Work on Liquid Argon at Fermilab

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Fermilab Institutional Review
June 6-9, 2011

Outline

- Introduction – why, what, who
- Many individual topics
- Conclusion

Introduction: Liquid Argon – Why

Liquid Argon is a bright Scintillator (40,000 photons/MeV) and allows free electrons to drift meters under practical strength electric fields.

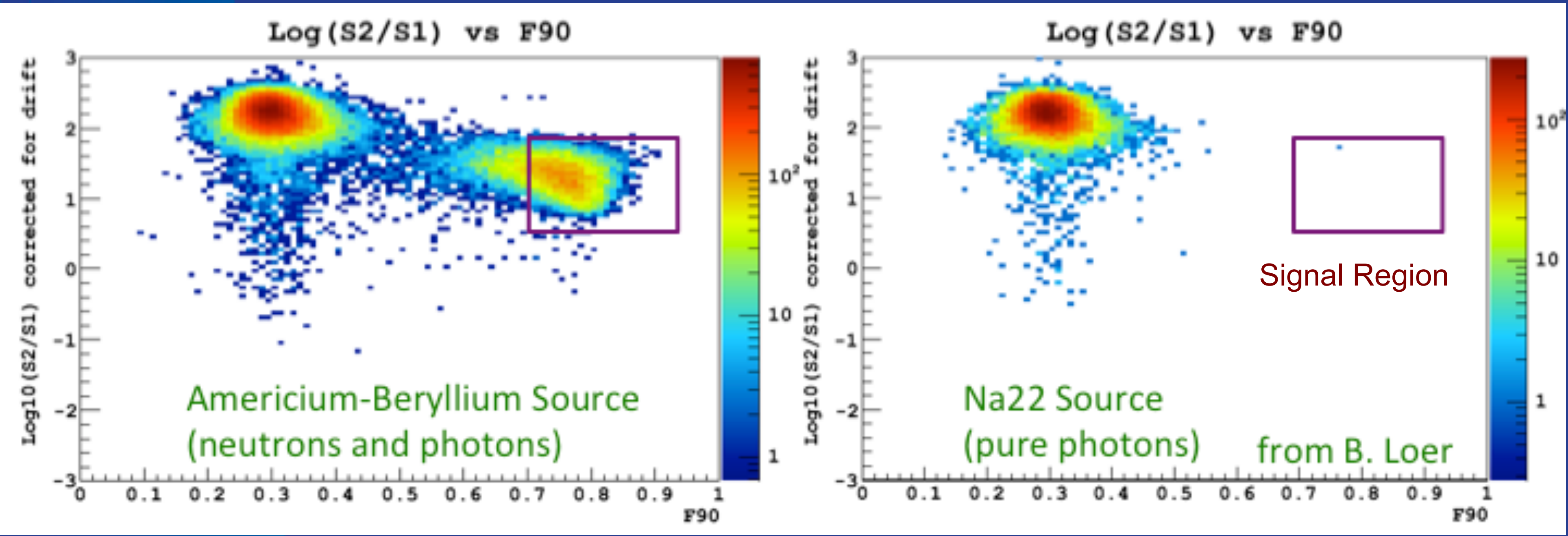
It presents an attractive Target Medium for:

Neutrino interactions where liquid Argon TPCs can produce bubble-chamber quality event images;

Dark Matter searches which exploit features of light and free charge produced in Argon by the recoiling nucleus to achieve excellent background rejection.

Introduction - Why

10 kg Prototype LArTPC for Dark Matter at Princeton

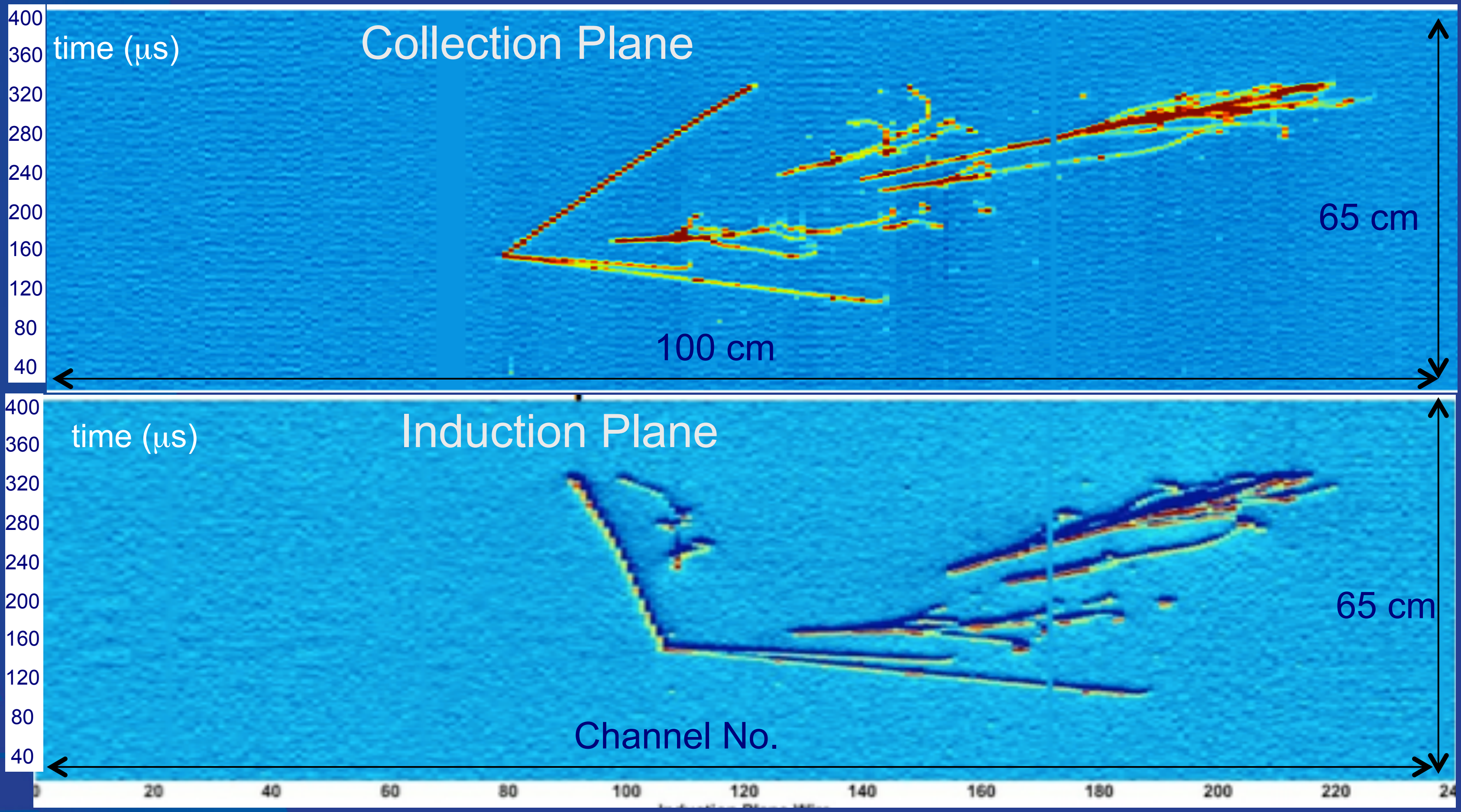


Separation between e-m induced events and nuclear recoils (neutron induced events) based on:

- light pulse time spectrum (x-axis) and
- light to free charge ratio (y-axis)

Introduction - Why

ArgoNeuT Event in NuMI Beam



Track topology, ionization density

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Introduction - What

Work at Fermilab started by A. Para in ~ 2004

Has evolved into significant program including:

- R & D facilities at PAB and the Liquid Argon Purity Demonstration
- ArgoNeuT exposure to NuMI beam
- Developments for Light Detection
- Depleted Argon Distillation Column for Dark Matter
- `LArSoft’ General Software Project for LArTPC detectors
- MicroBooNE experiment (E-974) about to undergo CD-2 review
- LArTPC proposal for the LBNE (Long Baseline Neutrino Expt)
- DarkSide 50 (E-1000) Dark Matter Search

(R & D funded   Scientific Effort   Projects)

Introduction - What

Our approach to LArTPC technical development :

Learn as much as we can from previous work

Develop hands-on experience and our own (new) infrastructure
- filters, cryogenics, pumps, HV feed-throughs, readout electronics

Look at technical topics which have not been fully explored previously
- material tests, in-liquid electronics, light detection

Put something in a neutrino beam to exercise a complete system
- ArgoNeuT

Demonstrate good electron lifetime *in an unevacuated commercial vessel*
- LAPD (Liquid Argon Purity Demonstration)

Developments from `Projects' that have broader implications:

LAr 35t *membrane* cryostat (35 ton liquid argon cryostat)
- general purpose cryostat technology

1 ktonne prototype of the LBNE Detector Module
- TPC & electronics appropriate for any ktonne scale LArTPC, anywhere.

Introduction - Who

Institutions collaborating in hardware R & D:

- Yale - Syracuse (ArgoNeuT construction and exposure)
- Michigan State University (TPC electronics)
- M.I.T and Indiana University (Light readout)
- BNL (TPC electronics and TPC design)
- Princeton (depleted Argon recovery and special cryogenics)
- UCLA (development of infrastructure for QUPID)

