The Liquid Argon Purity Demonstrator

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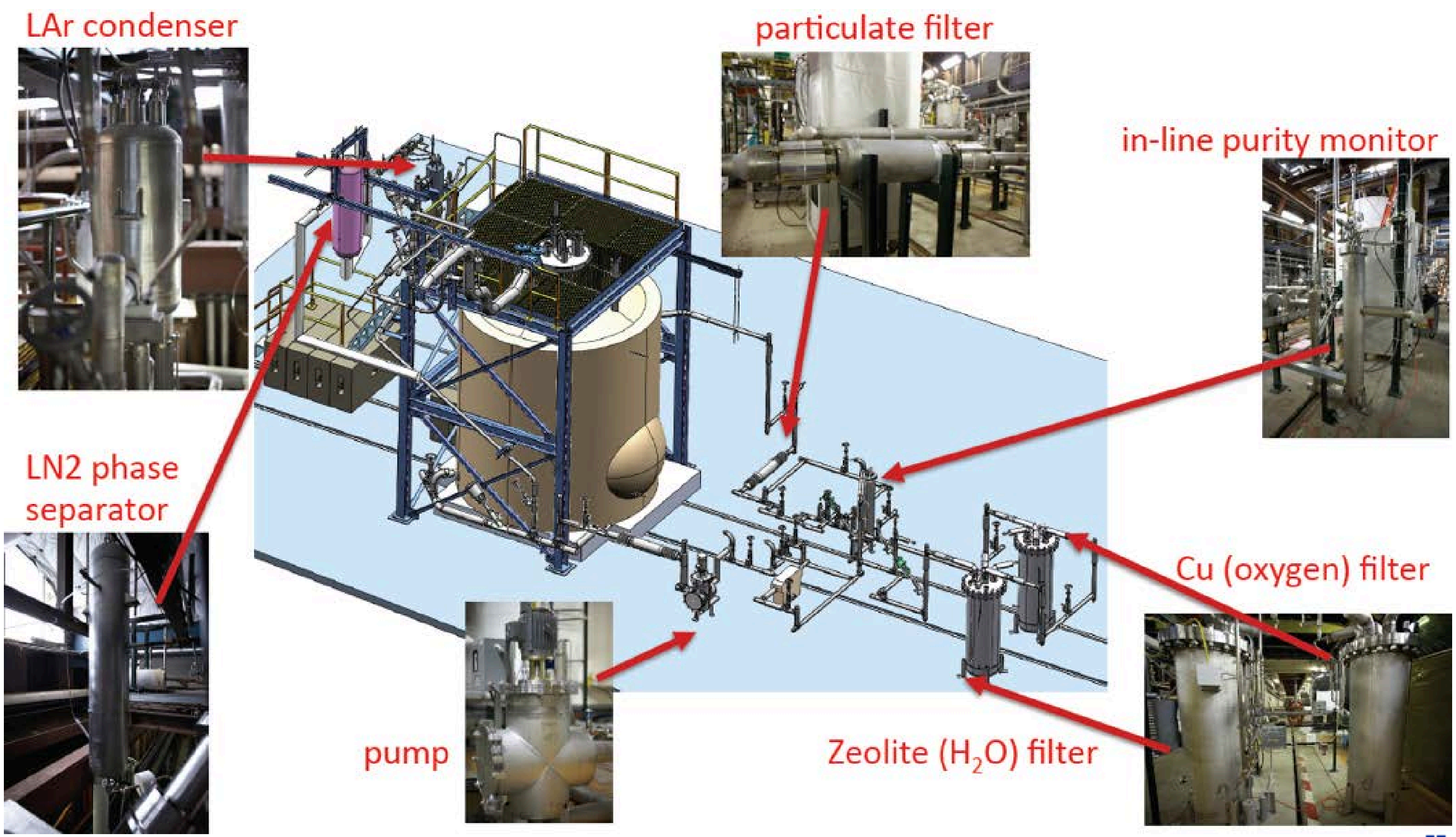
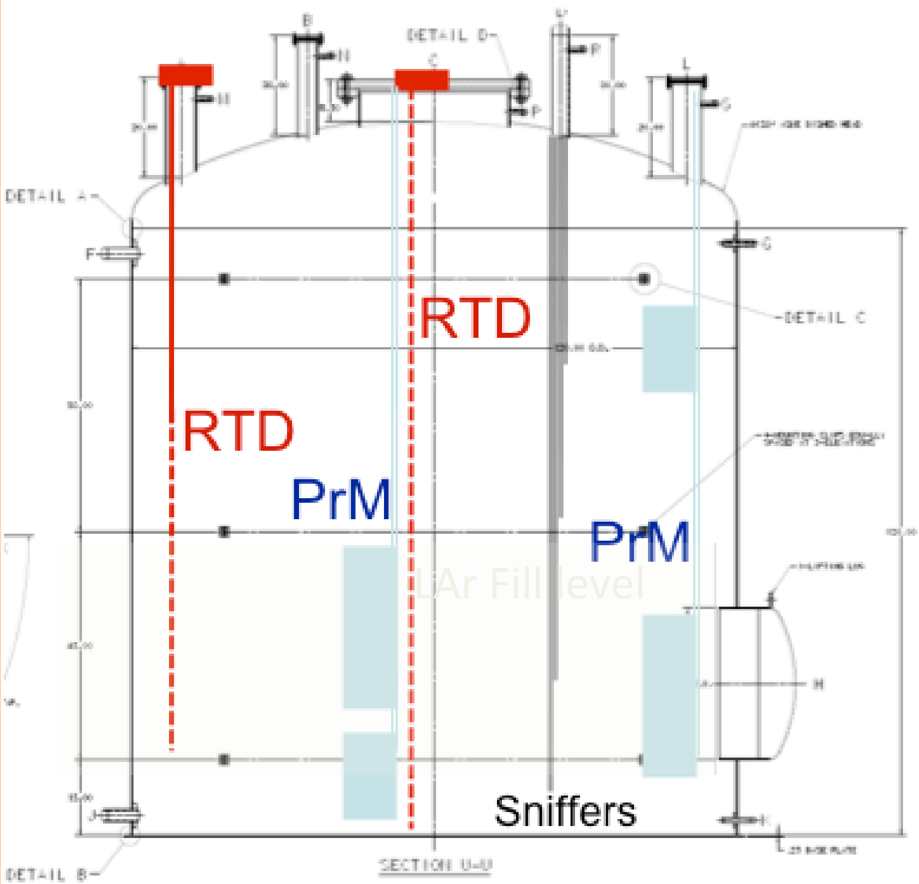
The LAPD is a 30 ton cryostat with a LAr purification and circulation system and extensive diagnostic equipment



Instrumentation for LAPD



Analytic Equipment

Oxygen meters (0.4 ppb sensitivity)

H20 meters (0.5 ppb sensitivity)

N2 meter (20 ppb sensitivity)

can sample multiple points

In the Tank

2 sets of 2 PrM (20 cm / 60 cm)

2 sets of 3 translating RTDs

Sniffer set to measure purge evolution

Inline

Purity Monitor

LAPD objectives

Main Objective: purity without evacuation

- Early LArTPC detectors were evacuated before filling with argon, and this process considered absolutely necessary to obtain a reasonable electron lifetime.
- Constructing an evacuable cryostat is impractical for large detectors
- Can you replace evacuation with "purge and filter"?

Secondary objectives:

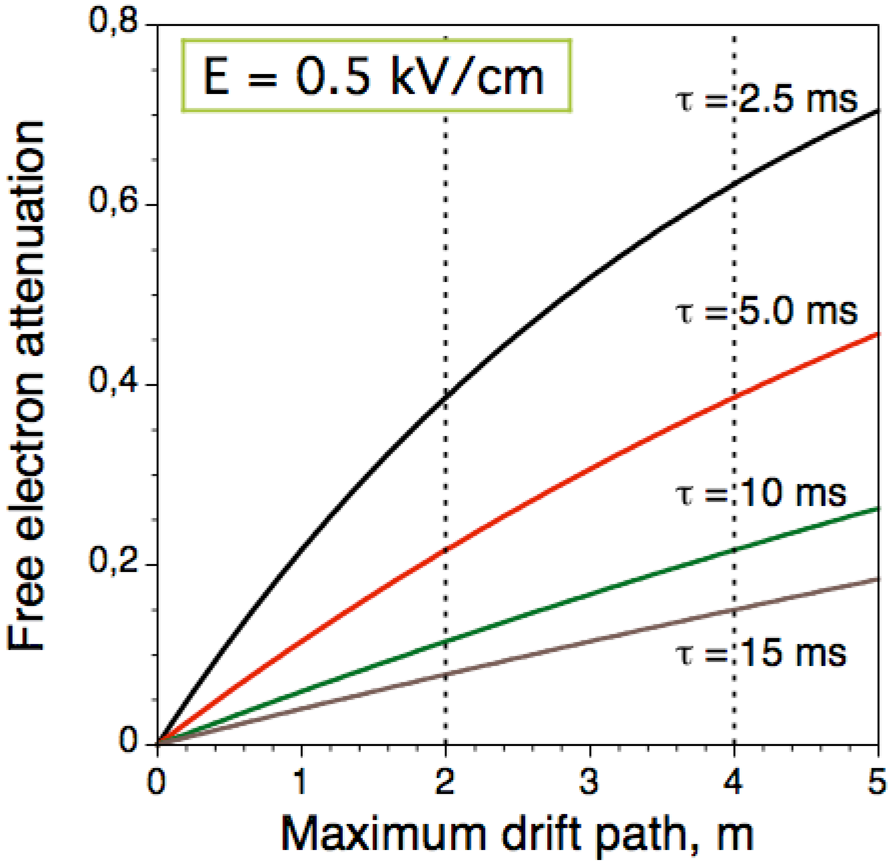
- Characterize filtration materials and measure filter capacity
- Is the purity is compromised by the presence of a TPC?
- Test thermal and fluid flow models

