Liquid Argon R & D at Fermilab

Something about Liquid Argon

Ongoing Work and prospects at Fermilab

R & D opportunities

Must acknowledge the ICARUS program for its pioneering work.

Must acknowledge Adam Para for starting the program at Fermilab

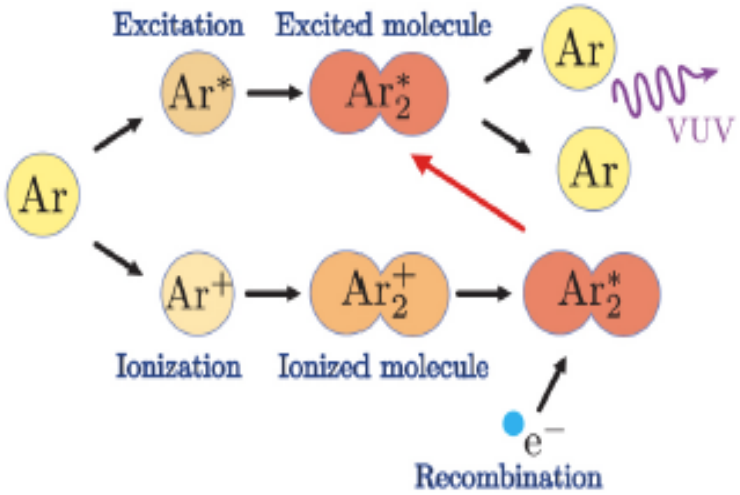
Noble Liquids are strong scintillators and allow electrons to be drifted over long (meters) distances under E fields of ~ 1kV/cm

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/cm^3]	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 x 10^6	15	1.6	0.09	0.03	
ppm in air	0	12	9500	1	0.1	

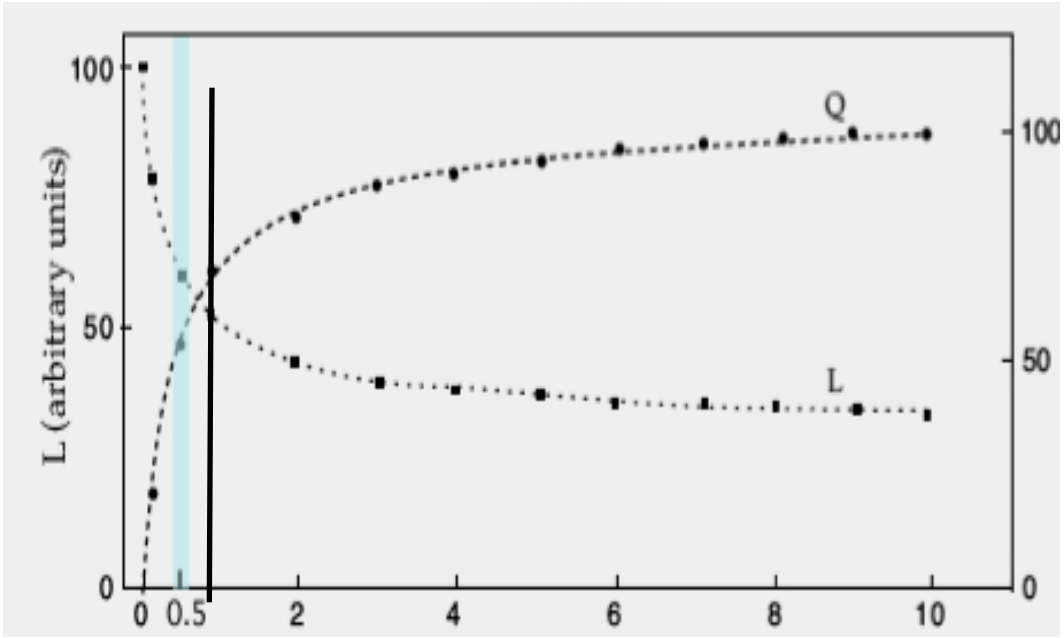
* at zero electric field
** at high electric field

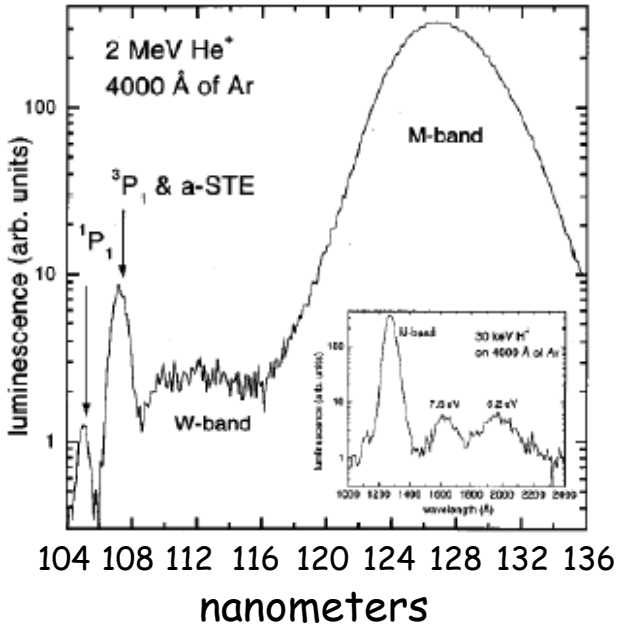
mechanism of light production



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:

τ(singlet) = 7 ns, τ(triplet) = 1600 ns

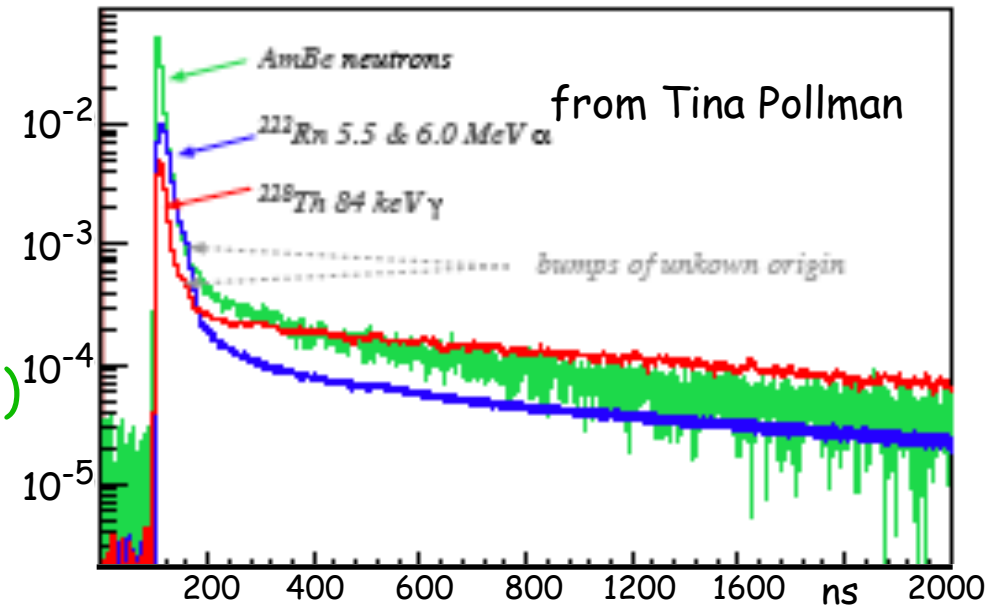
Fast/Slow depends on **ionization density**

I(fast)/I(slow) =0.3(γ),

= 1.0 (α),

= 3.0(neutron-recoils)

Light output time distribution for γ, α, and neutron-recoils



Basis of PSD (pulse shape discrimination) for rejecting e and γ events

(Other parameter used in 2 phase TPCs (eg Xenon 10/100) is light intensity to free electron charge 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 π^0 from ν_e CC scatters - θ_{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

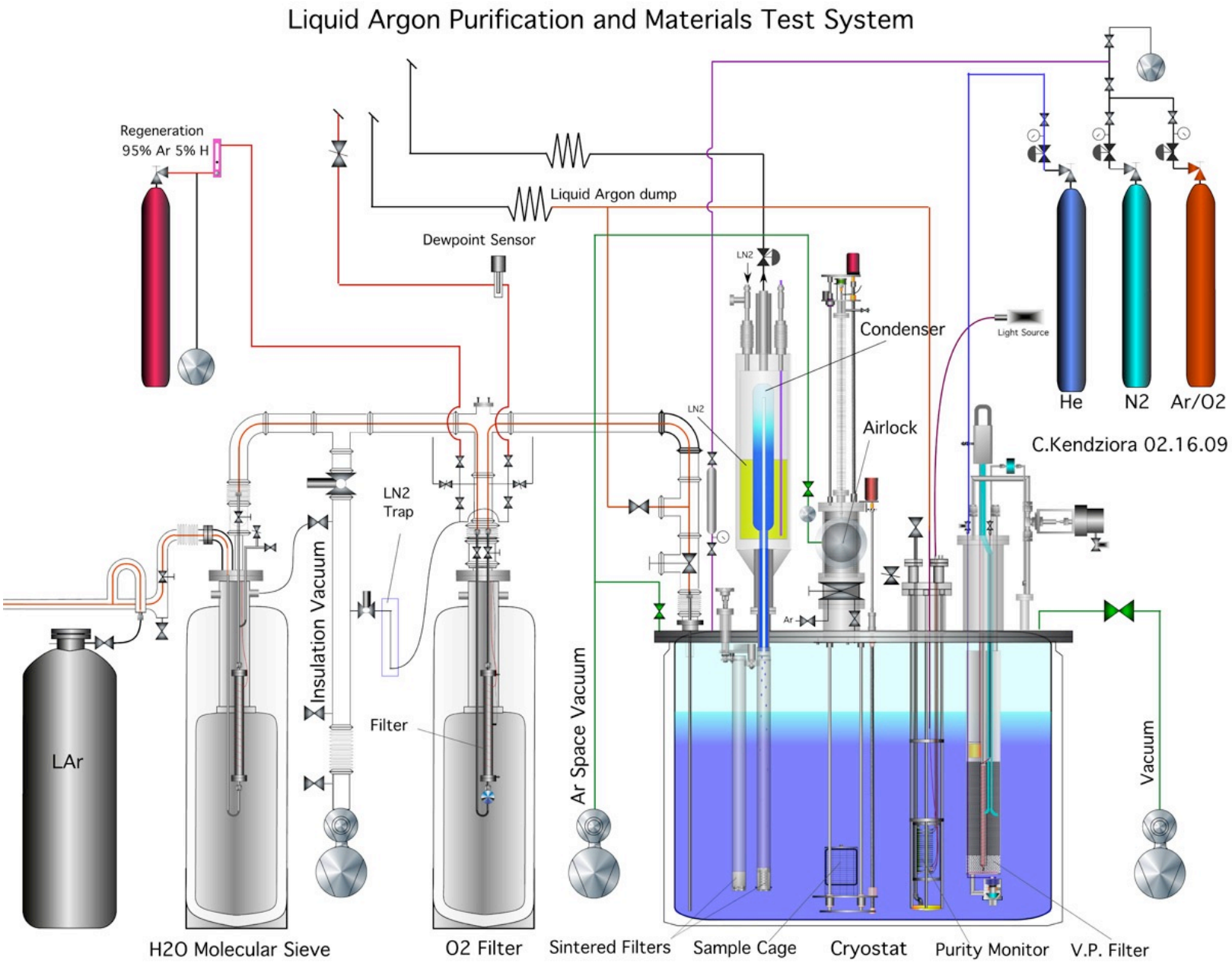
Electronics Test System with TPC

ArgoNeuT (T-962)

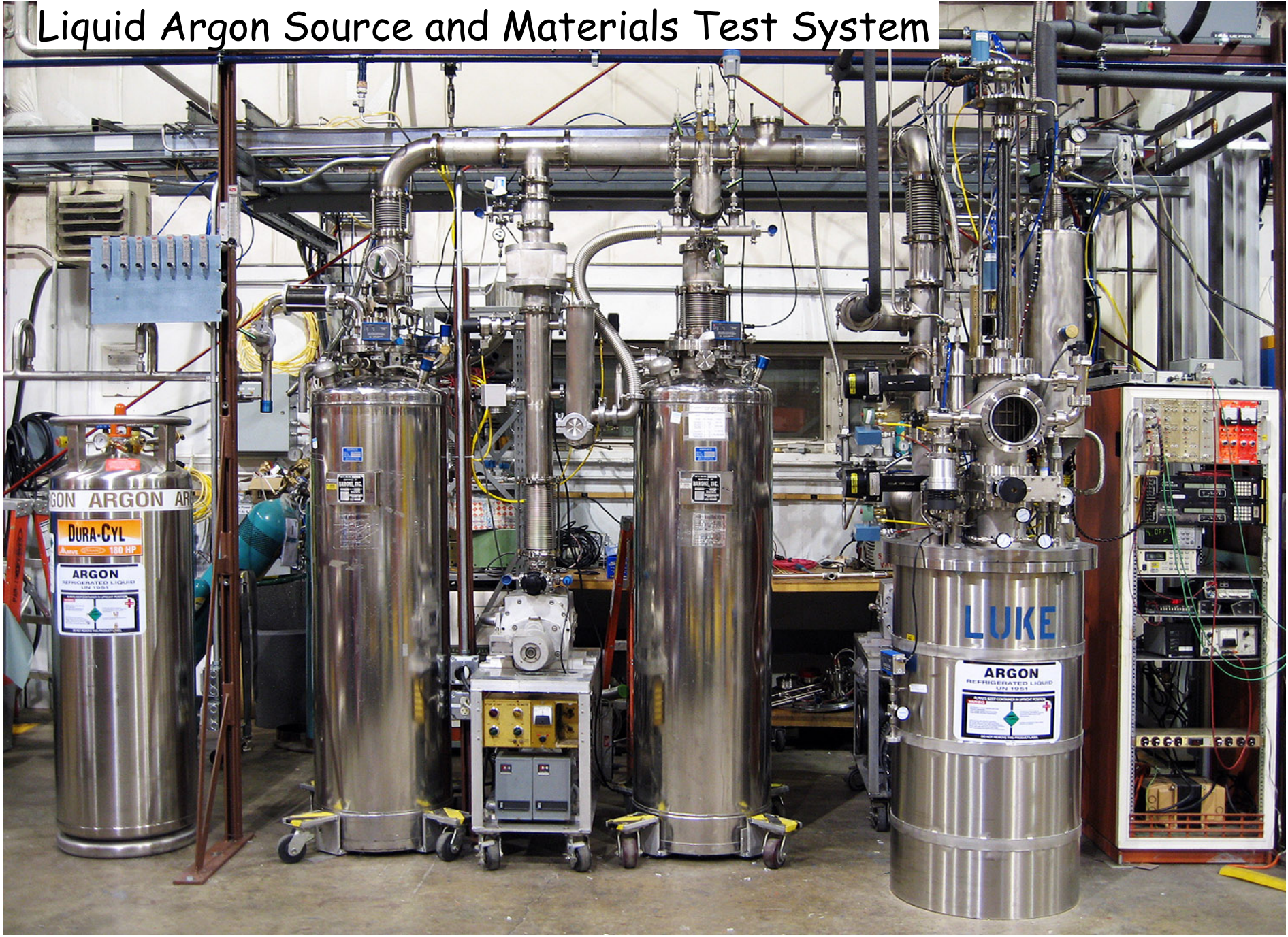
DarkSide 10 (prototype DM detector)

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
He
N2
Ar/O2
C.Kendziora 02.16.09
Airlock
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

