Gas Analyzers, Level Meters, Pressure Sensors

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Calibration/Cryogenic Instrumentation Workshop

5/2020

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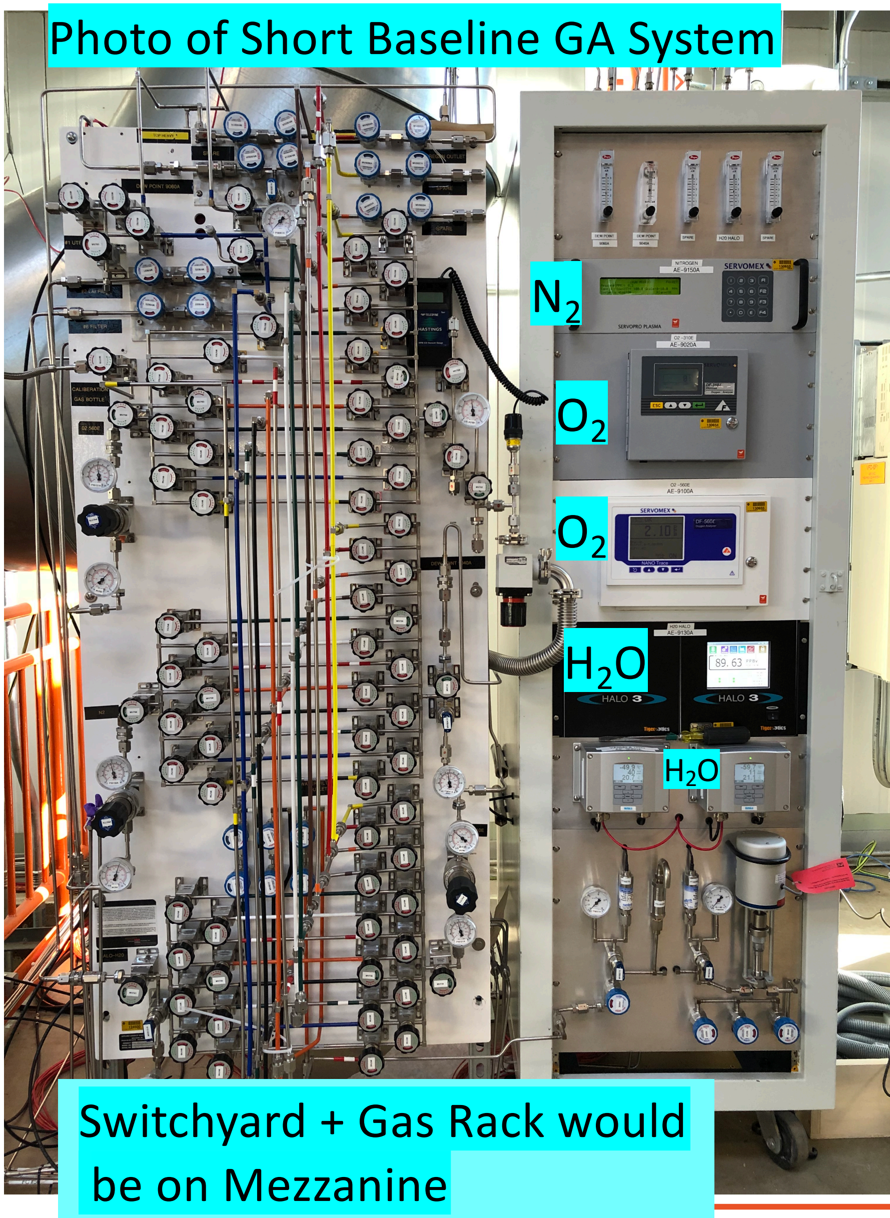
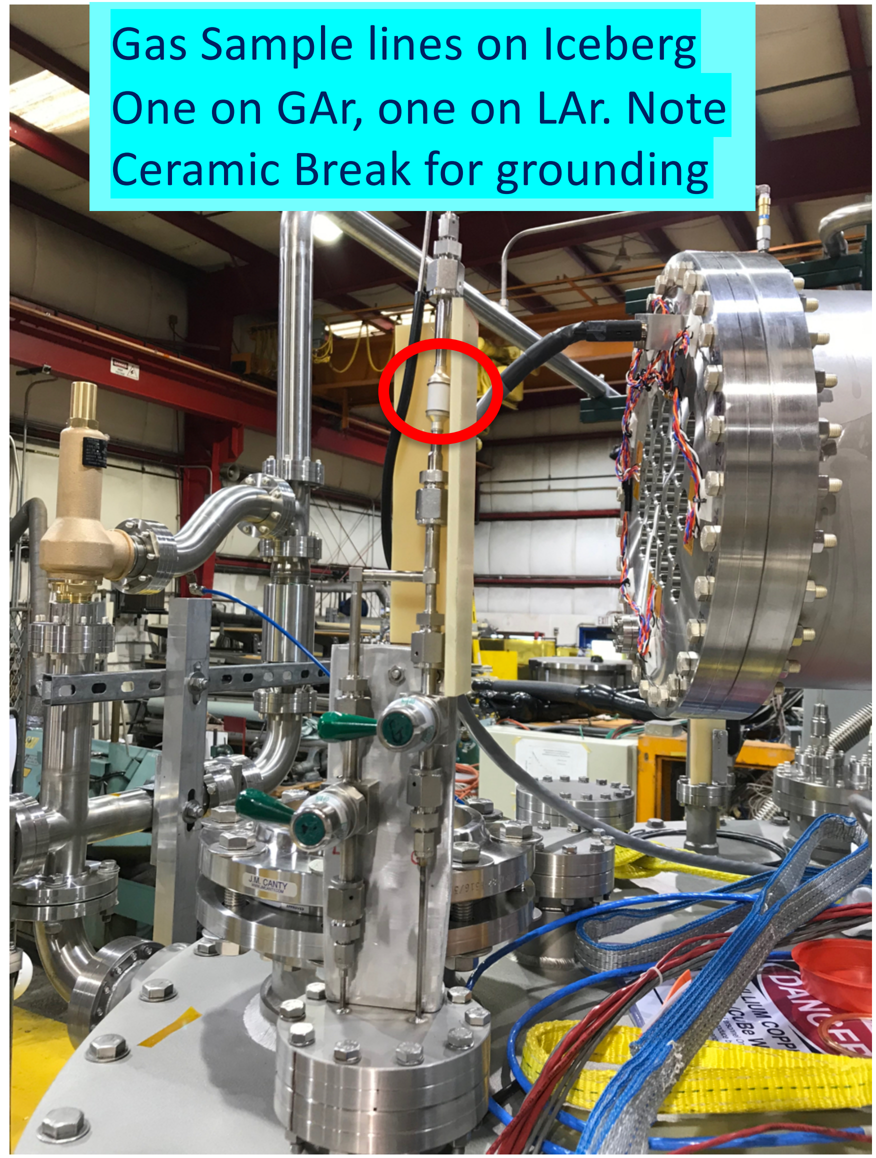
Gas Analyzers

