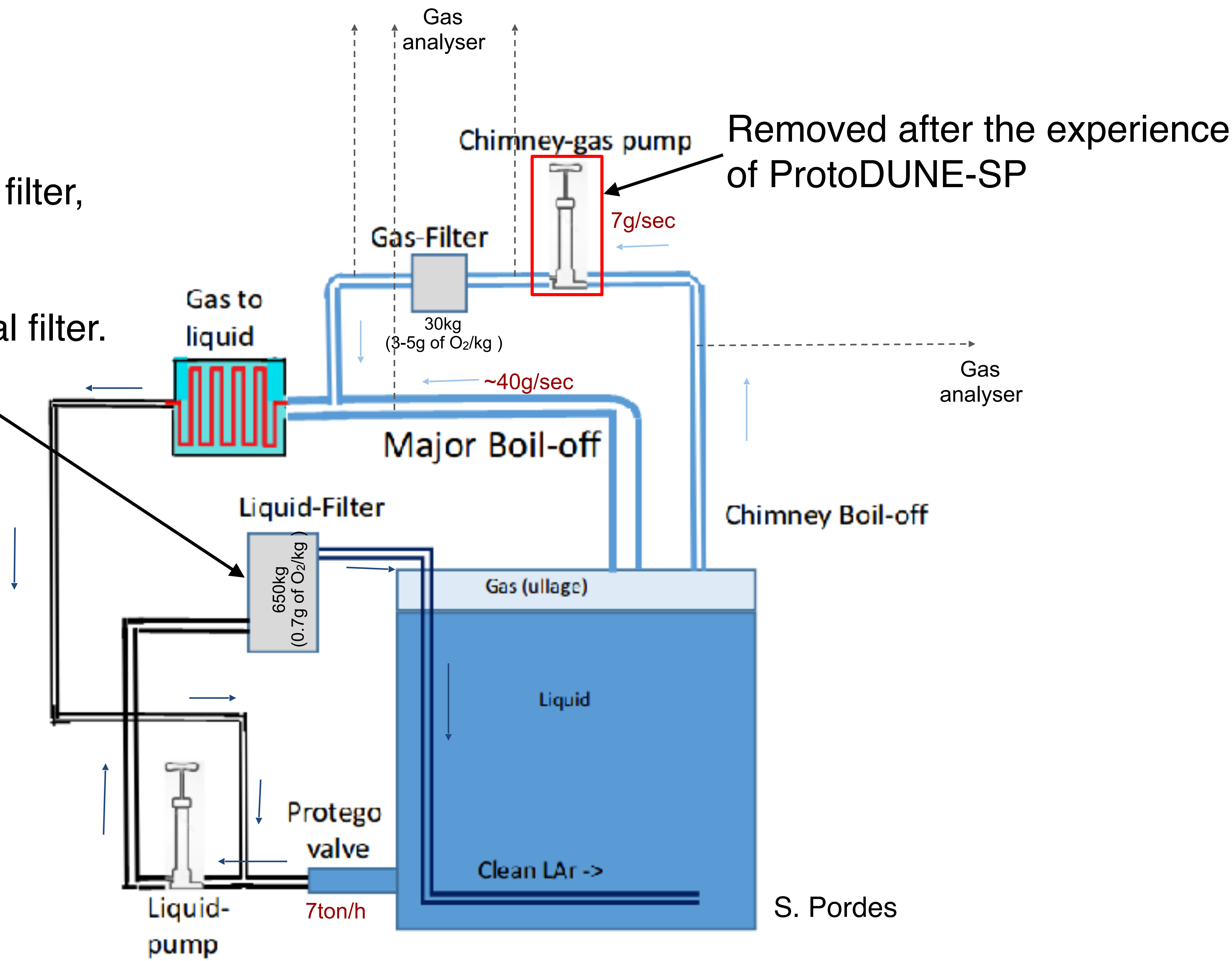
NP02 cryogenic operation

Filippo Resnati (CERN)

LBNC review - CERN - 5th of December 2019

Simplified cryogenic circuit

Series of filters:
- inlet mechanical filter,
- molecular sieve,
- Cu filters and
- outlet mechanical filter.



S. Pordes

Liquid filter clogging

Since the beginning of the liquid bulk purification in the middle of August 2019, the pressure across the liquid argon filters increased with time.

The pressure increase was mostly across the input mechanical filter.

In September the input mechanical filter was warmed up and inspected with an endoscope camera. Dust-like material was extracted, and the pressure at the restart was back to nominal.

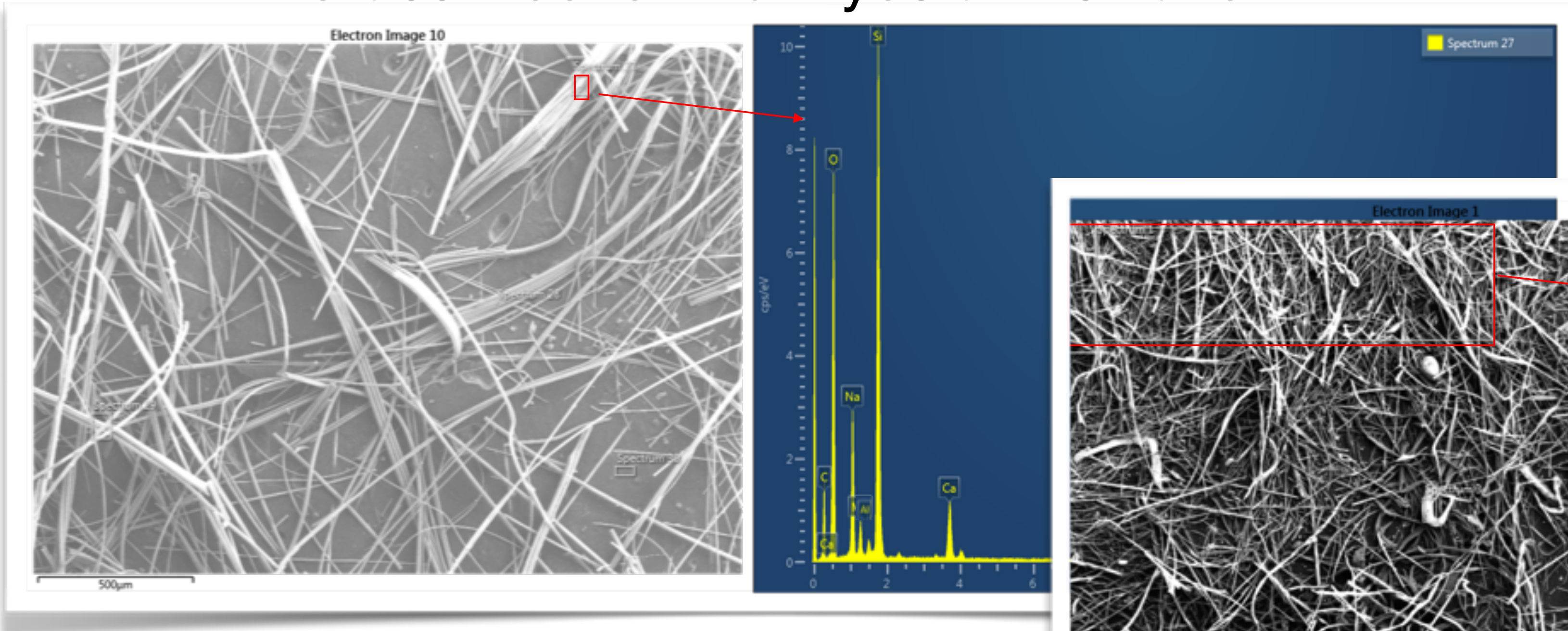
This unclogging operation was done six times. After the first one, the amount of dust extracted from the filters was negligible, and the rate of pressure increase reduced.

The source of the dust has not yet been identified.

