Liquid Argon R & D at Fermilab

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DOE Review Laboratory Detector R&D

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U.S. DEPARTMENT OF ENERGY

Fermilab

Work on Liquid Argon R & D at Fermilab

Liquid Argon – Why

Liquid Argon is a bright Scintillator (40,000 photons/MeV) and allows free electrons to drift meters under E fields of ~ kV/cm. It has a density of 1.4 tonne/m^3, and is readily available.

Liquid Argon presents an attractive Target & Detection Medium for:

Neutrino interactions

Liquid Argon TPCs can produce bubble-chamber quality event images with topology *and* ionization density -> particle ID/calorimetry

Dark Matter searches

The time development of the light pulse and the ratio of the amount of free charge to light produced by interactions in Argon provide powerful rejection of electron and photon background in WIMP searches

How to develop the expertise to enable a U.S Program for a multi-kiloton LArTPC

Learn as much as we can from previous work (especially ICARUS)

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

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

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

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

Expose LArTPC to a beam of known energy and different particle types
- *LArDBT (Liquid Argon Detector Beam Test)*

Technical Challenges for Liquid Argon

- Chemical purity of Argon to allow electron drift,
- 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

Technical Challenges for Liquid Argon

- Chemical purity of Argon to allow electron drift, ***(ν and DM)*** ***IP***
- Chemical purity to allow light production and propagation ***(ν and DM)*** ***IP***
- Detector Materials Qualification ***(ν and DM)*** ***IP***
- Cryostat and Cryogenics and associated safety issues ***(ν and DM)*** ***IP***
- TPC design ***(ν and DM)*** ***IP***
- TPC readout electronics ***(ν)*** ***IP***
- HV feedthroughs (>100 kV) and distribution ***(ν and DM)*** ***IP***
- Light Detection ***(ν and DM)*** ***IP***
- Data Acquisition ***(ν and DM)*** ***IP***
- Radio purity of Argon ***(DM)*** ***IP***

Fermilab Argon Portfolio (work started by A. Para in 2004)

- Materals and Electronics Test Facilities at the PAB
- ArgoNeuT - LArTPC exposure to NuMI beam
- Liquid Argon Purity Demonstration
- Low-radioactivity Argon Distillation Column for Dark Matter
- Electronics in the liquid (Cold Electronics) development
- Scene - measurement of light output from nuclear recoils at U.N.D.

- MicroBooNE experiment (E-974)
- DarkSide-50 (E-1000) Dark Matter Search
- LAr-34 proposal for the LBNE (Long Baseline Neutrino Expt)
- 35 ton Membrane-Cryostat Demonstration

- Light Readout (Indiana & M.I.T.)
- QUPID Photosensor (UCLA)

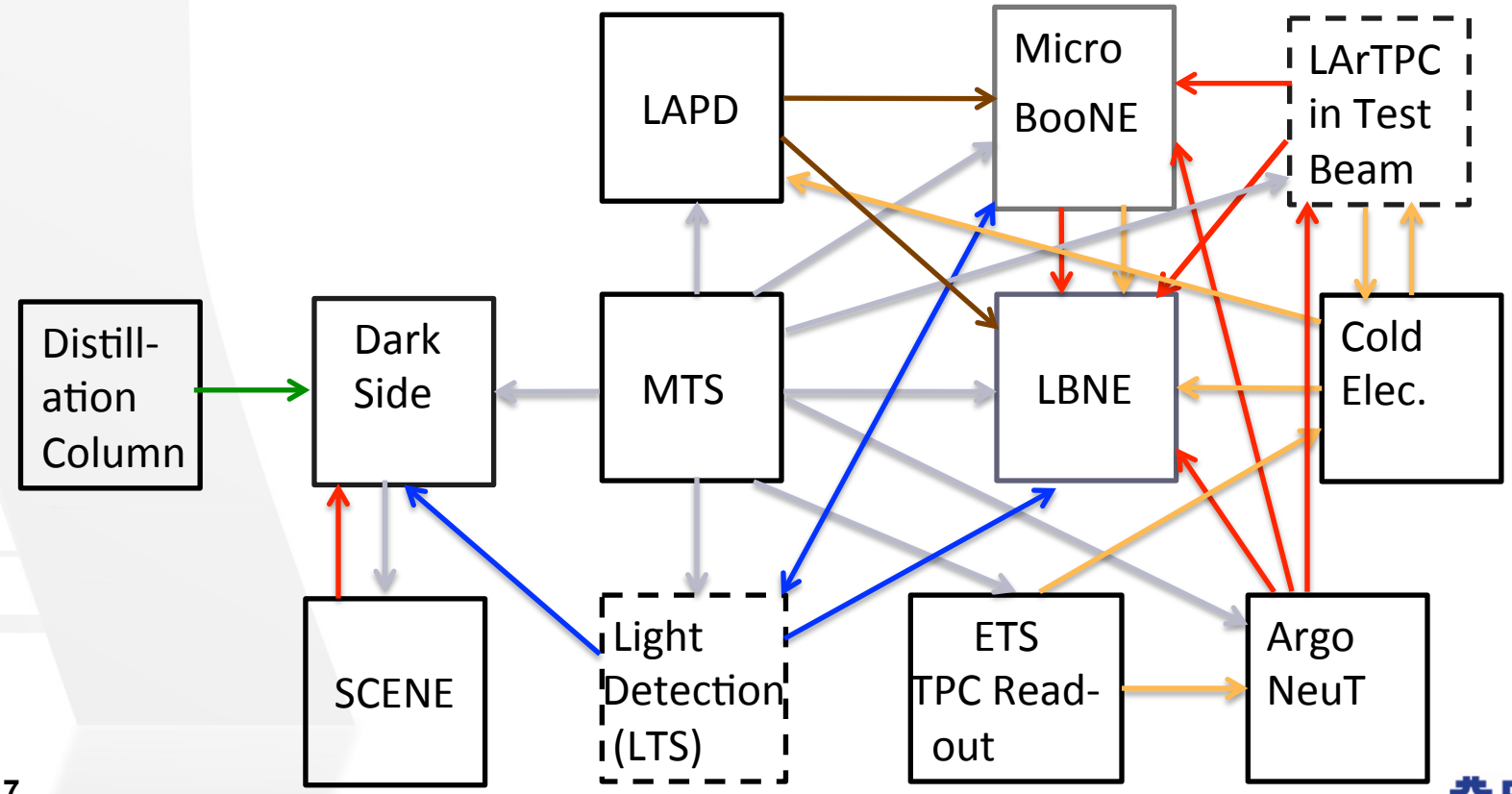
- `LArSoft' General Software Project for LArTPC detectors

