LArTPC R&D at FNAL

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Engineer's Week

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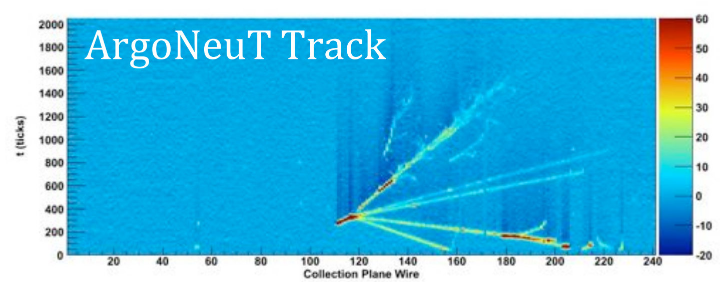
LArTPC R&D - Background

- Liquid Argon Time Projection chambers (LArTPCs) are detectors for long baseline neutrino oscillation physics
- Multi-plane high voltage wire chamber immersed in LAr
- Provide bubble-chamber quality event images by drifting ionization electrons created by neutrino-interaction-induced tracks
- These electrons are drifted along electric field lines to signal-readout wires
- Time, magnitude and position of each path can be reconstructed in software



LArTPC R&D - Background

- Argon is cheap and plentiful such that detectors with multi-kiloton active volumes have been proposed
- One key engineering challenge is the removal of electronegative impurities (O2, H2O) that capture the ionization electrons
- An oxygen equivalent concentration < 30 ppt is required to drift electrons over several meter lengths
- Drifting an electron several meters takes several ms which leads to the term electron lifetime
- For example, that is ***0.00075 grams*** of oxygen in a detector with 22,240 liters of liquid argon!
- I will talk about mainly about purification R&D

LArTPC R&D

- Began in 2005 at FNAL
  - FNAL effort initiated by Adam Para
  - Technology transfer from ICARUS collaboration which started LArTPC R&D in the 1980s
  - ICARUS efforts have culminated in a 600 ton detector located underground at Gran Sasso which is near taking physics data
- FNAL R&D efforts
  - Two 250 liter 'Test Stands' at PAB (operating)
  - ArgoNeuT - A 175 liter active volume LArTPC in the NuMI beam (operating and taking physics data)
  - LAPD - A 34 ton purification demonstration (summer 2010)
  - MicroBooNE - 170 ton LArTPC located along the Booster neutrino beam line (2013)

LArTPC R&D

- Role of `Test Stands' for Liquid Argon TPCs at FNAL
  - Gain hands-on experience and develop some expertise and infrastructure to deal with hardware and software challenges of liquid argon TPCs
  - Assure that individual components for full detector will work as required
    - Chamber electronics
    - Signal feedthroughs
    - Electron life-time purity monitors
    - High purity flanges and sealing techniques
    - Chemical purity qualification of detector construction materials
    - HV feedthroughs
    - Determine filter capacities

LArTPC R&D

- R&D Infrastructure developed at the Proton Assembly building
  - Two 250 liter liquid Argon vacuum jacketed cryostats
    - Material Test System (MTS) - Detector material qualification (chemical)
    - Electronics Test System - TPC electronics development
  - Two “single pass” filters
    - Oxygen, Water - (molecular sieve), homemade, regenerated in place
  - Cryostat internal liquid filter (both mole sieve and oxygen)
  - Purity monitors
  - Several “high end” commercial gas analyzers
- Material Test System can now achieve 10+ ms lifetimes routinely and sustain this purity indefinitely in a closed system

Test Cryostats and Infrastructure at PAB

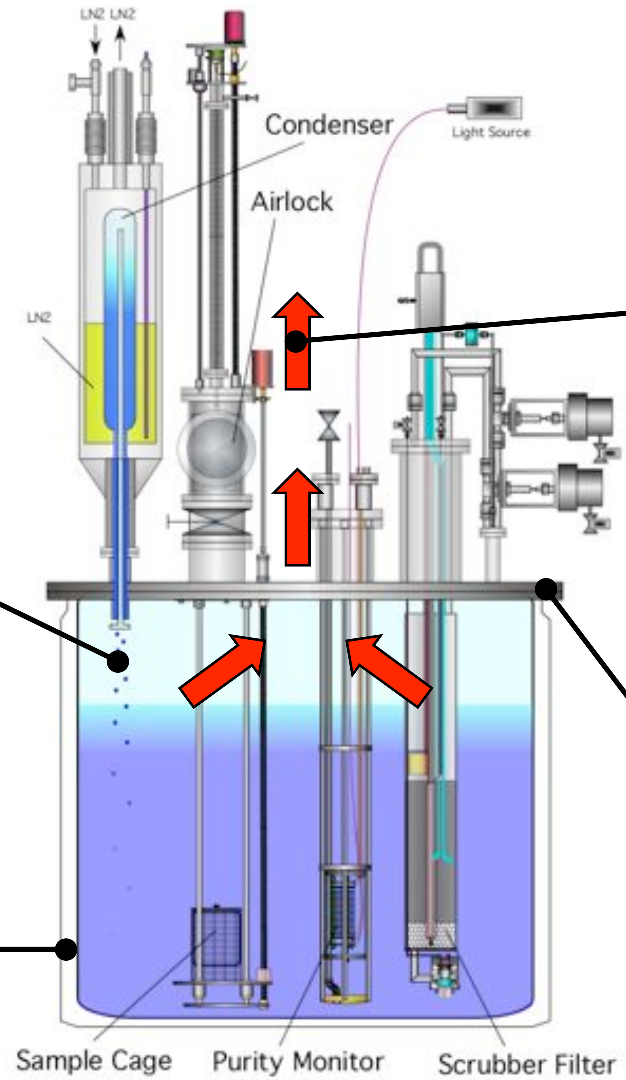
The Path to Long Lifetimes

- Initial success in the MTS.....
  - Evacuate cryostat to 10^-7 Torr
  - Back fill with industrial grade LAr thru the single pass filters
  - Several ms lifetime achieved while the argon boil off gas vented
  - Two key components were working - purity monitors and single pass filters….didn't seem too hard
- .....turned into frustration
  - LN2 powered condenser used to close the system reduced the electron lifetime from several ms to < 100 microseconds quickly (30 min)
  - Many straws were grasped
    - Condenser fabrication contamination - cut the condenser open
    - Possible cold leaks - carefully leak checked cold
    - Argon ice - raised LN2 temperature
    - Electrostatics associated with a non-conductive fluid - installed a HV rod under condenser

The Path to Long Lifetimes

Closed system:

LN2 condenses argon vapor and "rains" the liquid argon back into the cryostat



Open system:

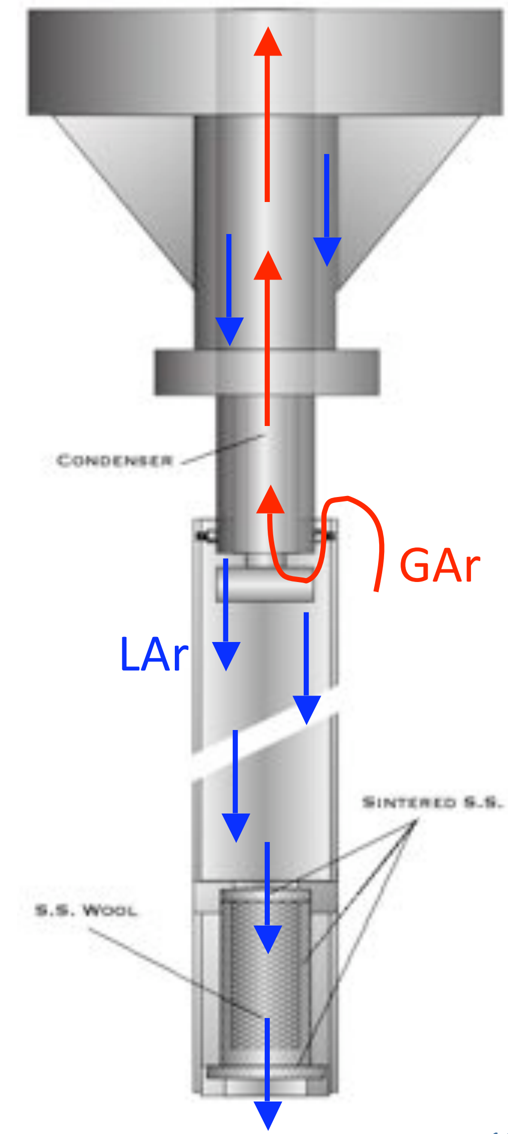
Ambient heat input vaporizes liquid argon and the argon vapor vents

Vacuum jacketed sides

Un-insulated removable top flange, typically near room temperature, significant heat leak

The Path to Long Lifetimes

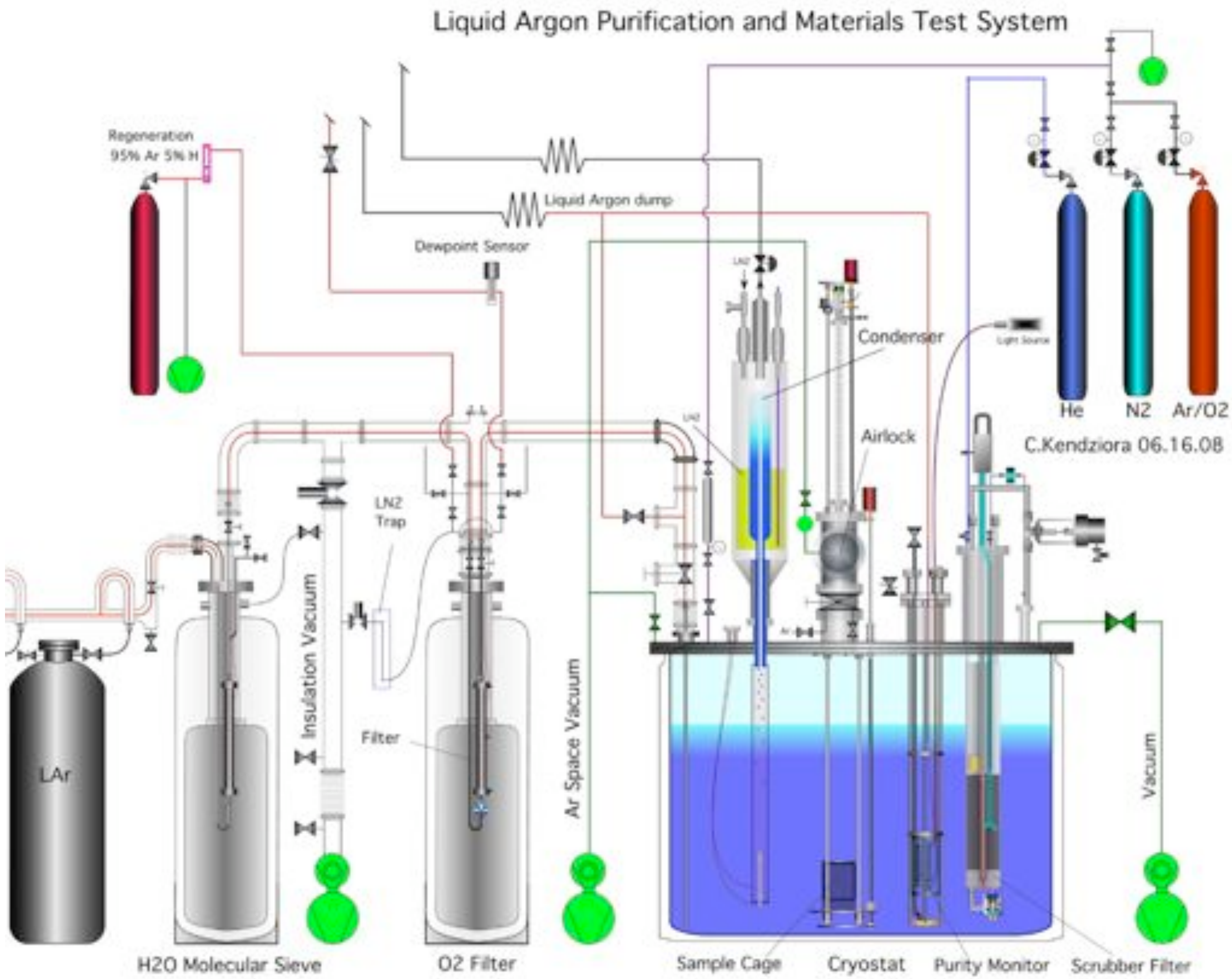
- Placed a sintered metal filter in the condenser return liquid path
  - Allowed operation of a closed system at several ms lifetimes
- Purchased a ppb H2O meter
  - Observed that H2O ↑ lifetime ↓
  - Became convinced the condenser was mixing H2O from warm surfaces into the LAr
  - Surprised that after weeks of turbo pumping prior to filling residual H2O was the culprit
- Now operate with a sintered metal filter filled with molecular sieve material
  - Sintered metal alone saturates quickly
  - Molecular sieve has yet to saturate



