# Liquid Argon R & D at Fermilab

Something about Liquid Argon

Ongoing Work and prospects at Fermilab

R & D opportunities

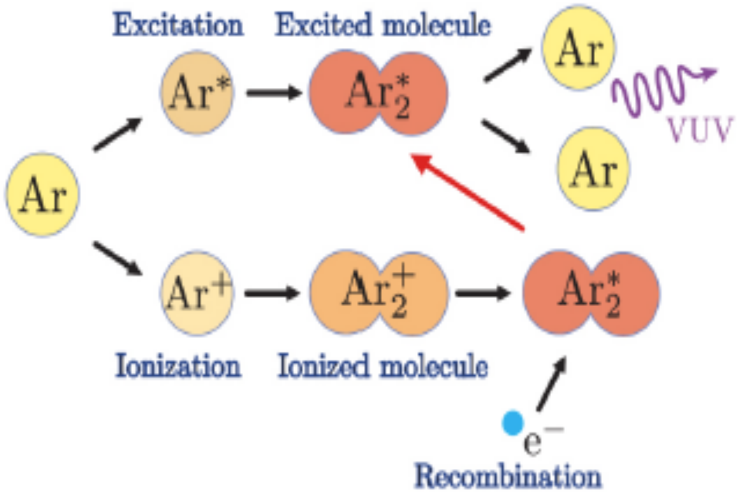
Noble Liquids are strong scintillators and allow electrons to be drifted over long (meters) distances under E fields of ~ 1kV/cm

from Mitch Soderberg

| | He | Ne | Ar | Kr | Xe | Water |
|---|---|---|---|---|---|---|
| Boiling Point [K] @ 1atm | 4.2 | 27.1 | 87.3 | 120.0 | 165.0 | 373 |
| Density [g/cm³] | 0.125 | 1.2 | 1.4 | 2.4 | 3.0 | 1 |
| Radiation Length [cm] | 755.2 | 24.0 | 14.0 | 4.9 | 2.8 | 36.1 |
| Scintillation [γ /MeV] * | 19,000 | 30,000 | 40,000 | 25,000 | 42,000 | |
| dE/dx [MeV/cm] | 0.24 | 1.4 | 2.1 | 3.0 | 3.8 | 1.9 |
| Scintillation λ [nm] | 80 | 78 | 128 | 150 | 175 | |
| e's/MeV ** | 39,000 | 46,000 | 42,000 | 49,000 | 64,000 | |
| Triplet life time (μs) | $13 \times 10^6$ | 15 | 1.6 | 0.09 | 0.03 | |
| ppm in air | 0 | 12 | 9500 | 1 | 0.1 | |

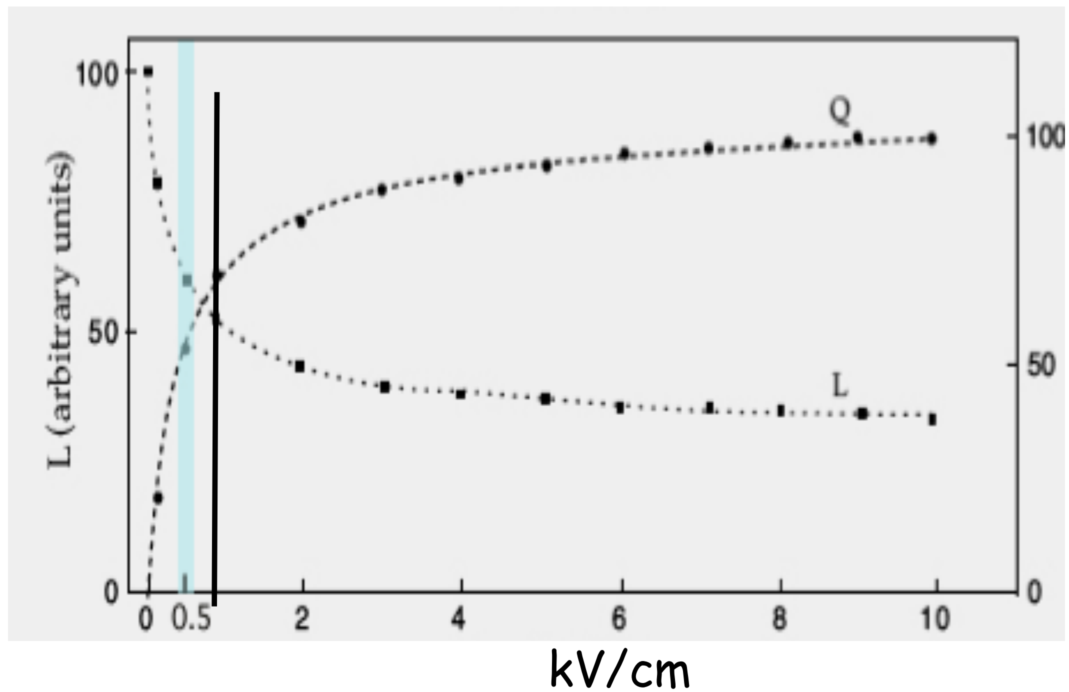
* at zero electric field
** at high electric field

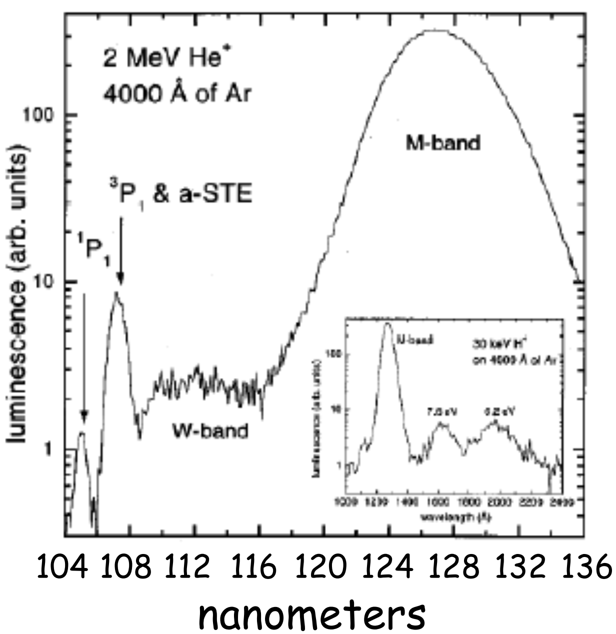
# mechanism of light production




dE/dx = 2.1 MeV/cm
ρ= 1.4 gms/cm$^3$

charge (Q) and light (L) yield vs electric field




5000 e/mm and 5000 photons/mm at 0.5 kV/cm

## Technical Issues for Multi-ton Argon Dark Matter detector:

- Chemical purity to allow electron drift (10's ppt O2 equivalent),
- Chemical purity to allow light production and propagation
- HV feedthroughs (>100 kV)
- TPC design
- Light Detection
- Data Acquisition
- Cryogenics and associated safety issues)
- Detector Materials Qualification
- Shielding from environment radiation
- Radio-purity of detector materials
- Radio purity of Argon

## Technical Issues for any Multi-ton Argon detector:

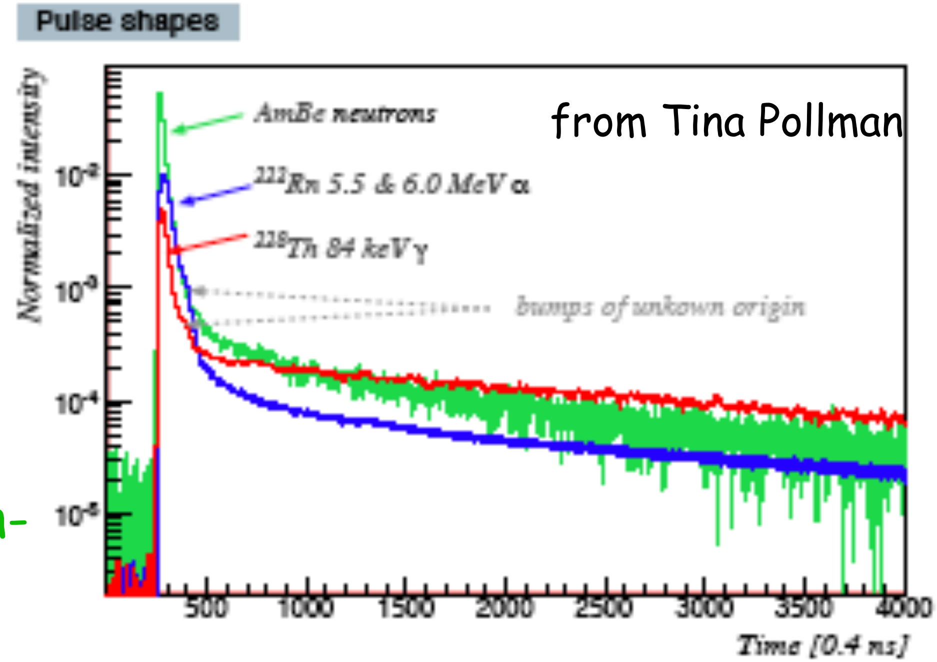
- Chemical purity to allow electron drift (10's ppt O2), ***(ν and DM)***
- Chemical purity to allow light production and propagation ***(ν and DM)***
- HV feedthroughs (>100 kV) ***(ν and DM)***
- TPC design ***(ν and DM)***
- Light Detection ***(ν and DM)***
- Data Acquisition ***(ν and DM)***
- Cryogenics and associated safety issues ***(ν and DM)***
- Detector Materials Qualification ***(ν and DM)***
- Shielding from environment radiation (*DM)*
- Radio-purity of detector materials (*DM)*
- Radio purity of Argon (*DM)*

# A nice feature of Argon (and Neon)

Scintillation has 2 components:
$\tau$(fast) = 7 ns, $\tau$(slow) = 1600 ns

Fast/Slow depends on **ionization density**

Time distribution of light output*
from Liquid Argon for $\gamma$, $\alpha$, neutron-recoils




I(fast)/I(slow) = 0.3($\gamma$), = 1.0($\alpha$), = 3.0(neutron-recoils)

Basis of PSD (pulse shape discrimination) for rejecting e and $\gamma$ events

(Other parameter used in 2 phase TPCs (eg Xenon 10/100) is light to free electron which is also strongly dependent on ionization density.)

# Bottom Lines for considering Argon as target medium

Neutrinos - excellent event identification,

powerful for distinguishing neutral current $\pi^0$ from $\nu_e$ CC scatters - $\theta_{13}$
(eff Ar/H20 ~ 5 per unit mass)

Proton Decay - sensitive to Kaon modes (unlike WC)

WIMPS - large mass, powerful background rejection

# Existing Stuff (has operated at least once)

Materials Test System

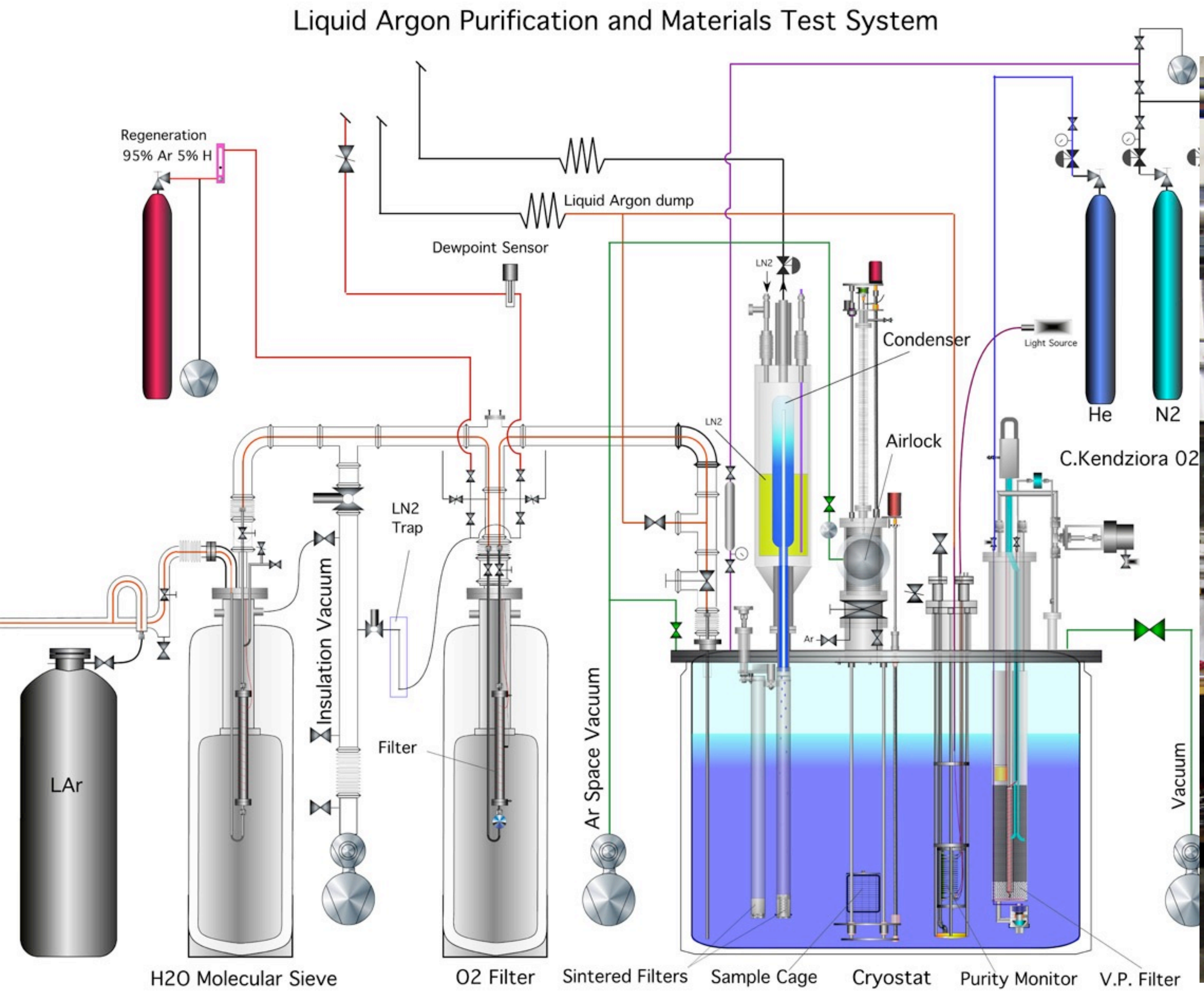
Electronics Test System with TPC

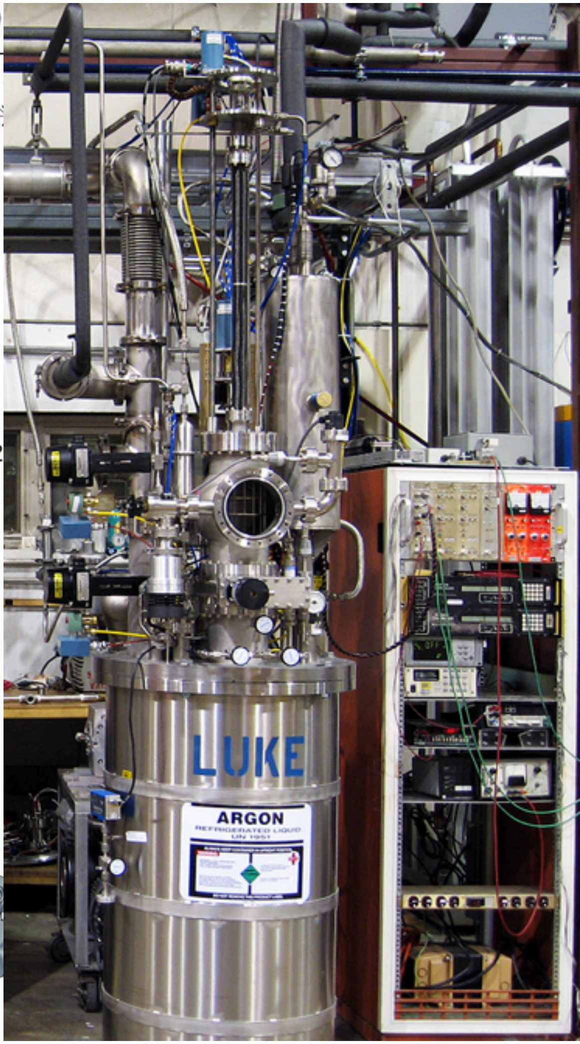
ArgoNeuT (T-962)

DarkSide 10 (prototype DM detector)

Cryogenic Distillation Column

# Liquid Argon Development Area at the PAB


Liquid Argon Purification and Materials Test System
Regeneration
95% Ar 5% H
Liquid Argon dump
Dewpoint Sensor
LN2
Condenser
Light Source
Airlock
He
N2
C.Kendziora 02
LN2
Trap
Insulation Vacuum
Filter
Ar Space Vacuum
Vacuum
LAr
H2O Molecular Sieve
O2 Filter
Sintered Filters
Sample Cage
Cryostat
Purity Monitor
V.P. Filter
LUKE
ARGON