R & D funded *Projects* *General Support* *Scientific Effort*

Relationships Between Present Projects

- Purity and Detector Materials, Filters, Controls
- Purity and Detector Materials, Non-evacuable Cryostat, Insulation, Filters
- Physics Capability
- Front-end Electronics
- Light Detection
- Low Radioactivity Argon

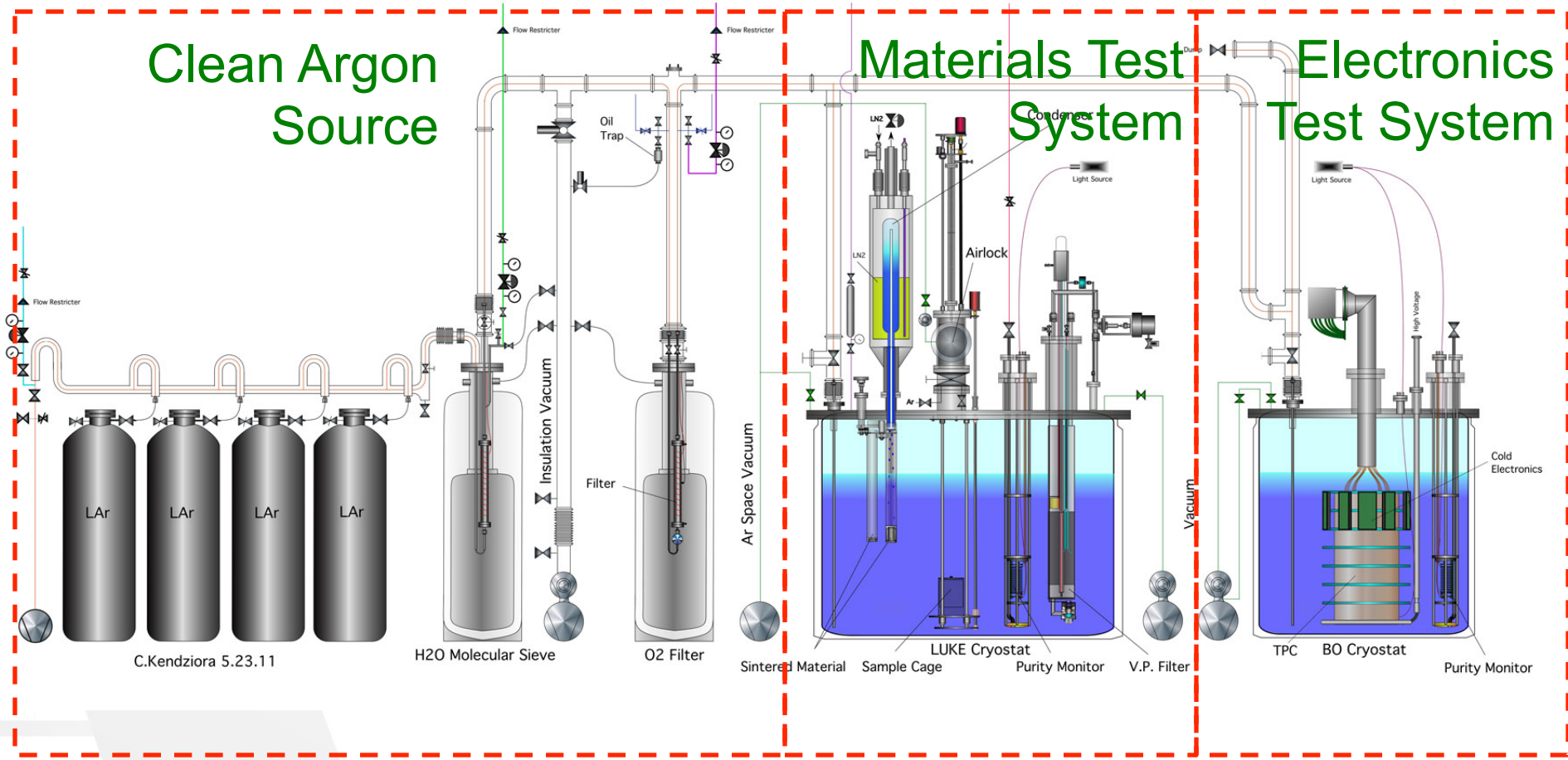
Present R&D | Future R&D | Projects



Liquid Argon Setup at the PAB

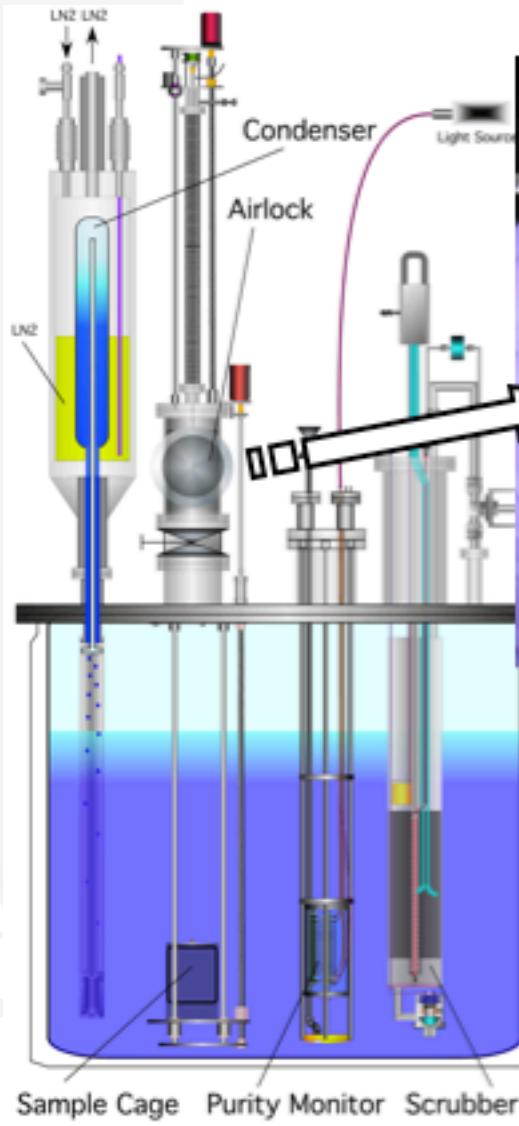
Liquid Argon Setup at the PAB

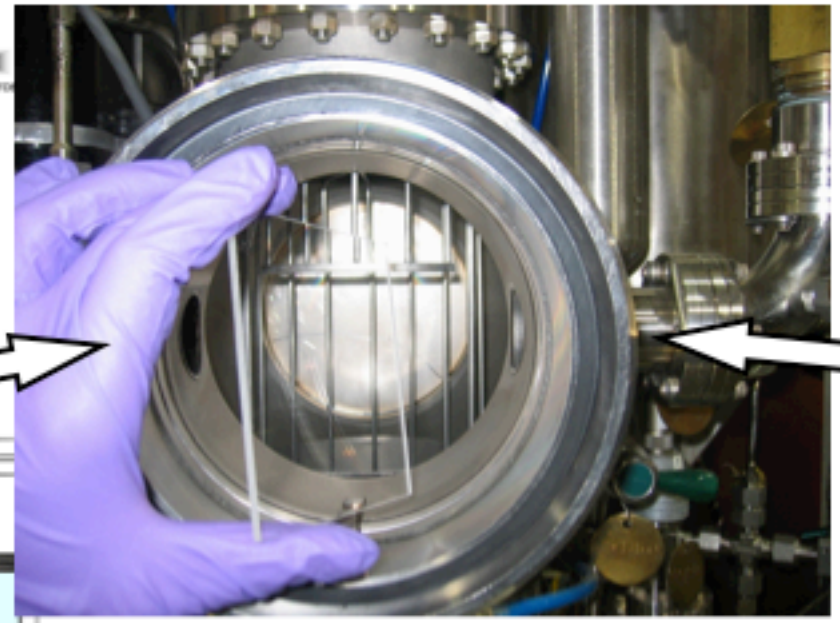
Liquid Argon Setup at the PAB



Schematic of Materials and Electronics Test Systems

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