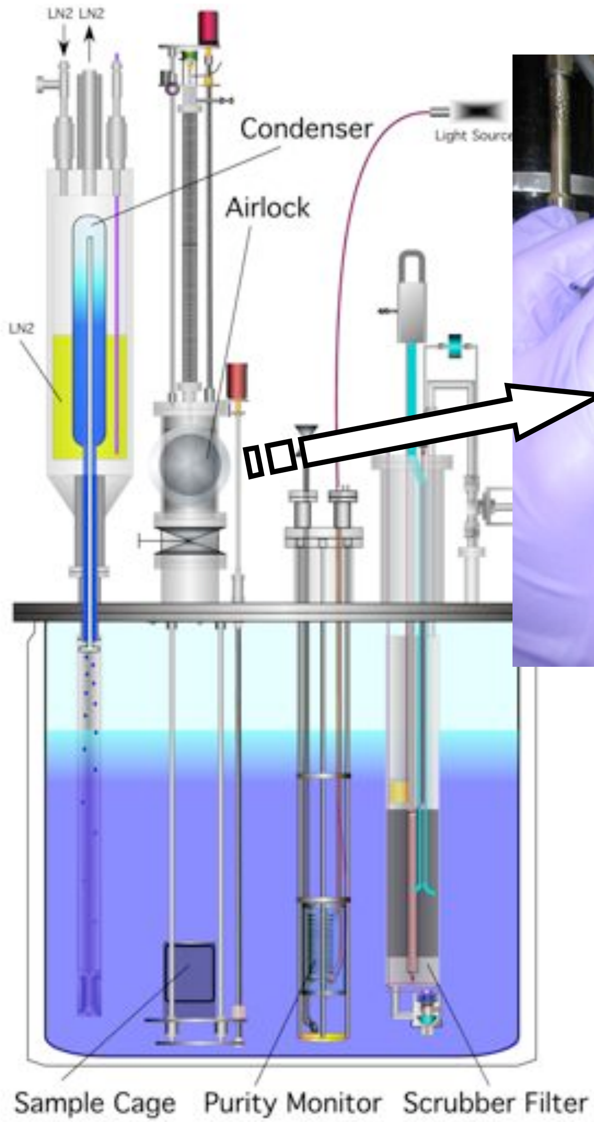
Materials Test System Features

- Once the system itself was understood the material test system could finally serve its purpose
- Materials can be inserted into ultra-pure liquid or vapor
  - Samples purged with argon vapor or evacuated prior to insertion
  - Insertion process itself does not introduce contamination as verified by routine "zero" tests
- Internal oxygen and water filter - 2 hour time constant
- Purity monitor
  - 200 usec to 10 ms electron lifetimes
  - O_2 equivalent of 1.5 ppb to 30 ppt
- Sampling points for commercial gas analyzers (O_2, N_2, H_2O)
- Injection of contaminates such as O_2, CO_2, N_2
- Liquid nitrogen powered condenser

Materials Test System Schematic



Materials Test System Airlock

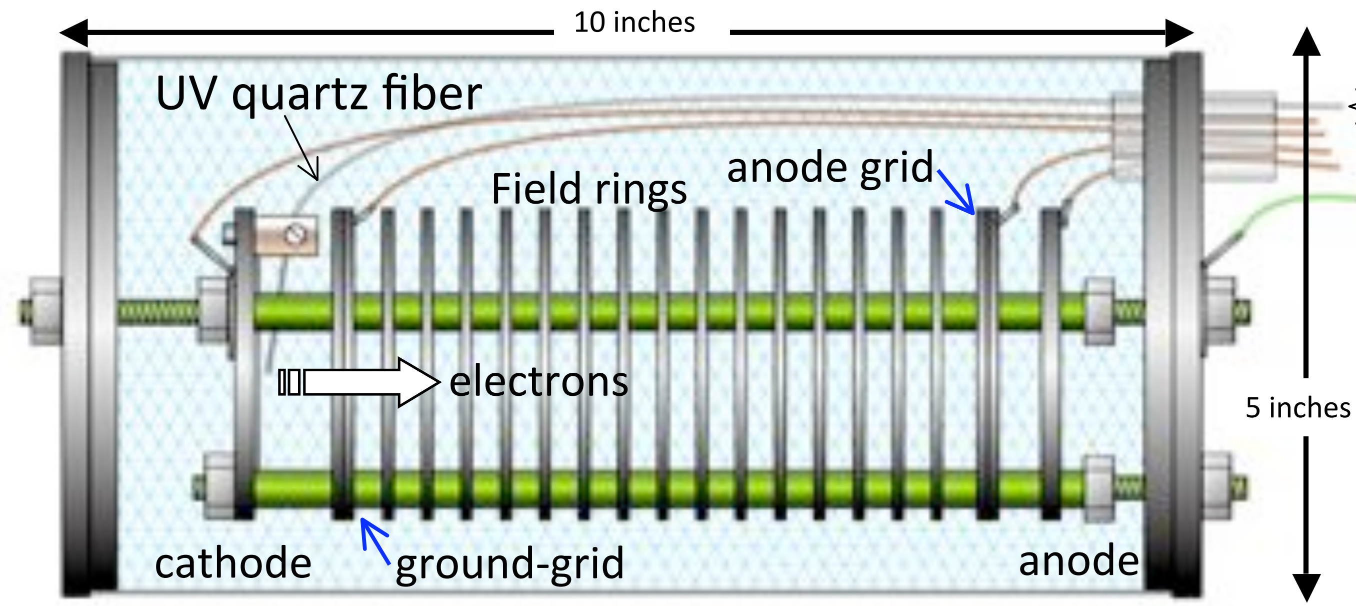


Insertion of a material sample into the airlock basket

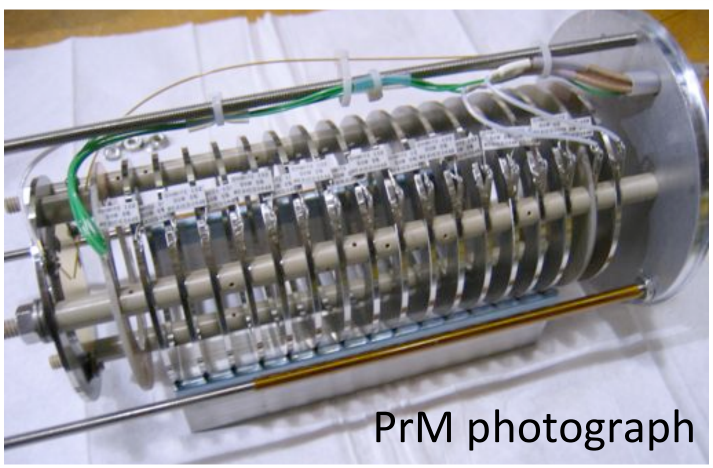
Purity Monitors

- Icarus Style Purity Monitors (PrM)
  - Mini drift-chamber at low drift-field
  - Measures quantity of interest directly (electron lifetime)
  - Does not identify contaminate
- Hardware (monitor, light-flashers, quartz-fibers, electronics readout) and software (DAQ) have operated continuously for months at a time
- Purity monitors are now fully automated, interlocked, and integrated into the cryogenic control system, lifetime can be monitored over the web from a browser