History:

- First Run: Sep. 2011 – Apr. 2012 (1/3 full)
- Second Run: Dec. 2012 – Sep. 2013 (full capacity, ~6000 gallons)
- Two journal articles: JINST **9** P07005 (2014), second in preparation

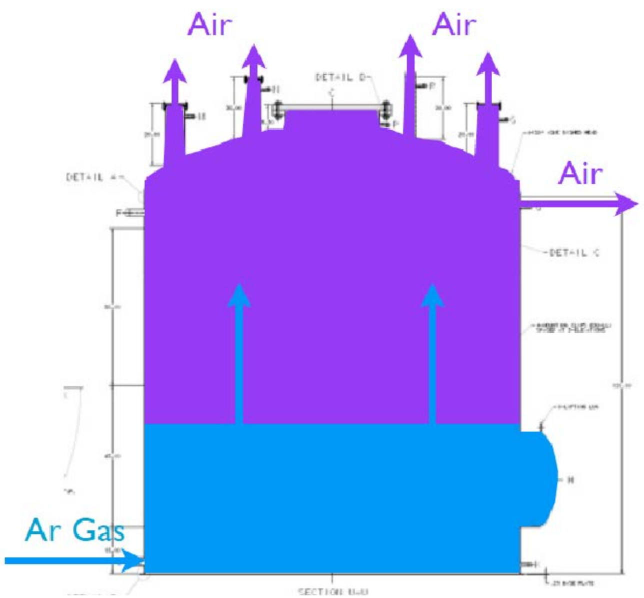
Purity Requirements

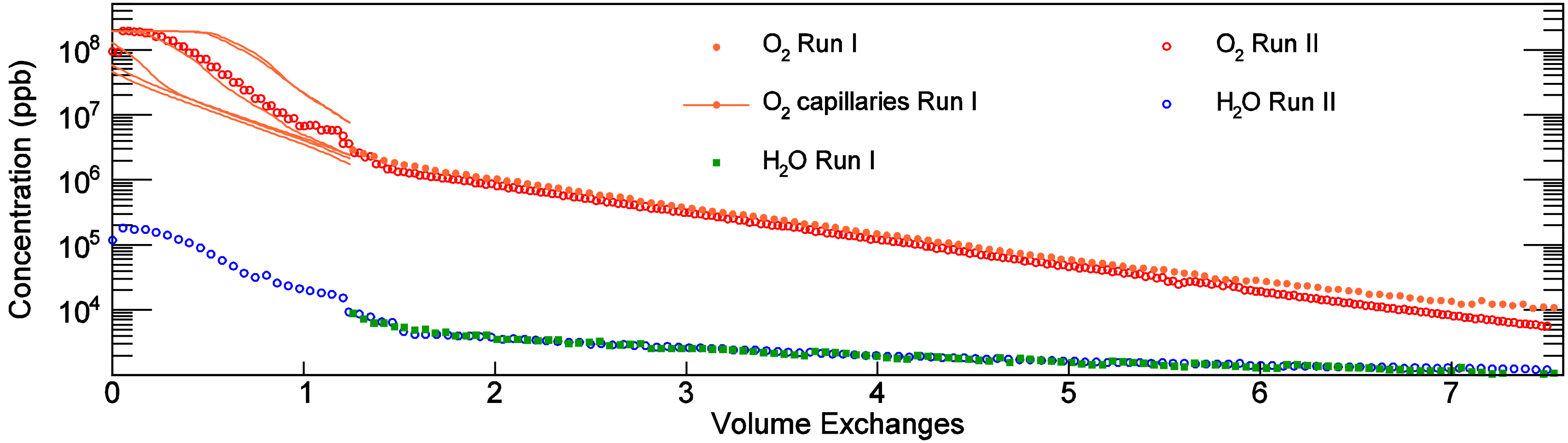
- For most TPCs, the purity requirements derive from the detector performance requirements (e.g. S/N per wire)
- Electron lifetime is determined by the concentration of electron absorbing contaminants such as O_2 and H_2O.
- EXAMPLE: If 20% signal loss over a 2m drift is tolerable
  - Need 5 ms electron lifetime, ~60 ppt O_2 contamination
  - LAr supply from commercial vendors typically 1 ppm
- Light-absorbing impurities also need to be removed! ($N_2 < 1$ ppm)



The Gas Piston Purge

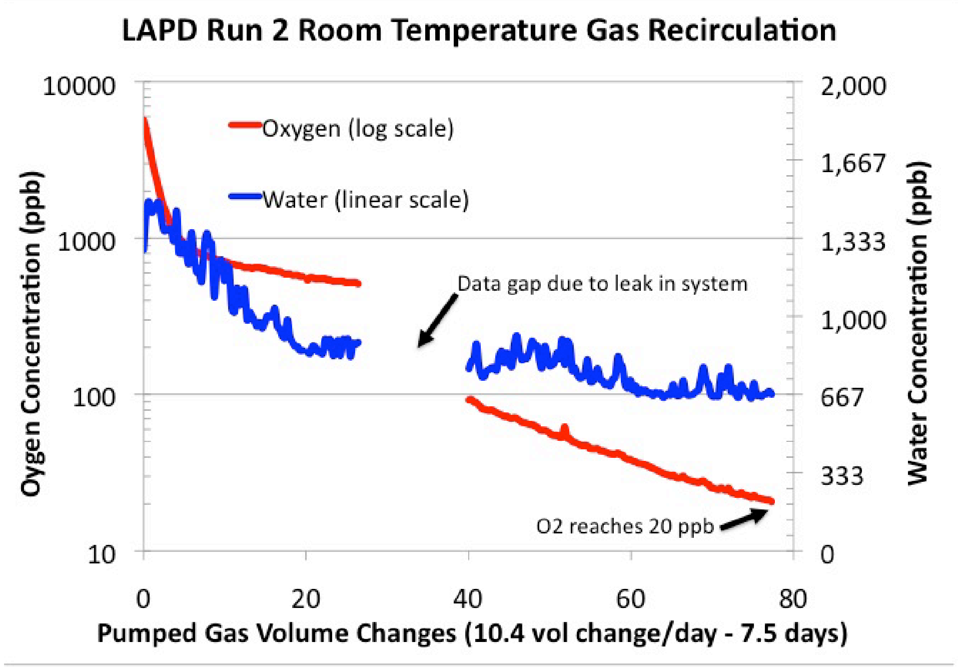
- Pump room temperature argon gas into the bottom of the tank
- Argon gas acts as a piston pushing ambient air out
  - O_2 from 21% to 6 ppm
  - N_2 from 78% to 18 ppm
  - H_2O from 200 ppm to 1.2 ppm
  - Measured using commercial gas analyzers