Materials Test System

`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.

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

Sample data on different materials (bad, good,OK in liquid)

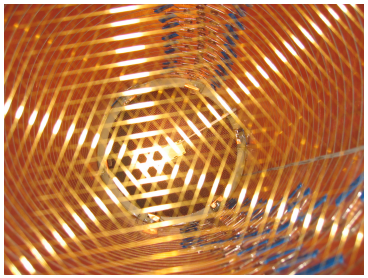
Electronics Test System

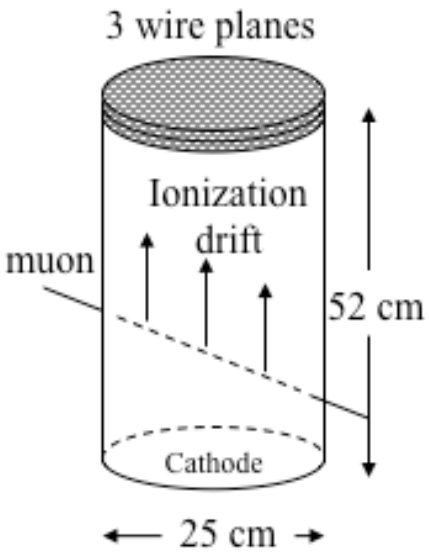
50 cm vertical drift TPC

HV 20 - 30 kV

3 planes of wires at 120^0

1st LAr TPC with U.S. electronics readout





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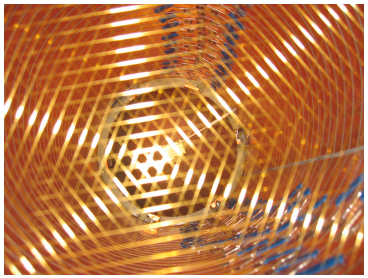

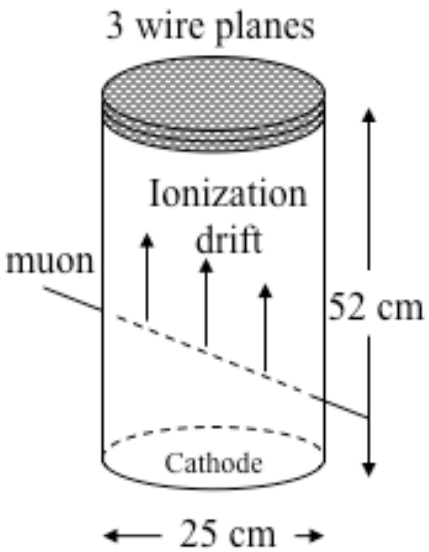

Electronics in the liquid Argon

For multi-kiloton LAr TPCs, there are significant advantages 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.

