protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

Stephen Pordes, Fermilab

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

1. Does the Cryogenic Instrumentation design meet the requirements? Are the requirements/justifications sufficiently complete and clear?
2. Does the design represent a good development path towards DUNE?
3. Does the design lead to a reasonable production schedule, including QA/QC, transport, installation and commissioning?
4. Is the installation plan sufficiently far advanced to assure that the detector can be installed as designed?
5. Are all internal interfaces between components (cryostat, cryogenics, TPC) documented, clearly identified and complete?
6. Are the interfaces with the slow control system well defined and understood?
7. Is the grounding and shielding of the Cryogenics Instrumentation understood and adequate?
8. Are operation conditions (when will/can instrumentation be turned on) listed, understood and comprehensive?
9. Are the analyses of the Cryogenics Instrumentation components sufficiently comprehensive for safe handling, installation and operation at the CERN Neutrino Platform?
10. Is the Cryogenics Instrumentation quality assurance, quality control and test plan adequate? Have applicable lessons-learned from previous LArTPC devices been implemented into the device testing and into the system design?

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

From the protoDUNE-SP TDR

The protoDUNE-SP apparatus includes instrumentation beyond the TPC and the photon detectors to ensure that the condition of the liquid argon is adequate for operation of the TPC. This instrumentation includes gas analyzers to monitor the purge of the cryostat and ensure that any remaining atmospheric contamination is sufficiently low, thermometry to monitor the cryostat cool-down and filling, purity monitors to provide a rapid assessment of the electron drift-lifetime independent of the TPCs, and a system of internal cameras to help locate any sparks due to high voltage breakdown in the cryostat.

In addition, two sets of precision temperature sensors are being deployed to measure the temperature gradients inside the protoDUNE cryostat. These temperature measurements exploit the opportunity protoDUNE-SP provides to check the predictions of the Computational Fluid Dynamics models being used to design the argon flow in the (much larger) DUNE cryostat.

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

Lead Scientists Involved:

Function	People
Co-ordinators	A. Cervera, (IFIC, Spain) & S. Pordes (Fermilab, USA)
Temperature sensors	Jelena Maricic (Hawaii, USA) & A. Cervera
Cameras	M. Kordosky (William & Mary, USA)
Purity Monitors	J. Bian (UC Irvine, USA) & A. Renshaw (Houston, USA)
Gas Analyzers	A.Hahn & S. Pordes
Controls System Interface	Flor Blaszczyk (Boston U., USA)
Measurements co-ordination	A. Hahn (Fermilab, USA)

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

Instrumentation functions:

1. Provide *fast and continuous* feedback on the state of the argon and the cryostat:
    - Temperature; pressure*: level*; contamination levels of oxygen, nitrogen, and water; drift-lifetime;
2. Provide information on potential source(s) of problems/verification of correct functioning
    - Vendor deliveries; purification failure; high voltage breakdown; mechanical failures; leaks
3. Provide data that will inform the cryogenic design of DUNE
    - Temperature distributions in the liquid and the ullage since temperature distribution drives the argon flow.

We are developing a rather more ambitious system than originally conceived.

* Provided by Neutrino Platform (plus environmental data (ambient pressure and temperature))

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

Instrumentation functions:

1. Provide *fast and continuous* feedback on the state of the argon and the cryostat:

RTDs – on membrane for cool-down,

– on argon inlet and outlet pipes, and above top ground plane for operations

Oxygen, Nitrogen, Water Analyzers with a range of sensitivity – connected to argon delivery,

to cryostat liquid and ullage, and to flow through feedthroughs

Purity Monitors – three in cryostat itself, one at the output of the purification system

– in the cryostat: follow the purification of the argon, assure that the argon is TPC quality (or not) in case the TPC reconstruction is not ready and look for variations in lifetime with depth

– at the output of the purification system: validate the operation of the purification system

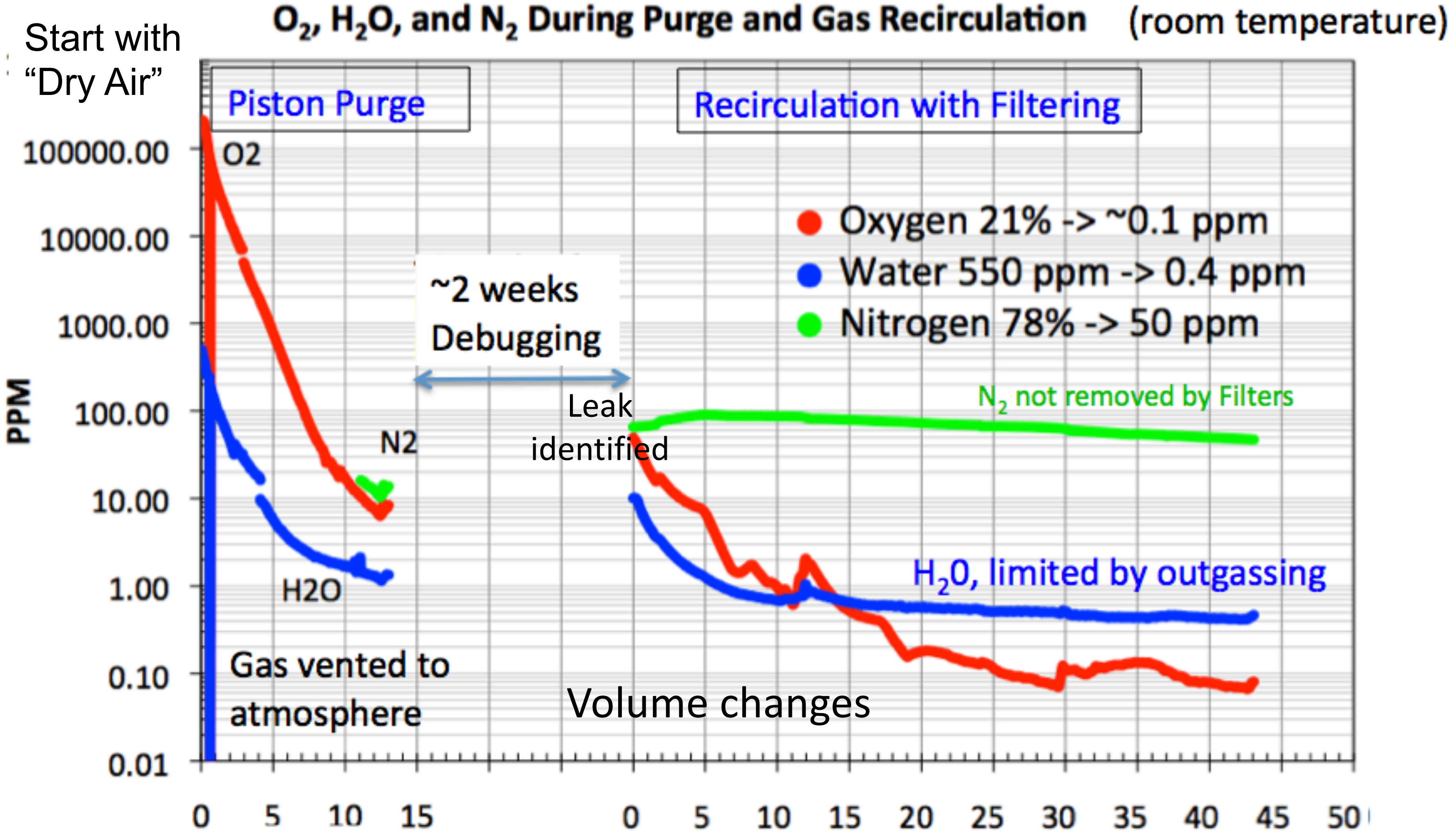
protoDUNE – single-phase Instrumentation - Overview