Introduction - What

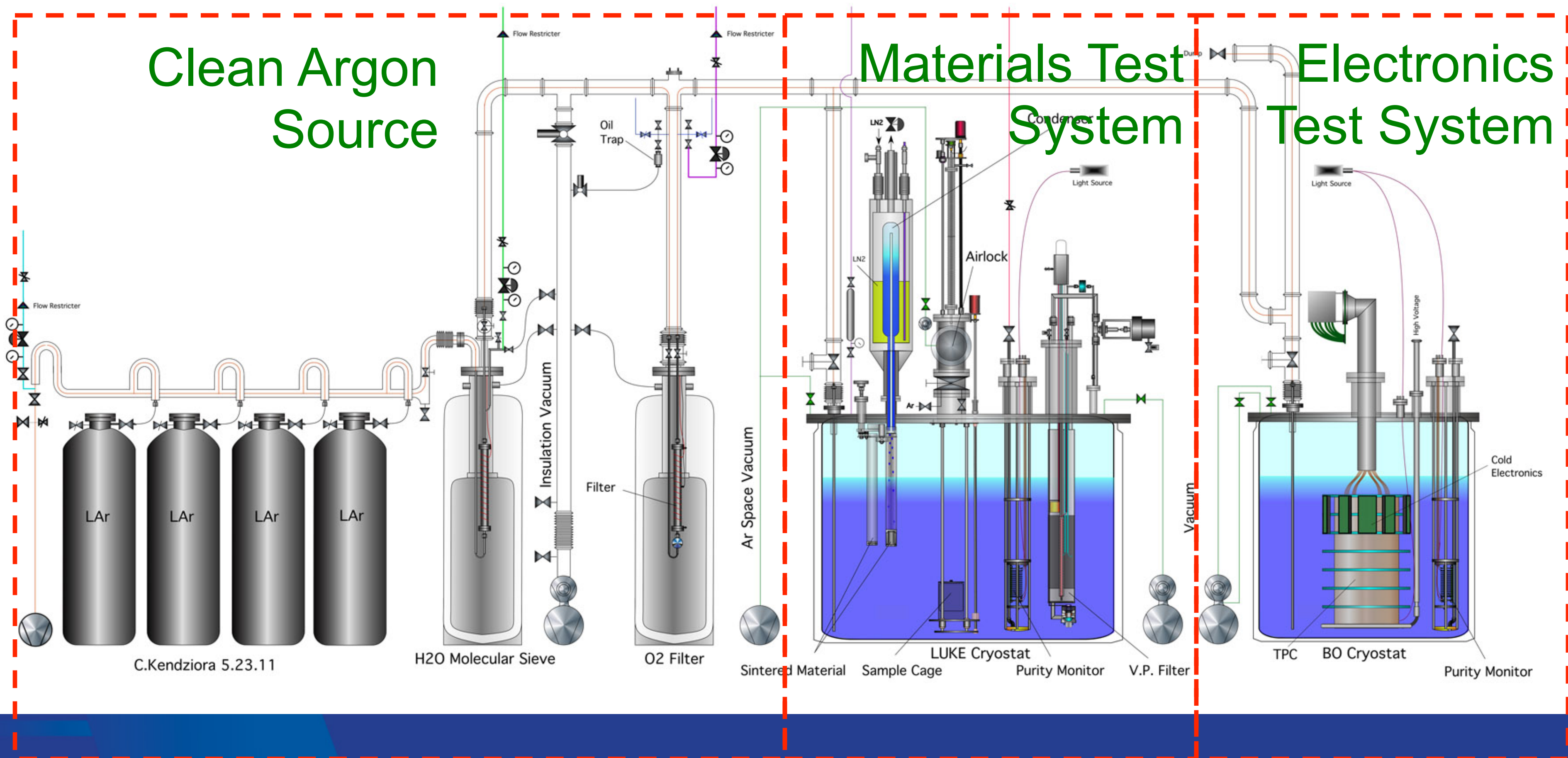
Technical Issues for Liquid Argon Neutrino or DM detector:

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

Facilities – Liquid Argon Setup at the PAB

Facilities – Liquid Argon Setup at the PAB

Schematic showing filters and cryostats of MTS and ETS



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Facilities – Materials Test System

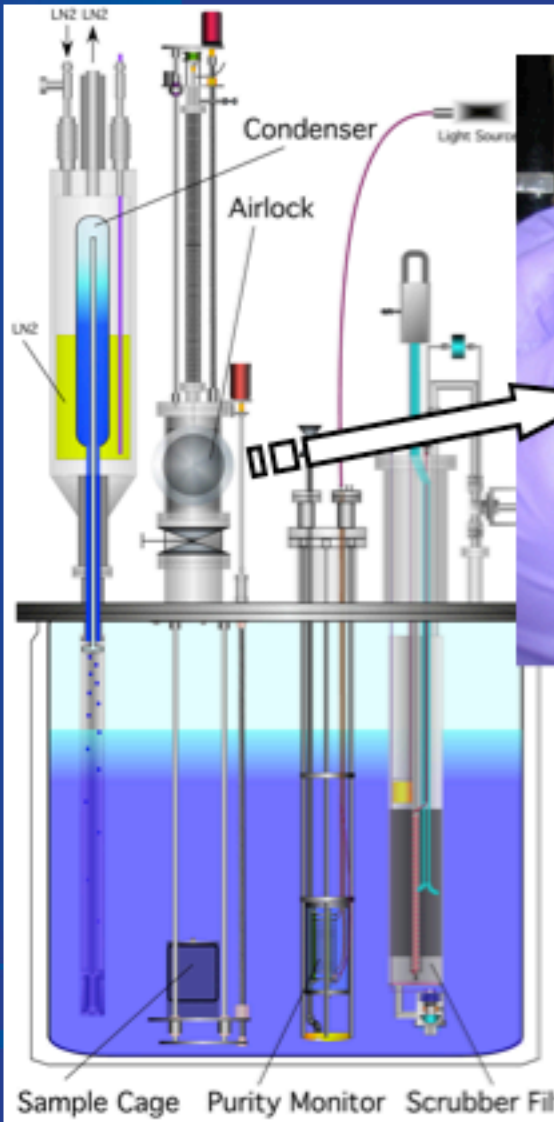
Test Candidate Detector Materials for contamination of Argon

Unique Facility

Features of Materials Test System

- External Filters regenerated in place
- 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 giving 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
- Argon sample points at source, after single-pass filters, and in cryostat gas and liquid.

Facilities – Materials Test System

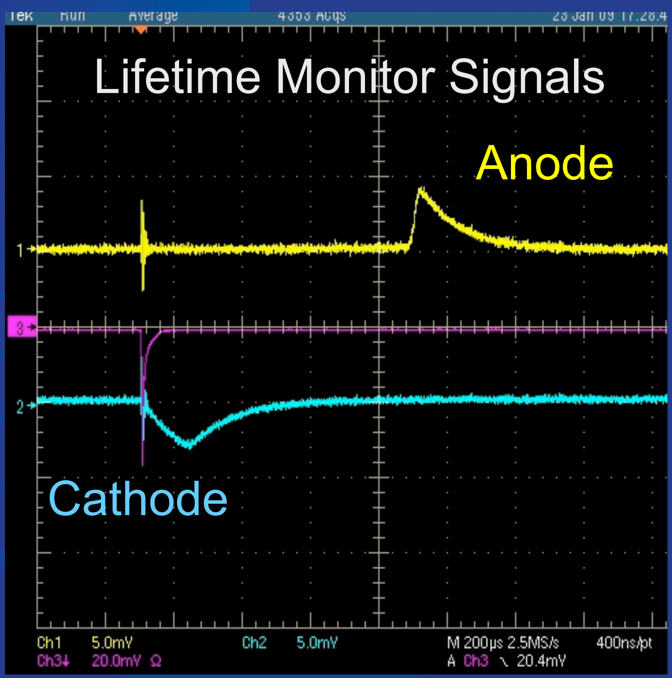


Sample volume 10 cm x 10 cm x 10 cm

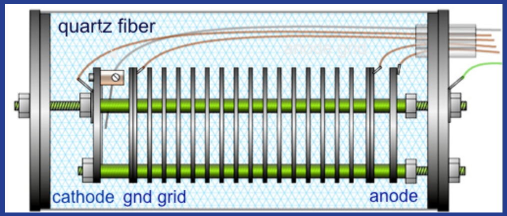
Argonlock can be purged with external argon, cryostat argon, and/or evacuated

Facilities – Materials Test System

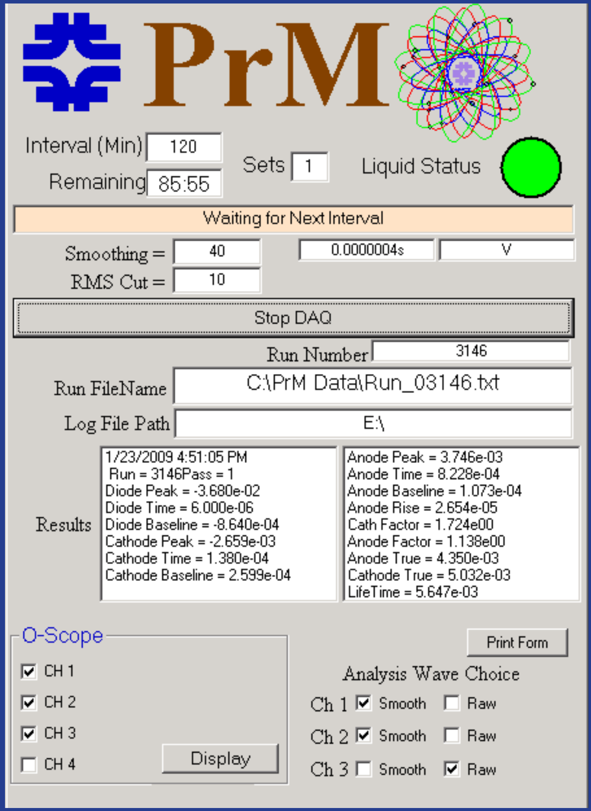
- Measure electron drift lifetime (0.3 milliseconds to 10 milliseconds)
- Measure Oxygen (0.5 ppb sensitivity) with oxygen meter (Delta-F & Tiger Optics)
- Measure H20 in gas (0.5 ppb sensitivity) with water meter (Tiger Optics)
- Cryogenic data, Lifetime Data, analytic instrumentation data in single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



