Towards multi-kiloton LArTPCs

Test Stands and Purification Demonstrations

Role of `Test Stands' for Liquid Argon TPCs in U.S.

0. gain hands-on experience and develop some expertise and infrastructure to deal with hardware and software challenges of liquid argon TPCs;

1. prototype devices for large detector;

2. assure that individual components for full detector will work as required (electronics, signal feedthroughs, life-time monitors, non-contaminating materials, HV feedthroughs)

European groups already have item 0 for many years - not so in the U. S.

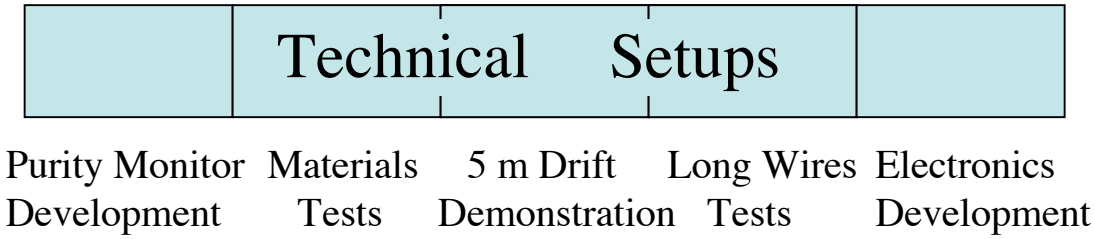
Issues for multi-kiloton detectors:

Argon-purity to enable long drift-distances
(1 ms drift-lifetime = 1.5 meters at 50kV/m)
Achieving clean argon without evacuation
(10 ms drift-lifetime ~ 30 ppt Oxygen equivalent)

Mechanical Construction of the TPC (wires >10 m)

Electronics: signal-noise, feedthroughs,cost ..
(big incentive to develop electronics that can go inside the cryostat - helps with S/N, feedthroughs, cost)

From 2005 submission to NuSag



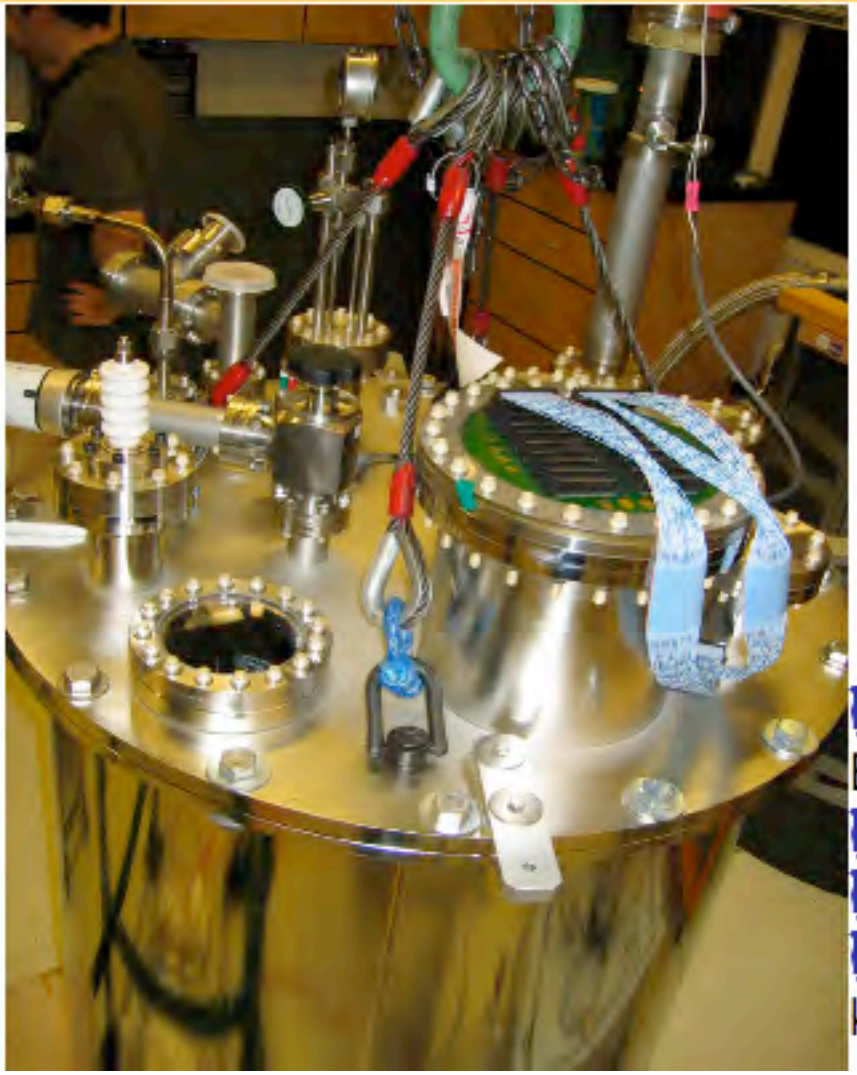
three of these are being pursued

Purity Monitor: photo-cathodes, light-sources

Materials Tests: ensure TPC materials do not contaminate Argon

Electronics: need to make our own electronics, (not available elsewhere)
wish to develop cold (in the cryostat) electronics,
wish to exploit new technologies

0: *Test Setup at Yale - 1st tracks in U.S.*



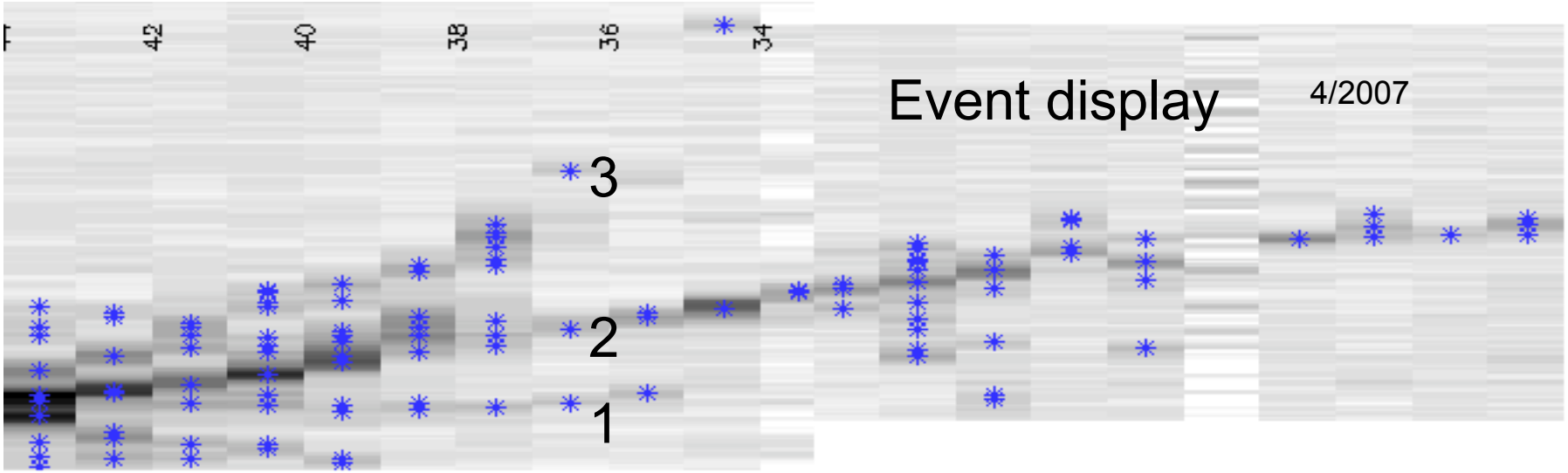
- ☑ 500 l vacuum vessel pumped down to E-5/E-6 mbar
- ☑ open bath of commercial LAr
- ☑ no active recirculation system
- ☑ relief valve from Hans Jostlein (FNAL) kept over-pressure below .3 atm

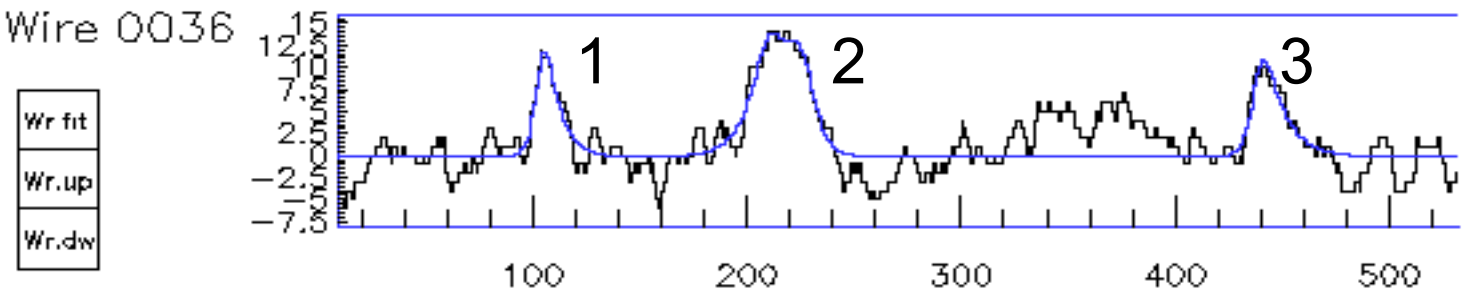
Test Setup at Yale - 1st tracks in U.S.

Open bath system

Fermilab oxygen-filter and TPC

Icarus electronics, signal-feedthrough and software





Test Setups at Fermilab

Luke: Materials Test System (MTS)
Bo: Electronics Test System - not yet in operation
Bell-Jar: Photo-cathode and light-fiber testing
L.A.P.D: 20 ton atmosphere to clean argon without evacuation - proposed to DOE for R&D funds (D. Finley)

Tests performed:
Milk-Can: Argon Piston
Moby-Dick: Purging a dirty tank to low Oxygen and water concent

Infrastructure Developments:

Single-pass clean Argon source with Oxygen & Water
Filters that are regenerated in place (non-proprietary)
Internal bubble-pump filter for Oxygen and Water
Fermilab versions of `purity monitor' and readout electronics
Nitrogen concentration measurement (relevant for light output)

Motivation for MTS:

test all materials that will go into the cryostat to ensure they do not contaminate the argon long-term.