- What are they?
  - Commercial Hardware Modules that analyse the amounts of a trace (= contaminant) gas in a carrier gas (argon) stream.
- Why are they useful?
  - During different stages of commissioning/operation they quantitatively give the levels of the contaminant gases in the sample volumes
  - Contaminant sensitivities range from the level in room air down to the sub ppb level.
    - Need multiple units to cover entire range and species.
- What contaminant gases are we looking for?
  - O_2 & H_2O impact the electron lifetime in LAr
    - 100 ppt O_2 equivalent levels give ~ 3 ms electron lifetime in LAr.
  - N_2 impacts the LAr scintillation light yields at levels > 1 ppm.

Fermilab DUNE

Gas Analyzer Hardware





Gas Analyzer Deployment

↑ = sampling port for GA's

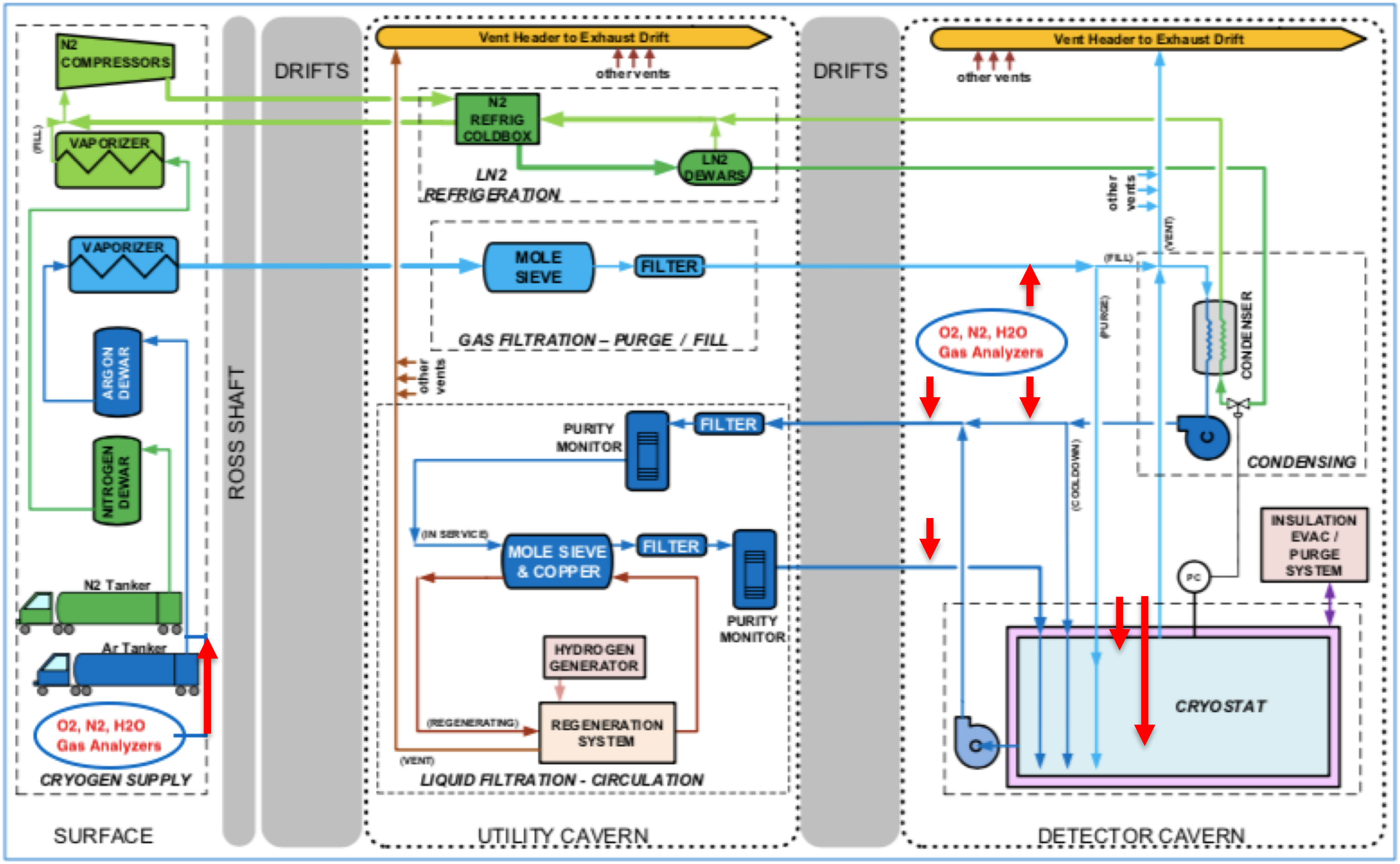


Figure 1: Process Flow Diagram for the LBNF cryogenics system

Gas Analyzer Deployment at Surface

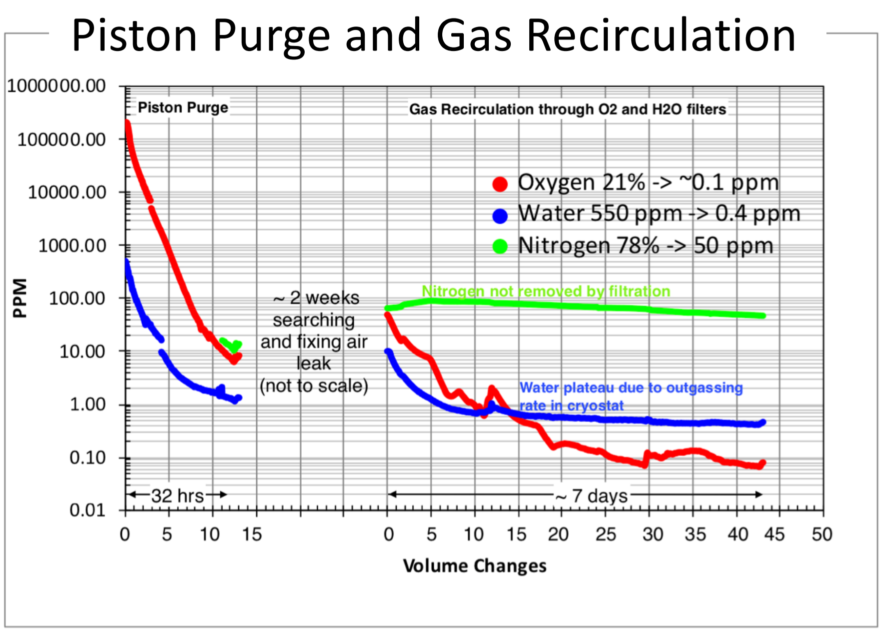
- Owned by LBNF
  - Monitor the vendor-delivered LAr
  - Moderate Precision Analyzers
    - Potential delivered LAr might have O_2, N_2, H_2O levels in tens of ppm to ~ hundred ppb range.
      - Want analyzers to cover this range.
      - Useful to track impurity loads to track Filter saturation performance.
    - Sample line connects to vapor line of delivery truck trailer.