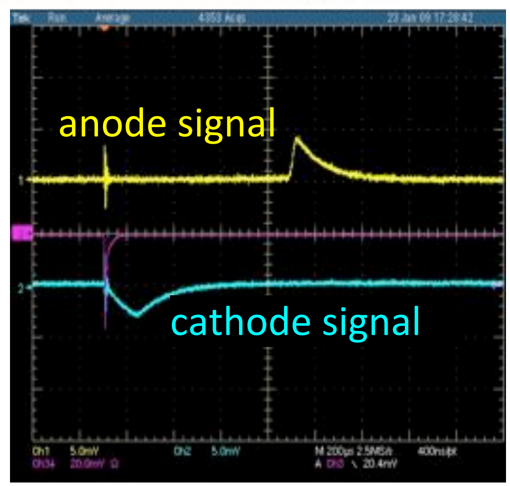
Purity Monitors



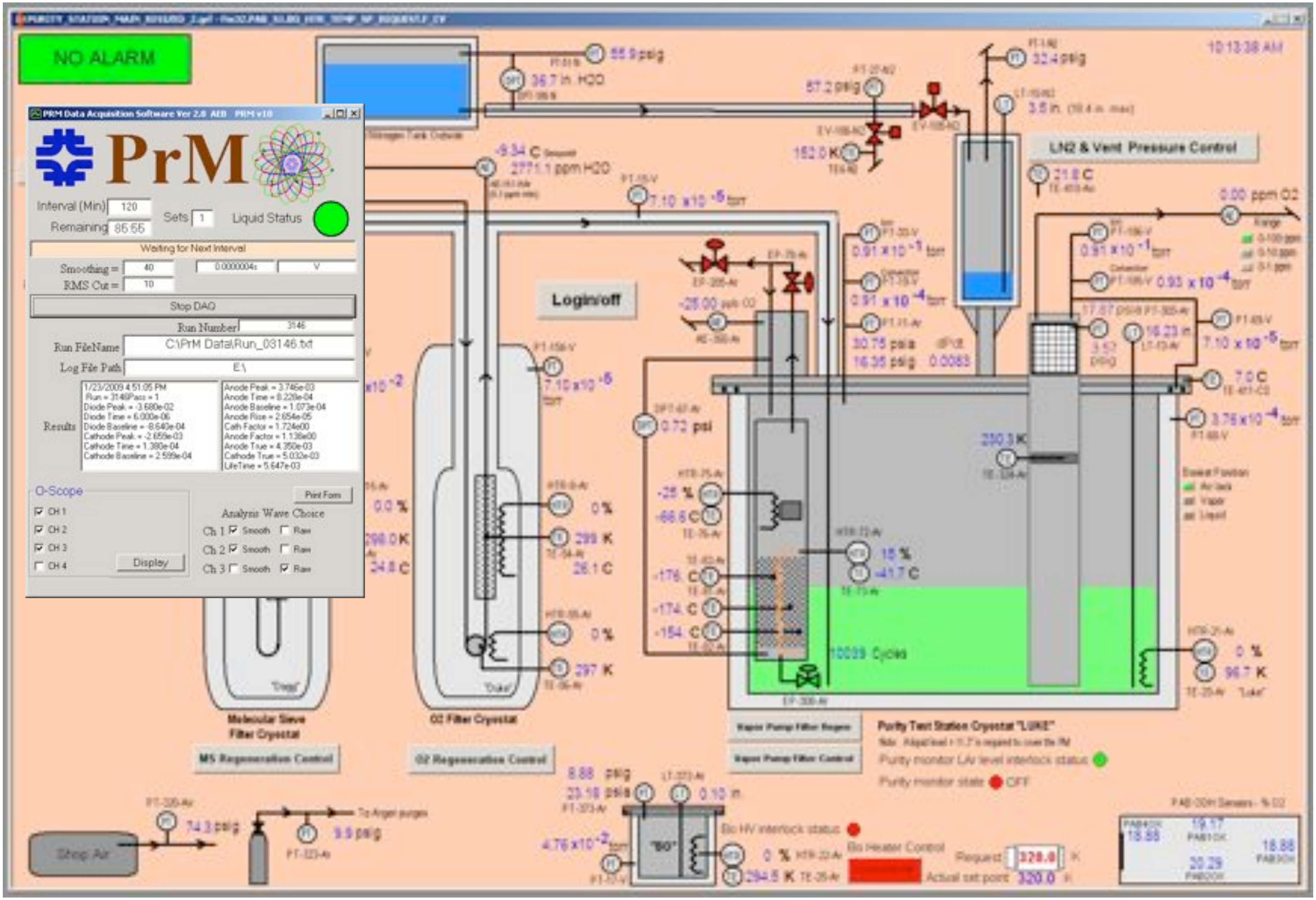
PrM drawing



PrM photograph

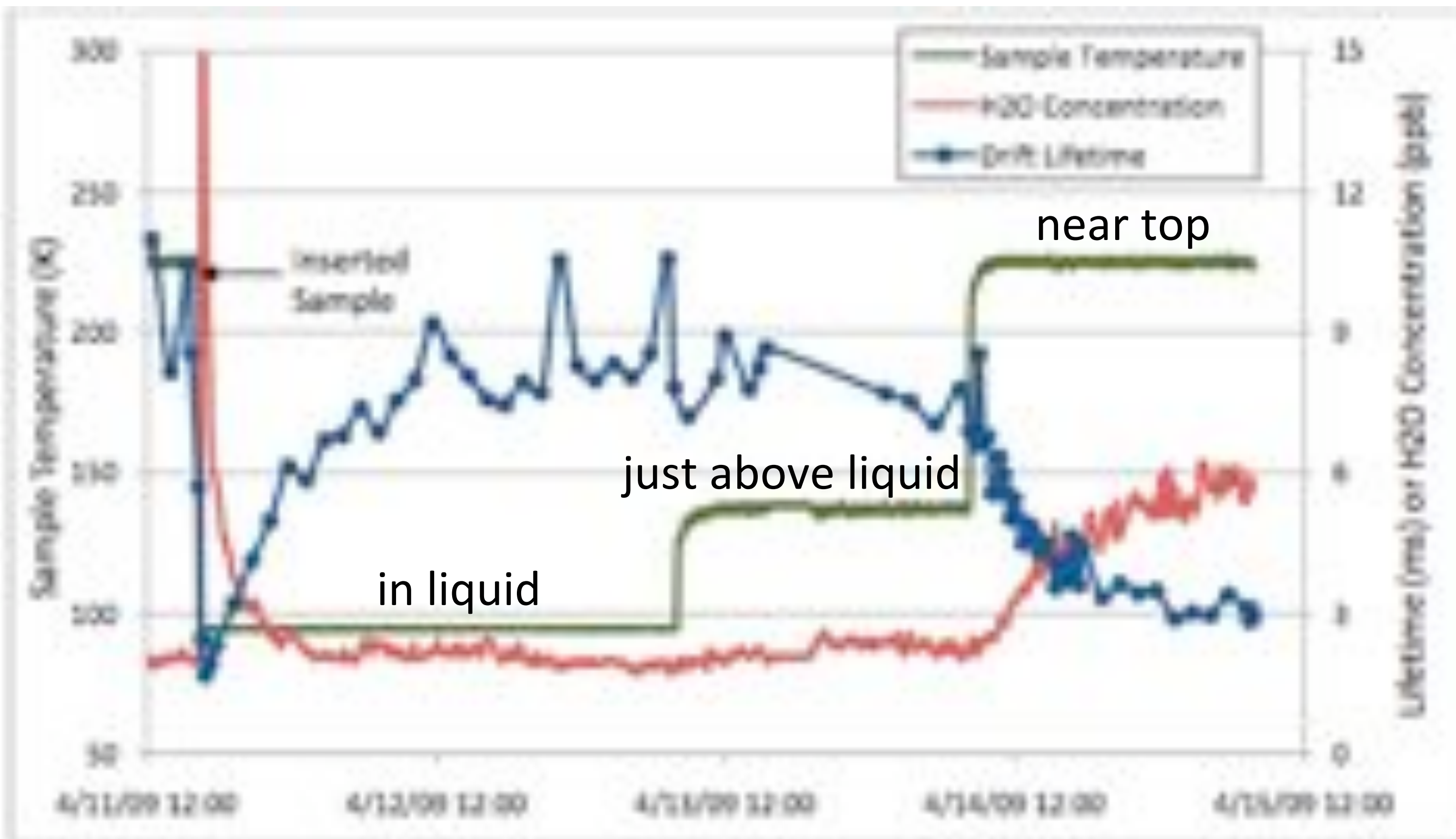


PrM scope signal


NO ALARM
PrM Data Acquisition Software Ver 2.8
PrM
Interval (Min) 120
Remaining 85.55
Sets 1
Liquid Status
Waiting for Next Interval
Smoothing = 40
RMS Cut = 10
Stop DAQ
Run Number 3146
Run FileName C:\PrM Data\Run_03146.txt
Log File Path E:\
Results
O-Scope
CH 1
CH 2
CH 3
CH 4