Instrumentation functions:

1. Provide *fast and continuous* feedback on the state of the argon and the cryostat:

Gas Analyzers monitoring the gas purge and recirculation phase of cryostat preparation –

Leak found when recirculation phase did not produce rapid improvement.



protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

Instrumentation functions:

2. Provide information on potential source(s) of problems/verification of correct functioning

- Gas Analyzers – check levels of oxygen, nitrogen, and water in delivered argon,

  follow the gas purge and recirculation phases, follow the initial stages of liquid purification,

- Camera System - identify locations of sparks in case of HV breakdown, general internal inspection

- Purity monitor at the output of the purification system - validate functioning of purification system and alert on saturation of purification filters before much liquid has entered the cryostat

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

Instrumentation functions:

3. Provide data that will inform the cryogenic design of DUNE

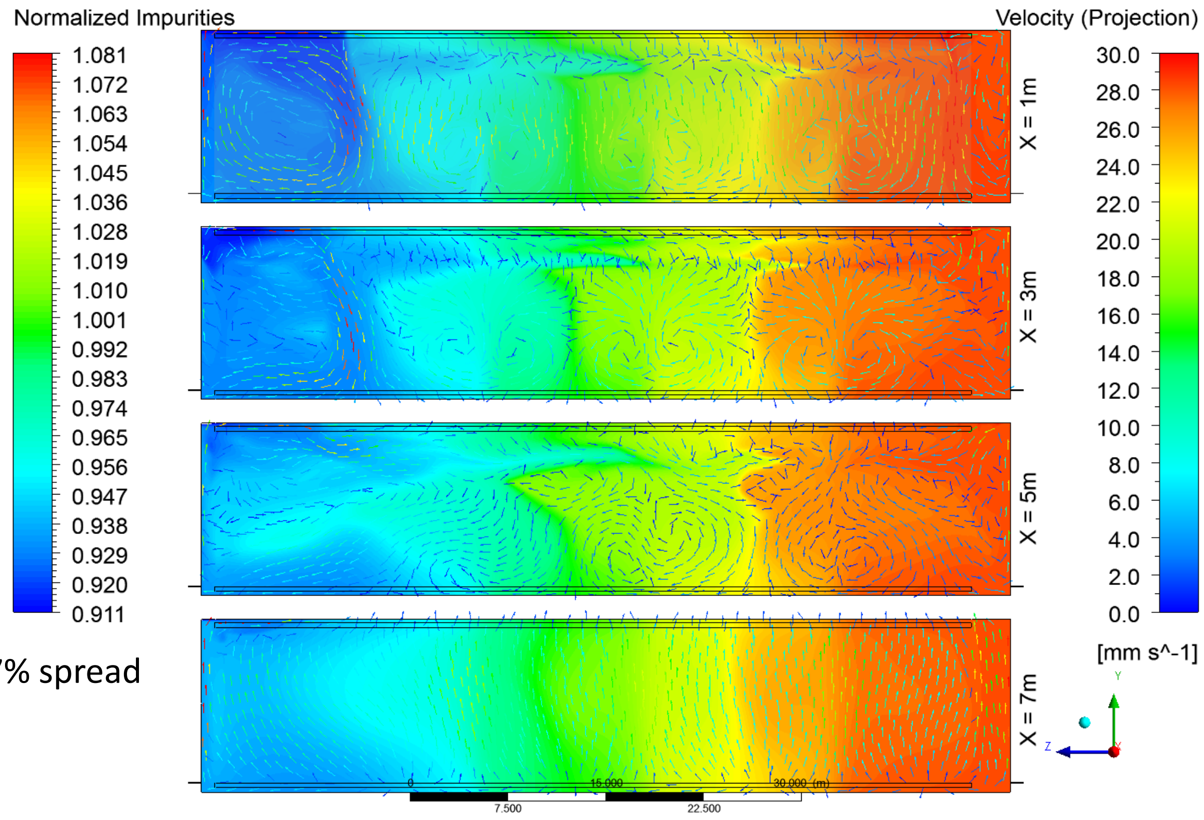
    - Temperature gradient monitors - measure the (small) temperature gradients that drive the argon flow and thereby determine the distribution of impurities.