Gas Analyzer Deployment at 4850 level

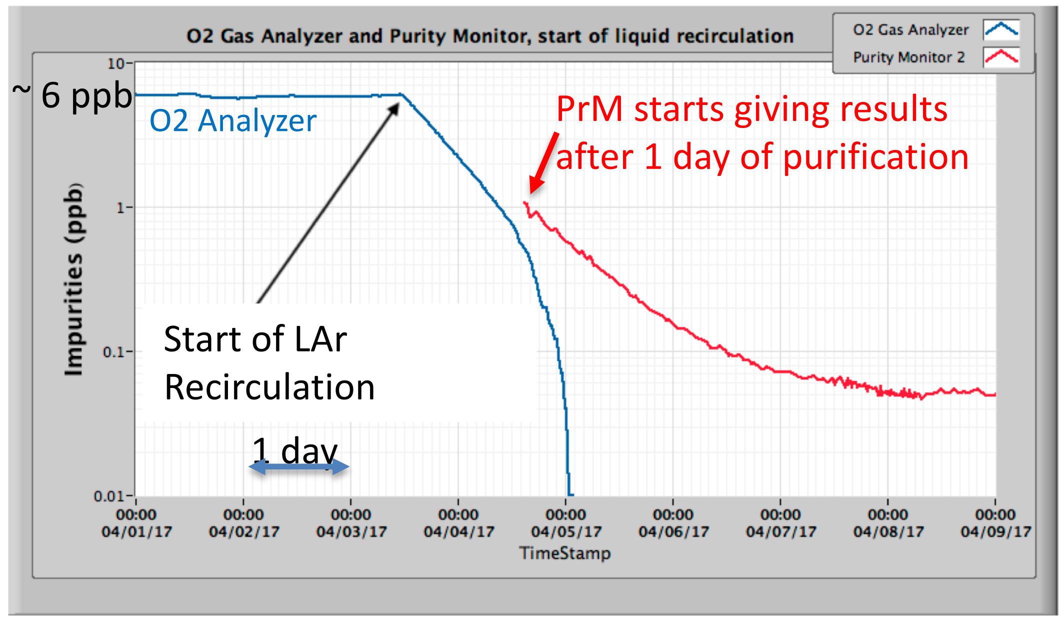
- Piston Purge and Gas Recirculation Monitoring –owned by Installation (?)
  - Coarse precision, from air levels of O_2, and H_2O to hundreds of ppm.
  - Moderate precision, from hundreds of ppm to sub-ppm of O_2, N_2, H_2O
- Cool Down, Filling, Operations (owned DUNE)
  - Monitor input and output of purification filters
    - Moderate precision O_2, N2 analyzers on input—looking for , contamination loads, any filter upsets
    - High precision O_2, on output (expect ~0 ppb if filter is working)
    - Complementary and supplementary to PrMs.
  - Monitor Cryostat Ullage and LAr volumes
    - High precision O_2, H_2O, N_2.
- It would be nice if the valving on Router Panel was remotely switchable to timeshare GA's between the various sampling ports & cryostats
- Currently the GA rack installation is planned for Cryostat 1 Mezzanine.
  - Perhaps Utility cavern might be a better location since plan is to share with Cryostat 2.

Some sample Gas Analyzer plots

Sample plots from 35 Ton runs (from TDR)



Cryostat Impurities as seen by O_2 Gas Purity Monitor as LAr purification starts



- Note: this was the initial Cryo Run of 35 Ton Cryostat (2/2014)—no TPC, so H_2O loading (< 1 ppm) is small.
- ProtoDUNE-SP, H_2O ~ 100 ppm after 20 volume changes.
  - 35T Phase 2 Run with TPC , H_2O level ~ 25 ppm.

ProtoDUNE gas pump failure

July 21 — **Gas pump injects air into the system and GAs filter exhausts**

GAr filter starts to saturate and exhaust around midnight

July 22 — **LAr filter exhausts and the problem appears**

LAr filter saturates ~7am and electron lifetime starts to drop. Around the lunch time, all lifetime is lost. LAr re-circulation stopped.

July 23 — **Checks for possible leaks**

Inspect the system and perform regular purity monitor measurements to monitor the system.

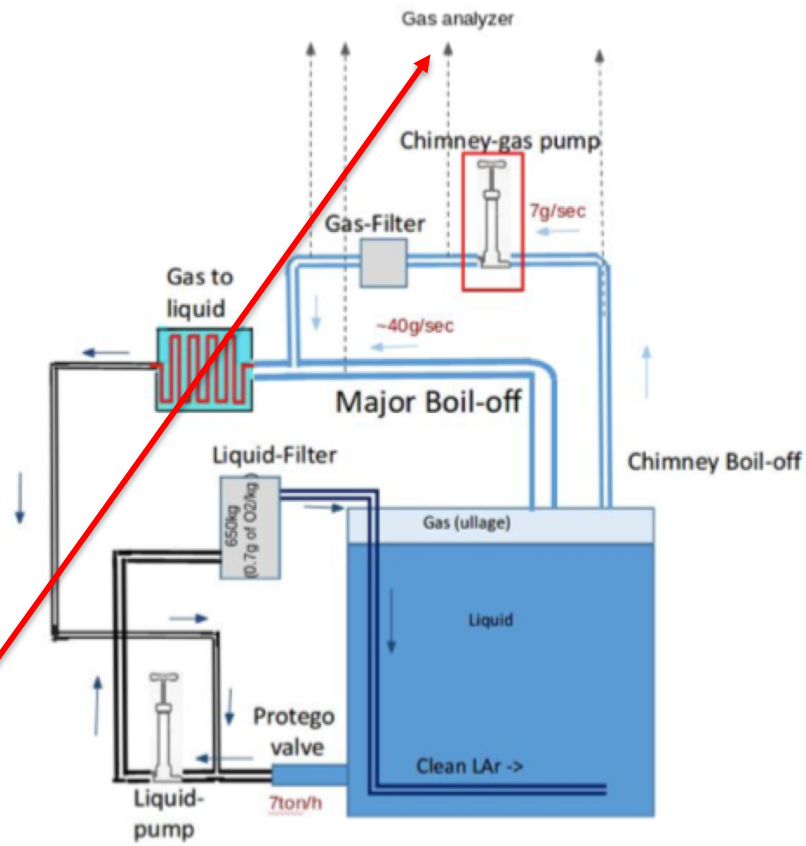
July 24 — **LAr filter regeneration**

July 25 — **GAr filter regeneration and smoking gun**

With LAr and GAr filters re-generated, impurities are trapped.