Lifetime Monitor Analysis

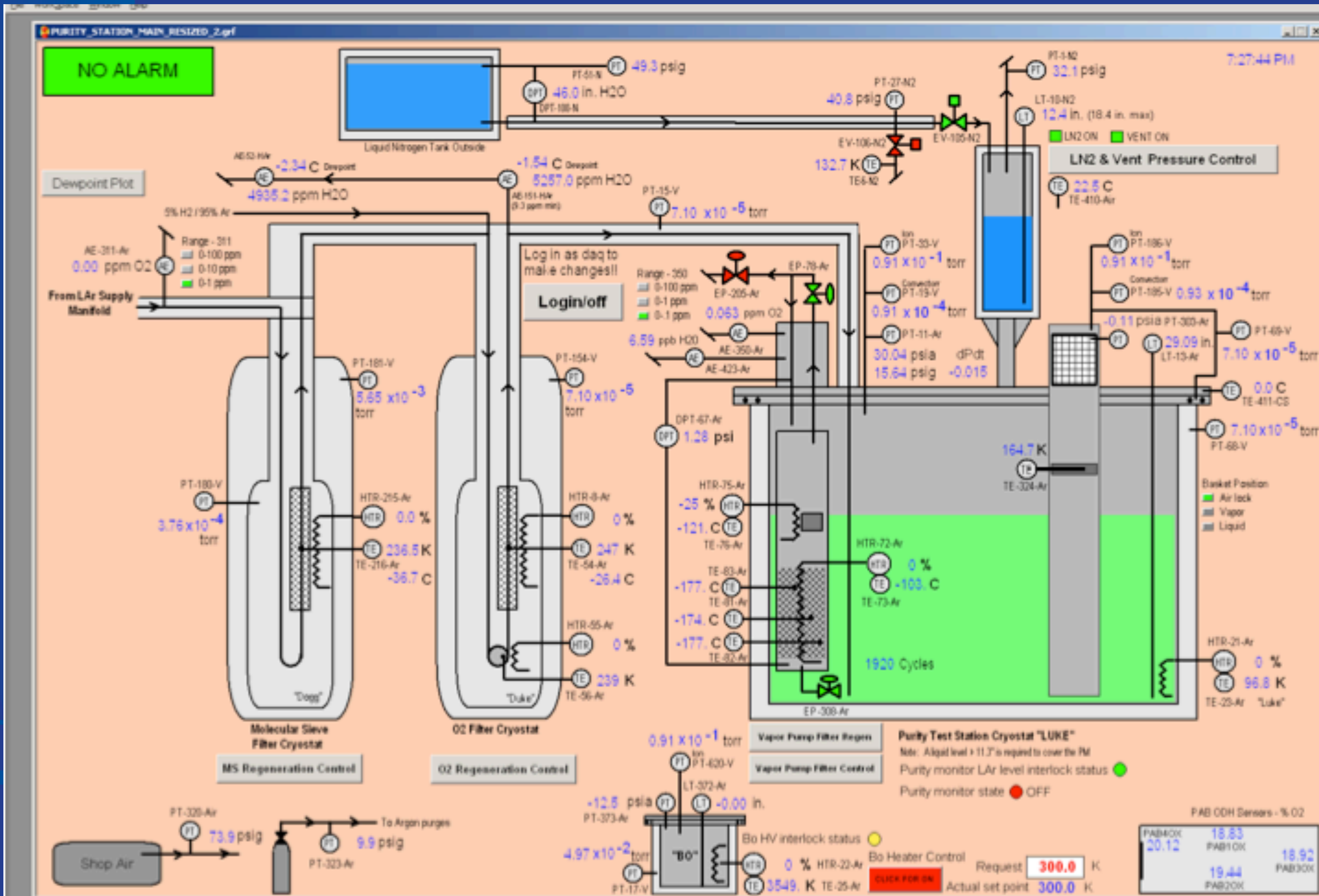


Lifetime Monitor a la ICARUS



Facilities – Materials Test System

Cryogenics Control Panel



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Facilities – Materials Test System

Sample data on different materials

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
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
Teppei TPB samples	9/4/10	purged 37 h	liquid /vapor	15, 300	6	
PrM feed tru (baked)	10/5/10	purged 25 h	warm/vapor	35, 20	3, 2	1396
Copper foil on mylar film	10/14/10	purged 26 h	warm/liquid/vapor	15, 10, 9	3, 8, 7	1409
Teppei SHV connector	10/25/10	purged 25 h	warm/vapor/liquid	35, 11, 0	2, 6, 6	1415
FR4	11/16/10	purged 25 h	warm/liquid/vapor	180, 20, 65	1.5, 6, 2.5	1429
Gaskets	3/11/11	purged 24 h	warm/liquid/vapor	8, 10	2.5, 8 , 7	1521
LBNE AP-219 Color. Developer	4/13/11	purged 25 h	warm/vapor	65, 15	4, >6	1722
LBNE RPUF Foam	4/22/11	evac. 26 h, pur.1 h.	warm	800	0.2	1729
LAPD LEDs	5/12/11	purged 49 h	vapor	0.6 ppb	10	1769

Facilities – Materials Test System

Filter Materials:

Industrial filter materials are capable of removing all electronegative materials (water, oxygen)and producing liquid with >10 milliseconds lifetime.

Data on filter capacity at our requirements are sparse;

Filters can be regenerated many times; we know how - using non-flammable Ar-H mix

Detector Materials:

Materials immersed in the liquid have no effect on lifetime;

Materials immersed in warm gas volume above the argon have:

- no effect on lifetime if the argon is venting at a certain rate;
- significant effect if the warm gas mixes with the liquid argon directly;
- metal surfaces outgas water vapor at significant rate and ... see above

Contaminants:

Absent leaks, water is the main concern; it comes from detector materials and the cryostat walls in the warm gas.

`A system to test the effects of materials on the electron drift lifetime in liquid argon and observations on the effect of water' R. Andrews *et al.*, Nucl.Instrum.Meth.A608:251-258,2009.

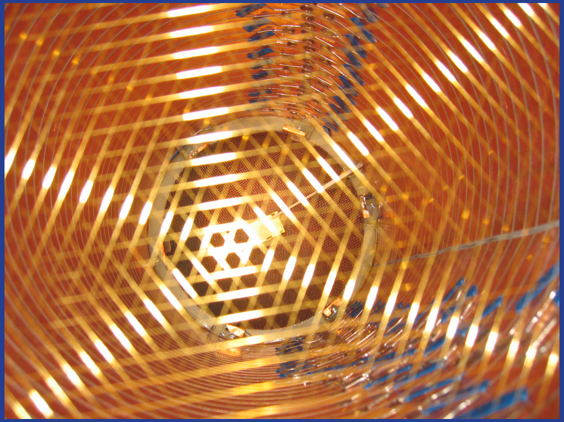
Facilities – Electronics Test System

1st LAr TPC with U.S. electronics readout

50 cm vertical drift TPC

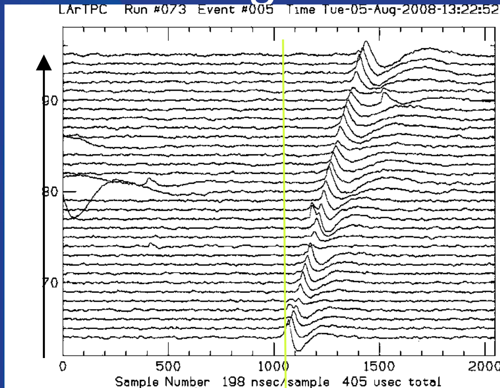
HV 20 - 30 kV

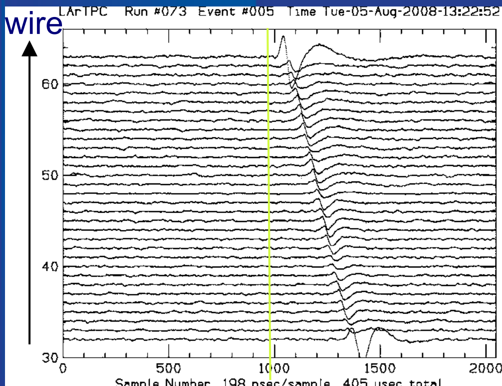
3 planes of wires at 120^0

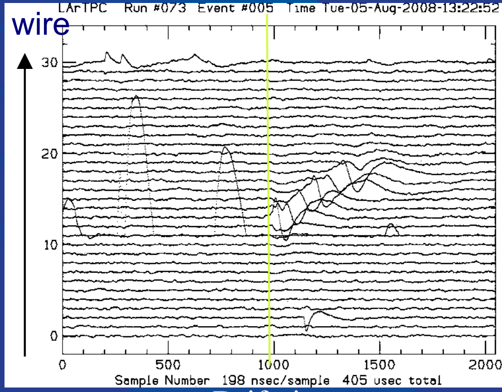


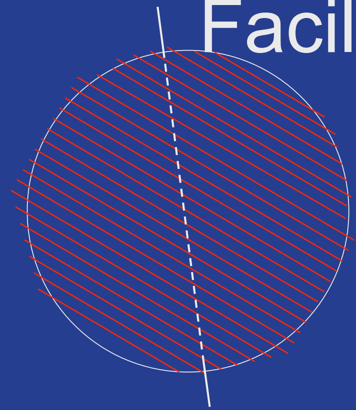
Facilities – Electronics Test System

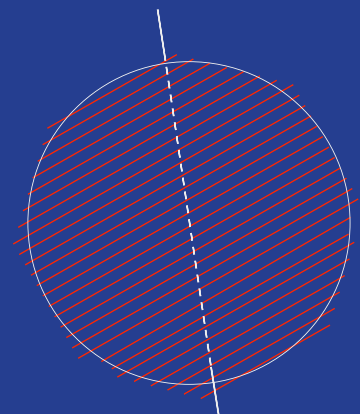
Raw Signals

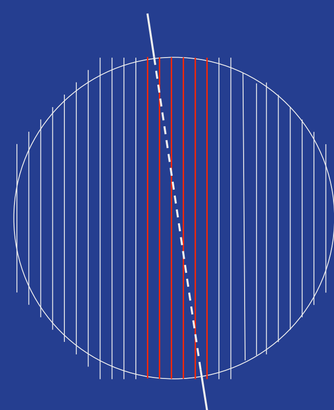






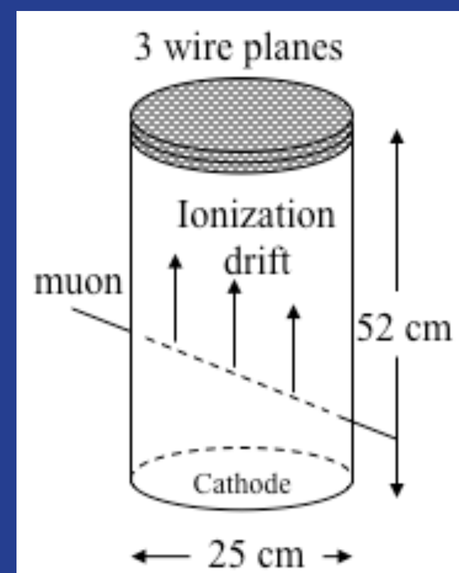






First U.S. made electronics.

Served as the test bed for development of ArgoNeuT electronics, and motivated the development of reconstruction software - including hit reconstruction techniques based on FFT.