CFD calculations are being used to inform the cryogenics for DUNE and protoDUNE is a good opportunity to check their validity – path to DUNE

protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

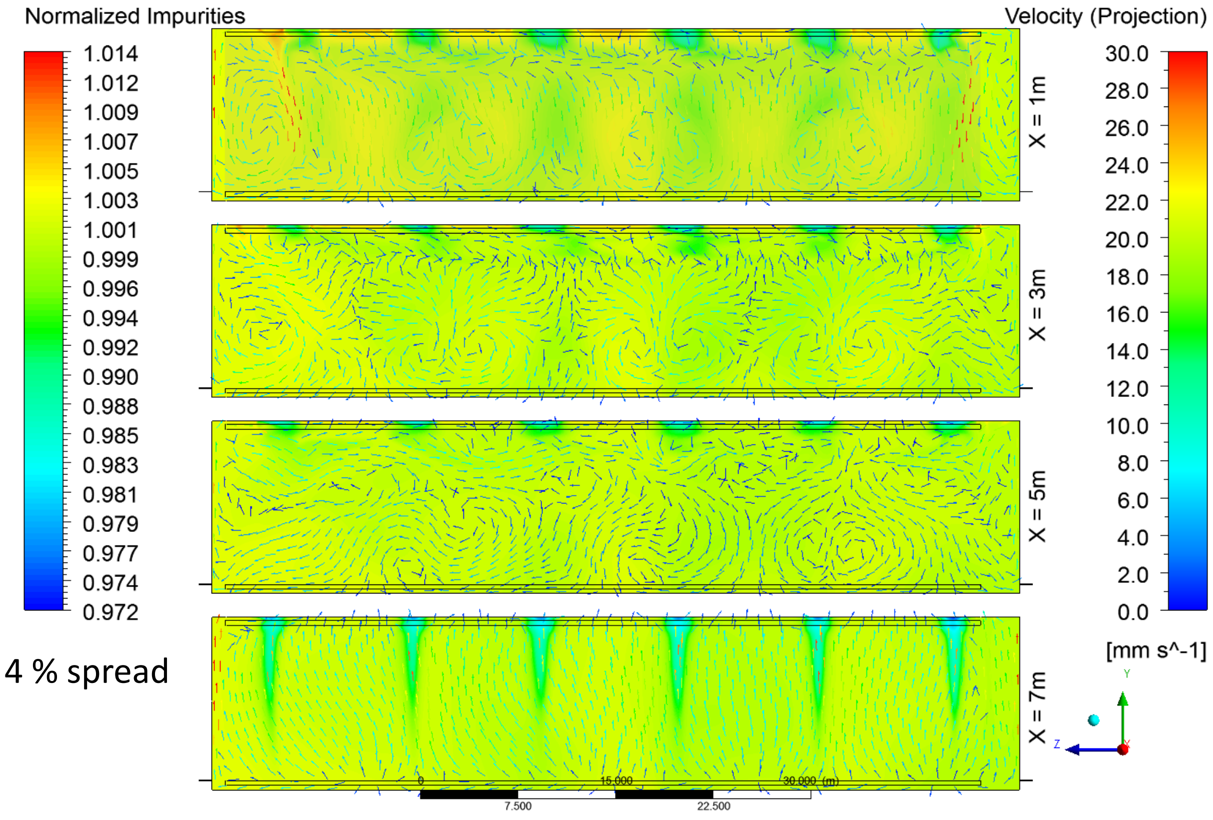
Impurity distribution along the length of a DUNE cryostat for a given contamination rate from the ullage
Example of CFD calculation provoked by question of whether DUNE needs pumps at both ends of the cryostat;

Single Inlet



17% spread

Manifold of Inlets



4 % spread

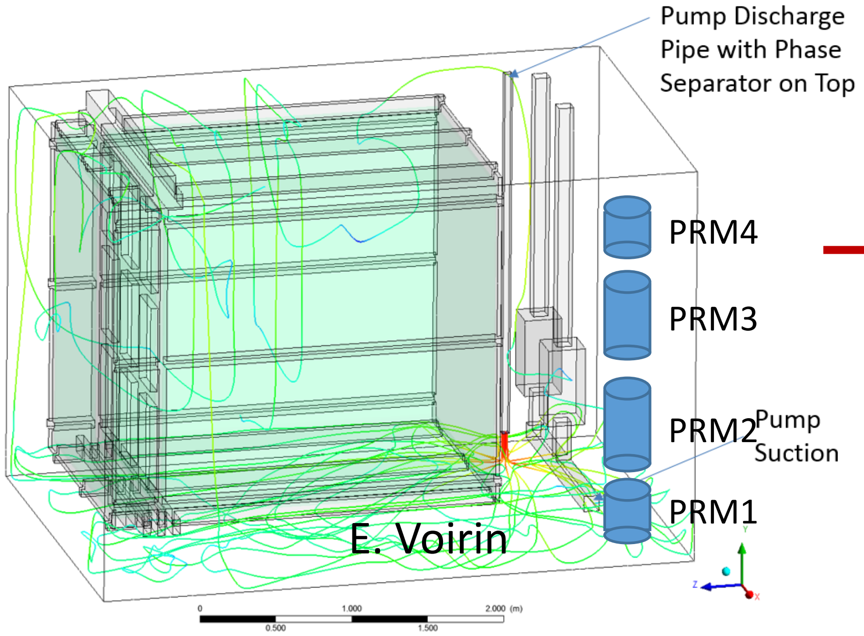
the manifold solution is considered satisfactory .. it had better prove so ..

