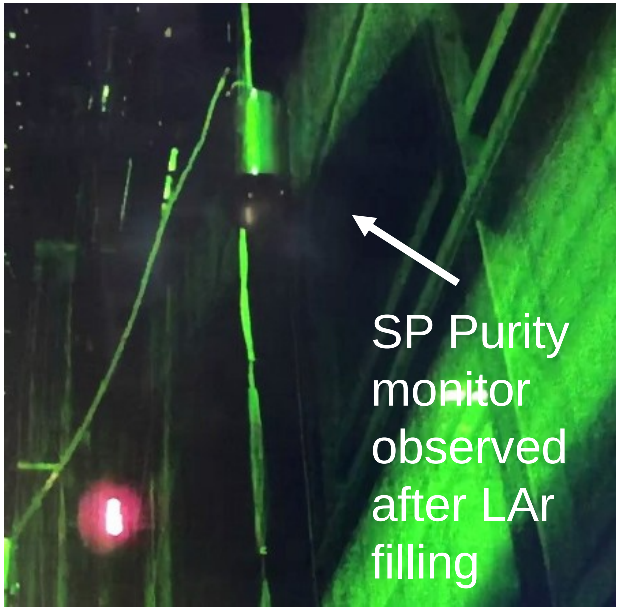
Stable temperature gradients within 2-3 mK during two years long

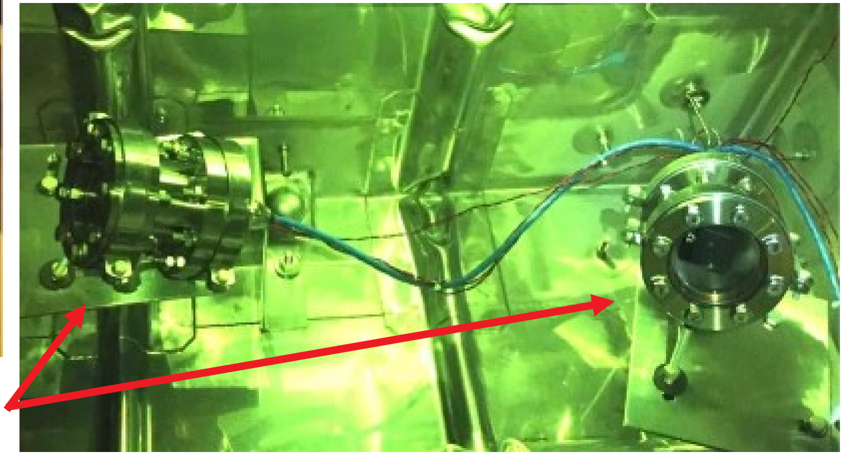


Cameras

Monitor cool-down and filling processes.
Monitor "High Voltage Systems" and inspect detector components.