Challenge for MTS:

Insert materials into clean argon without first putting the materials under vacuum. (Kiloton TPCs will not be evacuable)

Features of MTS:

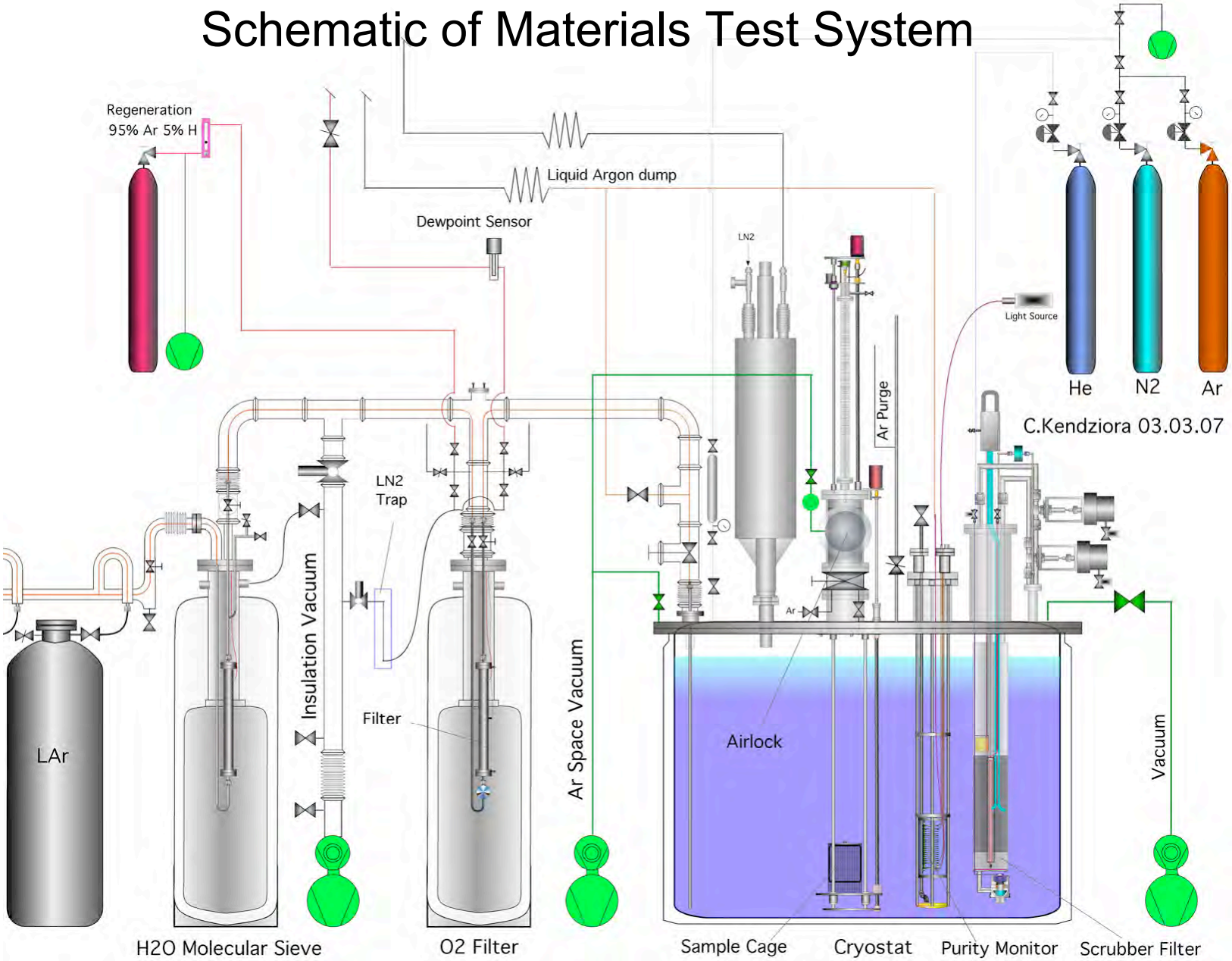
Single-pass fill system with oxygen (activated copper) and water (molecular sieve) regenerated in place.

Argon-lock plus drive and platform system to insert without evacuation;

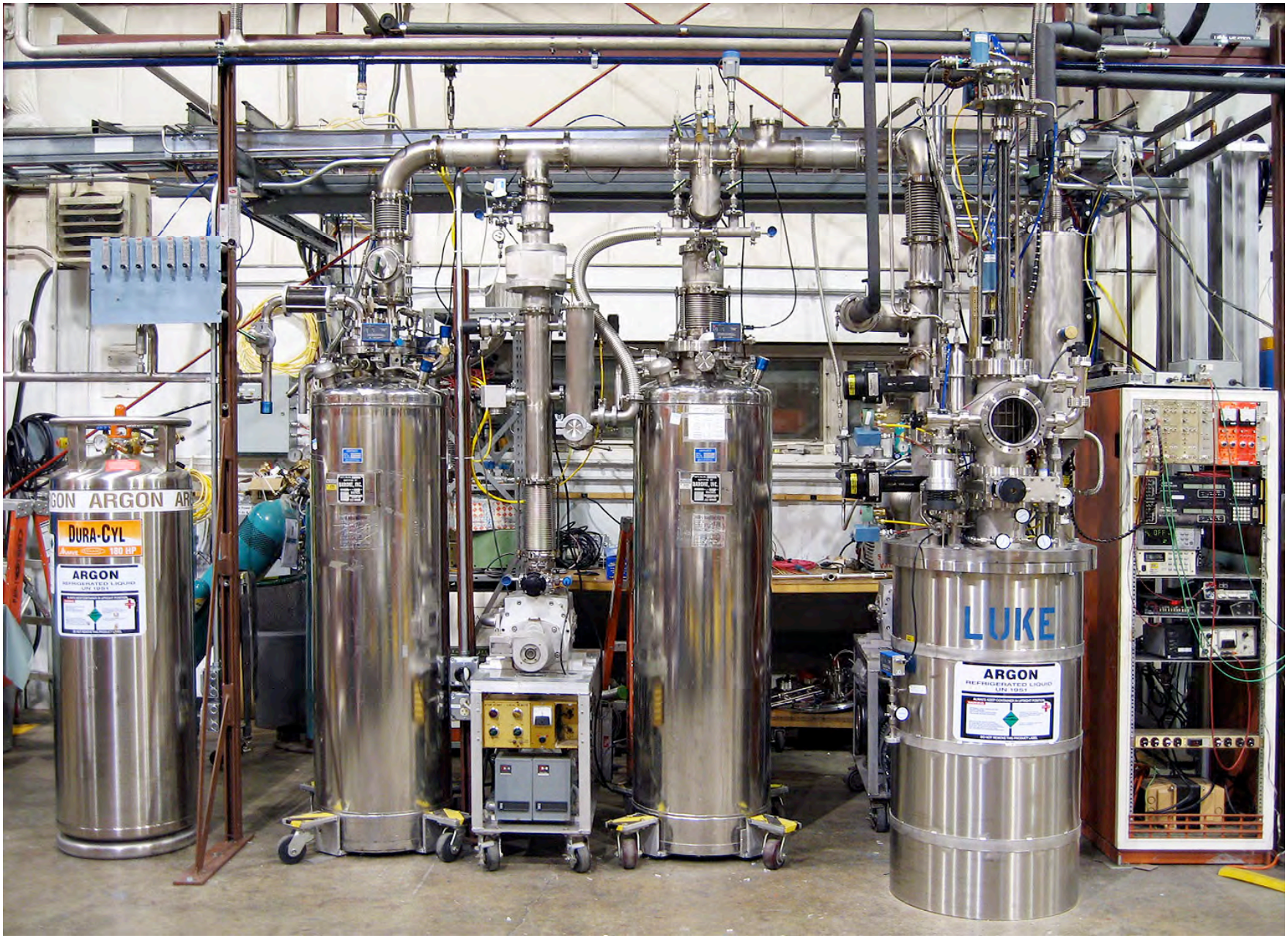
Internal filter-pump, gas-insertion line, gas-monitoring line,

Ability to put material in liquid, and in gas-phase at temperatures from 90K to 300K.

Schematic of Materials Test System



Photograph of MTS



The essentials of the MTS cryostat.

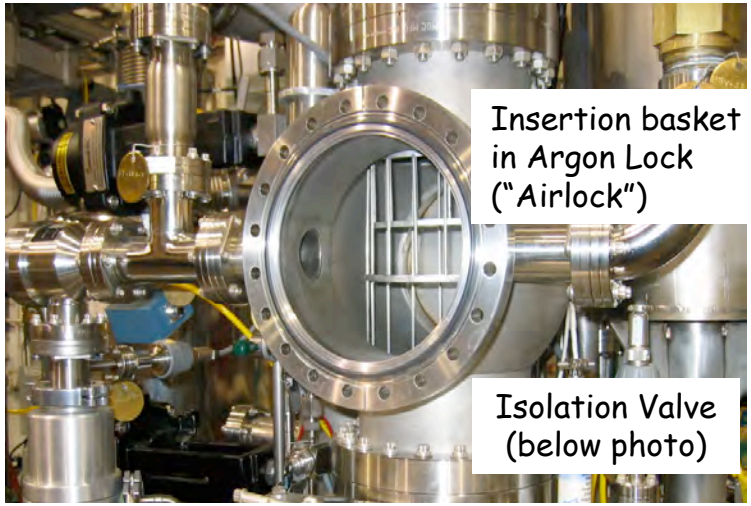
The main features are

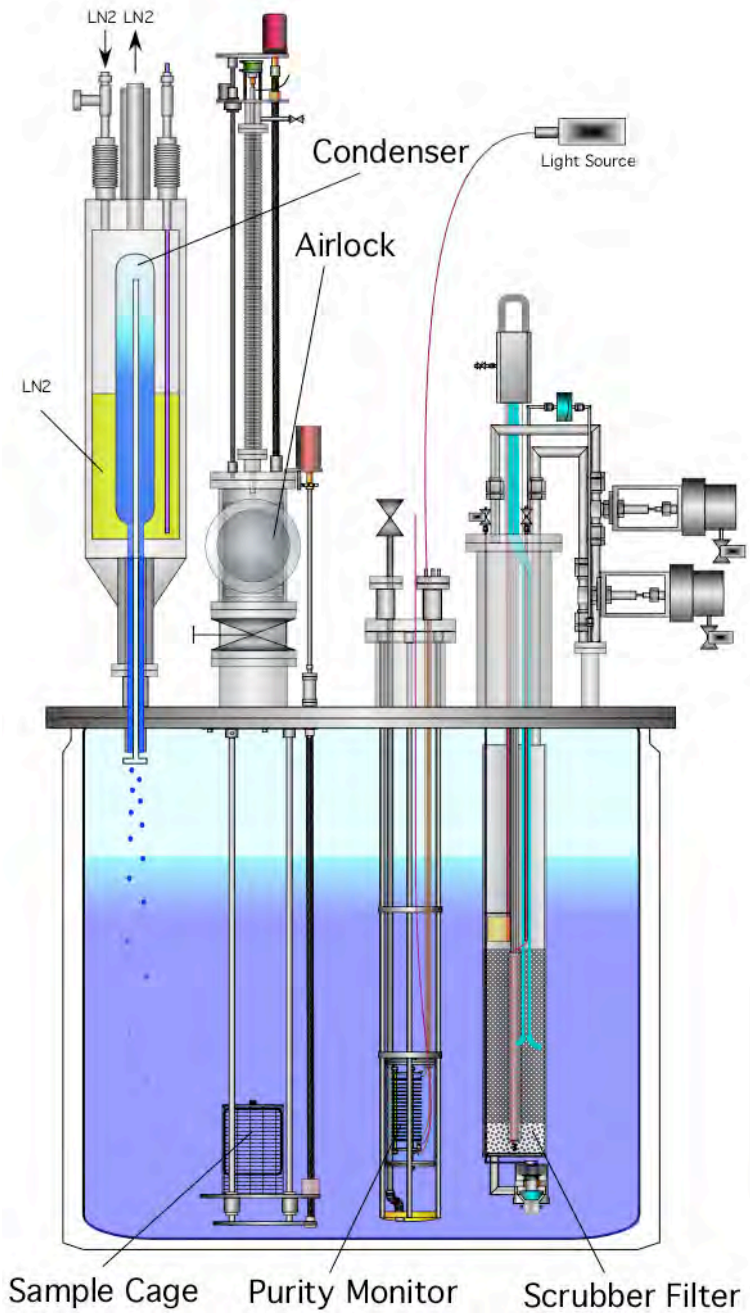
the condenser
(to maintain a closed system)

the sample insertion mechanism
(allows insertion of materials without evacuation)

the lifetime monitor (PrM)
(to measure the electron drift-lifetime)

the filter pump
(filled with zeolite and oxygen-filter material)