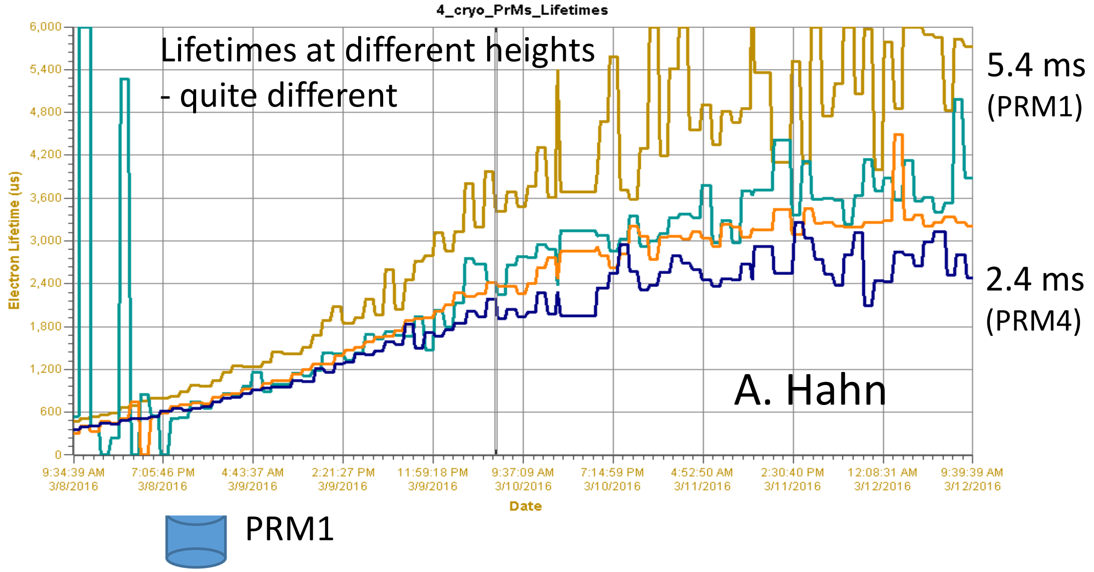
protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

The whole is more than the sum of the parts:

observation and understanding of lifetime differences at different depths in 35 ton (membrane) cryostat at Fermilab.

Original arrangement

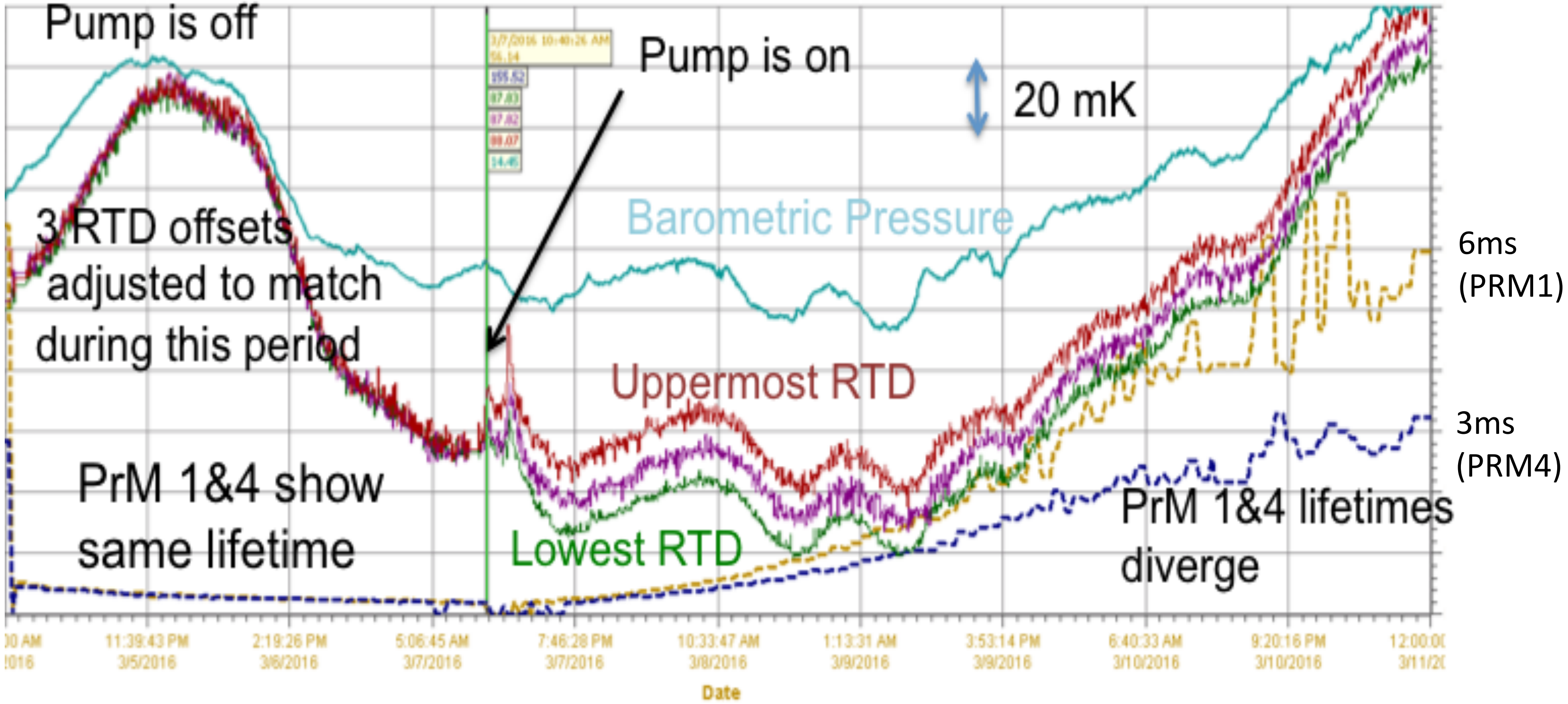




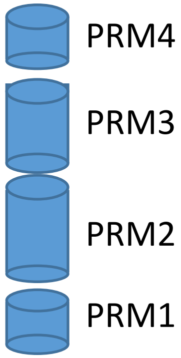
protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

The whole is more than the sum of the parts:

observation and understanding of lifetime differences at different depths in 35 ton (membrane) cryostat at Fermilab.