Example of cameras on SP

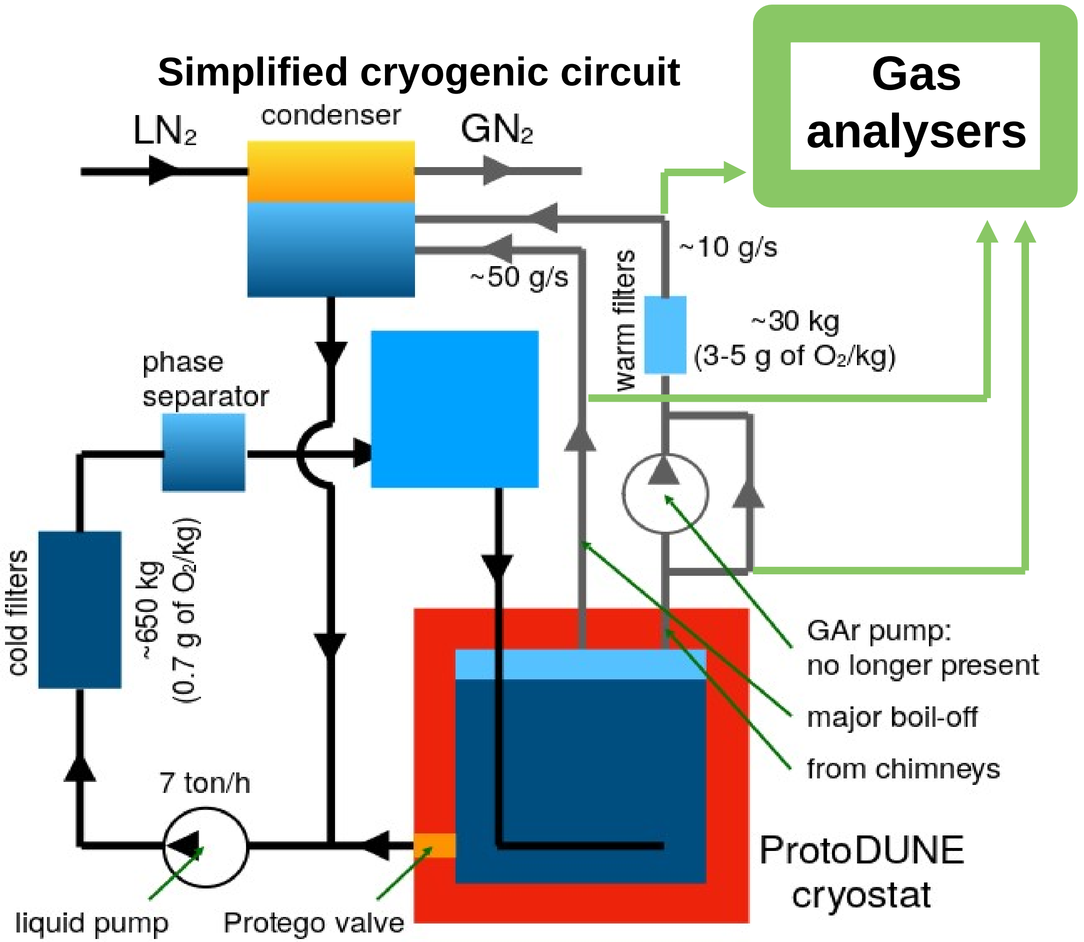
DP field cage and cryostat wall during filling

Gas analysers

Measure the amount of contaminants on GAr

We want:

- **Less than 100 ppt O_2 & H_2O** (100 ppt is equivalent to 3ms e^- lifetime).
- **Less than 1 ppm N_2** (more than 1 ppm affects scintillation light).

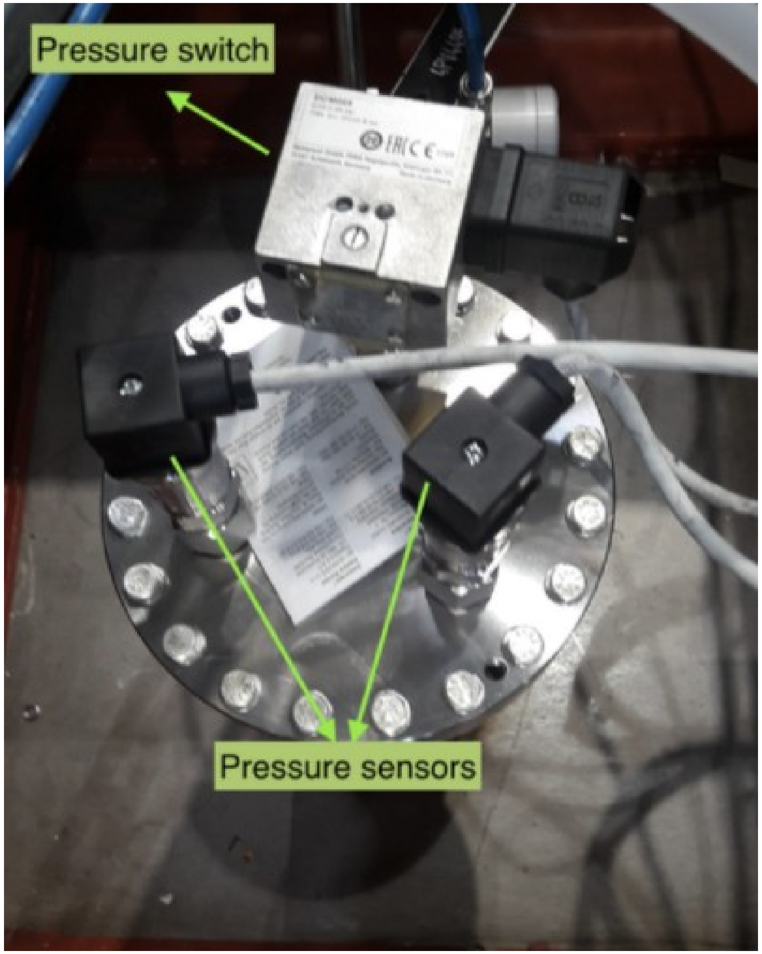


1ppb of O_2 (early stages of Single Phase)