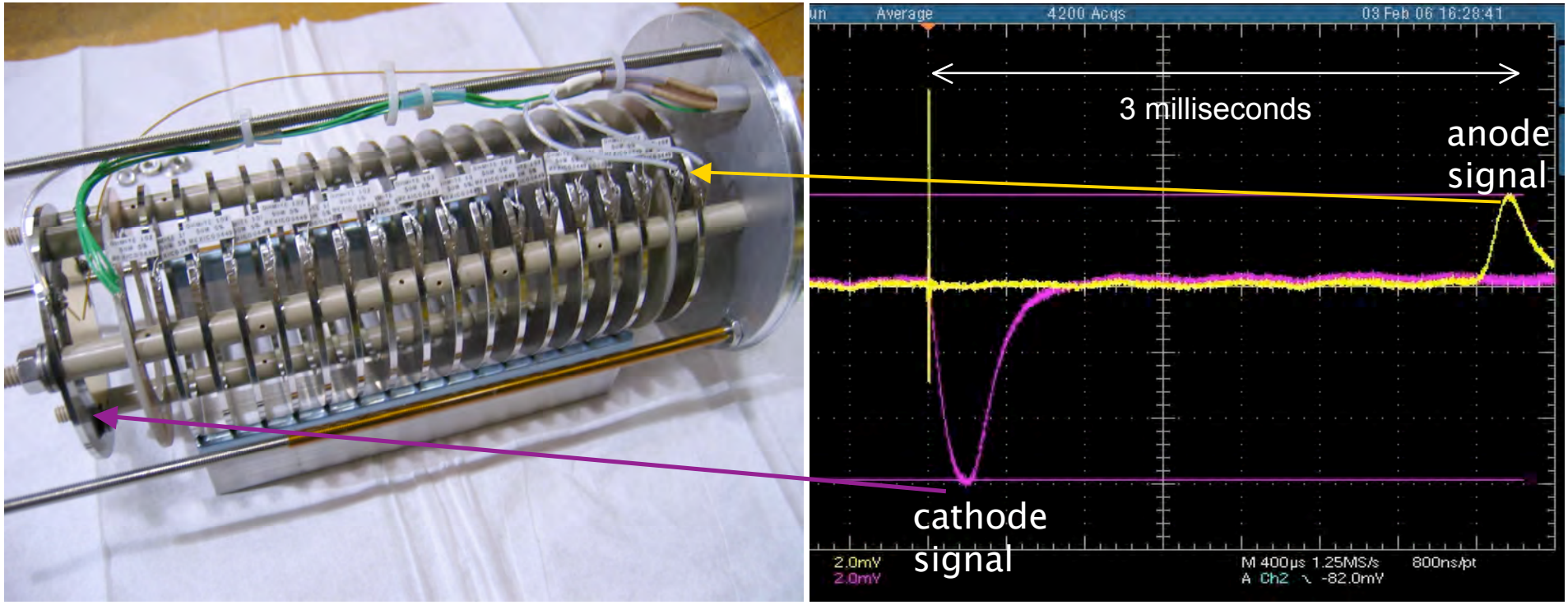


Lessons of type 0 learned:

Water from source argon and from materials outgassing is a serious challenge: zeolite/molecular sieves need to complement oxygen filters.

After that, we achieved many millisecond lifetimes with non-closed systems.

Nitrogen at ppm level does not affect drift-lifetime (cf ppt level for Oxygen)



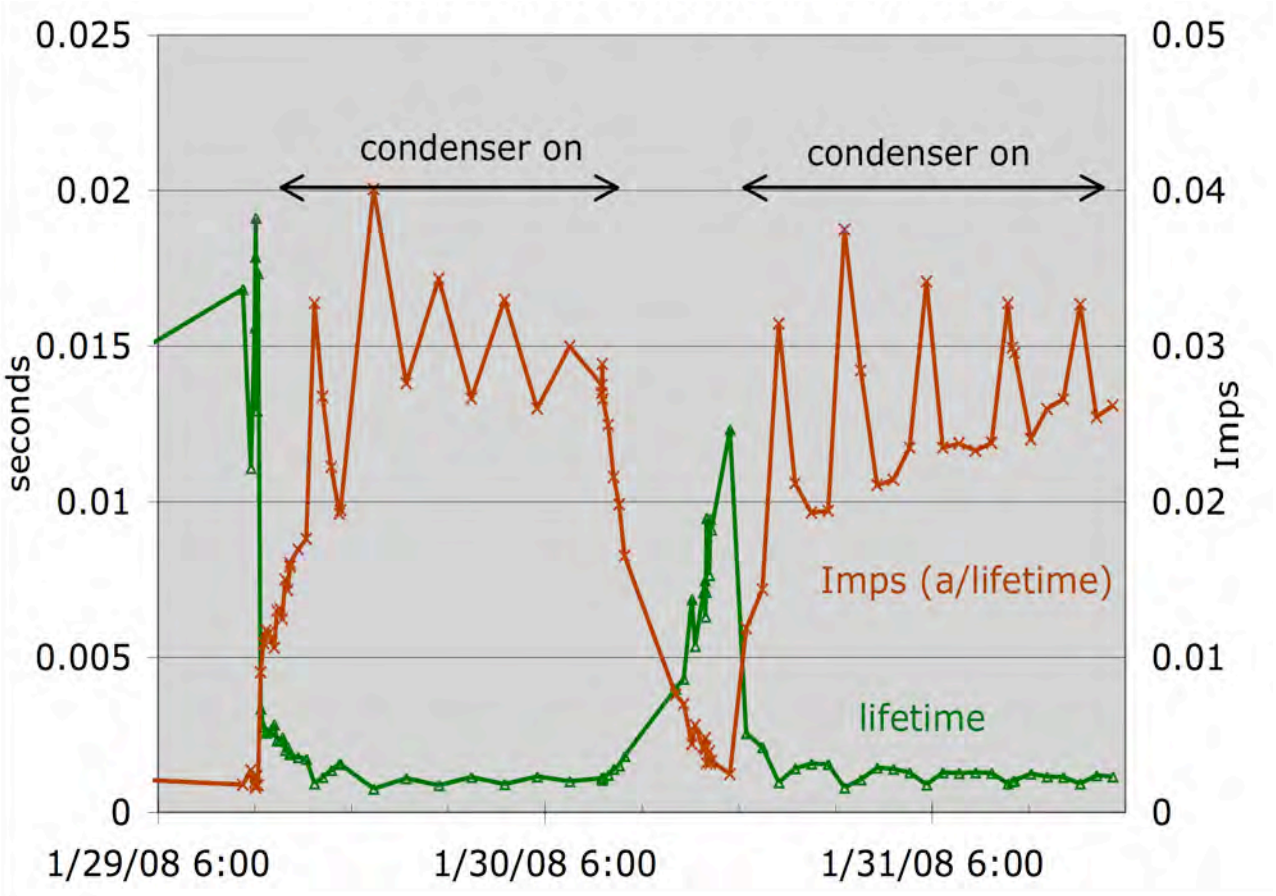
(G. Carugno et al., NIM A292 (1990))

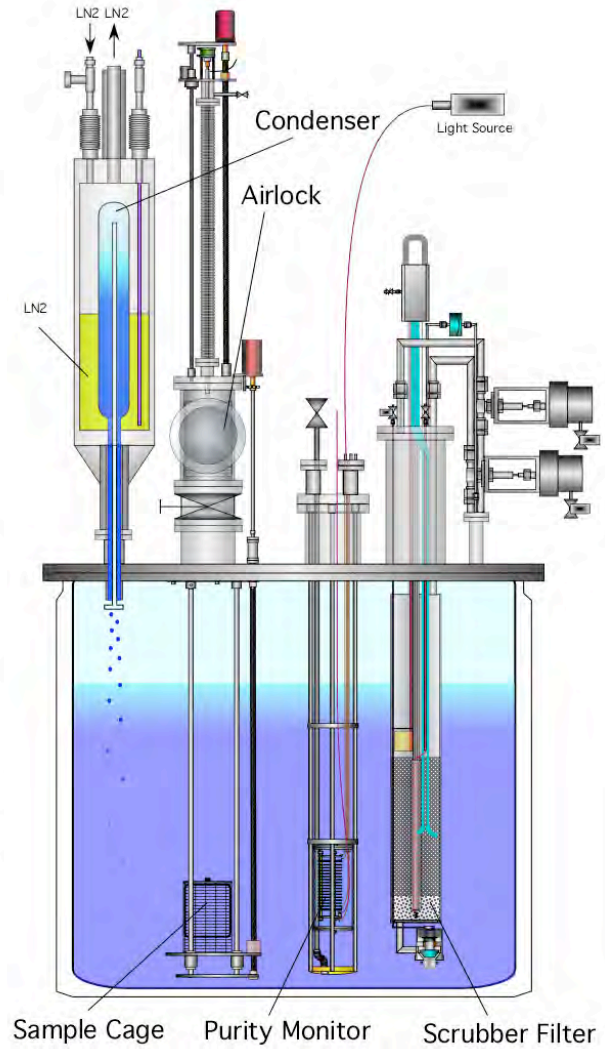
$Q_A/Q_C = e^{-t_{drift}/lifetime}$

Lessons of type 0 learned:

Raining condensers may be a problem

Effect of Condenser Operation on Lifetime





Cure for condenser effect:

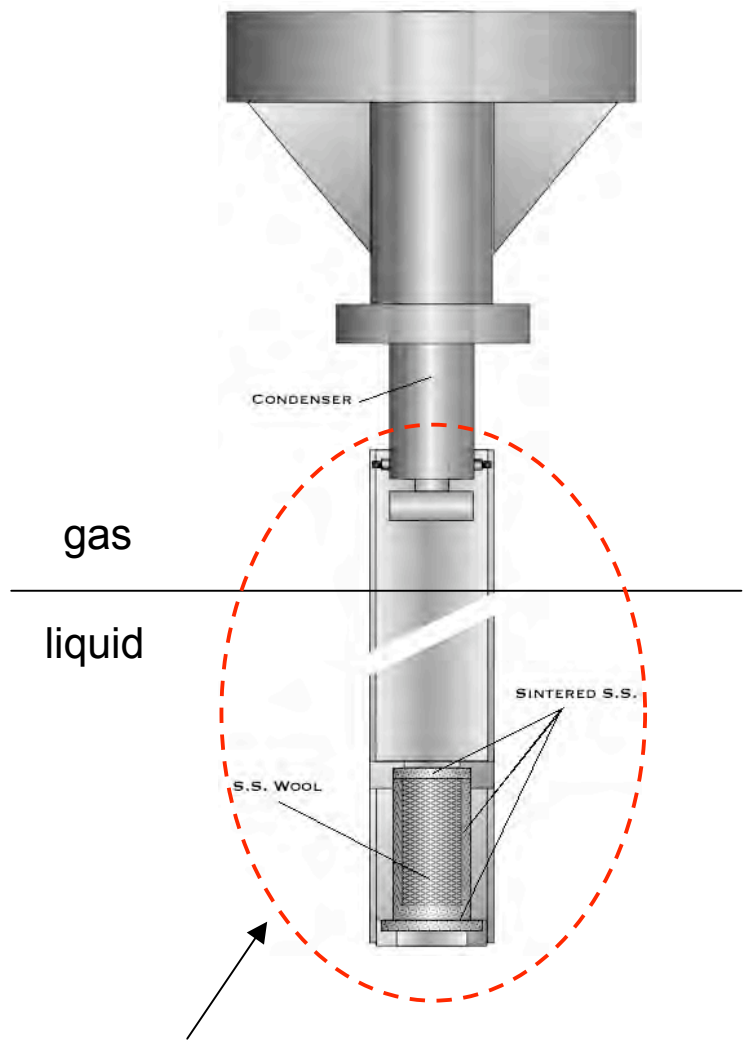
Effect (believed to be) caused by Argon ions developed as liquid drips from bottom of condenser through Argon gas onto liquid surface.