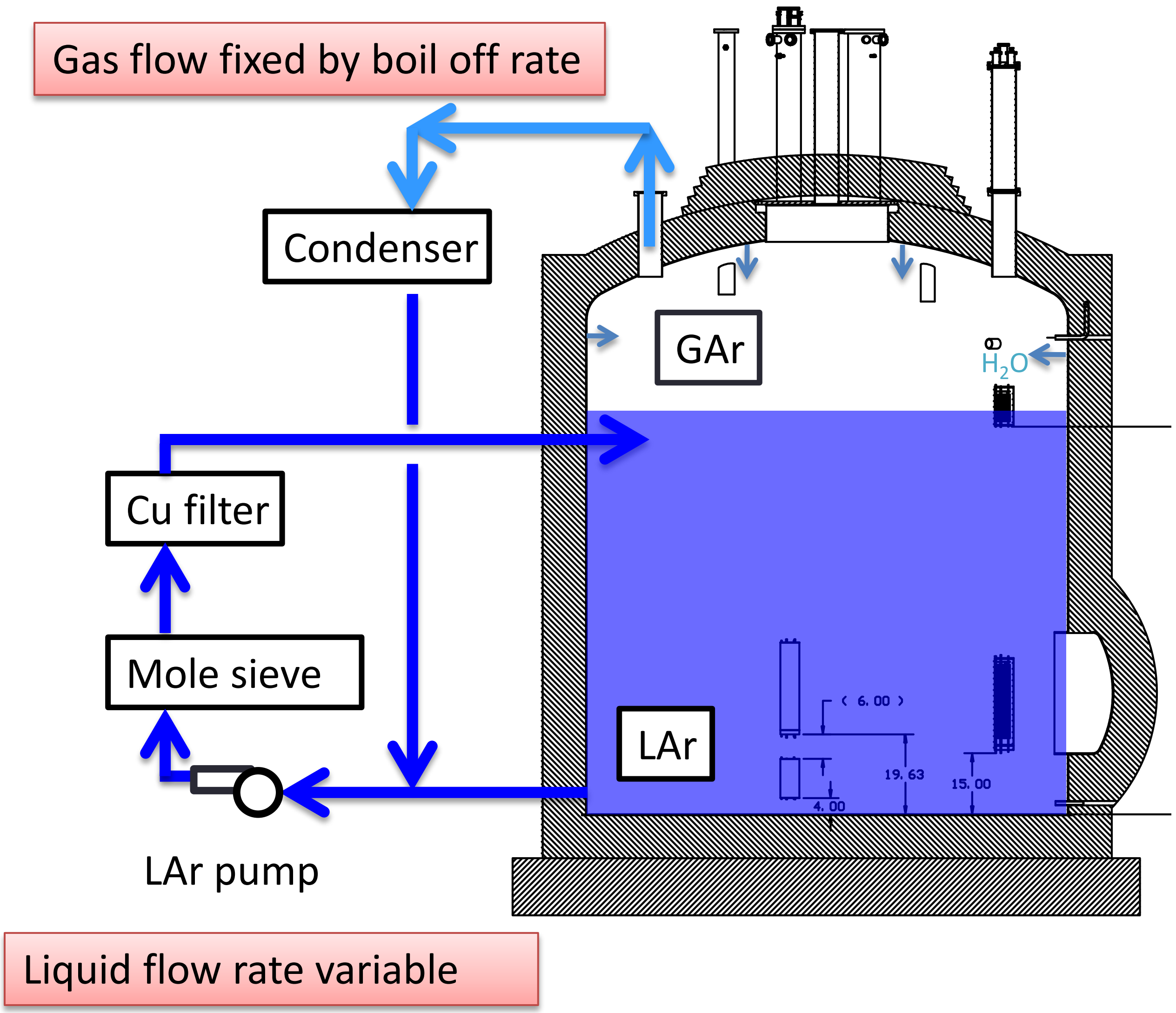


Gas Recirculation/filtration

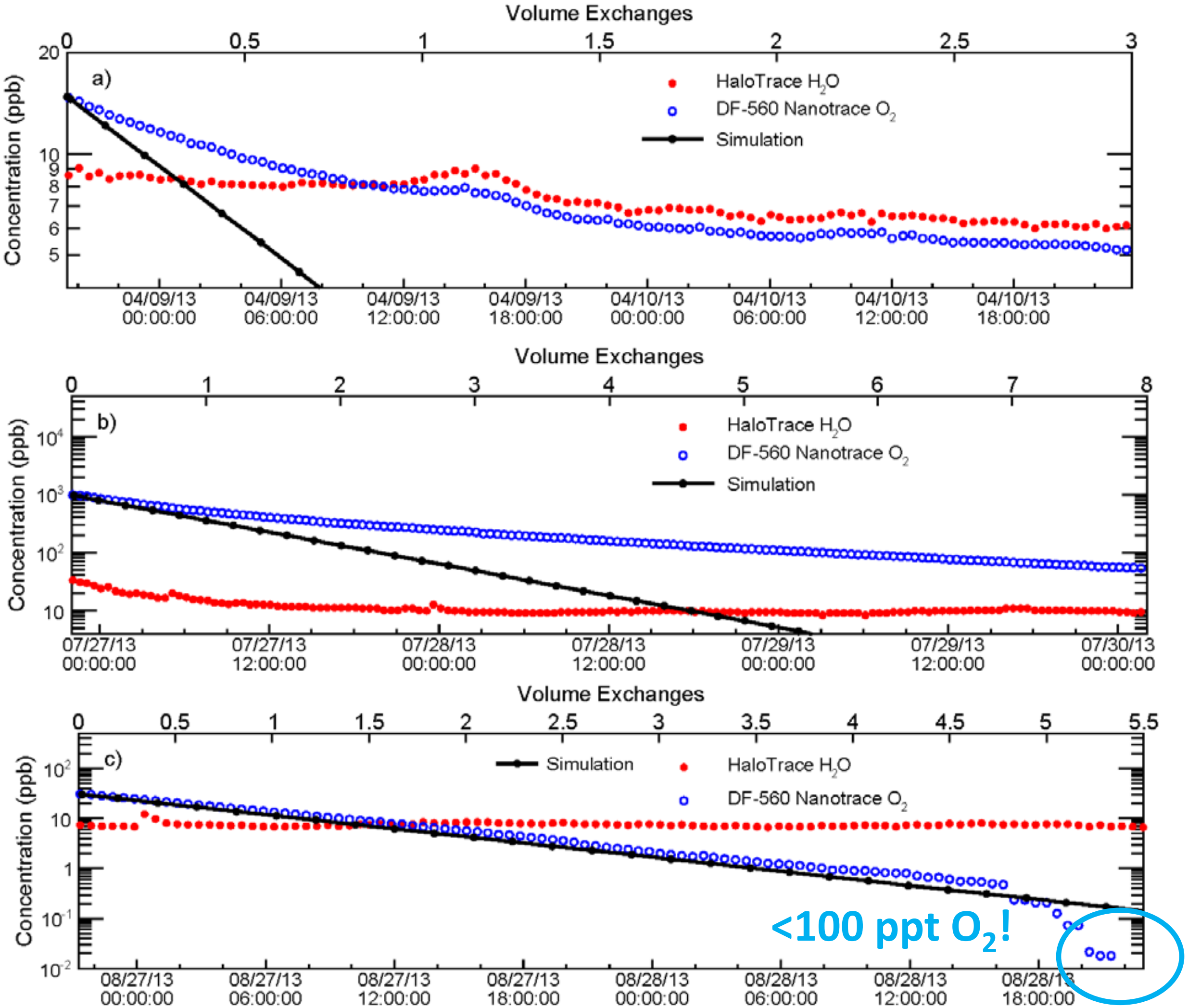
- Gas recirculation is not strictly necessary, but very useful for debugging – leaks or purity issues show up here.
- Recirculation rate of 1 volume exch. every 3.4 hours, slow enough that relevant leaks are not overwhelmed by filtration
- O_2 -> 20 ppb
- H_2O->667 ppb
- N_2 stable at 13 ppm



Recirculation and Filtration



Liquid recirculation



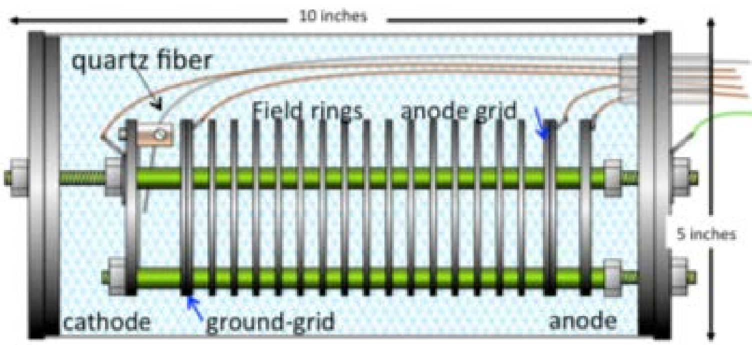
3 of the cleanups during run 2:

- April 2013: O_2 analyzer was out of calibration
- July 2013: filters saturated
- August 2013: after filter regeneration and analyzer calibration

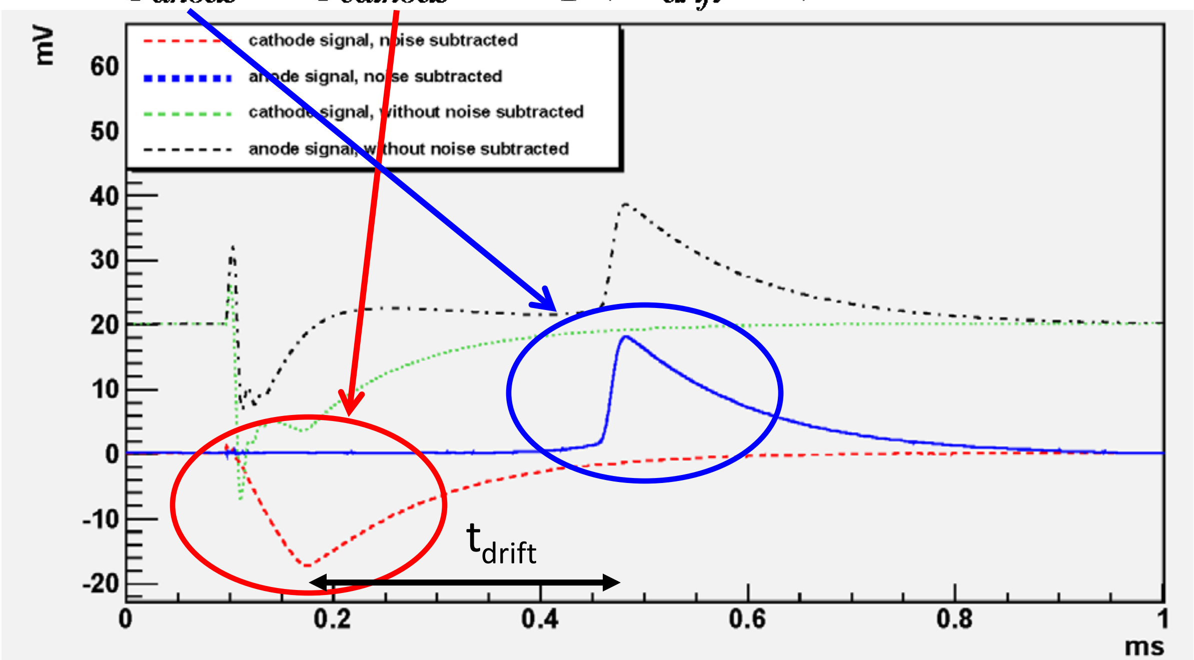
The water concentration is measured in the tank vapor space, while the oxygen concentration is measured from a sample of the liquid