Pressure sensors and level meters

Measuring LAr depth, cryostat pressure and charge readout planes (CRP) positioning (only DP)

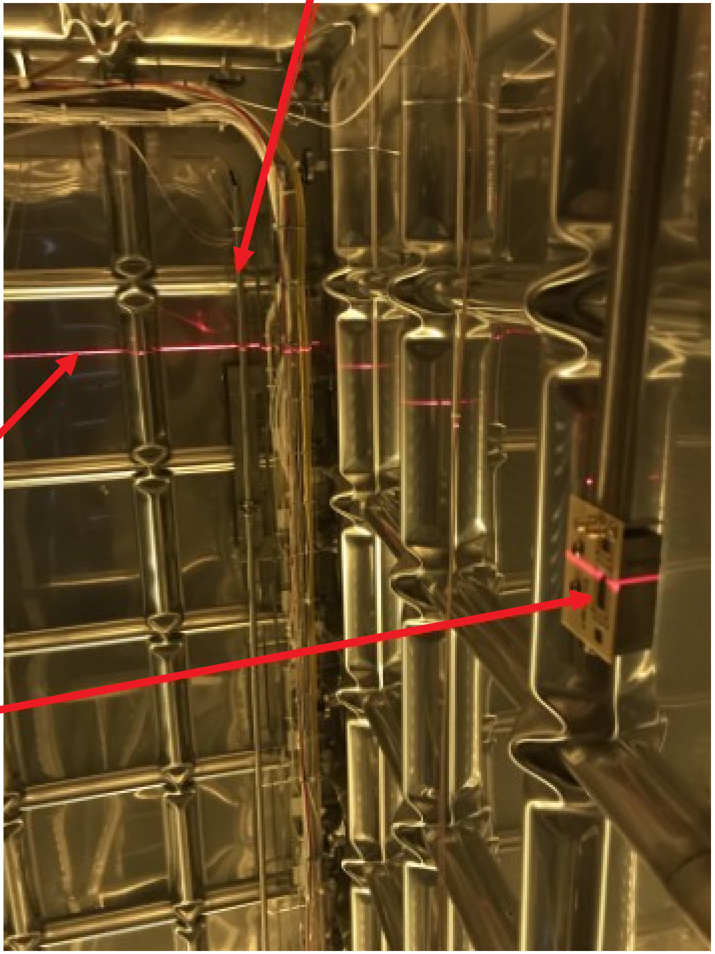
Single phase



4 m long level meter

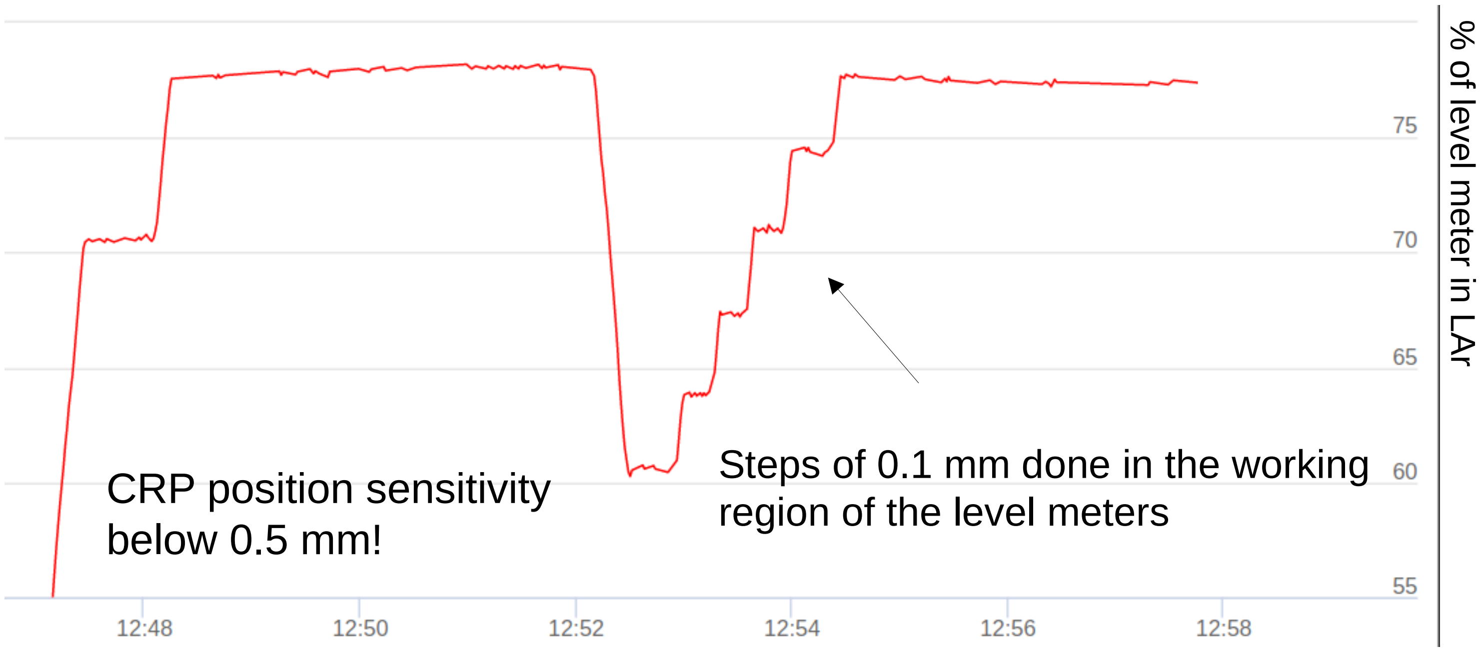
