# Preparation for May Review: Gas Analyzers, Level Meters, Pressure Sensors

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Cryogenics Instrumentation WG meeting

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# Content

- Introduction to systems
  - Gas Analyzers
  - Level Meters
  - Pressure sensors
- Response to Charges, Part 1
- Response to Charges, Part 2

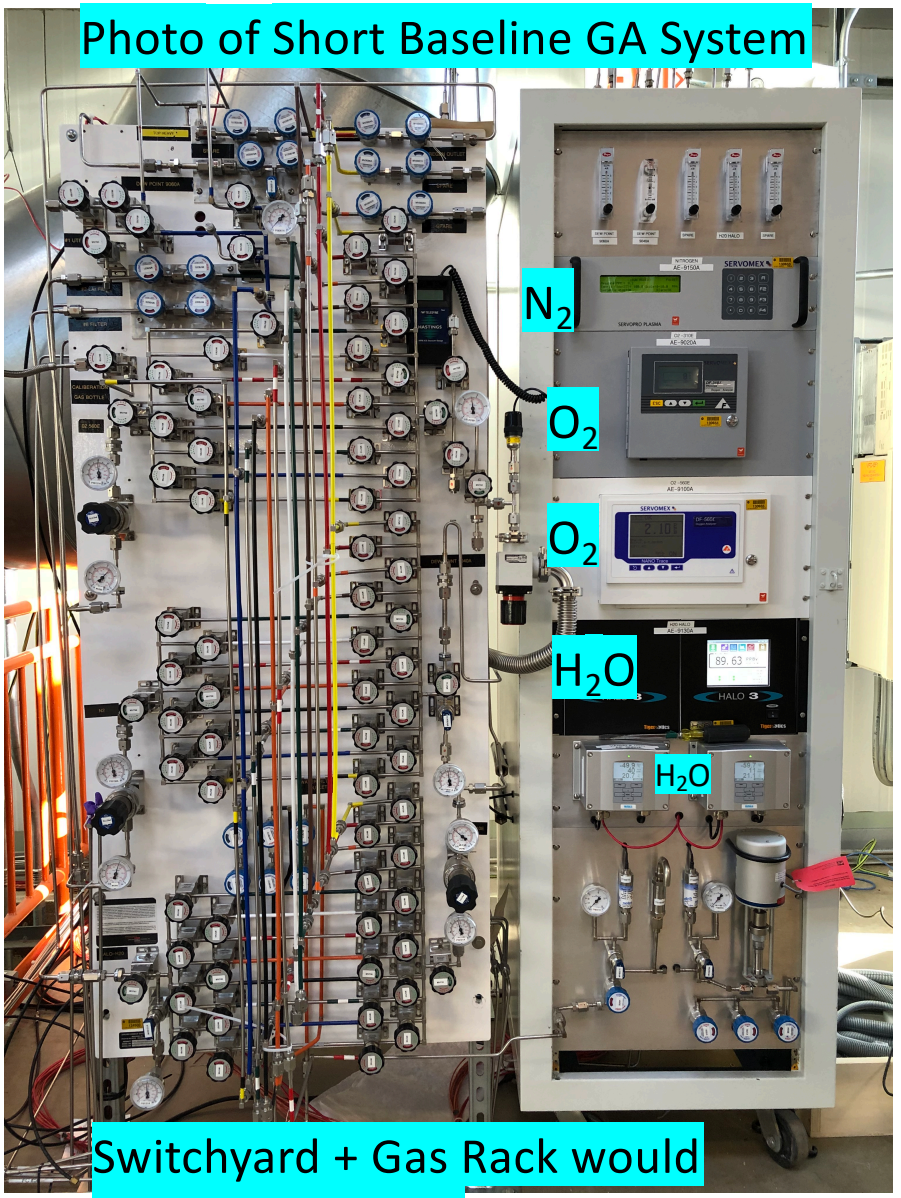
# Gas Analyzers

- What are they?
  - Commercial Hardware Modules that analyse the amounts of a trace gas in a carrier gas (argon) stream.
- Why are they useful?
  - During different stages of commissioning/operation they quantitatively inform on how the trace gases are being put in and removed from the main volume of argon
  - Sensitivities to the amounts range from the level in room air down to the sub ppb level
    - Need multiple units to cover entire range
- What trace 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