Liquid Argon Source and Materials Test System



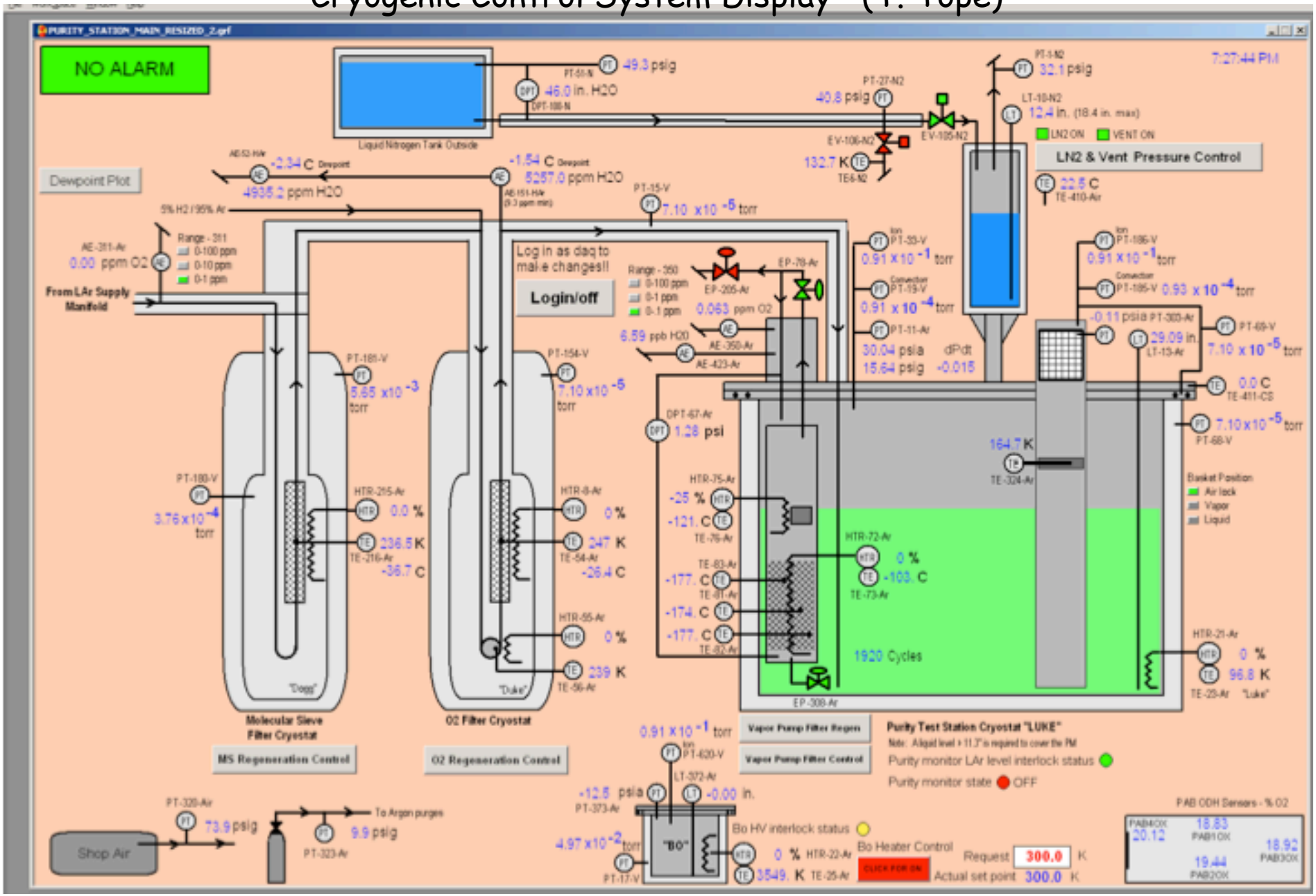
Features of Materials Test System

- 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

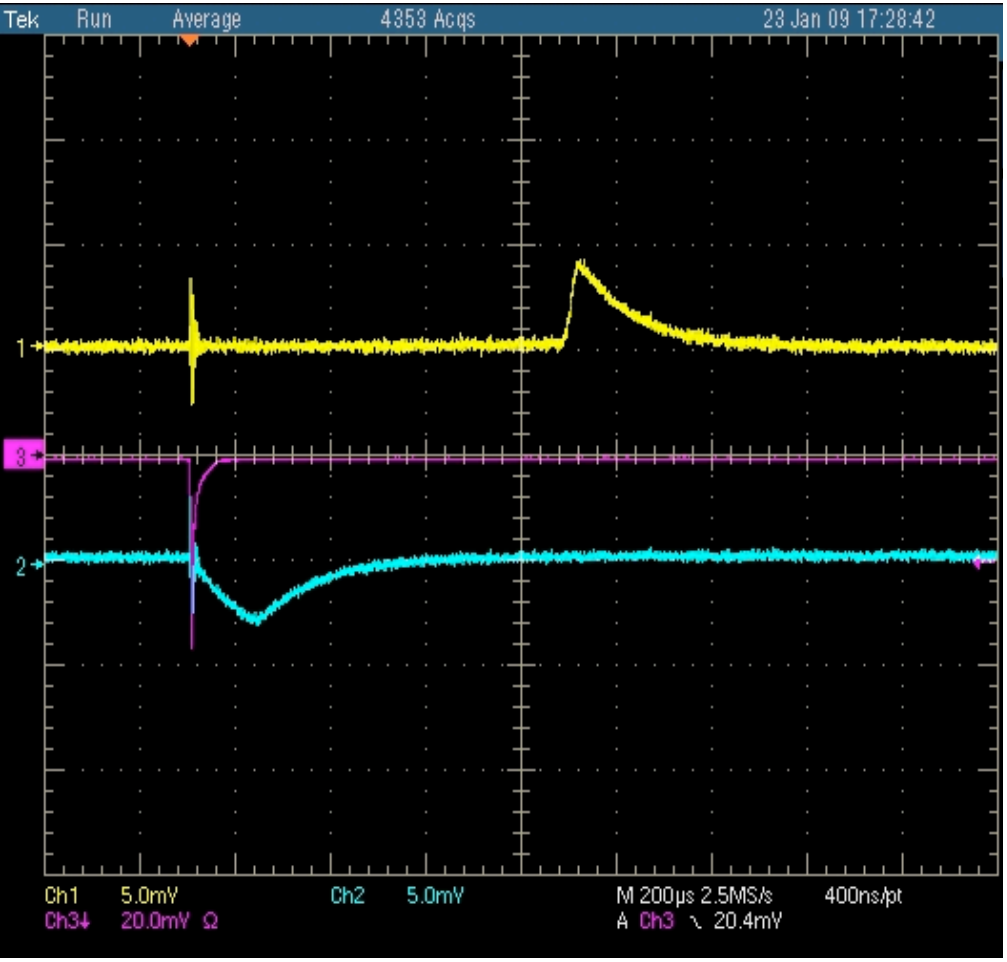
Measurement Features of Materials Test System

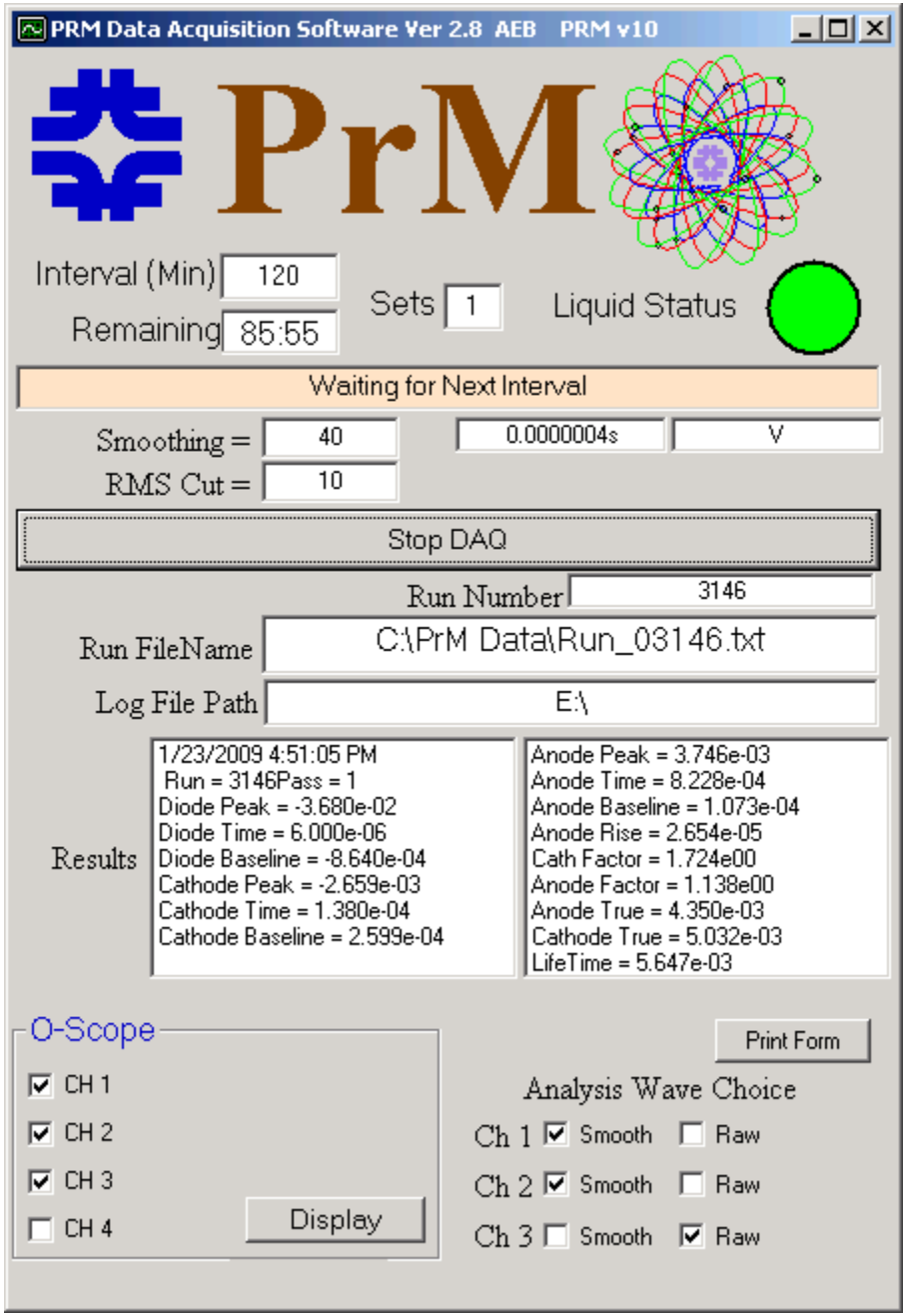
- Measure electron drift lifetime (0.3 milliseconds to 10 milliseconds)
- Measure Oxygen (0.5 ppb sensitivity) with oxygen meter (Delta-F & Tiger Optics)
- Measure H20 in gas (0.5 ppb sensitivity) with water meter (Tiger Optics)
- Cryogenic data, Lifetime Data, analytic instrumentation data in single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

Cryogenic Control System Display (T. Tope)



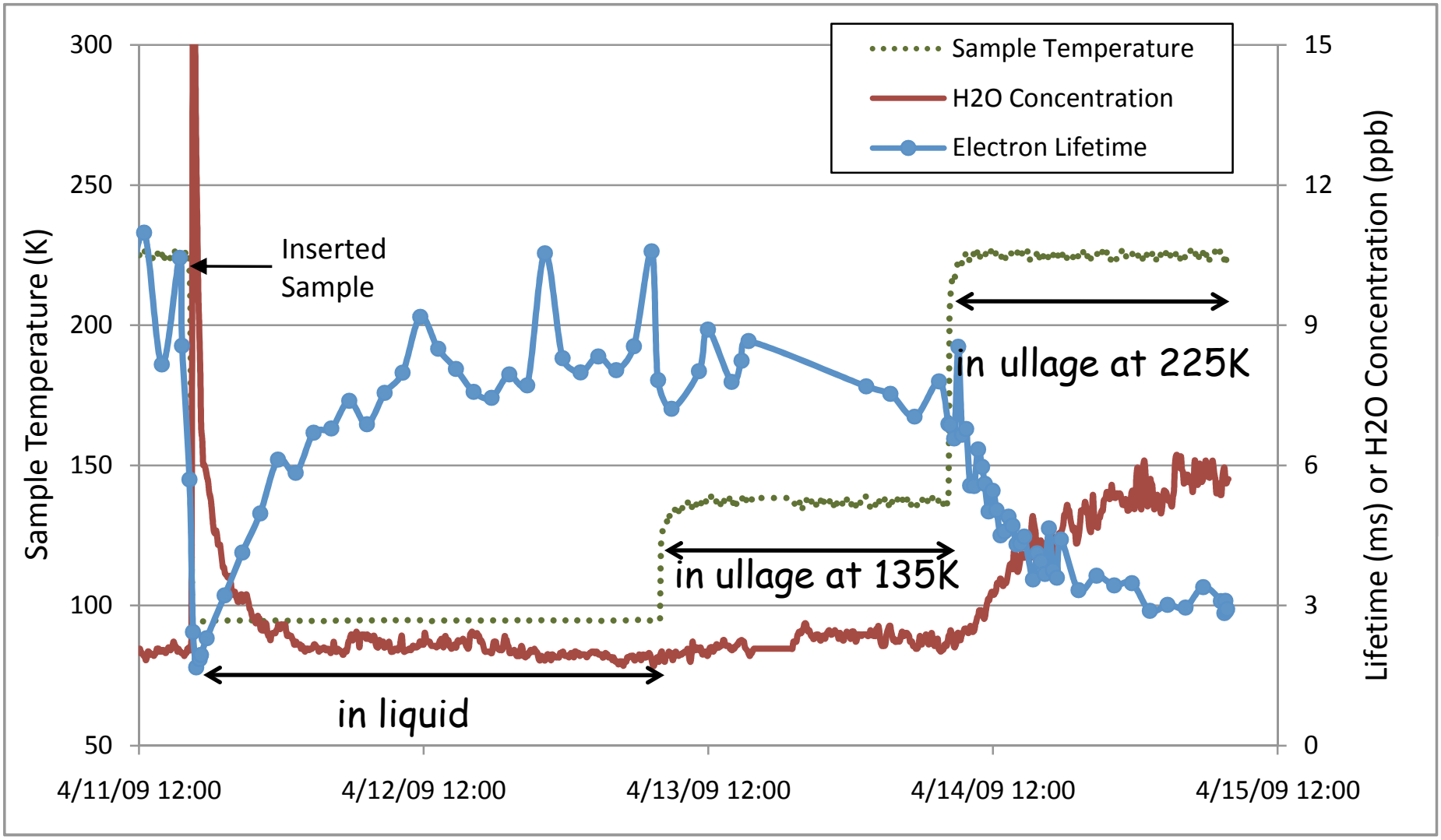
On-line data and DAQ





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

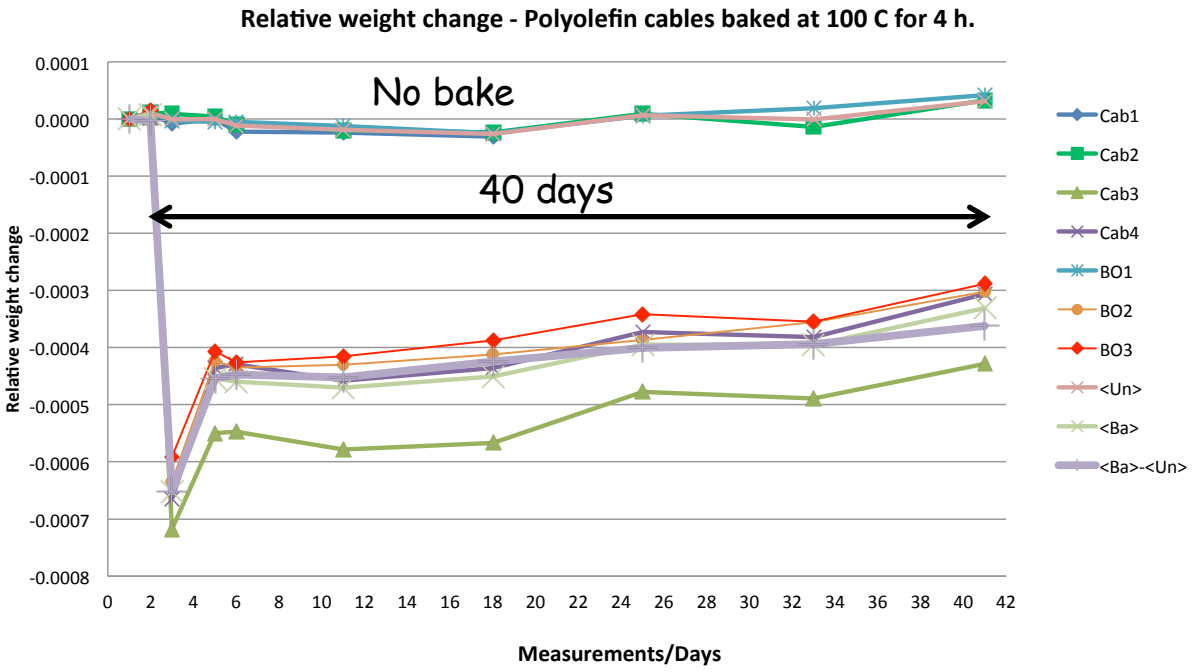
Material	Date test started	Preparation	Tests	Water [ppb]	Lifetime [ms]	LogBook #
Cleaning Solution	6/29/09	evac. 24 h	vapor/liquid	4	5	946
Vespel	7/9/09	evac. overnite	liquid/vapor	5-7	2-5, 4-6	960
MasterBond glue	7/16/09	purged 18 h	vapor/liquid	1.6	1.3- 2.9	974
Bostik	didn't pass submerging in the 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