Display
Print Form
Analysis Wave Choice
Ch 1 Smooth Raw
Ch 2 Smooth Raw
Ch 3 Smooth Raw
Login/off
LN2 & Vent Pressure Control
10:13:38 AM
Molecular Sieve Filter Cryostat
O2 Filter Cryostat
MS Regeneration Control
O2 Regeneration Control
Purity Test Station Cryostat "LUKE"
Purity monitor LAr level interlock status
Purity monitor state OFF
Shop Air
To Argon purges

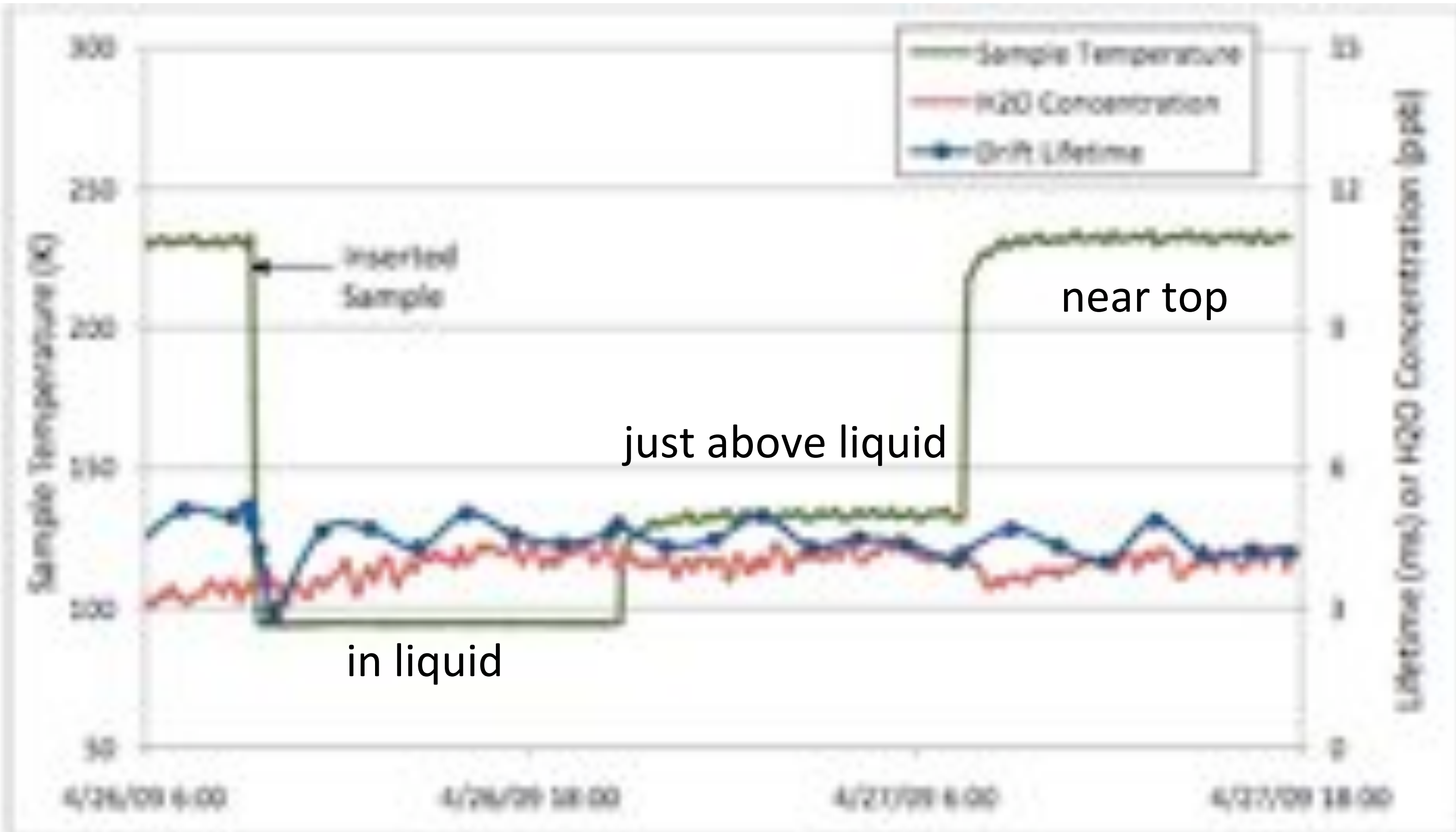
Typical MTS Result

Un-evacuated sample of FR-4, outgassing is a f(T)