# Gas Analyzer Hardware

Gas Samples On Chimney
One on GAr, one on LAr

Photo of Short Baseline GA System

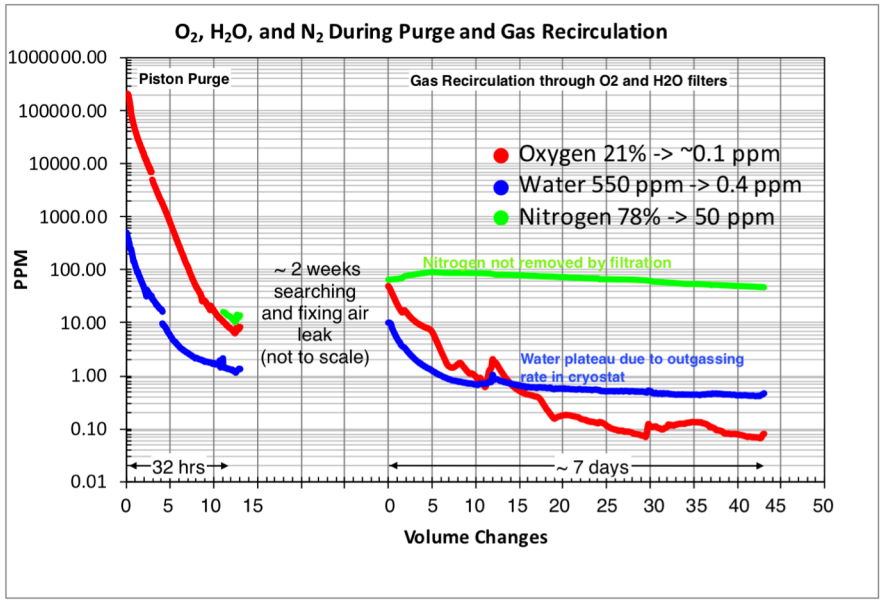



Switchyard + Gas Rack would be on Mezzanine

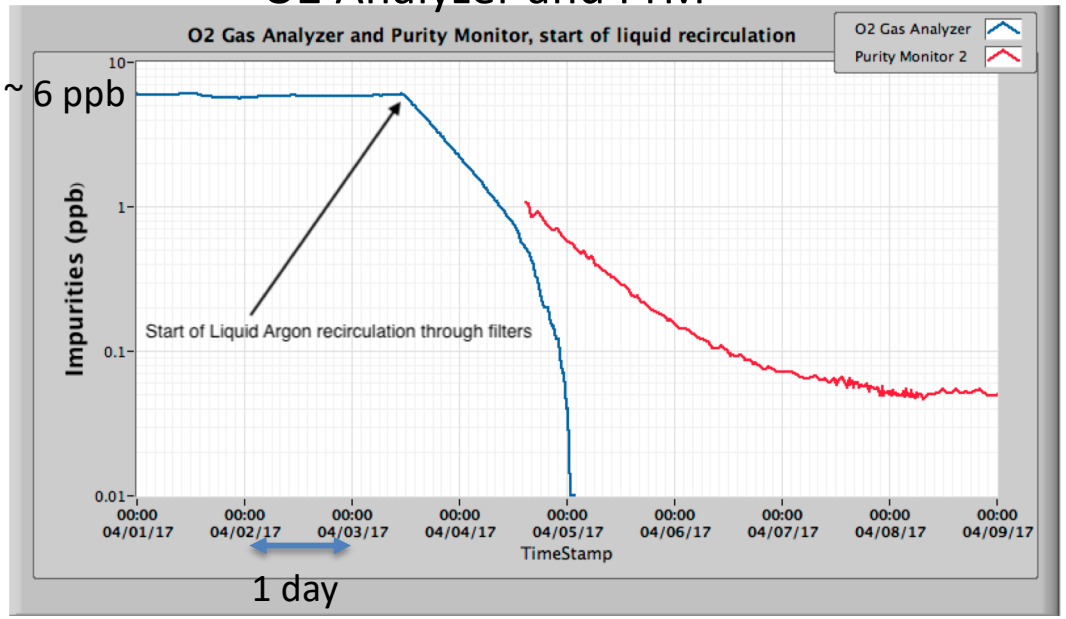
# Gas Analyzers

- When are they used?
  - Cryostat Gas Phase: Piston Purge & Vent, followed by GAr recirculation (through filters)
    - Levels ($N_2$, $O_2$, $H_2O$) drop from air (80%, 20%, 1%) to ppm and sub ppm levels
      - Note that N2 is only removed during the purge/venting phase.
  - Monitor trace gas levels during cooldown and filling
    - Monitor $O_2$ and $N_2$ levels in delivered LAr at sub ppm levels
      - Need moderate-precision $O_2$ and $N_2$ units at surface
    - Monitor $O_2$ filter input and output (at sub ppb levels) to check for filter saturation during filling
    - Monitor $O_2$ during the beginning of LAr recirculation to see levels drop
      - This could be done in cryostat, or at input of O2 Filter.
  - Monitor O2 filter inputs and outputs during operation—check for upset events
  - However, expect to use one installation for two cryostats, so need to share