# Liquid Argon Source and Materials Test System

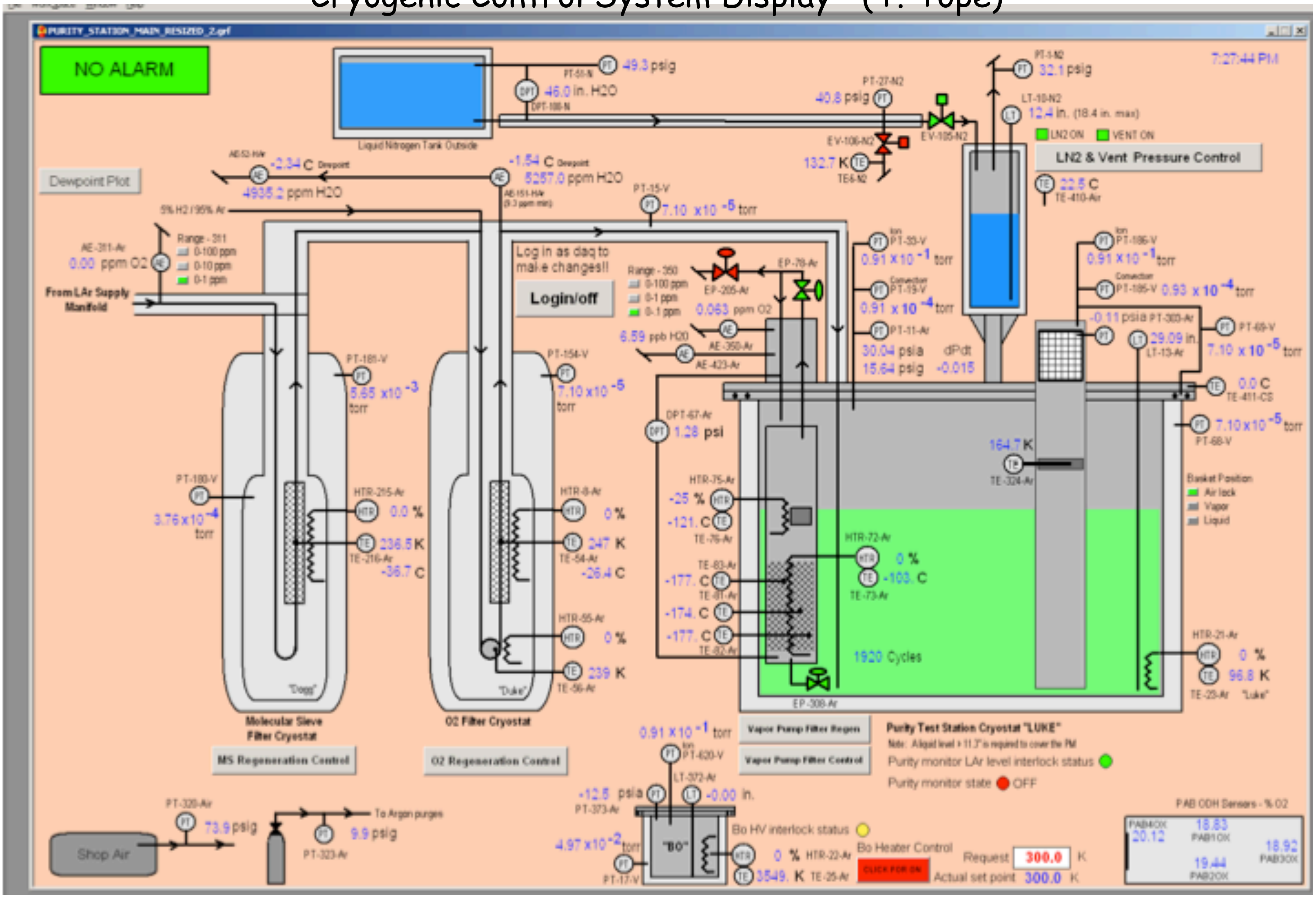
**Features of Materials Test System**

- Can insert materials into known clean argon
- Can insert materials after purging only or after pumping on them.
- Can position materials into liquid and into ullage with range of temperatures.
- Can insert known amounts of contaminant gases
- Nitrogen-based condenser can maintain liquid for long (weeks) studies
- Internal filter-pump can remove contamination introduced by materials – 2hr cycle
- Sample points at Argon Source, after single-pass filters, in cryostat gas and liquid

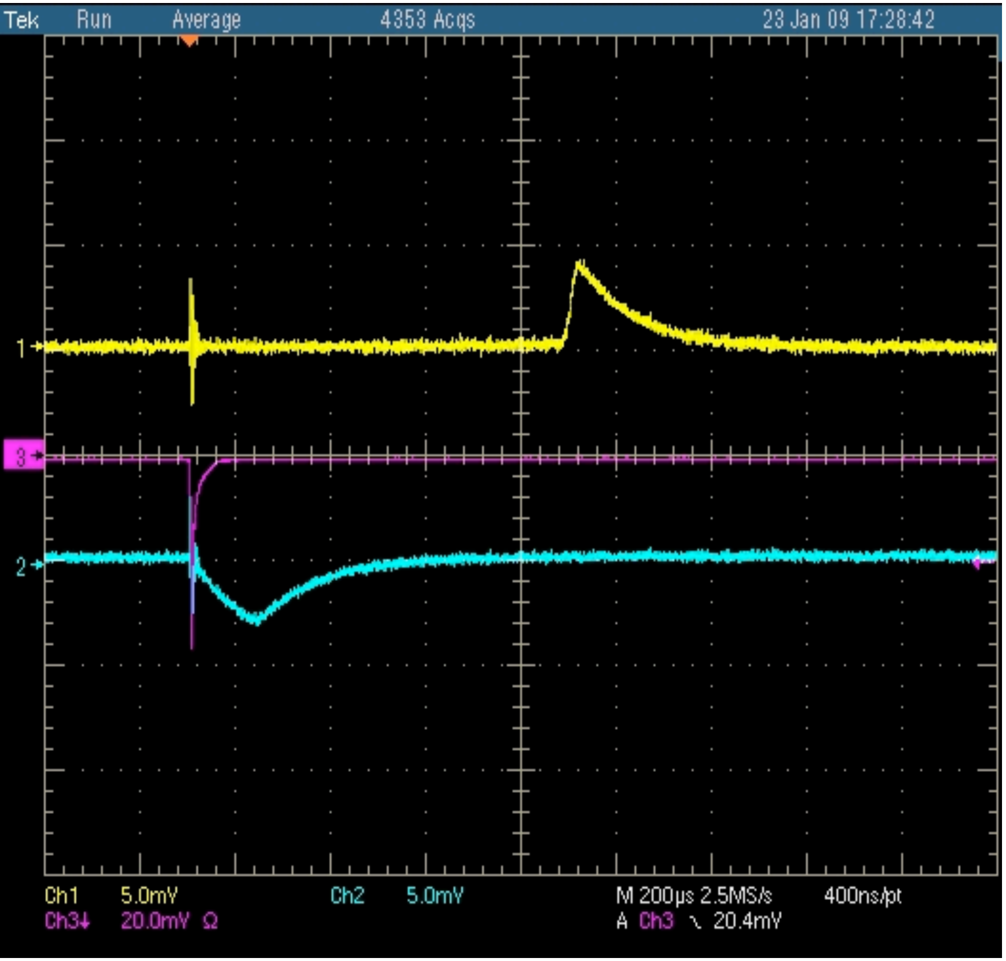
**Measurement Features of Materials Test System**

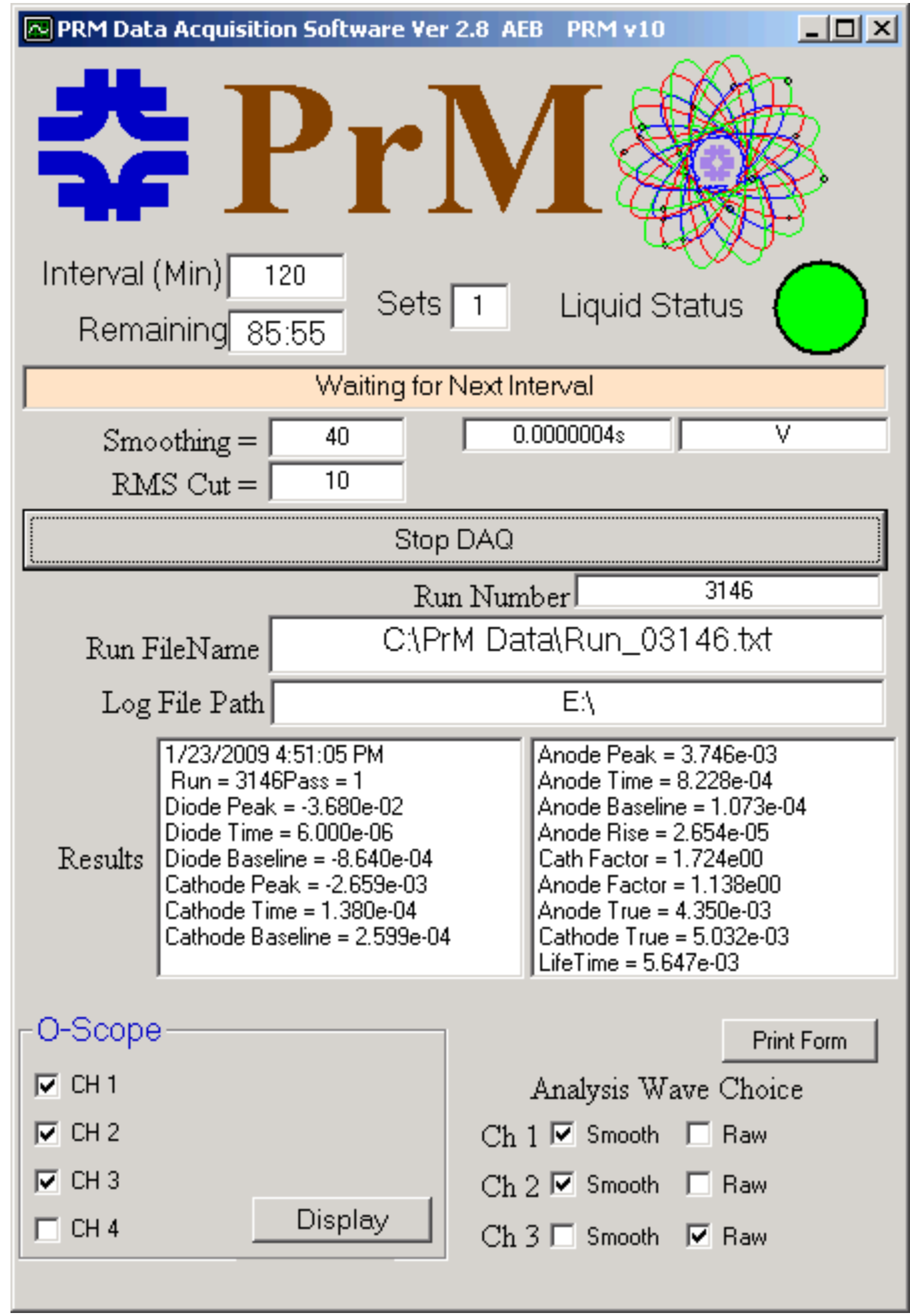
- Measure electron drift lifetime (0.3 milliseconds to 10 milliseconds)
- Measure Oxygen (0.5 ppb sensitivity) with oxygen meter (Delta-F & Tiger Optics)
- Measure H20 in gas (0.5 ppb sensitivity) with water meter (Tiger Optics)
- Cryogenic data, Lifetime Data, analytic instrumentation data in single data-base
- Runs 24/7 unattended except for filter regeneration and argon refills

# Cryogenic Control System Display (T. Tope)



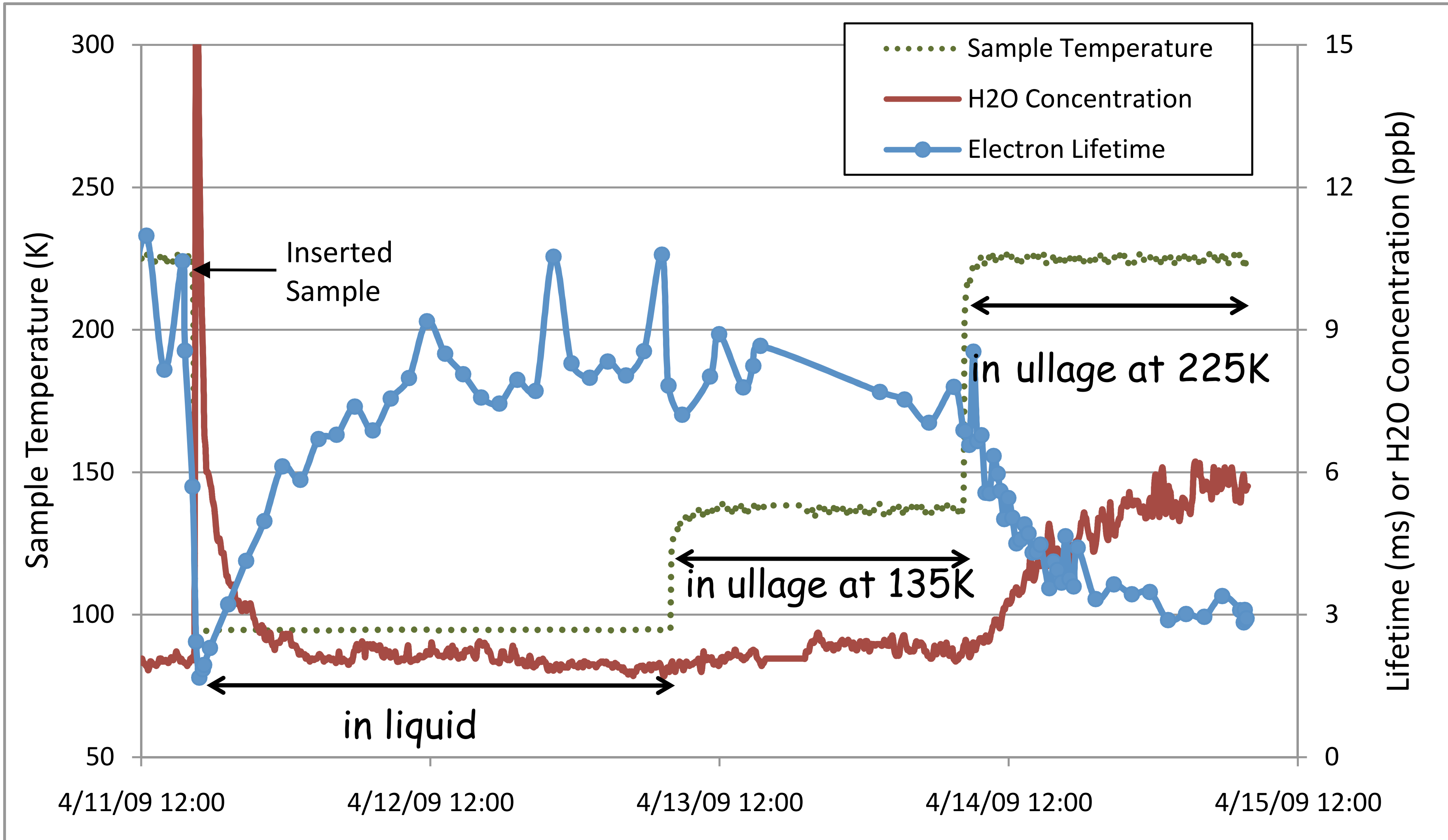
# On-line data and DAQ




A. Baumbaugh

# FR-4 Sample in Materials Test System showing effects in liquid, in cold ullage and in warm ullage



# A sample of materials tested

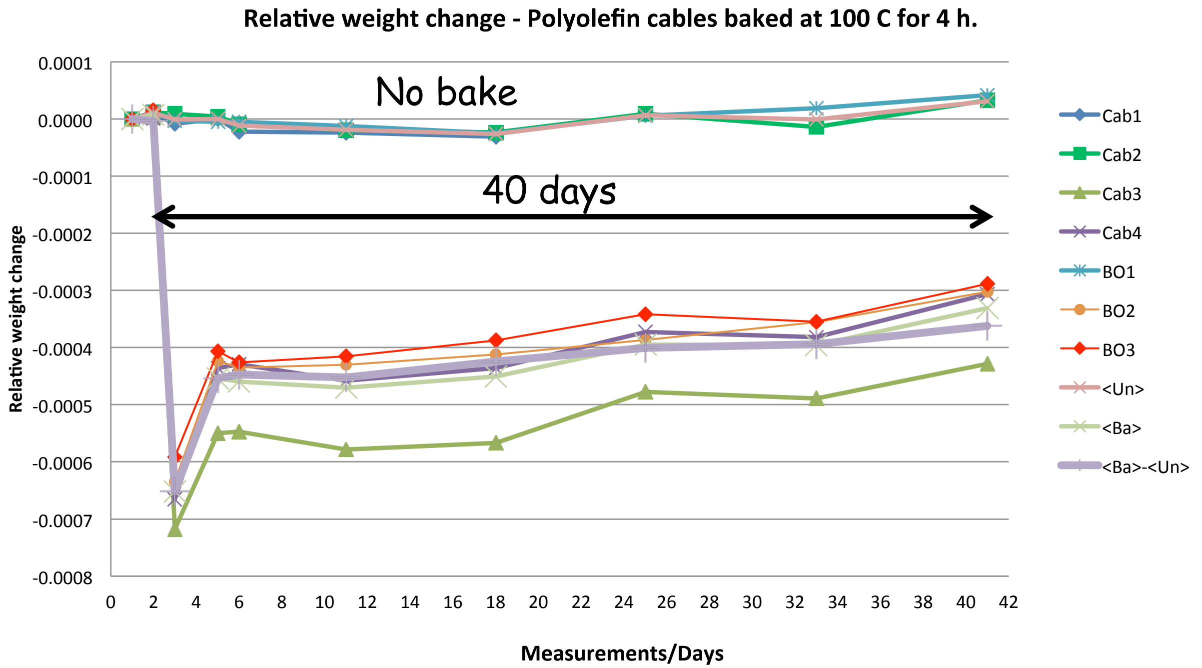
| Material | Date test started | Preparation | Tests | Water [ppb] | Lifetime [ms] | LogBook # |
|---|---|---|---|---|---|---|
| Cleaning Solution | 6/29/09 | evac. 24 h | vapor/liquid | 4 | 5 | 946 |
| Vespel | 7/9/09 | evac. overnite | liquid/vapor | 5-7 | 2-5, 4-6 | 960 |
| MasterBond glue | 7/16/09 | purged 18 h | vapor/liquid | 1.6 | 1.3- 2.9 | 974 |
| Bostik | didn't pass submerging in the liquid argon | | | | | 992 |
| LEDs | 7/31/09 | purged 38 h | vapor | 3.5 | 5 | 993 |
| Carbon filter material | 8/12/09 | evac. 24 h | liquid/vapor | 2 | 4-9 | 1000 |
| 962 FeedTru Board V2 | 10/12/09 | evac. 24 h | vapor/warm | 85 | 1-5 | 1062 |
| Teflon cable | 1/9/10 | purged 28 h | warm/liquid/vapor | 8-20 | 2-5 | 1175 |
| 3M "Hans" connectors | 1/29/10 | purged 46 h | warm/liquid/vapor | 5-12 | 3 | 1198 |
| 962 capacitors | 3/2/10 | evac. 24 h | warm/liquid/vapor | 6-14 | 3-6 | 1228 |
| 962 polyolefin cable | 4/12/10 | evac. 16 days | warm | 25-60 | 2 | 1237 |
| Rigaku feedthrough | 4/20/10 | purged 7.5 h | warm | 15 | 3 | 1250 |
| Rogers board (Teppei) | 4/23/10 | purged 26 h | warm/liquid/vapor | 40 | 2, 6-10 | 1254 |
| Arlon Board (Teppei) | 5/14/10 | evac. 0.5 h, pur.2 days | warm/vapor | 300, 80 | 1.3, 3.5 | 1263 |
| Polyethylene tubing | 5/24/10 | evac. 6 h, pur. 66 h | warm | 300-500 | 1 | 1278 |
| Teflon tubing | 5/27/10 | evac. 1 h, pur.17 h | warm | 9-13 | 4-5 | 1283 |
| Jonghee board | 5/28/10 | evac. 6 h, pur. 1.5 h | warm/vapor | 100,28 | 1.2, 5-8 | 1285 |
| Jonghee connectors | 6/4/10 | evac. 3.5 h, pur. 16 h | warm/vapor | 50 | 2-3 | 1290 |
| PVC cable | 6/14/10 | evac. 29 h, pur.1 h | warm | 120 | 1-2 | 1296 |
| Teppei TPB samples | 8/3/10 | purged 26 h | warm | 600-1600 | 0.7 | 1342 |