Typical MTS Result

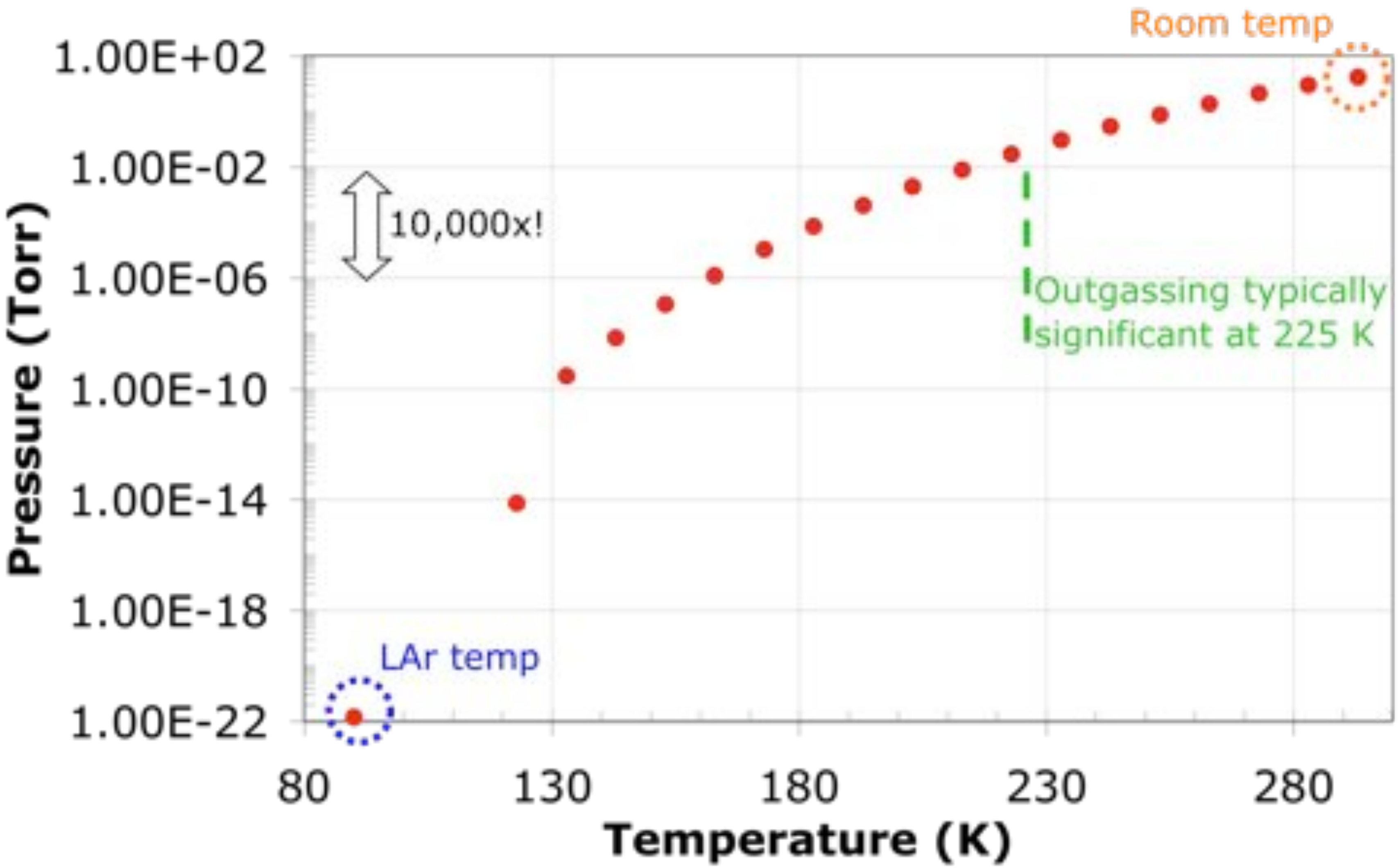
Evacuated sample of FR-4, no lifetime effect



Key MTS Findings

- Materials submerged in liquid do NOT decrease the lifetime
- Materials in vapor give off water which decreases the lifetime - H2O is the dominate contaminate
- Water out-gassing rate is a very strong function of the sample temperature and declines very slowly over time
- Venting the vapor space sweeps the water out of the cryostat before it can mix into the liquid and reduce the lifetime
- If water source is removed, liquid will slowly clean up on its own without active filtration

Water Vapor Pressure vs. Temperature



Material	Sample Surface Area (cm^2)	Effect of Material on Electron Drift Lifetime (LT)			Comments
		94 K liquid	≈120 K vapor	≈225 K Vapor	
Red-X Corona Dope[a]	100	None	None	LT Reduced from 8 to 1 ms; recovery observed.	H_2O concentration not monitored.
Deactivated Rosin Flux[b]	200	None	Not Tested	LT reduced from 8 to 1.5 ms recovery observed	H_2O concentration not monitored.
FR4	1000	None	Not Tested	LT reduced from 8 to <1 ms	Outgassed enough H_2O at 225 K to saturate sintered metal return.
Taconic[c]	600	None	Not Tested	LT reduced.	Sample outgases water at 225 K.
Hitachi BE 67G[d]	300	None	Not Tested	LT reduced; recovery observed	Sample outgases water at 225K; outgassing reduced over time.
TacPreg[e]	200	None	None	LT reduced; recovery observed	Sample outgases water at 225 K; outgassing reduced over time.
FR4, y-plane wire endpoint for uBooNE	225	None	None	LT reduced from 8 to 3 ms	Sample outgases water at 225 K.
FR4, y-plane wire endpoint for uBooNE	225	None	None	None	Sample was evacuated in airlock prior to testing
FR4, y-plane wire cover for uBooNE	225	None	None	None	Sample was evacuated in airlock prior to testing
Devcon 5-min epoxy	100	None	None	LT reduced from 10 to 6 ms; some recovery observed	Sample outgases water at 225 K.

[a] GC Electronics, Part # 10-5002

[b] Kester Soldering Flux, Formula #1587, heated to approximately 450 F for 1 minute.

[c] Taconic #TPG-30-0045-35, Grade TPG-30, Lot #CBD7002 107053001

[d] Fiberglass laminate of non-halogenated material.

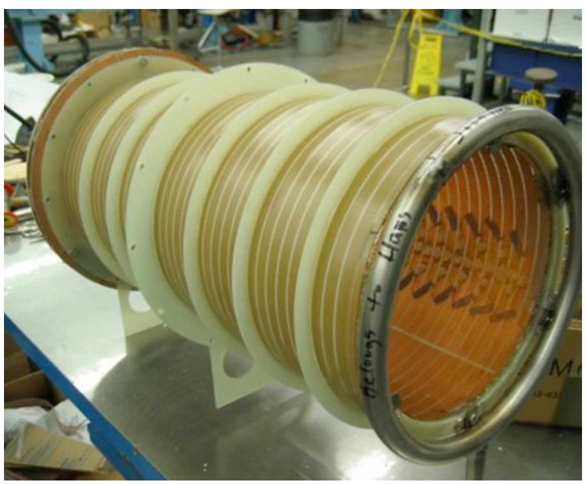
[e] Taconic #TLG-30-0600-HH/HH, Lot #10707111B, copper cladding mechanically removed from one side.

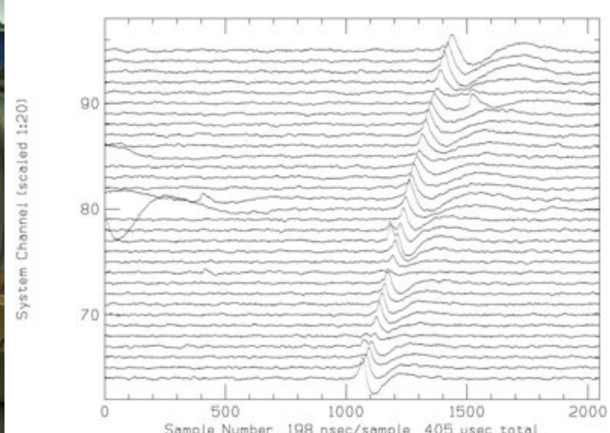
Key MTS Findings

- MTS was successfully filled without evacuation
  - Purged with filtered GAr until 1 ppm O2 reached in cryostat
  - Purge was limited by diffusion from multiple dead volumes on top flange
  - Filled with LAr thru the single pass filters
  - Electron lifetime after fill was "zero"
  - Cryostat internal filter cleaned up the Argon and a several ms lifetime was reached in a few days