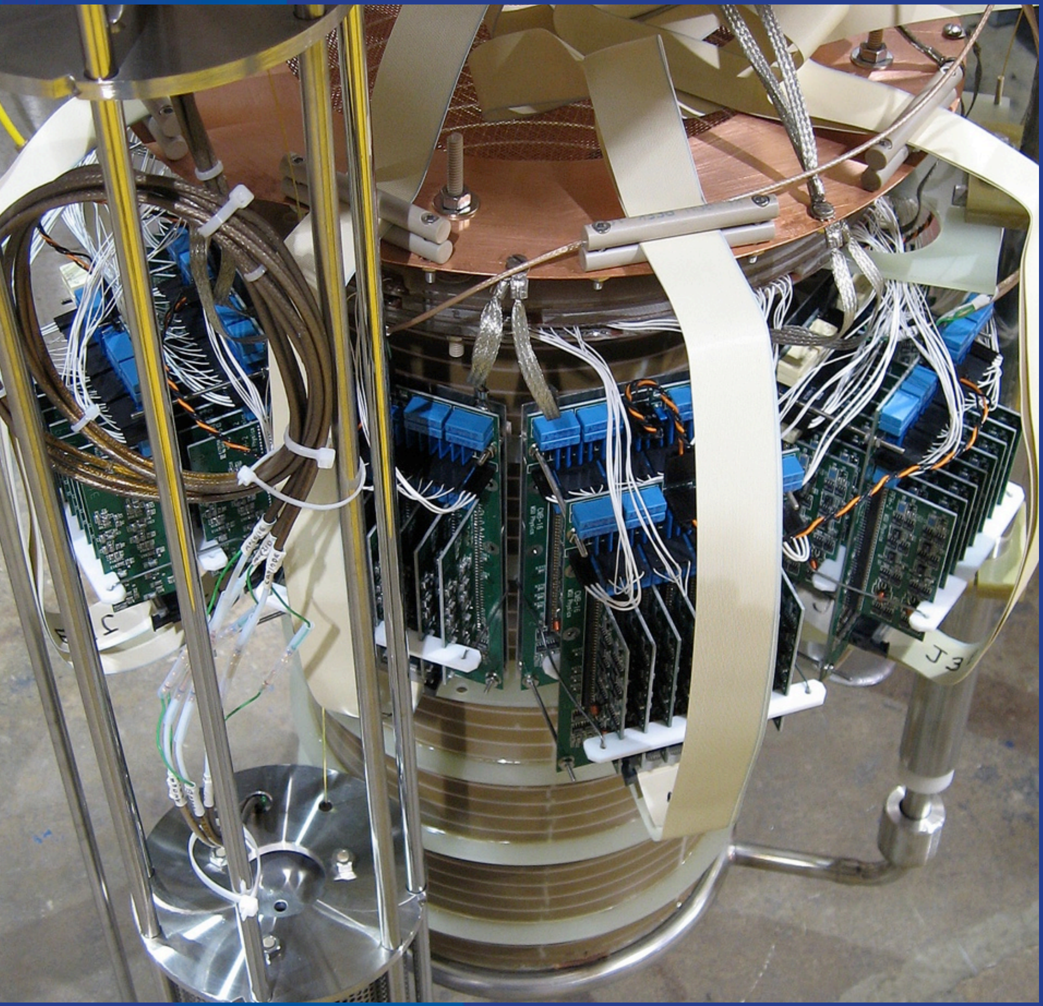
Facilities – Electronics Test System

For enormous (multi-kiloton) LAr TPCs, there would be significant advantiages in putting the electronics in the liquid argon and multiplexing the signals before transmitting them out of the cryostat.

Advantages:

- Lower capacitance seen by an amplifier close to the TPC wire can improve signal to noise compared to amplifier some meters from the wire.
- Ability to put amplifiers anywhere on the TPC avoids having to bring the signals to top of detector, or to have feed-throughs in liquid.
- Multiplexing signals inside the cryostat reduces the number of feed-throughs reducing cost and chance of leaks.
- Multiplexing signals reduces cable plant inside detector and thus reduces sources of contamination and out-gassing.

1st in-liquid `CMOS' electronics on a LArTPC – built at Michigan State Univ.

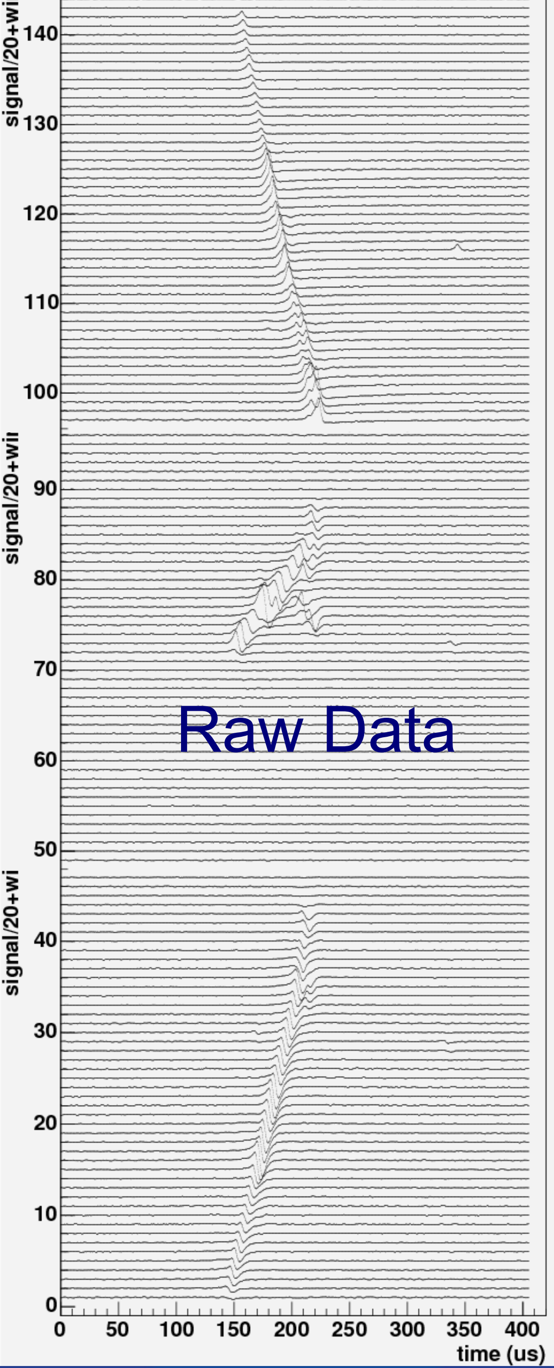


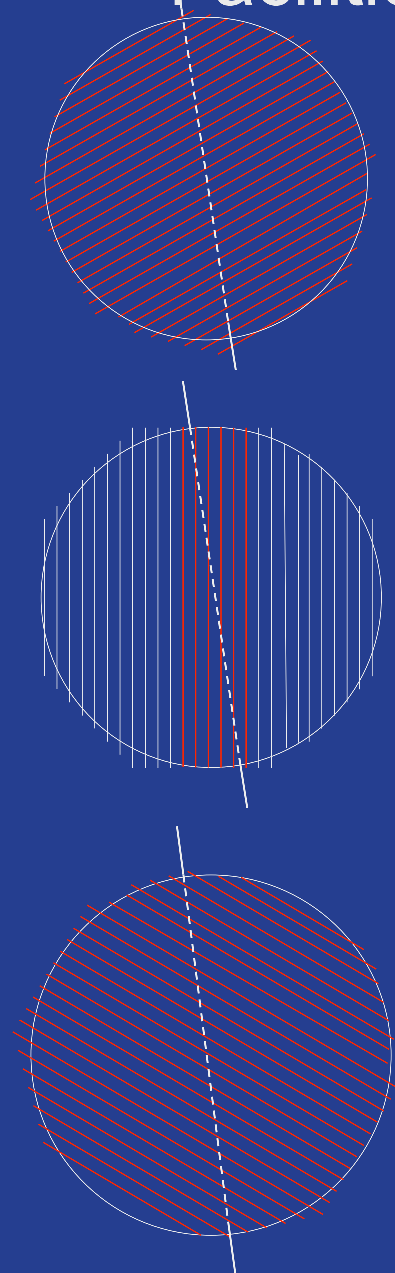
CMOS based design.

- Common technology.
- Operates well at 90K.
- Can be converted to ASIC.

- Capacitors and Inductors require careful selection.
- Connectors and cabling need careful testing.
- All connections need robust mechanics.

Facilities – Electronics Test System





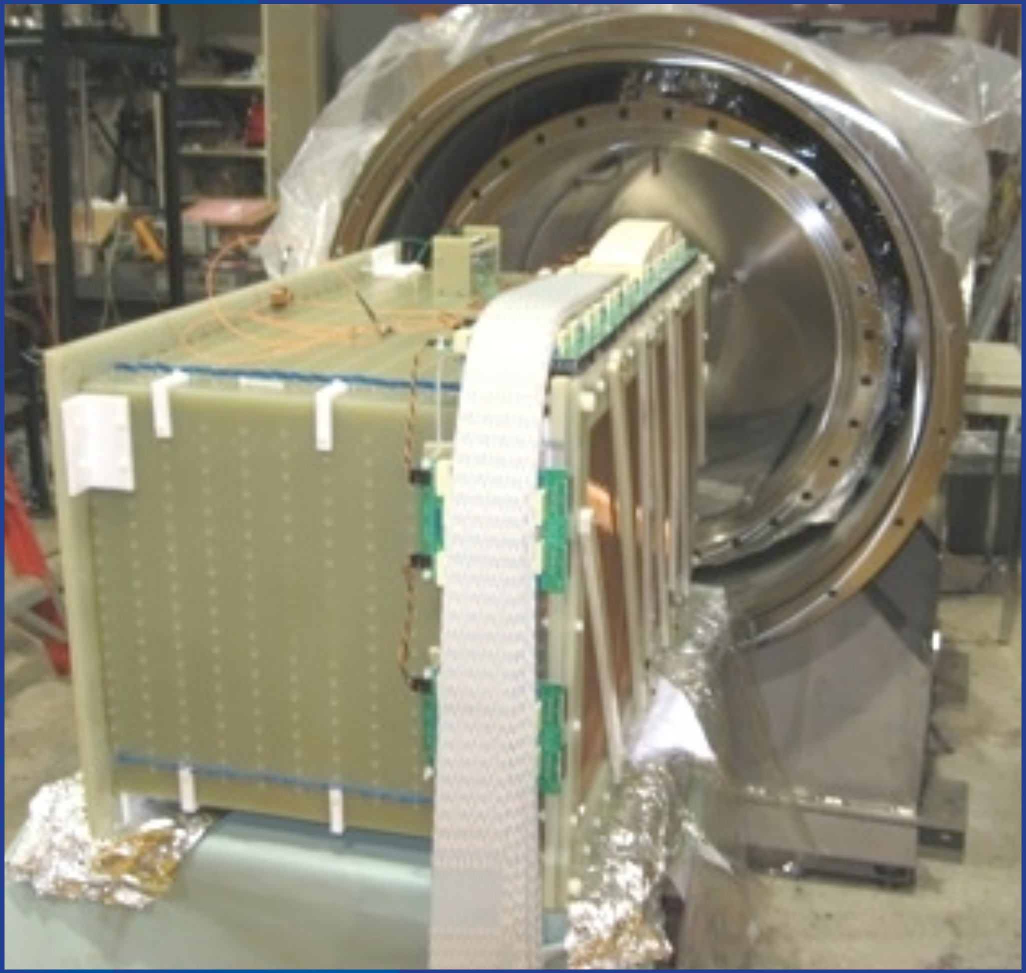
In-liquid electronics

S/N looks very promising

Analysis in progress

PPD EE dept. looking at long term issues to do with operation at low T. Results are encouraging