Purity Monitors

- Produce electrons with Xe flashlamp on (photo)cathode
- Measure electron signal loss from cathode to anode to find lifetime τ



$$Q_{anode} = Q_{cathode} \times \exp(-t_{drift} / \tau)$$



NIMA 292, 580 (1990)

Charge-integrating amplifier => Qa,Qc are pulse heights after removing RC distortion of pulse shape

Q_A/Q_C during LAPD run 2

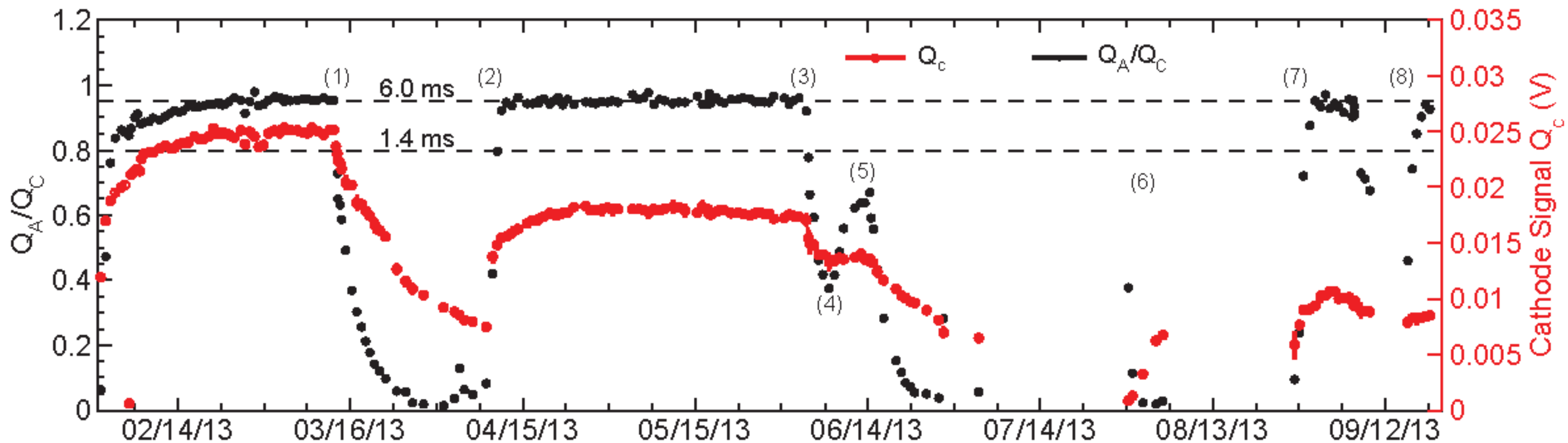
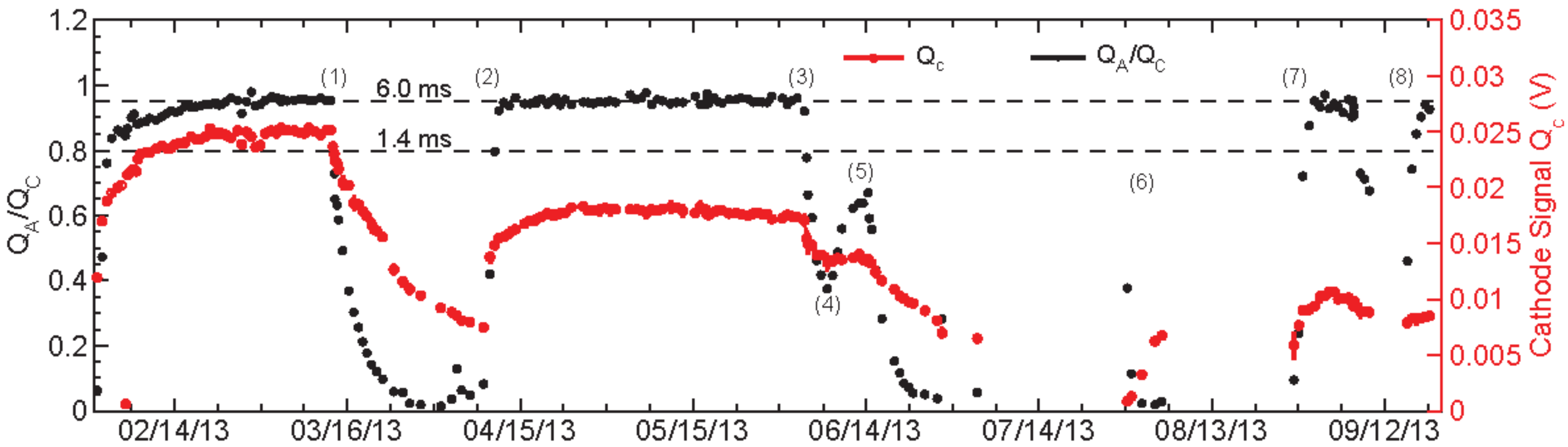


Figure 22. The cathode signal (Q_C) indicated as open red circles and the anode-to-cathode ratio (Q_A/Q_C) indicated as solid black circles for recirculated liquid argon over all LAPD running. The andode-to-cathode ratio is correlated with electron lifetime, calculated at values of 0.95 and 0.8. Gaps in the data occur when either the purity monitors do not have sufficient resolving power or when they were not operating. Special events are enumerated with the following descriptions: (1) Circulation pump trip for an extended time period. (2) Beginning of contaimation cleanup, see Figure 20a. (3) Pump trip lasting one hour resulting in subsequent zero flow to the filters (4) Start of flow to filters after the pump trip. (5) Stopped pump for removal and repair (6) Start of second cleanup, see Figure 20b. (7) Start of third cleanup, see Figure 20c. (8) Pump restart after a few-day period to insert a digital camera.

JINST **9** P07005 (2014)

Q_A/Q_C during LAPD run 2



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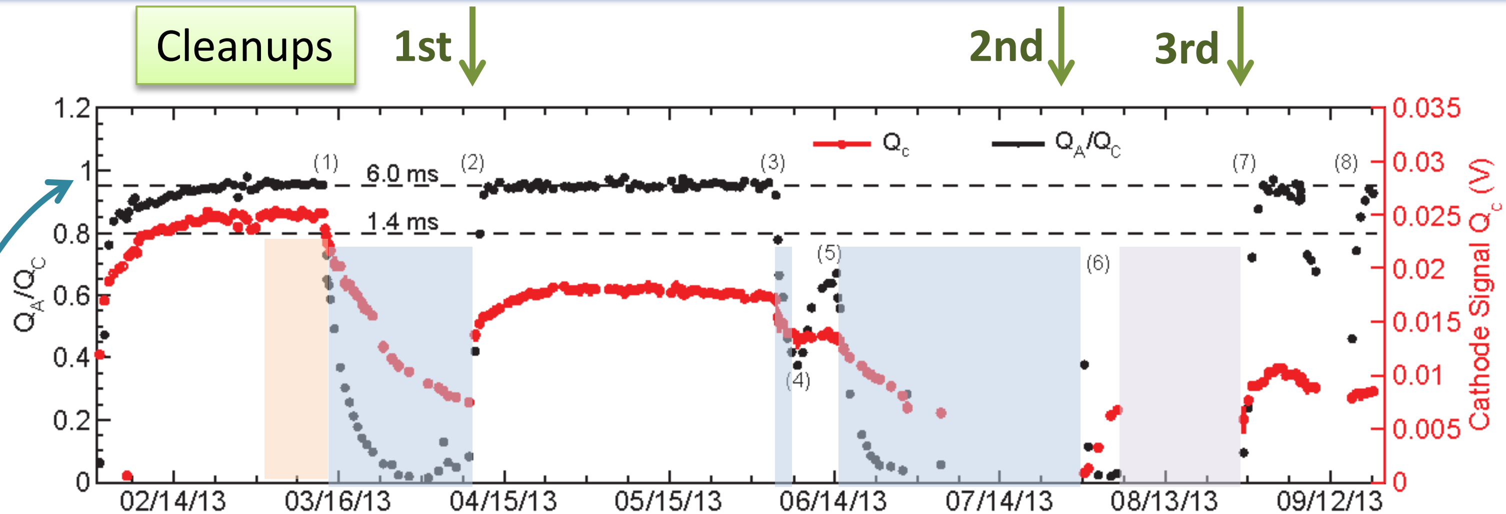
Achieved electron lifetimes > 6 ms!