Extended condenser return into liquid by adding pipe with sintered SS and SS wool to discharge ions.

Effect eliminated.

Will verify explanation by replacing pipe and SS material with a rod at some voltage to attract ions directly.

Significant for design of large tanks where we are considering N2 condenser coils in the ullage



Modification to condenser output

Features of Operation:

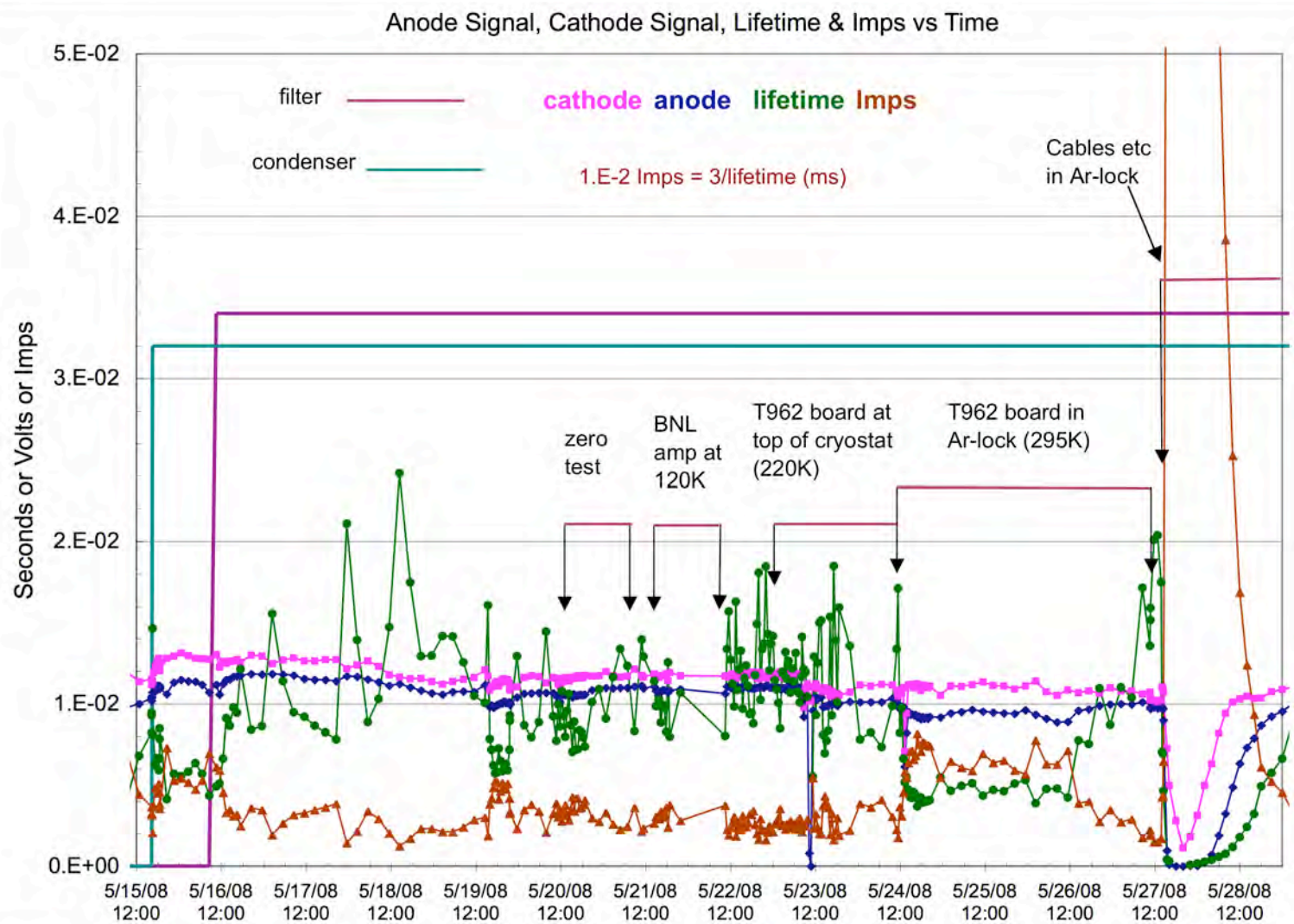
1) can measure lifetimes up to ~ 10 milliseconds
($\tau = t_{drift}\, Q_a/(Q_c-Q_a)$, when $Q_c \sim Q_a$ measurement diverges)
(we have made and tested a PrM which is 3 times longer)

2) can put samples in liquid and in gas from liquid temperature to room temperature (in Argon Lock). Little effect seen in liquid or cold-gas; large effects have been seen in warm gas.

3) internal filter effective in removing contaminants from cable-ties, cables and connectors

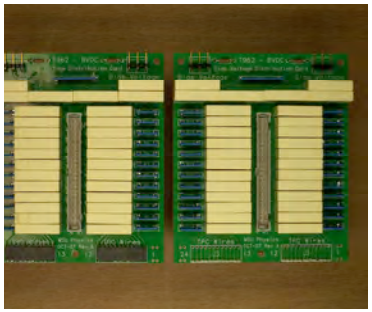
4) venting improves the life-time

Plot from on-going run where we have tested a BNL pre-amplifier, a T-962 blocking capacitor board and a mass of cable-ties and cable.

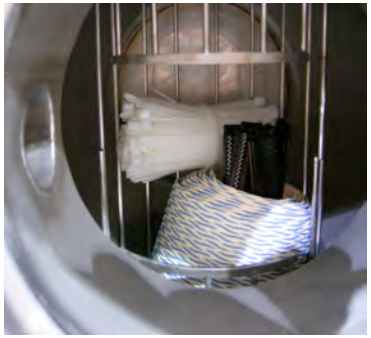


BNL pre-amp

T962 Capacitor Board



Cables & Cable-ties



Motivation for Bo:

Provide a system with signals from an actual TPC in LAr to test performance of front-end electronics (as developed at MSU and BNL).

Features of Bo:

Cylindrical TPC, 96 channels in 3 planes, with 50 cm drift and 24 cm diameter; separate purity monitor (PrM); there is space for electronics in the cryostat when we come to test `cold' electronics.

(TPC also has gold photocathode on cathode so it can act as its own PrM)

Present front-end electronics designed and built at Michigan State; MSU has provided DAQ, using DZero ADC and memory boards, and trigger.

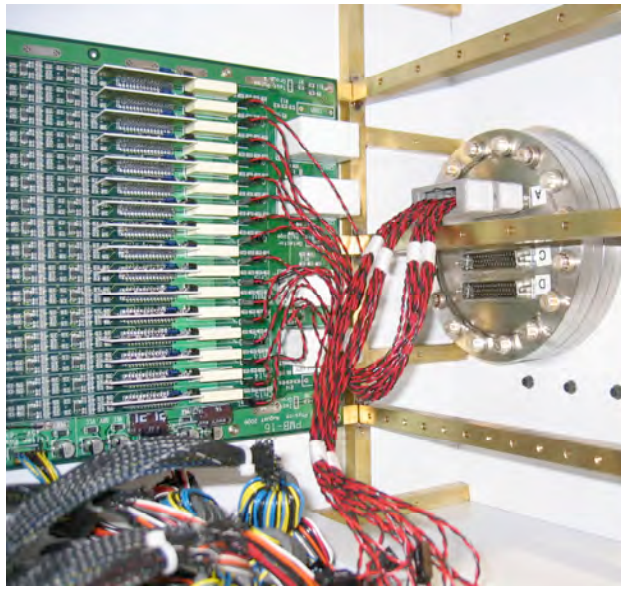
Present Challenge for Bo:

Resources to complete the cryogenics system while developing Luke. (Electronics from MSU have been ready for > 1 year).

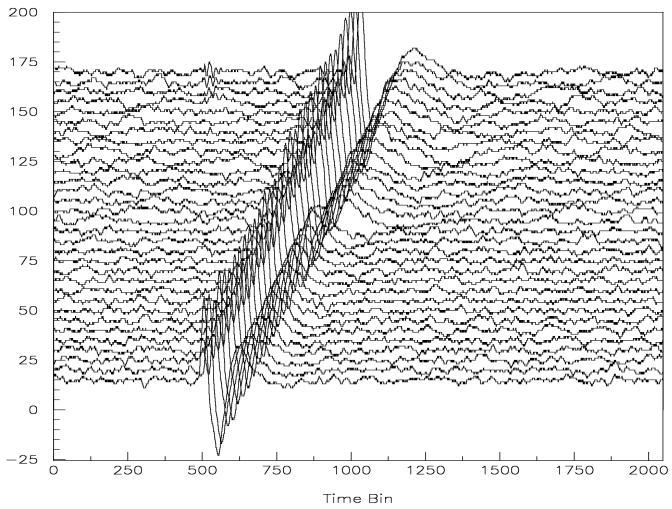
Development of local reconstruction and display software (may hear relevant stuff in ArgoNeut talk)

TPC being inserted into Bo:

Electronics Installation (Michigan State)