Nominal level

60 mm long level meter



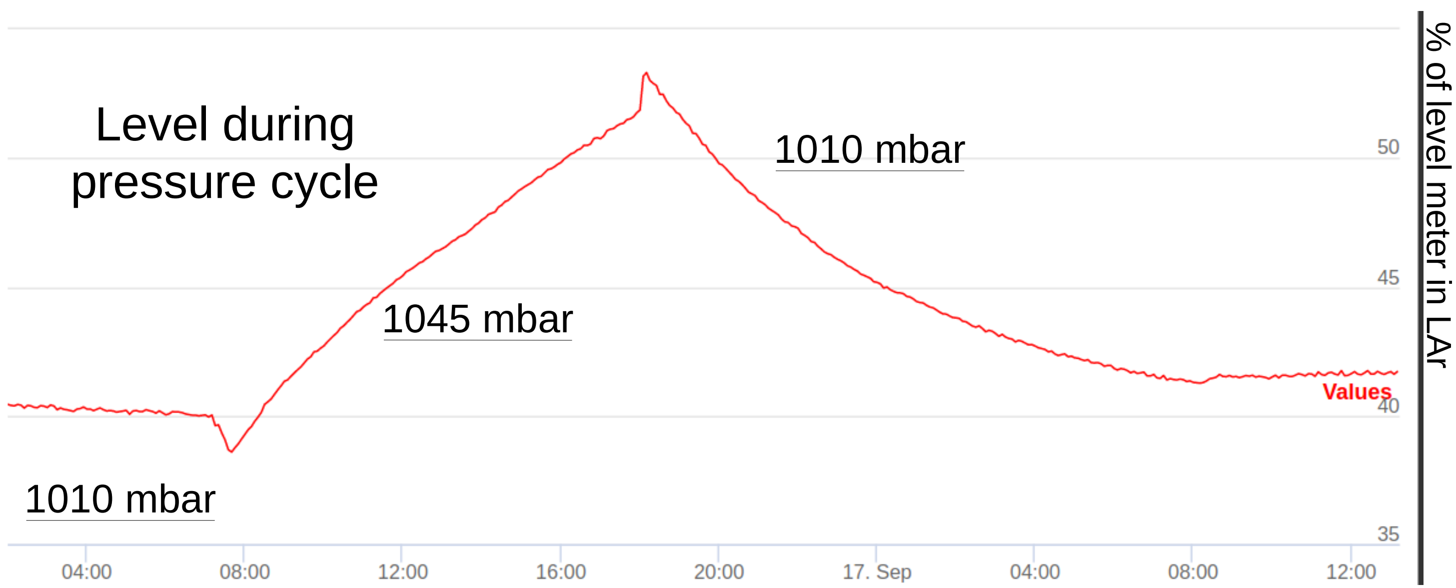
Dual phase

Pressure sensors and level meters

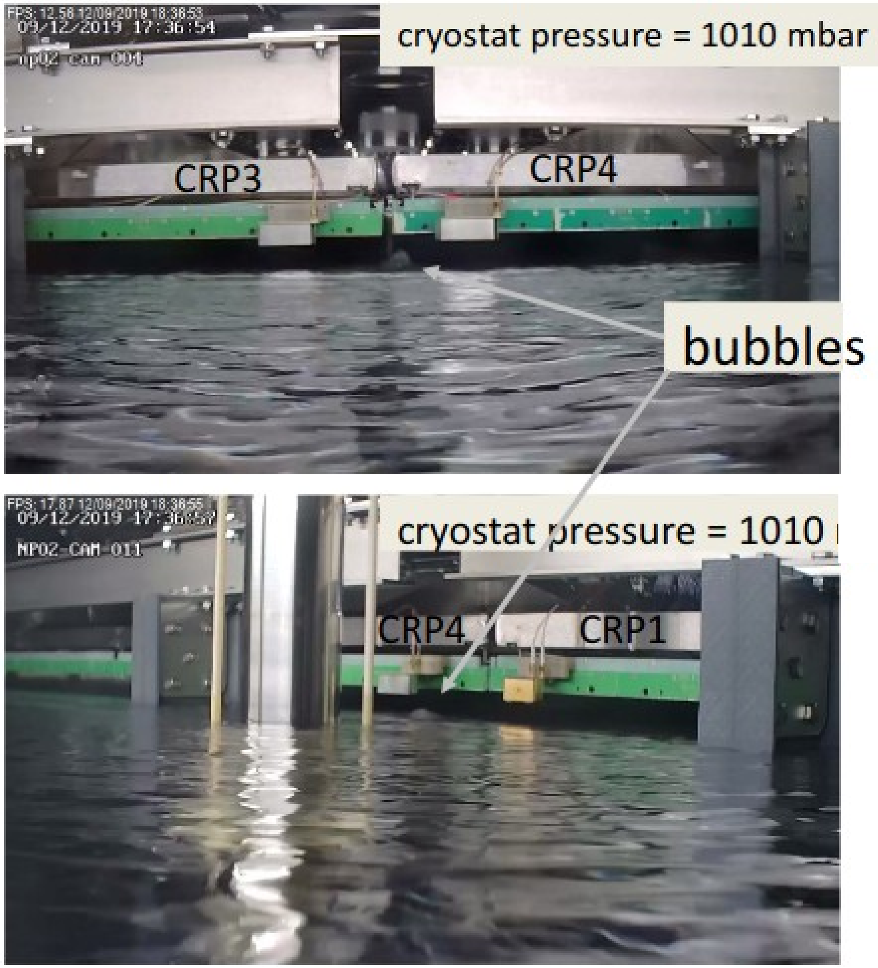


In the dual phase it is essential to know the distance that