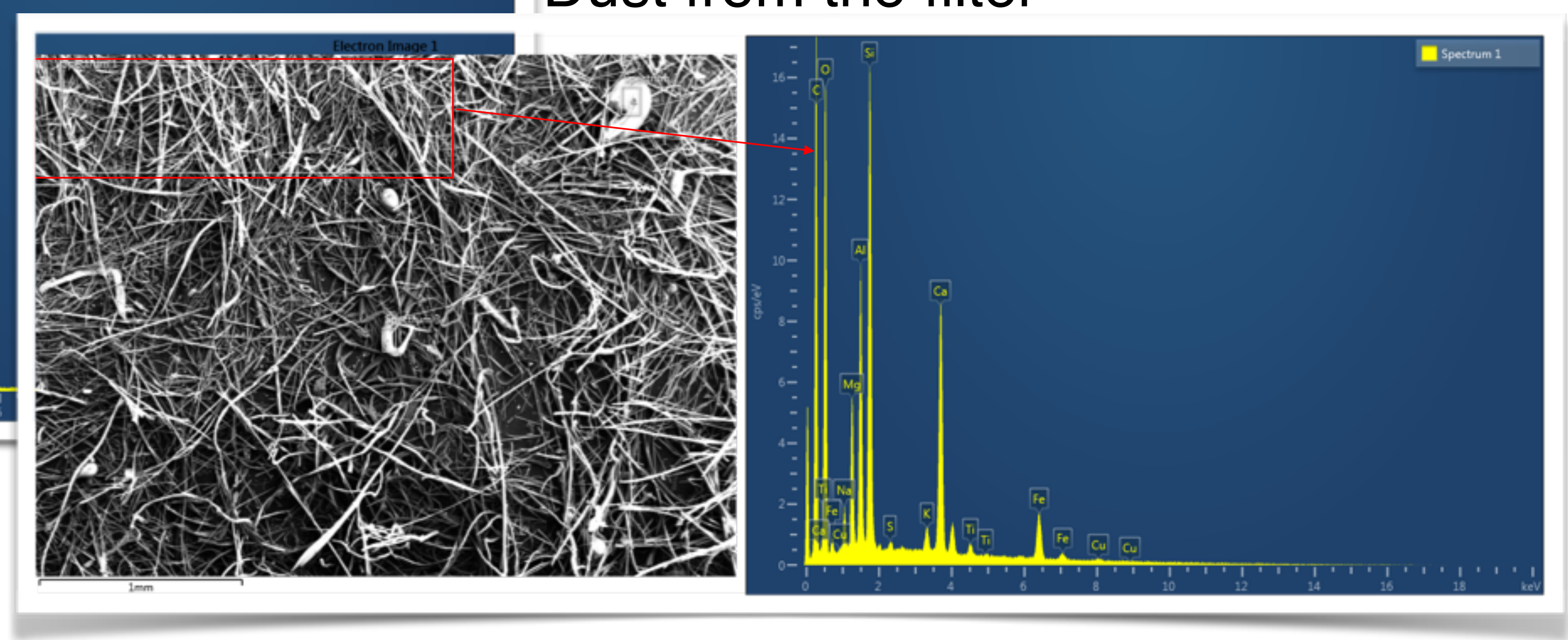
Analysis of the samples

Comparison between

Glass wool of the cryostat insulation



Dust from the filter



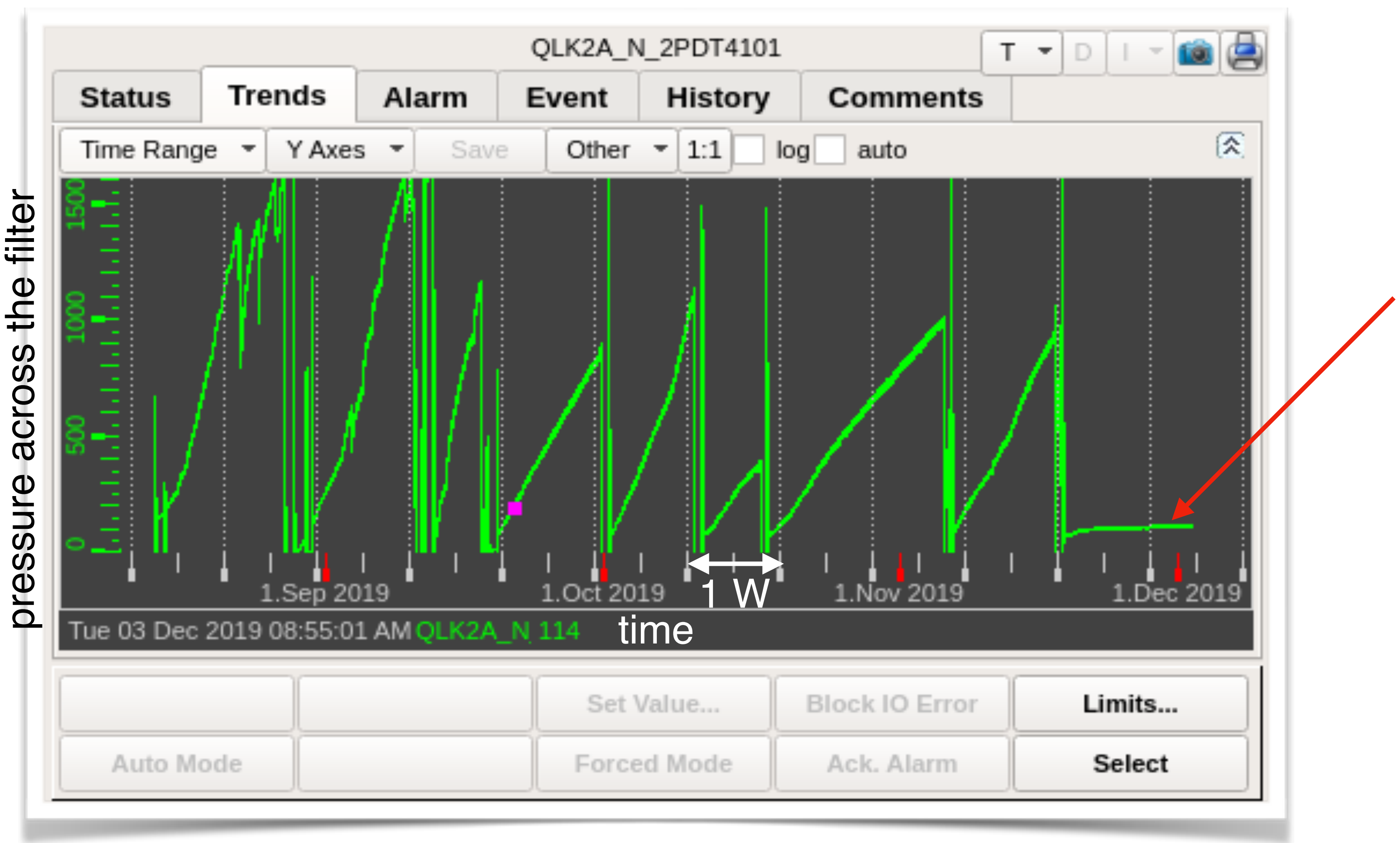
Chemical composition:
Si, O, C, Al, Ca, Mg, Na in common, though at different ratios.
The dust from the filter also contains Fe, Cu, Ti, K.
Results not conclusive. Waiting for results of additional samples.

The dust is not conductive and it floats in liquid argon.
The rate of pressure increase is lower when the boil-off is vented (not condensed).
This suggests that the source of the impurity is in the vapour/gas circuit.

Filter unclogging

The liquid circulation was interrupted twice to warm up the filters, inspect and extract the dust.
Since middle of September, the filter unclogging is treated as maintenance activity:
- The liquid pump is *not* stopped, the filter is bypassed and only partially warmed up.
- The filter is purged with gas argon from outlet to inlet.
- The bypass is closed, the filter cooled and the purification restarts.

This operation (that takes 18 h) has little impact on the pressure and level in the cryostat.
It was done when necessary to avoid the pressure across the filter exceeding 1 bar.



Since the last unclogging operation in middle of November, the pressure across the filter is stabilising below 200 mbar.

Next steps

Circuit improvement design:
- Two inlet mechanical filters in parallel to decouple maintenance and operation.
- More easily accessible filters in separate cryo-boxes to speedup the maintenance.

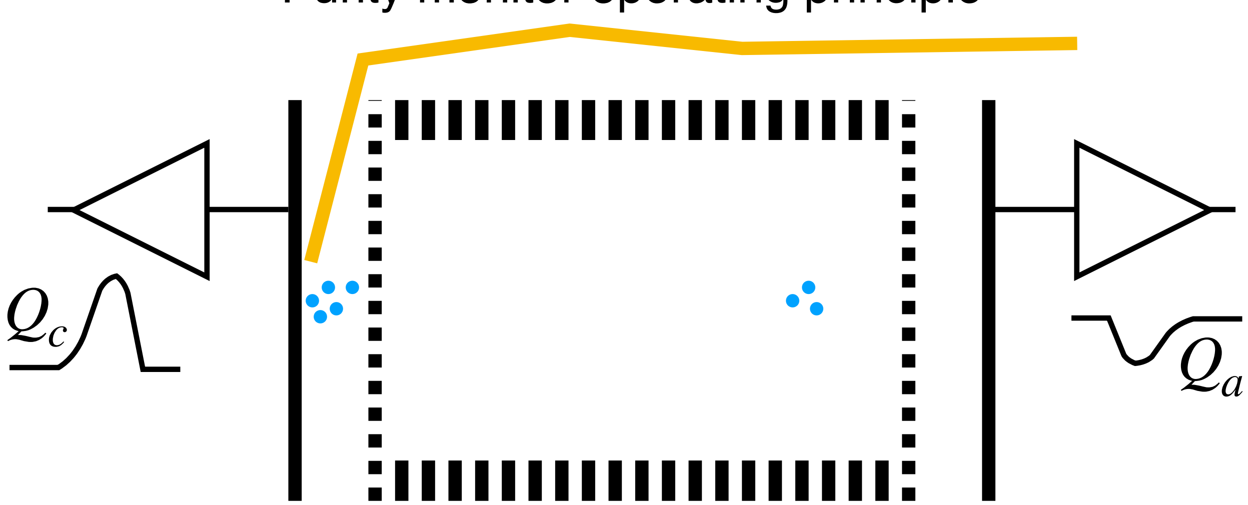
Open questions:
- Where is the dust coming from?
- Is the dust trapped in the filter and/or in the inlet pipes of the filter, and the unclogging procedure only disperses the dust that the liquid flow then tends to re-compact?

Moving forward and assess the situation:
- Bypass the inlet mechanical filter, dismount it and inspect it. Purification can continue (we are confident that the dust would not clog the molecular sieve nor the Cu cartridge).
- Decide whether to implement the design changes or to remove the inlet mechanical filter.