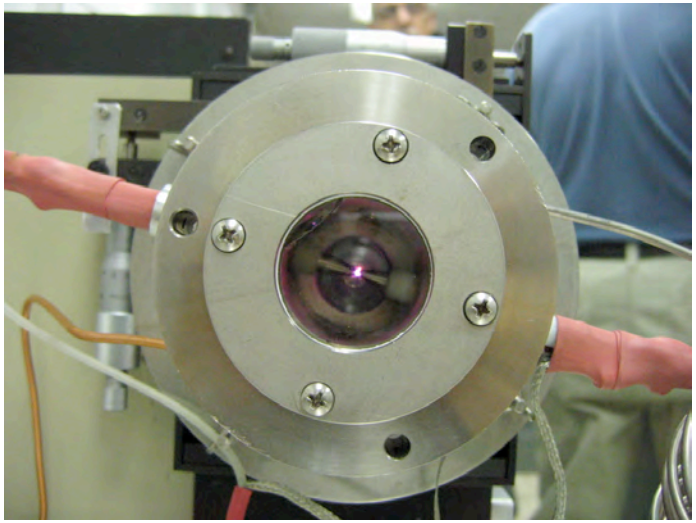


Response to Test Inputs and Noise Check

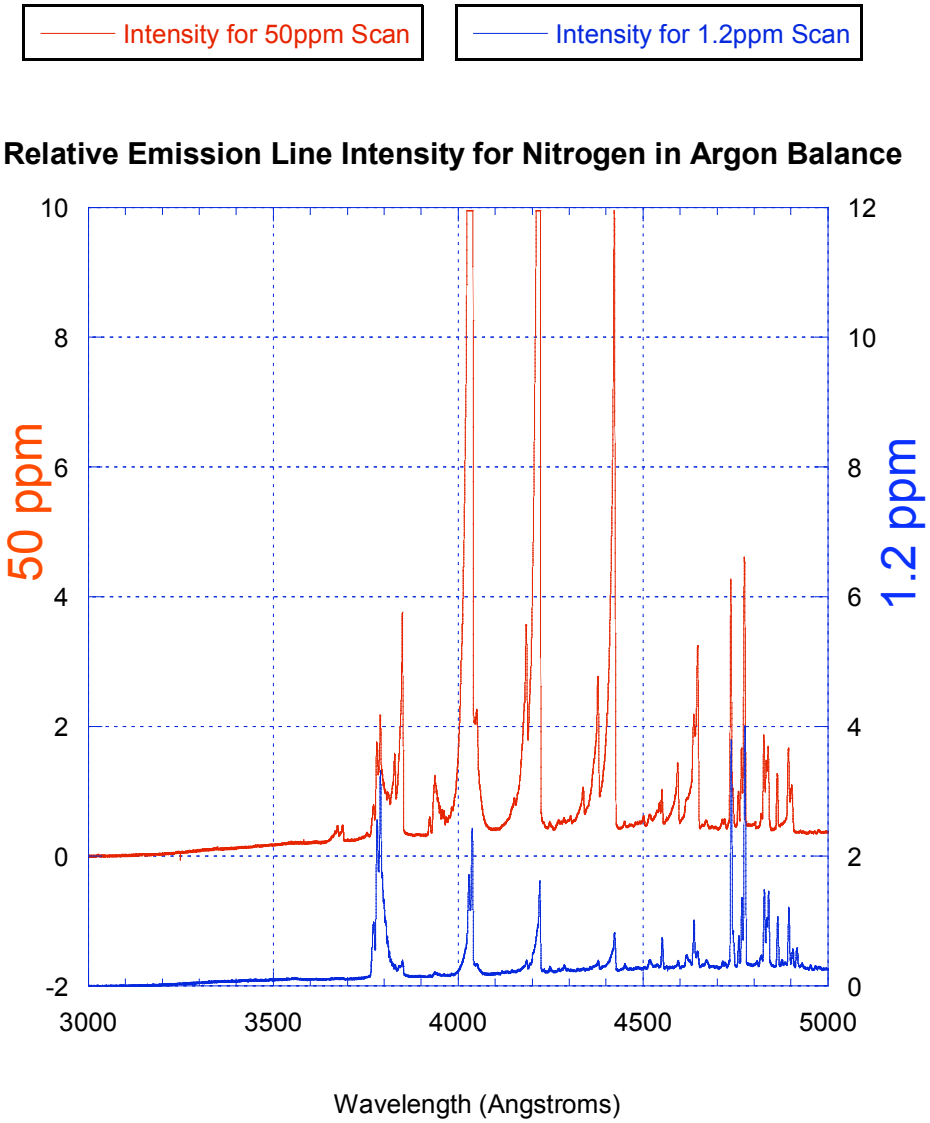


Nitrogen in Argon Measurement
(*based on Nitrogen in Helium for Tevatron)*

arc-cell, monochromator, PMT



the arc



Materials Test System (Luke) summary:

achieving item 0 - crucial education
powerful system for testing materials
some interesting features of operation yet to understand

Electronics Test System (Bo)

exists - awaiting final safety review

Turn to Purification:

filtration systems (operating on bulk liquid (and gas?))
achieving clean argon from atmosphere without evacuation
(all current LArTPCs are evacuated)

Filtration Systems:

The MTS has demonstrated we can make and regenerate our own filters to operate on source argon (few ppm oxygen). This also means we can investigate different filter materials as we wish. The present combination of zeolite and activated copper seems quite effective.

Scheme to remove atmospheric oxygen without evacuation.

There is ~200 times as much Oxygen in the atmosphere of the vessel as in the source Argon (assuming 1 ppm Oxygen concentration) . Purging with argon-gas can reduce the Oxygen to better than a ppm at which point one can either introduce liquid argon and re-circulate through the liquid Argon purifier system or pass the gas through a gas-purification and recirculation system.

We have run tests to demonstrate the effectiveness of purging and to see what levels of Oxygen and water can be achieved with a simple gas-purification system.

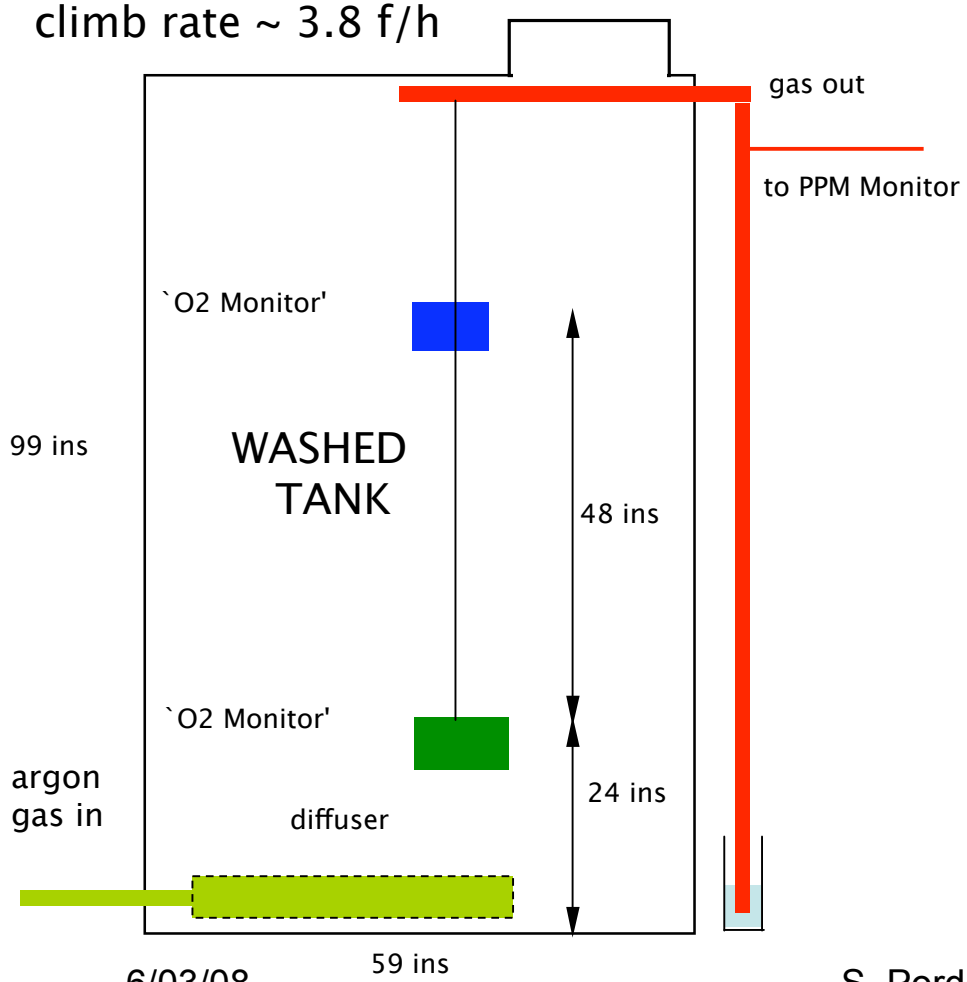
A group at Fermilab has requested funds for a 20 ton test to show that we can achieve good lifetime without evacuation in an industrial vessel including the materials of a TPC (but not an actual assembled detector).

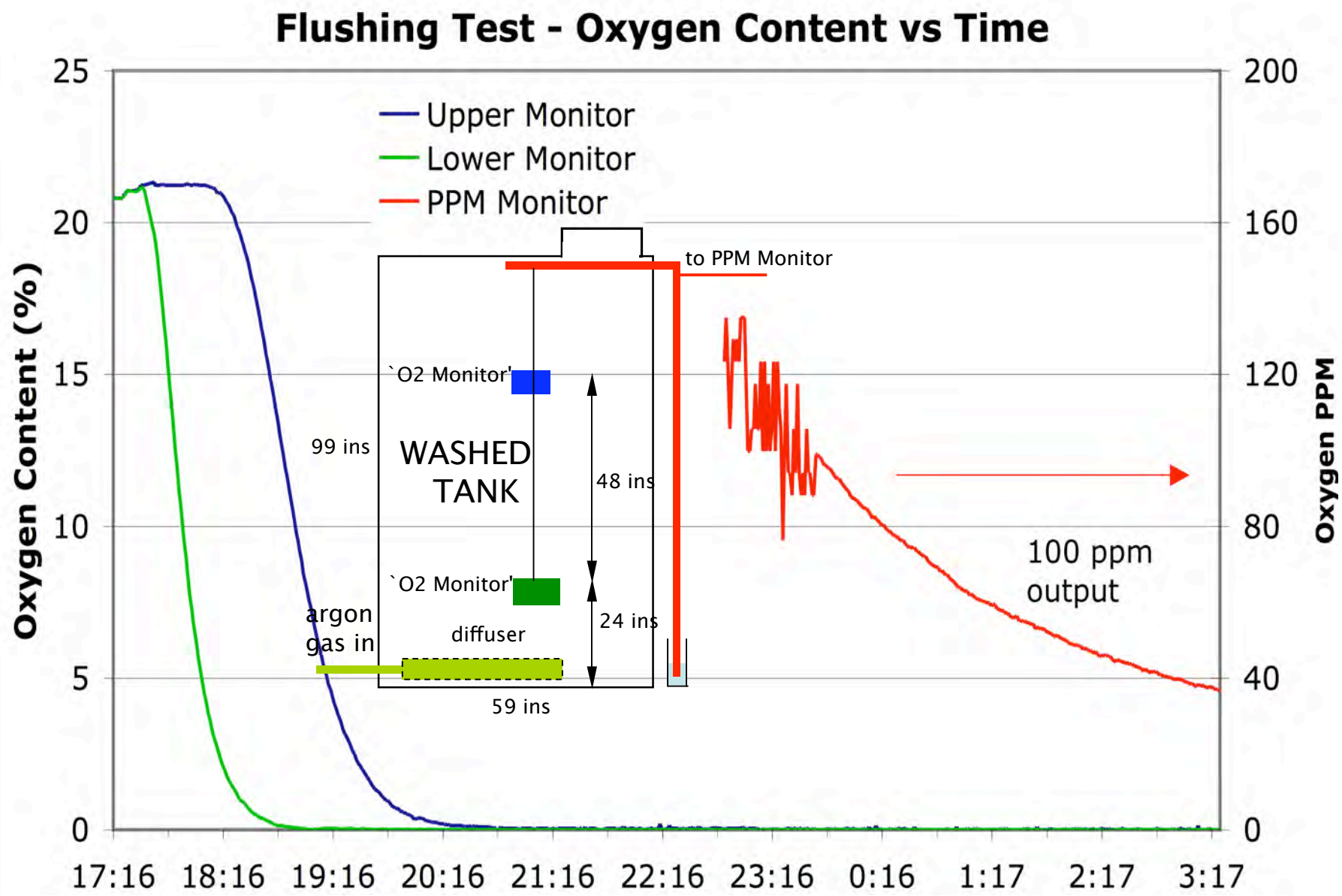
MicroBooNE proposes to start its first run without evacuation. If this succeeds, it will be the first demonstration of achieving a large working LArTPC without evacuation.