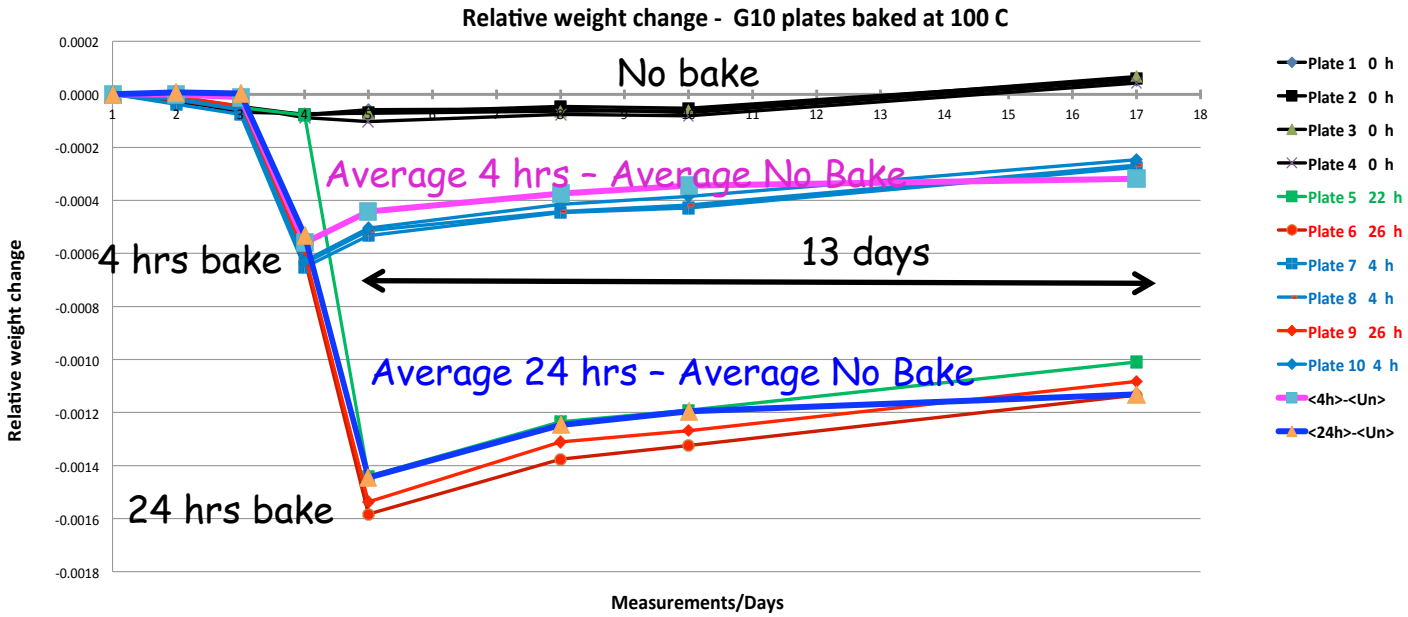
A useful database is http://outgassing.nasa.gov/ which gives removable water content

Water is the enemy.

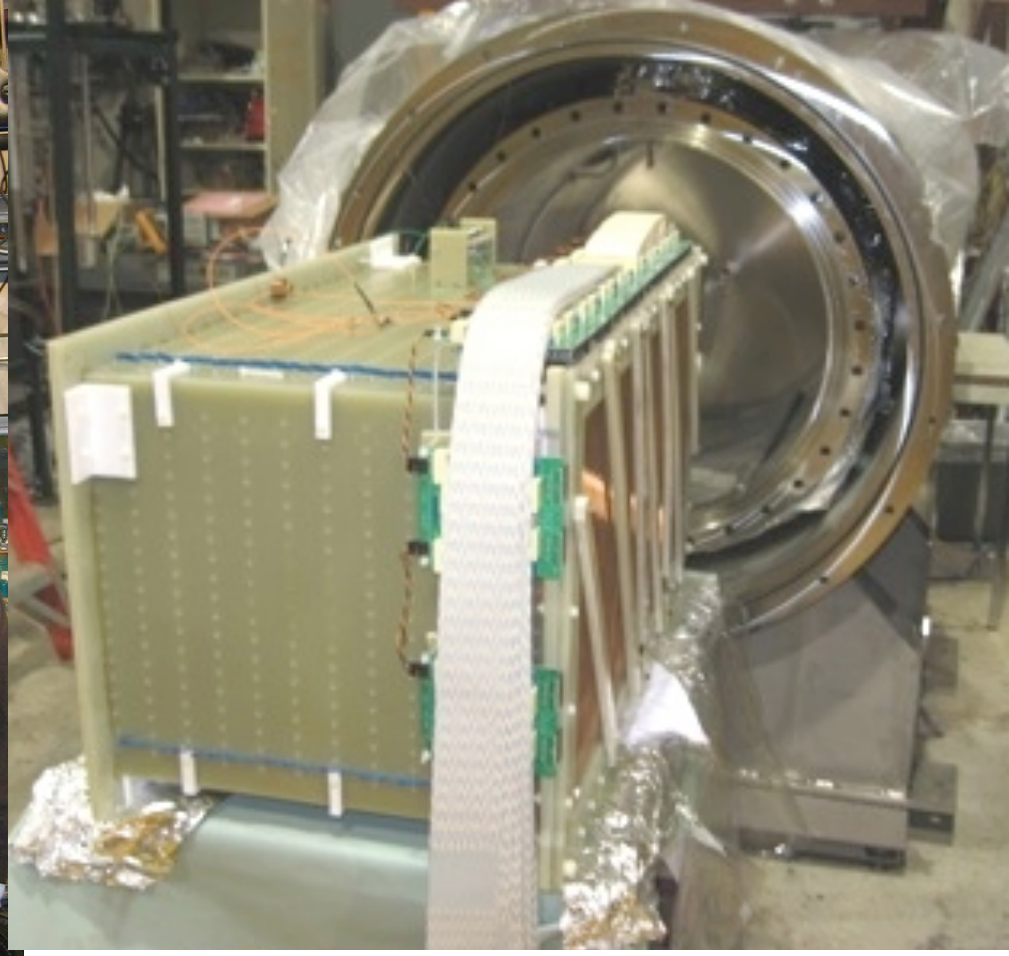
How long should one bake?

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

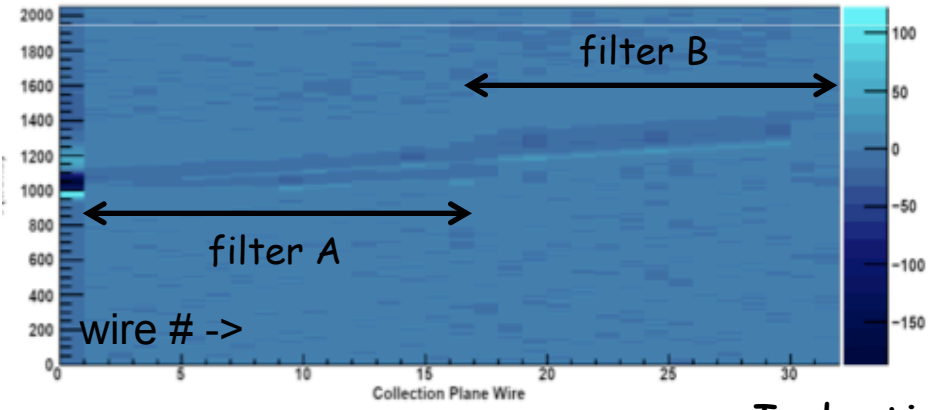
Electronics and hit reconstruction developed on BO

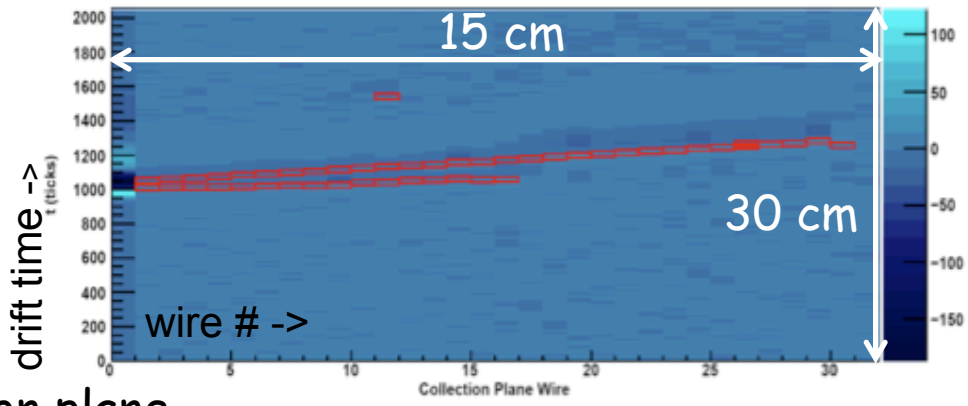
Electronics Test System- track finding and two track resolution

Raw Data

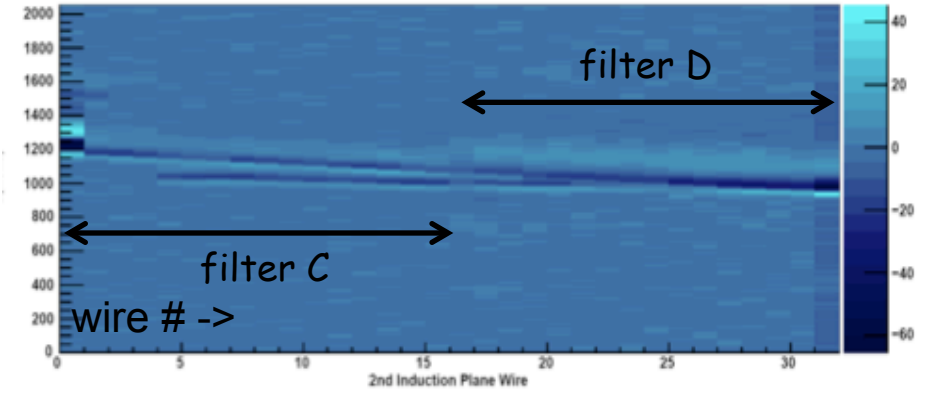
Collection plane

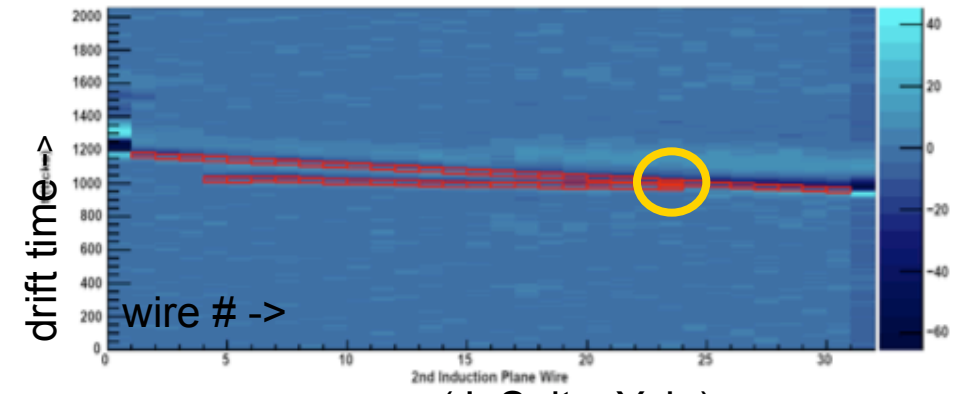
`Hits' found





Induction plane



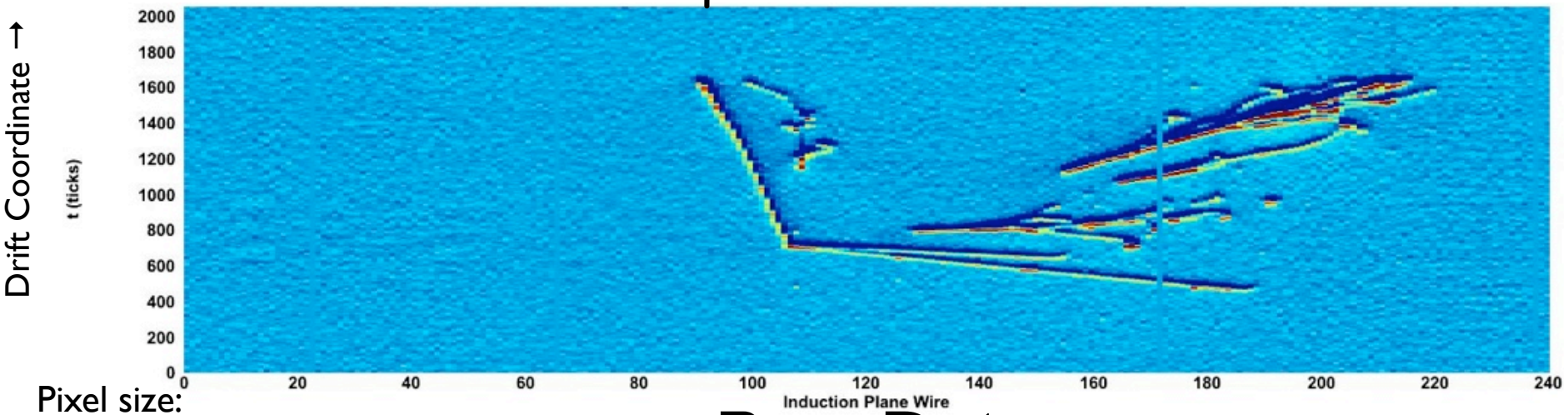


(J. Spitz, Yale)