Q_A/Q_C during LAPD run 2



Circulation Pump off

Filter regeneration

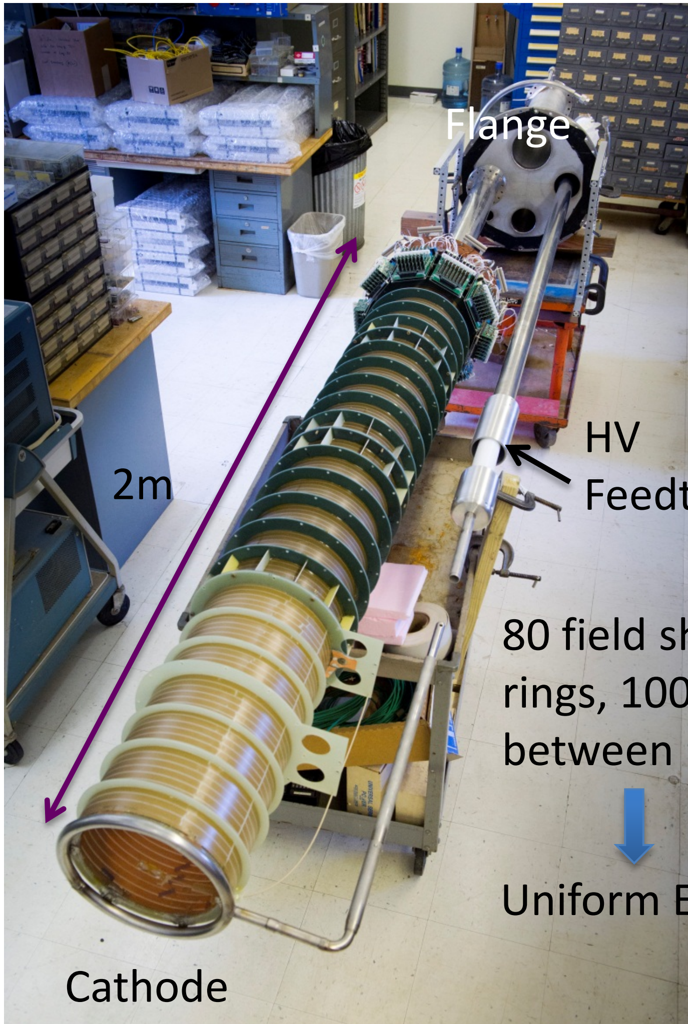
Figure 22. The cathode signal (… es and … Q_A/Q_C) indicated as solid black circles for recirculated liquid argon over all LAPD running. The andode-to-cathode rat … hen eit … pe- cia … me pe … ng in … for re … 8) Pur

Recirculation rate varied in this period!
Qa/Qc appears saturated, limit to sensitivity of short PrM?

Lower limits for the electron lifetime are shown for measured values Qa/Qc=0.8 and 0.95.

Eventually limits PrM precision and is under study. Deterioration of the flash lamp intensity? Deterioration of the photo cathode surface due to exposure to contaminants?

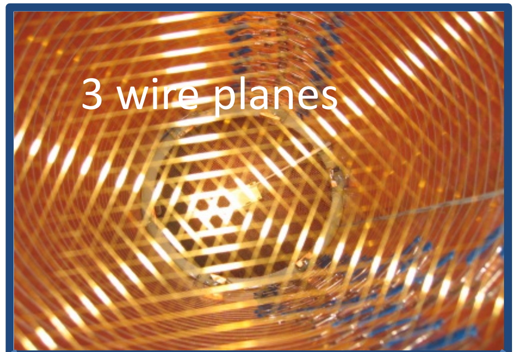
LongBo TPC in LAPD (MSU & FNAL)