# Some GA plots from 35T runs



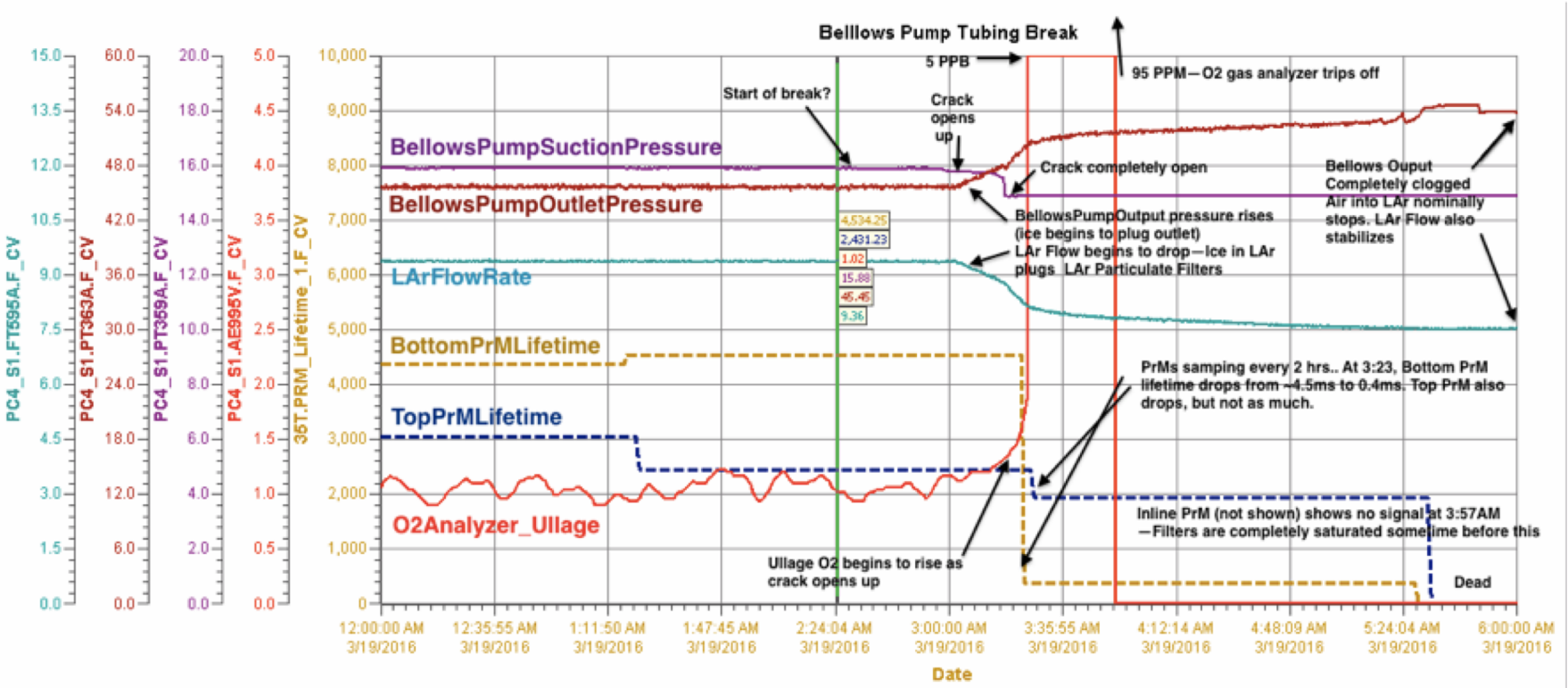

Start of LAr recirculation-
O2 Analyzer and PrM




Note this was the first Cryo Run of the 35 Ton Cryostat (2/2014)—there is no TPC inside, so $H_2O$ loading is small.

# Some GA plots from 35T runs

## Tubing Break Timeline--3/19/2016




| Pen Name | Description | Value | Eng Units | High Over Range | Low Over Range |
|---|---|---|---|---|---|
| 35T.PRM_Lifetime_1.F_CV | Lifetime calculated from AnodeTrue Cat... | 4,534.2 | us | 4,534.2 | 0.0 |
| 35T.PRM_Lifetime_4.F_CV | Lifetime calculated from AnodeTrue Cat... | 2,431.2 | us | 3,044.0 | 0.0 |
| PC4_S1.AE995V.F_CV | Analyzer Delta F NanoTrace O2 (F_CV) | 1.020 | PPB | 96,572.172 | -0.043 |
| PC4_S1.PT359A.F_CV | suction line to vent purge bellows pump... | 15.9 | PSIA | 15.9 | 14.8 |
| PC4_S1.PT363A.F_CV | vent purge bellows pump outlet (F_CV) | 45 | PSIA | 55 | 45 |
| PC4_S1.FT595A.F_CV | from argon pump to first filter (F_CV) | 9.4 | GPM | 9.4 | 7.5 |