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

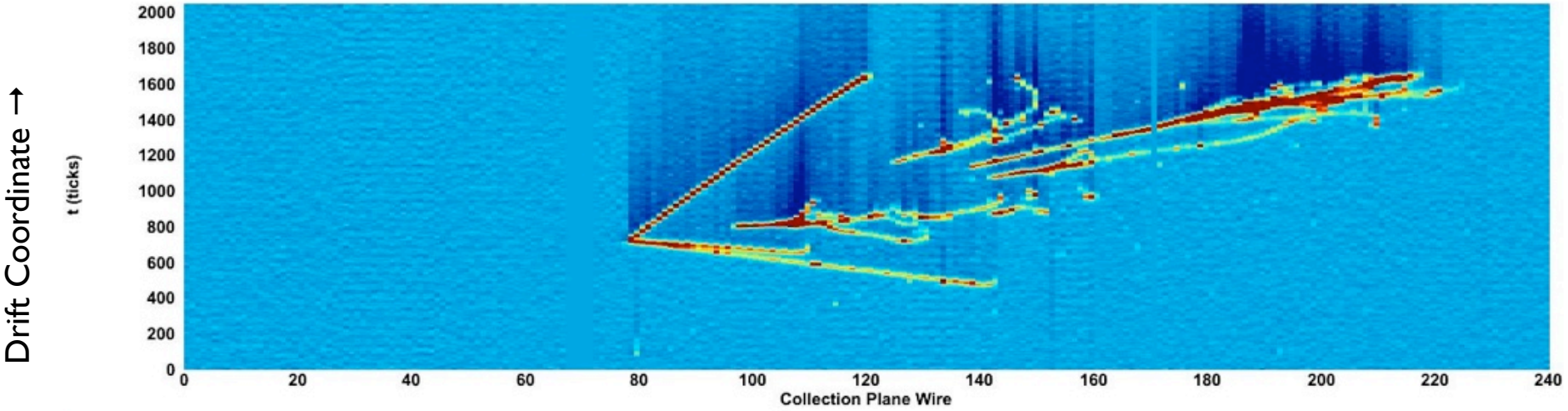
ArgoNeuT Neutrino Event

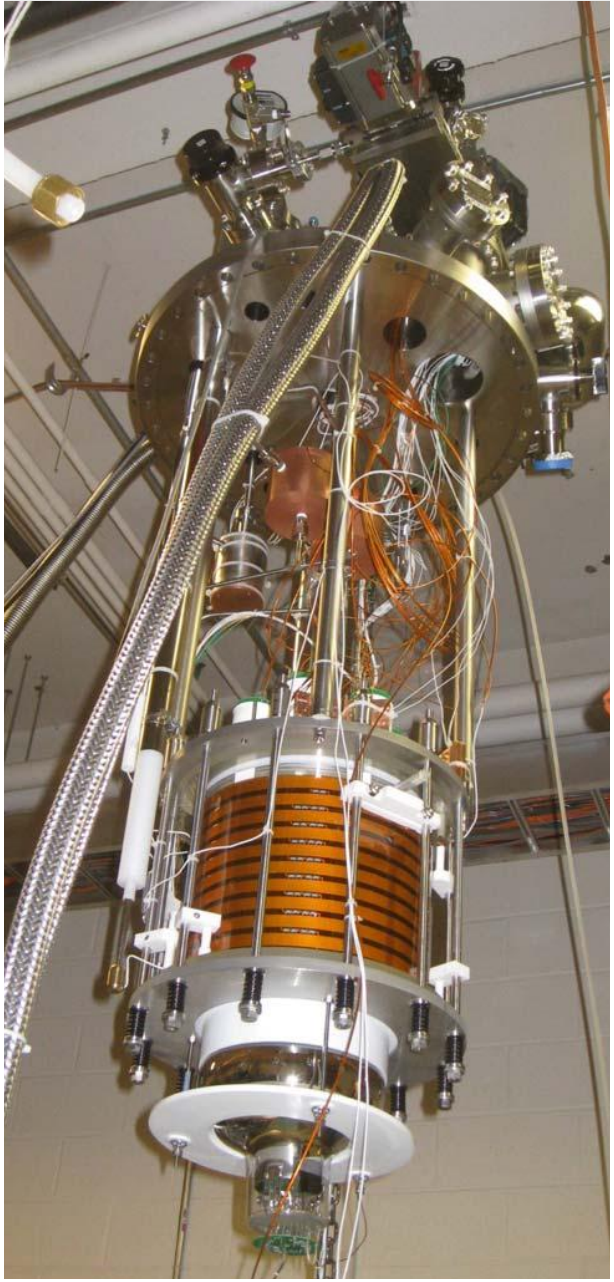
with 4 photon conversions



Pixel size:
4mm x 0.3mm

Raw Data

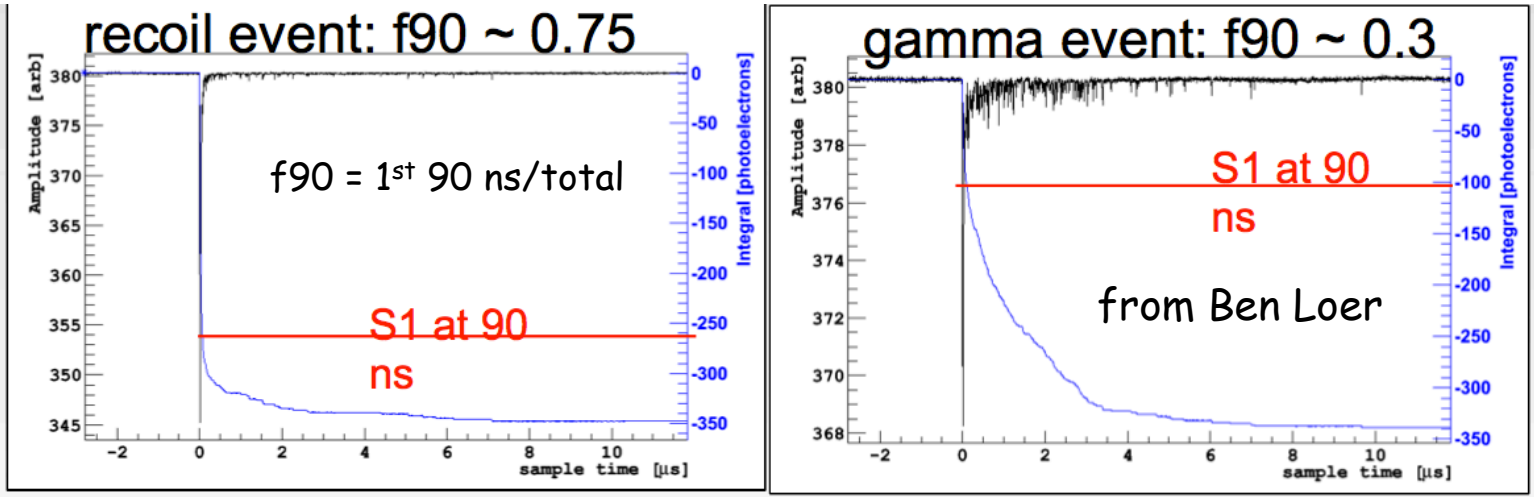


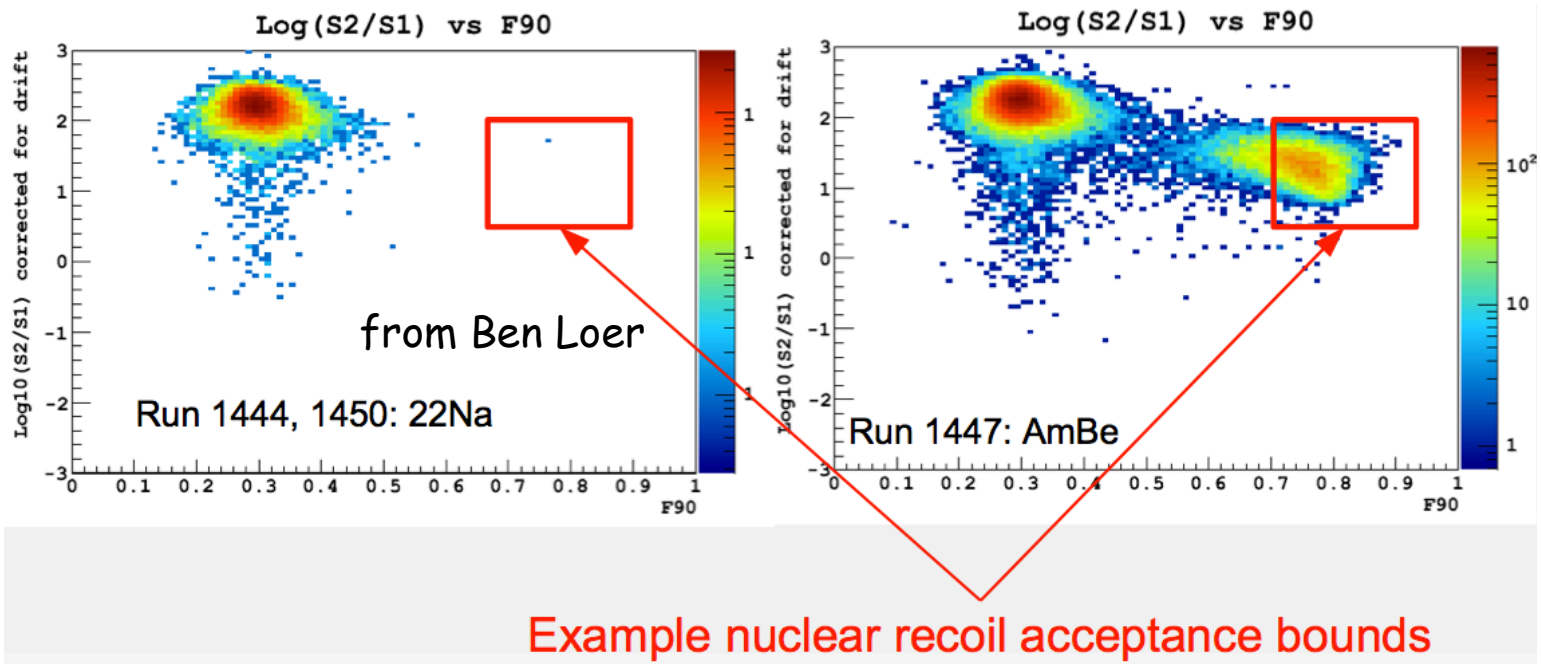


DarkSide 10 at Princeton

DAr Cryogenic Distillation Column at the PAB

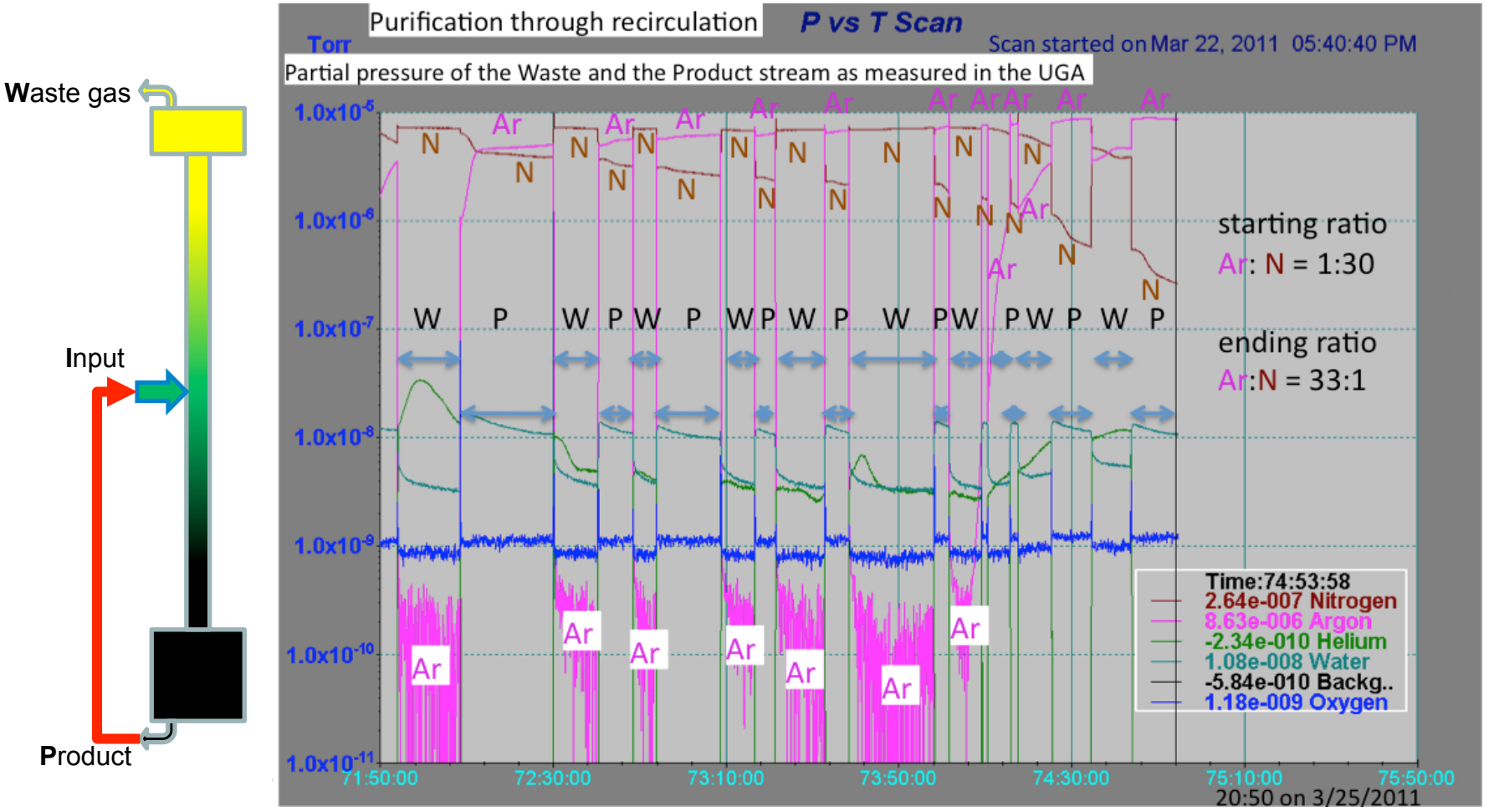
DarkSide -10 (prototype) Surface Data





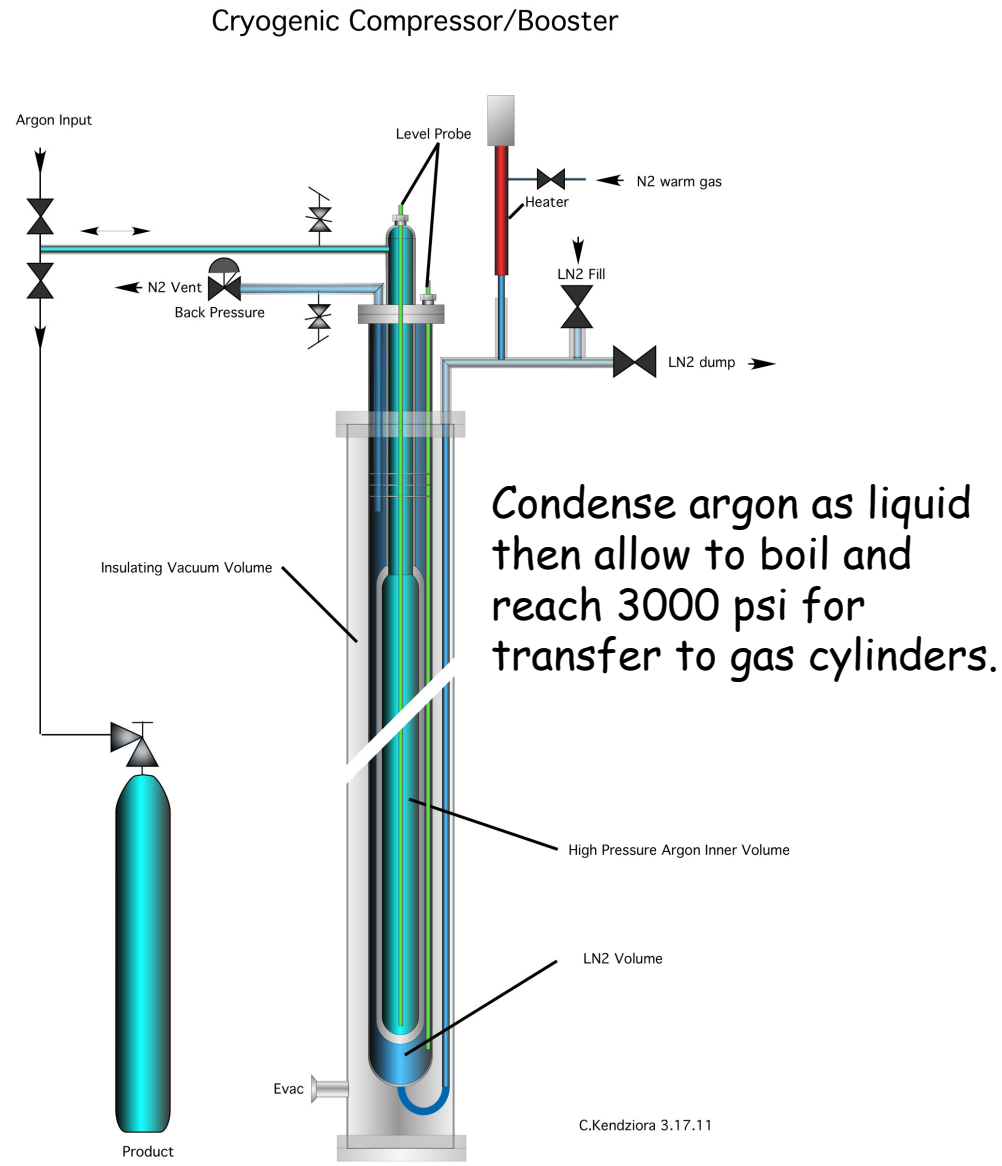
Off to Gran Sasso

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.