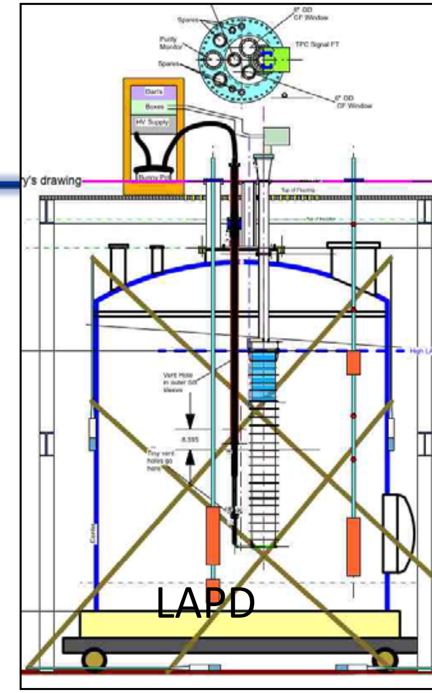


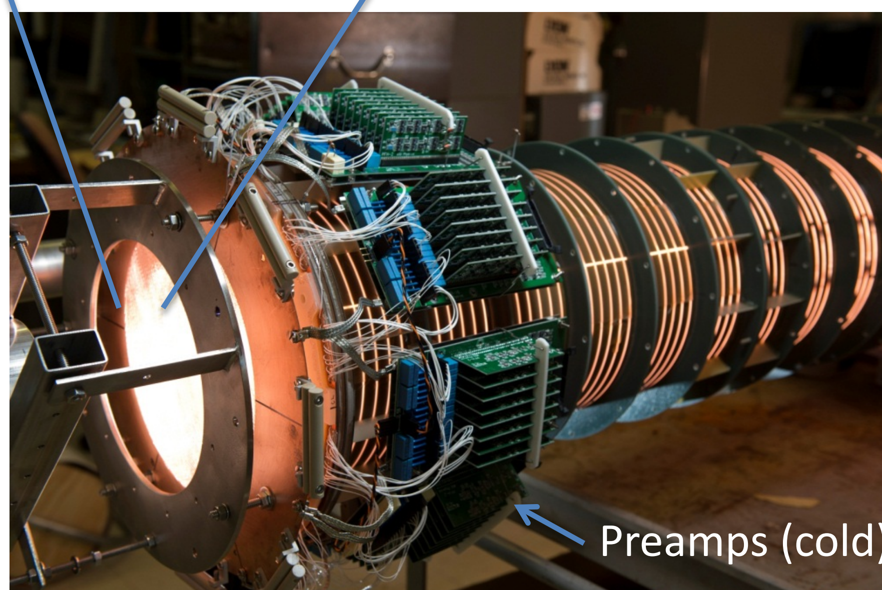
HV Feedthrough

80 field shaping rings, 100 MΩ between rings

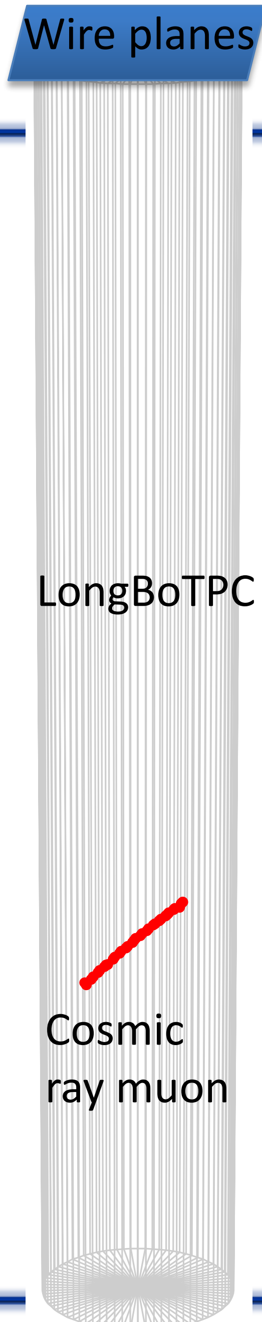
Uniform E field

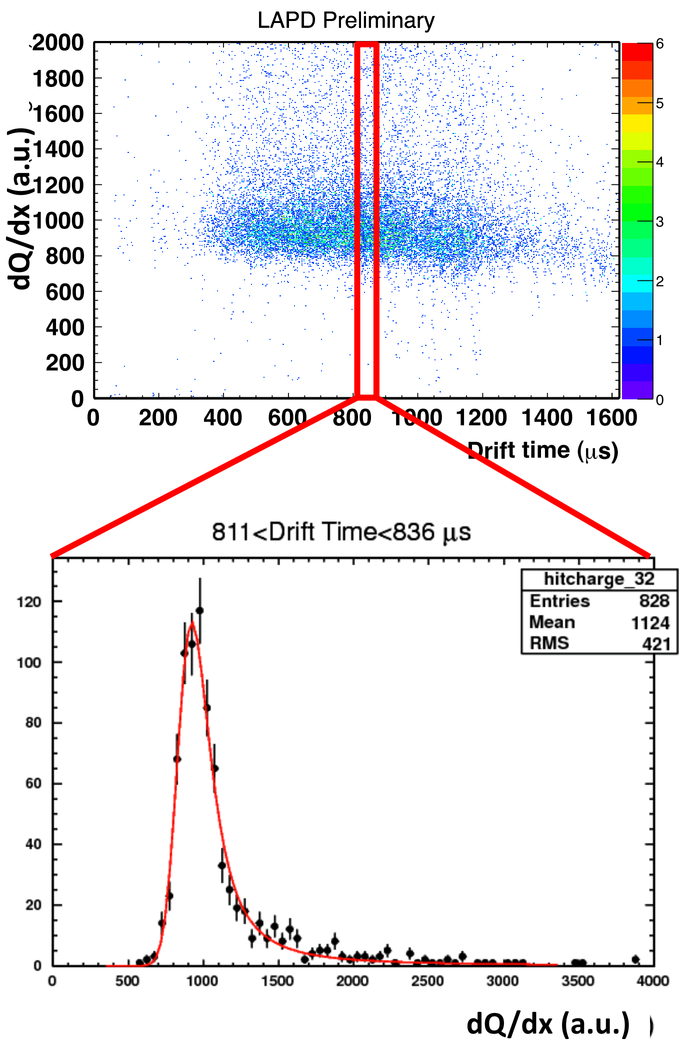




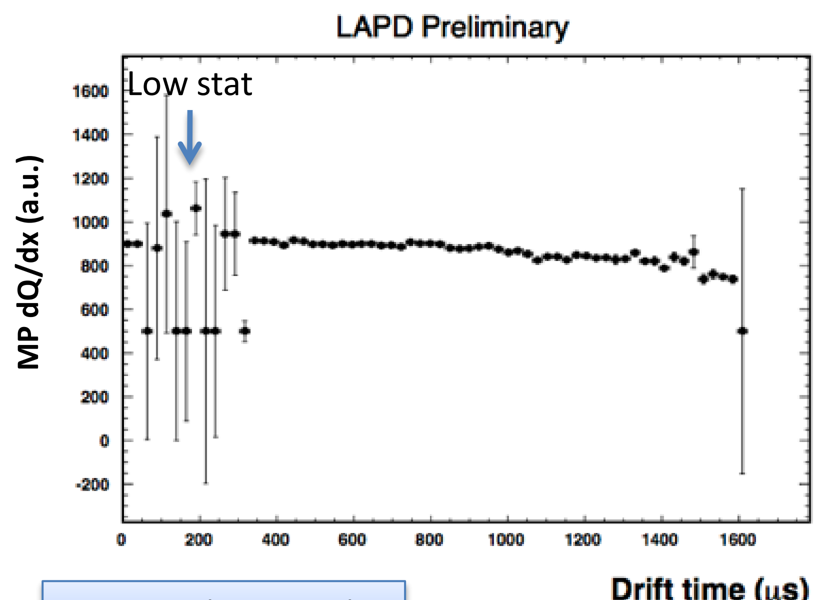


Measuring Purity with Muons



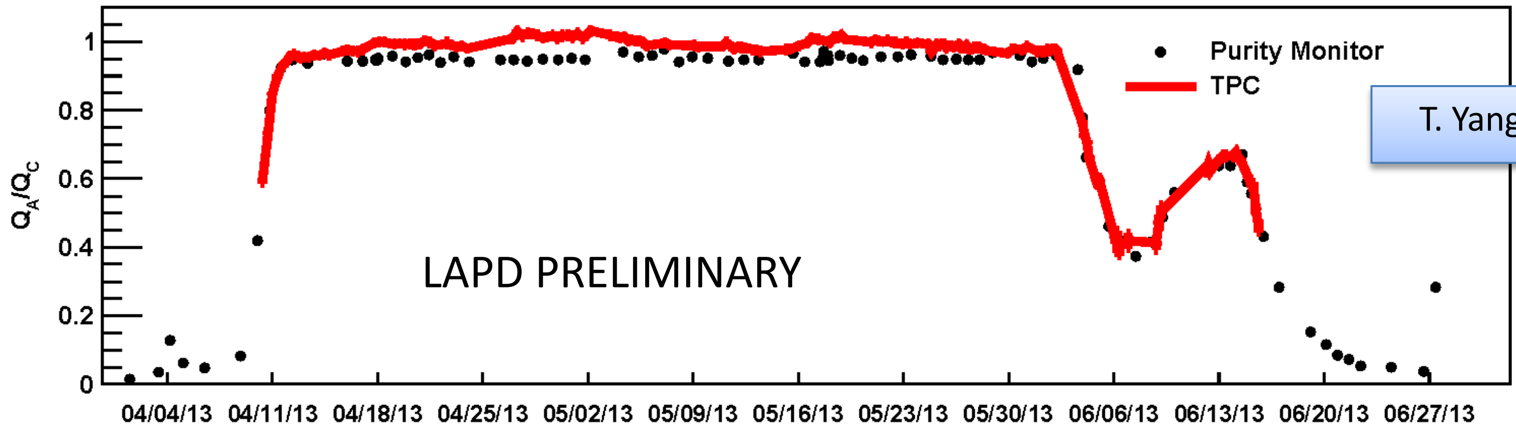


— Select single muon events between 50° < θ < 70° and remove δ rays
— Use dQ/dx of muon hits as a function of drift time to measure charge attenuation
— Less than 15% attenuation for 1 ms of drift time (1.3 m @ 0.35 kV/cm)

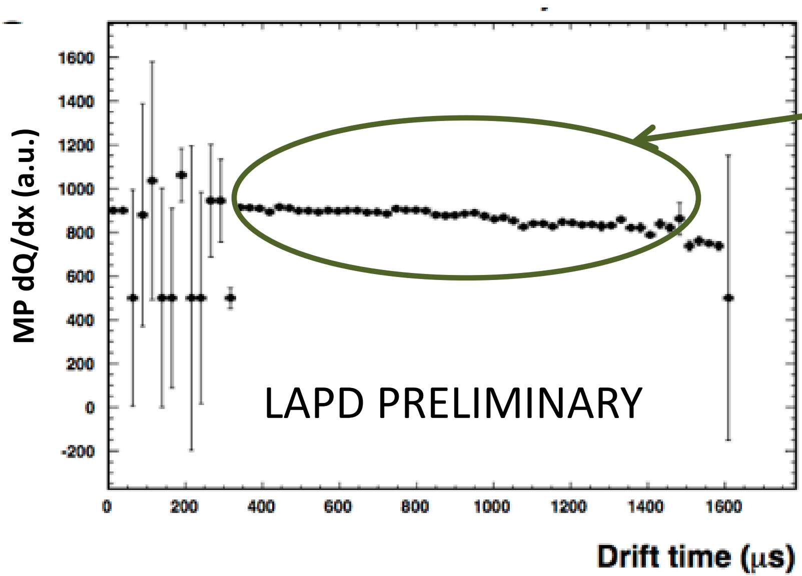


T. Yang (Fermilab)

First comparison of TPC and Purity Monitor



T. Yang (Fermilab)

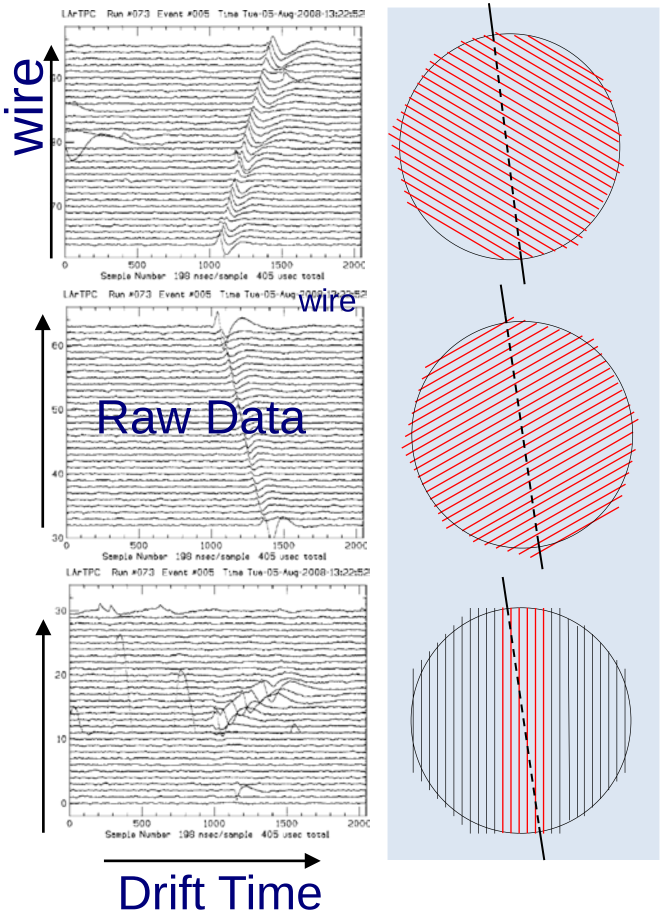


- Fit this region to obtain lifetime τ : $Q=Q_0\exp(-t/\tau)$
- Calculate Q_A/Q_C for comparison using PrM drift time t=0.3 ms: $Q_A/Q_C=\exp(-t/\tau)$
- Note that the PrM values for Q_A/Q_C are lower limits after accounting for systematic uncertainties
- Systematic uncertainties for the TPC data have not yet been investigated