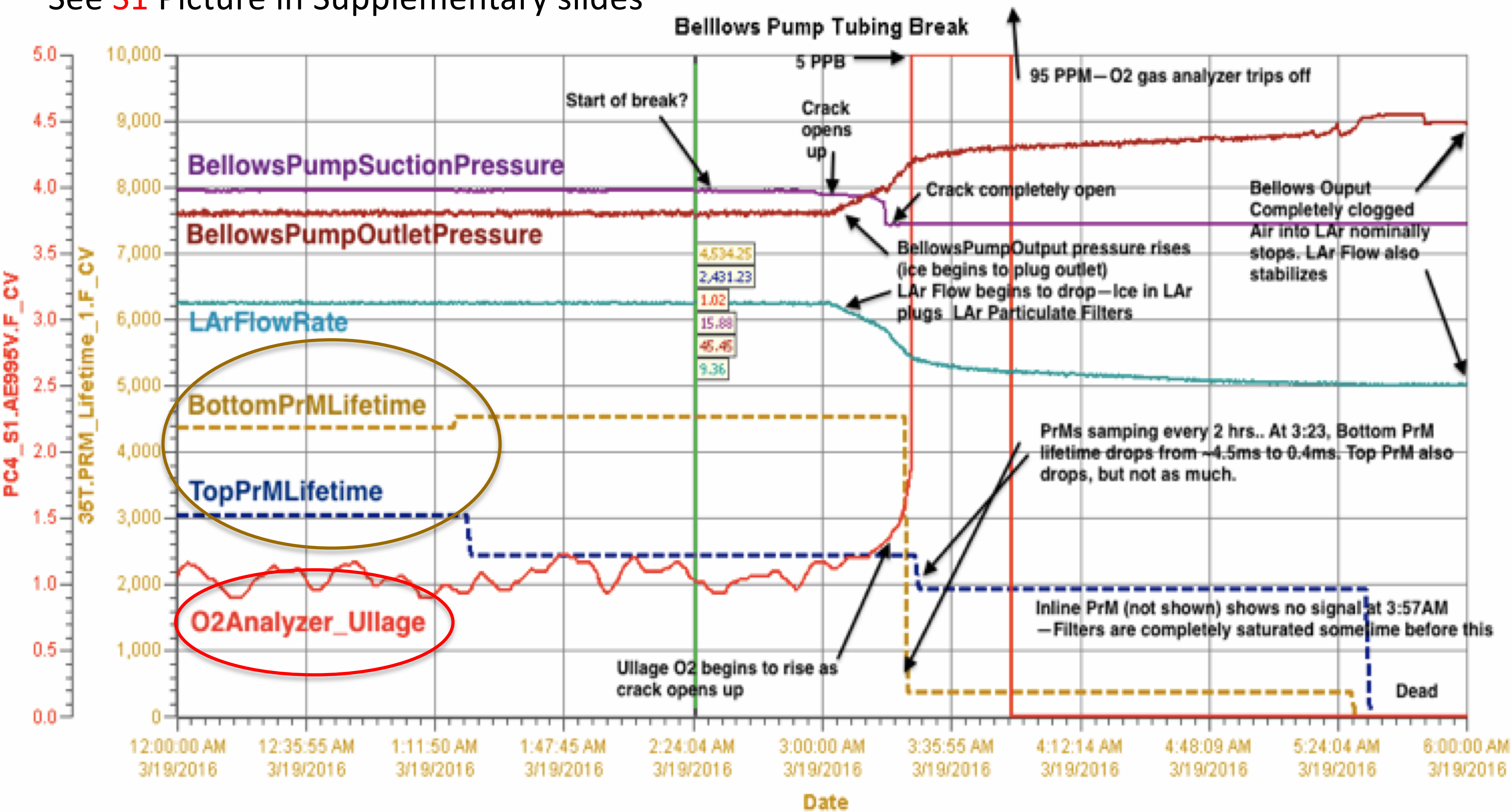
July 26 — **GAr filter saturated. Source of problem understood**

Gas analyzer overflowed at the pump output. Gas circulation pump stopped and excluded from the cryogenic circuit.



Similar issue from 35T run- Break in vapor tube injects air into LAr recirculation system.

See S1 Picture in Supplementary slides



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Gas Analyzer Budget

System	Cost/piece	Quantity	Total	Comment
Gas Analyzers	$128,000.00	1	$128,000.00	Cost of the analyzer modules. Does not include the Surface Installation
Piping/routing panel	$157,800.00	1	$157,800.00	Gas Routing panel, piping, vapor compressor pump,
Total Cost			$285,800.00	
Cost Breakdown				
N2 Gas Analyzer	$30,000.00	1	$30,000.00	Range is 100 ppm ->10 ppb. Note: DUNE currently owns one unit
Coarse precision O2 Analyzer	$2,000.00	1	$2,000.00	20% (air) to ~1/2 %. Used at start of purge
Intermediate O2 Analyzer	$5,000.00	1	$5,000.00	0.5% to ~ ppm. Remainder of purge
Precision O2 Analyzer	$10,000.00	1	$10,000.00	50 ppm -> 3 ppb. End of purge to through gas recirculation. Monitor filter inputs
High precision O2 Analyzer	$40,000.00	1	$40,000.00	20 ppm -> 100 ppt. Monitor filter outputs. Bottoms out at ~ 1 ms lifetime.
Coarse H2O analyzer	$3,500.00	2	$7,000.00	Commonly referrd to as "Dewpoint" meters. From ~20kppm (normal air humidity) to ~ 10 ppm
High precision H2OAnalyzer	$34,000.00	1	$34,000.00	20 ppm -> 1 ppb. Sample ullage of cryostat or chimneys..
Gas Routing Panel	$40,000.00	1	$40,000.00	Based on MicroBoone Routing panel. Includes valves on/at Routing panel.
Piping	$30,000.00	1	$30,000.00	Costs of tubing and any valves on sample ports.
Vapor Compressor Pump	$6,800.00	1	$6,800.00	Most analyzers need input pressures ~ 10 psig (~2/3 of an atmosphere above barometric pressure).
Small Dry Pump	$1,000.00	1	$1,000.00	Used to evacuate piping lines before switching to gas analyzers.
Labor	$80,000.00	1	$80,000.00	Includes both the routing design, installation, and leak checking of the piping from the sample ports to the GasRouting Panel. (Labor is 320 hrs engineer/designer, 480 hrs of tech)