Challenge:

Need demonstration in CMOS technology -> convert to ASIC

1st in-liquid `CMOS' electronics on a LArTPC
– built at Michigan State Univ (D. Edmunds) on KA-15 contract

CMOS based design.

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

Electronics on test TPC – ready to be submerged in LAr

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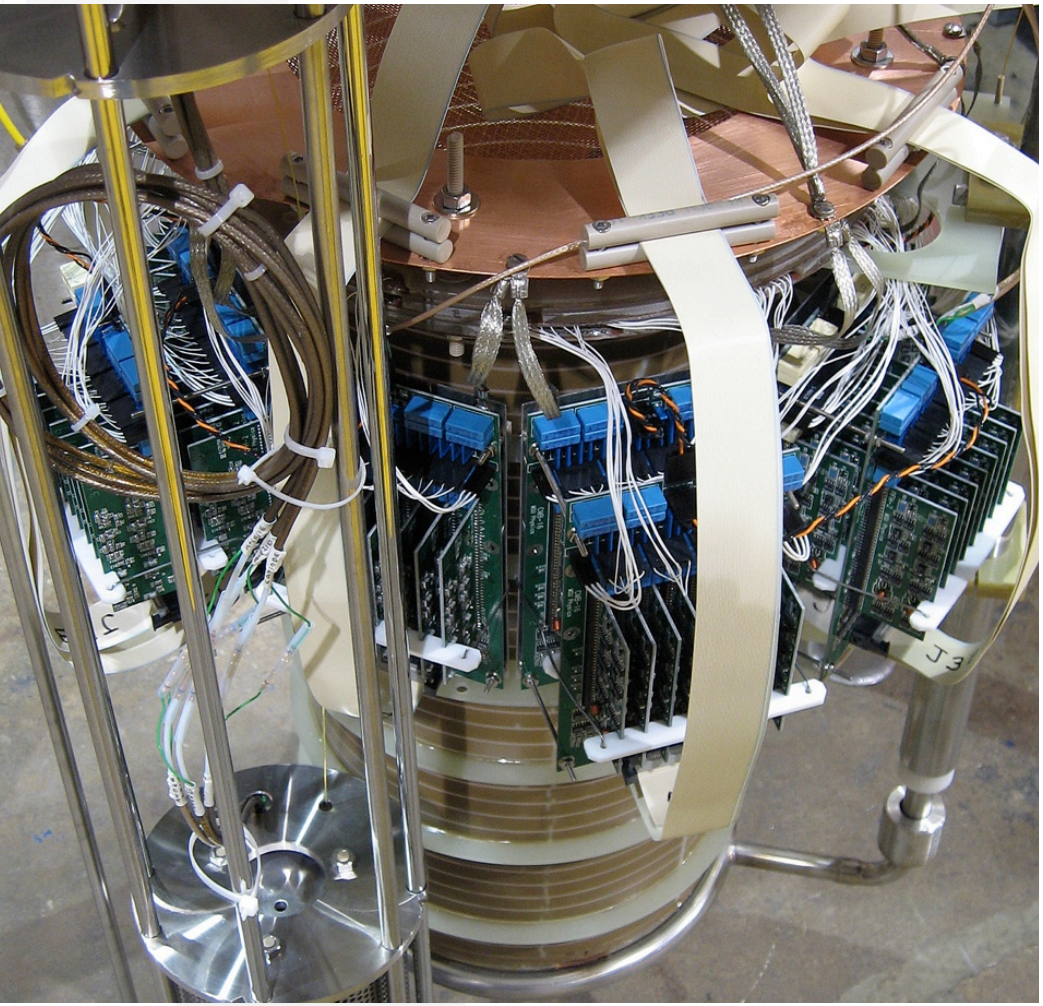


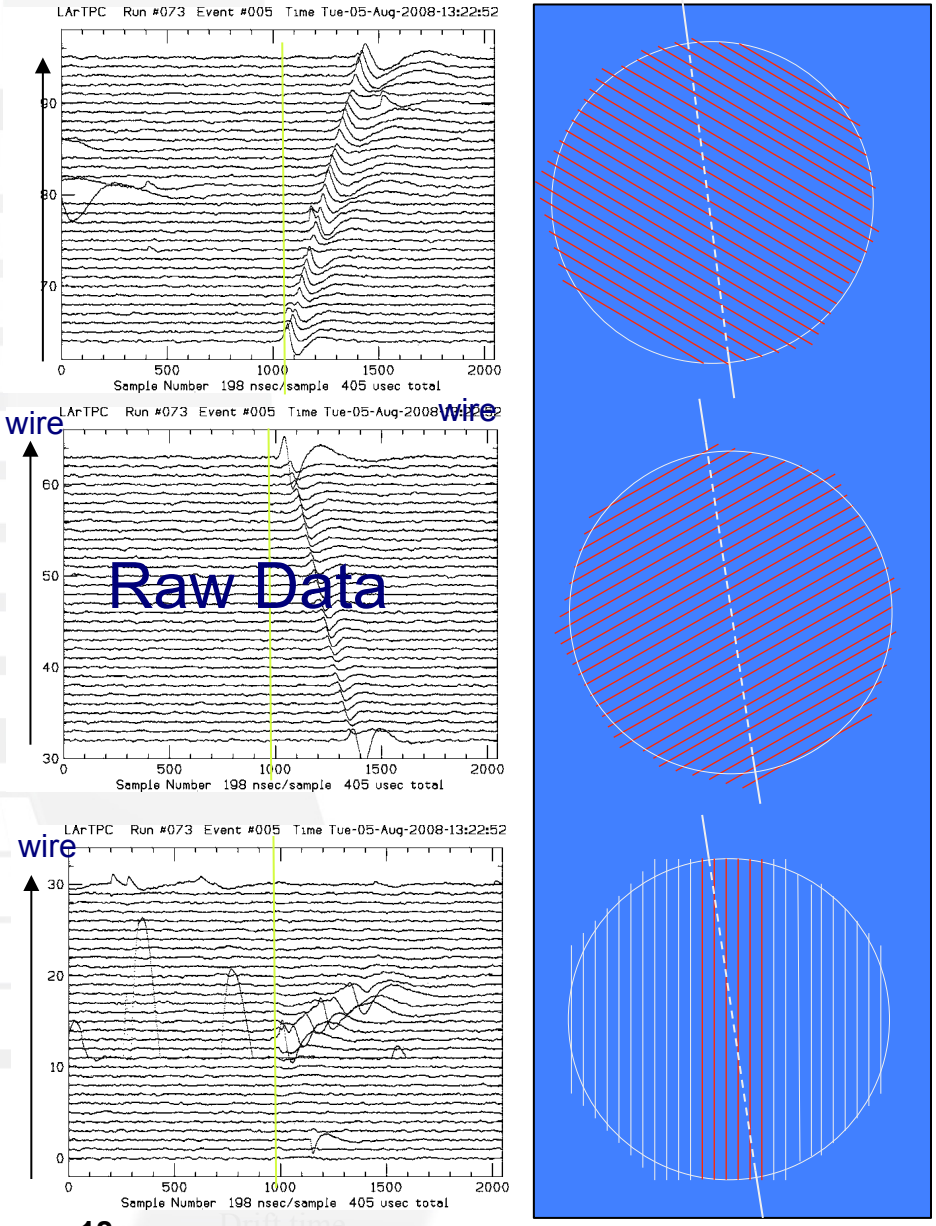
Electronics on test TPC – ready to be submerged in LAr