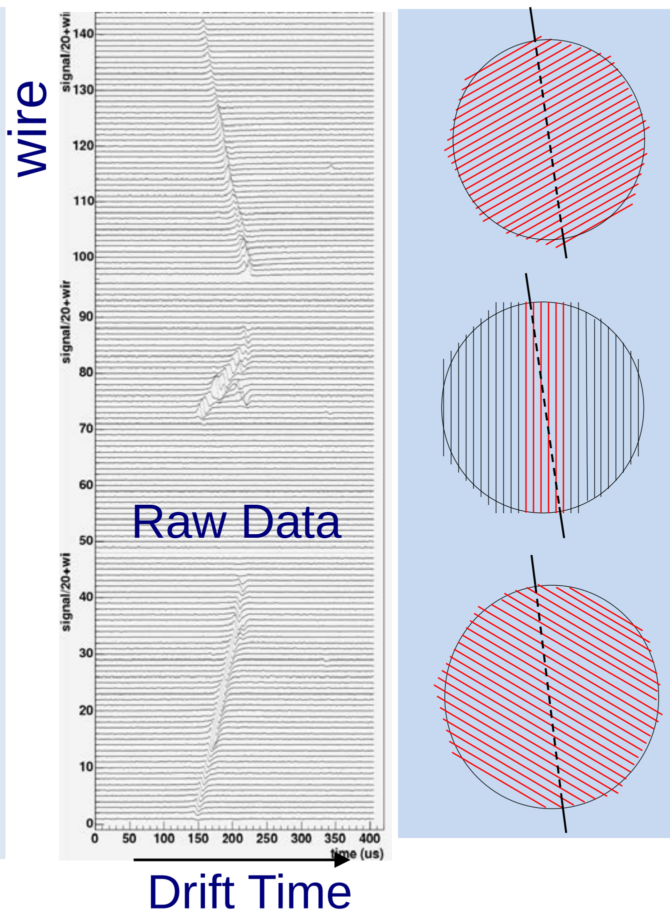
Pre-amplifier Development at Fermilab

(Short) Bo Electronics test-stand data from 2010-2012

Warm amps S/N = 15

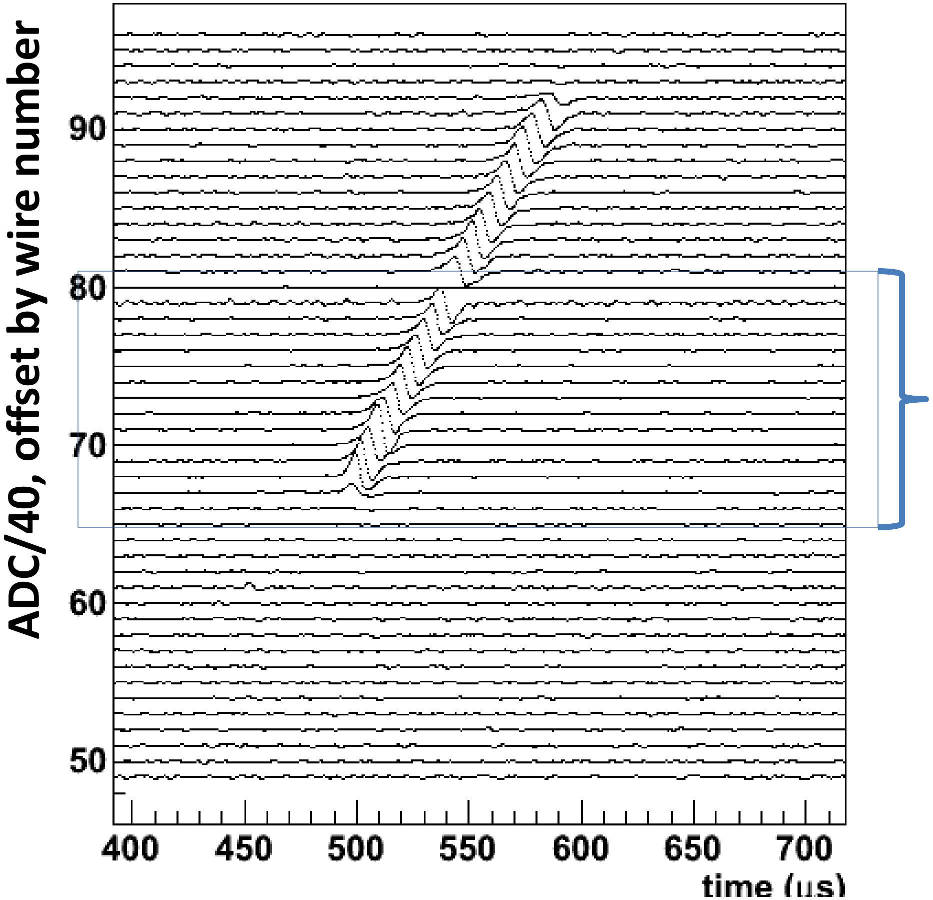


Amps in liquid S/N >30



Test of BNL ASIC with LongBo (MSU)

ASIC performs even better than discrete circuitry



<u>Pre-amplifiers: ASIC vs Discrete</u>

- Comparable signal collected
- Less noise on ASIC channels

Pedestal RMS measured to be 75% of the discrete channels.

16 ASIC channels with gain setting 25 mV/fC (1 ADC=5.317 mV) . Remaining channels discrete.

Dead/noisy ASIC channels believed to be damaged during initial HV discharge.

Extract/access devices inside the cryostat

confirmation that we can recover the electron lifetime after interventions

- History
  - RTD spooler removed (1/29/2013 and 7/19/2013)
  - HV feed thru removed and reinserted (7/2013)
  - Wire plane bias voltage feed thru replaced and purity monitor string removed (7/10/2013)
  - Second HV feed thru inserted for independent tests (7/19/2013) and later removed (9/2013)
  - Camera inserted (9/2013)
- Roughly 0.2-0.4 ppm O_2 was added to the liquid during each intervention. The filters are designed for 1.5 ppm O_2.
- Liquid loss is inevitable

Summary

- An electron lifetime >6 ms was achieved without evacuation and with a TPC inside the liquid. **Piston purge works!**
- The lifetime measured by the purity monitor has a direct correlation to the lifetime measured by the TPC and is therefore a relevant monitor of the argon purity for a LArTPC detector
- The purity was recovered multiple times after interventions
- There is an entire session on HV feedthroughs and breakdown in LAr . . . .

BACKUP

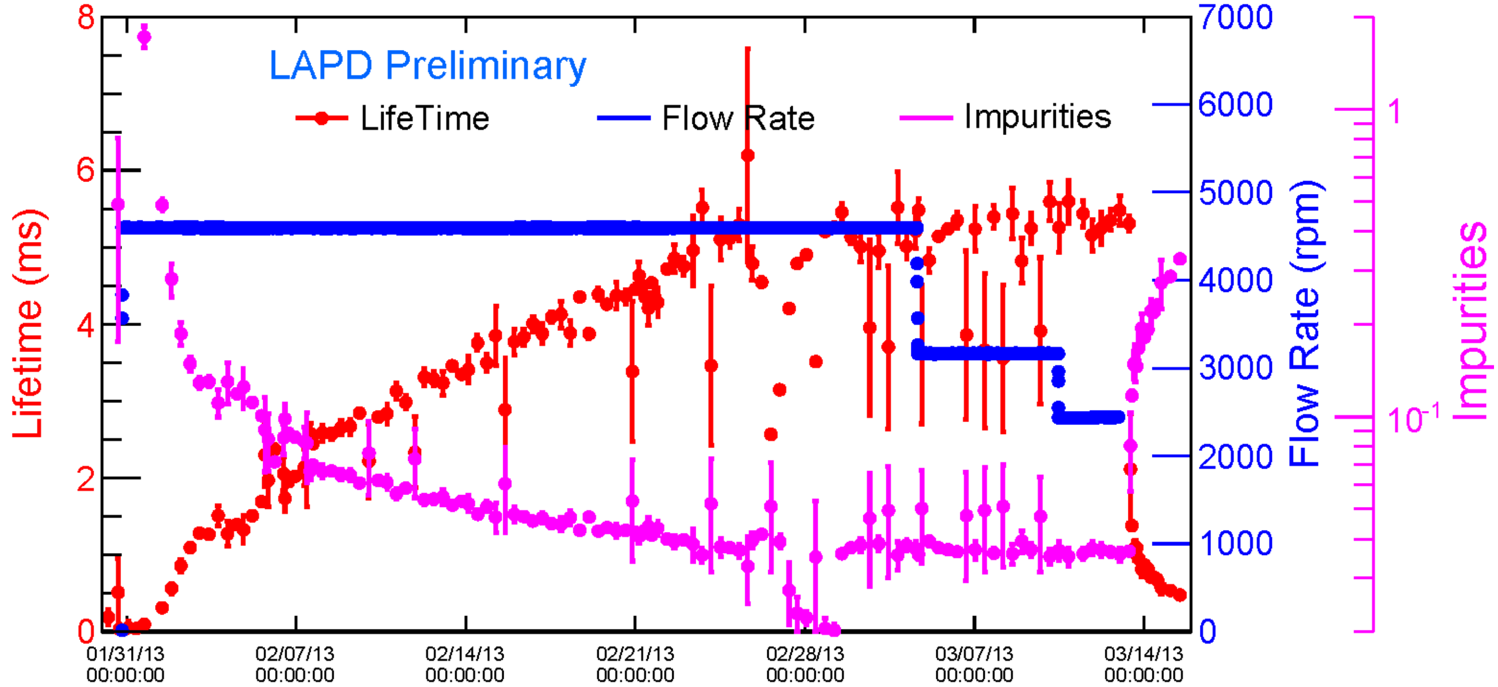
Filter material capacity

Table 3. Capacity of the oxygen and water filters. Each row in the table indicates the amount of contamination presented to the filters during the indicated phases of operation. The gas recirculation phase indicates the filter loading at room temperature, all other phases are for liquid argon temperatures. It is difficult to estimate the amount of water removed from the liquid.

	Oxygen (g)	Water (g)
Gas recirculation	0.38	0.98
Cryostat filling	5.68	–
Integrated ullage outgassing during pumped liquid filtration	1.41	1.39
Pumped liquid filtration	24.09	–
Total	31.56	2.37
Gram species per kilogram filter material	0.49	0.04

JINST **9** P07005 (2014)