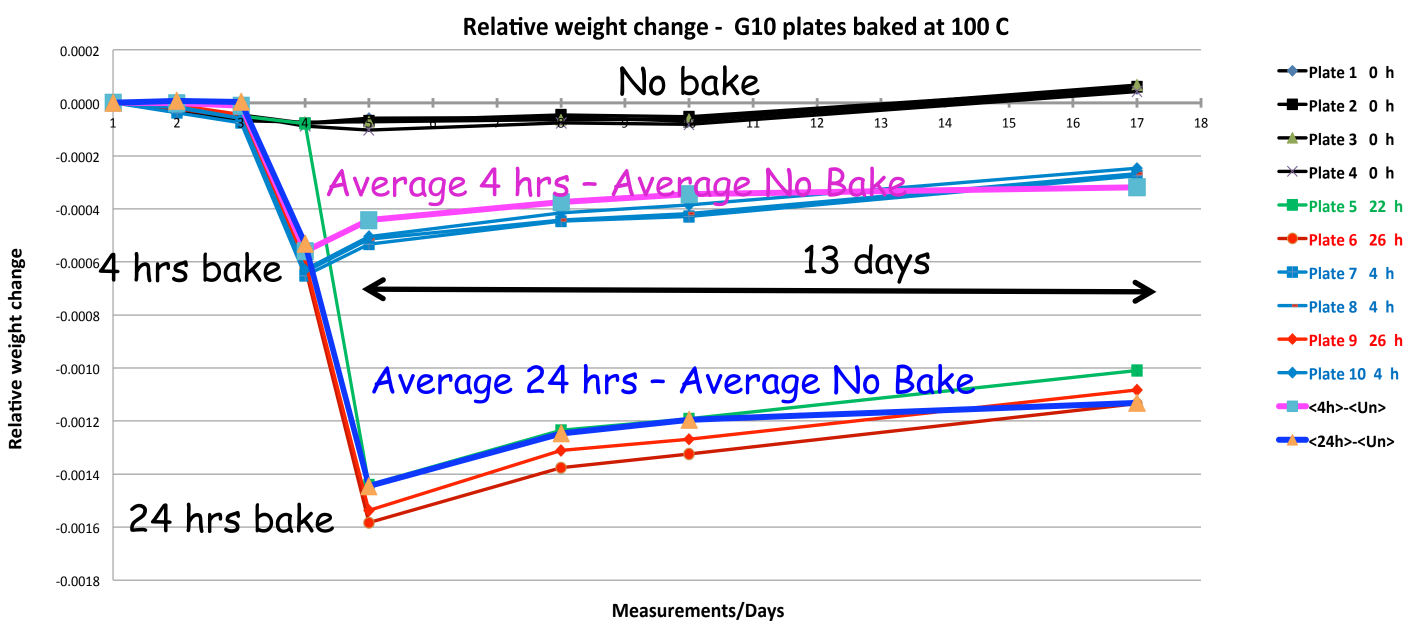
A useful database is http://outgassing.nasa.gov/ which gives removable water content

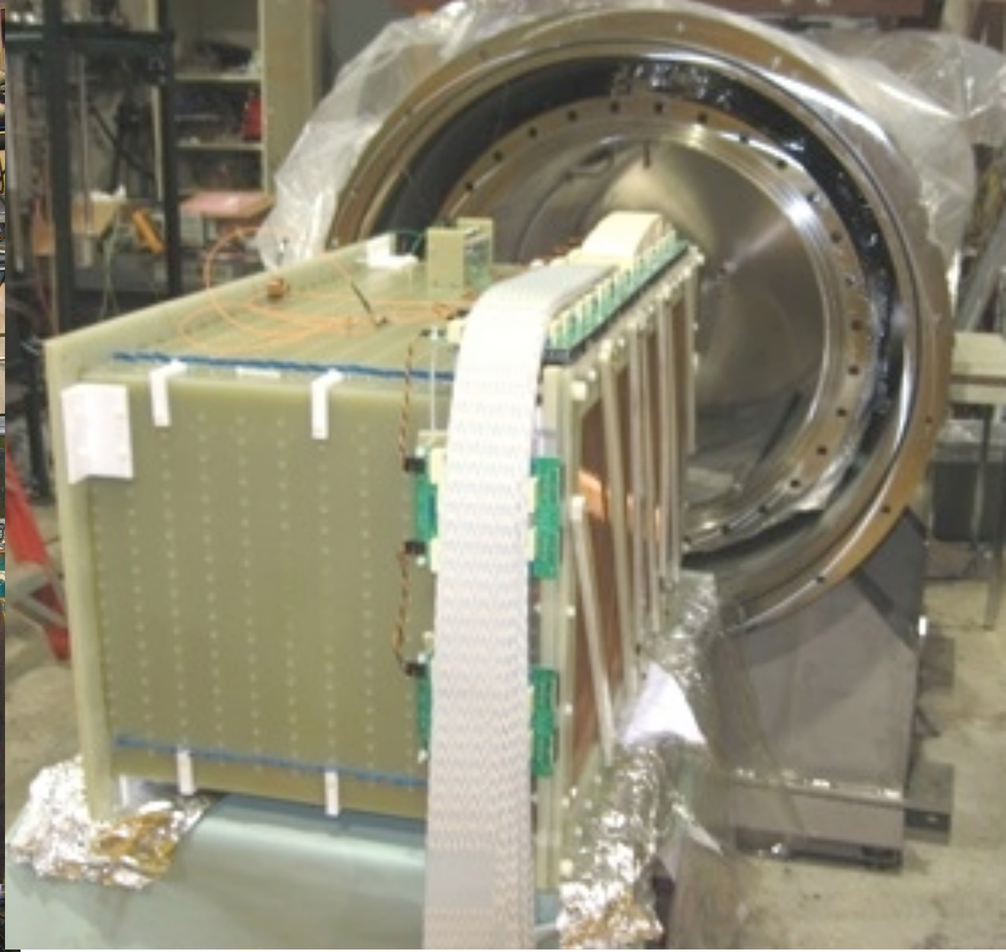
Water is the enemy.

How long should one bake?

How rapidly is water Re_sorbed (ad or ab)



First LAr TPC at Fermilab
Michigan State Readout,
FNAL Mechanics, Purification,
HV feedthrough

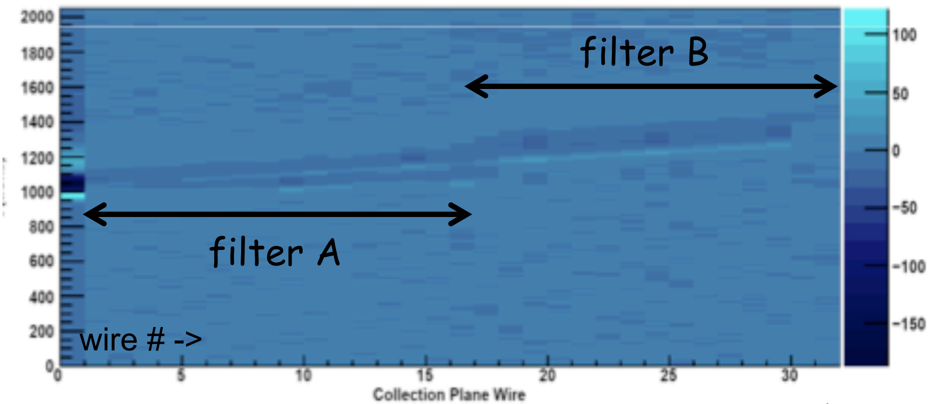
ArgoNeuT (T-962) (FNAL, MSU, Yale) ran in NuMI Beam 2010

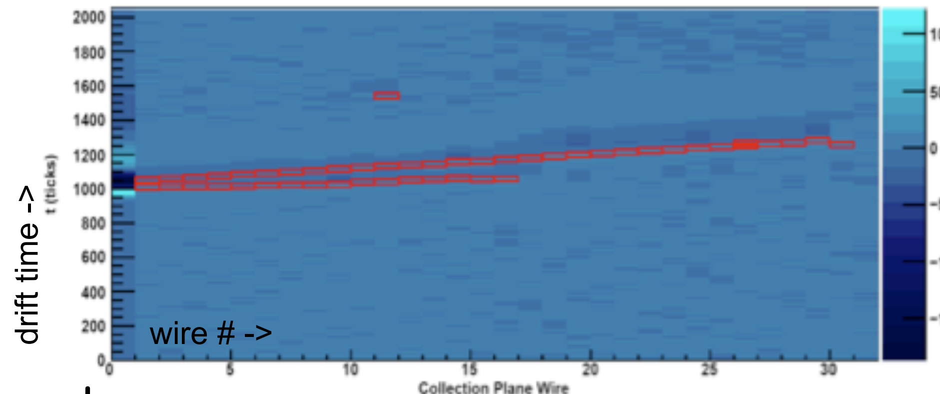
Complete system – real ν events

Electronics and hit reconstruction developed on BO

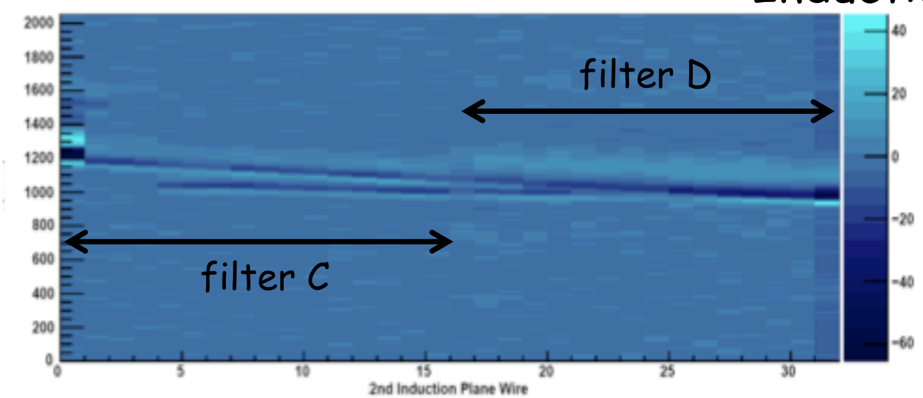
# Bo Data - track finding and two track resolution

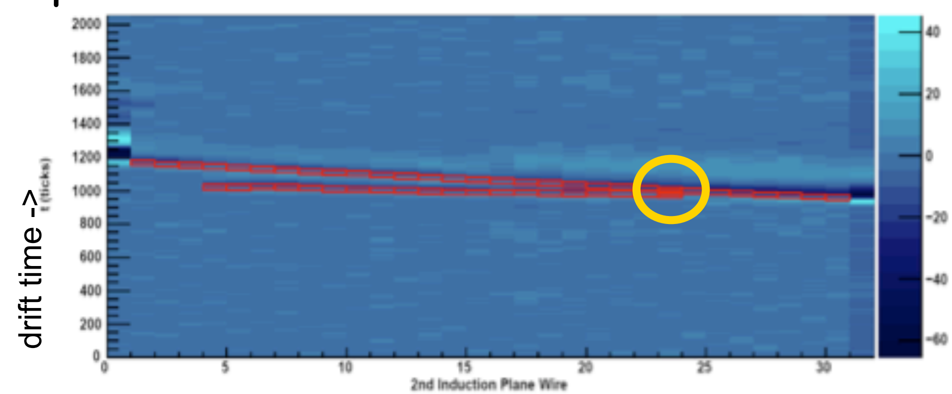
Collection plane




Induction plane



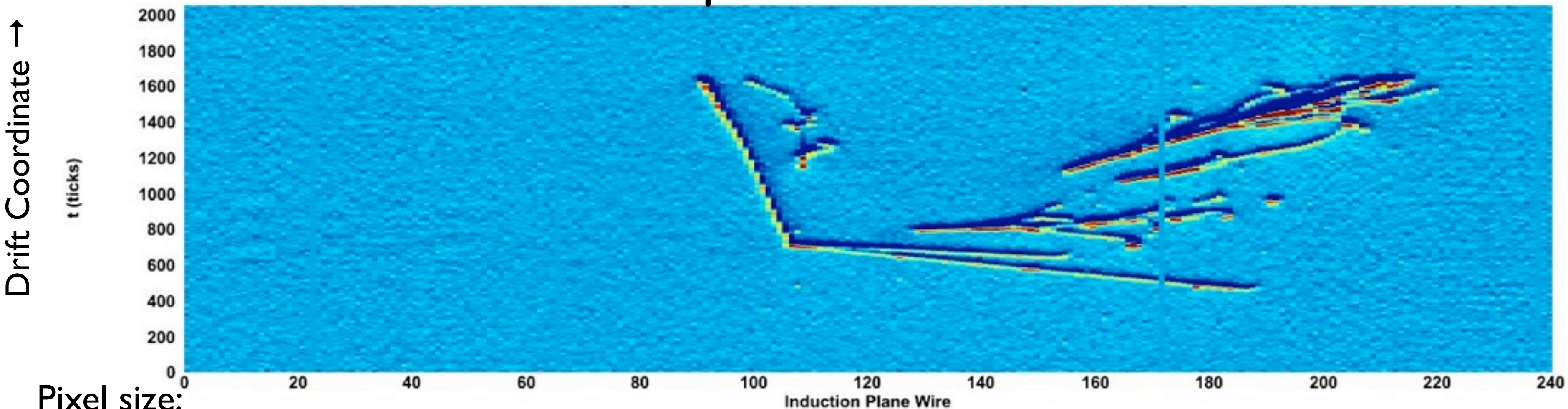




(J. Spitz, Yale)

Check simulations –
Filter types B & D have acceptance at lower frequency.
Which give better resolution, signal/noise etc ?