CMOS based design.

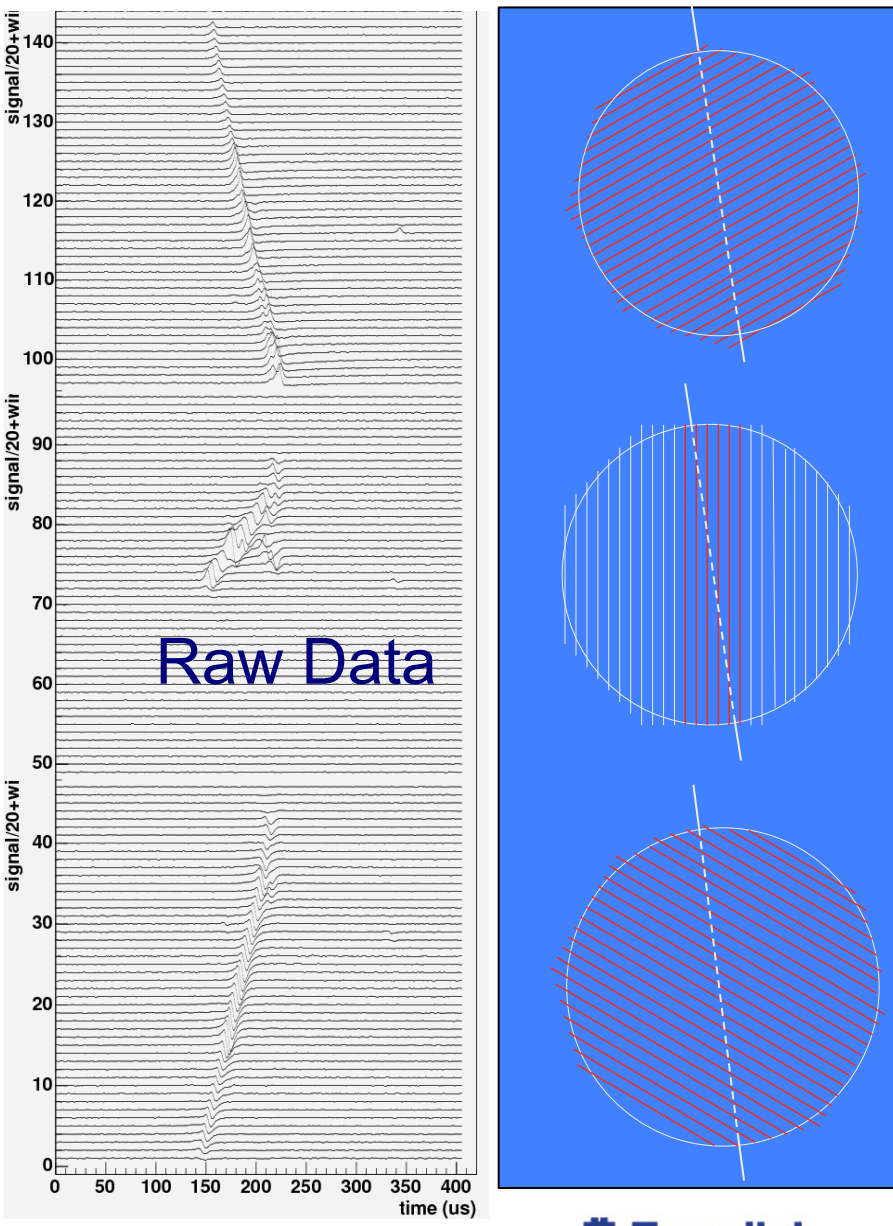
- Common technology.
- Operates well at 90K.
- Can be converted to ASIC.
- Passive components require careful selection.
- Connectors and cabling need careful testing.
- All connections need robust mechanics.