The Argon Piston

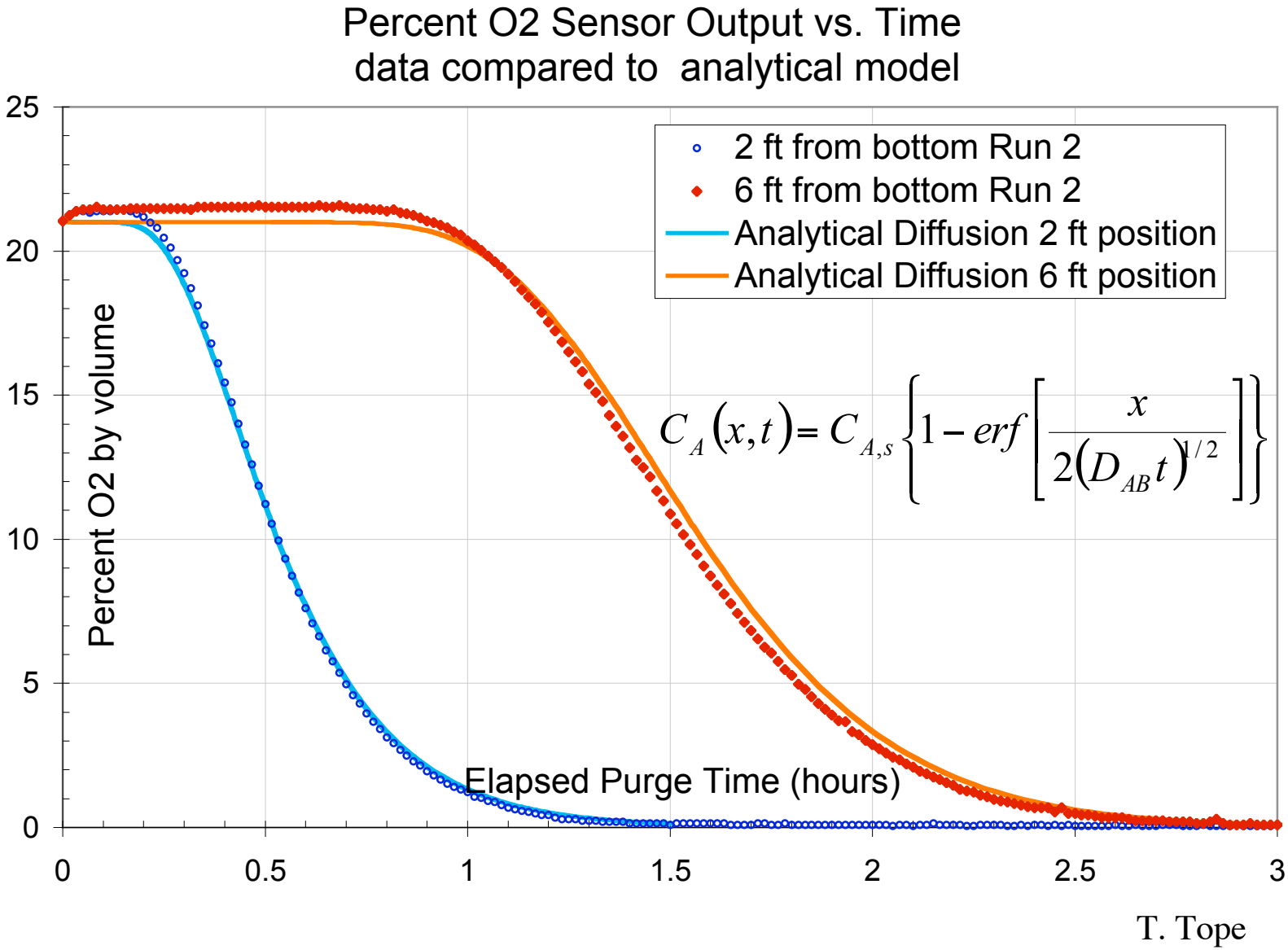
insert Argon gas at bottom of tank over large area at low velocity;

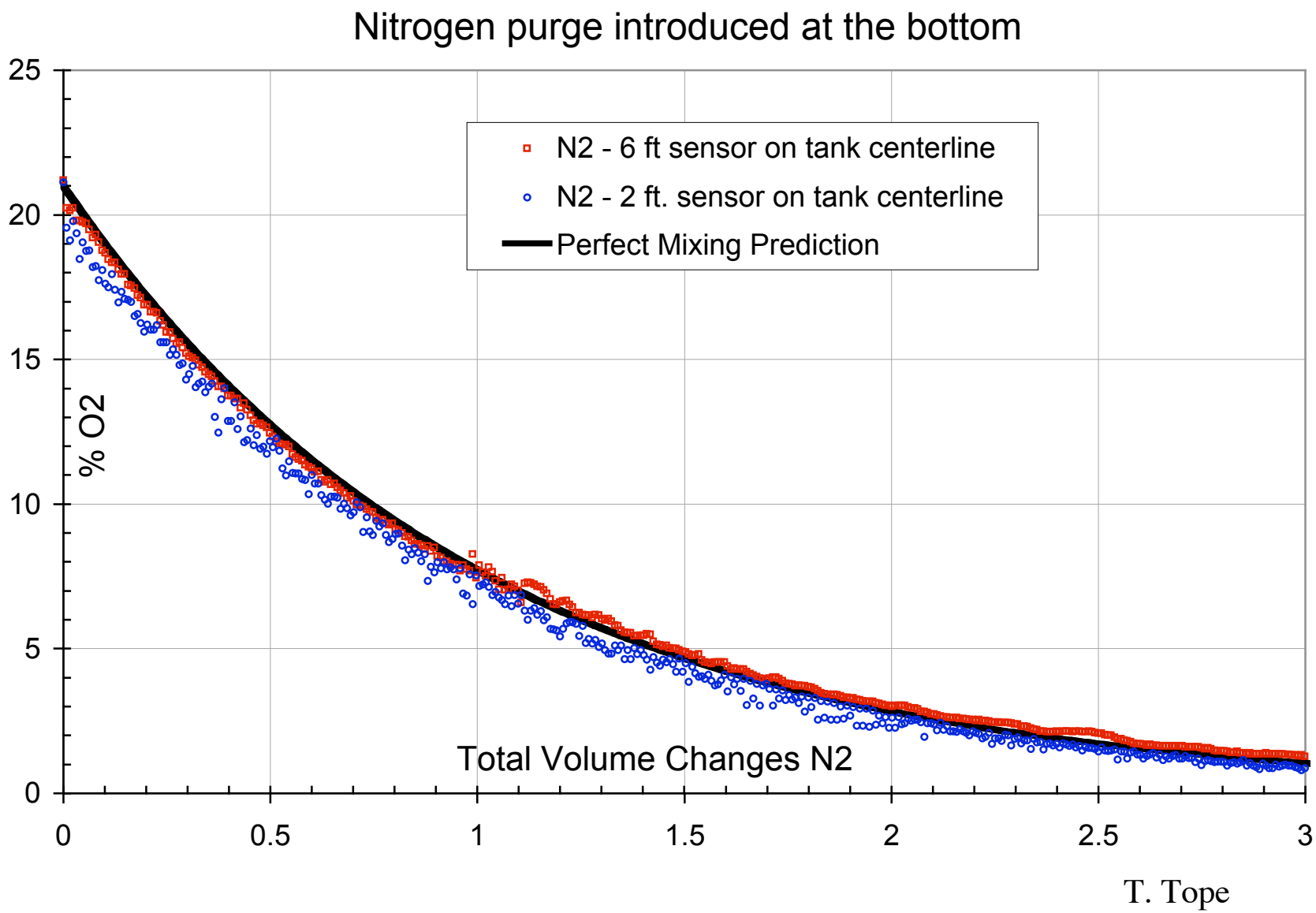
tank volume = 157 cf
tank cross section = 19 sf
flow rate ~ 73.2 cf/h
climb rate ~ 3.8 f/h





to 100 ppm (reduction of 2,000) takes 6 hrs = 2.6 volume changes
(cf simple mixing, which predicts ln(2000) = 7.6 volume changes)


Percent O2 Sensor Output vs. Time
data compared to analytical model
2 ft from bottom Run 2
6 ft from bottom Run 2
Analytical Diffusion 2 ft position
Analytical Diffusion 6 ft position
$C_A(x,t) = C_{A,s}\left\{1 - erf\left[\frac{x}{2(D_{AB}t)^{1/2}}\right]\right\}$
Percent O2 by volume
Elapsed Purge Time (hours)
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
T. Tope


Nitrogen purge introduced at the bottom
N2 - 6 ft sensor on tank centerline
N2 - 2 ft. sensor on tank centerline
Perfect Mixing Prediction
% O2
Total Volume Changes N2
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3

T. Tope

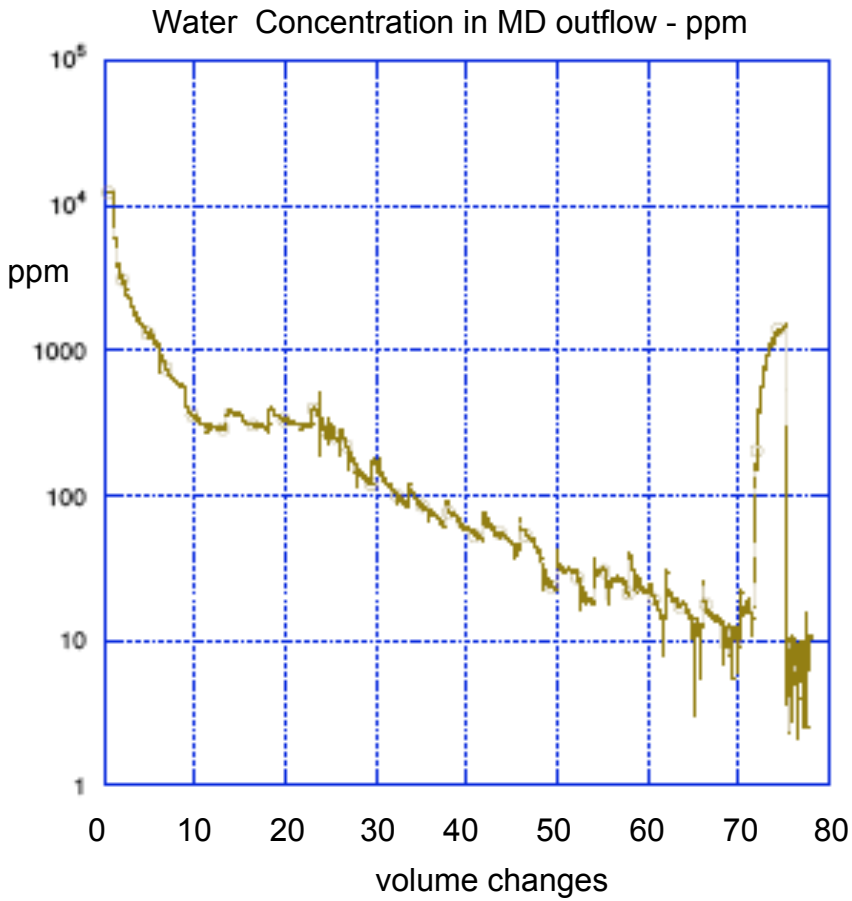
From atmosphere without evacuation
Purge Test of a `dirty' vessel - Moby Dick