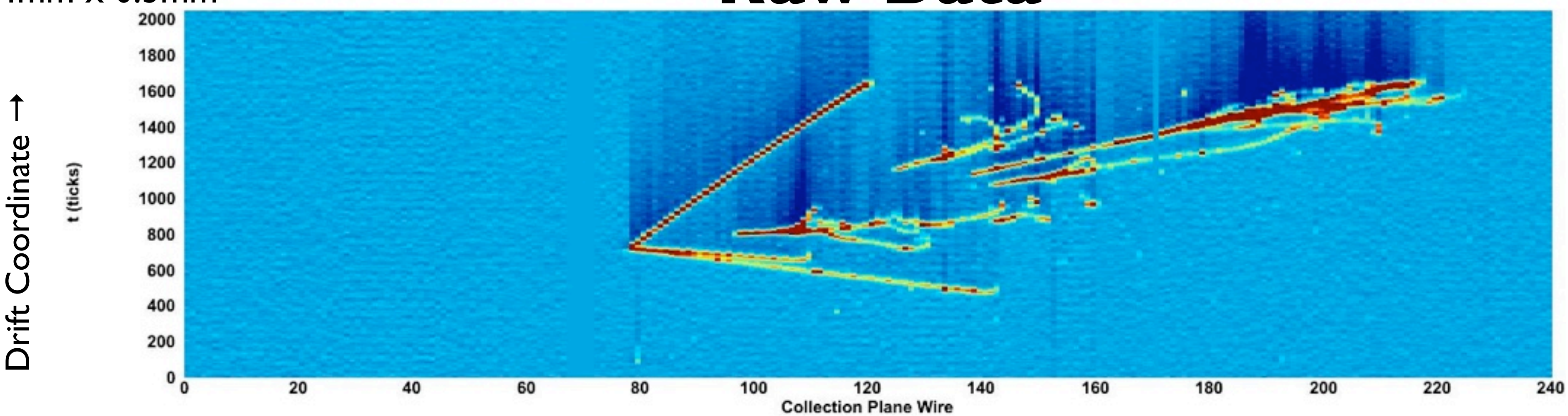
# ArgoNeuT Neutrino Event

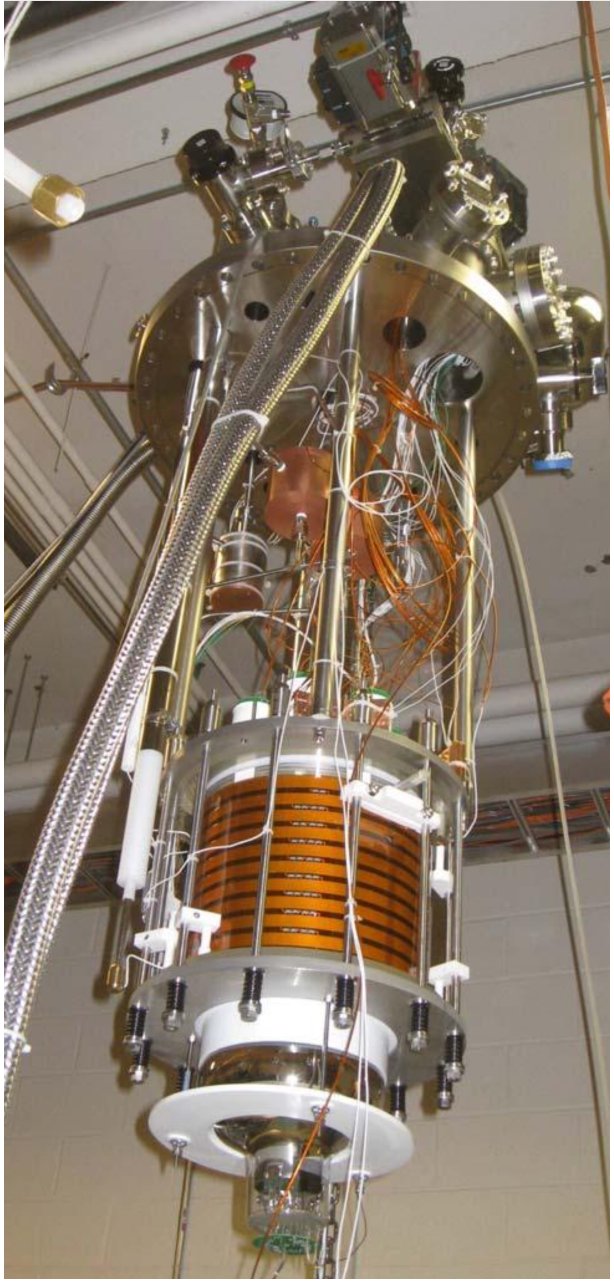
## with 4 photon conversions




Pixel size:
4mm x 0.3mm

**Raw Data**

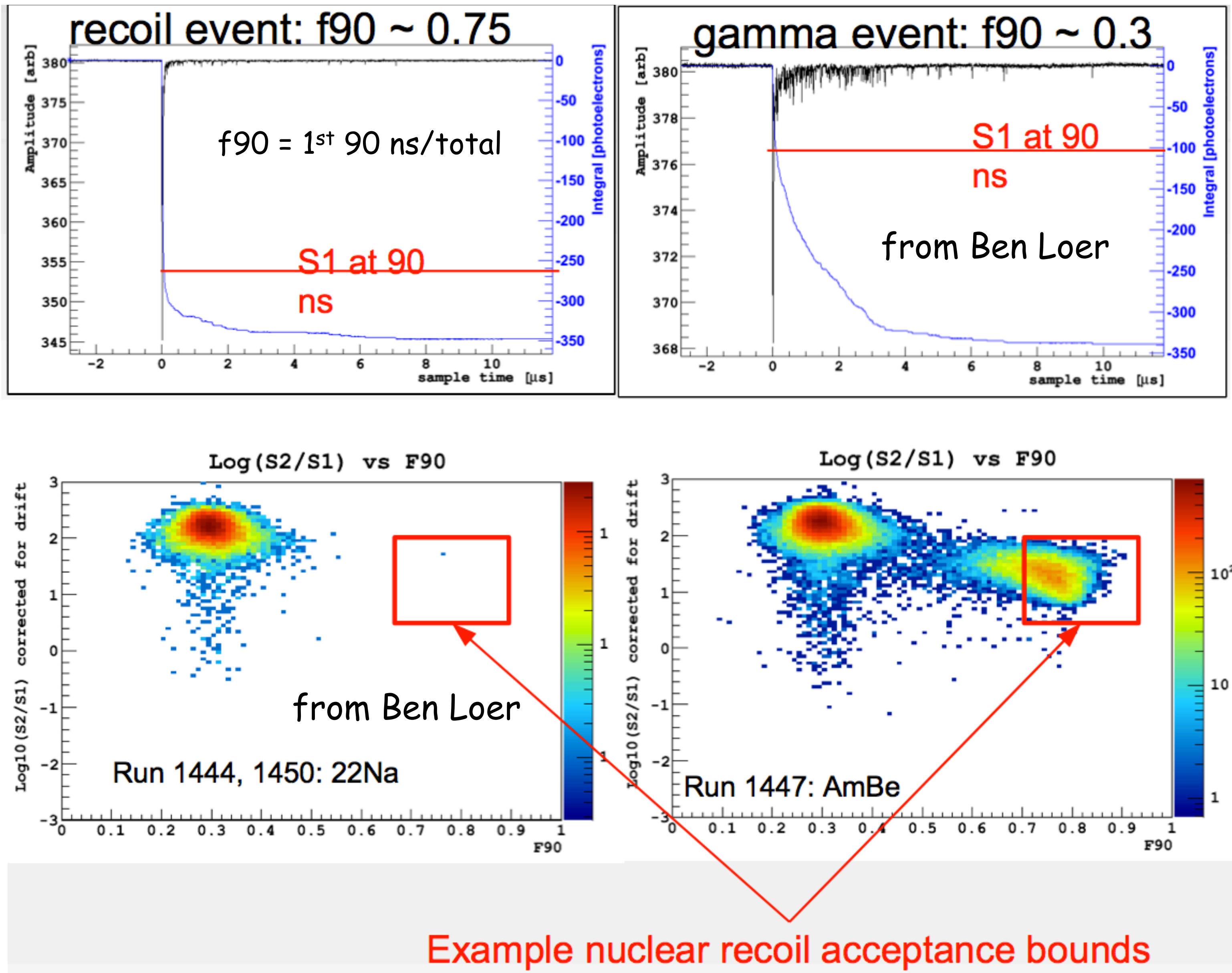




DarkSide 10 at Princeton

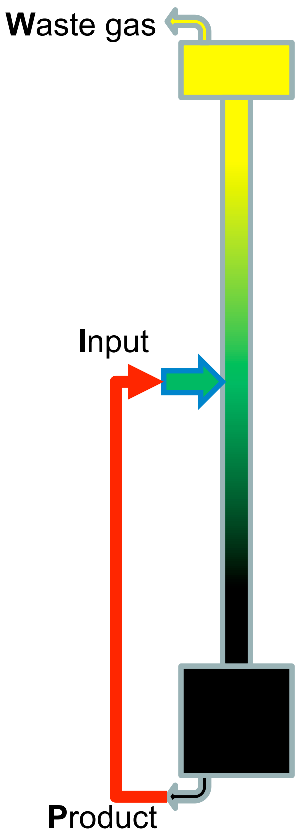
DAr Cryogenic Distillation Column at the PAB

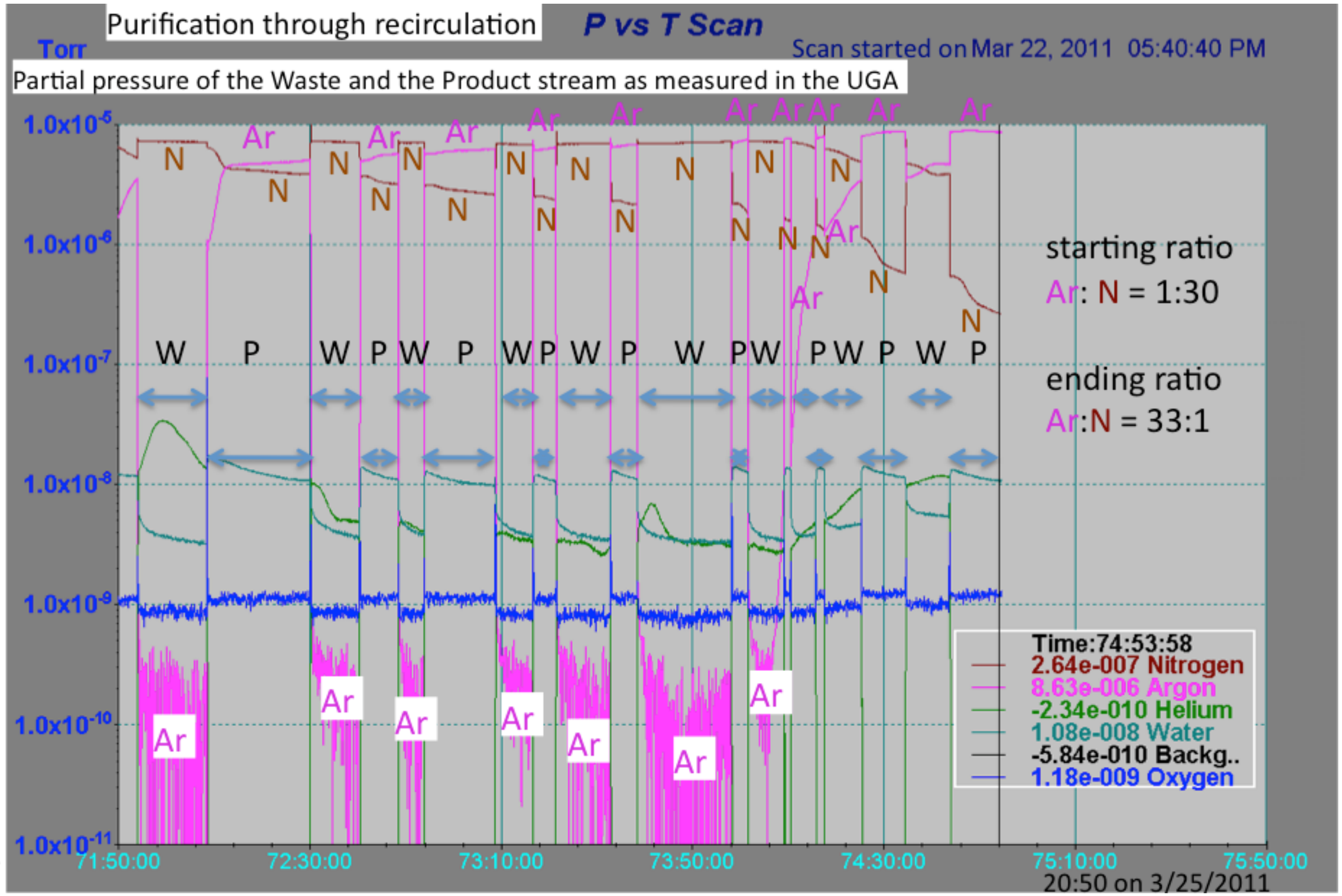
# DarkSide -10 (prototype) Surface Data




Off to Gran Sasso

# First run of cryogenic distillation column at the PAB

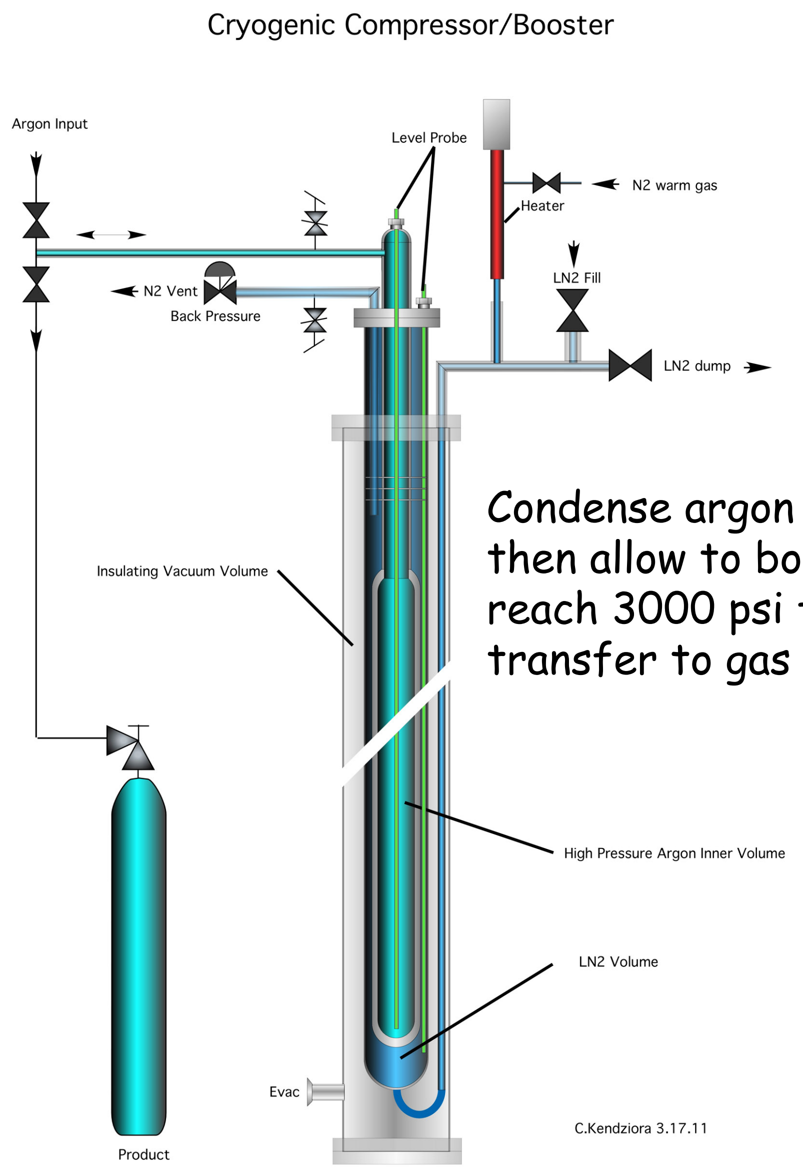



Starting with Ar:N = 1:30, ending with Ar:N =33:1
(goal is 1,000,000 : 1)

# Scheme for storage of depleted Argon (as gas) how to achieve high enough pressure.

## CC-B at the PAB 5/4/2011




Condense argon as liquid then allow to boil and reach 3000 psi for transfer to gas cylinders.

Stuff just about to operate

LAPD (Liquid Argon Purity Demonstration)

In-liquid electronics on electronics test stand

# Liquid Argon Purity Demonstration in PC4

Liquid Argon Purity Demonstration

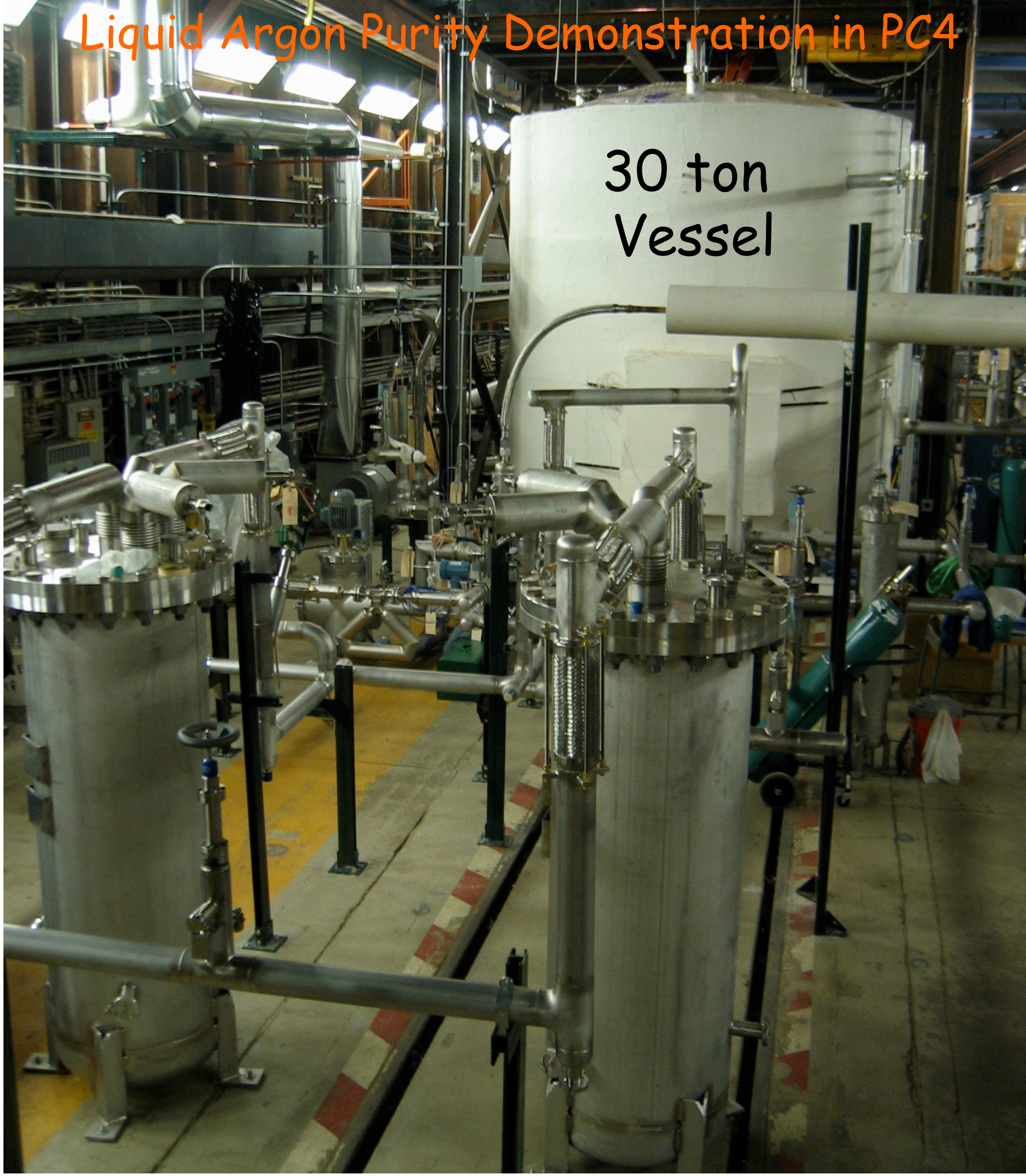
All current LArTPCs are evacuated before filling with Argon. However, difficult (= expensive) to construct multi-kiloton cryostat to be evacuable.
=> Demonstrate good life-time in an industrial vessel without evacuation.

Atmosphere will be removed by `argon' piston, then argon gas will be circulated through filters to achieve ~ 1 ppm Oxygen.

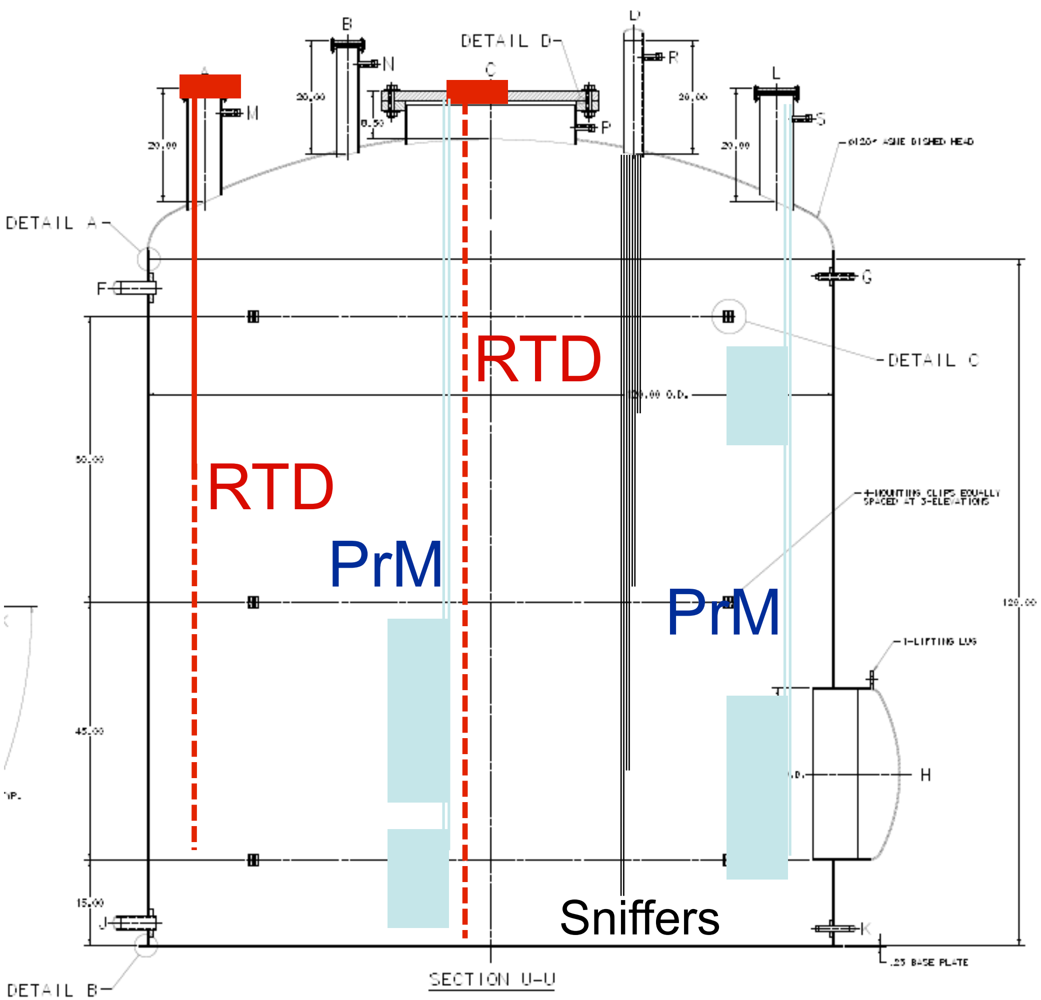
Heaters in the insulation can warm the walls to 60 C.