Electronics Test Stand

- 96 channel TPC with 50 cm drift
- 1st US LArTPC electronics
- Receives pure liquid from single pass filters
- Maintains several ms lifetime while venting
- Cold electronics, condenser, internal filter upgrade underway





Motivation for a Large Test System

- Current systems use evacuation as a preliminary cleaning step
- This is extremely difficult to scale to very large volumes – especially mechanically.
- Physics requirements for Liquid Argon detectors are showing that large volumes are required. (5 kTon minimum)
- Hence we must study alternative filling schemes

Liquid Argon Purity Demonstration - LAPD

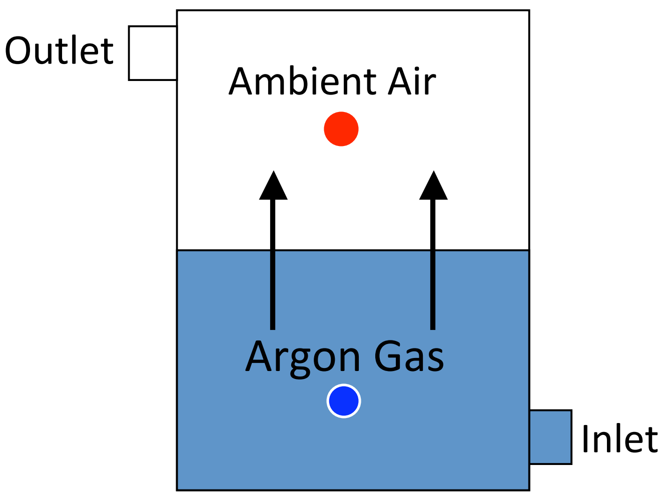
- Goal - achieve 10 ms drift lifetime in an industrial tank
  - Tank cannot be evacuated, must be purged from atmosphere
  - Fabricated from as rolled stainless steel plate, no special surface finish
  - Foam insulated
- 34 ton Argon capacity
  - 10 foot diameter x 10 foot height
  - 5,875 gallons (22,240 liters)
- Test of several key purification components required by larger detectors
  - High purity magnetically coupled liquid pump (Barbor-Nichols), volume change in 8 hrs
  - Larger filter beds
  - Vapor phase purification
  - Commercial bellows sealed cryogenic valves
  - Inline purity monitor (in piping)

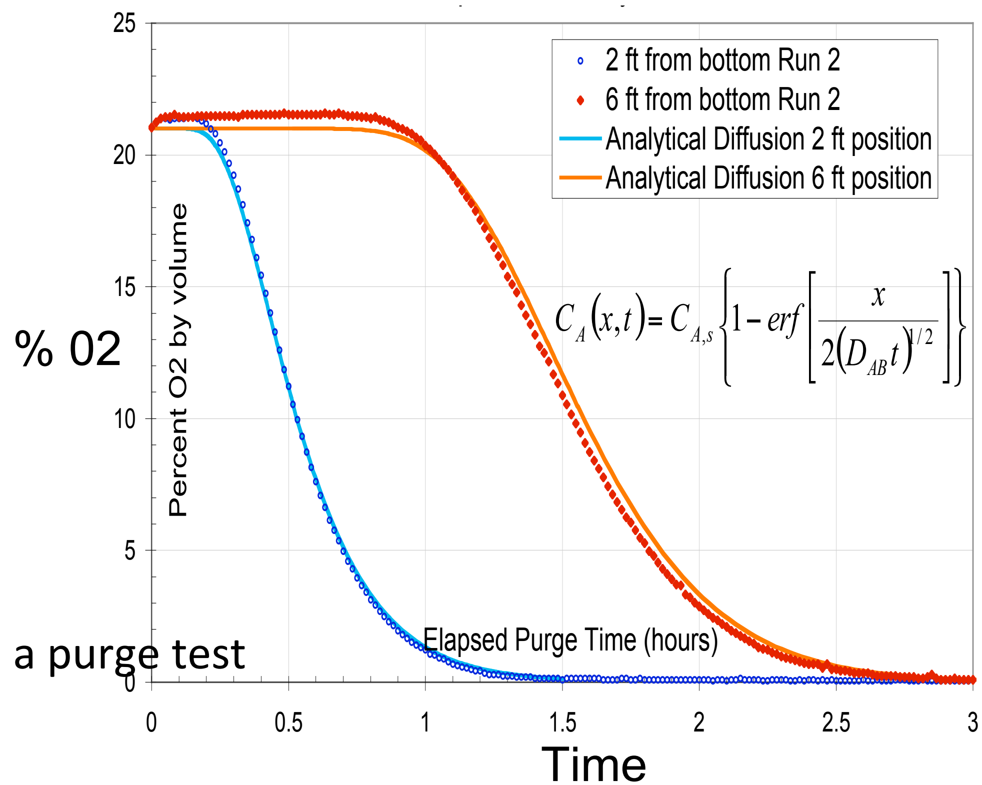
Liquid Argon Purity Demonstration - LAPD

LAPD tank being lowered into PC4
MAWP 3 psid internal 0.2 psid external, similar to much larger LNG tanks
0.18 inch thick stainless steel plate shell

Liquid Argon Purity Demonstration - LAPD

- Step 1 - Displace Air with an Argon piston
- To 100 ppm O2 (reduction of 2,000) takes 2.6 volume changes, simple mixing takes 7.6 volume changes