	Description	Value	Eng Units	High Over Range	Low O
F_CV	Lifetime calculated from AnodeTrue Cathode...	56.1	us	6,208.7	
F_CV	Lifetime calculated from AnodeTrue Cathode...	155.5	us	2,945.4	
_CV	Temperature of the top RTD (#1) on spooler #1	87.829	K	87.956	
_CV	Temperature of the middle RTD (#2) on spool...	87.820	K	87.952	
_CV	Temperature of the bottom RTD (#3) on spoo...	88.074	K	88.202	
F_CV	Barometric Pressure in PSIA (F_CV)	14.455	PSIA	14.512	

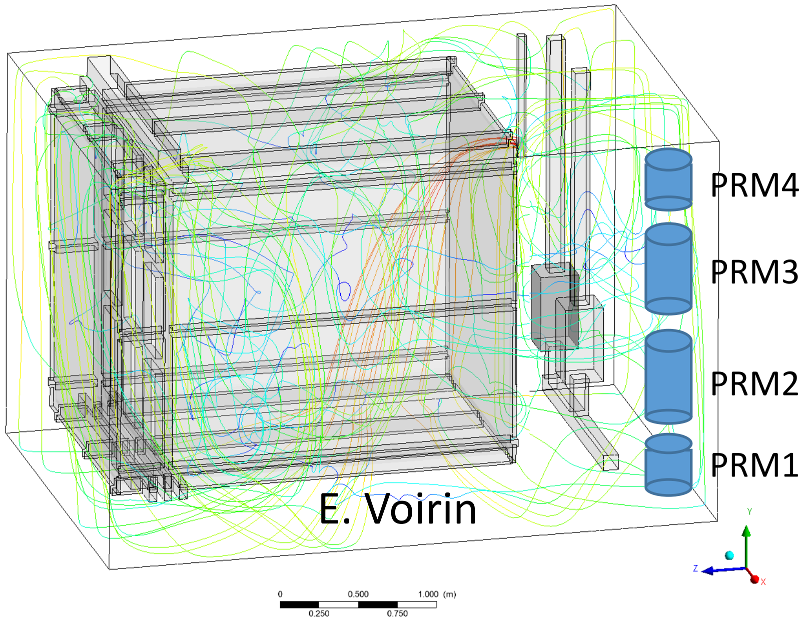


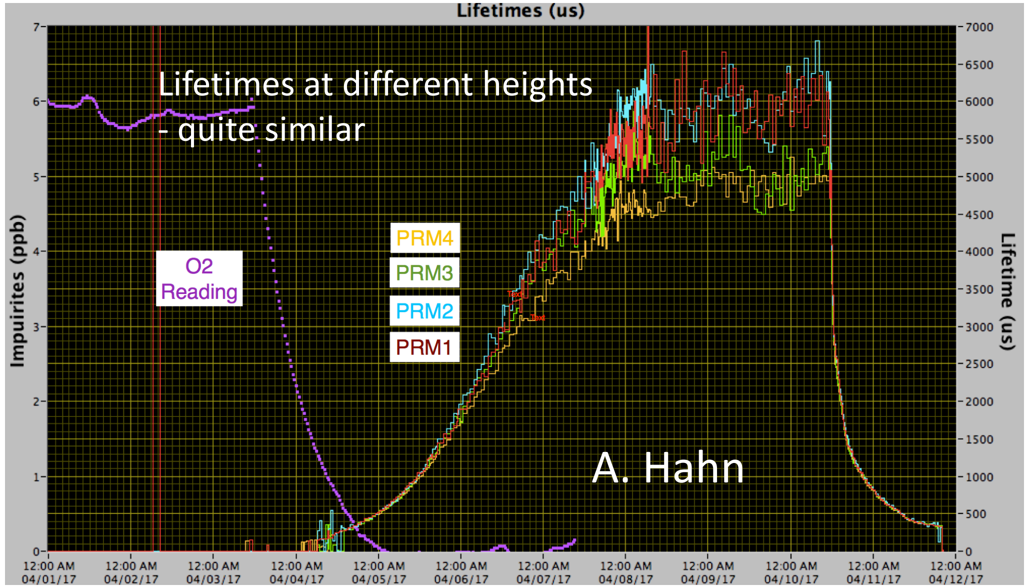
protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

The whole is more than the sum of the parts:

observation and understanding of lifetime differences at different depths in 35 ton (membrane) cryostat at Fermilab.

New arrangement (cold liquid at 2/3 height)



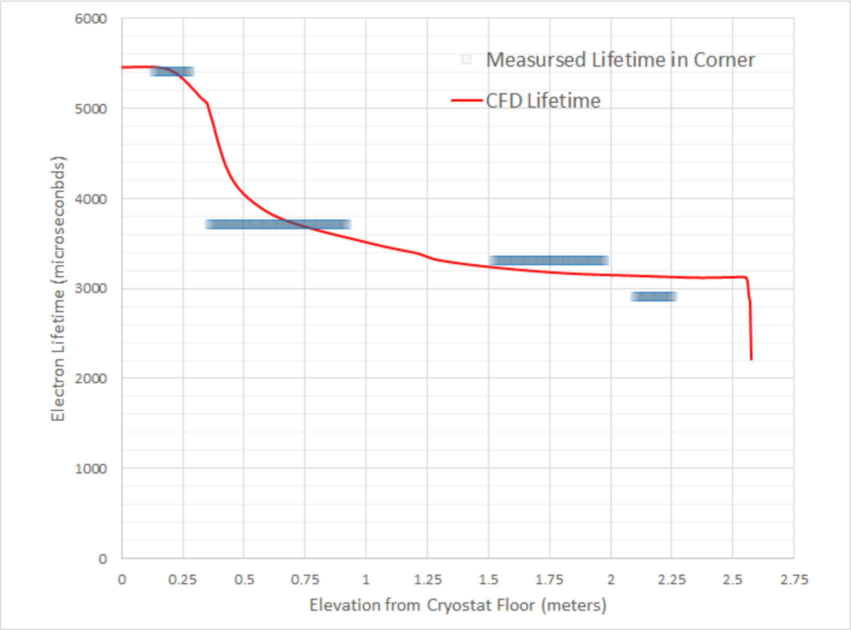


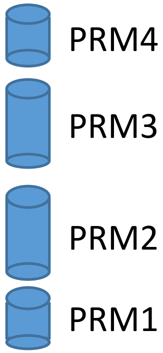
protoDUNE – single-phase Cryogenic and Argon Instrumentation - Overview