e^- travel on gas and the pressure of the gas!

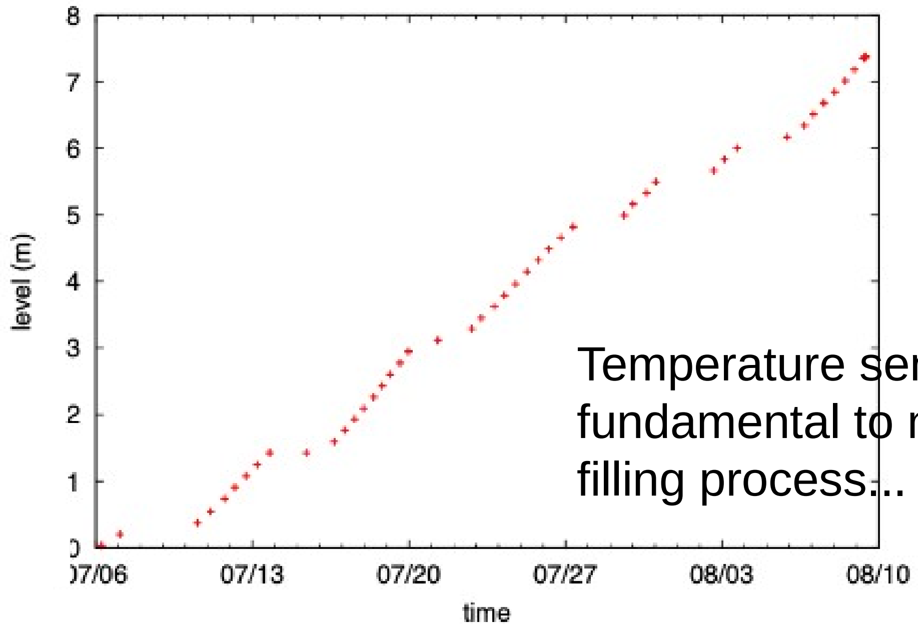
Pressure determines LAr level and temperature. Small variations on any of them can produce variations on the others → they have to be precisely monitored!