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

Level Meters

- Six capacitive LM could be place at 4 corners of cryostat, 2 midway on opposite 58 m sides.
- Ensure LAr level is above TPC Upper Ground planes
  - TPC Drift Field HV will be interlocked to the Level Meter
    - LAr level > 2 cm above Ground planes (for example)

Plot from TDR

Capacitive | Differential P

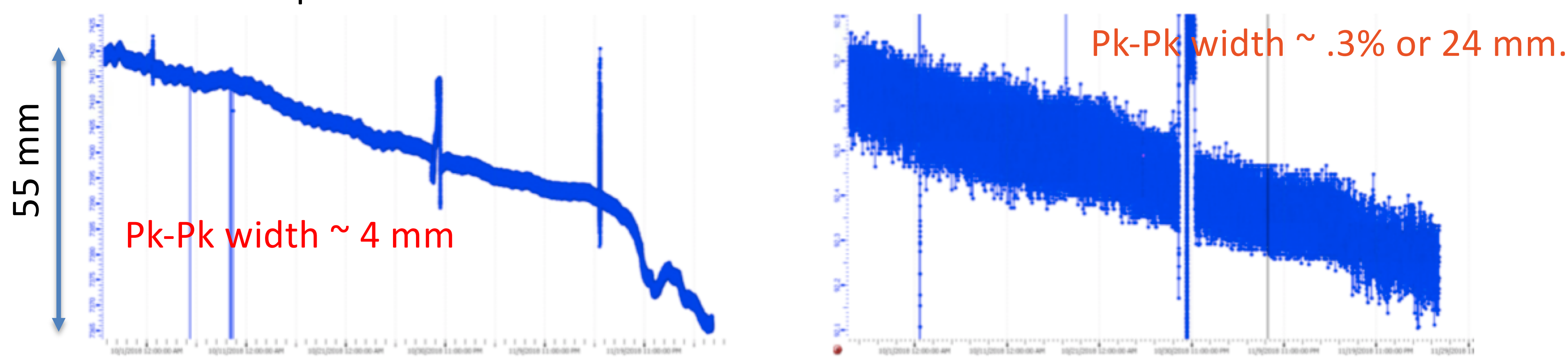


Figure 8.21: Evolution of the ProtoDUNE-SP LAr level over two months. Left: Measured by the capacitive level meter. Right: Measured by the differential pressure level meter. The units in the vertical axis are percentages of the cryostat height (7878 mm).

Pressure Sensors—owned by LBNF

- What are they?
  - Hardware devices that measure the pressure—either
    - Gauge—pressure over atmosphere
    - Absolute—includes the barometric pressure + the gauge pressure
- How do they work?
  - Roughly, a force over an diaphragm area.
    - Gauge-- one side of diaphragm is open to the atmospheric pressure.
    - Absolute—one side of diaphragm is at vacuum.
- The cryostat will be regulating on this absolute pressure sensor.
  - LAr saturation temperature depends on absolute pressure.
  - The drift velocity is dependent on the LAr saturation temperature.
- Gauge Pressure is important to measure the forces on cryostat since membrane cryostats cannot withstand large pressure differentials with the barometric pressure.
- Key point is they should be directly accessible through Slow Controls to CALCI and DUNE

ProtoDUNE Pressure sensors

From TDR

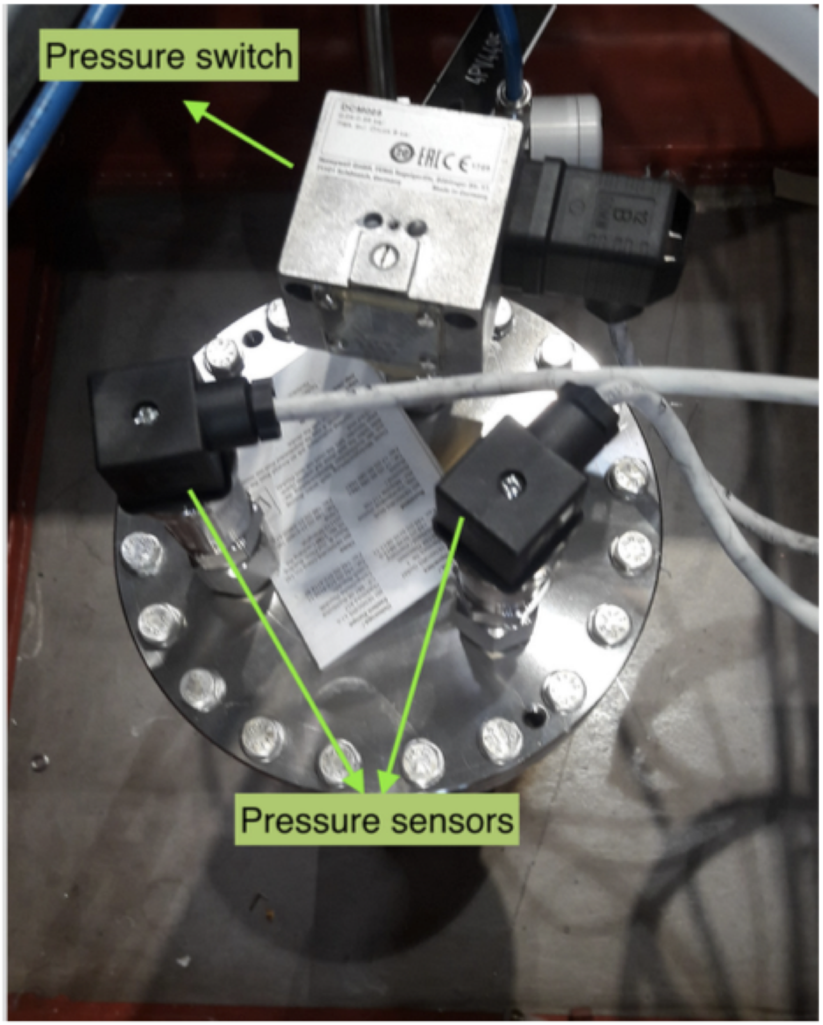


Figure 8.22: Photograph of the pressure sensors installed on a flange in ProtoDUNE-SP.