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

CC-B at the PAB 5/4/2011

Stuff just about to operate

LAPD (Liquid Argon Purity Demonstration)

In-liquid electronics on electronics test stand

Liquid Argon Purity Demonstration

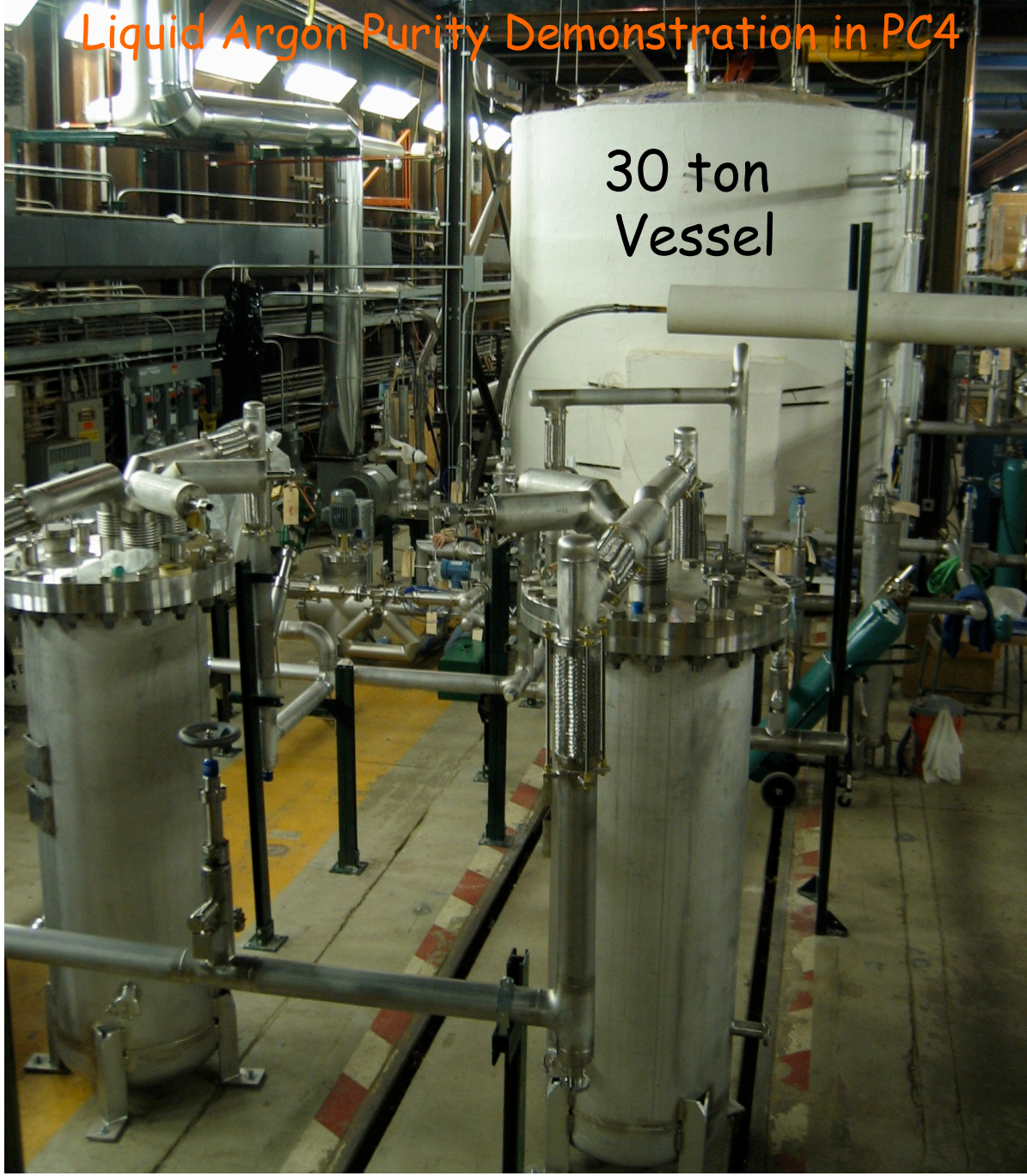
All current LArTPCs are evacuated before filling with Argon. However, difficult (= expensive) to construct multi-kiloton cryostat to be evacuable.
=> Demonstrate good life-time in an industrial vessel without evacuation.

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

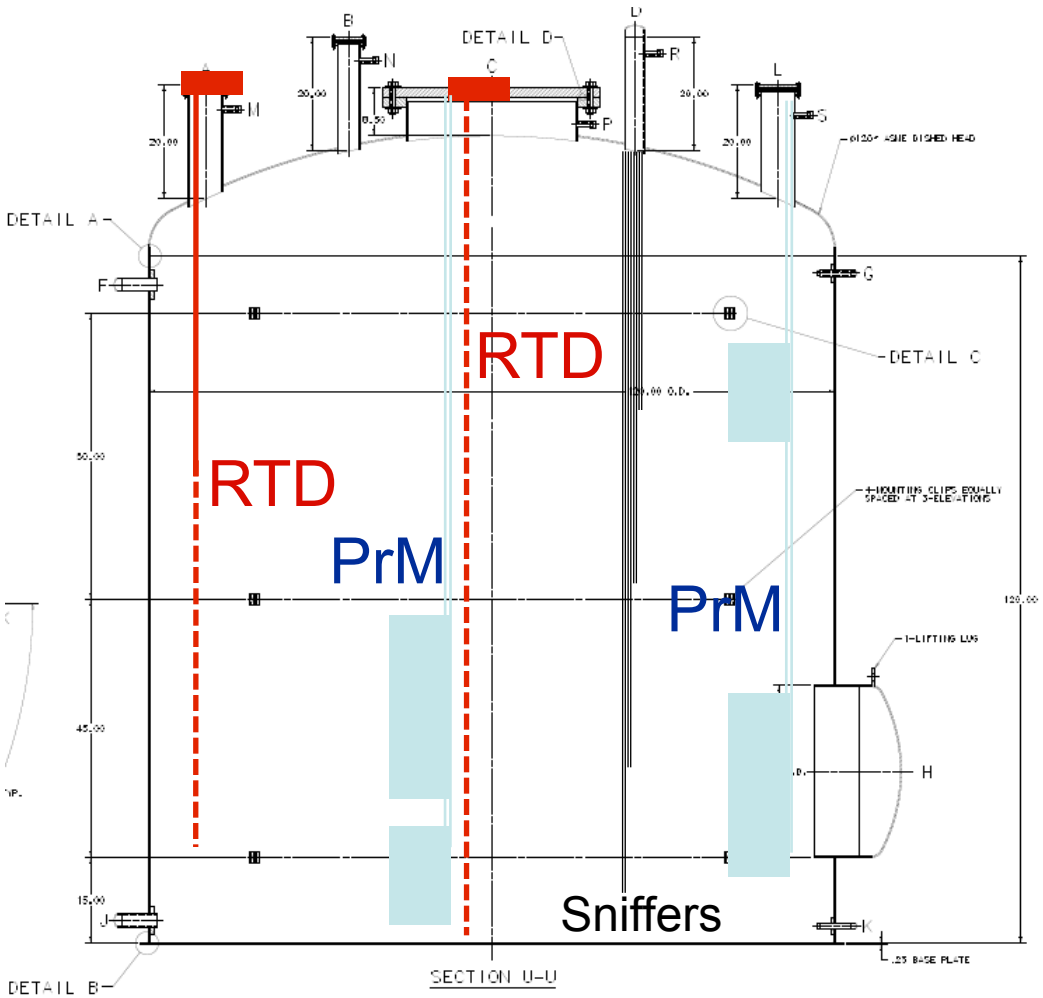
Heaters in the insulation can warm the walls to 60 C.

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)