3/19/2016 12:00:00 AM — 3/19/2016 6:00:00 AM

# Gas Analyzer Budget

| | | | | | |
|---|---|---|---|---|---|
| | FD-SP | | | | |
| | System | Cost/piece | Quantity | Total | Comment |
| | Gas Analyzers | $137,760 | 1 | $137,760 | Cost of the actual analyzers |
| | Piping/routing panel | $156,800 | 1 | $126,800 | Estimate of the piping/routing panel, vapor compressor (pump), hardware fittings + labor to a real cryostat |
| | **Total cost** | | | $264,560 | |
| | | | | | |
| | **Cost Break-down** | | | | |
| | N2 Gas Analyzer | $30,000 | 1 | $30,000 | 100 ppm->10 ppb |
| | Coarse O2 analyzer | $2,000 | 1 | $2,000 | 20 % (air) to 1/2 %-- start of the purge. |
| | Intermediate O2 Analyzer | $5,000 | 1 | $5,000 | 0.5% to ppm--Remainder of purge |
| | Fine O2 Analyzer | $10,000 | 2 | $20,000 | 50 ppm ->3 ppb--End of purge through Gas Recirculation. 2nd one to monitor LAr deliveries at surface. |
| | Precision O2 Analyzer | $40,000 | 1 | $40,000 | 20 ppm -> 100 ppt Part of Gas Recirculation through liquid purification (electron lifetimes ~ 1 ms) |
| | Coarse H2O analyzers | $3,380 | 2 | $6,760 | These are Dewpoint Meters, used to measure H2O from normal air humidity values (20 kppm) to 1 ppm. |
| | H2O Analyzer | $34,000 | 1 | $34,000 | 20 ppm to 1 ppb--sampling of argon vapor spaces after cooldown. |
| | | | | | |
| | Routing Panel | $30,000 | 1 | $30,000.00 | Based on MicroBoone Routing Panel cost--includes valves on/at Routing Panel. This connects the piping from the cryostat(s) on one side to the gas analyzers on the downstream side. |
| | Piping | $40,000 | 1 | $40,000.00 | Costs for piping, any valves on cryostat, hardware |
| | Vapor Compressor Pump on Cryostat | $6,800 | 1 | $6,800.00 | This pump raises the vapor pressure from the ~10 kPa (1.5 psi) of the cryostat to to ~ 70 kPa (10 psi) needed by a gas analyzer. |
| | Labor | $80,000 | 1 | $80,000.00 | Includes both the routing design, installation, and leak checking of the piping from the cryostat to the Routing Panel |
| | | | | | |
| | FD-DP | | | | Will use same analyzers for DP, but will need to include piping/valves that would run to the 2nd cryostat |
| | System | Cost/Piece | Quantity | Total | |
| | Analyzers | $0 | 0 | $0 | The same analyzers from SP will serve |
| | Piping/Valves | $126,800 | 1 | $126,800 | Same as SP but without the Routing Panel which is shared. |
| | | | | | |
| | **Total cost** | | | $126,800 | |
| | | | | | |
| | **Cost Break-down** | | | | |
| | Routing Panel | 0 | 0 | 0 | Shares routine panel with SP. |
| | Piping | $40,000 | 1 | $40,000 | Costs for piping, any valves on cryostat, hardware. Should be approximately the same cost as the SP. |
| | Vapor Compressor Pump (on cryostat) | $6,800 | 1 | $6,800 | This pump raises the vapor pressure from the ~10 kPa (1.5 psi) of the cryostat to to ~ 70 kPa (10 psi) needed by a gas analyzer. |
| | Labor | $80,000 | 1 | $80,000 | Includes both the routing design, installation, and leak checking of the piping from the cryostat to the Routing Panel |

# Level Meters

- What are they?
  - Hardware devices that calculate the depth of the Liquid Argon volume
- How do they work?
  - Differential pressure transducer systems
    - Measure pressure in the upper vapor space and pressure near or at the bottom of the liquid volume -> $\Delta P = \rho g h$
    - Sensitivities according to D. Montanari precision is 0.1% of 14 m range, or $\pm$1.4 cm
    - Cryo will supply the DPT system
  - Capacitive Level Transducers
    - A coaxial cylindrical capacitor fills with LAr, which changes capacitance due to change of dielectric constant of the LAr height.
    - Sensitivity according to one manufacturer is 0.25% (4-20 mA output)
      - Would only instrument the top ~ 1 m of LAr
        - But distance to the flange is on the order of 2.5 m (ullage+insulation+chimney height
        - Not sure of what the PD-SP one was like
    - Use AC excitation to measure capacitance

Commercial Level meters with different fittings

# Level Meters

Plot from TDR

Figure 8.21 shows the evolution of the ProtoDUNE-SP LAr level over two months as measured by the differential pressure and capacitive level meters.