Lessons Learned—Alarms & Interlocks

- In general we have found that PrMs, Gas Analyzers work well and provides useful information
- However we have been less successful in implementing alarms using these devices that would help protect the experiment from upsets.
  - 35 Ton tubing break—injects air into recirculating LAr
  - ProtoDune Filter saturation during fill
  - ProtoDune Pump failure—injects air into recirculating LAr.
  - MicroBoone various low purity top offs
- <u>At a minimum we need to alarm experts</u>
- <u>At another level, should we automatically turn “things” off?</u>
  - We do have HV interlocks on Level Meters.
  - Recognizing those “things” turning off may have their own negative ramifications especially if this was a false alarm.
  - Need a Risk analysis to be sure of doing good, and not doing harm.

Response to Charges, Part 1 (a)

- Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?
  - Gas Analyzers
    - I don't think this is applicable for this device
  - Level Meters
    - Useful to provide input to the Computational Fluid Dynamics (CFD) calculations for Liquid and Vapor space of Cryostat.
  - Pressure Sensors
    - Relationship here is to provide precision pressures and as a result, allow the Temperature measurements to take account of any changes. Temperature changes feed into drift velocities.

Response to Charges, Part 1 (b)

- Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?
  - As far as I know, nothing on these 3 topics has been directly raised in previous workshops.
  - We have used the GA systems on multiple installations at FNAL.
  - Level Meters, Pressure sensors worked successfully on ProtoDUNE-SP & DP
- Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?
  - Gas Analyzers
    - The Gas analyzer rack and switchyard are located on the mezzanine and are on building ground. To mitigate grounding issues to detector ground, the gas tubing run is isolated at the cryostat feedthrough by a ceramic break. Also the tubing is insulated with shrink-wrap tubing where it can make contact with the detector ground.
    - A flow aperture can be placed at the chimney that will restrict the gas flow in case any break might occur in the gas line. Plus gas flow is away from cryostat.
    - A vapor compressor is required to supply the needed gas pressure and flow to the gas rack. I believe any issue here can be mitigated by where this compressor is located.
  - Level Meters & Pressure sensors
    - If the grounding rules are followed as was done in ProtoDUNE, I don’t believe there are any issues

Response to Charges, Part 1(c)

- Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?
  - Gas Analyzers
    - Medium to Precision Gas Analyzers (3x O_2, N_2, and H_2O) were lent to ProtoDUNE-SP, but except for the precision O_2 unit, they were not used. I believe coarse analyzers (O_2 and H_2O) did exist and were used for the Gas Purge and recirculation. Two of the borrowed analyzers (H_2O and N_2) have been returned to FNAL.
    - They could be returned to PD-SP II if they were going to be installed. Currently no high precision (sub-ppb) O2 Monitor is available from FNAL for loan.
  - Capacitive Level Meters
    - I think the plot given in this presentation shows the system performance. The plan is to use the 4 m CERN LM in the PD-II run
  - Pressure Sensors
    - This system was used for the previous ProtoDUNE run to regulate the cryostat pressure, so I believe this has demonstrated its worth.

Response to Charges, Part 1(c)

- Does the functionality of the system justify its overall cost?
  - Gas Analyzers
    - In my opinion, the diagnostic capability when things don't go the way you think they should make these systems invaluable. All LAr systems at FNAL include the gas analyzers described here. They cannot be procurred and installed, in a timely manner, after a problem occurs.
  - Level Meters
    - Costs are on the order of ~$2.2k per device (including flange) + wiring to the control system. The DUNE FD is a very large cryostat, and I believe that warrants monitoring the level at the 4 corners plus the two midway points.
  - Pressure Sensors—costs are covered by LBNF.
    - Costs per flange as shown is ~$4k. This is essential to cryostat operation. Two are needed for redundancy.