Lifetime measurements

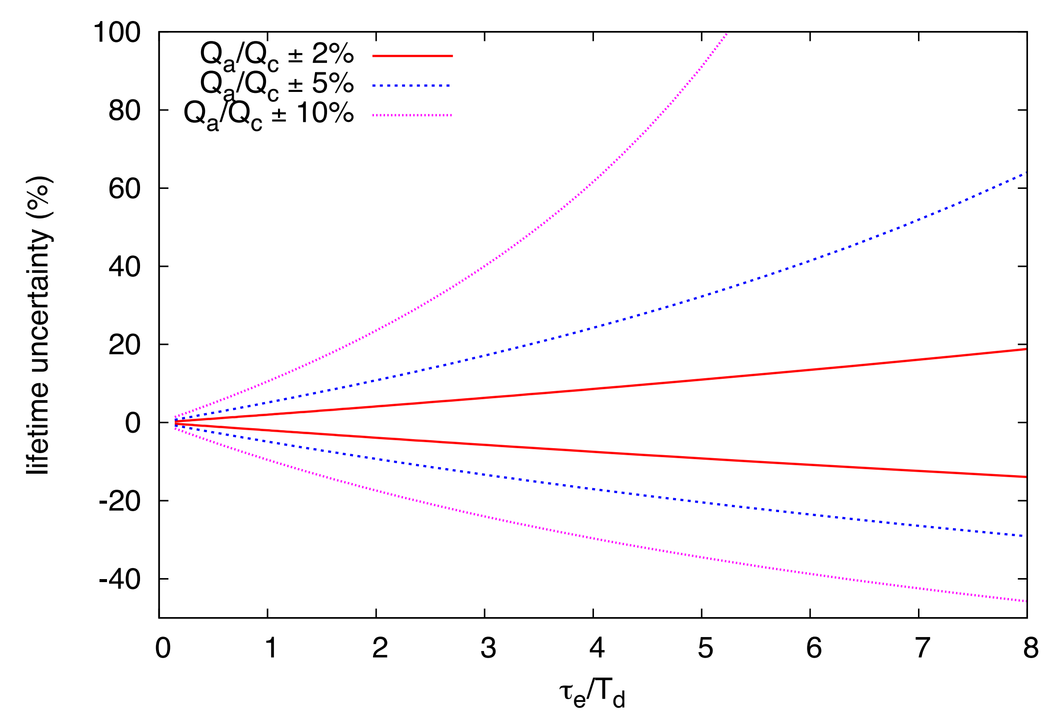
Three tools to measure the drifting electron lifetime:
- Two short (~20 cm) purity monitors, located along a vertical cryostat corner. One on the floor and the other at about 2.5 m. Extremely useful during filling. Effective when lifetime is < 1.5 ms.
- One long (~50 cm) purity monitor, installed next to the bottom short purity monitor. Effective when lifetime is > 1.5 ms.
- The TPC, the most sensitive device, that needs careful treatment to take into account the space charge and the inhomogeneity of the drift field.

Purity monitor operating principle



$$\tau_e = -T_d / \ln\left(\frac{Q_a^*}{Q_c}\right)$$

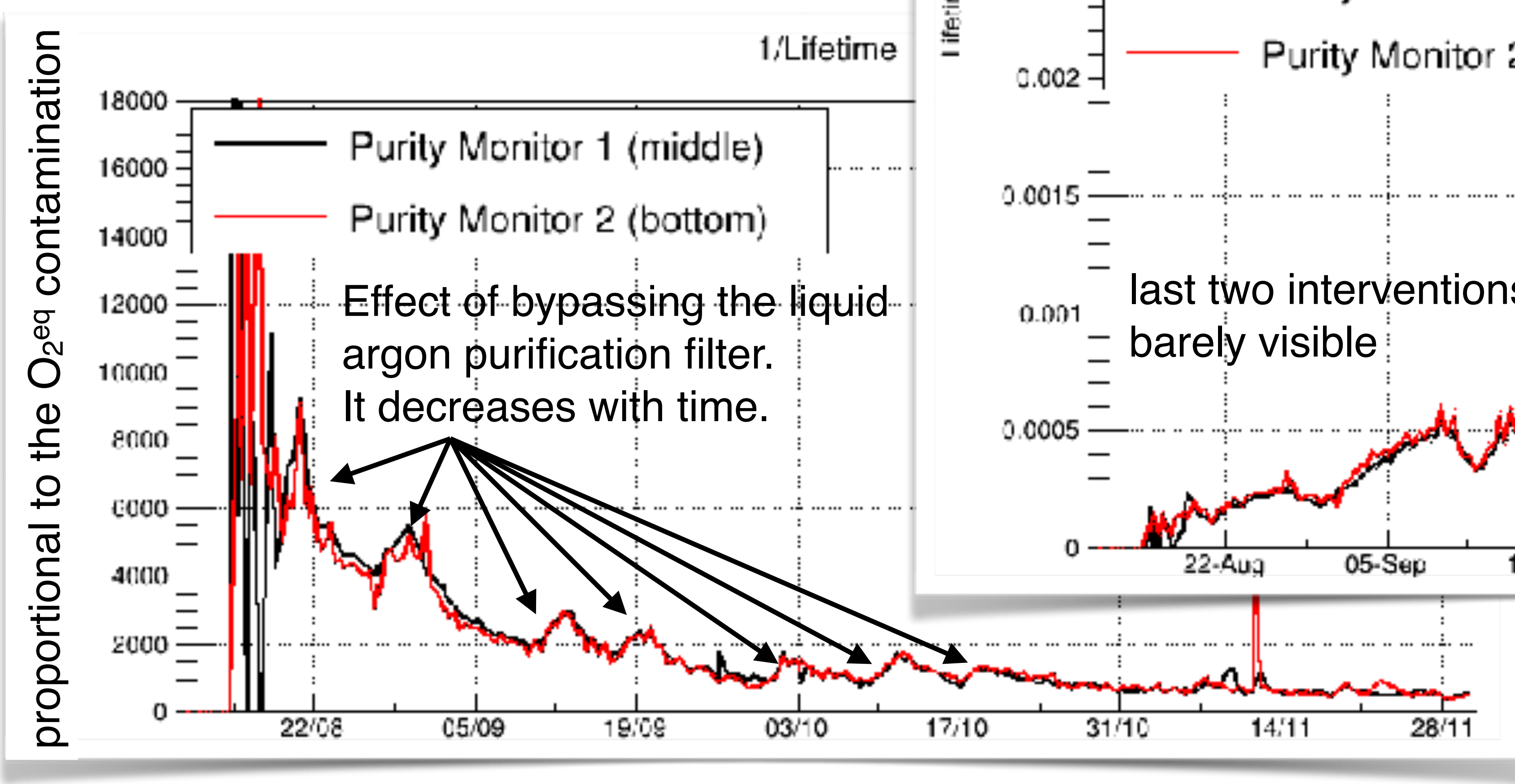
*corrected

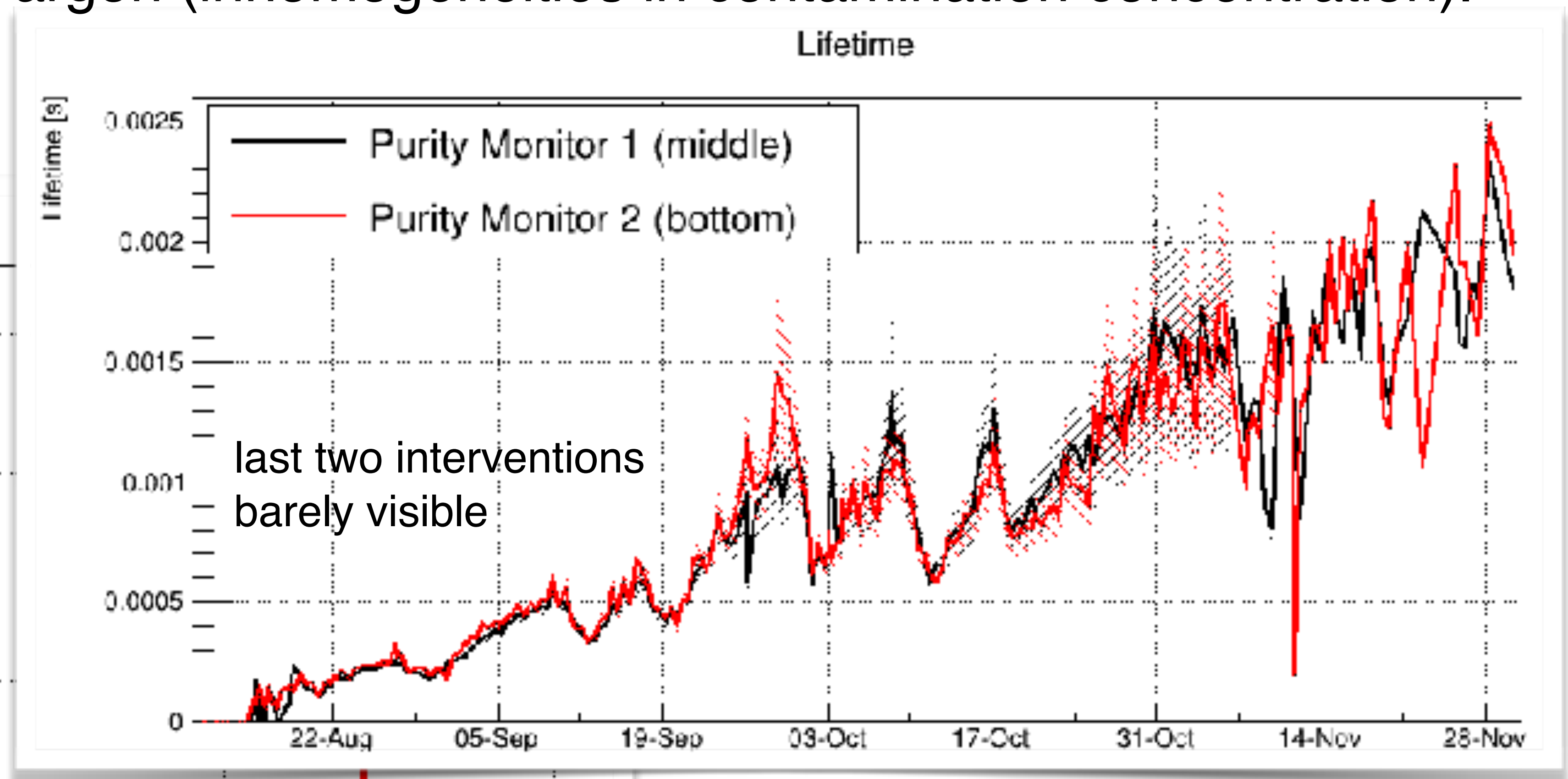


Short purity monitors

Except for the very beginning, the reported lifetime improvement was always slower than expected given the recirculation speed. Filter unclogging procedures are only part of the cause. Additional considerations:

- Systematic uncertainties in the purity measurements.
- Inefficiency of the filter (not compatible with the filling performance).
- Poor mixing of the clean and dirty argon (inhomogeneities in contamination concentration).