Pk-Pk width ~ .3% or 24 mm

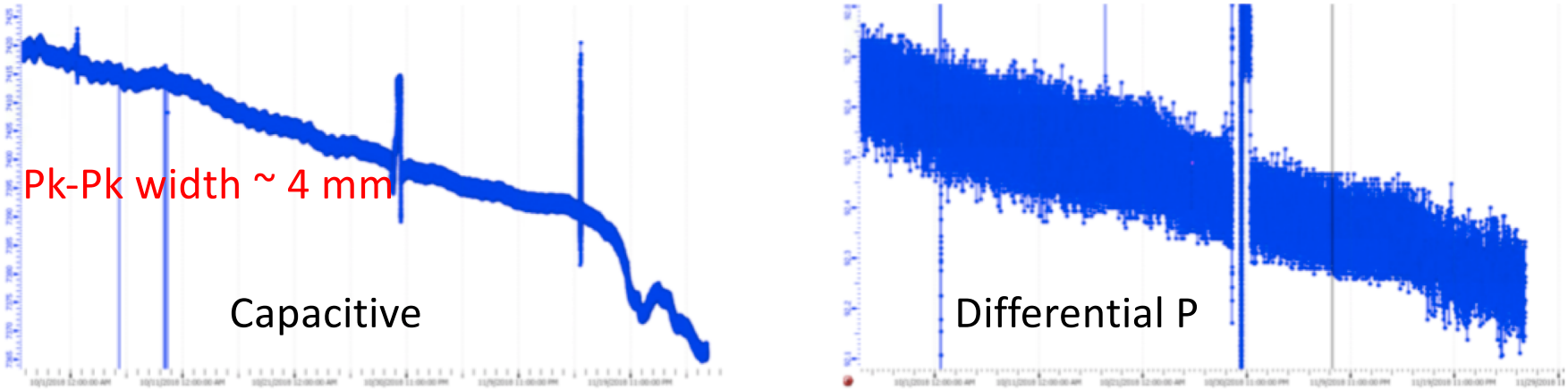



Figure 8.21: Evolution of the ProtoDUNE-SP LAr level over two months. Left: Measured by the capacitive level meter. Right: Measured by the differential pressure level meter. The units in the vertical axis are percentages of the cryostat height (7878 mm).

# Pressure Sensors

- What are they?
  - Hardware devices that measure the pressure—either
    - Gauge—pressure over atmosphere
    - Absolute—includes the barometric pressure + the gauge presure
- How do they work?
  - I believe this is just 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.
- Since the cryostat will be regulating on absolute pressure, it seems reasonable to have an Absolute pressure sensor for Instrumentation
  - The cryo saturation temperature depends only on the absolute pressure, so gauge pressure is not very useful (I think).
  - The drift velocity is dependent on the LAr temperature.
  - I am not positive of precision here, but impact of any potential absolute pressure change needs to propagate through the entire LAr volume.
  - Gauge Pressure is important to understand forces on cryostat
- Why not just use the Cryo sensor?