SUCCESS -> S/N > 30

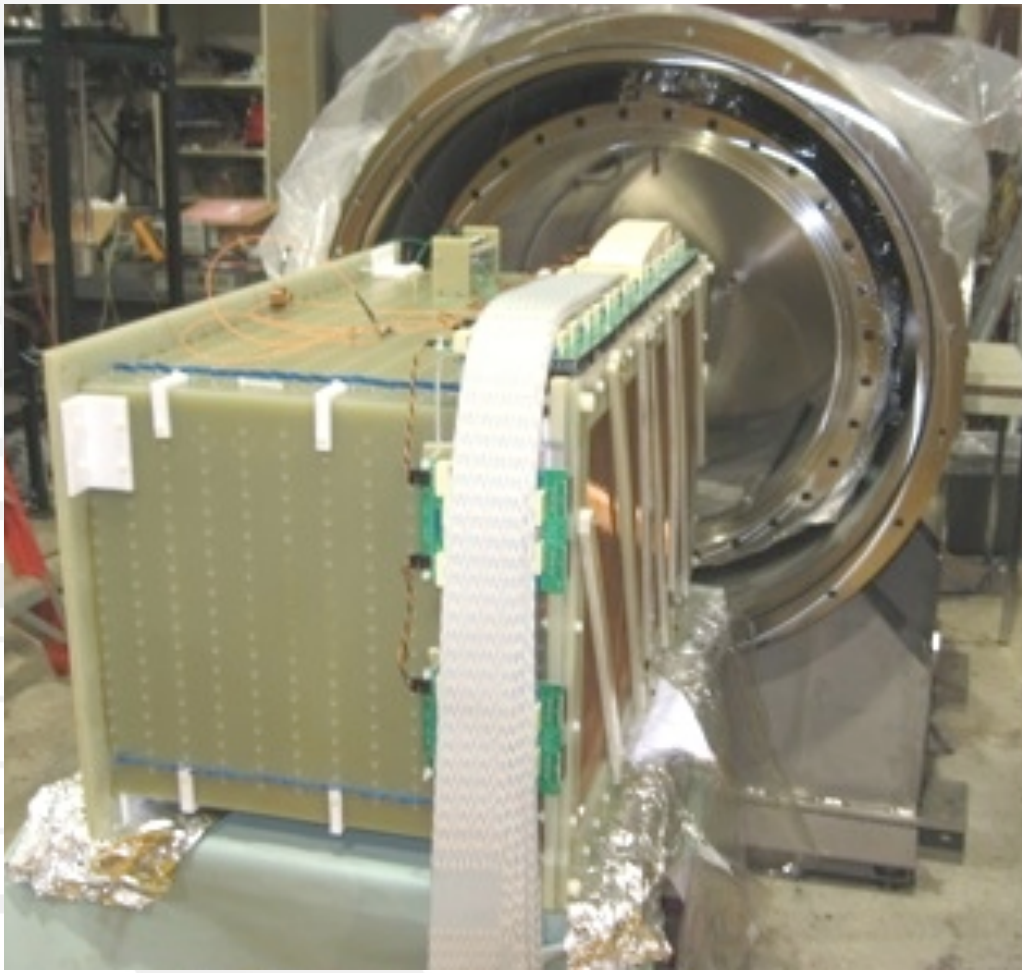
Warm amps S/N = 15



Amps in liquid S/N >30



ArgoNeuT-T962: LArTPC exposed to NuMI Beam



Bern (CH), FNAL, Italy, KSU, MSU, Syracuse, Texas, Yale

1m x 50 cm x 50 cm;

2 views +/- 30^0 to vertical;

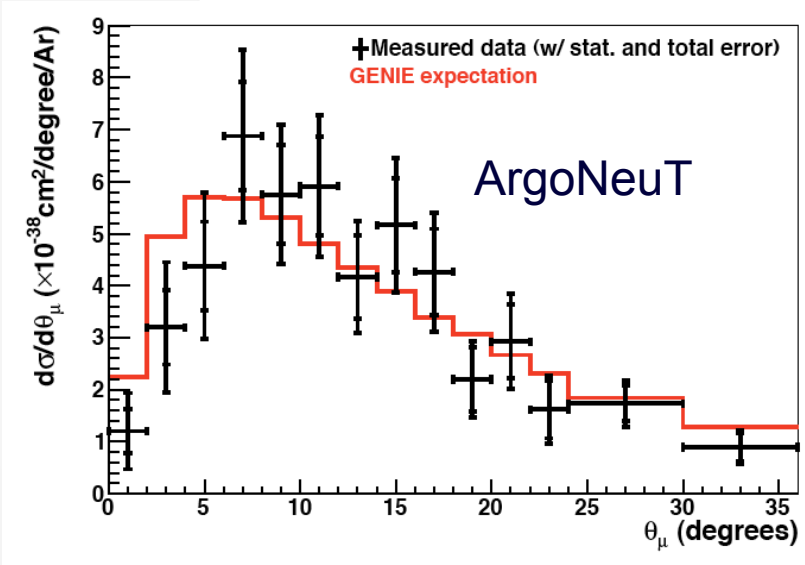
480 channels total;

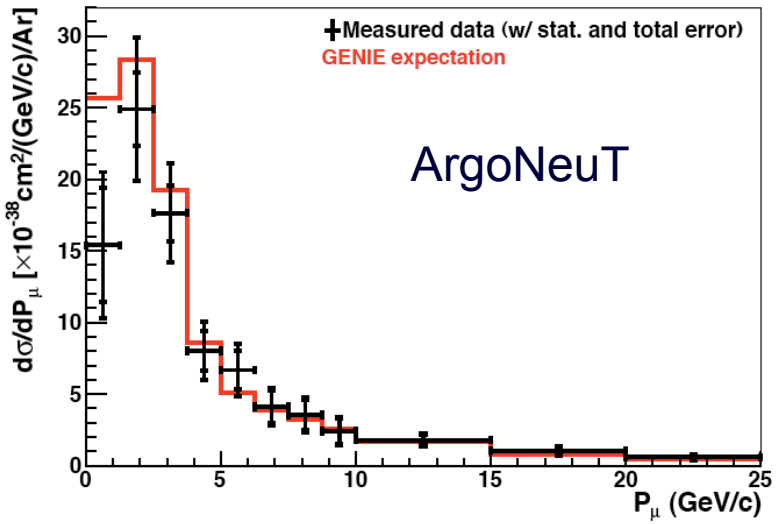
External (warm) electronics

Ran in NuMI beam

neutrino (1 month)

anti-neutrino (4 months)