ArgoNeuT-T962: LArTPC exposed to NuMI Beam



FNAL, Italy, MSU, Syracuse, Yale

1m x 50 cm x 50 cm

2 views +/- 30^0 to vertical

480 channels total

External electronics

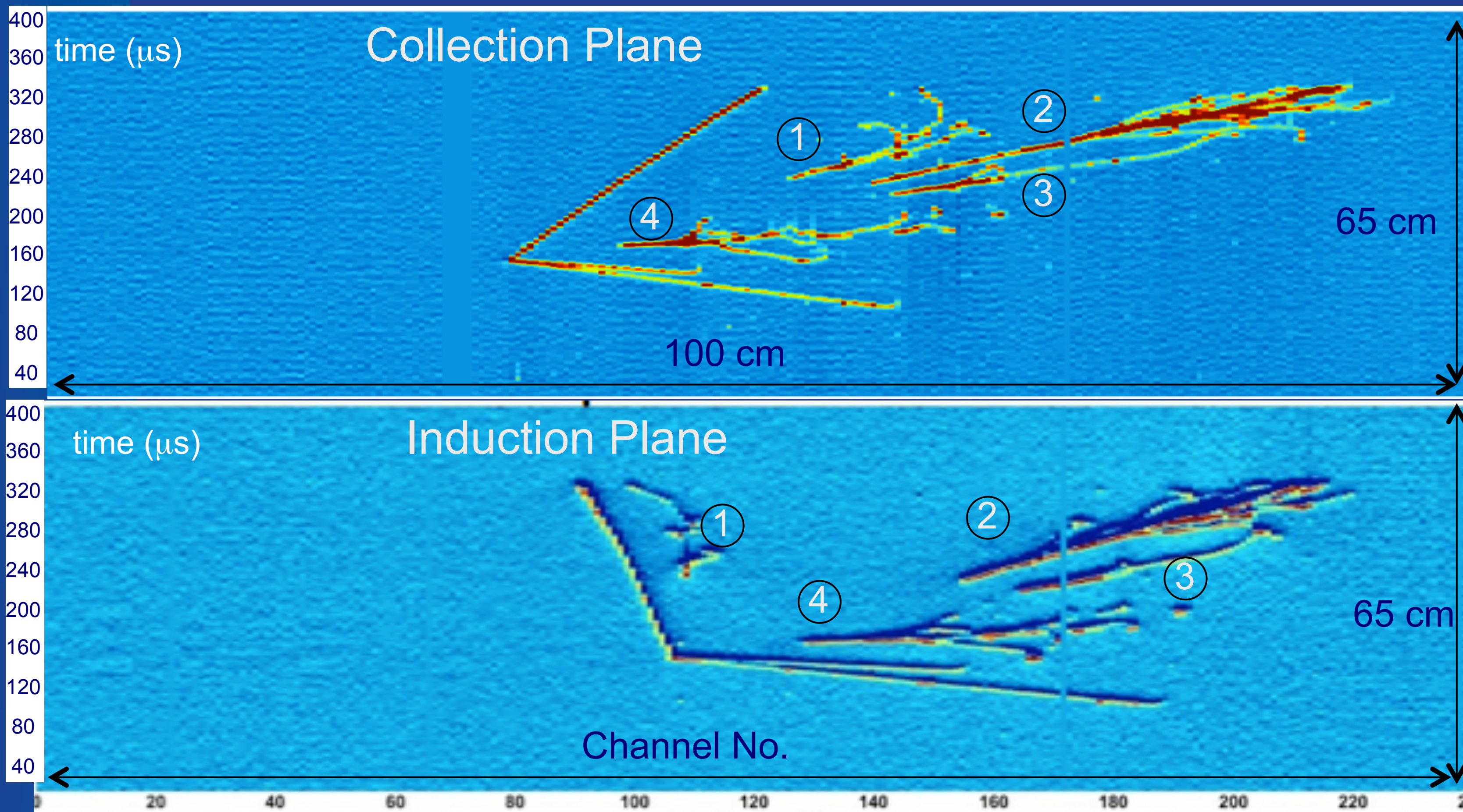
Ran in NuMI beam

neutrino (1 month)

anti-neutrino (4 months)

ArgoNeuT-T962: LArTPC exposed to NuMI Beam

Event with 4 photon conversions



Invaluable data set on *ν* interactions in Argon

Analysis in progress – results in Summer

Challenges for multi-kiloton scale detectors

Liquid Argon Purity Demonstration

All previous LArTPC detectors have been evacuated before filling. Remove this constraint on the cryostat for large detectors.

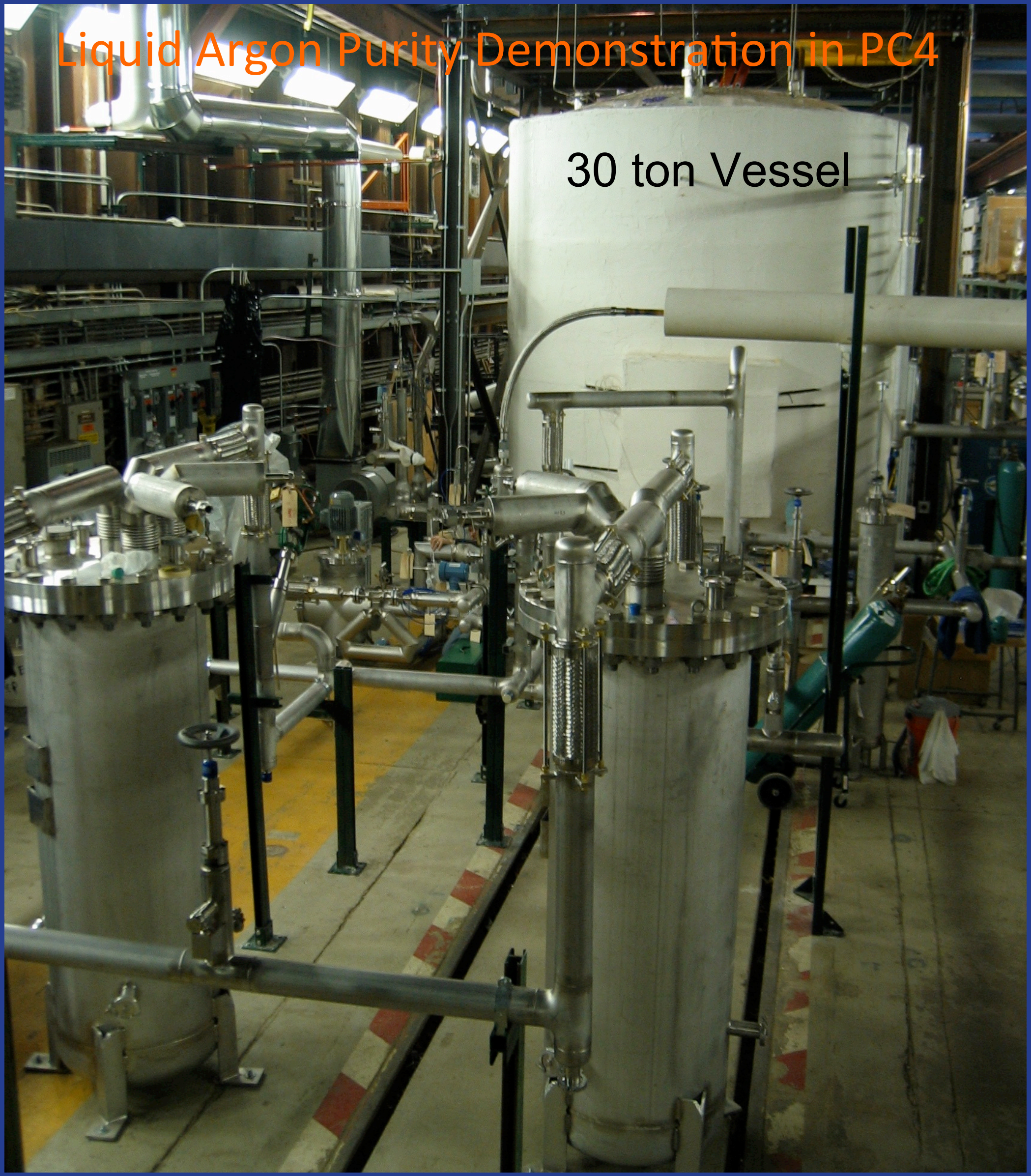
Demonstrate good life-time in an industrial vessel without evacuation.

First multi-ton purification system designed and built at Fermilab.

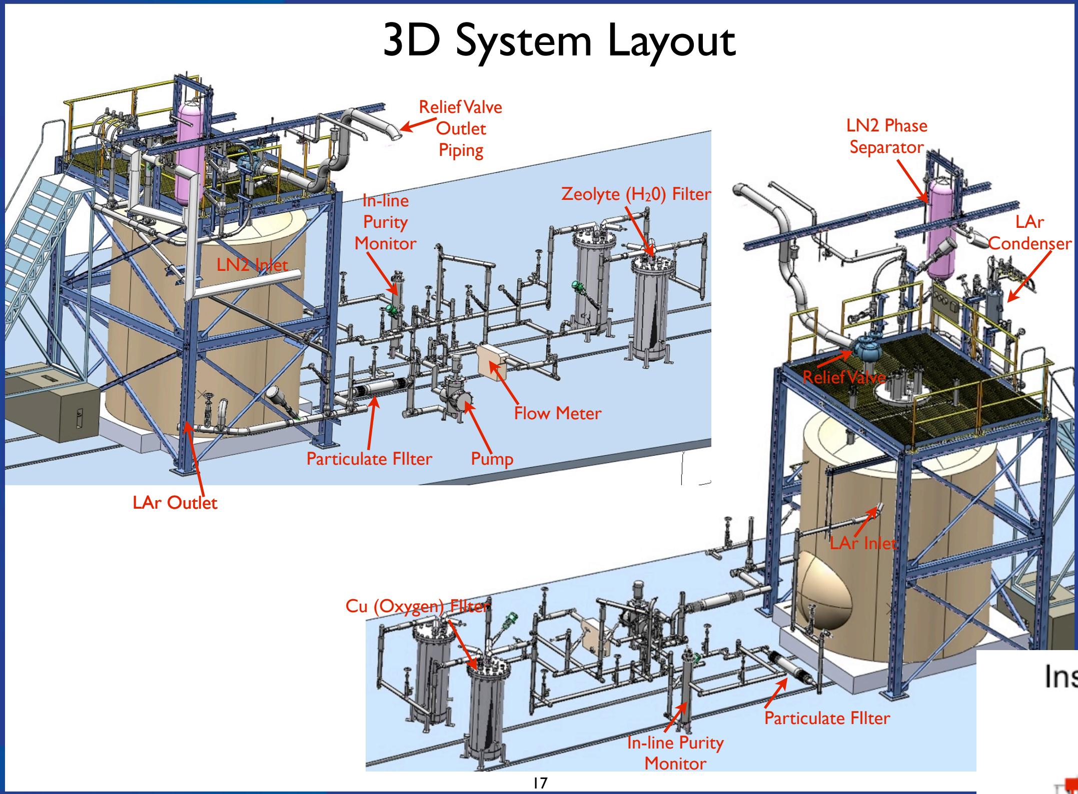
Expect to start commissioning early June using *Argon Piston*™ to remove atmosphere and then circulate through filters (seen in foreground)