# ProtoDUNE Pressure sensors

From TDR

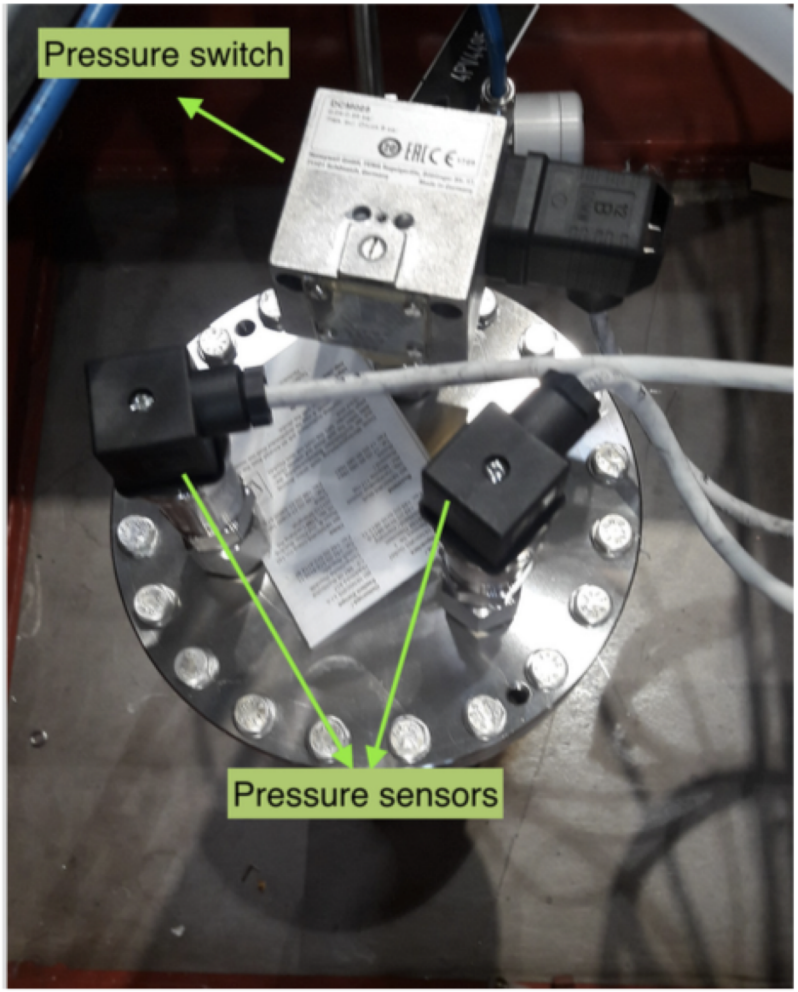



Figure 8.22: Photograph of the pressure sensors installed on a flange in ProtoDUNE-SP.

# Response to Charges, Part 1 (a)

- Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role?
  - Gas Analyzers
    - The Gas analyzers are used during the gas phase, monitors of the LAr deliveries, and the early phase of running when the Purity Monitors are not yet completely operational. They can also be used to monitor the LAr flows for accidents that can contaminate the LAr volume.
  - Level Meters
    - From the plot shown, the capacitive level meter show details that are not obvious in the Differential pressure level meter. This can be used to track the level and/or feed in makeup GAr
  - Pressure Sensors
    - Clearly the pressure sensor(s) has a vital role in regulating the pressure of the cryostat. It isn't obvious whether there needs to be a separate Instrumentation version.
- 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
    - I don't think this is applicable
  - 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. Not sure the level of precision for this.

# 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, none of these systems were addressed in previous workshops.
  - We have used the GA systems on multiple installations at FNAL
- 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 as a result are on “Building Ground”. To mitigate any grounding issues to detector ground, the connecting gas tubing is isolated at the cryostat feedthrough by a ceramic break (see photo in this presentation). Also the tubing is insulated with shrink-wrap tubing where it can make contact with the detector ground.
    - A flow aperature can be placed at the chimney that will restrict the gas flow in case any break might occur in the gas line. A vapor compressor is required to supply the needed gas pressure and flow to the gas rack. In this case the flow is away from the cryostat (and not into it!). I believe any issue here can be mitigated by where this compressor is located.