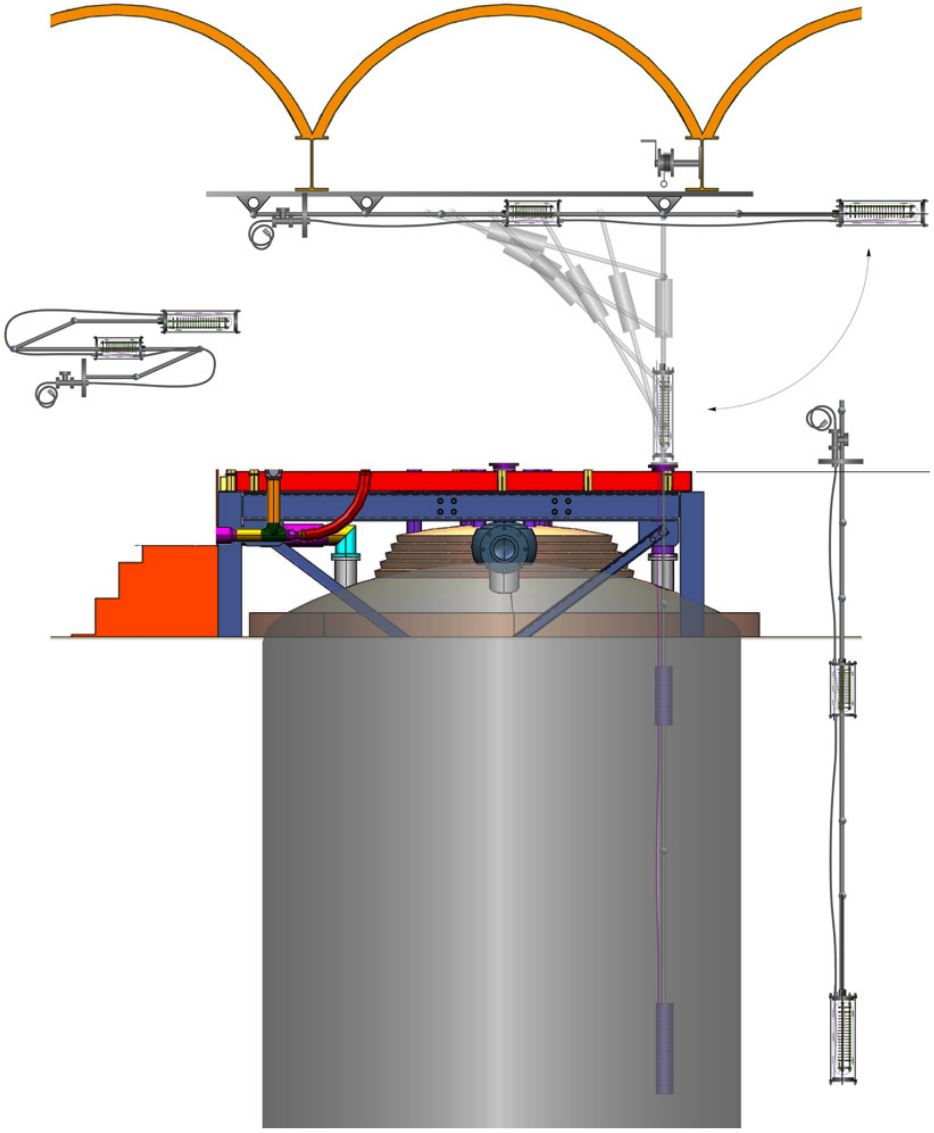
2 sets of 3 translating RTDs

Sniffer set to measure purge evolution

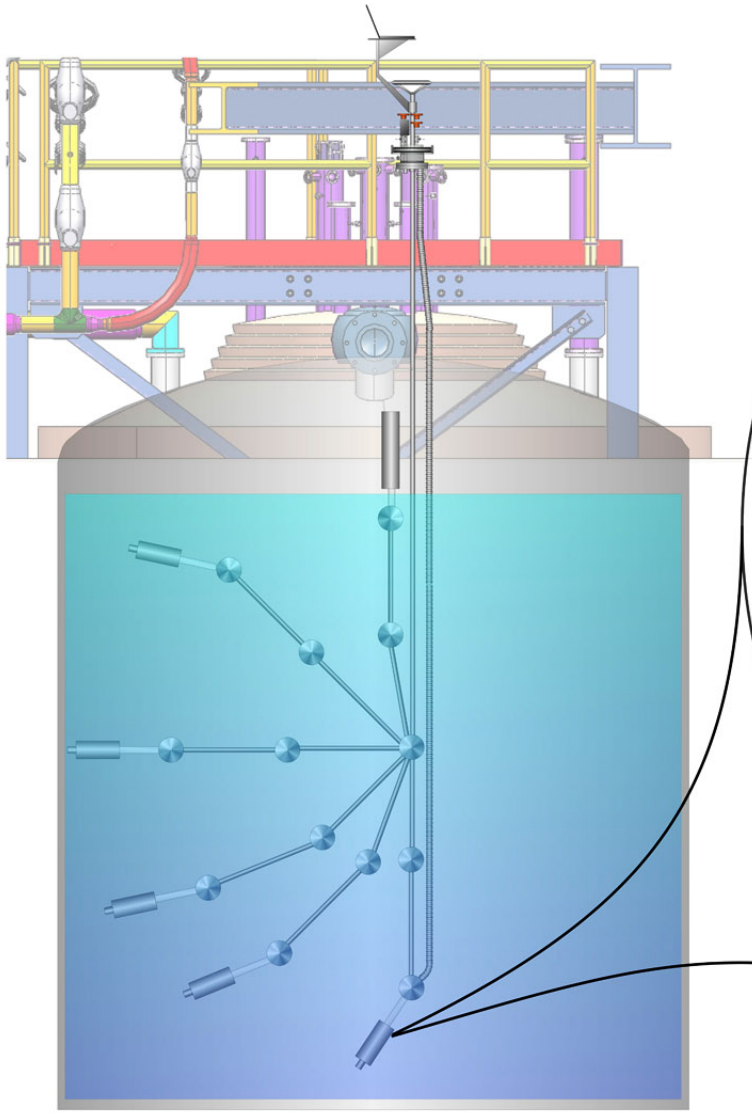
Inline

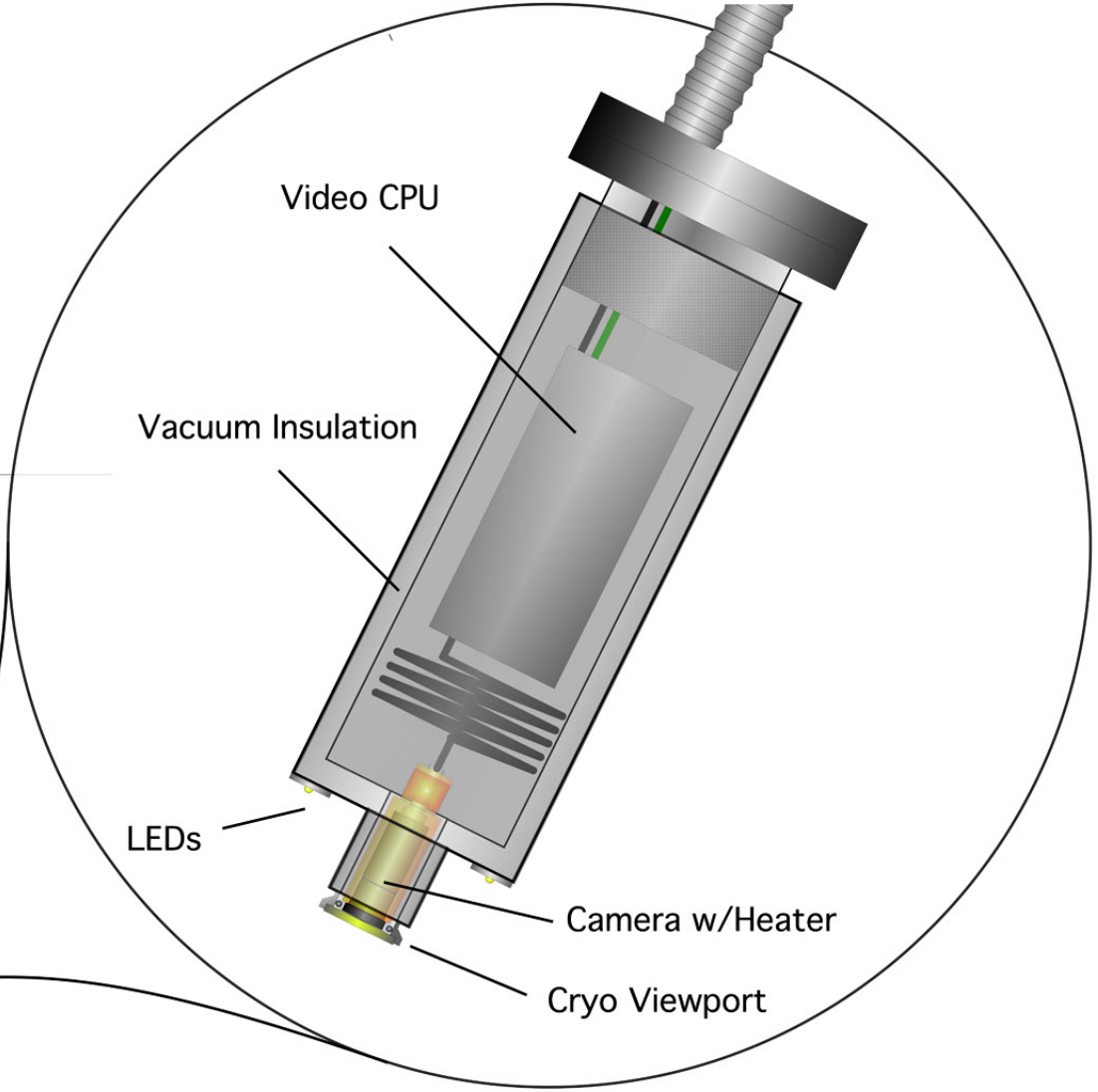
Purity Monitor

Insertion Mechanism for Purity Monitors into LAPD



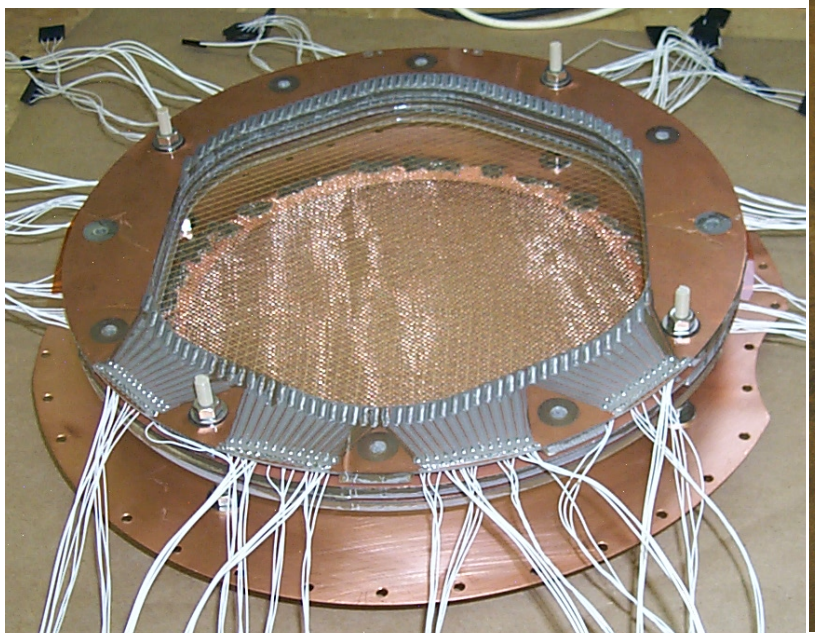
Camera in liquid Argon





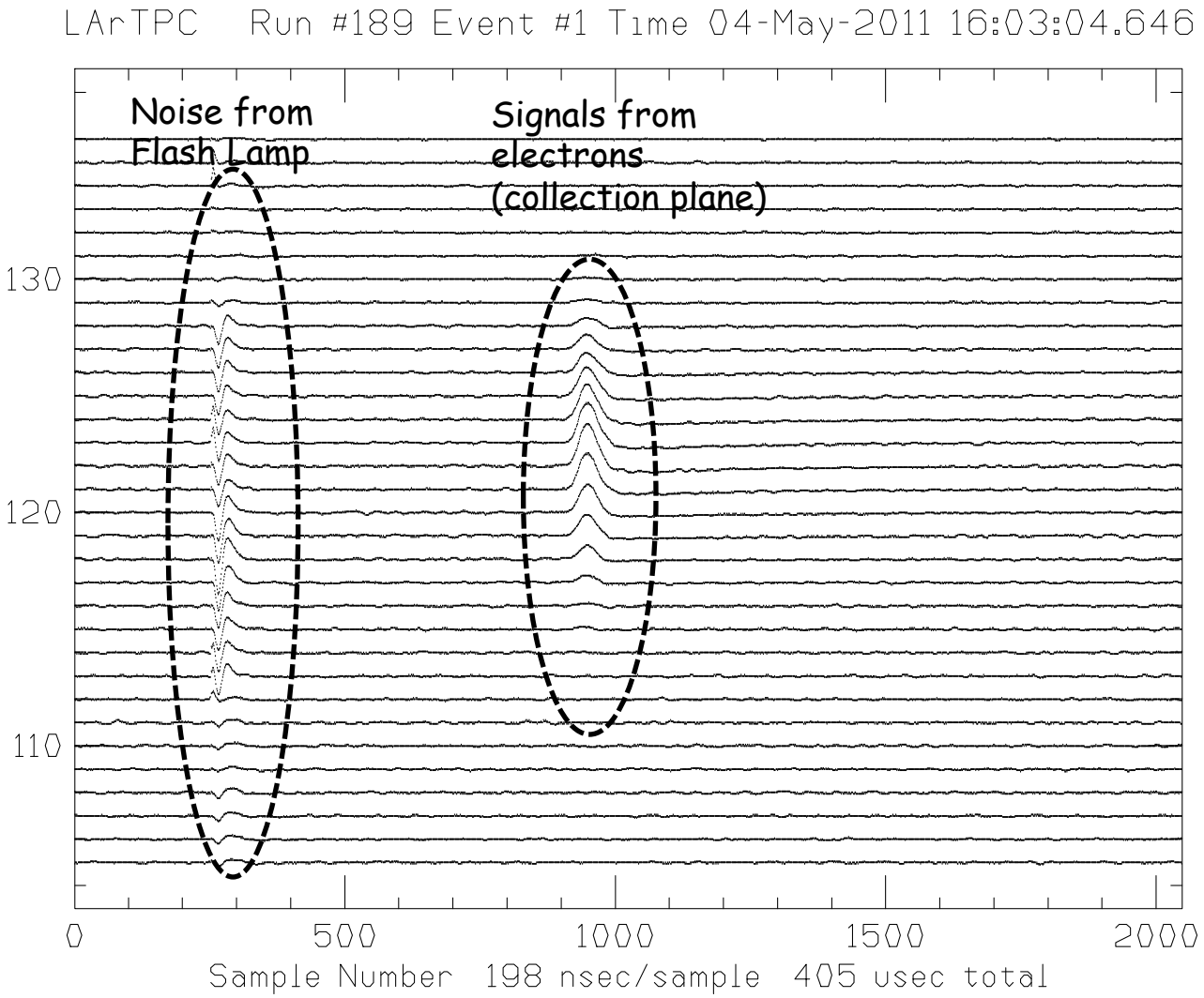
First Test of **cold (in liquid) electronics** developed by Dan Edmunds of Michigan State University. Electronics are installed around 50 cm drift-length TPC before installation into Cryostat.

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)

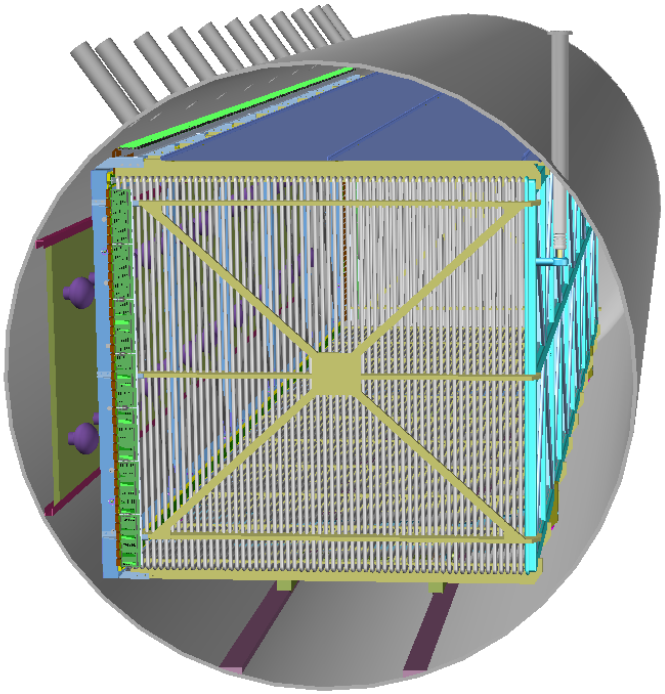
QUPID (Quartz Photon Intensifier Detector)

DarkSide 50 (E-1000)

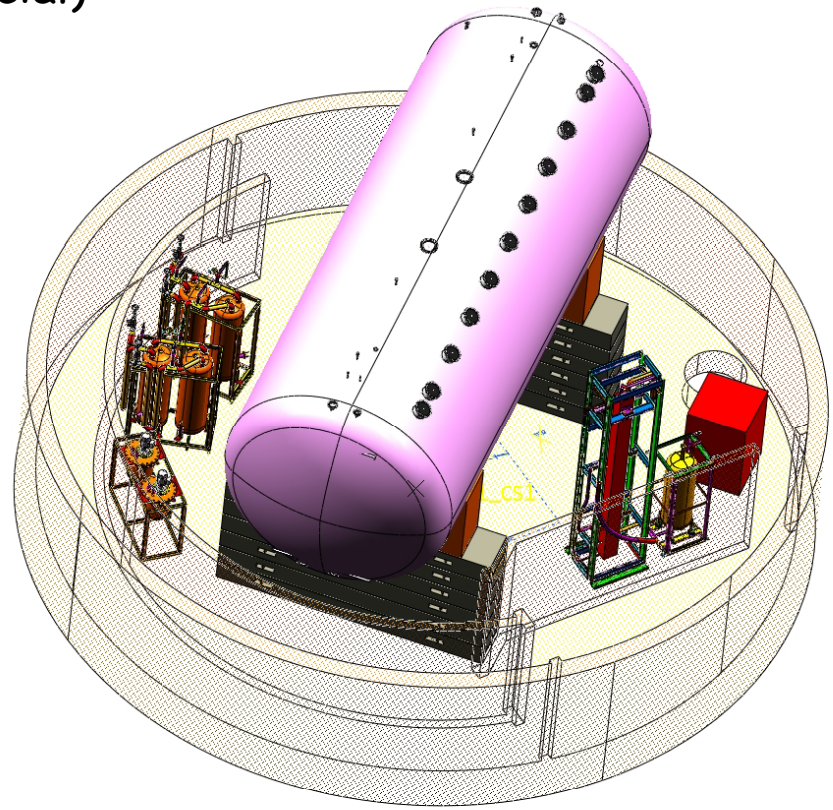
Proposal for LArTPC Test Beam Calibration Experiment (B. Rebel)

MicroBooNE (E-974) Schematics

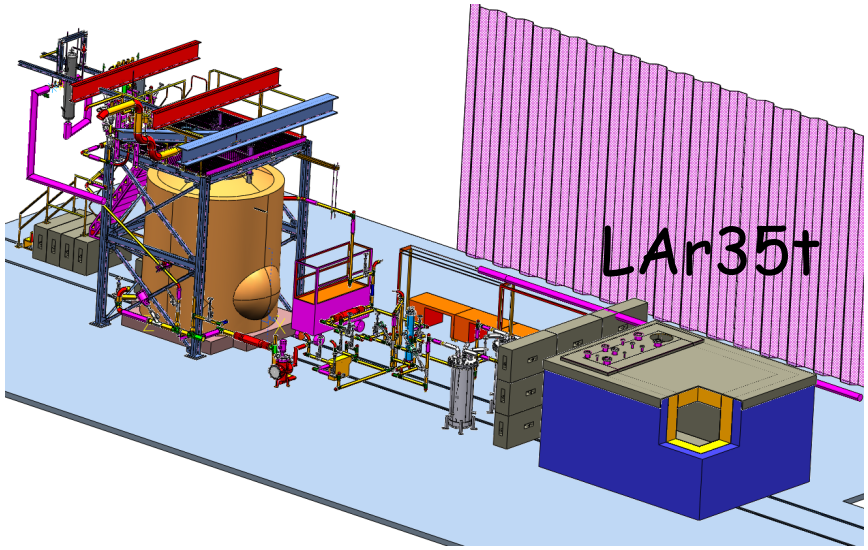
TPC and PMTs in Cryostat
8000 channels, 180 tons ~80 tons fiducial)