The whole is more than the sum of the parts:

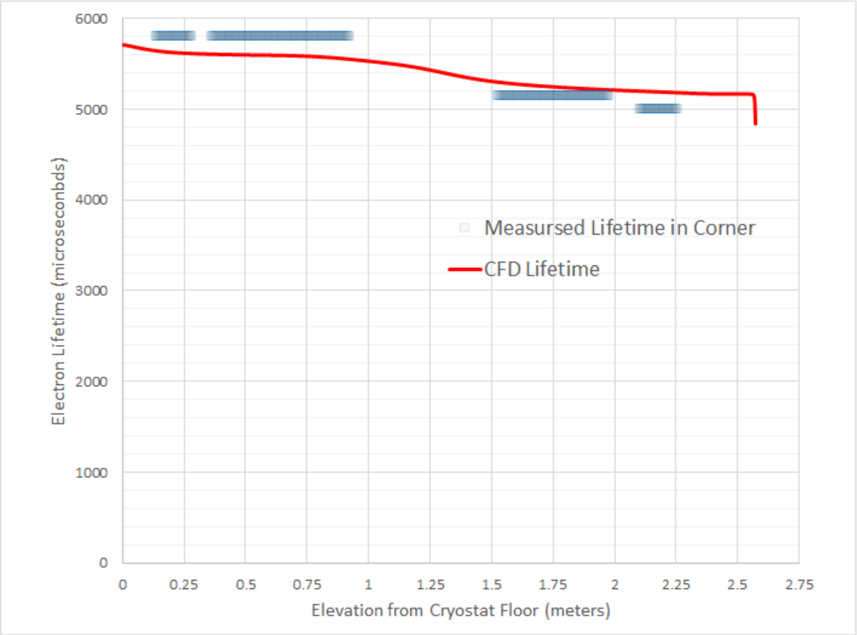
observation and understanding of lifetime differences at different depths in 35 ton (membrane) cryostat at Fermilab.

Old arrangement (cold liquid at bottom)





New arrangement (cold liquid at 2/3 height)



Cryogenic and Argon Instrumentation interfaces

1. Items which exploit devices inside the cryostat - tightly coupled to other installations both mechanically and logistically

2. Items which come as assemblies and are installed into the cryostat – coupled logistically to detector schedule and mechanically to specific ports and general infrastructure

3. Items which are external to the cryostat and interface with the external cryogenics

All items have some required interface to the detector controls system

Items type 1 & 2 require identified ports on the cryostat

Cryogenic and Argon Instrumentation interfaces

1. Items which exploit devices inside the cryostat - tightly coupled to other detector installations both mechanically and logistically – temperature sensors on piping, on the TPC, and on the cryostat membrane; cameras

2. Items which come as assemblies and are installed into the cryostat – coupled logistically to detector assembly schedule – in-cryostat purity monitors (3); Hawaii temperature profiler; Valencia temperature profiler

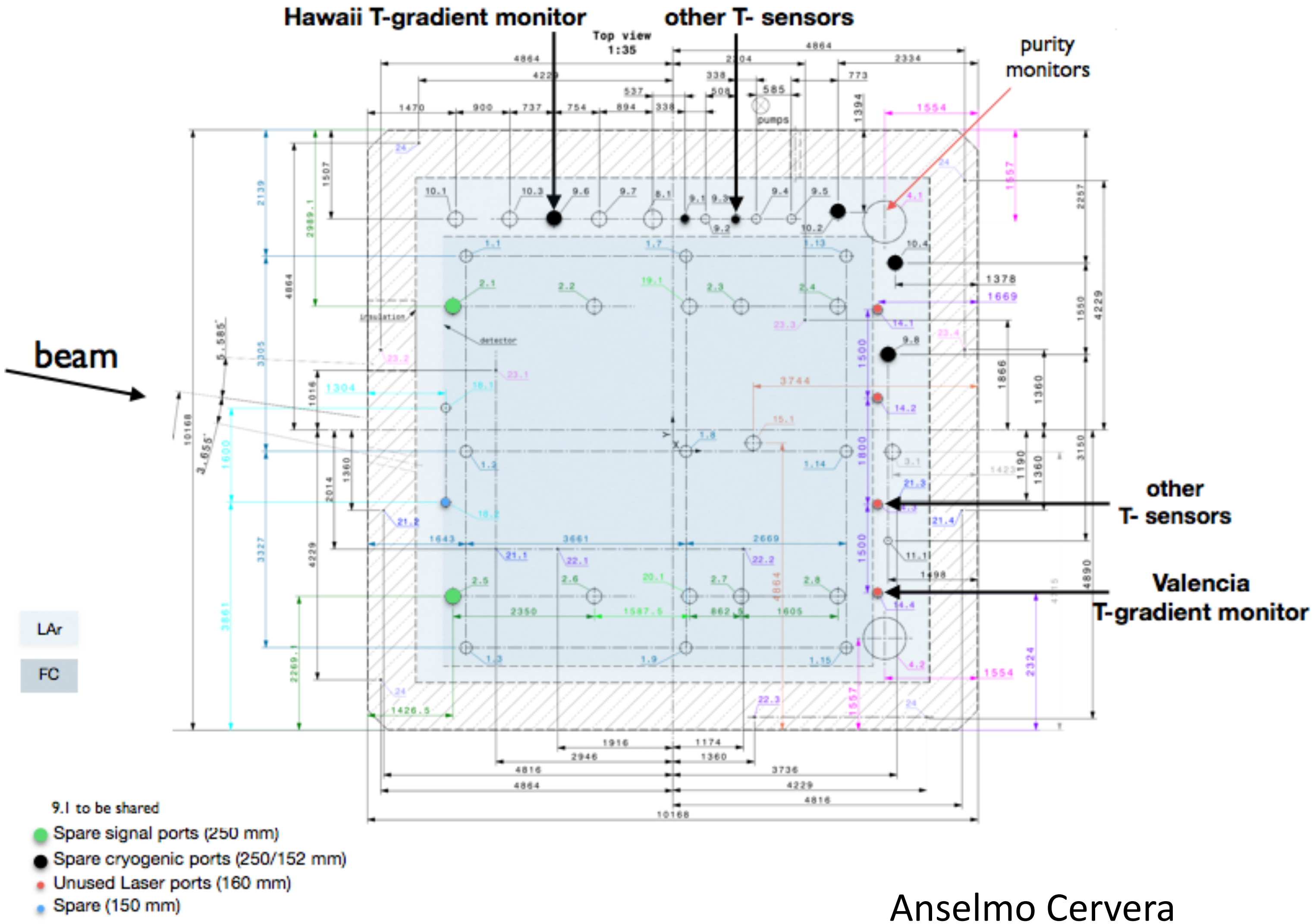
3. Items which are external to the cryostat and interface with the external cryogenics – purity monitor after purification system; gas analyzers