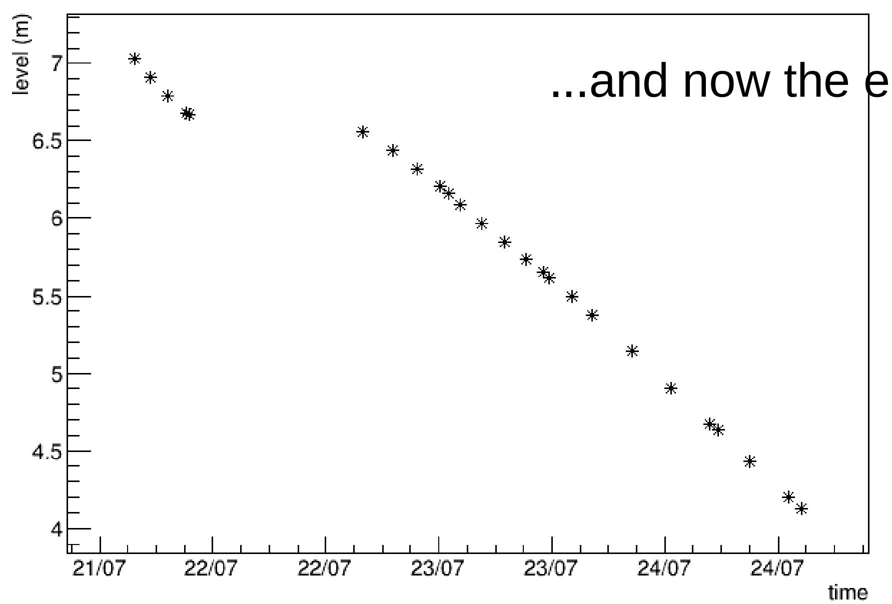
A few examples



Cameras have been used to find bubbles location and source



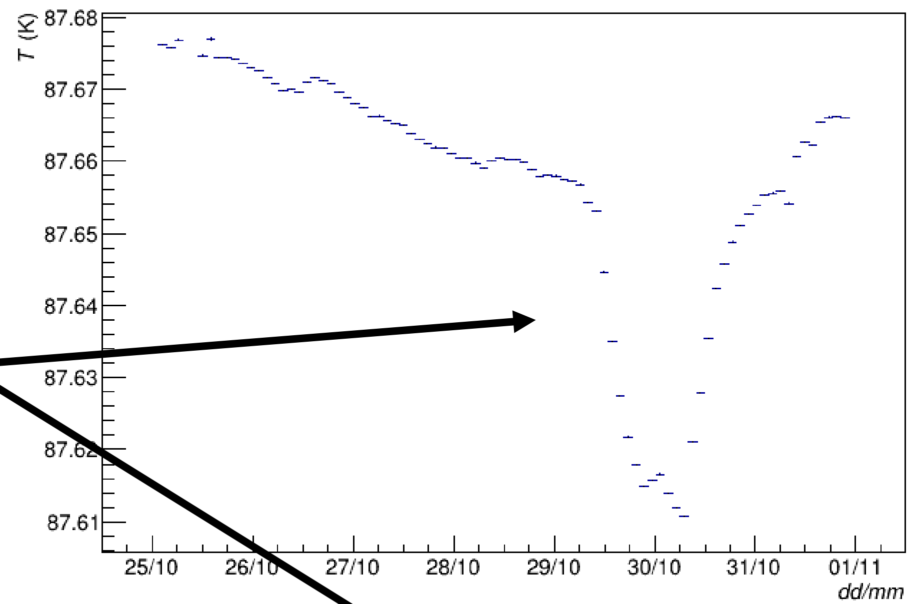
Temperature sensors were fundamental to monitor the filling process...