Filtration system sized for 30 tons of Argon at 1 ppm Oxygen. Pump will circulate entire volume in <24hrs.

Expect to start commissioning very soon.



# 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)

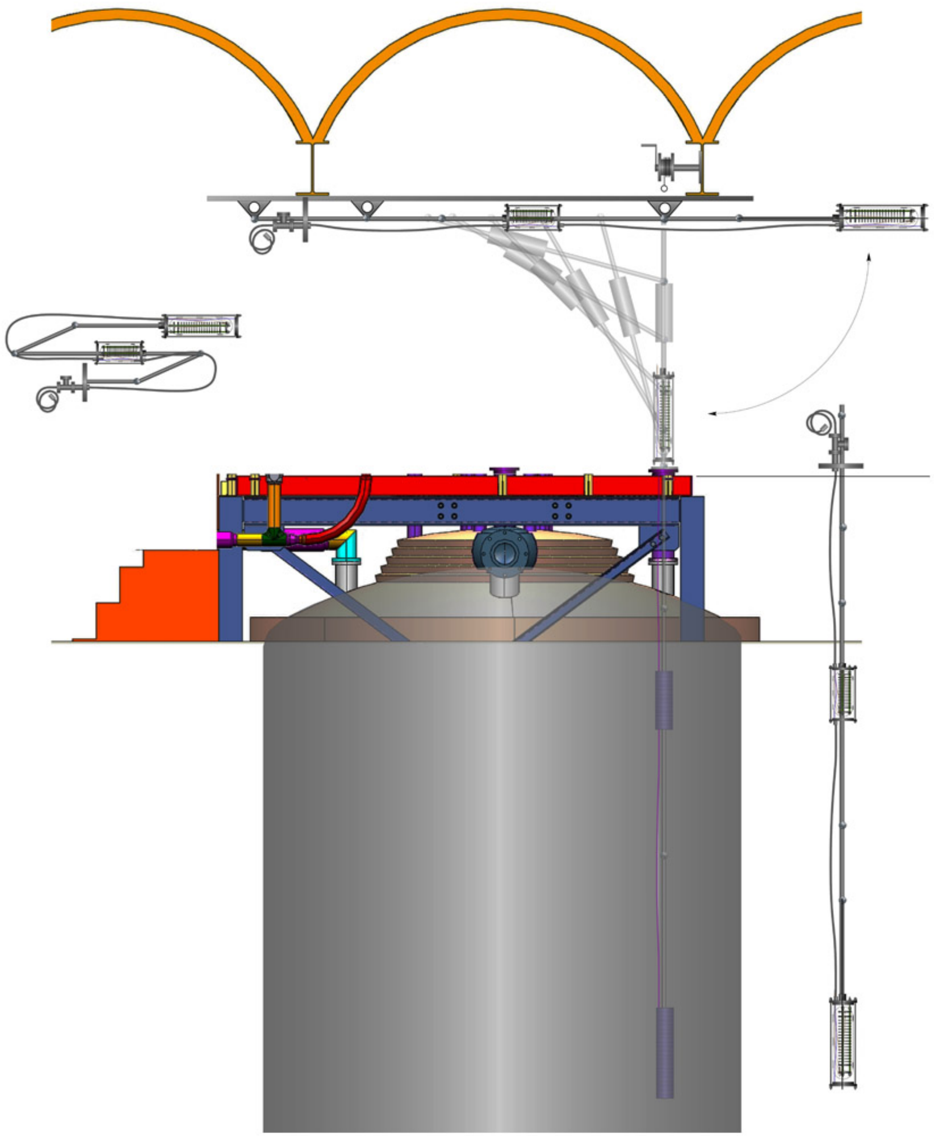
2 sets of 3 translating RTDs

Sniffer set to measure purge evolution

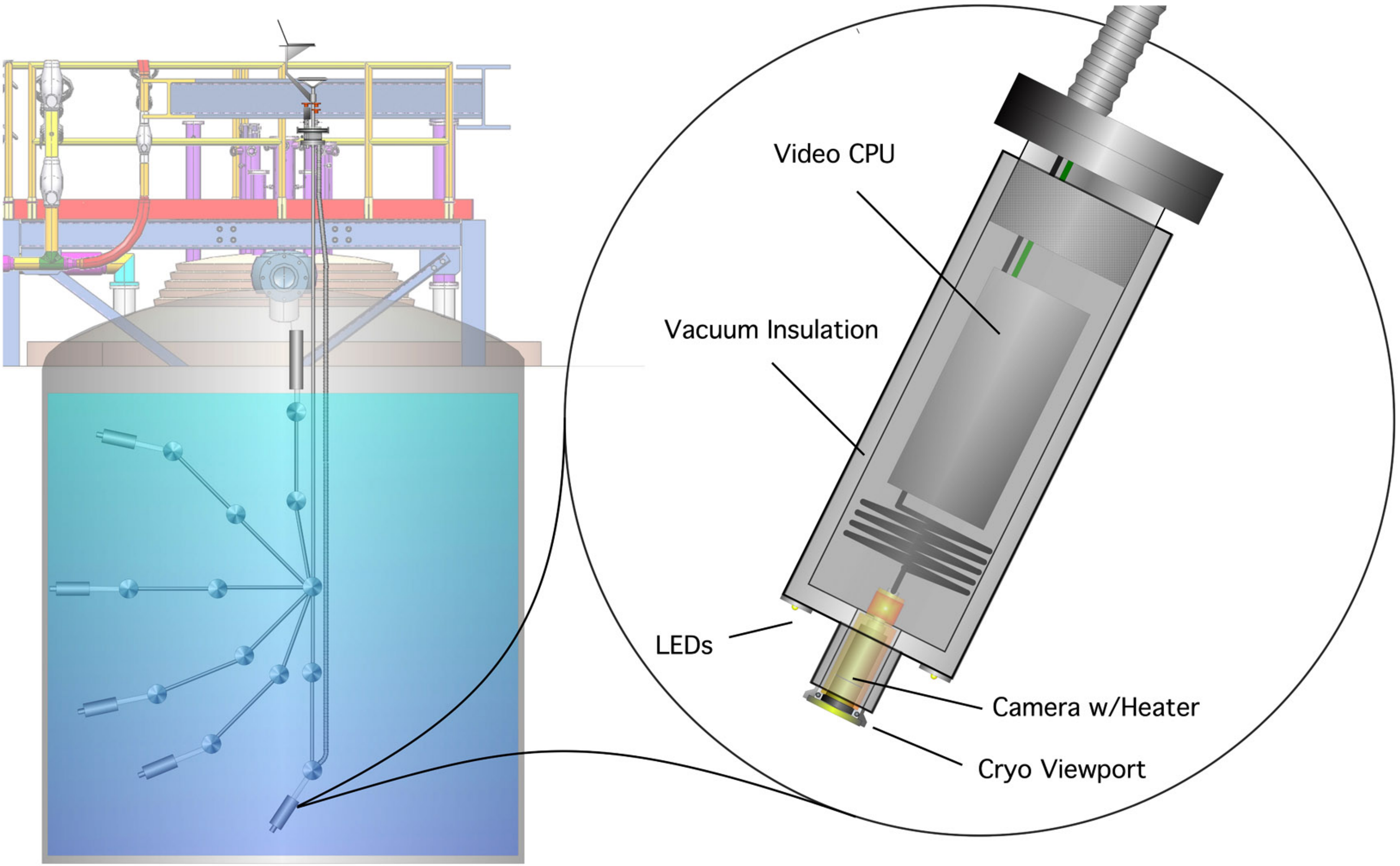
*Inline*

Purity Monitor

# Insertion Mechanism for Purity Monitors into LAPD

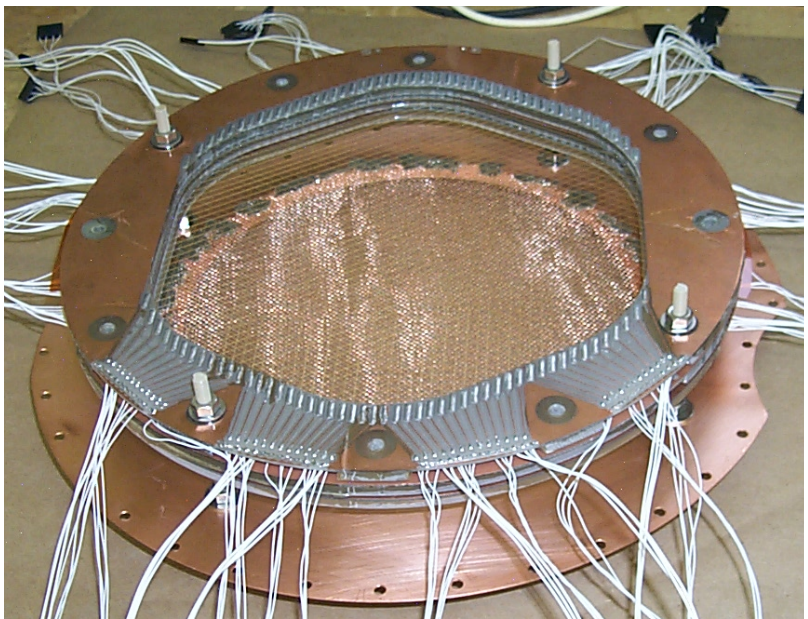



# Camera in liquid Argon



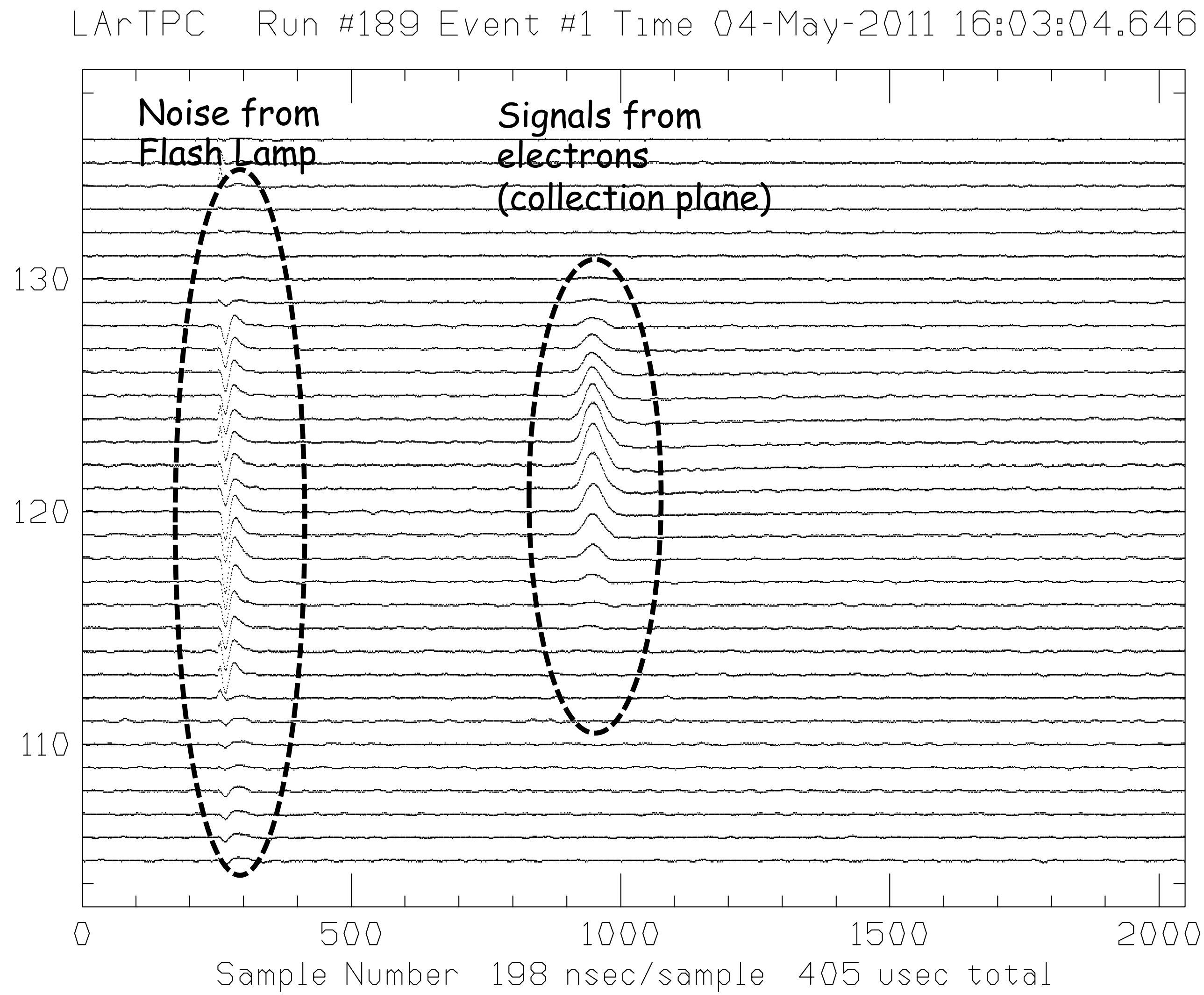
First Test of **cold (in liquid) electronics** developed by Dan Edmunds of Michigan State University. Electronics are installed around 50 cm drift-length TPC before installation into Cryostat.

3 wire planes at 120 degrees to each other.



# Cold Electronics Testing ..

Signals at room temperature from photo-electrons produced at gold photocathode at bottom of TPC illuminated with Xenon flash lamp



# Stuff in the Design Phase

MicroBooNE (E-974)

LAr35t (35 ton demonstration of membrane cryostat)

LAr1 (1 ktonne prototype for LBNE)

QUPID (Quartz Photon Intensifier Detector)

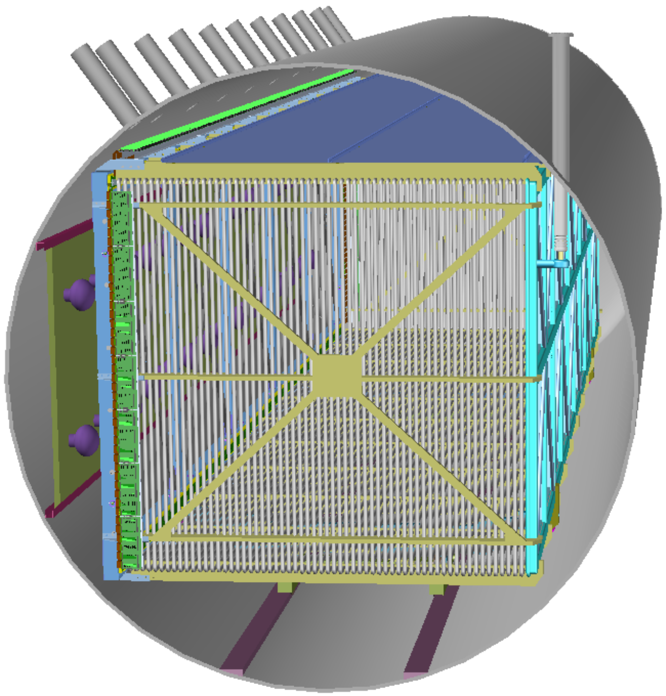
DarkSide 50 (E-1000)

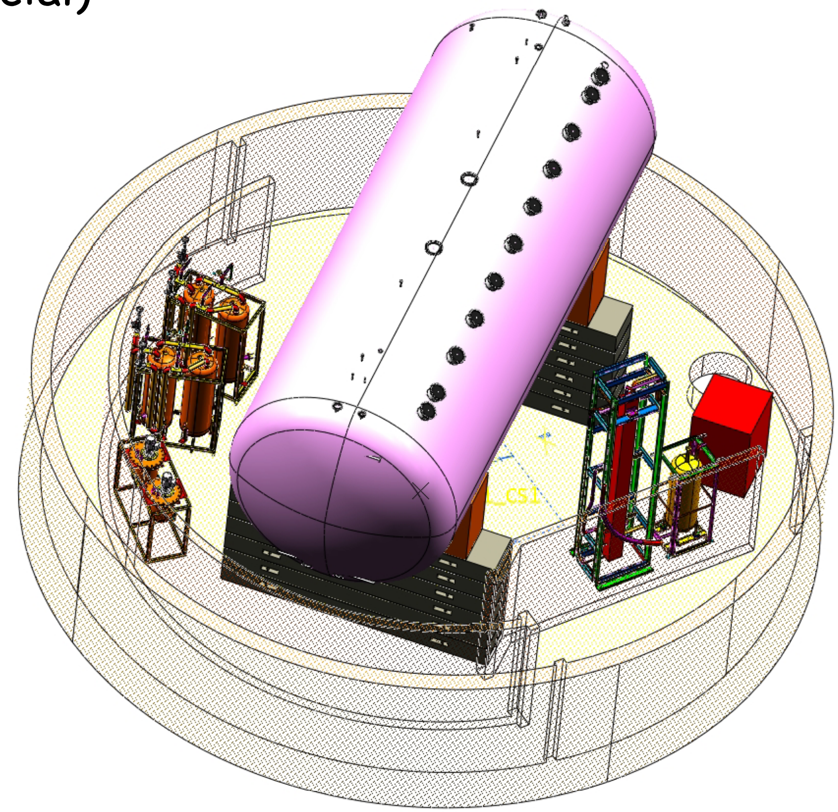
Proposal for LArTPC Test Beam Calibration Experiment (B. Rebel)

# MicroBooNE (E-974) Schematics

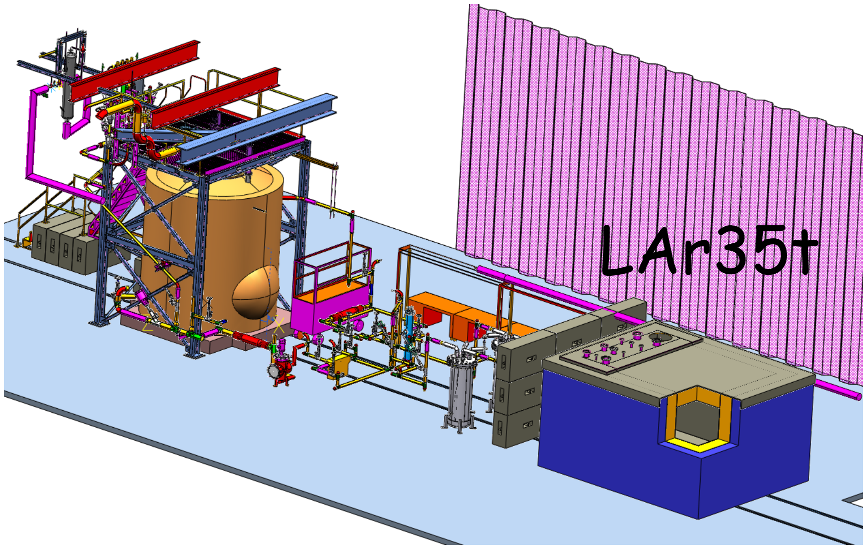
**TPC and PMTs in Cryostat** | **Cryostat in MicroBooNE hall**