Items type 1 & 2 require identified ports

All items interface with the detector controls system

Proposed assignment of ports for Instrumentation ..

ID	Diameter	Proposed Description
1.1	200 mm	West Transfer Rail N support
1.2	200 mm	West Transfer Rail Center support
1.3	200 mm	West Transfer Rail S support
1.7	200 mm	Center Transfer Rail N support
1.8	200 mm	Center Transfer Rail Center support
1.9	200 mm	Center Transfer Rail S support
1.13	200 mm	East Transfer Rail N support
1.14	200 mm	East Transfer Rail Center support
1.15	200 mm	East Transfer Rail S support
2.1	250 mm	Spare TPC Signal port N
2.2	250 mm	N Signal cable feedthru 2
2.3	250 mm	N Signal cable feedthru 3
2.4	250 mm	N Signal cable feedthru 4
2.5	250 mm	Spare TPC Signal port S
2.6	250 mm	S Signal cable feedthru 2
2.7	250 mm	S Signal cable feedthru 3
2.8	250 mm	S Signal cable feedthru 4
3.1	250 mm	High Voltage feedthru
4.1	710 mm	Manhole NE & Purity Monitors
4.2	710 mm	Manhole SE
6.1	1200 x 730(	Temporary Construction Opening (TCO)
7.1	250 mm	Beam Window North
7.2	250 mm	Beam Window Center
7.3	250 mm	Beam Window South
14.1	160 mm	Spare
14.2	160 mm	Spare
14.3	160 mm	Temperature measurements
14.4	160 mm	Temperature Proflle 2 (Valencia)
15.1	250 mm	Calibration Fibers
18.1	150 mm	Spare near CPA line West side (left)
18.2	150 mm	Spare near CPA line West side (right)
19.1	250 mm	Spare on North APA signal cable port line
20.1	250 mm	Spare on South APA signal cable port line
8.1	304 mm	GAr combo
9.1	152 mm	Diff. pressure and Membrane Temperatures
9.2	152 mm	LAr distribution
9.3	152 mm	Temperature Measurements
9.4	152 mm	LAr back to condenser
9.5	152 mm	GAr Boil off
9.6	250 mm	Temperature Profile 1 (Hawaii)
9.7	250 mm	LAr Cooldown
9.8	250 mm	Spare
10.1	250 mm	Main PSV/VSV
10.2	250 mm	Spare
10.3	250 mm	Backup PSV/VSV
10.4	250 mm	Spare
11.1	125 mm	Instrumentation



Anselmo Cervera

CENDUNCR0078 https://edms.cern.ch/ui/file/1543241/3/NP04_penetrations_drawing.pdf

NOTE: ports have not been assigned for the cameras

Temperature Sensors.. ~100 total ..

16 membrane, 22 Hawaii profiler, 36 Valencia profiler, 12 low in cryostat, 8 on top ground plane

Technical challenge is **achieving a system with relative (sensor to sensor) calibration stable to ~ 10 mK** (not needed for membrane sensors) – also part of a path for DUNE - **CERN development project**

Installation and interface issues are: **schedule, how to place membrane and volume sensors, how to preserve calibration, how to route cables inside the cryostat,** (cannot weld anything to the walls (unlike the IHI cryostats)) **external cabling and connection to the DCS**

Services required per sensor – 4 wire readout of RTD resistance

Anselmo Cervera and his team for the membrane and bulk temperatures and the Valencia gradient monitor - presentation

Jelena Maricic (Hawaii) for the Hawaii temperature profile measurement (TP) - presentation

Cameras

Mike Kordosky (William & Mary)

Technical challenge is getting a camera system that works in the cold, with sufficient sensitivity (acceptance x gain) and with flexible software..

Installation issues to be resolved: **where and how to place, and when**

35 ton experience with system from ETHZ has been invaluable – behavior in cold, cable-type and sensitivity to cable-length, streaming and preserving data for inspection.