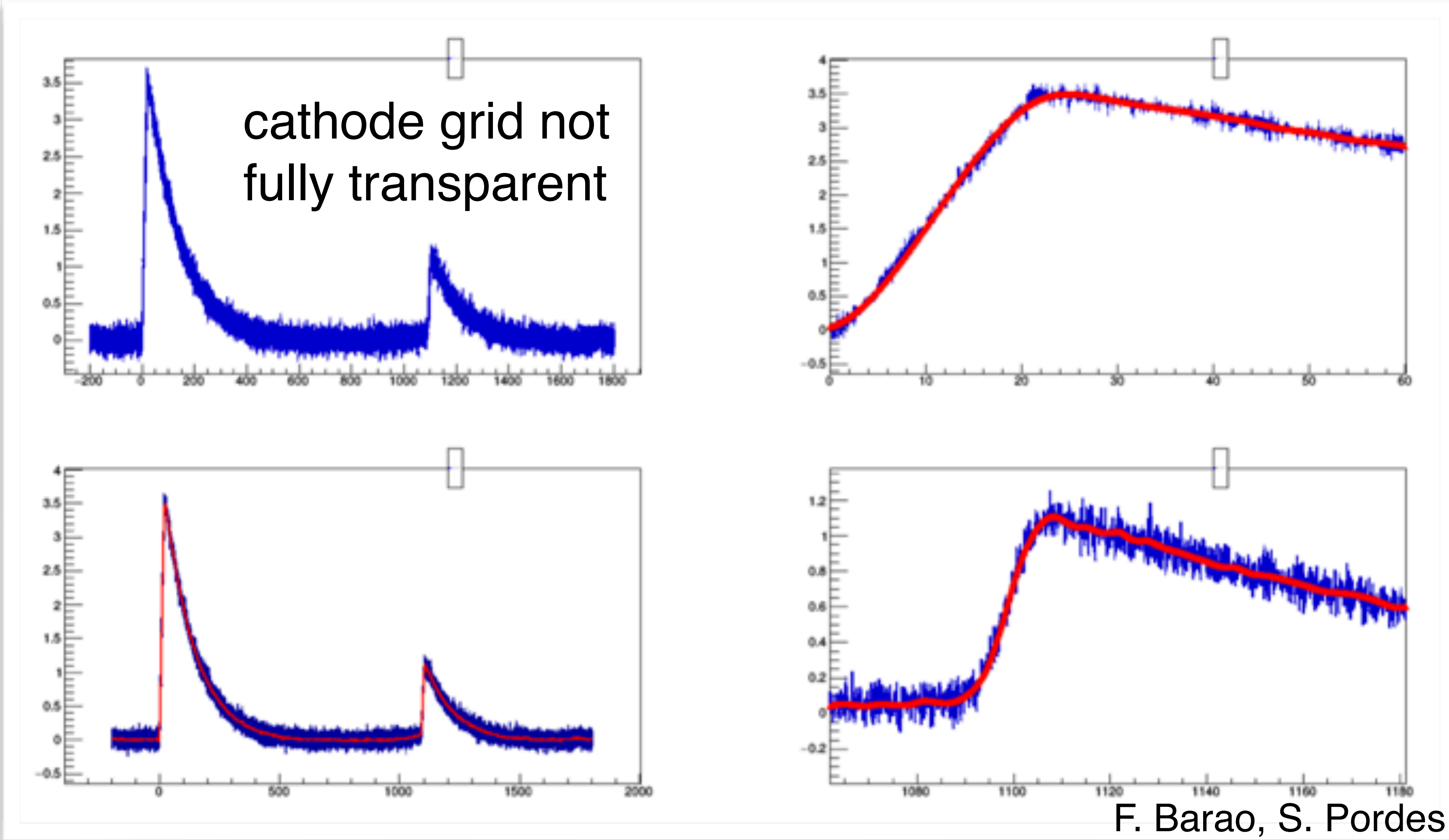


A. Basharina, L. Cremonesi, L. Manenti

Note: many detector components installed in the vapour tend to outgas. Outgassing can be an important contribution on the achievable purity.

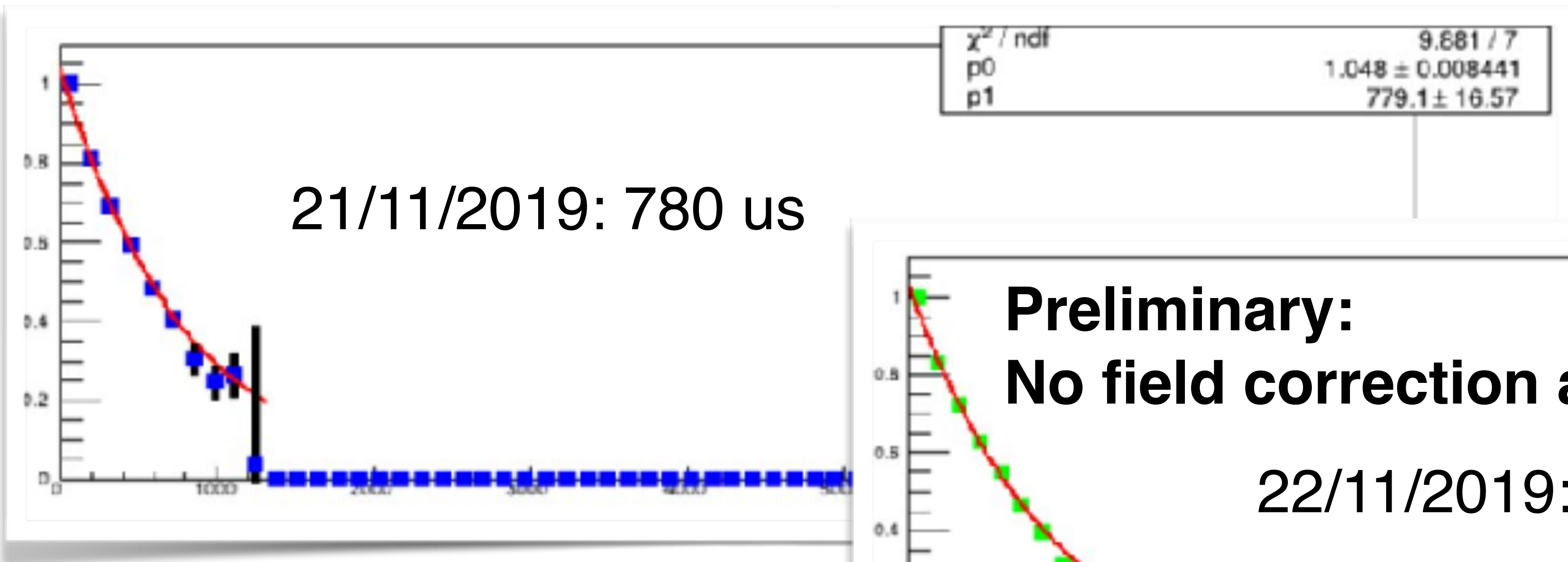
Long purity monitor

The lifetime evaluation is significantly larger than for the short purity monitors. As of the 2nd of December, lifetime was measured to be above 7 ms, considering the most conservative uncertainties.