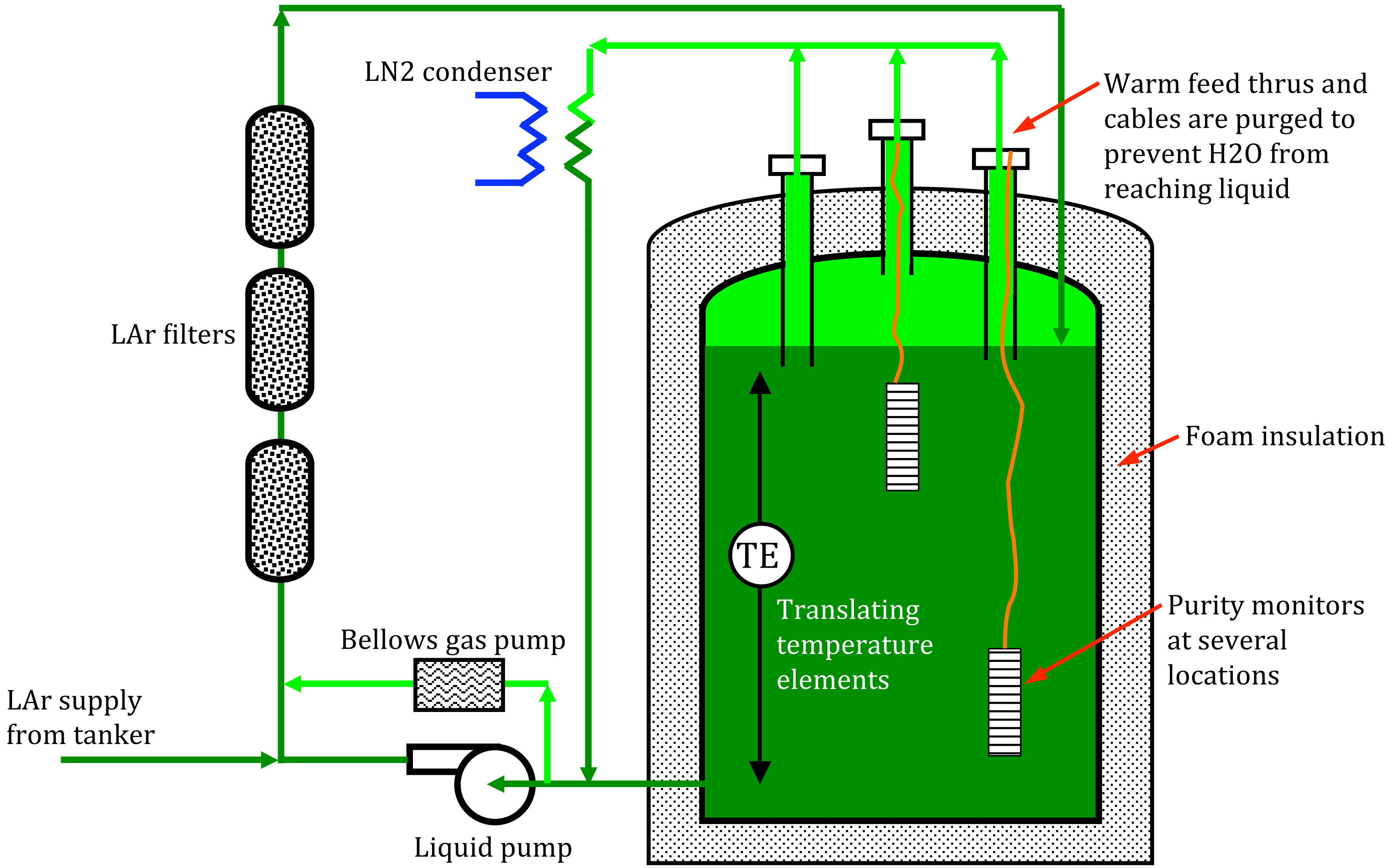


Data from a purge test

Liquid Argon Purity Demonstration - LAPD

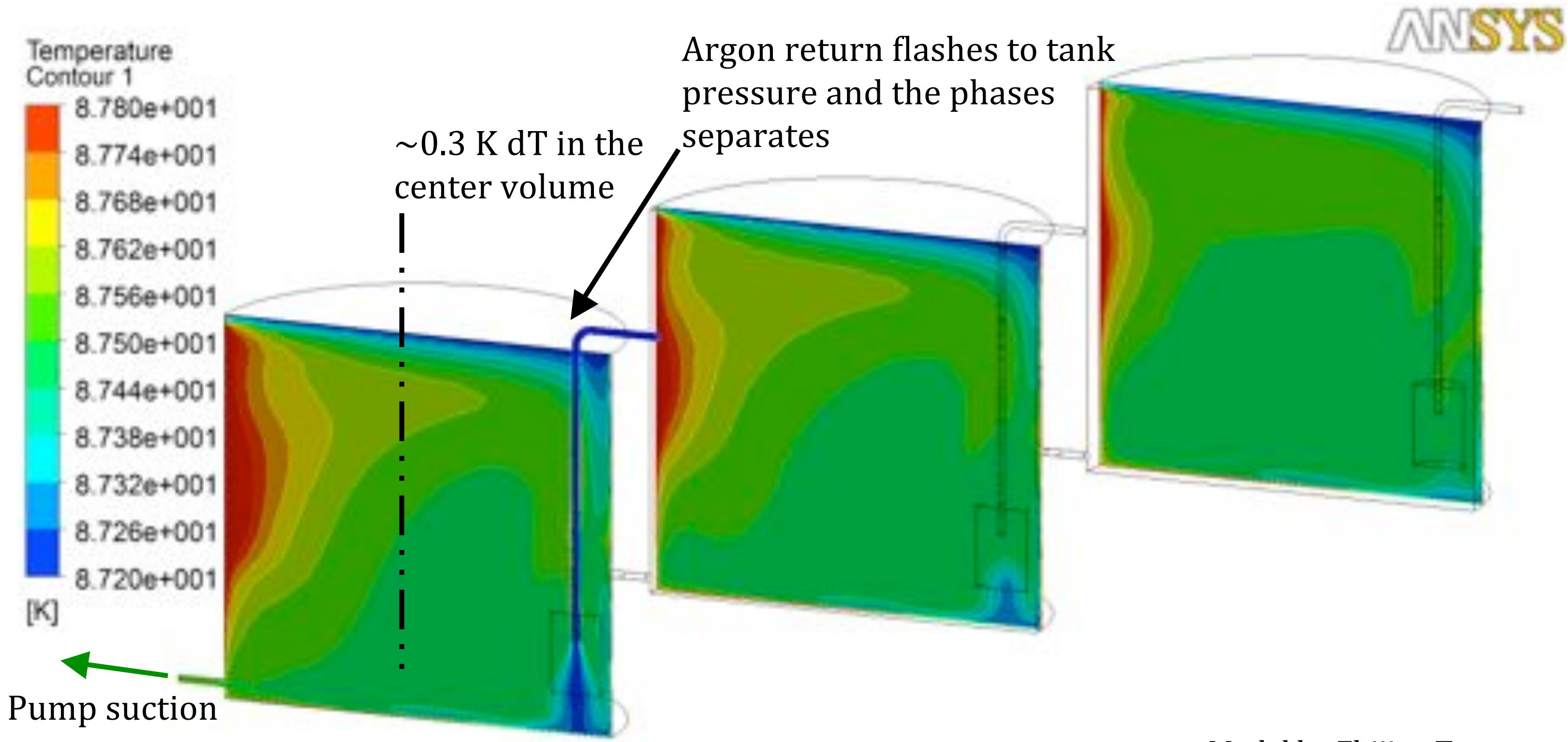
- Step 2 - Circulate Argon gas in tank thru filters using a high purity bellows compressor, heat tank shell
- Step 3 - Fill tank with LAr passed thru filters, tank will vent during the filling process
- Step 4 - Turn on LN2 powered condenser to close system and start pumping LAr thru the filters
- Run #1 - Engineering instrumentation and purity monitors only (very little non-metallic material in tank)
- Run #2 - Place a representative amount of detector materials inside the tank
- Run #3 - …………

Liquid Argon Purity Demonstration - LAPD



Liquid Argon Purity Demonstration - LAPD

- Translating temperature sensors will be compared to computer model predictions (CFD)



Model by Zhijing Tang

Liquid Argon Purity Demonstration - LAPD

- Predicted fluid velocity is in the 2-3 mm/sec range for filtering at an 8 hr time constant

Fig.8 Stream Lines

Model by Zhijing Tang

Questions????

- MANY people at FNAL, other national labs, and universities have contributed to the liquid argon TPC effort which has made it an exciting project to be a part of