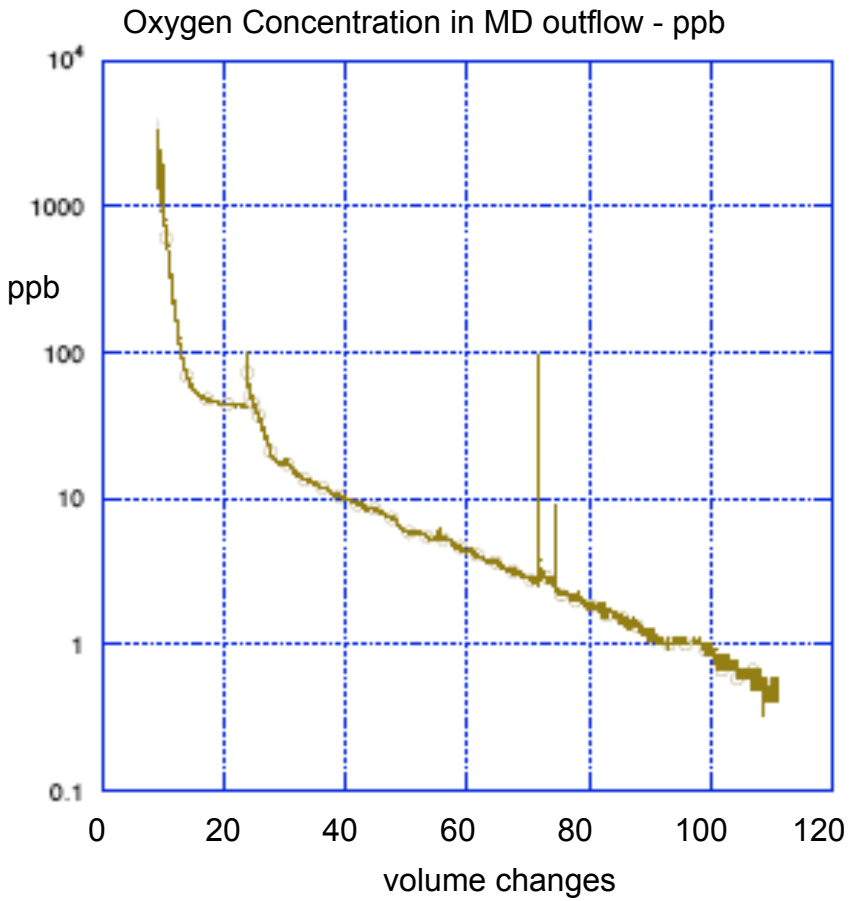
No attempt to clean after hydrostatic pressure test;
The vessel was previously used for compressed air storage.

History of Moby Dick purging:

Oxygen concentration fell to 1 ppm in 10 volume changes (Argon Piston); a recirculation-purification system then reduced the Oxygen concentration to <1ppb (1 ppb gas ~ 1.1 ppt liquid)

0.1 ppb Oxygen meter





Liquid Argon Purity Demonstration - LAPD (D. Finley & R. Schmitt)

Industrial vessel,, trucked in to site, foam insulation, TPC materials (no assembly), 20 tons Lar, lifetime monitors, flow meters, RTDs

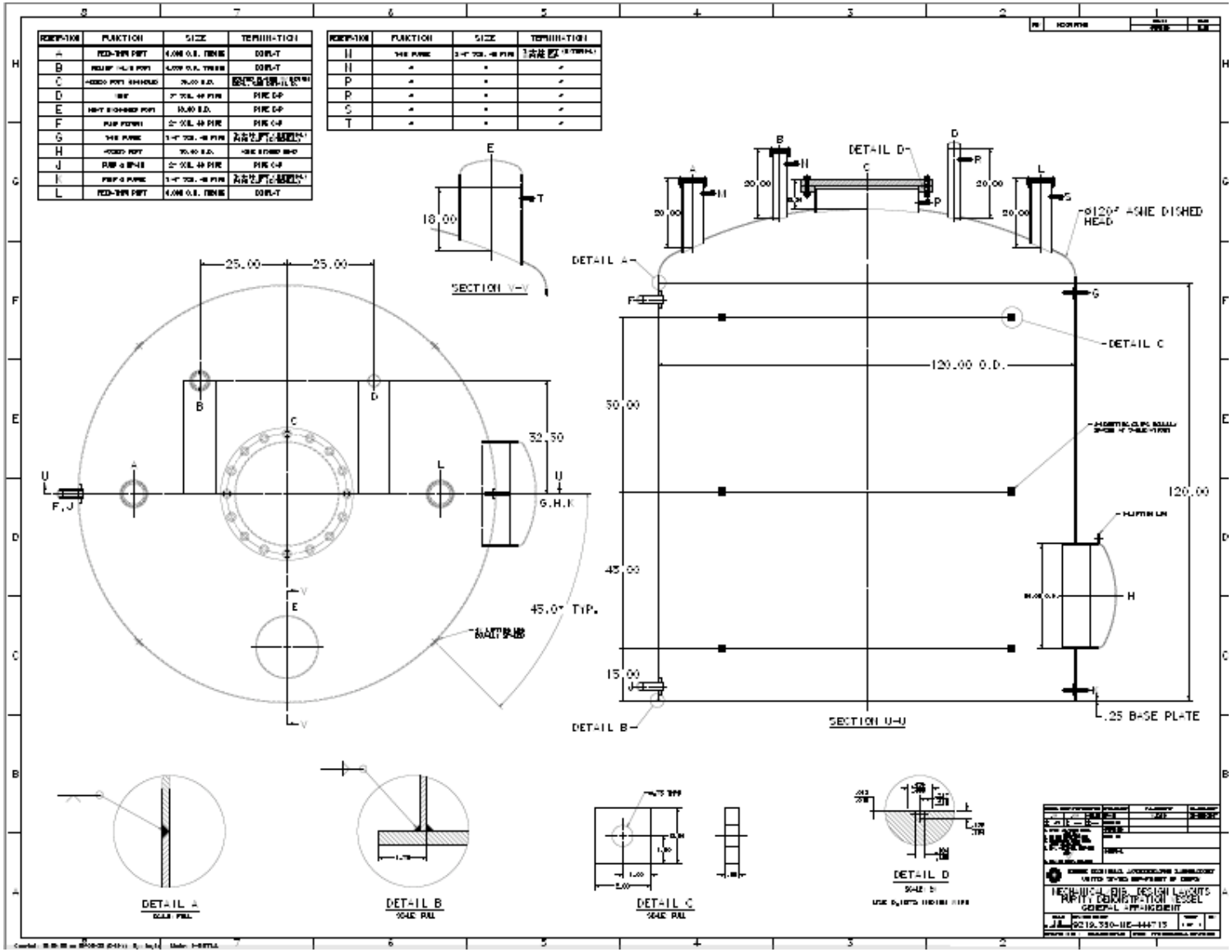
M & S (only) cost $300,000 - requested funding from DOE R&D funds.

Designed to test/demonstrate ability to achieve good lifetime within a year of receipt of go-ahead. Can also check flow and temperature distributions

Speed is of the essence:

- if successful, provides encouragement for MicroBooNE test (with real detector and real events) and larger devices;
- if initial failure, provides some time to investigate and implement changes for MicroBooNE

Tank Design for Liquid Argon Purity Demonstration



MicroBooNE plan:

Devote two months to achieve clean argon without evacuation; purge with warm Argon-gas to the ~ppm Oxygen level, recirculate gas with water and oxygen filters, then introduce liquid and recirculate through liquid filtration system.

backups

Kephart questions:

1)Planned Source of Argon : Linde, Air Products. We enquired 2 years ago re 50 ktons. Could be supplied in 3 to 6 months. A spec of ~few ppm was considered reasonable by the vendors. We've been using stock dewars for the MTS - they are a few ppm. Conformance to the oxygen spec can be measured with a commercial Oxygen meter. The Argon goes into a buffer-tank and a sample is filtered and measured with a `purity monitor'. It then passes through a single-pass purifier into the vessel.

2) Ar purification scheme: Single pass liquid purifier into vessel. Liquid recirculation purifier on vessel. Gas recirculation is not decided. Oxygen filter (activated copper on alumina) removes oxygen and other electro-negatives; zeolites remove water. Evacuable large vessels are not practical - hence the efforts to demonstrate we can purge successfully. MicroBooNE is evacuable but will devote time and effort to this demonstration. Leak-checking on the non-evacuable vessel is done with gas overpressure (small), and radiography to check the welds.

3) Analysis and monitoring of impurities: The critical test is the lifetime monitor. We have commercial oxygen monitors good down to 100 ppt. For general analysis we are looking to see if chromatographs have adequate sensitivity.

4) Plumbing: we will use steel and metal seals everywhere we possibly can. We have found acceptable valves to use for the MTS - there is some experience at BNL and Fermilab on these. We are aware of the issues of trapped volumes producing virtual leaks and where unavoidable will purge or pump on these regions.

5) Feedthroughs: The issue of feedthroughs has attracted a lot of work. ICARUS has a patented signal feedthrough based on PC boards with no through vias. ArgoNeut uses a modification of the BTeV feedthrough which uses a PC board but does not rely on it for any strength or seal. The present design of MicroBooNE uses a modified version of feedthroughs designed for Atlas. HV penetrations follow the

Kephart questions continued

5) (cont) ICARUS design of F. Sergiampietri that has been tested successfully to 150 kV. Yes (or no) - we do not plan to use SF6.

6) Control: ICARUS uses a nitrogen shield around their vessel to control the temperature. We do not propose to do this for large tanks. The mechanical analysis group at Fermilab has studied the temperature and flow distributions in large vessels (and MicroBooNE) assuming various heat-loads and finds remarkably uniform temperatures and low convection speeds without such external systems. The question of whether the Nitrogen condensing coils to remove the heat input are located in the ullage or outside is not settled. In general, the temperature of the Argon will be set by the temperature of the Nitrogen - which is set by the pressure in the condensing coils.

7) Materials: The Materials Test System is designed to study the effect of the materials used to construct the detector.

8) Monitoring: A set of purity monitors distributed appropriately through the detector will be used to monitor the state of the liquid argon. We are considering various designs for these but none of them presently involves a radioactive source. (There have been monitors based on radioactive sources)

Ridox™ Reagent removes 99% of the oxygen present in laboratory gases

Ridox™ Reagent removes oxygen from your gas systems, simply and efficiently. Merely pass the gas through a simple tube or bed of Ridox Reagent.

Just heat the Ridox Reagent to an operating temperature of from −40°C to +200°C, based on the temperature of the gas to be treated. No cumbersome heating and cooling of gas required. Under normal use, Ridox Reagent will remain active through numerous cycles.

Removal of unwanted oxygen protects oxygen-sensitive materials, such as reactive chemicals, high purity metals, and biological specimens. Improves the performance of analytical instruments that may be adversely affected by trace oxygen in carrier gases.