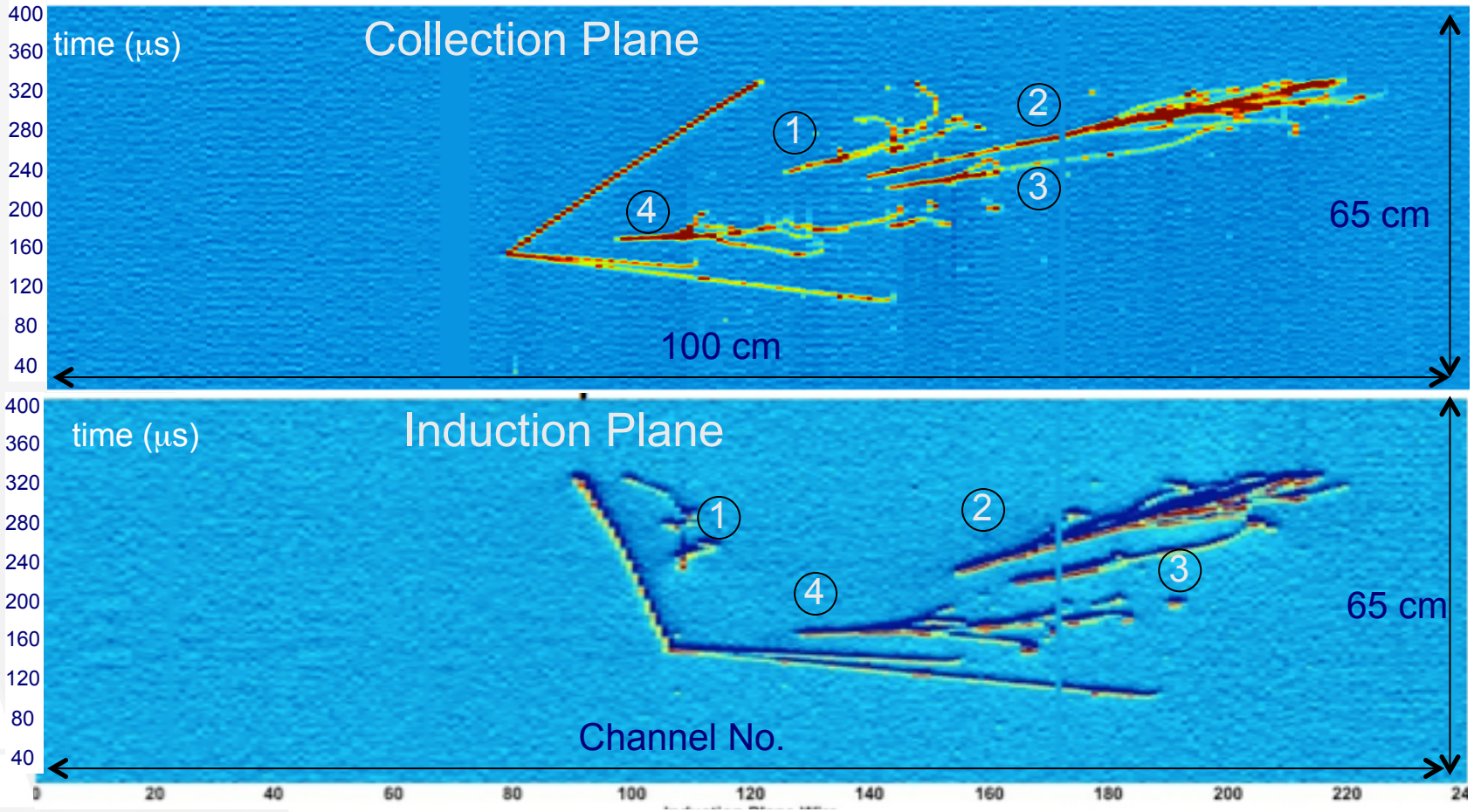




- Data in NuMI beam for 5 months in 2009-2010 – only interruption: cryocooler failure
- First measurements of differential cross sections for neutrino-Ar interactions have been made from the neutrino mode data
- Published in PRL 108, 161802 (2012), 2 more papers on the arXiv: 1205.6747 and 1205.6702
- Analyzed with LArSoft reconstruction and simulation package (no hand scanning)

ArgoNeuT in NuMI Beam

Event with 4 photon conversions (2 π^0)



Invaluable data set of ν interactions (~10,000) in Argon

Liquid Argon Purity Demonstration

All existing LArTPC detectors have been evacuated before filling. Probably not practical for kiloton detectors