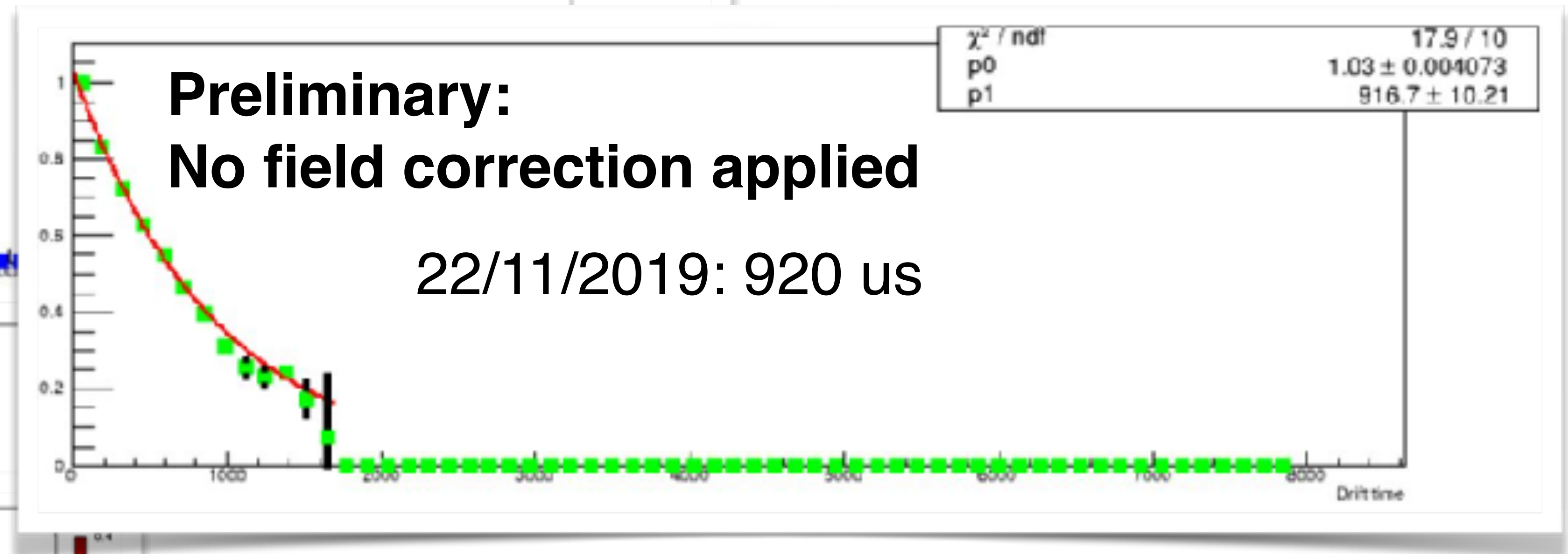


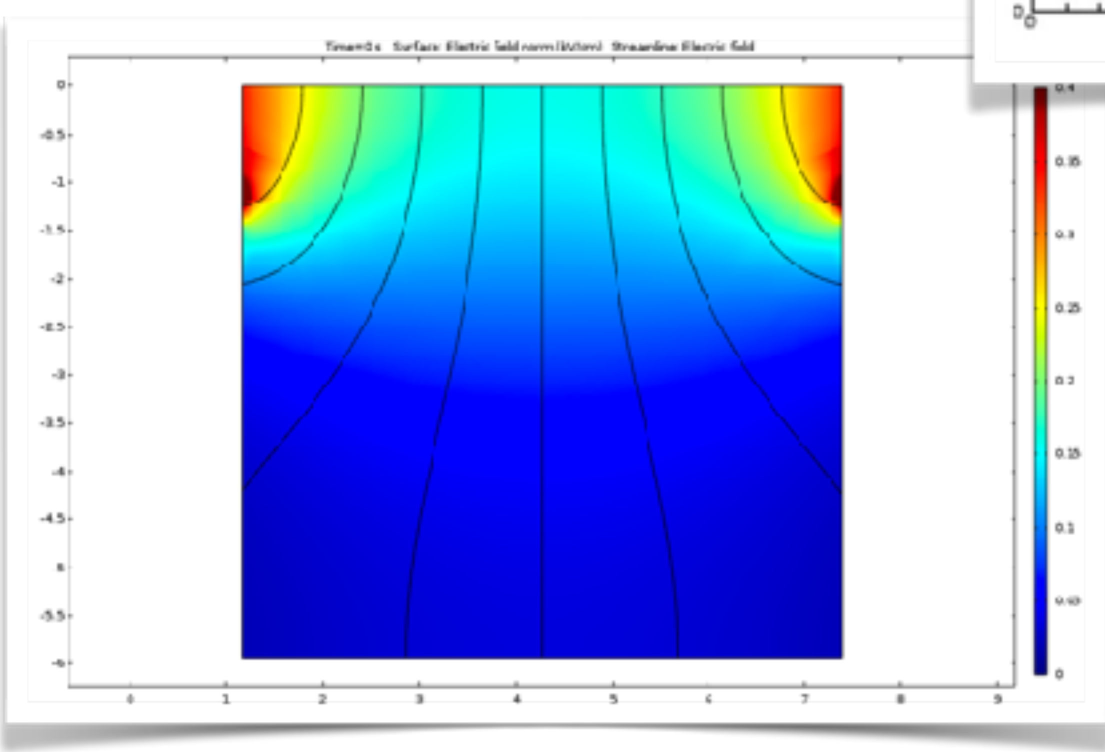
Studies of the long and short purity monitors are ongoing to understand better the systematic uncertainties and the source of the discrepancy in the measurements.

TPC measurement



D. Autiero, V. Galymov





To accurately measure the lifetime from TPC events, the drift field inhomogeneities should be carefully treated.

If the measurement is confirmed, does this imply very large inhomogeneities in the contamination distribution?

Work in progress

Understand the discrepancy in the purity monitor measurements:
- Improving the grid transparency evaluation.
- Studying the systematic uncertainty from the electronics.
- Improving the noise situation (camera power supply)

On the TPC:
- Understanding and quantifying the electric field inhomogeneities and their effect.
- Exploiting the newly installed Cosmic Ray Tagger.

Study the electron lifetime in different cryogenic conditions to understand the source of impurities (venting the boil-off, change the fraction of the purified gas recirculation, change the liquid argon pump flow, inject purified argon also from the top (from the sprinkler, tbd), …)

Argon bubbles in NP02

In two locations:
- At the HV feedthrough.
- At the field cage.

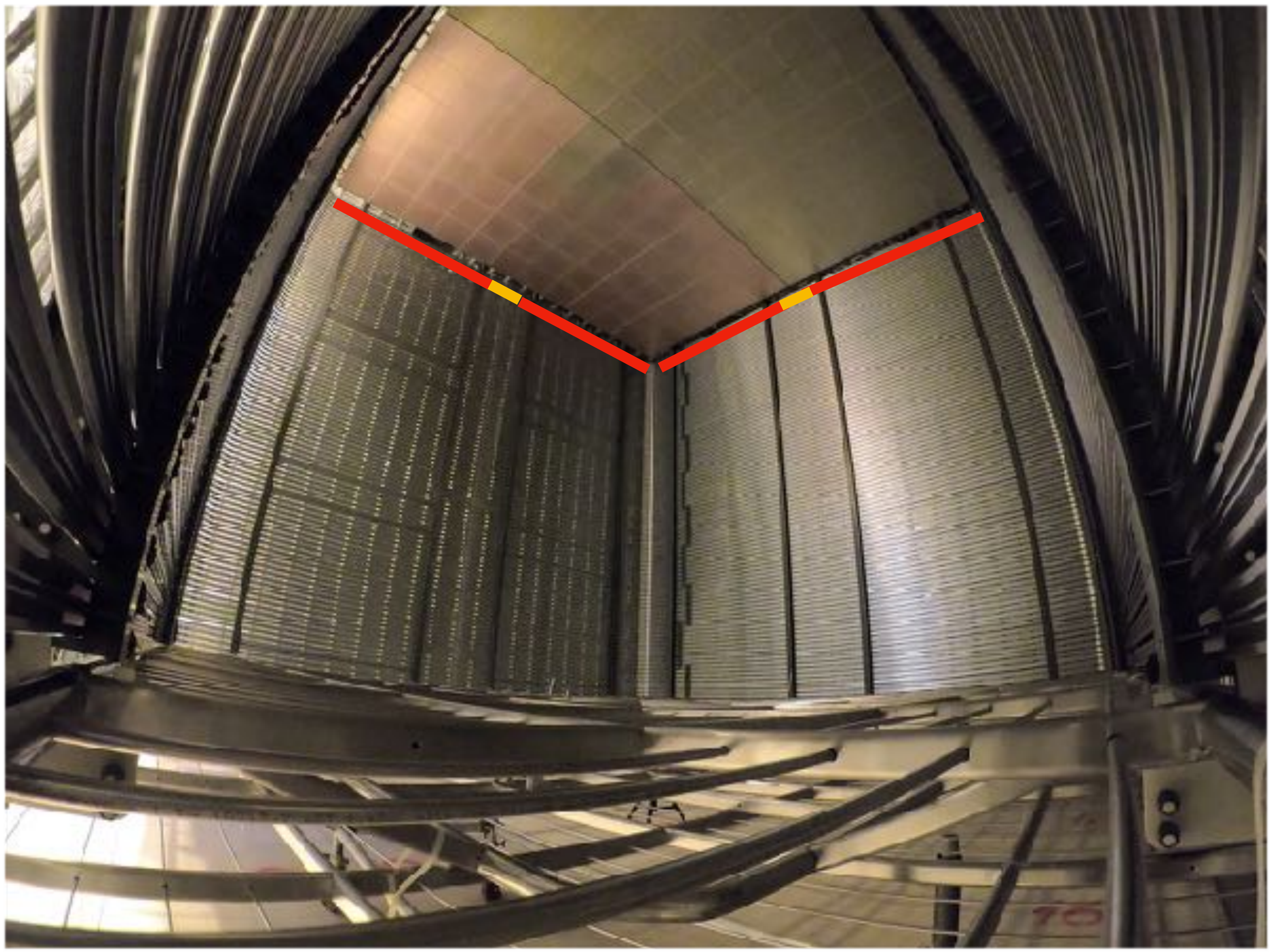
In both cases it is difficult to alter the status: Temperature of the feedthrough (warmer or colder) has little/no impact on the frequency of the bubble formation. More difficult to state something about their size.