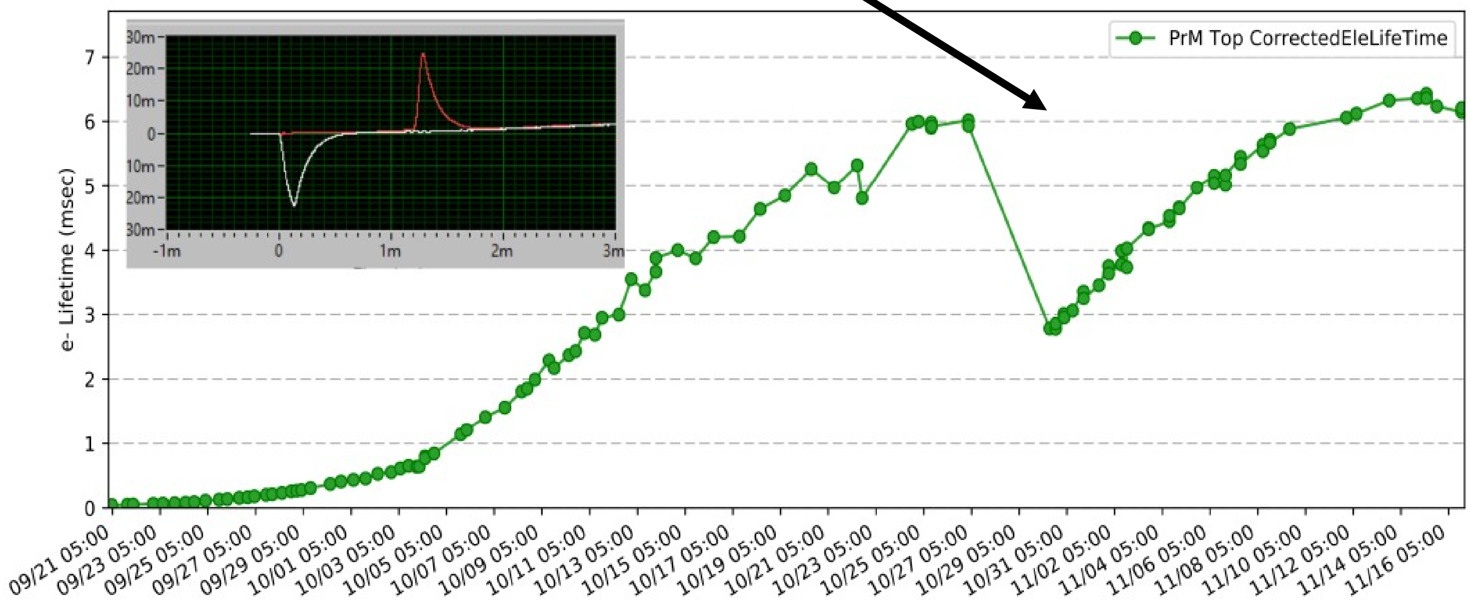


...and now the emptying!

A few examples

Drops on purity and temperature pointed out to cryogenic problems



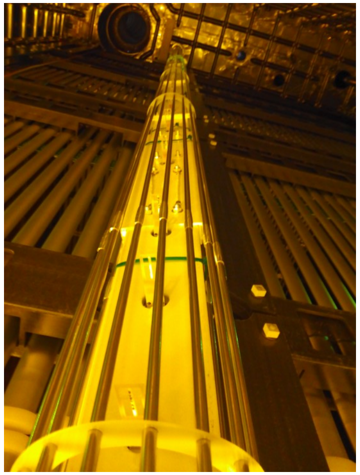


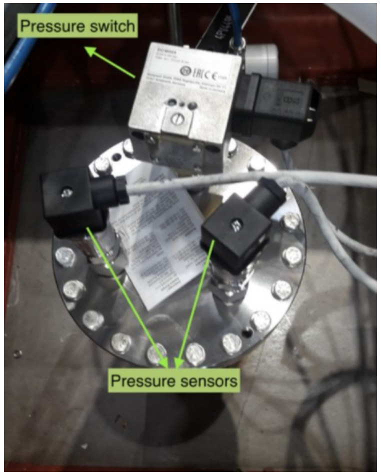
Conclusions

Cryogenic instrumentation is essential to ensure long-time operation and quality of big “cold” experiments as ProtoDUNE or DUNE, not only by providing information and control over possible or unexpected problems but also providing inputs for the later physics results.