Stage 1 – bare tank

Stage 2 – with detector materials



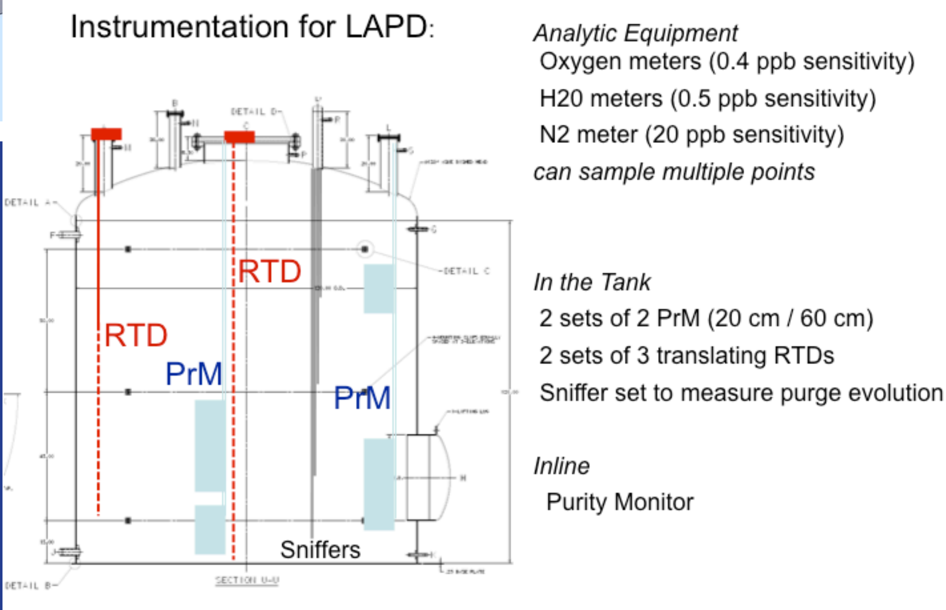
Challenges for multi-kiloton scale detectors



Complex cryogenic system – valuable learning experience

Will measure evolution of tank atmosphere (Oxygen and water)

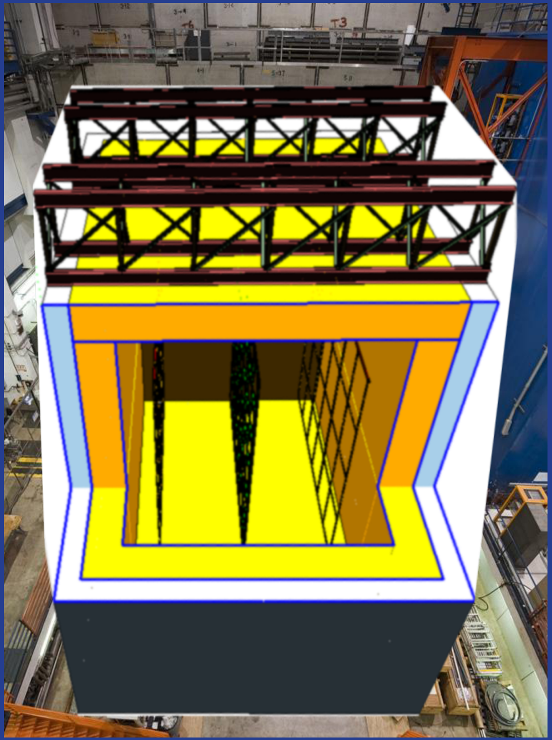
Will measure liquid temperatures throughout tank to check models of convective flow



Challenges for multi-kiloton scale detectors

Membrane Cryostat Technology

based on modern LNG transport technology

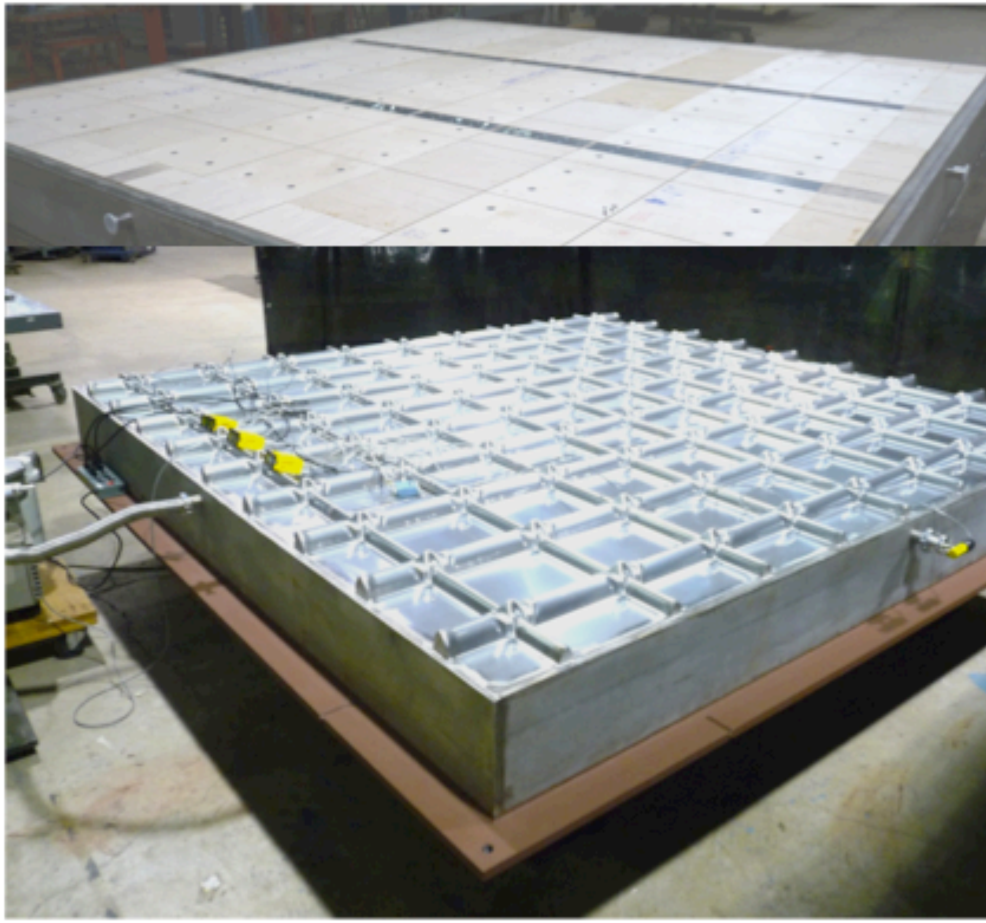


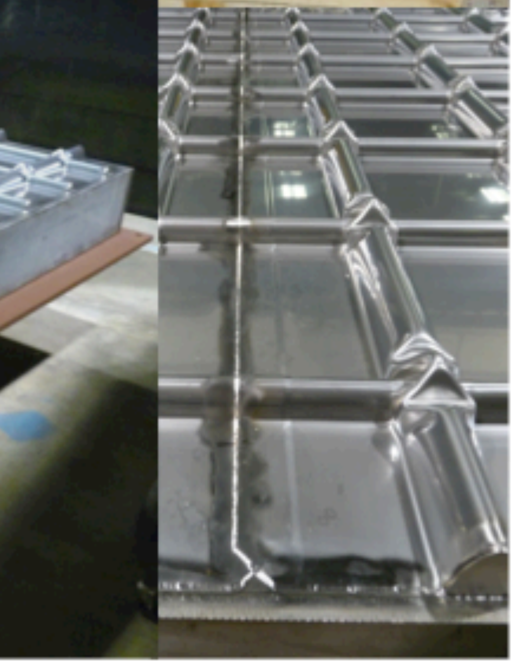
The LAr35t cryostat is our first foray into the use of membrane cryostats. It will use the same cryogenics and purification system as developed for the Liquid Argon Purity Demonstration.

The LAr1 (ktonne) is designed to be built in the DZero pit where there is significant liquid argon infrastructure. It is intended to validate technologies adopted for kton neutrino detectors.

First steps with the Membrane Technology

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.





R & D to develop alternative leak-check procedures to avoid use of contaminating chemicals

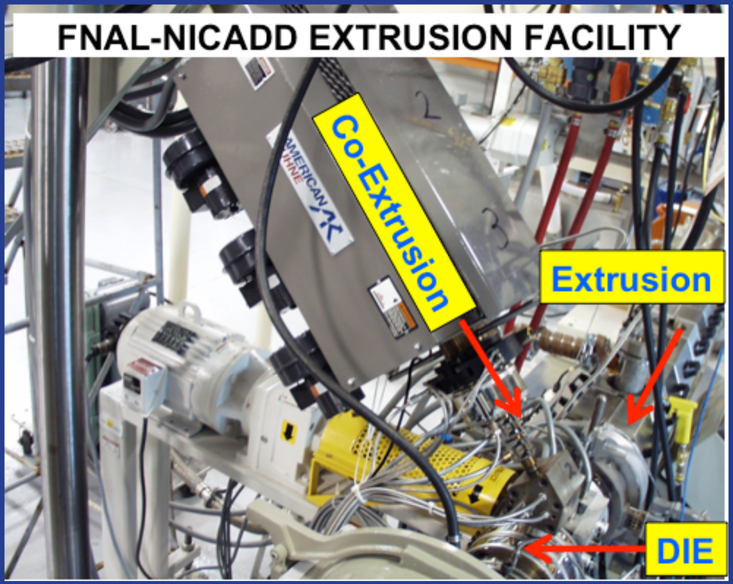
Light Readout R & D - M.I.T & Indiana

Light signal might be a useful trigger. Argon light is 128 nm wave-length-shifters (WLS) are used to convert the 128 nm to visible.

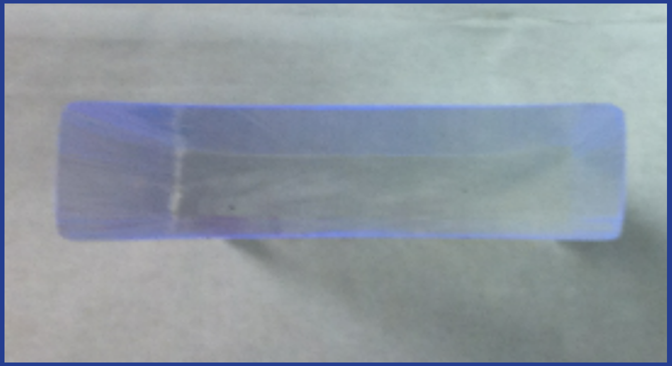
Typical arrangement is for PMTs with WLS around the periphery of the Argon volume.

This is both costly (paying for PMT area) and inefficient (far from the action) for large volume detectors. Can one wave-length shift and collect light throughout volume and route it to photodetectors?