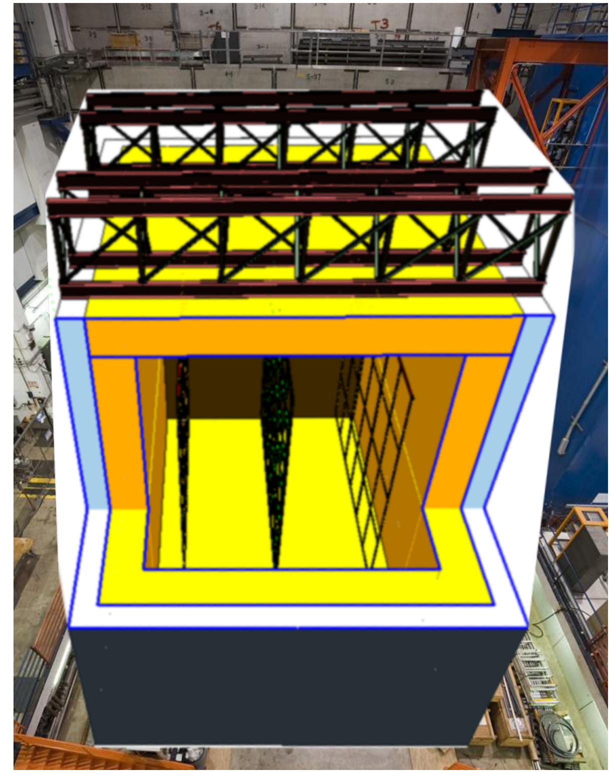
8000 channels, 180 tons ~80 tons fiducial)



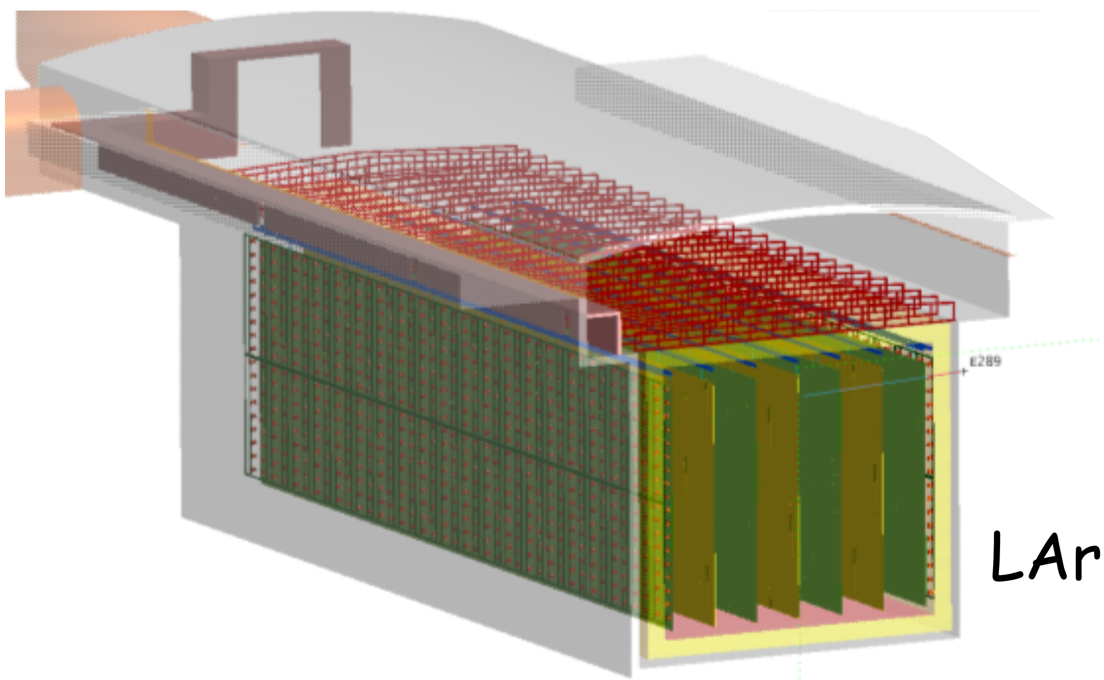


R & D goals: Cold (ASIC) electronics; 2.6 m drift;no evacuation
Event reconstruction, Library of Argon Interactions,
Cosmic backgrounds, 100% livetime DAQ



LAr1 at DZero

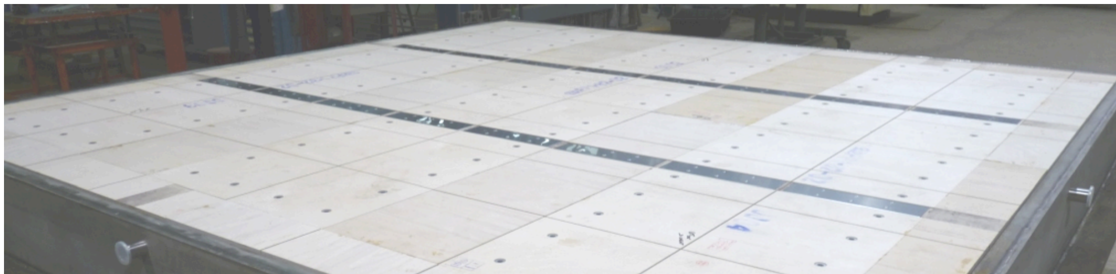


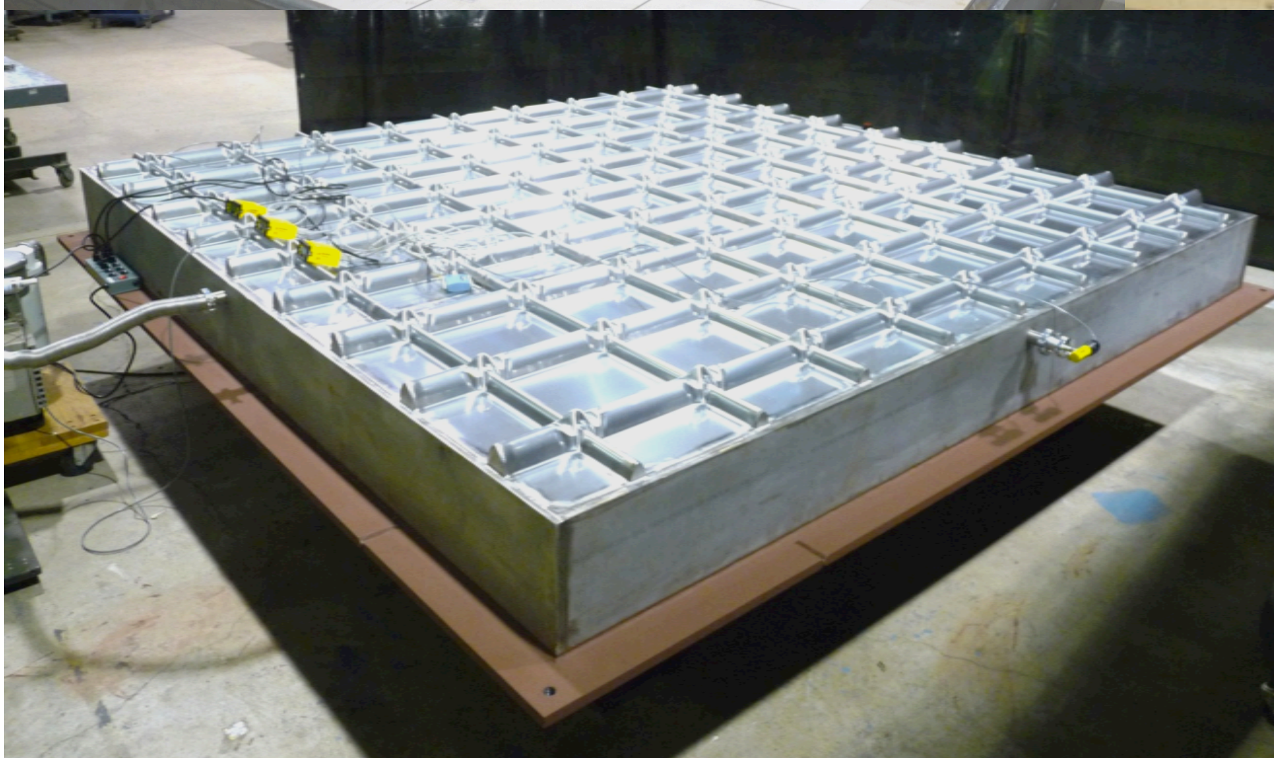
LAr20 at DUSEL

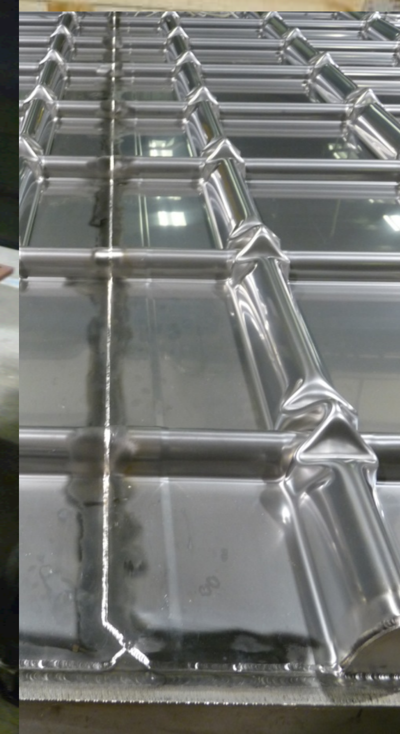
R. Rucinski & B. Baller

# Membrane Cryostat R & D (R. Rucinski/B. Baller)

Assembly of first membrane panel showing: delivery crate, (from Korea to Fermilab), insulation backing,  weld between two overlapping panes, and 3 panel section ready for leak testing.



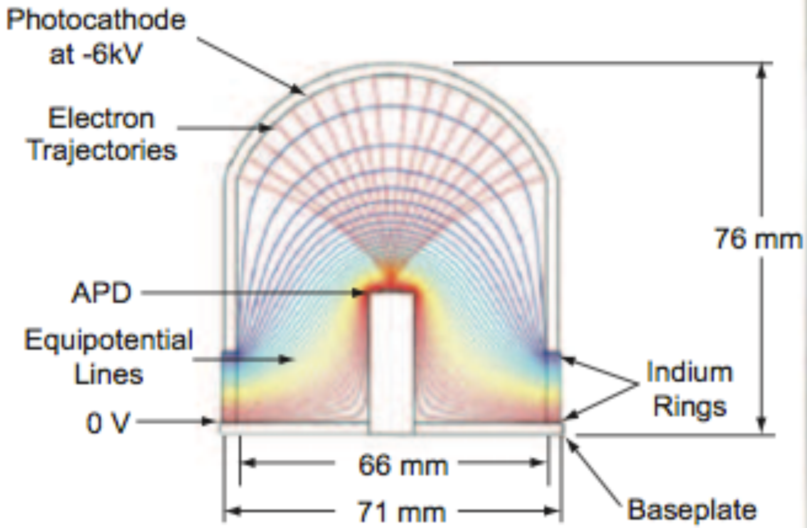




QUPID - low radioactivity photo-detector
UCLA/ Hamamatsu

PPD EE dept. (M. Utes) designing HV source for testing

1st samples in a month




Minimum no. of feed-throughs, low-radioactivity glass

# Continuing Topics of R & D largely glossed over ...

Tracking (ionization) Read-out (GEMS, LEMS in gas)

Light Read out (PMTs, SiPMs, TPB coated extrusions, TPB-based Scintillator with wave-shifting fibers)

Charged and photon Beam calibrations (B. Rebel)

High Voltage Feedthroughs and Generation (Cockroft-Walton ? )

Lifetime Measurement with VUV LEDs and better photo-cathodes,or with radio-active sources.

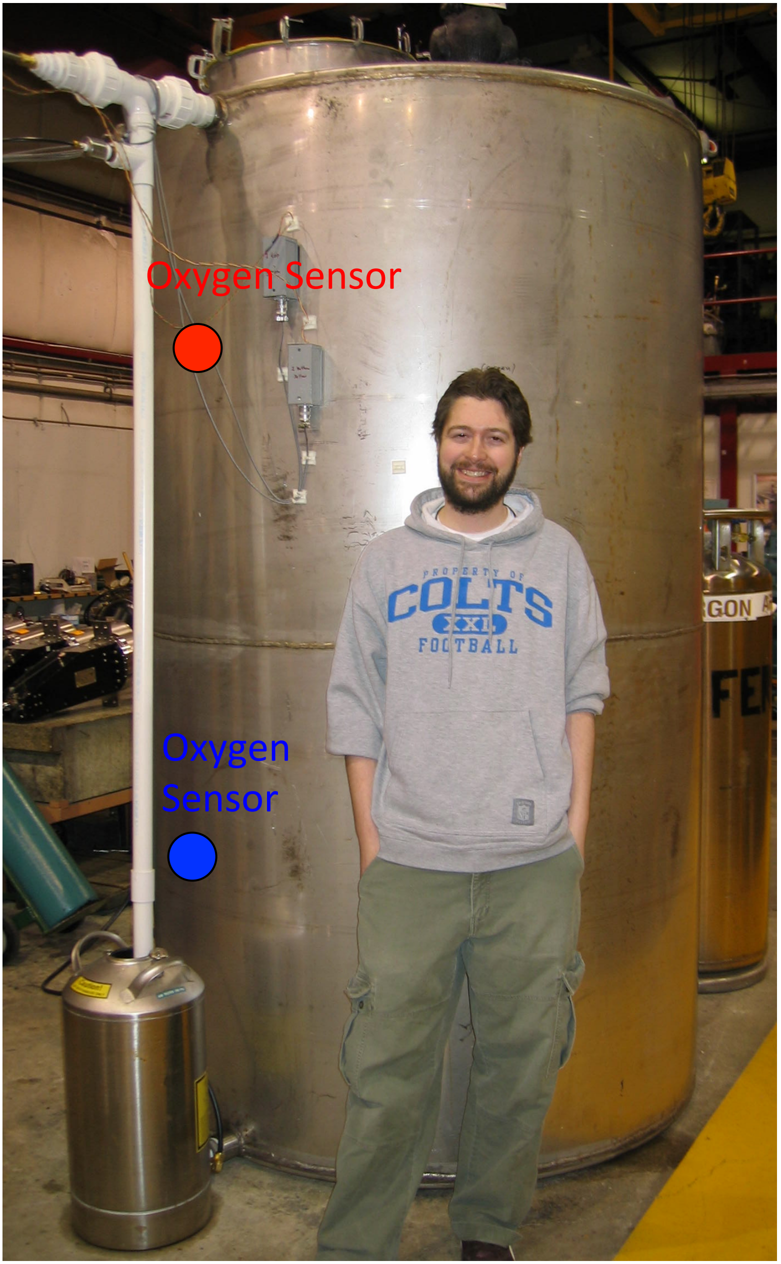
Cold electronics development.

Low radio-activity Photo-detectors.

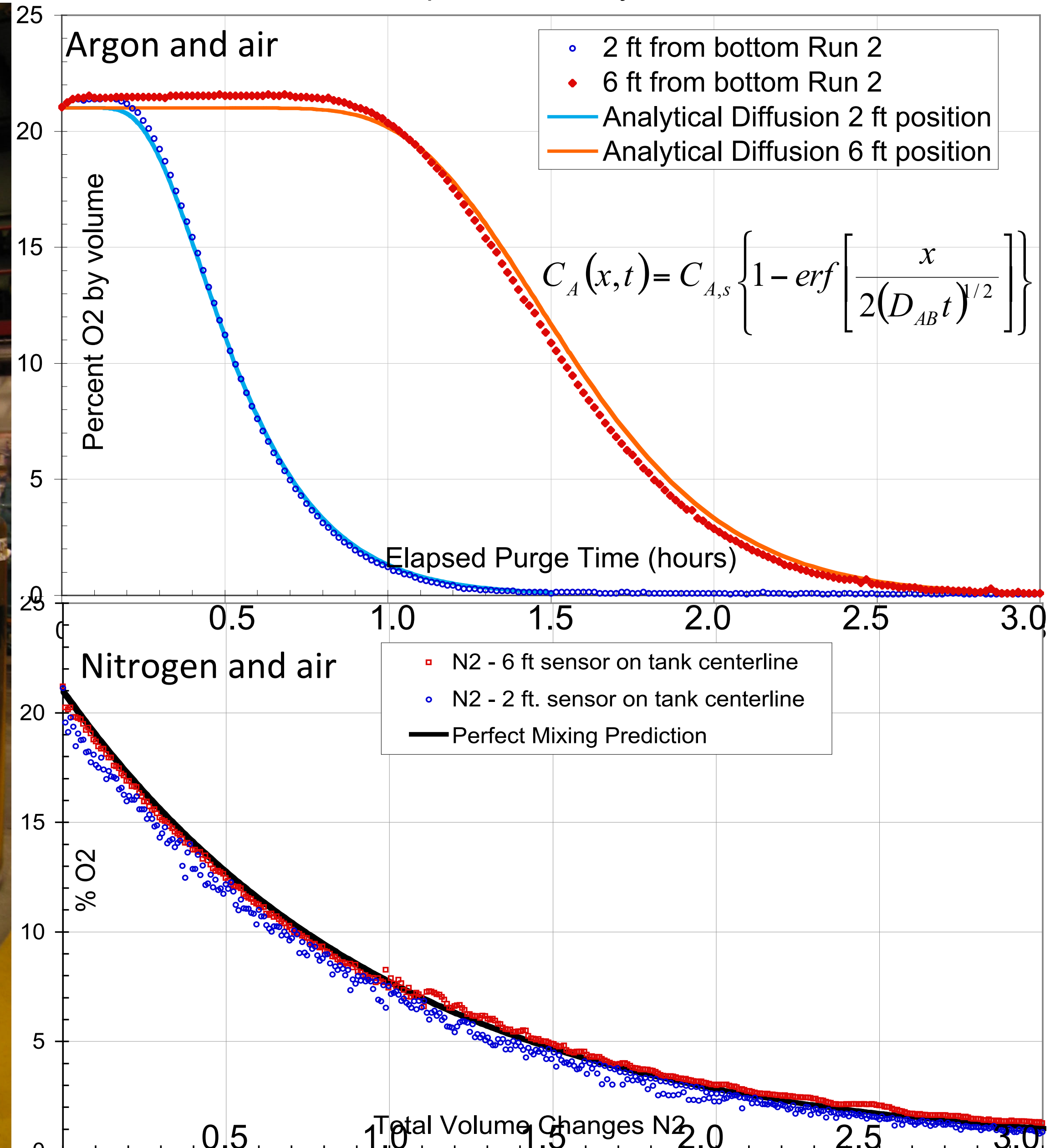
DAQ & Software - from in-line pattern recognition and trigger to 100% live to simulation to reconstruction & event identification under the aegis of LArSoft (B. Rebel)