    - The gas flow is through and out of the analyzers. I estimate the total flow to be on the order of 5 slpm of argon gas. I am not sure what the acceptable leakage rate from a cryostat is.
  - 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
    - Gas Analyzers (3x $O_2$, $N_2$, and $H_2O$) were lent to ProtoDUNE, but except for one $O_2$ unit, they were not used. I believe the coarse analyzers ($O_2$ and $H_2O$) for the purge did exist and were used for the Gas Purge and recirculation. Two of the borrowed analyzers (H2O and N2) have been returned to FNAL.
  - Level Meters
    - I think the plot given in this presentation shows the system performance
  - Pressure Sensors
    - This system was used for the previous ProtoDUNE run to regulate the cryostat pressure, so I believe this has demonstrated its worth.

- 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.
  - Level Meters
    - Costs are on the order of ~$2k per device +wiring to the control system. I believe it is warranted to have two (at least) of these devices.
  - Pressure Sensors
    - I don't have the costs for this, but it is a vital device.

# 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 might be useful but not fully justified in terms of its contribution to overall detector performance.
  - Advantageous – Good arguments exist for why this system might be useful but not fully justified in terms of its contribution to overall detector performance.
  - Debatable – System could potentially be useful but not fully supportable based on current arguments.
- Gas Analyzers—Highly Desirable—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—Highly Desirable
- Pressure sensors---Essential to have two to regulate the cryostat pressure. Whether a special one is needed for Instrumentation alone, I think that is debatable.