Electron lifetime and Liquid Recirculation Rate

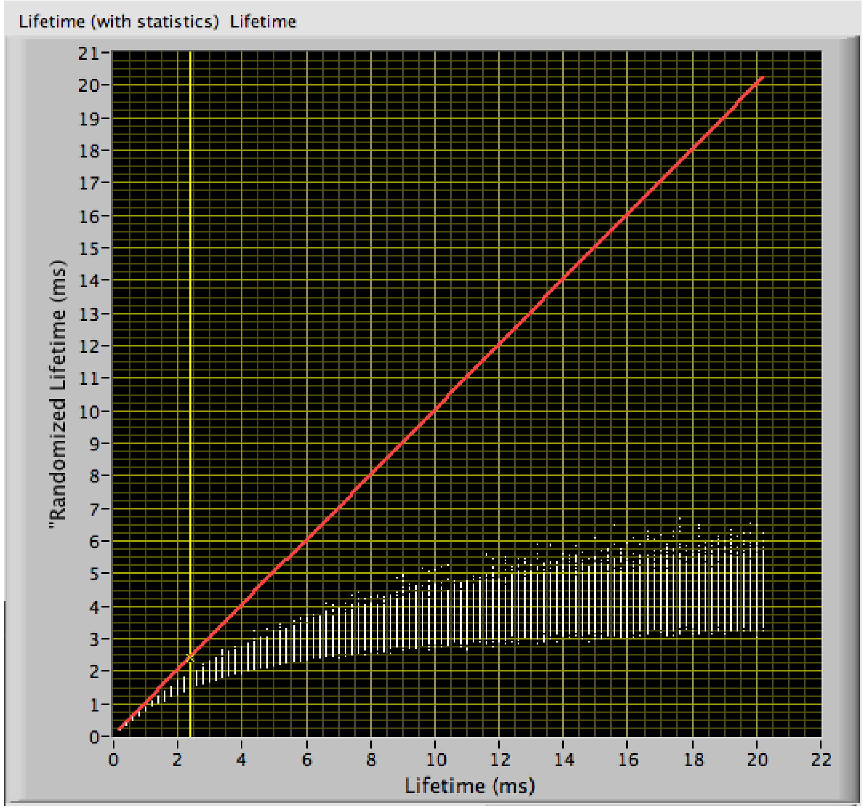


Purity Monitor Systematic Uncertainties

- Anode acceptance (drift field dependent).
  - Assumed to be 100%.
- Uncertainty on RC time constant used to remove electronics response (~2% on Qc)
- Cathode signal correction – what fraction of electrons counted in the number Qc did not make it to the cathode grid?
  - Assumed 0%, depends on voltages on cathode and cathode grid (and electron lifetime?)

Note that all 3 items are treated such that the reported values for Qa/Qc and τ are lower limits.

- See LArTPC docdb 1064, 1092 for more details

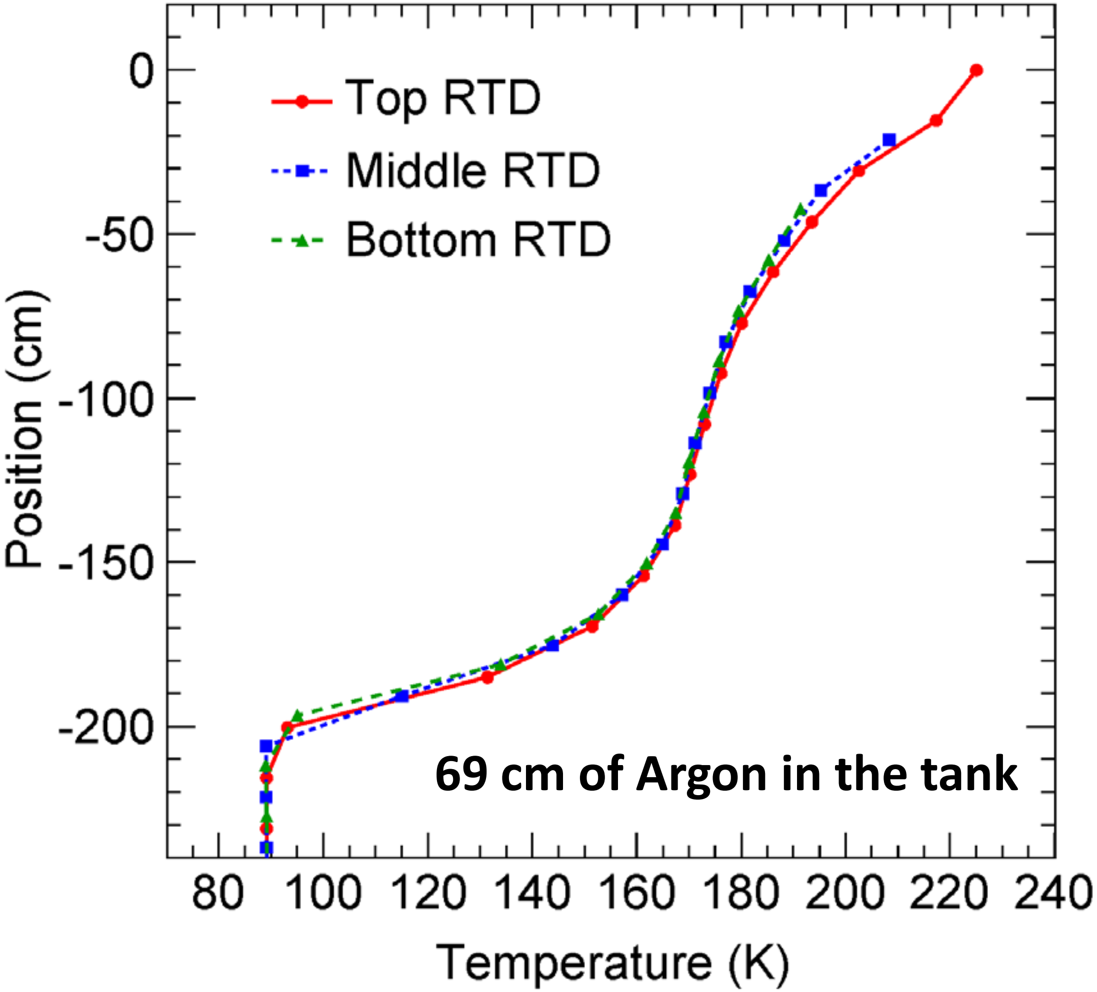


- 5% offset in Qa
- rms noise on Qa and Qc is 0.05*Qc
- Red line – actual purity
- White points, results of 1000 dice throws

Purity Monitor Settings

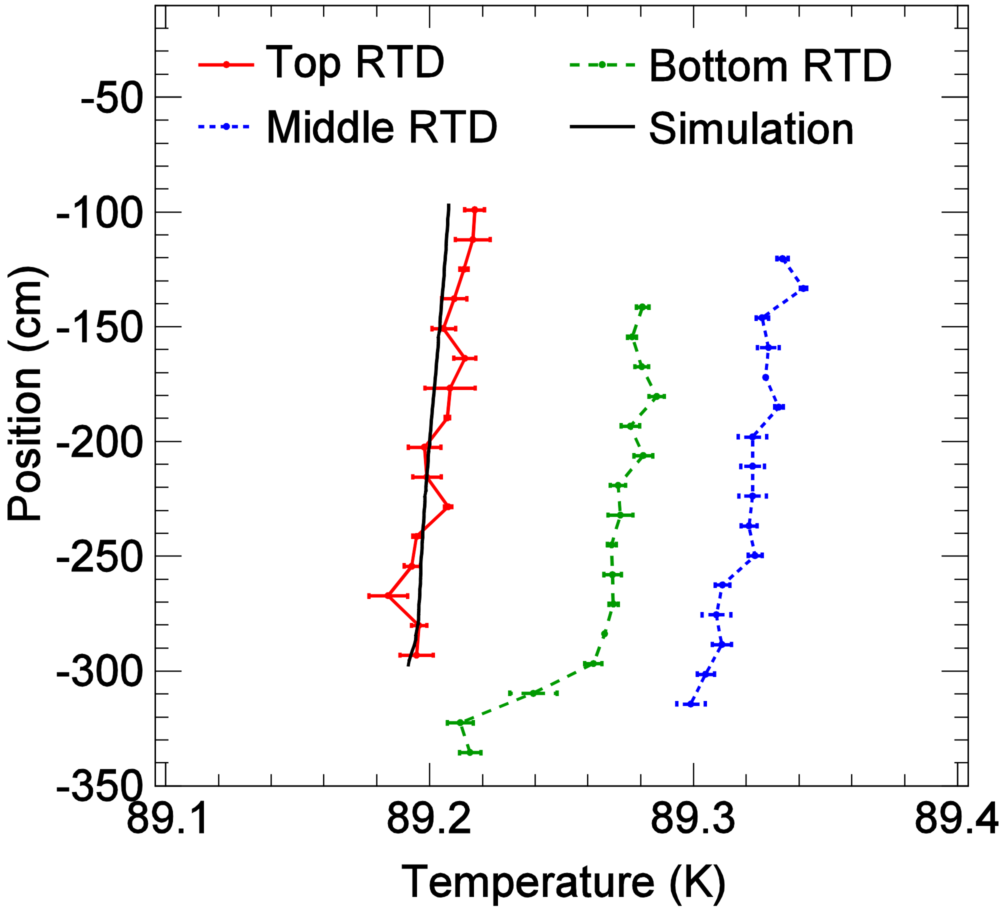
	Long monitor	Short monitor
Cathode, Anode disk, grid diameter	8 cm	
Cathode-Cathode Grid gap	1.8 cm	
Anode Grid-Anode gap	0.79 cm	
Anode disk/Cathode disk thickness	0.23 cm	
Anode grid/Cathode grid thickness	0.24 cm	
Field-shaping ring thickness	0.23 cm	
Gap between rings	0.79 cm	
Cathode-Anode total drift distance	50 cm	19 cm
Cathode grid to Anode grid distance	47 cm	16 cm
Number of field-shaping rings	45	15
Number of resistors	46	16
Nominal Cathode Voltage	-100 V	-100 V
Nominal Anode Voltage	5 kV	2 kV
V_{AG}/V_A	0.948	0.865
Electric field between cathode grid and cathode	56 V/cm	56 V/cm
Electric field between cathode and anode grids	101 V/cm	108 V/cm
Electric field between anode and anode grid	329 V/cm	342 V/cm

RTD measurements in gas



RTD measurements in full liquid volume

the temperature models are pretty good



3D modeling

complex system requires lots of 3D modeling to make the piping system manageable