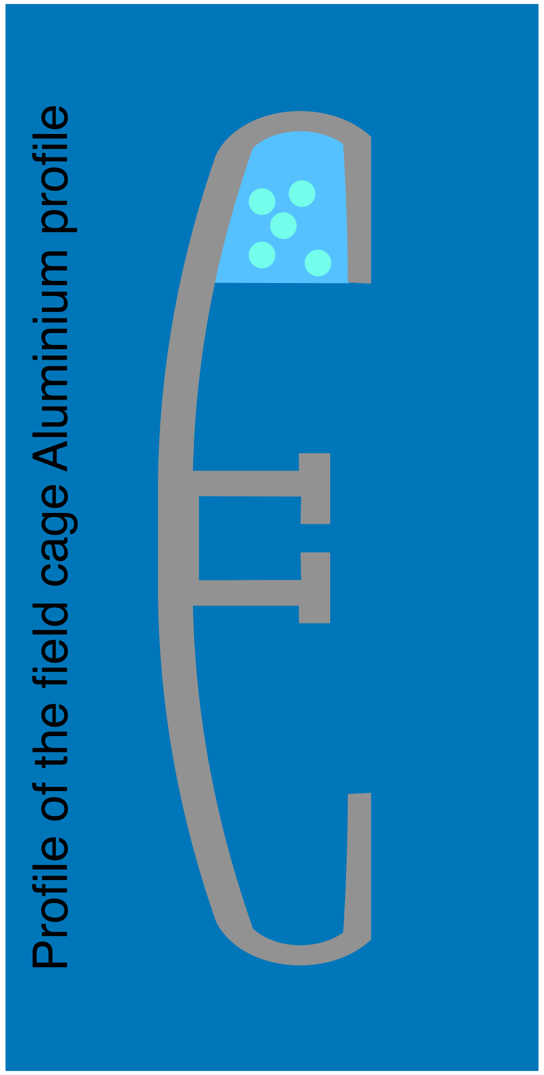
Bubbles disappear temporarily when raising the pressure:
- Saturated temperature is higher at higher temperatures.
- The argon is no longer in thermal equilibrium (colder).
- The heat input goes to increase the argon temperature.
- Evaporation is reduced.

It’s a transient behaviour:
- The equilibrium is re-established in the order of a day.

Argon bubbles in NP02

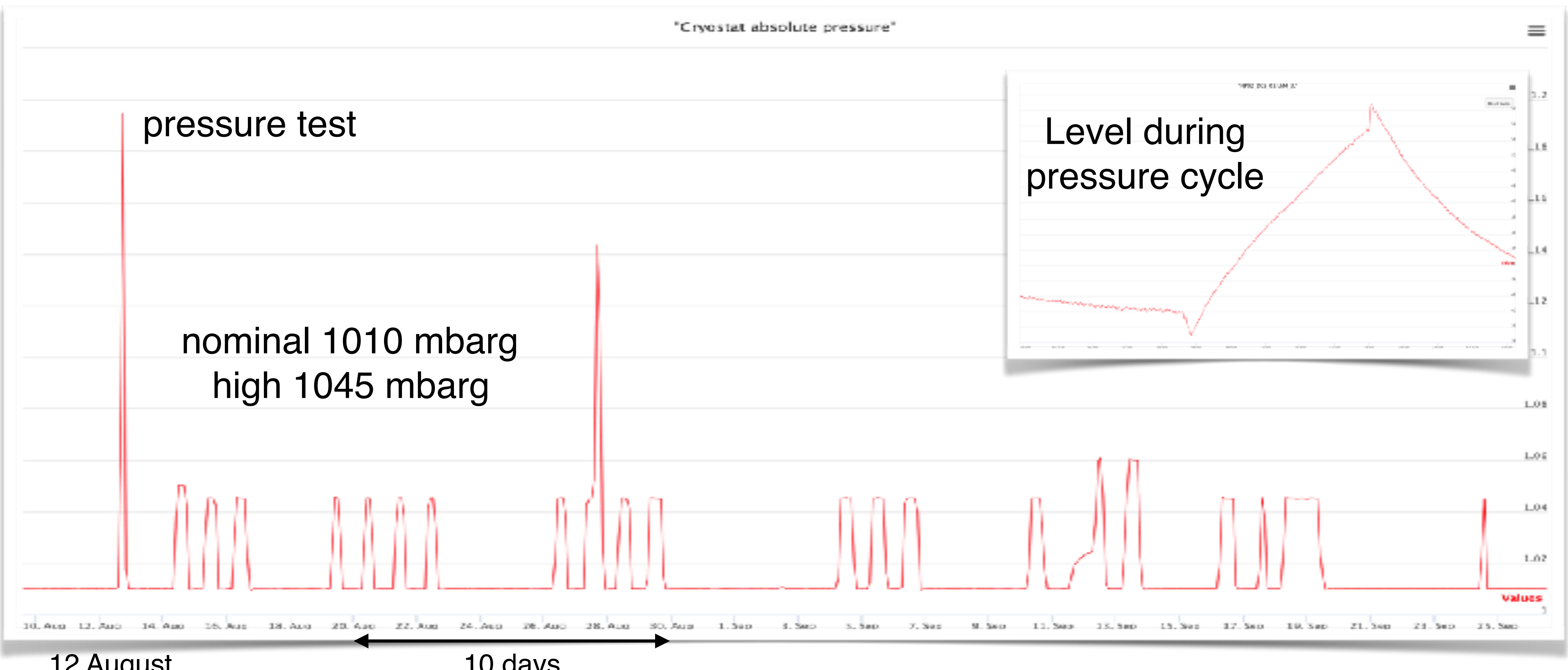
The position of the source of these bubble is known. Their cause is not yet clear.
On the uppermost field cage profile (~10 cm below the liquid argon surface) argon bubbles are trapped in a pocket made by the field cage profile.
Argon bubbles come out at the clips that join two consecutive profiles.





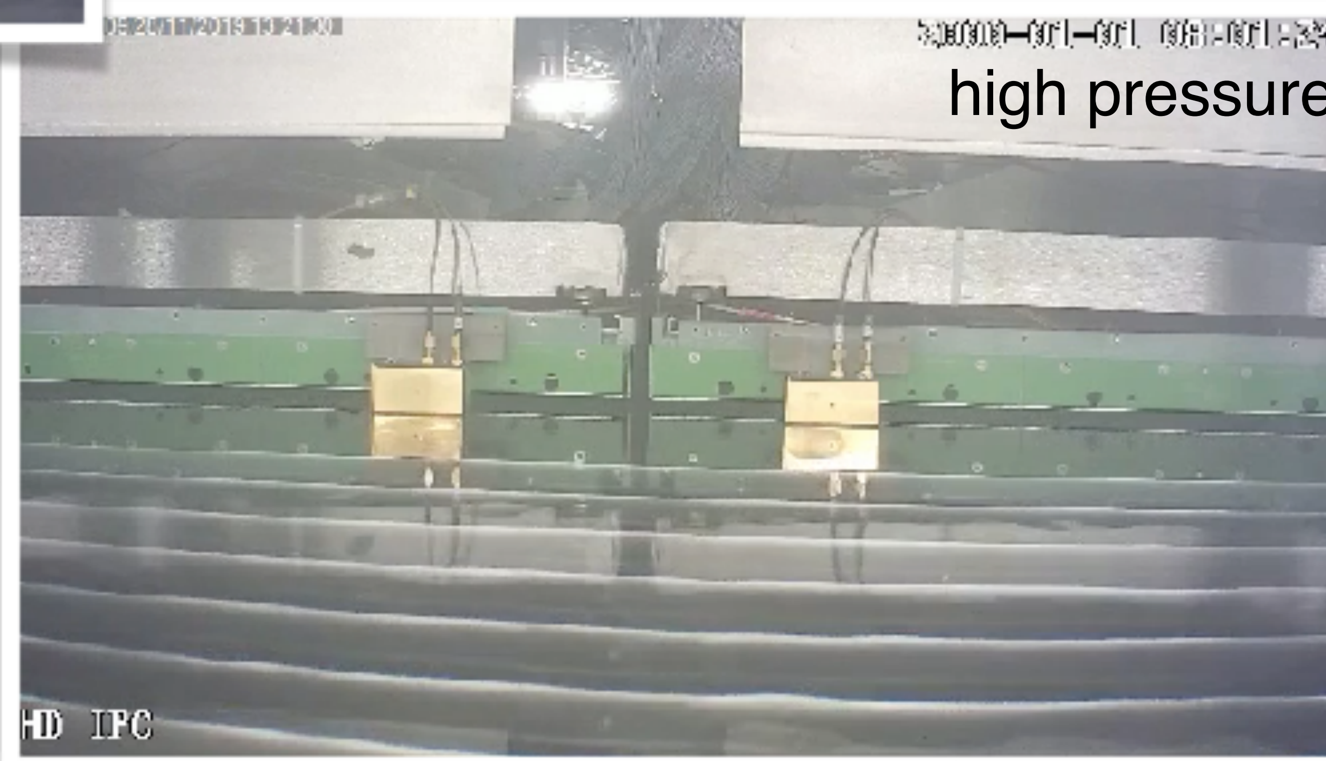
Cryostat operation

In August and September, in order to avoid bubbles the pressure in the cryostat was raised. The absence of bubbles allows the correct CRP positioning and ensures that there are no waves large enough to *wet* the LEMs or expose the extraction grid in the liquid to the vapour. The cycles were on a daily basis typically lasting 8-12 hours without bubbles. Temperature of the vapour and the liquid and the liquid level all change.