# End & random back-ups

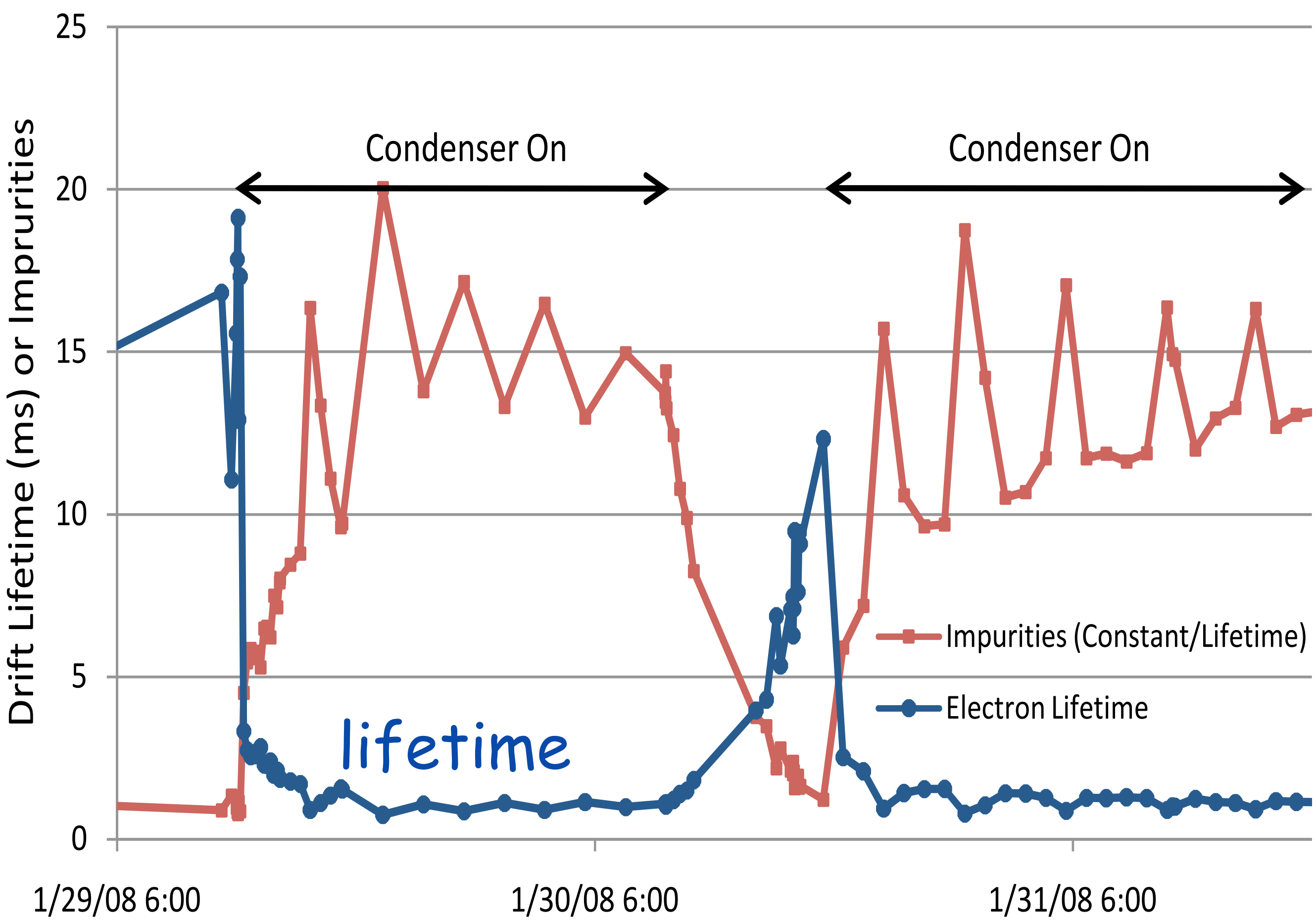
# Argon Piston Demonstration

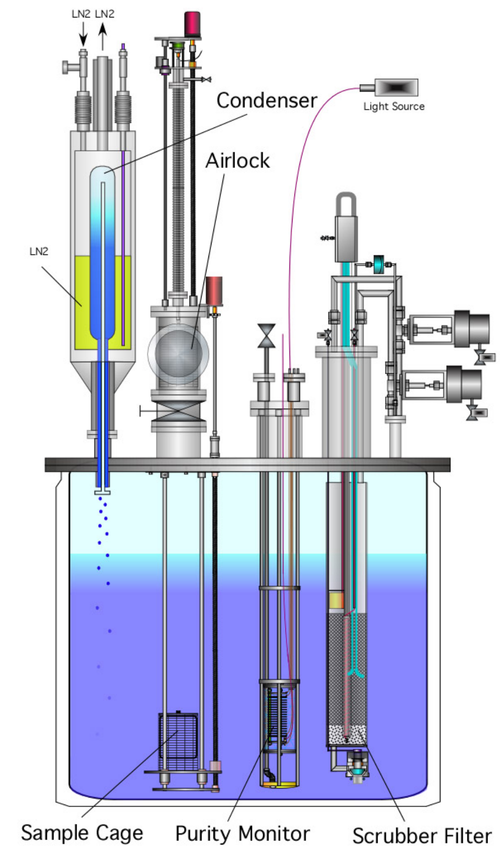



Percent O2 Sensor Output vs. Time
data compared to analytical model



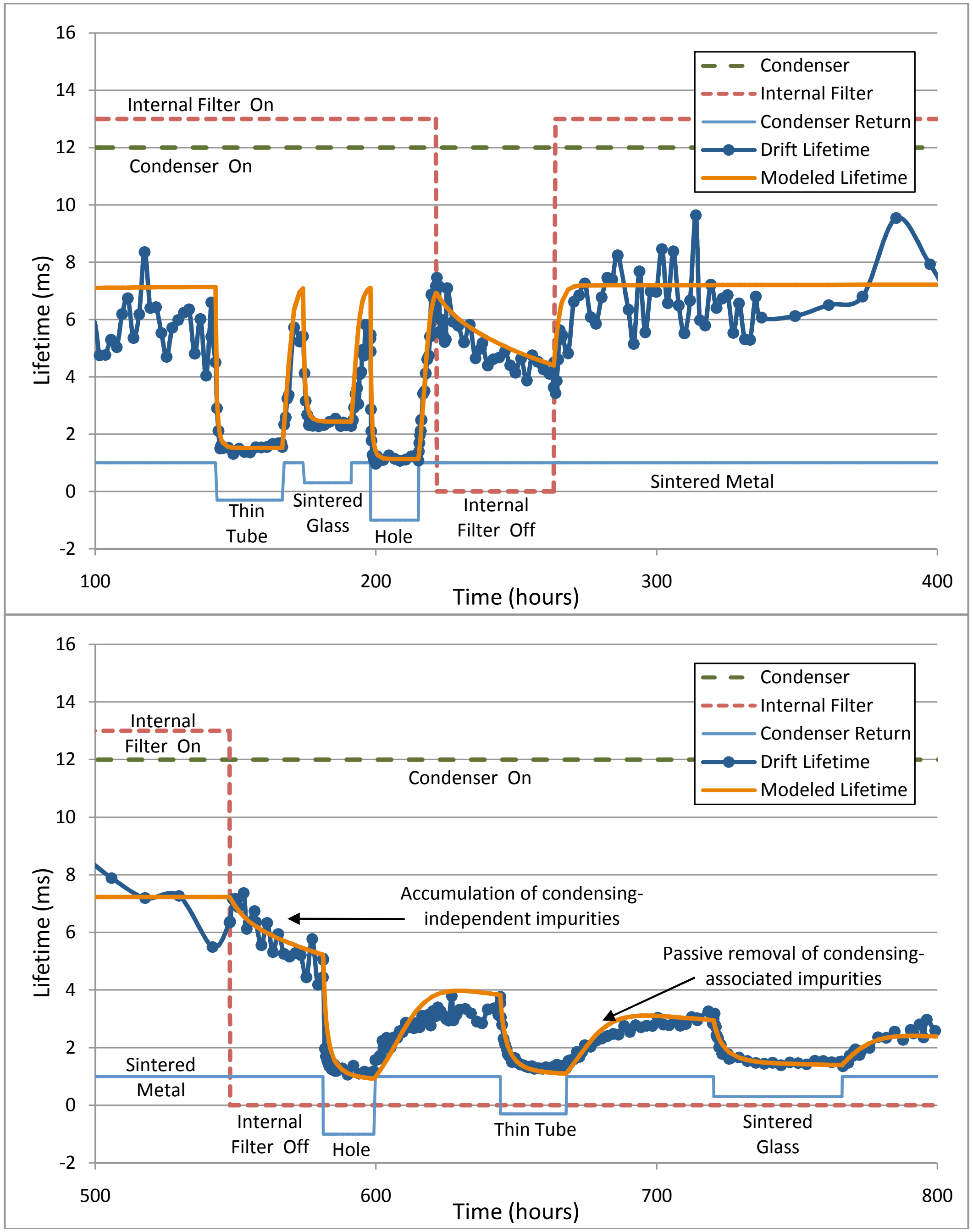
Our first experience of a closed system – returning re-condensed argon directly to liquid

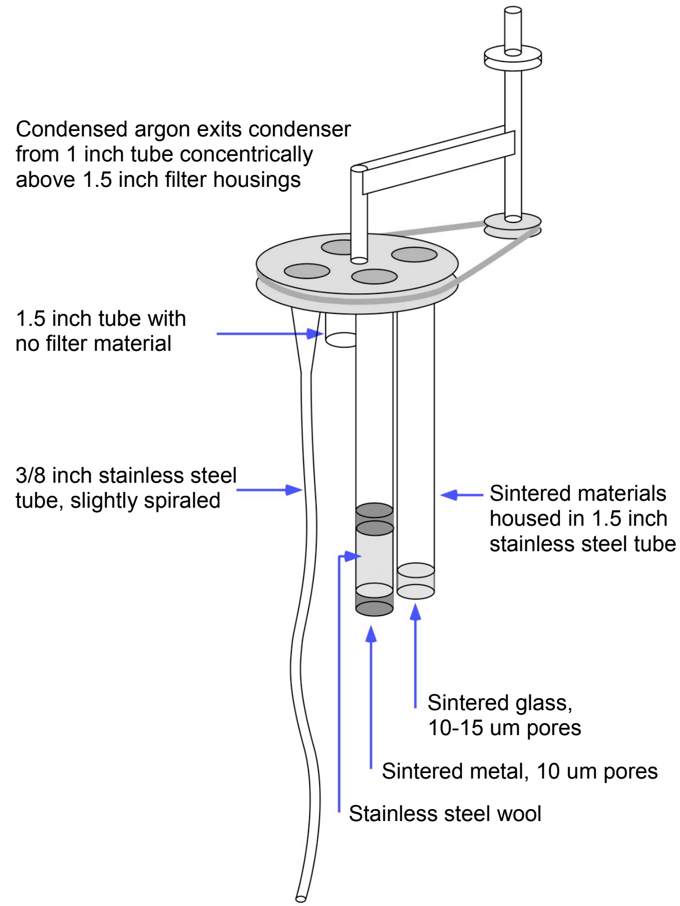



Water is the enemy – it lurks in the warm ullage

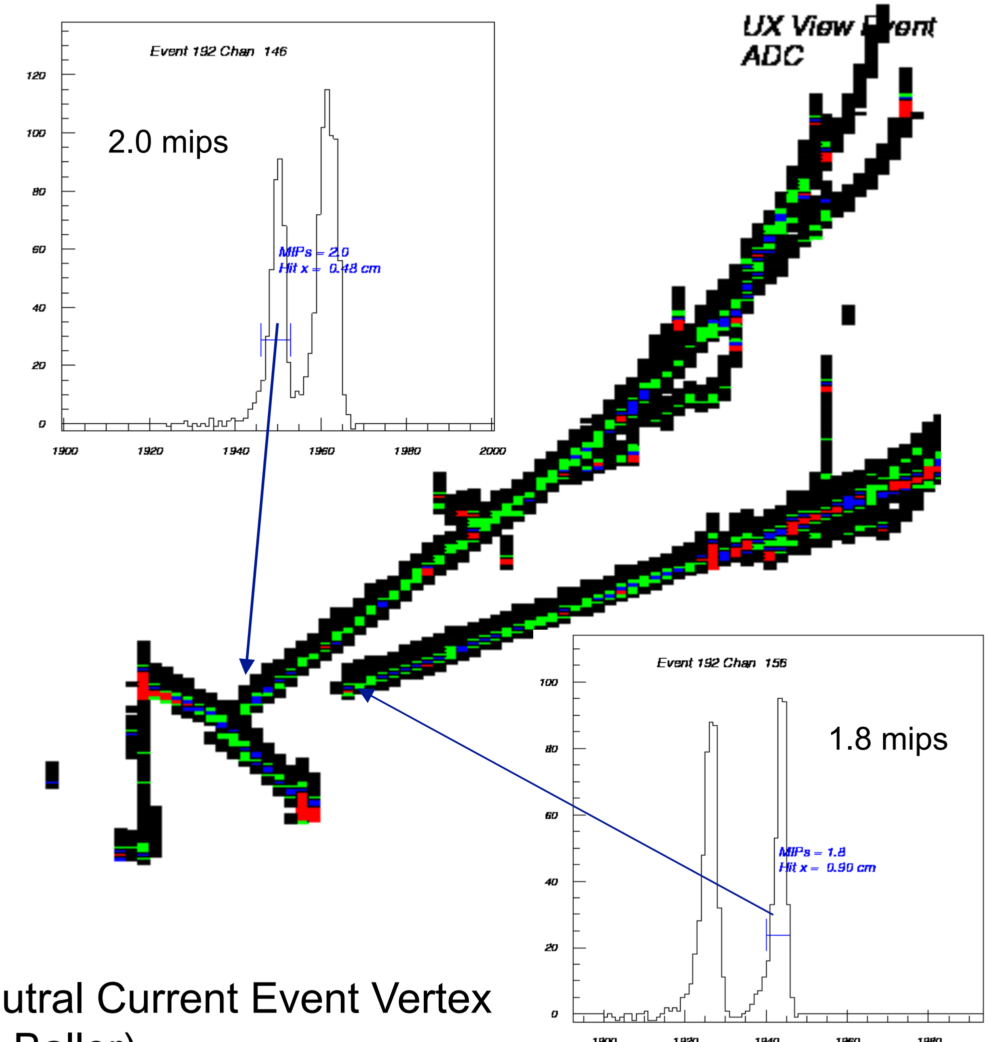
# Drift Lifetime Study with different returns



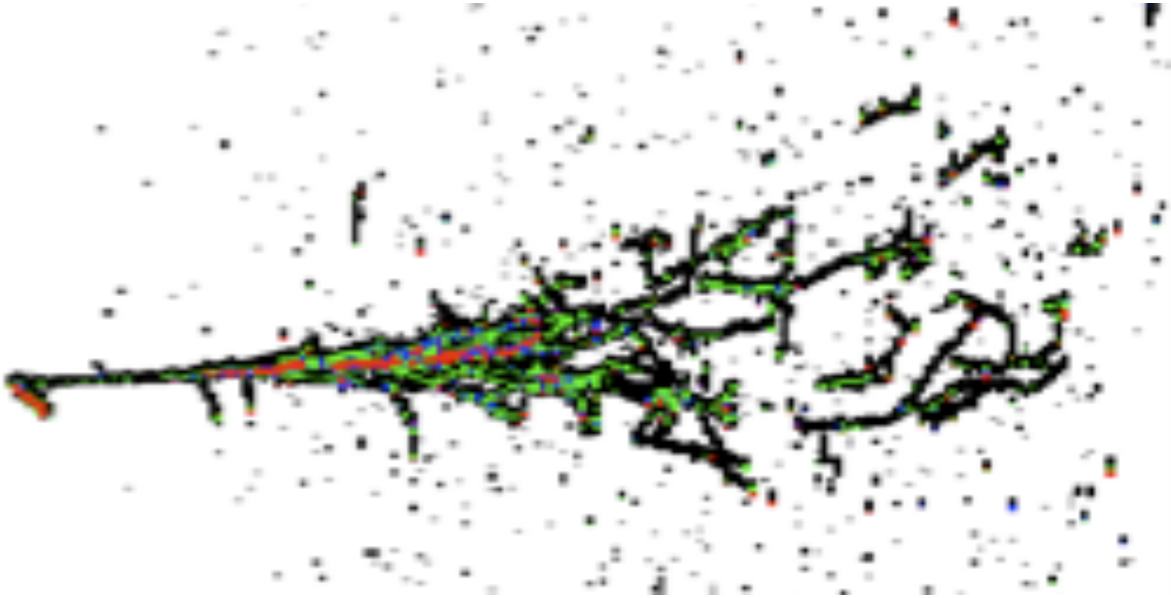



# Simulation Software:

- Full Simulation of events in the detector starting from ionization through signals induced on wires through amplifier shaping and Fourier deconvolution etc
  - –know what to expect using `typical' parameters
  - –investigate alternatives (wire spacing, wire angles)
  - –develop pattern recognition and event ID algorithms