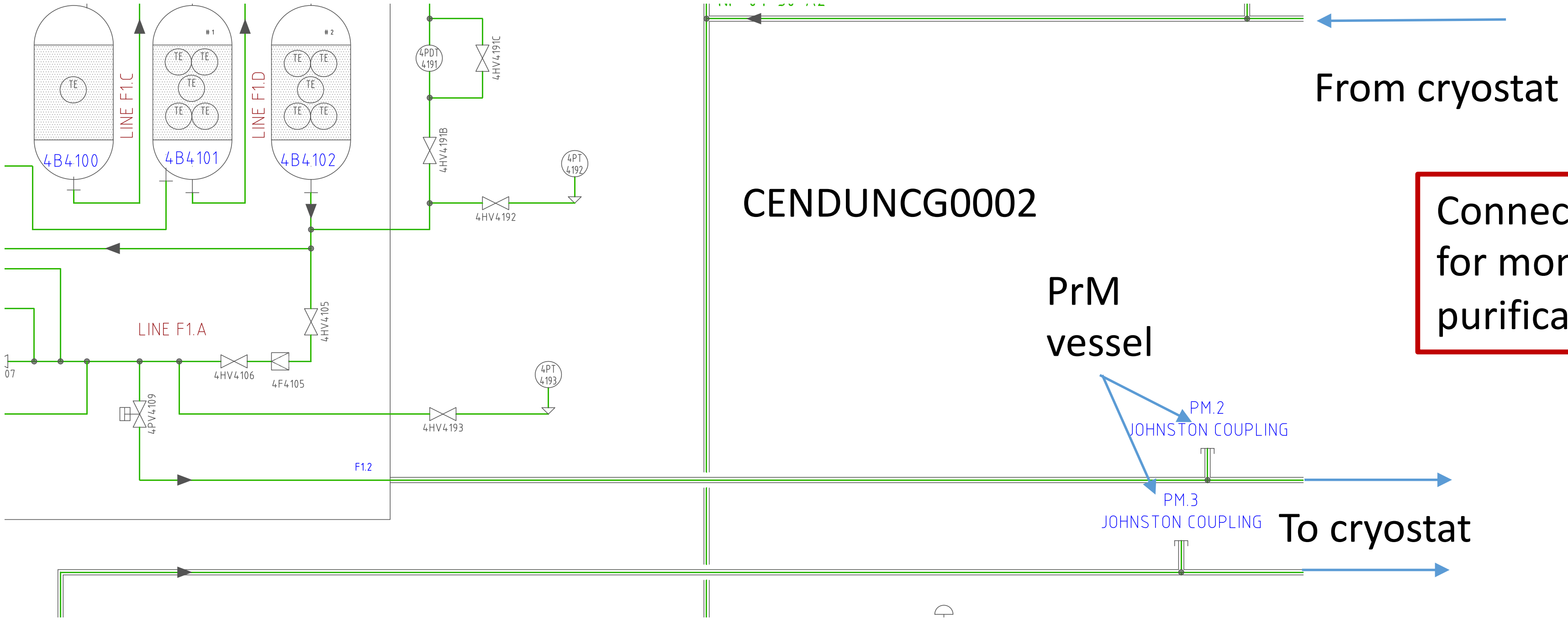
Purity Monitors (4 total)

Jianming Bian (UC Irvine) & Andrew Renshaw (Houston)

Refurbishing Icarus purity monitors – using Fermilab electronics ..

One recently brought to Fermilab from UC Irvine and tested in relatively clean argon – worked quite nicely

See https://indico.cern.ch/event/630004/ for PrMon test signals



Connection points for monitor after purification system

Purity Monitor Interfaces and operating conditions ..

Cryostat Monitors:
Space on cryostat near feedthrough for flash-lamp system – electrical box 50 cm x 30 cm x 20 cm
Power for flash lamp system 24 V, 3 A
Space and power for 3 signal amplifiers - 3 double wide NIM modules, 0.5 A +/- 12V

Purification System:
Space near inline vessel for flash-lamp system – electrical box 50 cm x 30 cm x 20 cm
Power for flash lamp system 24 V, 3 A
Space and power for 1 signal amplifier – 1 double wide NIM module running at 0.5 A +/- 12V

In front-end racks: not too far (<30 m)
HV power supplies per purity monitor -20V to - 400V (10 uA) and +200V to +4,000V (10 uA)
Windows computer running LabVIEW or equivalent containing digitizing electronics, 2 channels per purity monitor (we use ALAZAR 310 2-channel 12 bit 20 MS/s), with access to HV supplies and 24 V supply to flash-lamp.

DCS
Permission to flash lamp, permission to turn on HV, connection for recording of signal parameters and lifetimes

Gas Analyzers
These are all commercial devices ..

Installation & Services required:
Space and power for devices (0.5 relay rack) (NP)
Clean 6 mm (1/4 inch) lines to the rack (NP)
Switchyard to allow analysis of different streams by any given instrument (protoDUNE-SP)

DCS
Most devices provide 4-20 mA readout – some offer ethernet and/or RS232. We would prefer digital readout where possible.

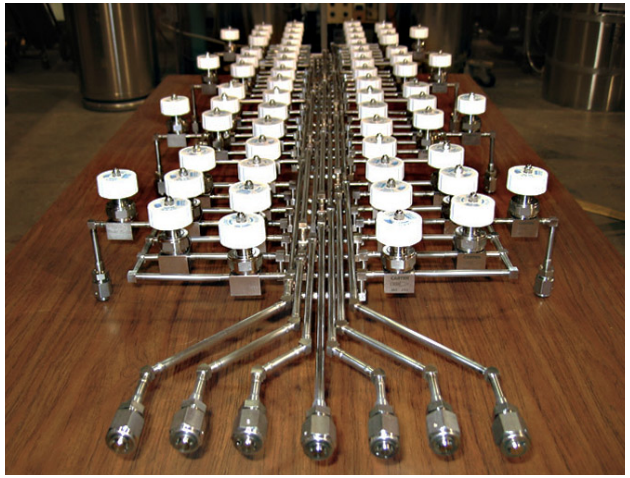
Input	Output to
Received liquid	Halo, DF310E, Servopro N2, fast purge
Cryostat during purge	DF310E, Servopro N2, Vaisala, Halo, fast purge
Cryostat Liquid	Halo, DF 550, Servopro N2, fast purge
Cryostat Ullage	Halo, DF 550, Servopro N2, fast purge
Feedthrough flow	Halo, fast purge
Nitrogen Calibration	Servopro N2, fast purge

Preliminary Switchyard IO list (6 x 7)

Various H_2O, N_2 and O_2 Gas Analyzers

from Alan Hahn

Example Switchyard skeleton



Recognize:

- Need to complete designs .. Clarify interactions with other apparatus
- Need to define QA/QC procedures at CERN
- Need to develop requirements for above at CERN (facilities, people)
- Need to refine/verify schedules ..
- Need to refine interface with DCS

Please see:

https://indico.cern.ch/event/617303/attachments/1420922/2231423/Cryogenics_instrumentation_overview.pdf

for a more complete response to the charge questions