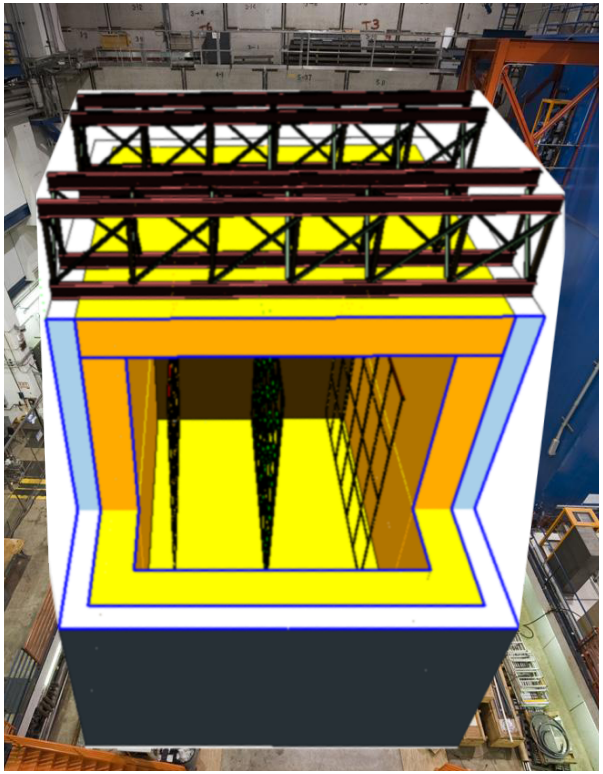


Cryostat in MicroBooNE hall

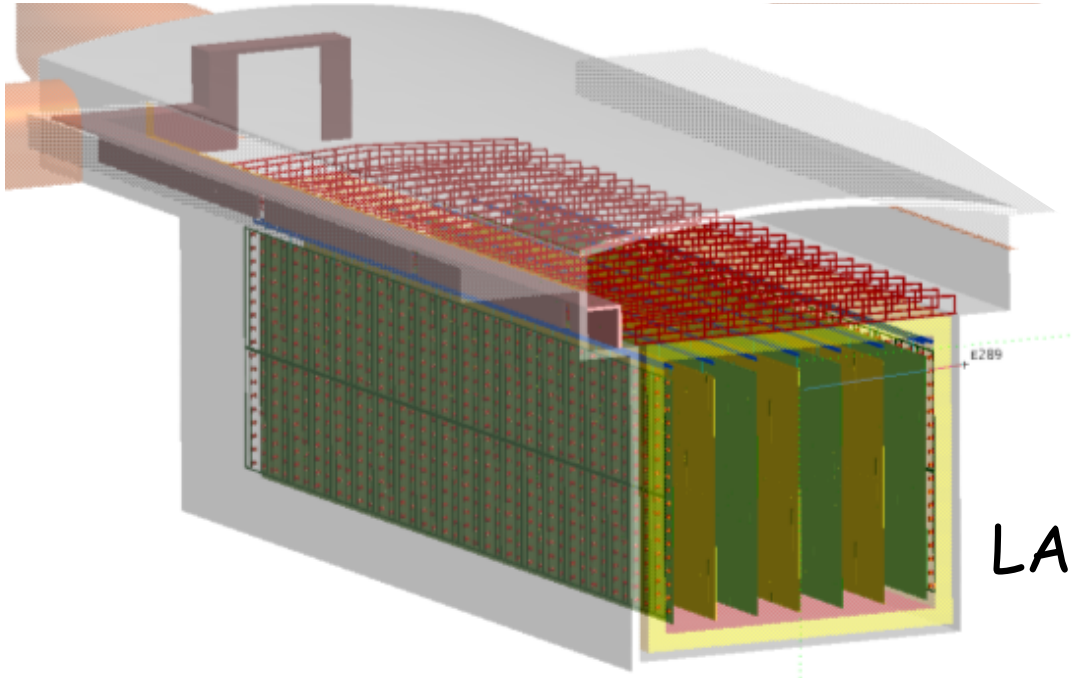


R & D goals: Cold (ASIC) electronics; 2.6 m drift;no evacuation
Event reconstruction, Library of Argon Interactions,
Cosmic backgrounds to `proton decay', 100% livetime DAQ





LAr1 at DZero

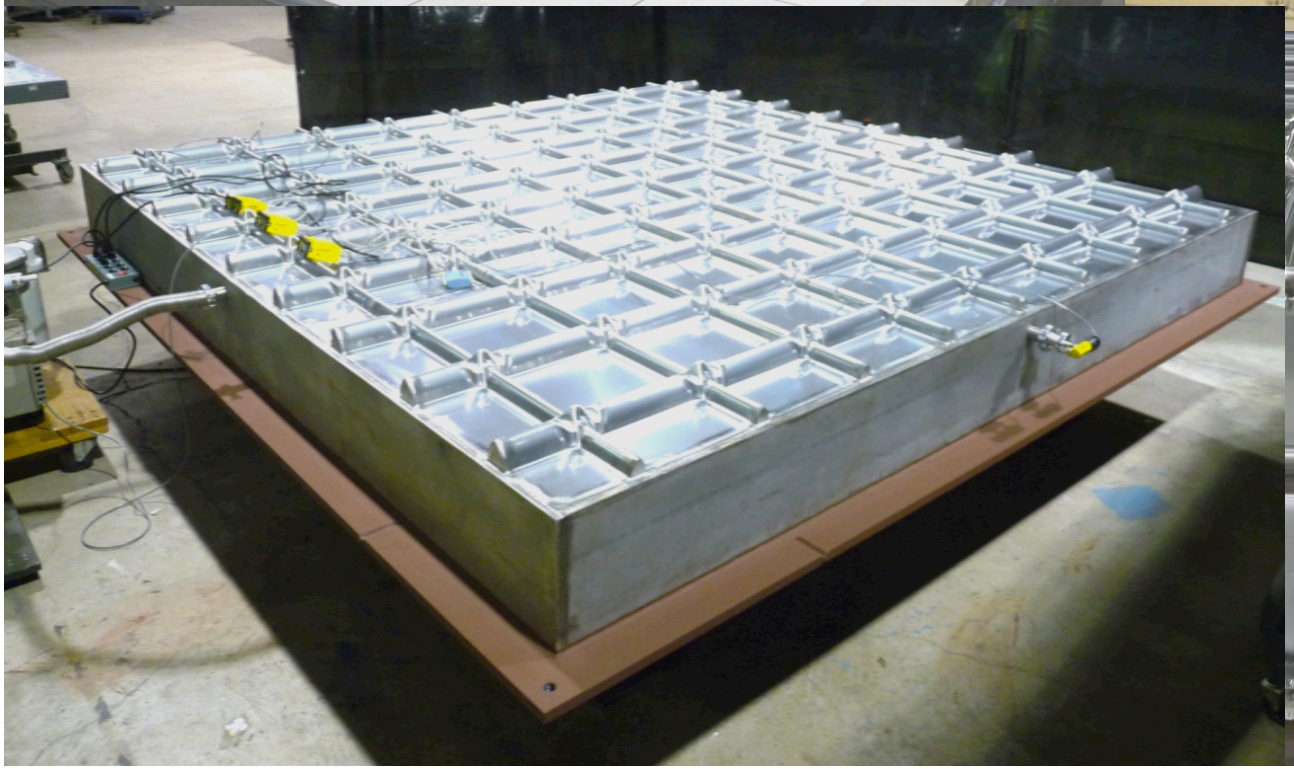


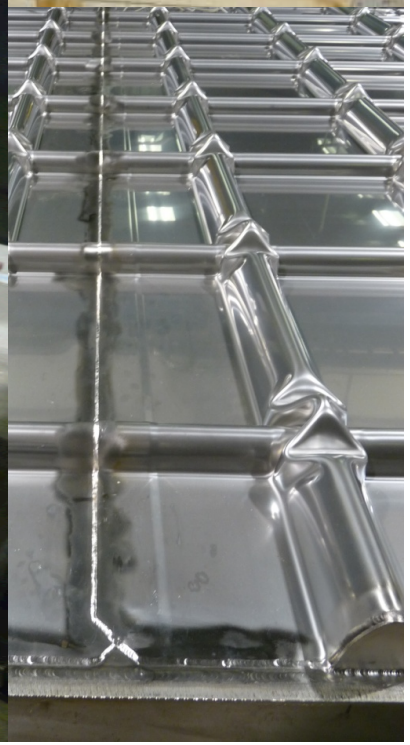
LAr20 at DUSEL

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.

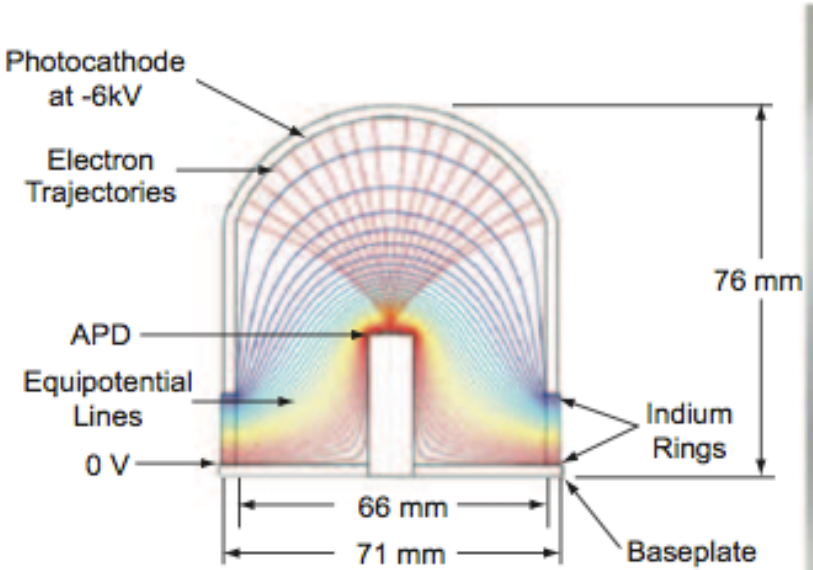




QUPID - low radioactivity photo-detector
UCLA/ Hamamatsu

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 deserving of more discussion ...

Tracking (ionization) Read-out (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.

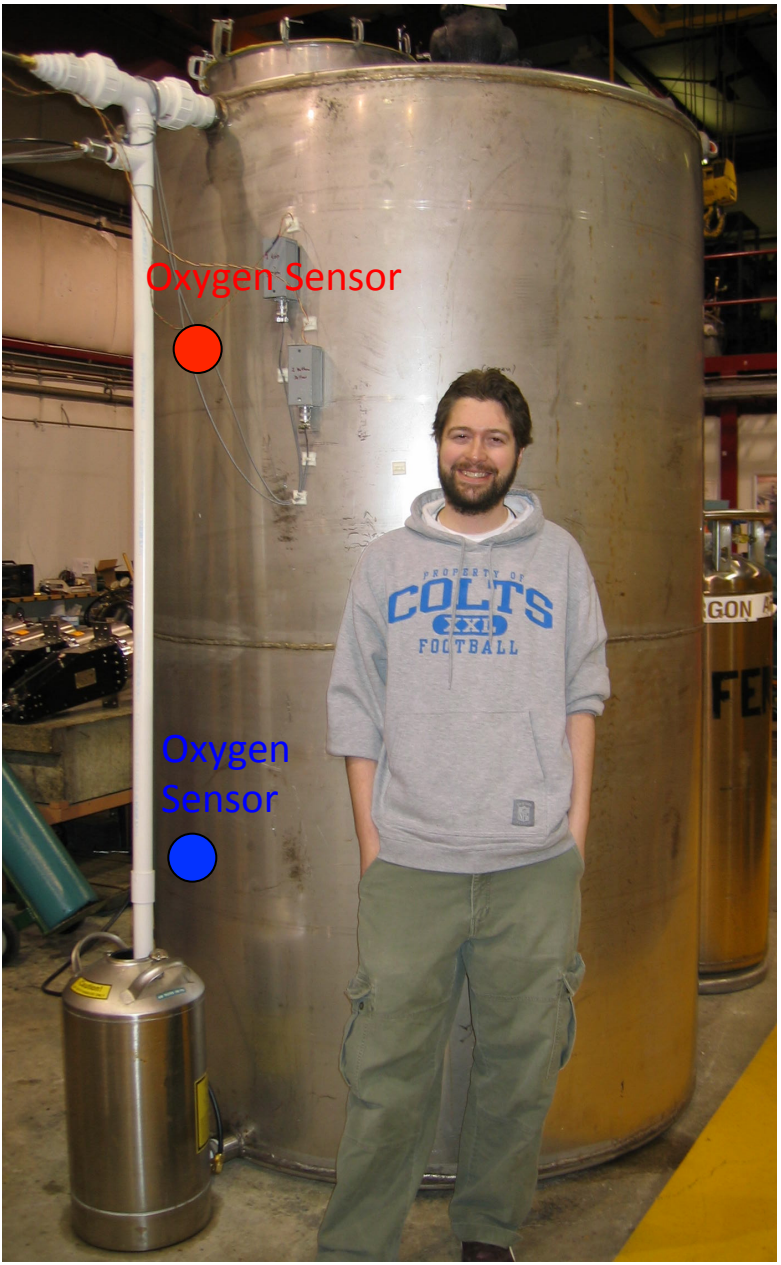
Cold electronics development.

Low radio-activity Photo-detectors.

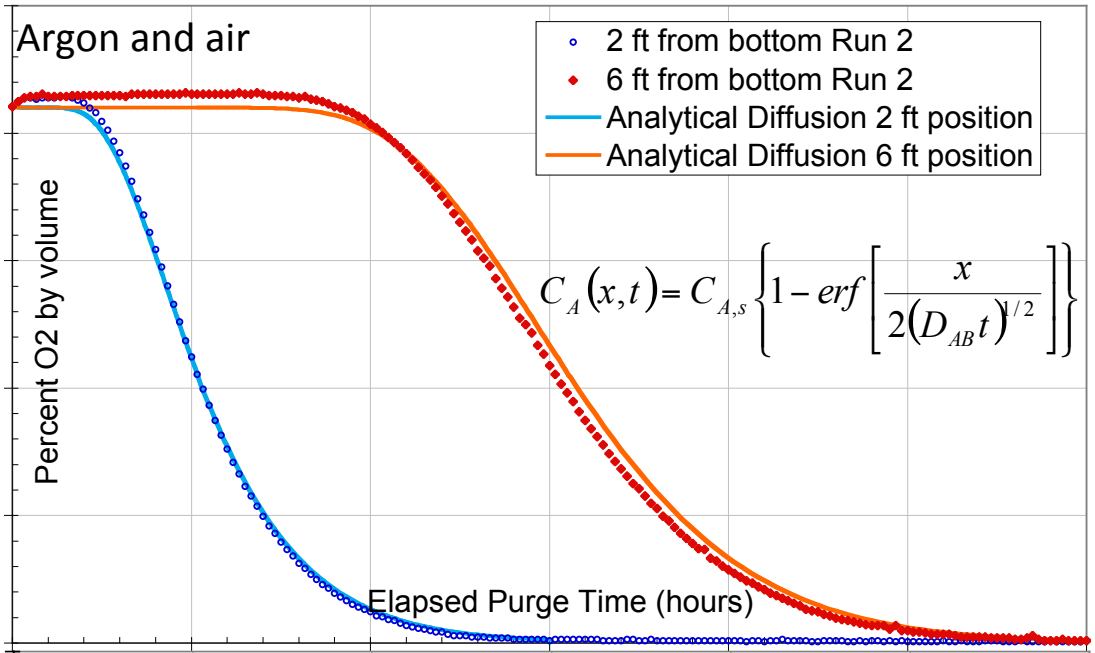
DAQ & Software - from in-line pattern recognition and trigger to 100% live to simulation to reconstruction & event identification under the aegis of LArSoft (B. Rebel)