A concept: clear polystyrene light guide clad with thin layer of WLS in a polystyrene matrix. Issue is attenuation length along the light-guide because of the cladding layer.



A sample of a polystyrene bar co-extruded by the NICADD-FNAL extruder with an outside layer of polystyrene containing 1.5% bis-MSB. Note the blue is only evident in the surface layer, not throughout the volume.



Dark Matter – Depleted Argon Distillation

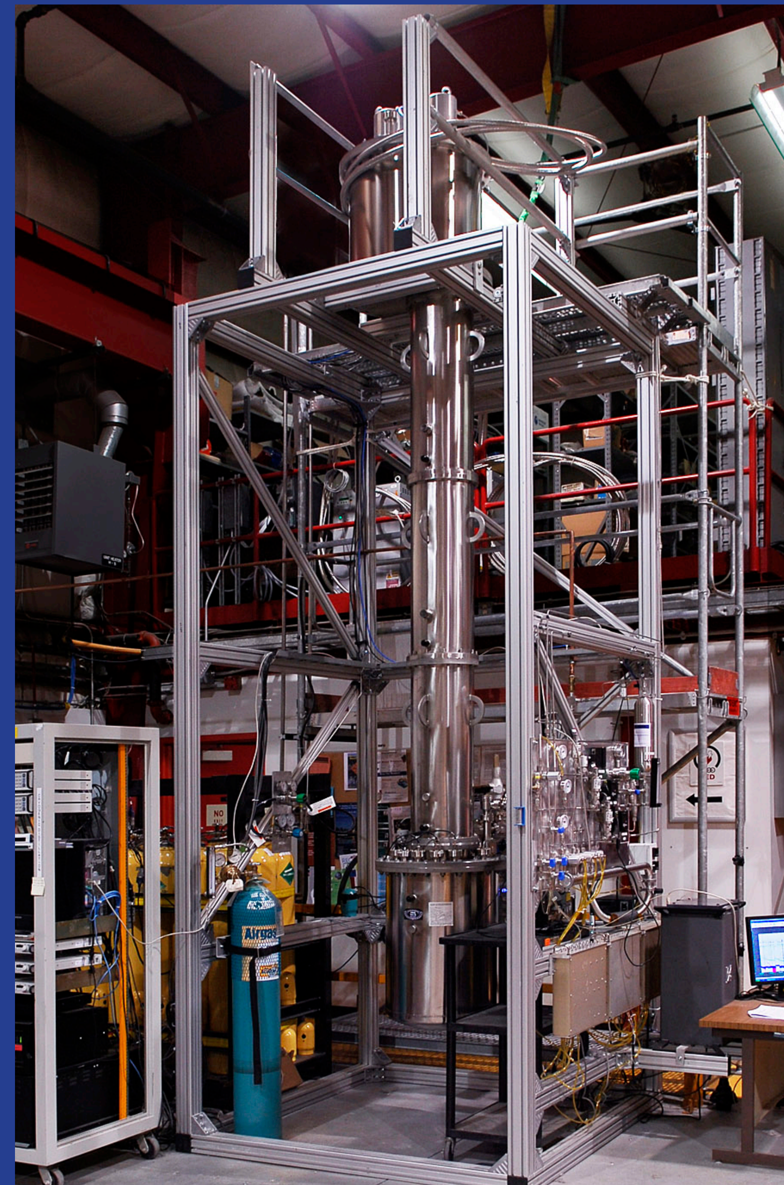
Atmospheric Argon contains ^{39}Ar which produces a background rate of 1 Bq/kg limiting the size of LAr Dark Matter 2-phase TPCs to ~ 1 ton because of dead-time.

Commercial CO_2 wells have been found * which contain 400 ppm Argon with <1/25 (measurement limit) the atmospheric concentration.

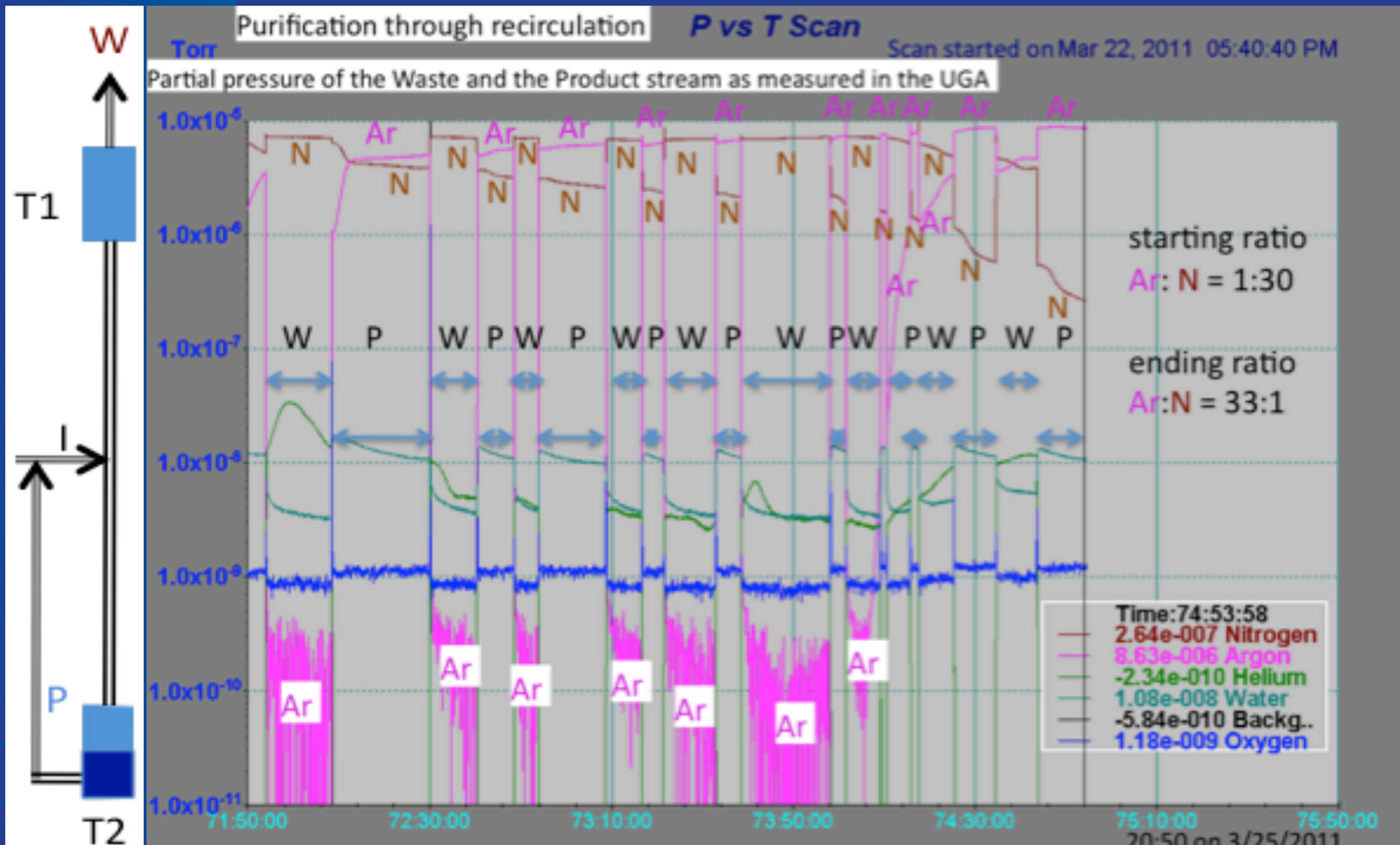
This Argon represents an unique resource for the Dark Matter program.

After removal of the CO_2 a mixture of 3% Ar, 27% He and 74% N_2 is obtained. Fermilab has agreed to host the distillation column designed to separate the Argon.

The basic column was designed at Princeton. It was assembled, safety reviewed, and has had its first run at FNAL. A series of upgrades to increase throughput is underway.



First Distillation



Can distill efficiently but so far only in batch mode

Upgrades planned to improve cooling at input to achieve continuous distillation

Condenser-Booster (to put Argon into high pressure cylinders) is to be brought online

One Slide on Software

It is recognized that detector simulation and event reconstruction are important for the success of the Lar technology, and present a significant challenge given the wealth of data the detector provides.

LArSoft is a framework for Detector Simulation and Reconstruction in Liquid Argon TPCs.

It is supported by the Fermilab Computing Division in its ART framework.

It provides many types of event (Cosmic Ray, Neutrino Interaction, Single Particle) and propagates the resultant charge (and light) through the Argon.

The user defines the detector geometry and signal processing.

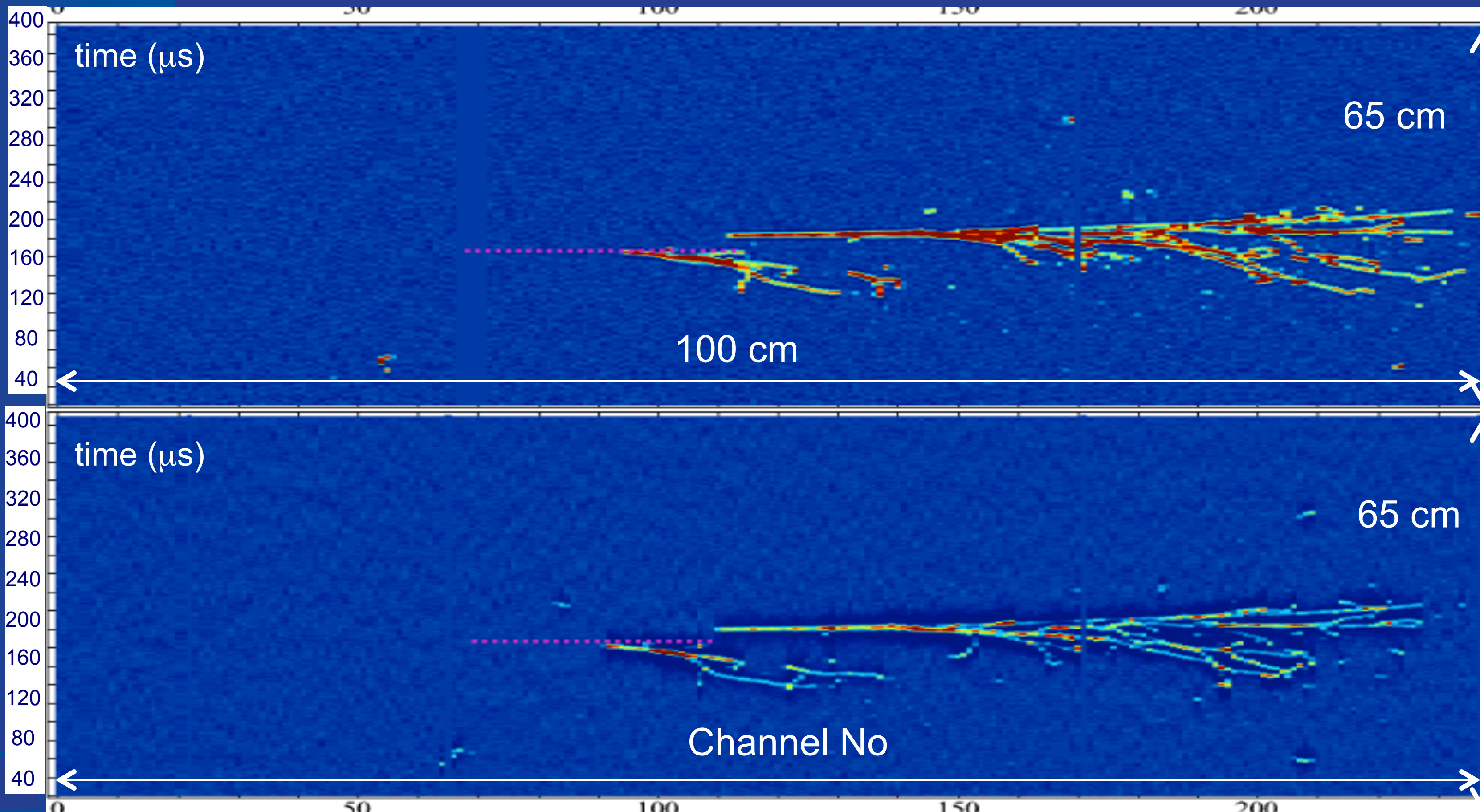
LARSoft has contributors from:

Bern (CH), Columbia University, Fermilab, LNGS (It), Kansas State University,

M.I.T., Michigan State University, Syracuse and Yale.

One Slide on Software

LArSoft Simulation of a π^0 in ArgoNeut - cf slide 24



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Liquid Argon Conclusions – In progress

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

Liquid Argon Conclusions - Summary

Vigorous and broad range of activities in Liquid Argon at Fermilab

Stimulating technical challenges and a collaborative environment

Comprehensive program of tests and prototypes towards deployment of kiloton and multi-kiloton neutrino detectors

Synergies with Dark Matter searches recognized and exploited

Recognition of the importance of simulation and reconstruction software and a significant commitment to their development.

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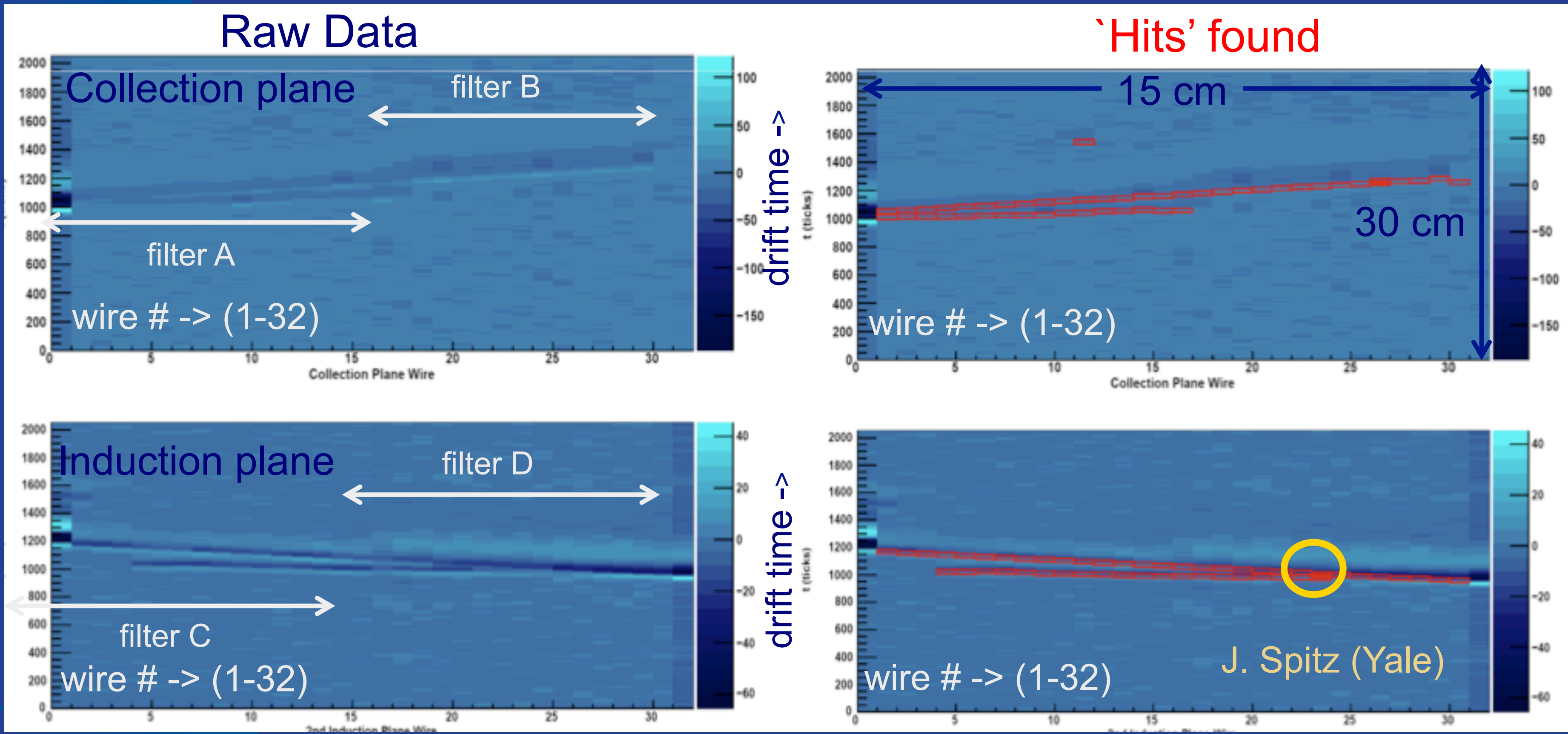
Backups

Introduction - What

Technical Issues for Liquid Argon Neutrino detector:

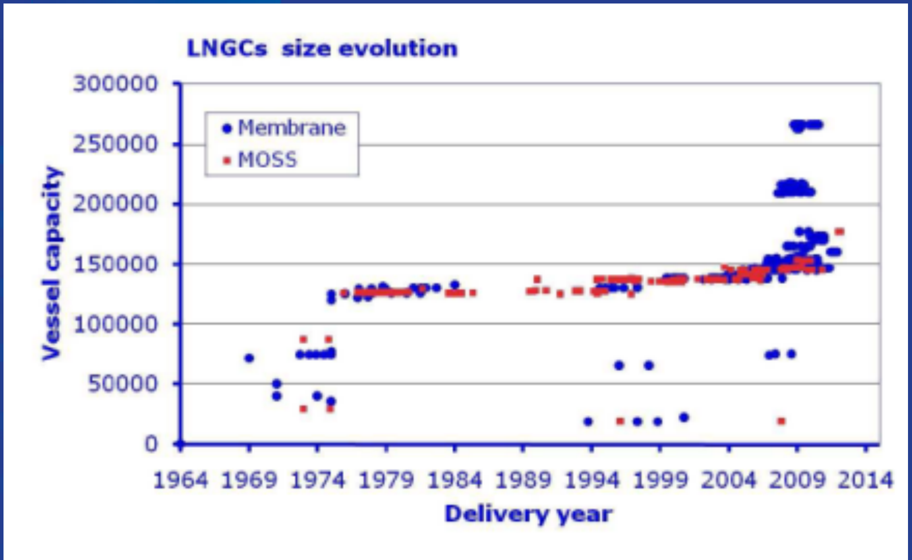
- Chemical purity of Argon to allow electron drift (10's ppt O2 equivalent),
- Chemical purity to allow light production and propagation
- Detector Materials Qualification
- Cryostat and Cryogenics and associated safety issues
- TPC design
- TPC readout electronics
- HV feedthroughs (>100 kV) and distribution
- Light Detection
- Data Acquisition

Example of use of TPC data – for electronics development



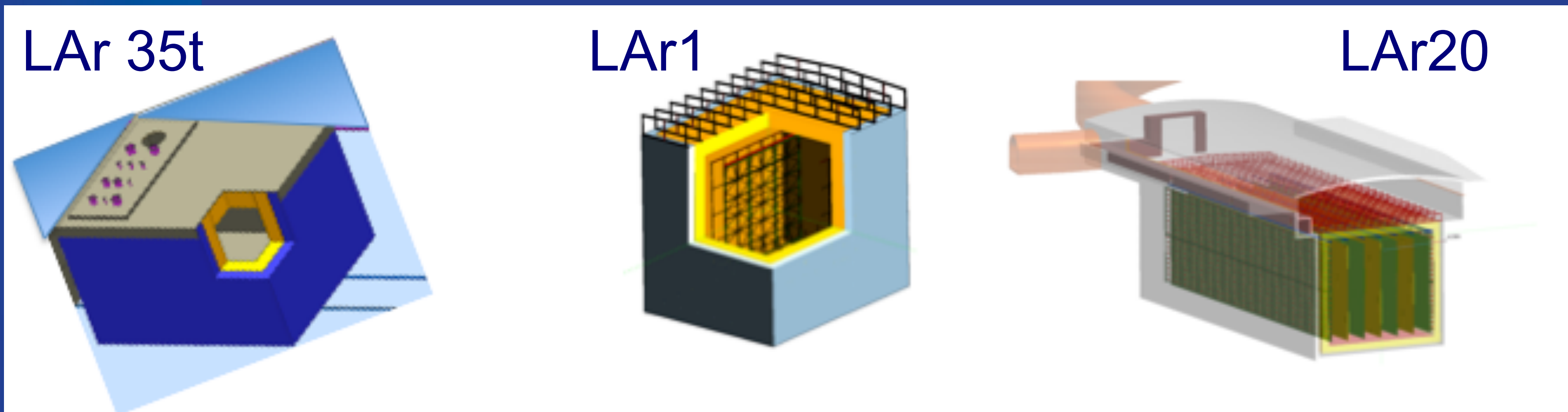
Ionization signals are small (~15,000 e) and slow – important to restrict bandwidth of system. Note the signal region is broader with filters B & D which have acceptance at lower frequency. These sort of data were used to optimize front-end filter bandwidth for resolution and two-track separation.

LNG tanker membrane cryostat



The LNGC "Tembek", one of the thirty-one 216,000 m³ LNG carriers ordered by Nakilat and delivered in 2008

Some steps on the path to the LBNE 25 ktonne cryostat based on Membrane panel construction as used in LNG carriers Well-suited to construction in a cavern.



Demonstration of the membrane cryostat technology

Prototype of the LAr20 detector validating TPC design and the assembly procedures.

One module of the LBNE detector

Distillation Column Design and Realization