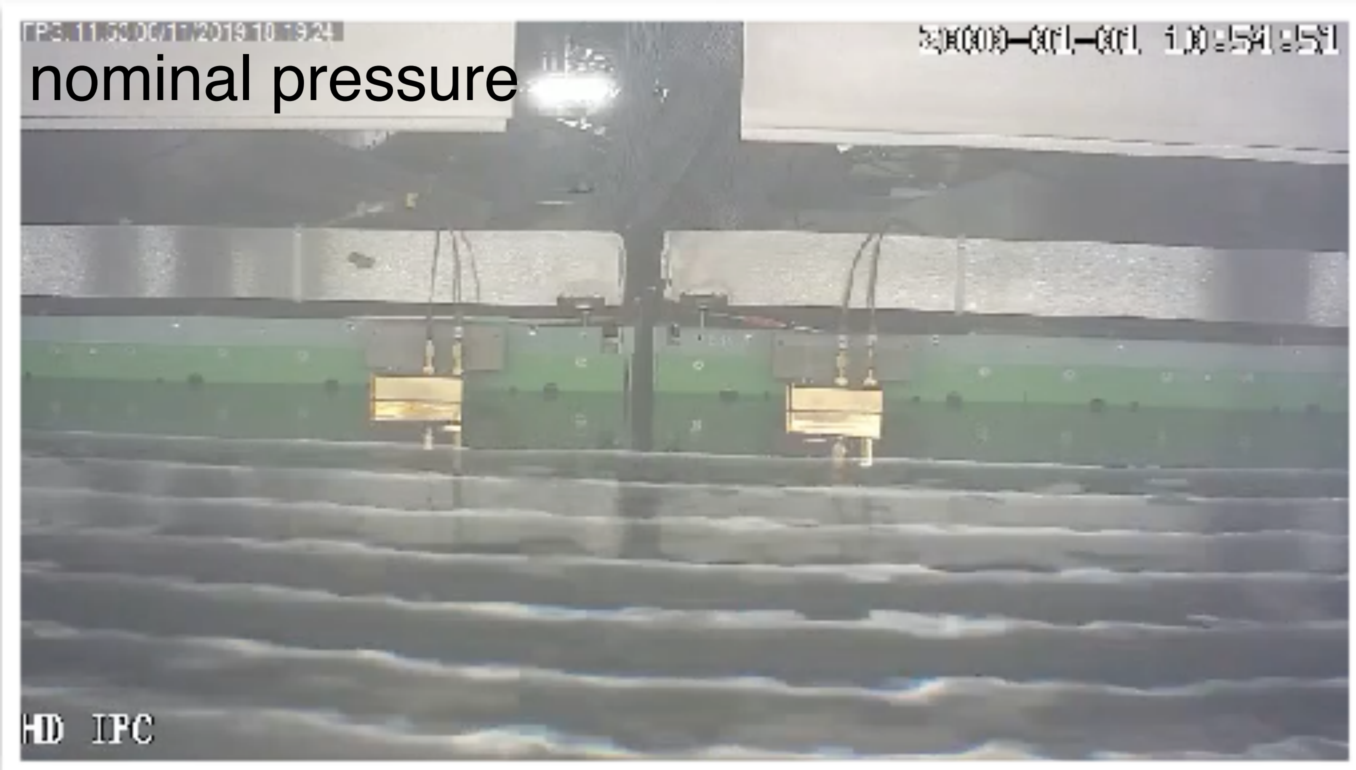
Nominal-high pressure cycles

Pressure cycles have the net effect of increasing the average temperature of the liquid argon with respect to the nominal temperature, which results in considerable bubbling during the periods at nominal pressure.

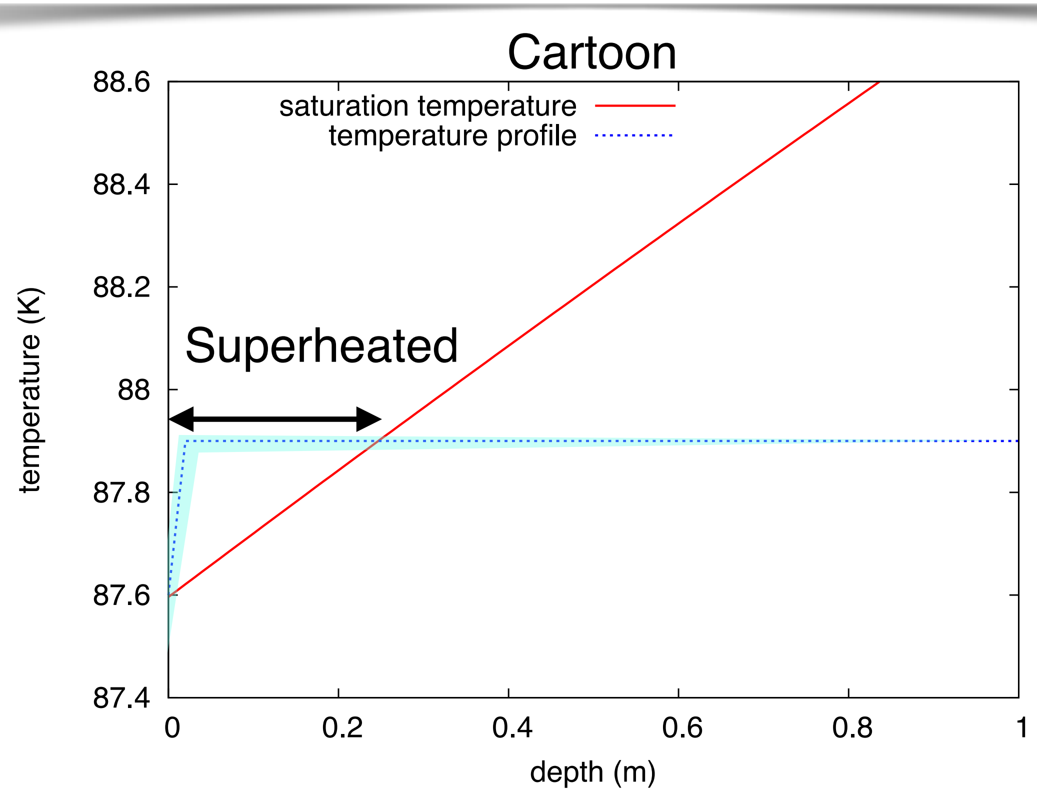


For this reason, it was decided to stop the cycles and keep the system stably at nominal pressure for 5 days to let the liquid bulk thermalise. Bubbles did not disappear by themselves, but…

Nominal-high pressure cycles

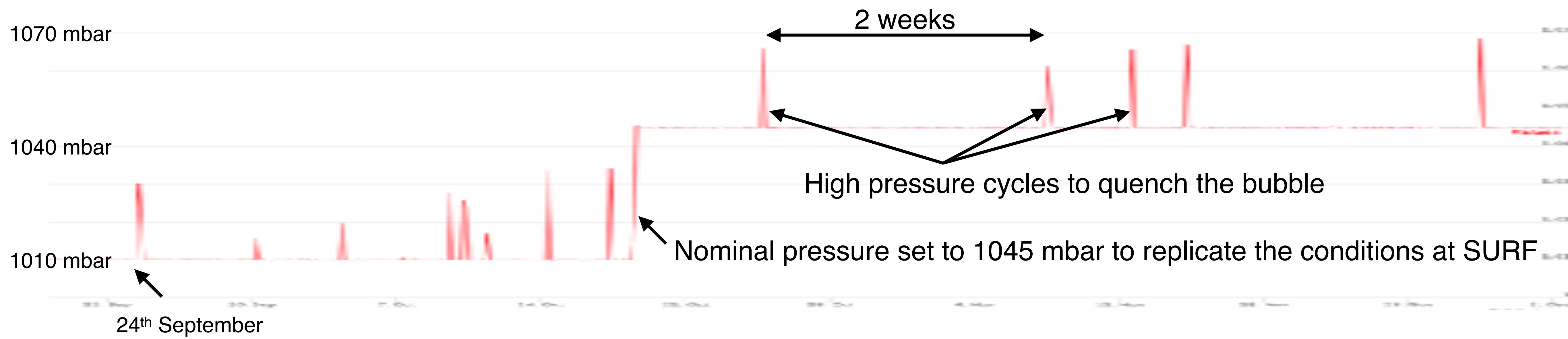


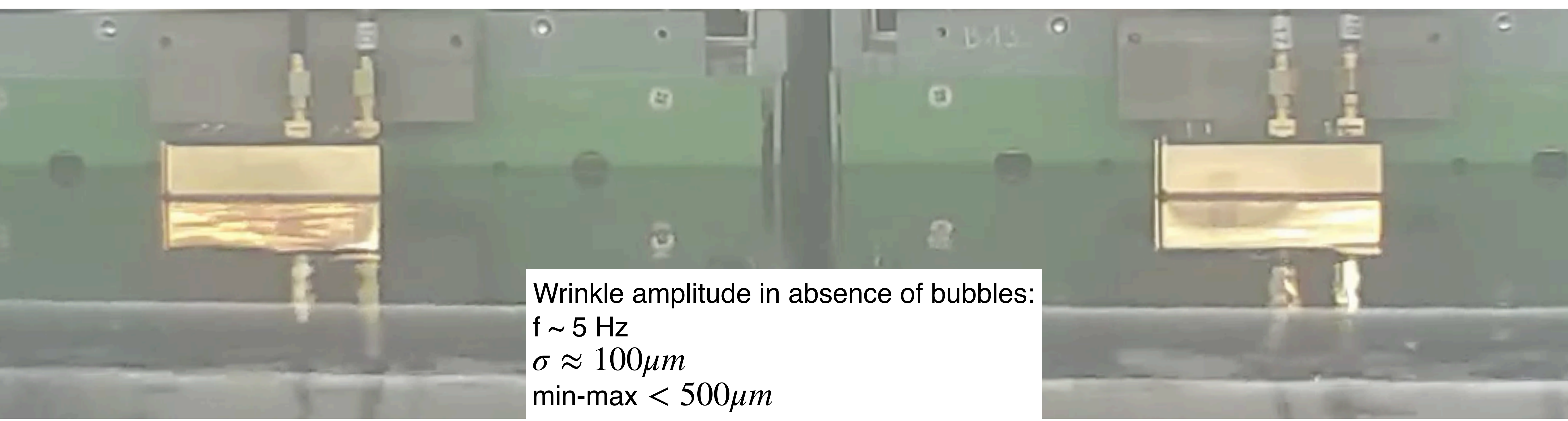
Since the 24th of September there has been a change in behaviour: after a short (~3h) pressure cycle the bubbles do not re-appear for several days after the system returns to nominal pressure.