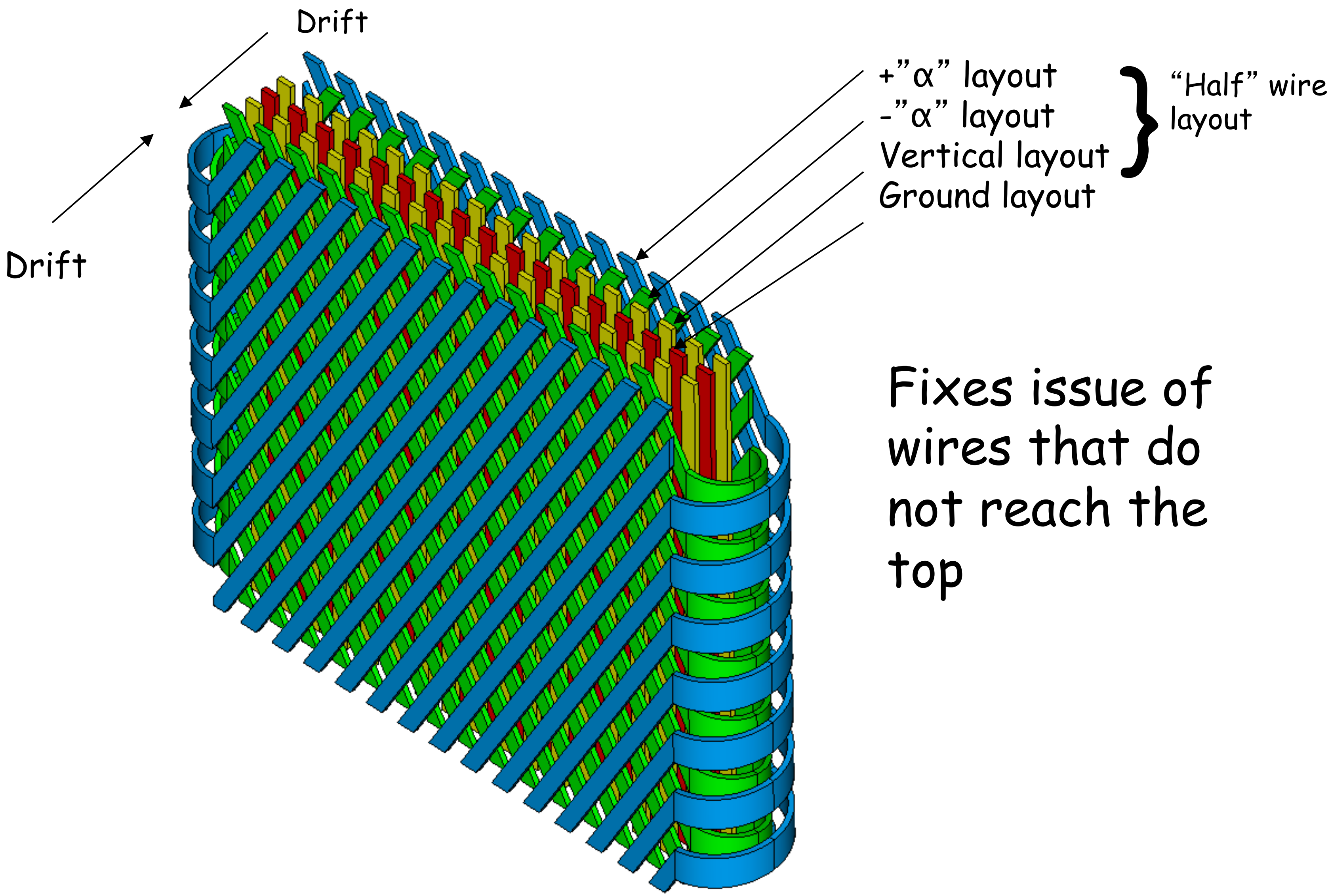

Neutral Current Event Vertex
(B. Baller)



Text book
Electrons

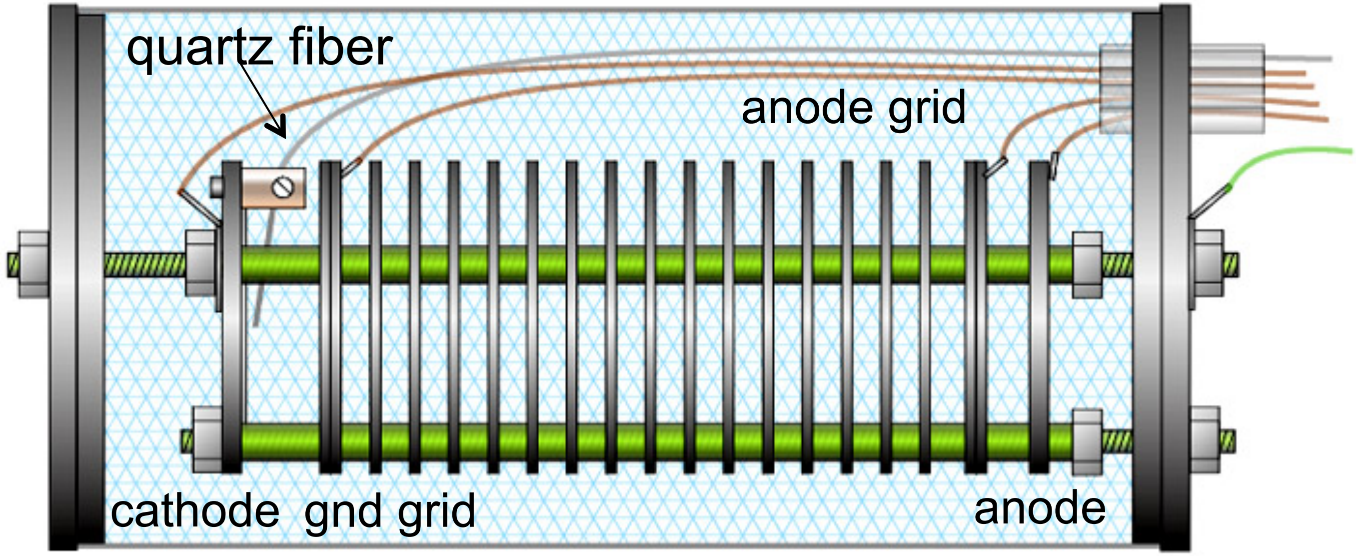
$\nu_e + n \rightarrow e^- + p$

# WIRE LAYOUT (proposal)

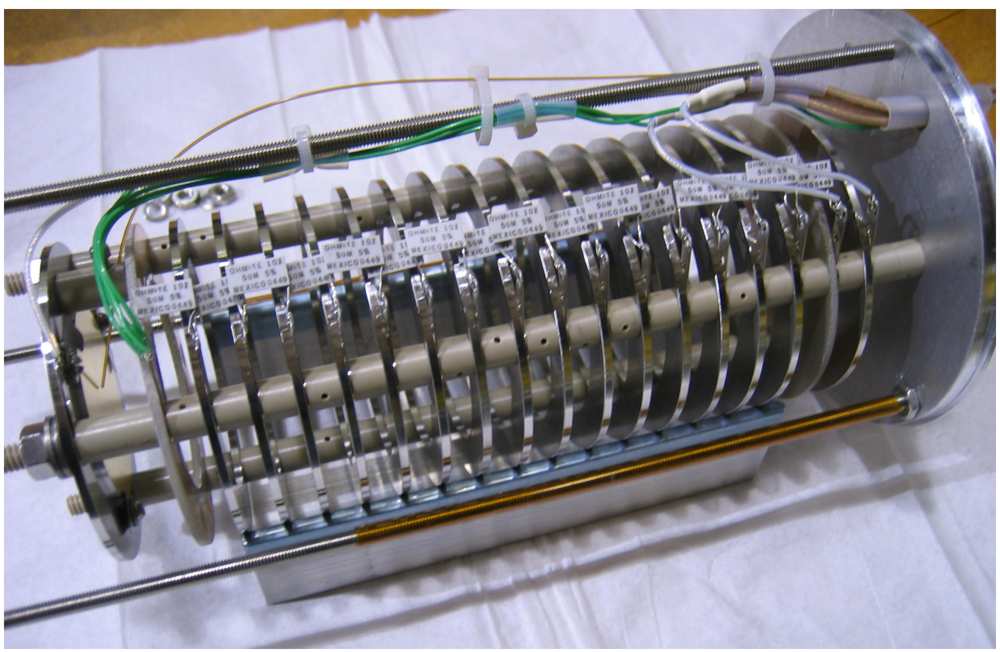



Fixes issue of wires that do not reach the top

PrM drawing



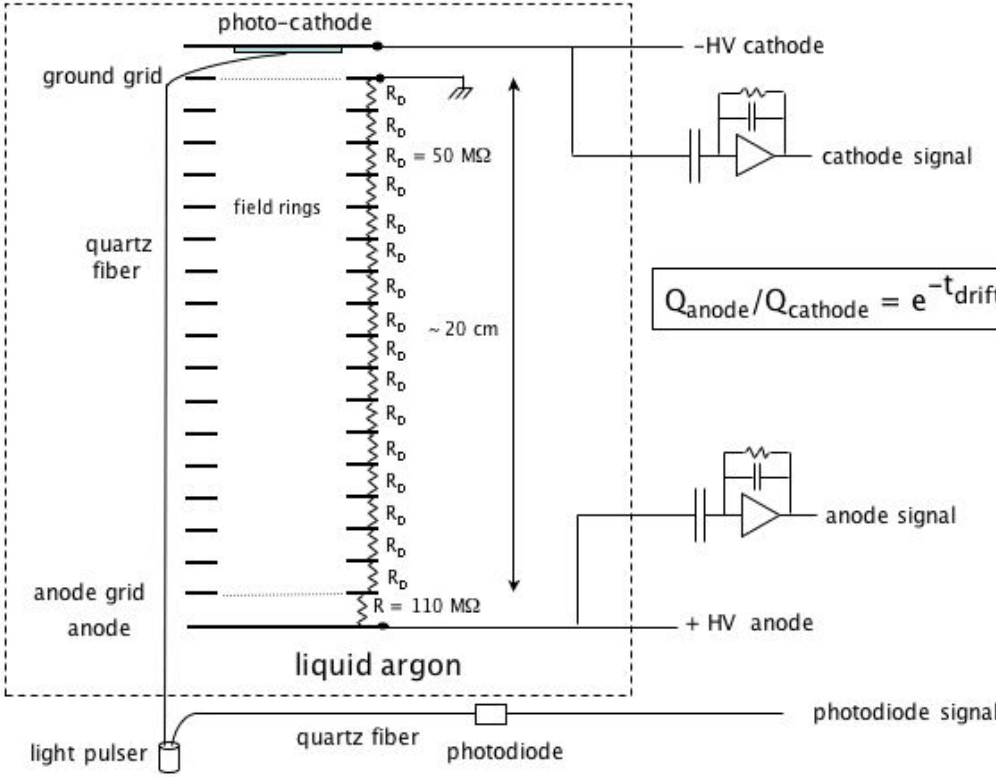

C.Kendziora2/3.05



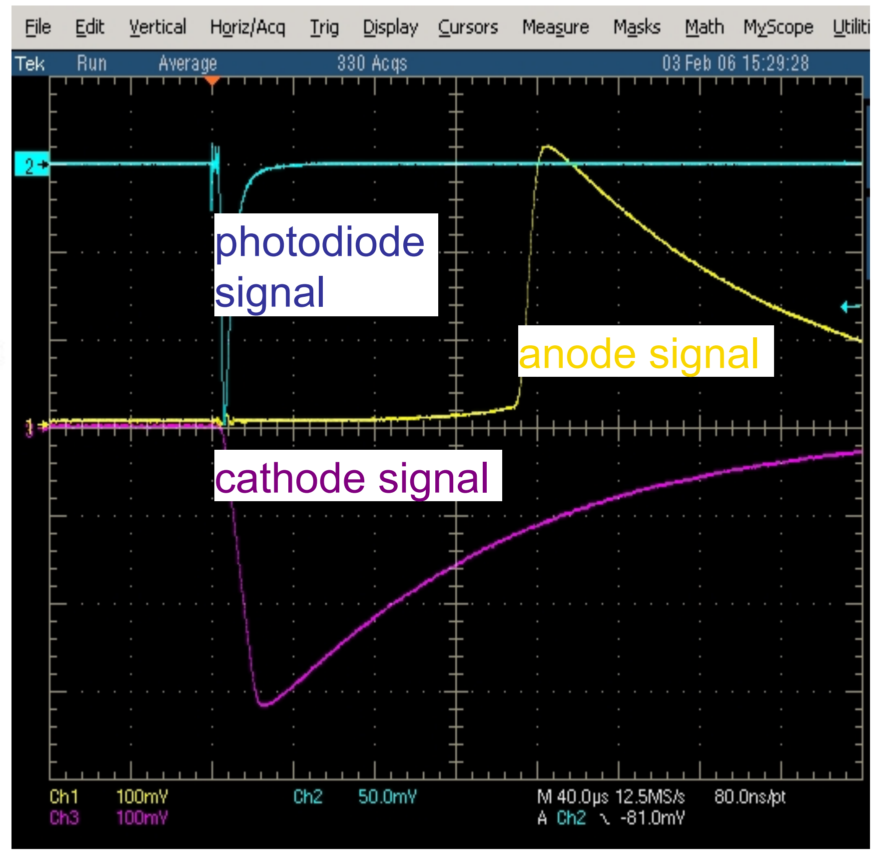
PrM photograph

# Drift lifetime Measurement

Schematic of Liquid Argon Purity Monitor (PrM)

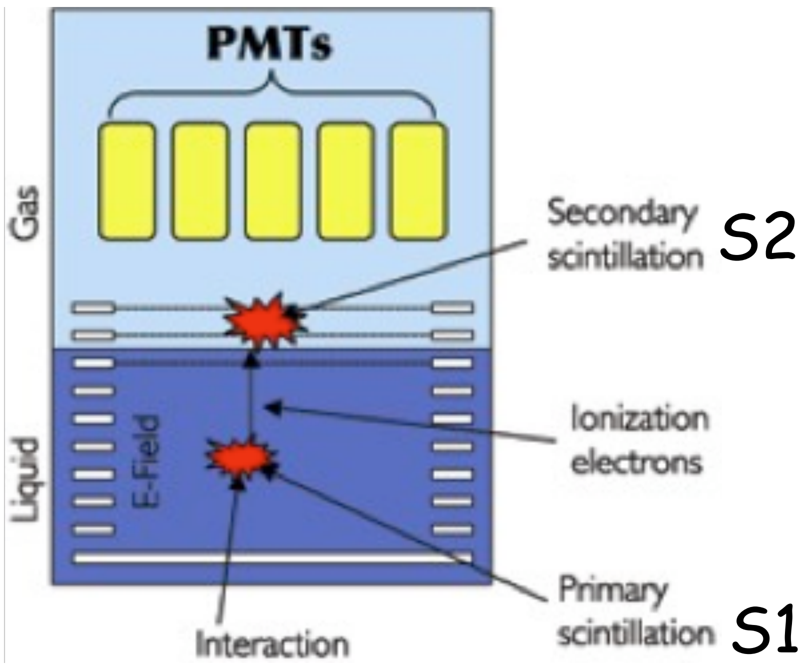



$$Q_{anode}/Q_{cathode} = e^{-t_{drift}/\tau}$$

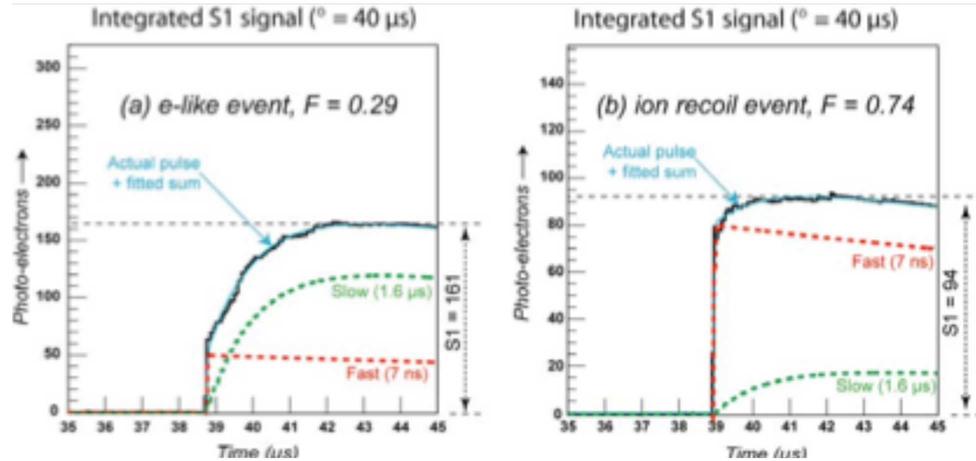



G. Carugno, NIM A 292 (1990)

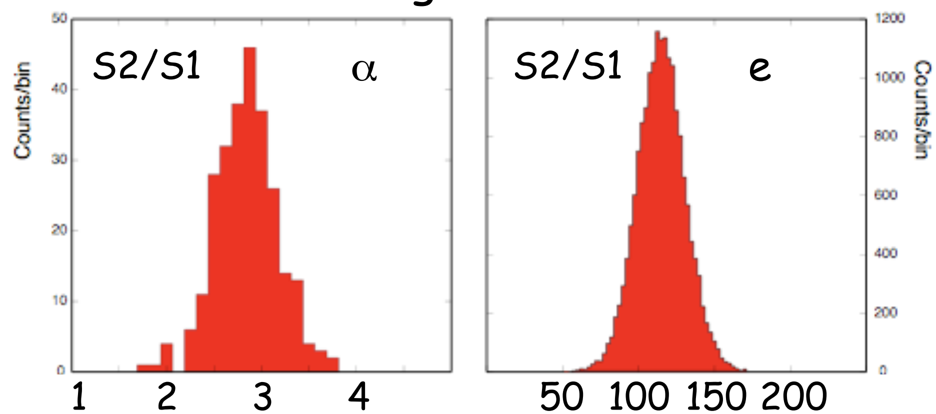
# from WARP




fast/slow




surviving ionization




S1 (energy, time distribution -> particle dE/dx)

S2 (ionization that escapes recombination -> particle dE/dx)

S1 PSD rejection ~$10^{5-6}$, S2/S1 rejection~$10^2$, com. $10^{\wedge 7-8}$

# *Some LArTPC Technical Issues for Neutrino Detectors*

**Argon Purity**

- **From atmosphere to purity without evacuation**
- How to remove impurities from Argon (filter gas as well as liquid?)
- What impurities matter and how to measure drift lifetime
- What are the sources of contamination and how to avoid/remove them without pumping (vessel, plastics=> surface physics)

**Vessel Design**

- Design, **(Underground) Construction**, Safety
- Cryogenics (cooling system and insulation )
- Thermodynamics (argon temperature and flow distribution)

**Detector Design**

- HV system
- Mechanical reliability - **TPC constructed in situ or externally**
- Constraints from electronics (eg readout only at top?)
- Light collection scheme; (for `triggering' and pattern recognition)

**Electronics & DAQ**

- Amplifiers, multiplexing, digitizers - **in cryostat?** Feedthroughs
- Signal/noise (large capacitance) and constraints on TPC design
- Zero suppression, signal processing, local event recognition capability, **100% livetime (not just beam spill)**

**Simulation & Reconstruction**

- Real and simulated signals on wires; develop signal processing
- Event generation in argon
- Vertex and pattern recognition; cosmic ray rejection; event reconstruction