DUNE’s cryogenic instrumentation has been tested and prototyped in ProtoDUNE. It has been extensively used during filling, commissioning and operation of the cryostat and the detector, playing a fundamental role.

For the near future: improved cryogenic instrumentation will be tested at ProtoDUNE second run before its final deployment in DUNE.





Backup

Backup

- PrM HV varied (0.25 kV-3 kV) allows for range of drift time from 150 us to 3 ms
- Increase UV light by using 8 optic fibers for each PrM
- At ProtoDUNE-SP regular purity 6 ms, Qa/Qc = 0.7 → no saturation
- Each PrM measurement lasts 20 seconds with 200 UV flashes, provide high precision, localized electron lifetime
- Measured e-lifetime at ProtoDUNE-SP: 35us - 8 ms

Transparency correction

$$\frac{Q_A}{Q_C} = e^{-\frac{t}{\tau}} \qquad \tau = -\frac{t}{\ln(\frac{Q_A}{Q_C})}$$

For high purity, when drift time t is small, $\frac{Q_A}{Q_C} \to 1, \ln\left(\frac{Q_A}{Q_C}\right) \to 0$, fluctuation in Q_A/Q_C causes a large fluctuation in τ measurement, so we run purity monitor at low Anode/Cathode HV (-50/250V, -50/500V) to increase drift time and lower Qa/Qc, improving sensitivity.

However, since the Cathode HV:Anode HV is not 1:20, the cathode grid is not fully transparent, a transparency correction is needed:

$$\left(\frac{Q_A}{Q_C}\right)_{50/250}^{corrected} = \left(\frac{Q_A}{Q_C}\right)_{50/250} \cdot f_{trans}$$

$\left(\frac{Q_A}{Q_C}\right)_{50/250}$: anode-to-cathode signal ratio taken at cathode HV=-50V, anode HV=250V

f_{trans}: transparency correction factor

Backup

Temperature sensors

- Vertical temperature profilers (58x)
  Mostly for LAr level evaluation and differences with purification on and off

- Vapour temperature sensors (24x)
  Correlate temperature with LEM gain. Evaluate heat input from the roof

- CRP structure temperature sensors (28x)
  Evaluate deformation of the CRP structure due to thermal gradient

- Cryogenic pipes temperature sensors (6x)
  Evaluate differences between purification on and off

- Insulation space temperature sensors (21x)
  Access insulation performance during cool down and filling

- Temperatures sensors underneath the cryostat (9x)
  Access insulation performance during cool down and filling

Backup

Level Meters

- What are they?
  - Hardware devices that calculate the depth of the Liquid Argon volume
- How do they work?
  - Differential pressure transducer systems –Supplied by LBNF Cryo
    - Measure pressure in the upper vapor space and pressure near or at the bottom of the liquid volume -> $\Delta P = \rho g h$
    - (D. Montanari) precision is 0.1% of 14 m range, or $\pm$1.4 cm
  - Capacitive Level Transducers
    - A coaxial cylindrical capacitor fills with LAr, which changes capacitance with the height of LAr.
    - Sensitivity according to one manufacturer is 0.25% of full length(4-20 mA output)
      - Would only instrument the top ~ 1-2 m of LAr
        - But distance from the flange to LAr surface is on the order of 2.5 m (ullage+insulation+chimney height), so need 3.5-4 m or so length.
    - Uses AC excitation to measure capacitance

Commercial Capacitive Level meters

Backup

For PD-DP it is fundamental to measure the liquid argon level at a sub mm level precision in order to control the level and the horizontality / position of the CRPs

Three kind of sensors in NP02:
- 2x 4 m long capacitive (cylindrical) level meters installed along one vertical corner of the cryostat (*O*(800 pF)).
Follow the filling and coarse measurement of the stability of the liquid argon level.
- 14x 25 mm long capacitive (planar) level meters installed around the four CRPs (*O*(80 pF)).
Adjust the horizontality and the position of the CRPs.
- 2x 60 mm long capacitive (planar) level meters installed at the cryostat corners (*O*(80 pF)).
Precise measurement of the liquid argon level feedback to cryo.

Custom made electronics (X. Pons et al.) insensitive to the cable length:
- The concept works very well. Adding 12 m long cables, values change ~1%.
- 2-3% variation related to the electronics temperature: current source stability to be solved.