When used in a central purification unit, Ridox Reagent purifies the entire inert gas supply of a large multi-purpose laboratory. Assures individual labs of oxygen free nitrogen for all their needs: analytical, reaction inert blanketing and inert chambers.

What is Ridox Reagent?

Ridox is a highly active metal deposited on an inert aluminum oxide carrier. The reagent is in the form of dark gray, irregular shaped granules (8-14 mesh).

The reagent, as received, is in the oxidized state, and must be reduced before first use. Reduced Ridox has a slight red cast, which gradually turns dark gray, upon oxidation.

During use Ridox gathers and retains oxygen by a chemical reaction, which turns the reduced Ridox metal into a metal oxide again.

Ridox can be regenerated for further use, by once again reducing the metal oxide to a metal.

Removal of oxygen from gas with Ridox

Reduced, Ridox reagent will remove oxygen from various gases, when the method outlined below is followed:

1. Select an operating temperature from -40 to 200°C, based on the temperature of the gas to be treated.
2. Place Ridox reagent in any non-oxygen-permeable container, e.g. glass. Be sure that all fittings are installed in a way that minimizes air infusion, and prevents downstream air leakage.
3. Purge all lines (to and from the container) of oxygen.
4. Pass the gas to be treated through Ridox Reagent.

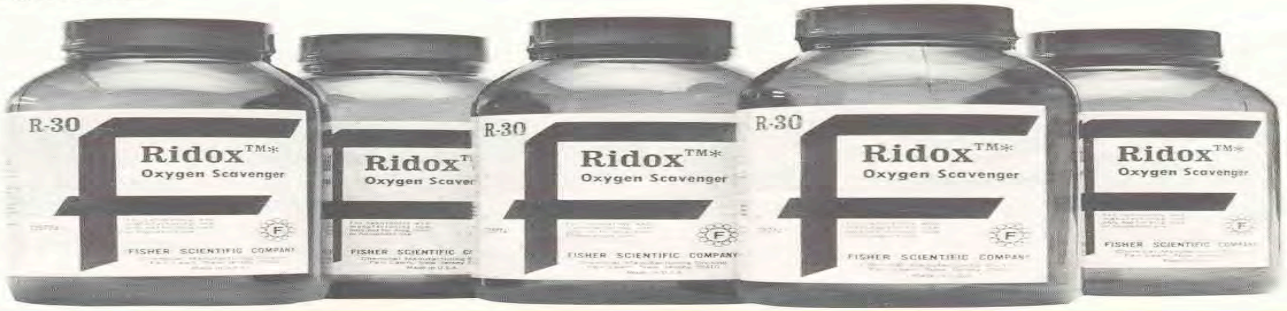
If Ridox is regenerated with hydrogen, water will be produced, and may condense in the cold exit lines. This possibility should be taken into consideration, when designing a system for regeneration with hydrogen.

Ridox reagent can be used to remove oxygen from the following gases:

1. inert gases (nitrogen, helium, argon, krypton and xenon.)
2. aliphatic hydrocarbon gases (alkanes and alkenes, but not alkynes.)
3. low boiling aromatic gases (benzene, toluene and alkylbenzenes.)
4. carbon monoxide
5. carbon dioxide
6. diethyl ether

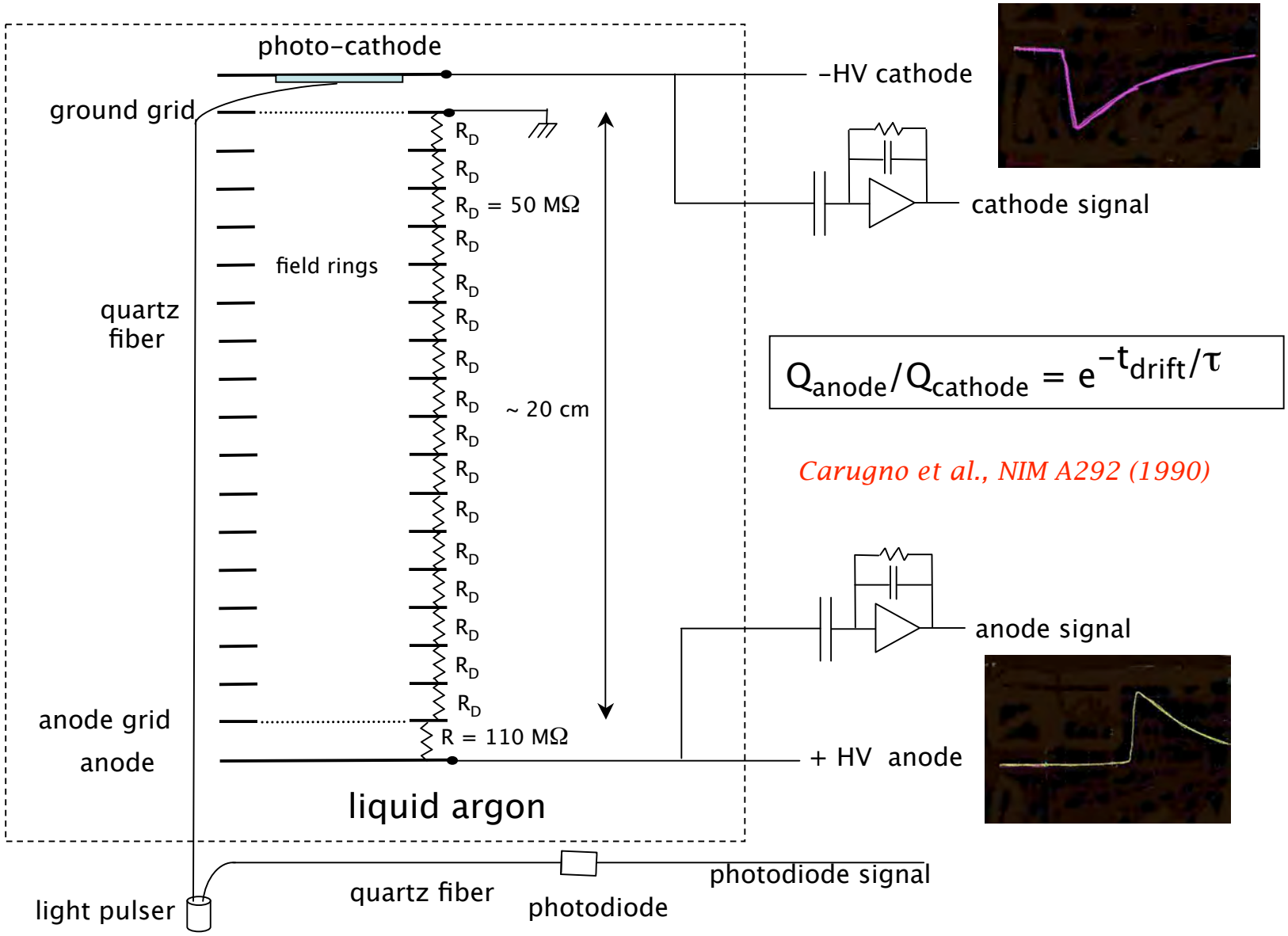
Materials that temporarily poison Ridox

Certain materials cause temporary poisoning of Ridox Reagent, e.g.: ammonia, and amines (butylamine, triethylamine, ethylene, diamine, pyridine).

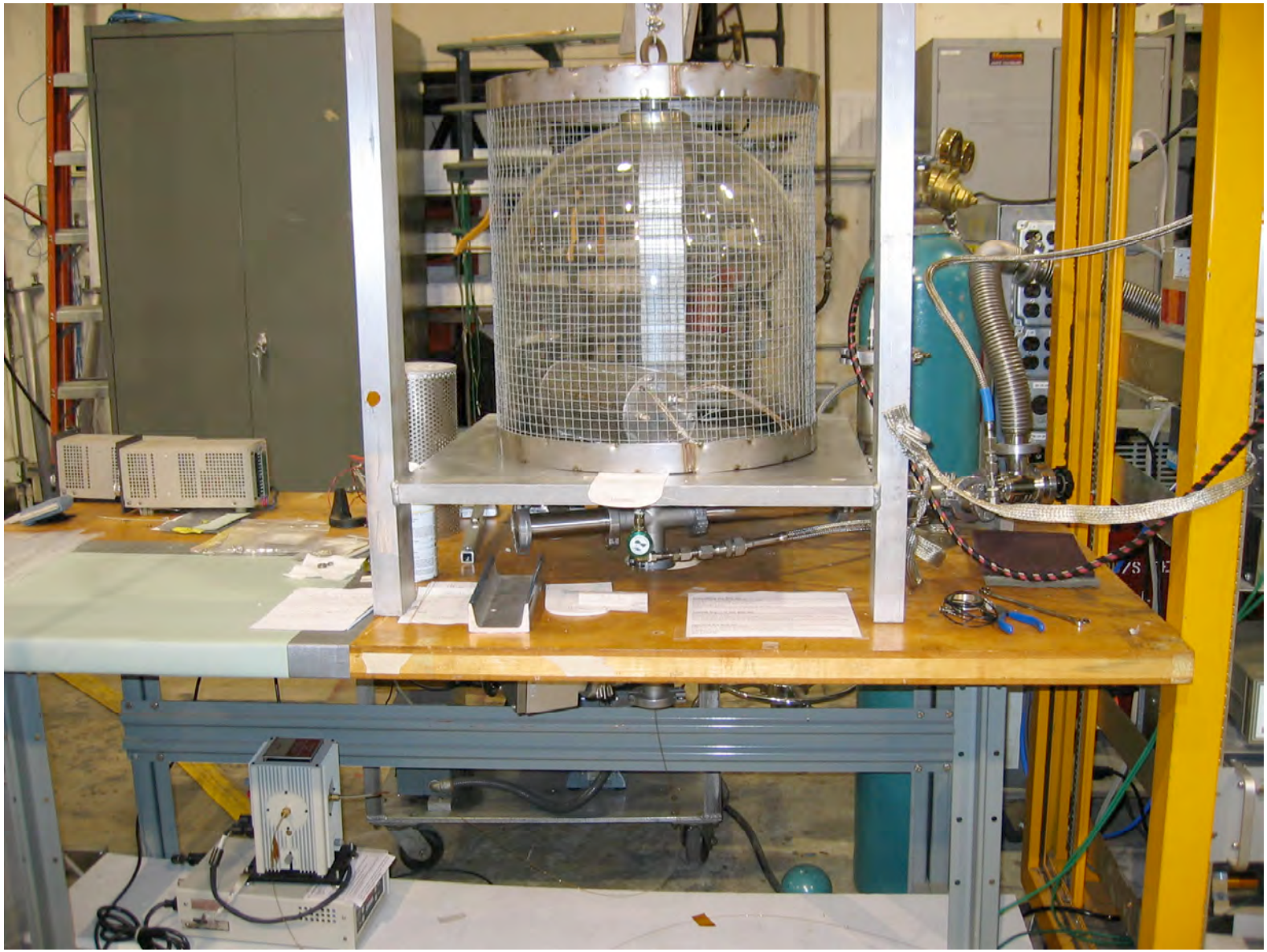


Fisher Scientific Company

Schematic of Liquid Argon Purity Monitor (PrM)



$$Q_{anode}/Q_{cathode} = e^{-t_{drift}/\tau}$$

Carugno et al., NIM A292 (1990)

Bell-jar station for rapid turn-around testing in Argon Gas