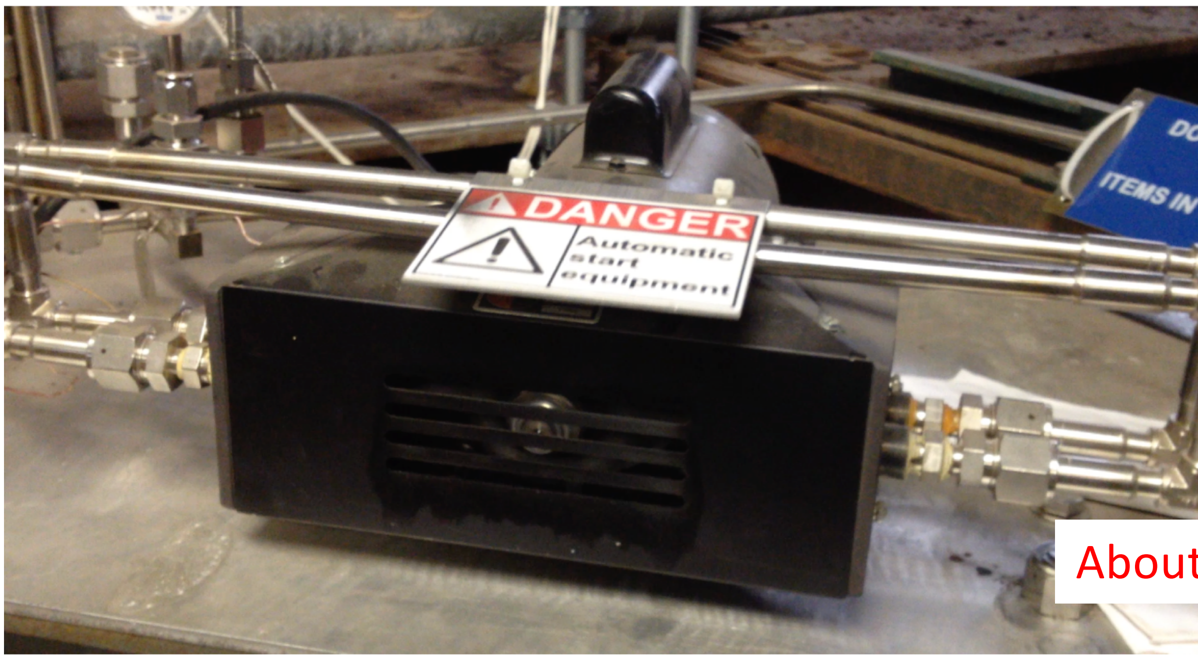
Response to Charges, Part 2

- Based on their evaluations of the individual systems, the review committees are asked to classify each of the proposed systems in terms of the following categorizations
  - Essential – Experiment should not be run without this system in place.
  - Highly-desirable – Strong justification for including this system but not viewed as absolutely necessary.
  - Advantageous – Good arguments exist for why this system….
  - Debatable – System could potentially be useful but ……
- Gas Analyzers—**Essential**—they play a unique role early in the operations, and complement the Purity Monitors during the operations. Since they are external devices, if one breaks it can be repaired or replaced.
- Level Meters—We are not completely sure what to expect on the first DUNE FD cryostat. I think all six are **Essential.**
- Pressure sensors---**Essential** to have two (redundancy) to regulate the cryostat pressure.
- General Comment: The first DUNE FD will establish the baseline for the remaining 3 Cryostats. I believe it is important to have instrumentation to document its commissioning and operation. This is part of my motivation for the "essential" designation.

Supplementary Slides

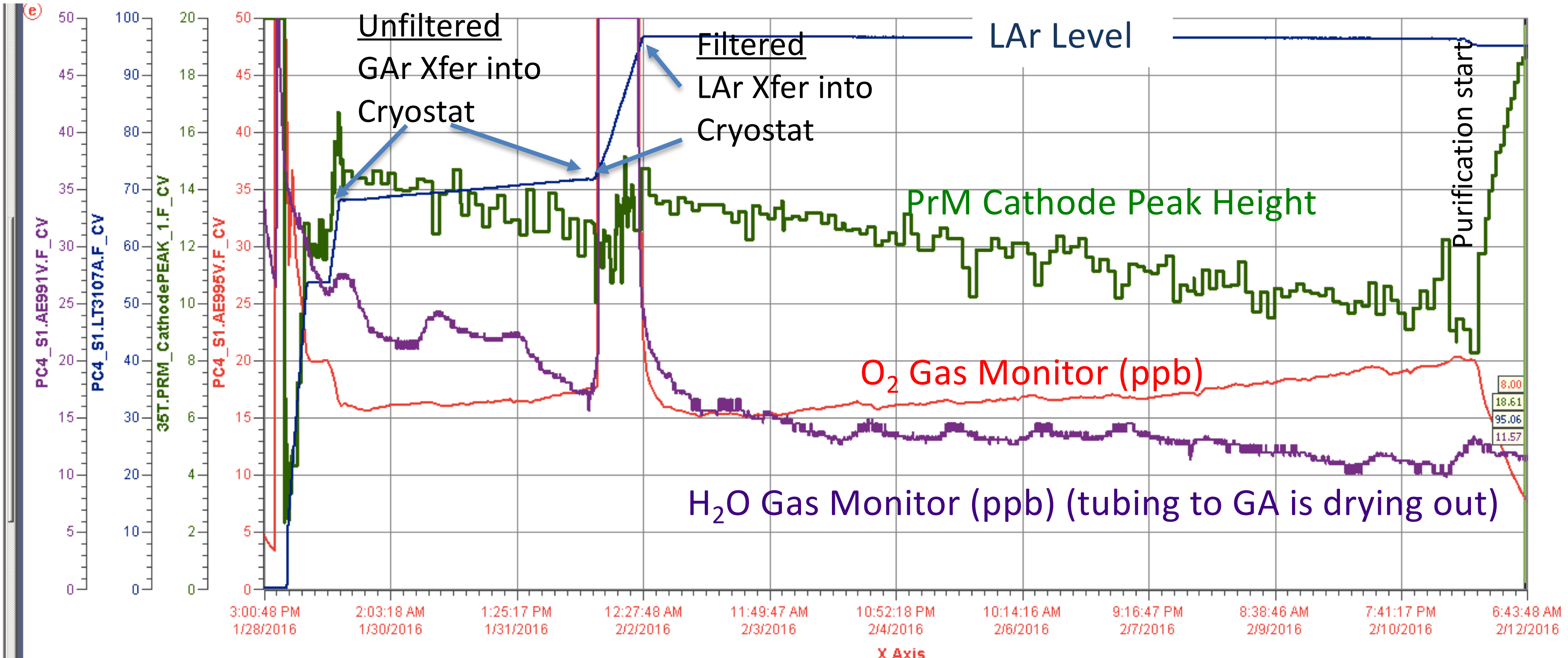
This broken tubing is on the suction side of pump that was pulling GAr out of LAPD, compressing it and injecting it into the LAr coming from 35T just before the purification filters.
This was how we were raising the LAr level in the Cryostat.

S1



Bellows Pump

35 Ton, Phase 2, Impurities during Cryostat Fill



- Filtered LAr transfer is higher purity than LAr in cryostat, overall cryostat purity improves.
  - Cathode Peak Height rises (more electrons make it to cathode grid), GA O_2 Impurities drop
- Unfiltered GAr transfer is lower purity than Cryostat LAr
  - Cathode Pk drops, O_2 GA measured Impurity rises
- O_2 impurity and Cathode Peak Height drops before start of purification—small air leak (?)
- GA Sampling is from LAr volume.