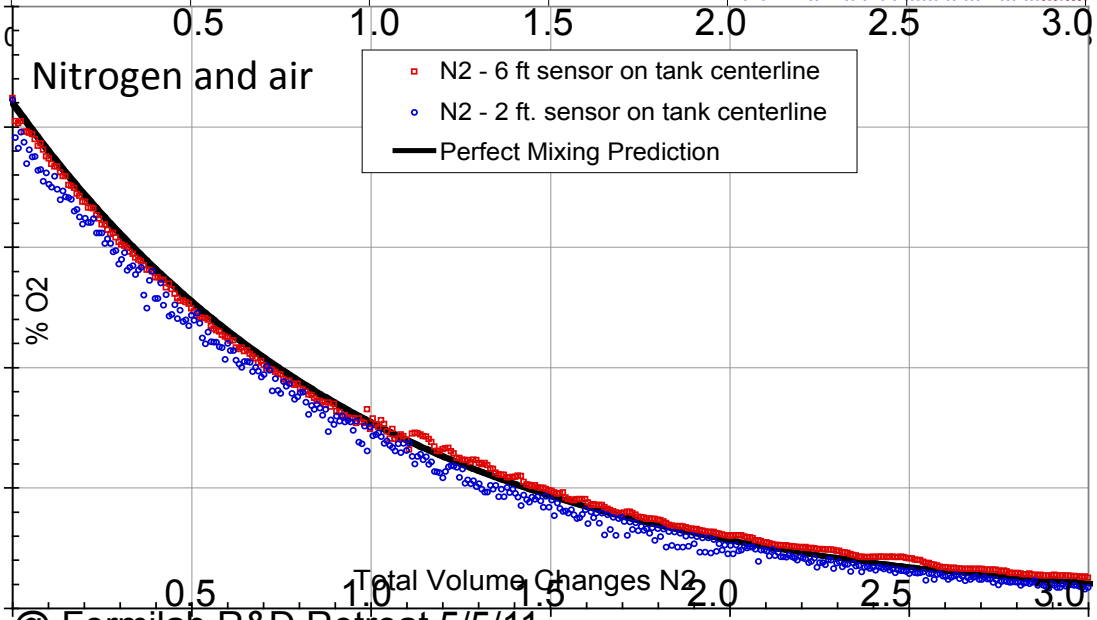
End & random back-ups

Argon Piston Demonstration

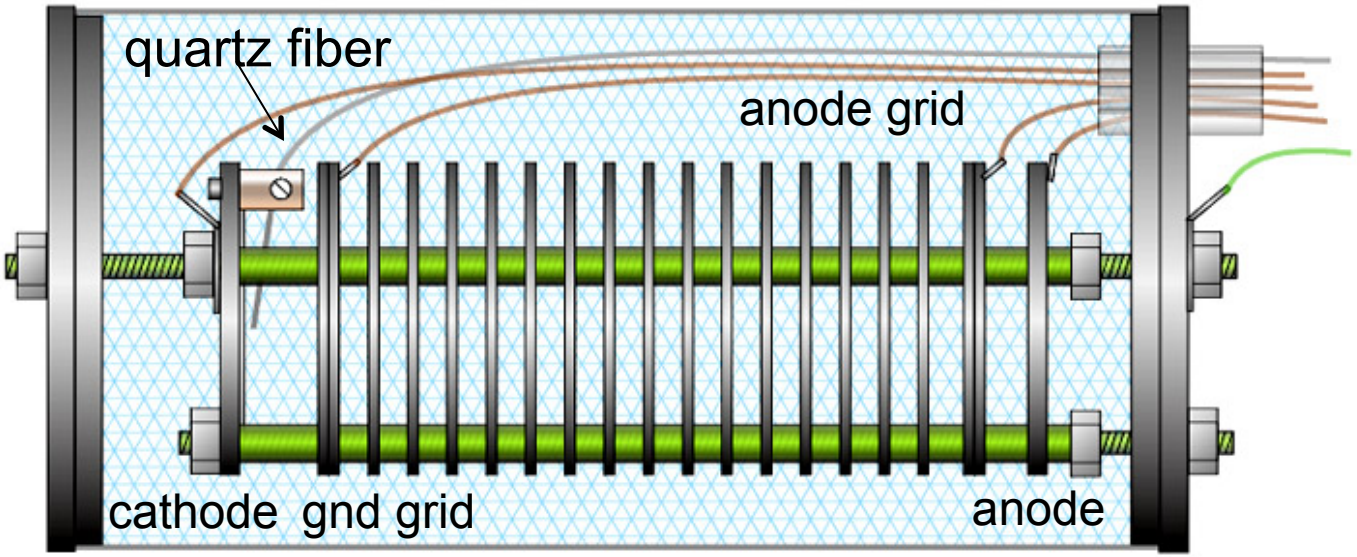


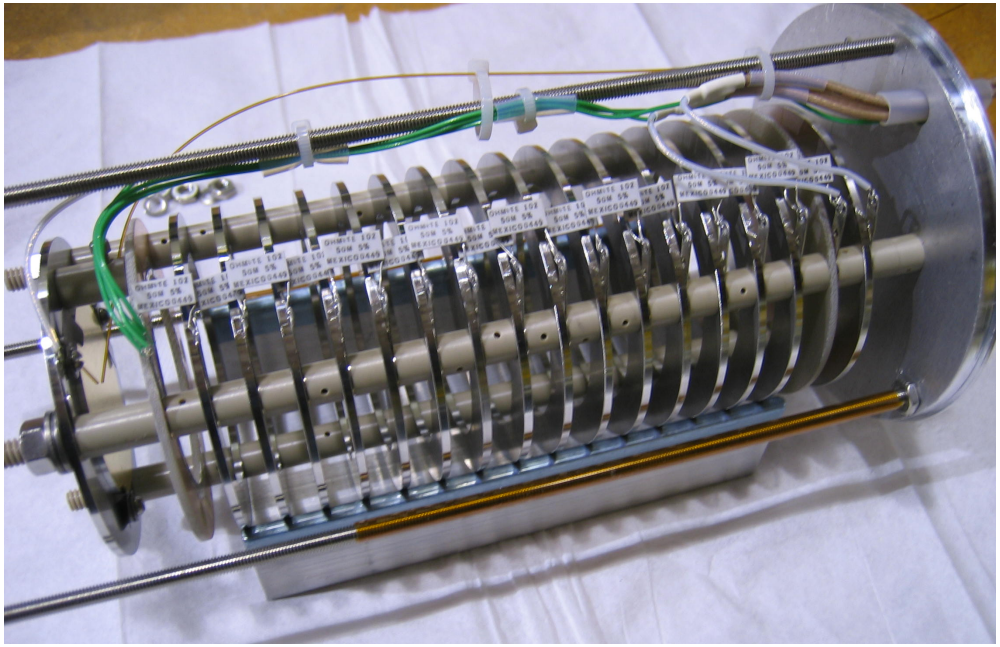
Percent O2 Sensor Output vs. Time
data compared to analytical model





PrM drawing

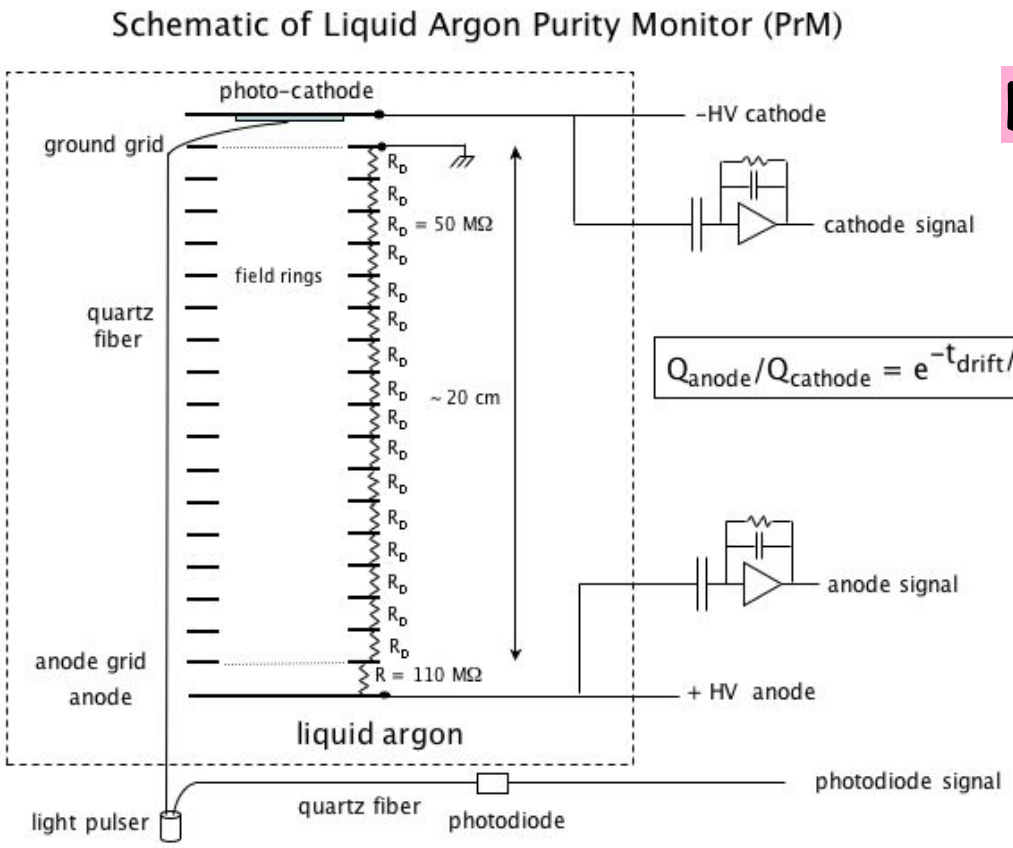




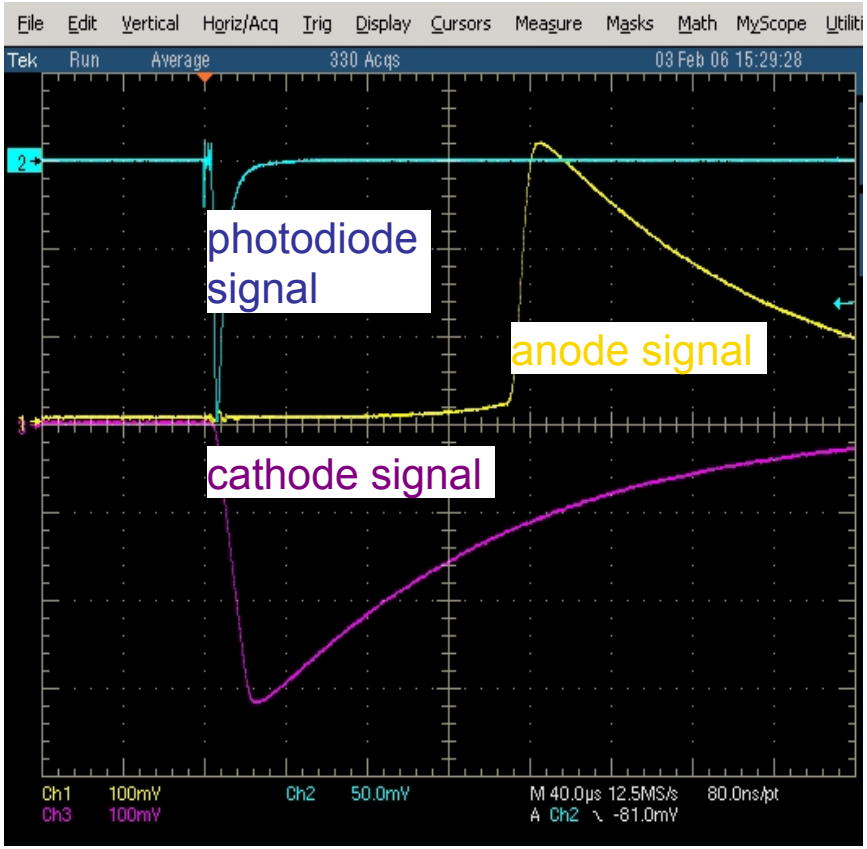
C.Kendziora2/3.05

PrM photograph

Drift lifetime Measurement

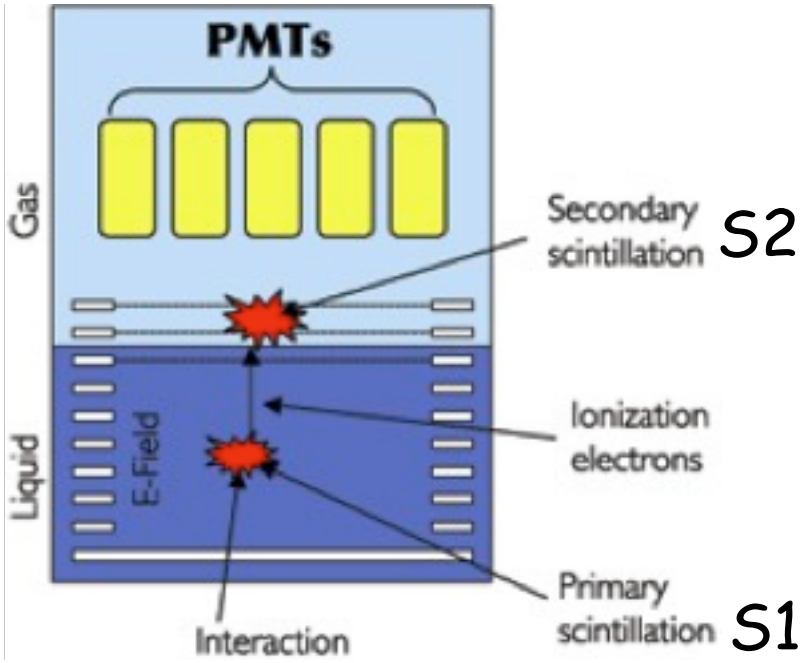


$$Q_{anode}/Q_{cathode} = e^{-t_{drift}/\tau}$$

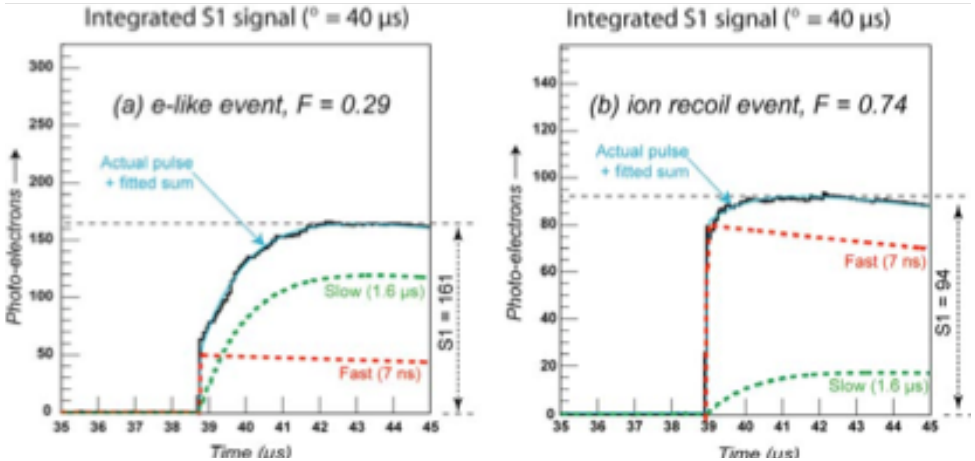


G. Carugno, NIM A 292 (1990)

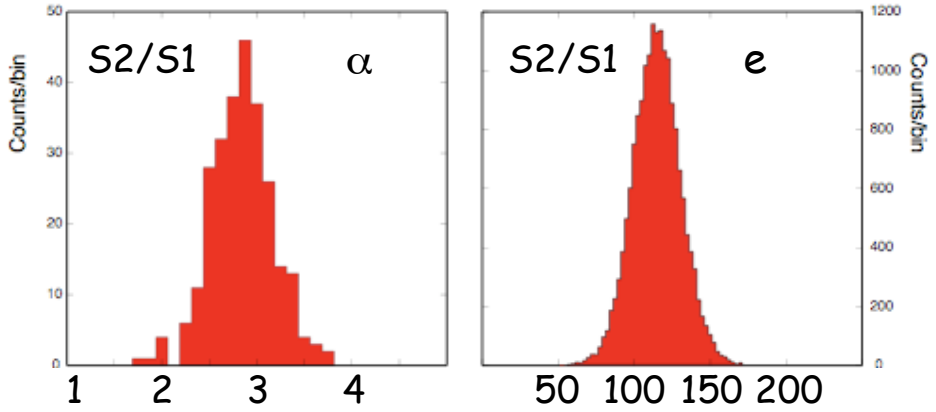
from WARP



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. $10^{\wedge 7-8}$