Present status of the surface

Long periods without bubbles at the field cage





Wrinkle amplitude in absence of bubbles:
f ~ 5 Hz
$\sigma \approx 100 \mu m$
min-max $< 500 \mu m$

Related seismic studies

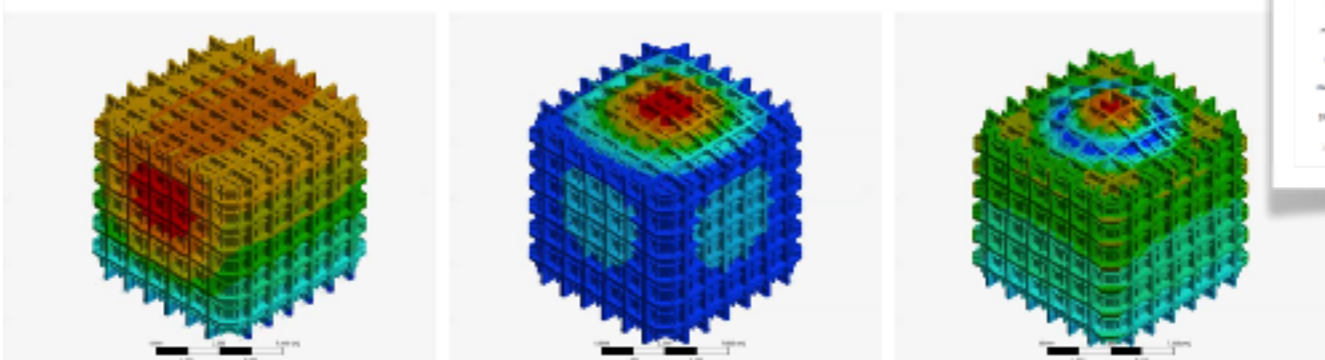
Seismic analysis validated with measurement when the cryostat was empty:
10 Hz and 25 Hz resonance predicted by the model.

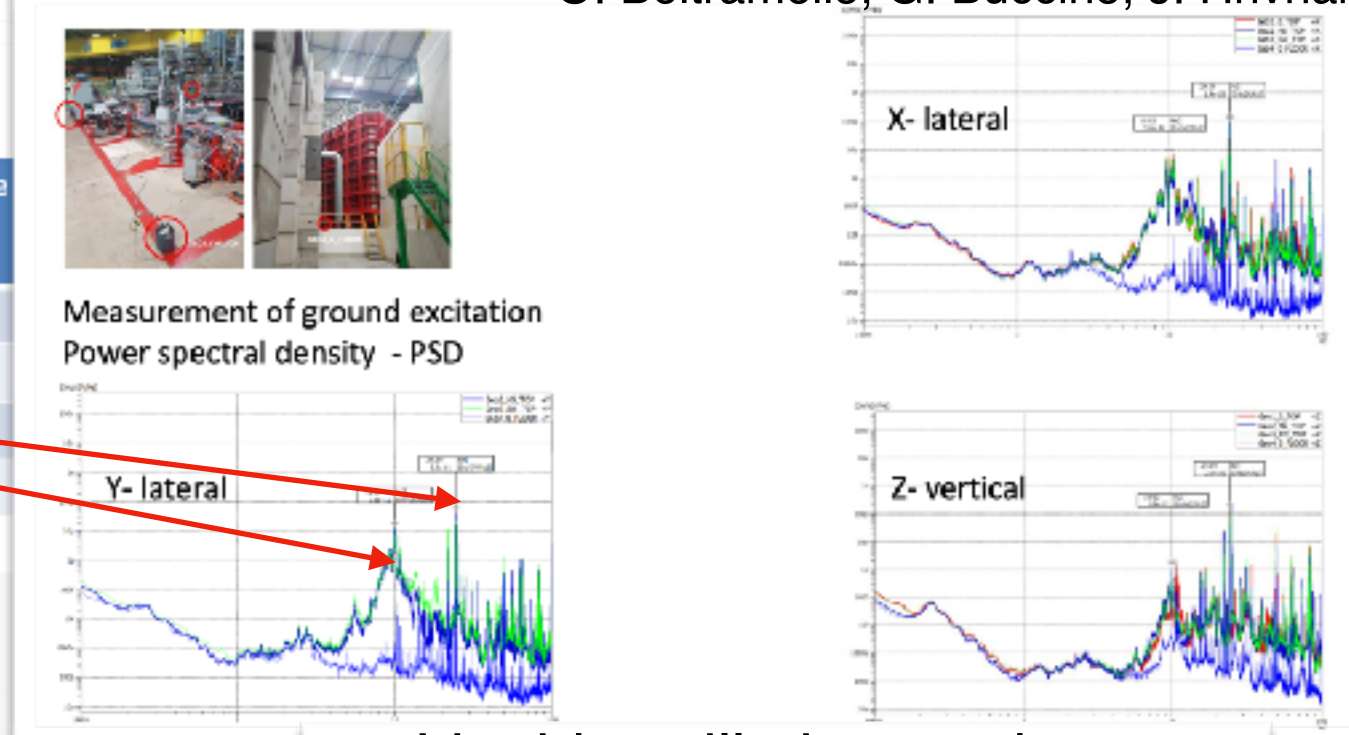
O. Beltramello, G. Buccino, J. Hrivnak

Modal analysis

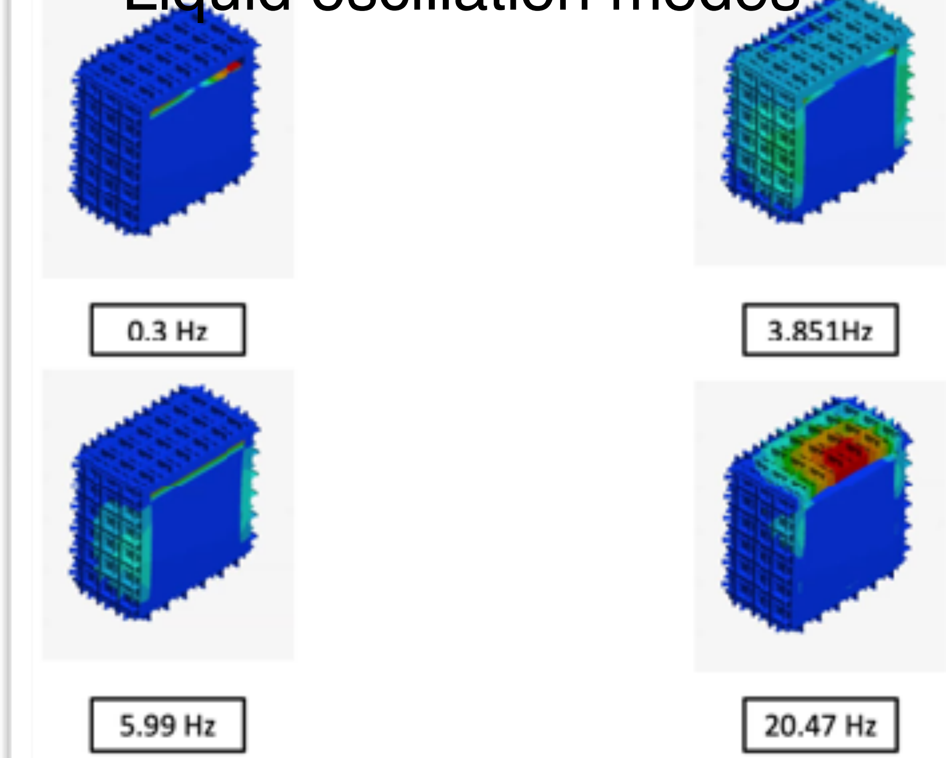
NP02 empty – bearing pad modeled at base

Mode	F (Hz)	Ratio effective mass to total mass – X (%)	Ratio effective mass to total mass – Y (%)	Ratio effective mass to total mass – Z (%)
2	9.31	99.05 %		-
3	9.31		99.05 %	-
4	24.4	-	-	12 %
22	69.05	-	-	69.5 %





Liquid oscillation modes



The model predicts mixed (liquid/cryostat) mode at 4 Hz and 5 Hz. Same frequency range as for the wrinkles on the surface. Any relation? Validation of the seismic model with the cryostat full is ongoing.

Summary

The mechanical filter of the liquid argon purification system was clogged with dust-like material.
Established a procedure to unclog the filter and allow 1-2 weeks of continuous circulation.
Since middle of November, after six uncloggings, the situation is much improved: presently the pressure across the filter is stabilising well below the 1 bar limit.
Improvements in the liquid argon circuit are under study.

Drifting electron lifetime is measured with two types of purity monitors and with TPC events.
Lifetime improvement rate lower than for ProtoDUNE-SP due to the clogging of the filter and possibly the more outgassing material in the vapour phase.
Presently the lifetime estimations range from ~1 ms (TPC) to > 7 ms (long purity monitor).
Studies to understand these discrepancies are ongoing.
Systematic campaign to characterise the lifetime in different cryo-conditions is being planned.

Bubbles have been observed from the HV feedthrough and from the field cage. The latter are not present most of the time since the end of September.
In absence of bubbles, the amplitude of the wrinkles on the liquid surface is 100 um (rms).
Studies to relate the liquid surface wrinkles and the cryostat response to seismic activities are ongoing.