Fermilab DUNE

Example GA plots from ICEBERG Fill

O_2 filter saturation

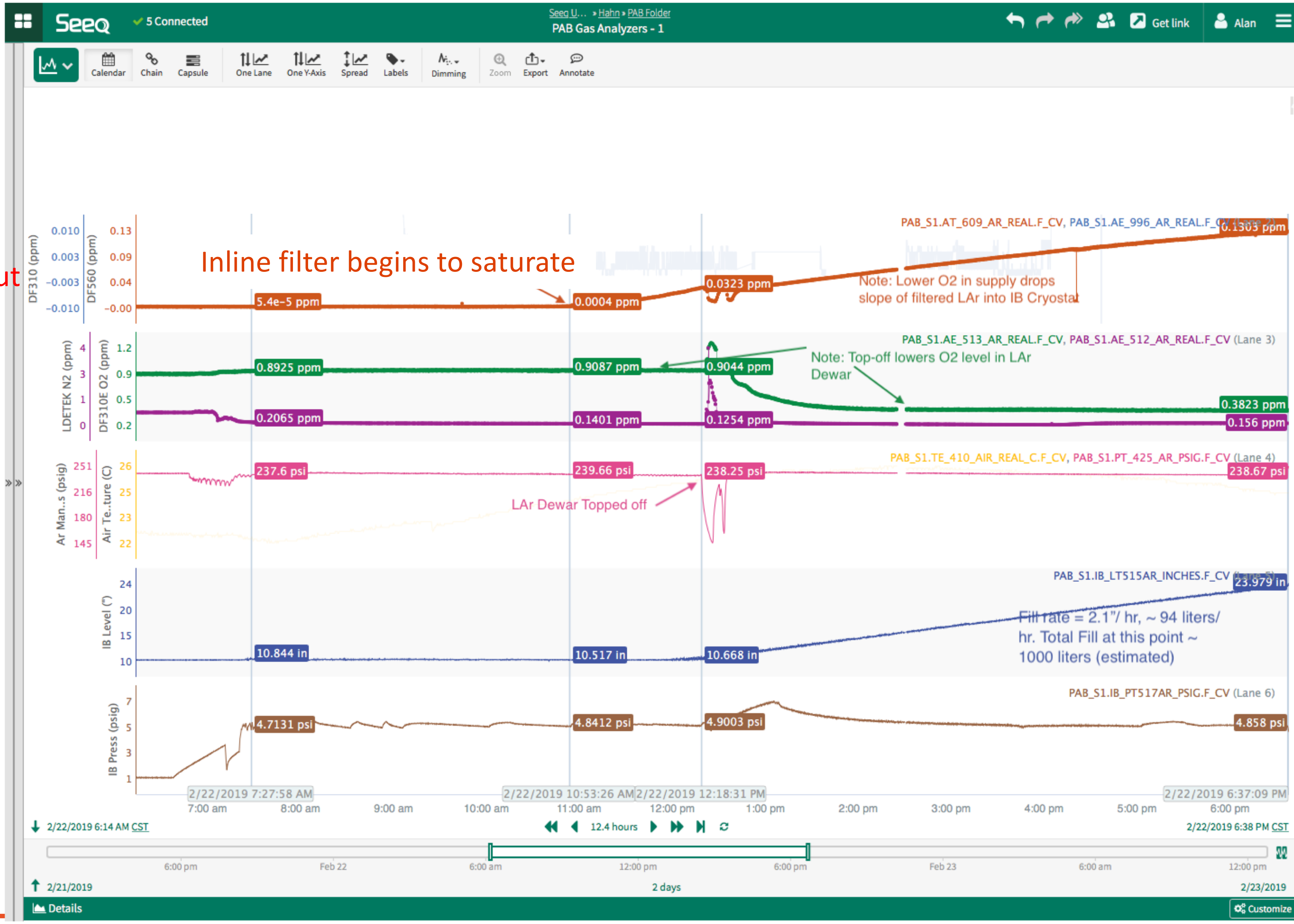
O_2 (ppm) @Filter Output

N_2, O_2 (ppm) @Filter input

LAr Supply psig

LAr level “

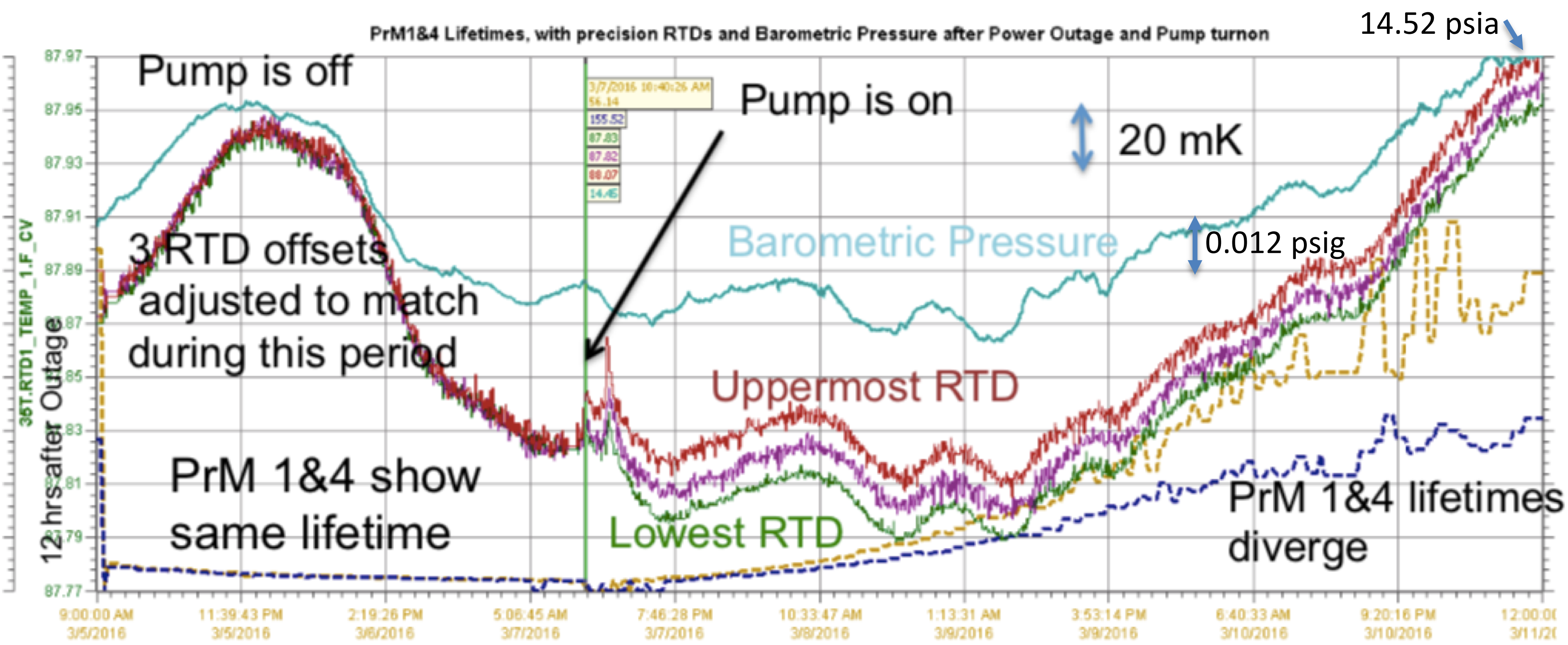
Cryo psig



Fermilab DUNE

Power Outage (and pump off) provides another opportunity to verify the stratification.

PrM1&4 with 3 Precision RTDs (also at different heights in Cryostat)



- Note sensitivity of RTD temperatures to Barometric Pressure ~ 20 mK/0.012 psi
- Barometric Pressure changes on this plot ~ 0.06 psig (peak to peak)
- 35T regulated Ullage on gauge pressure

Sensitivity of Drift time to Cryo Pressure Change (0.5 -> 0.6 psig, relative to 1 atm)