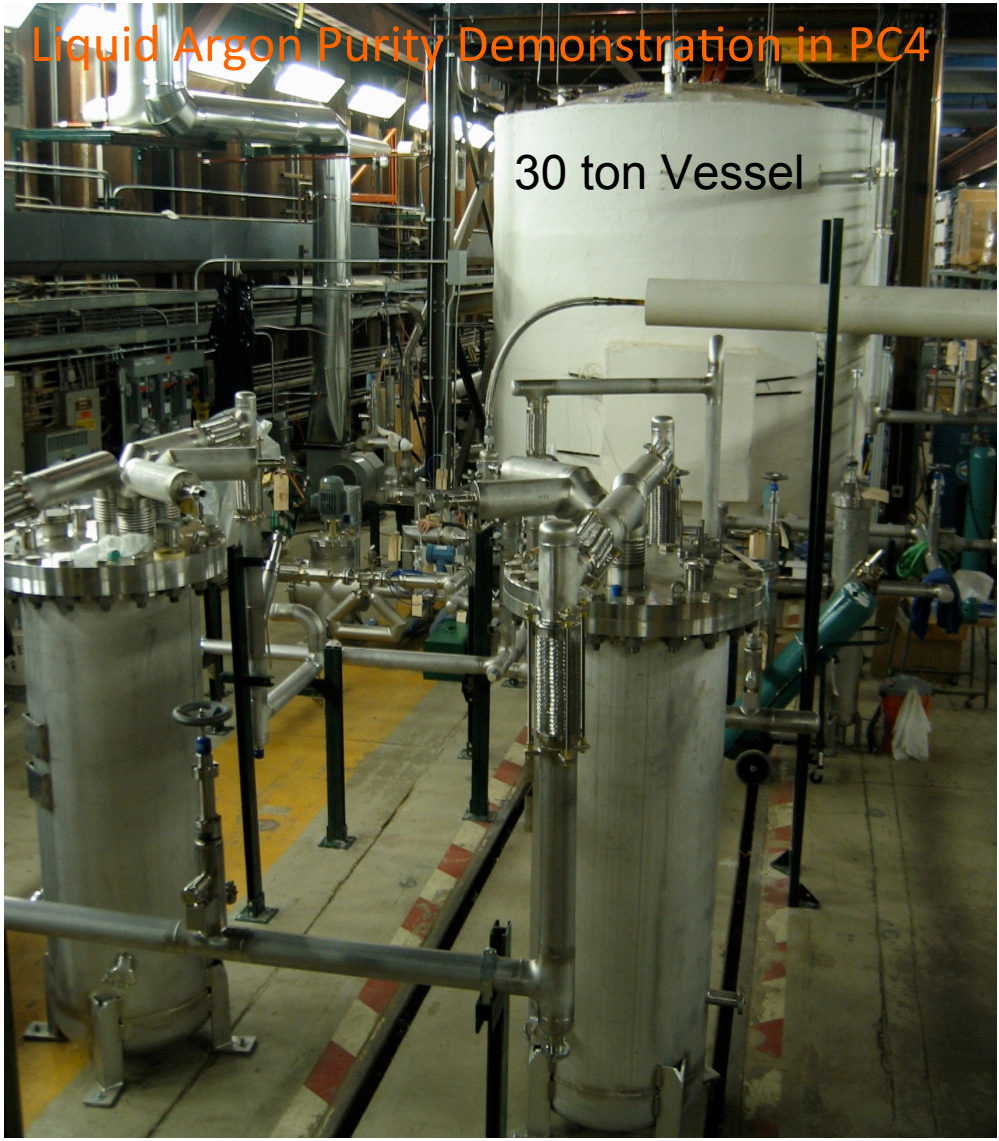
Goal: Demonstrate good life-time **in an industrial vessel without evacuation**.

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

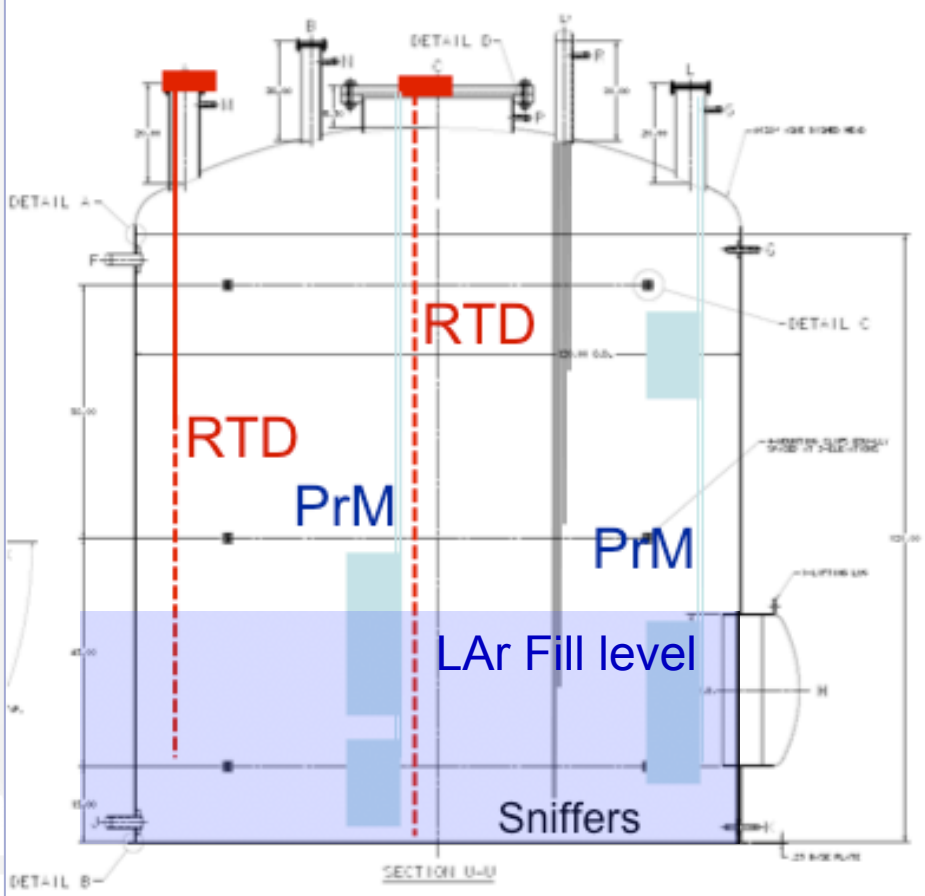
Commissioning started in October 2011

Stage 1 – bare tank & Instrumentation

- Sniffers for evolution of gas purge
- Analyzers – for O_2, N_2, and H_2O levels
- RTDs – for temperature (gradients)
- Purity Monitors - for drift-lifetime



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)

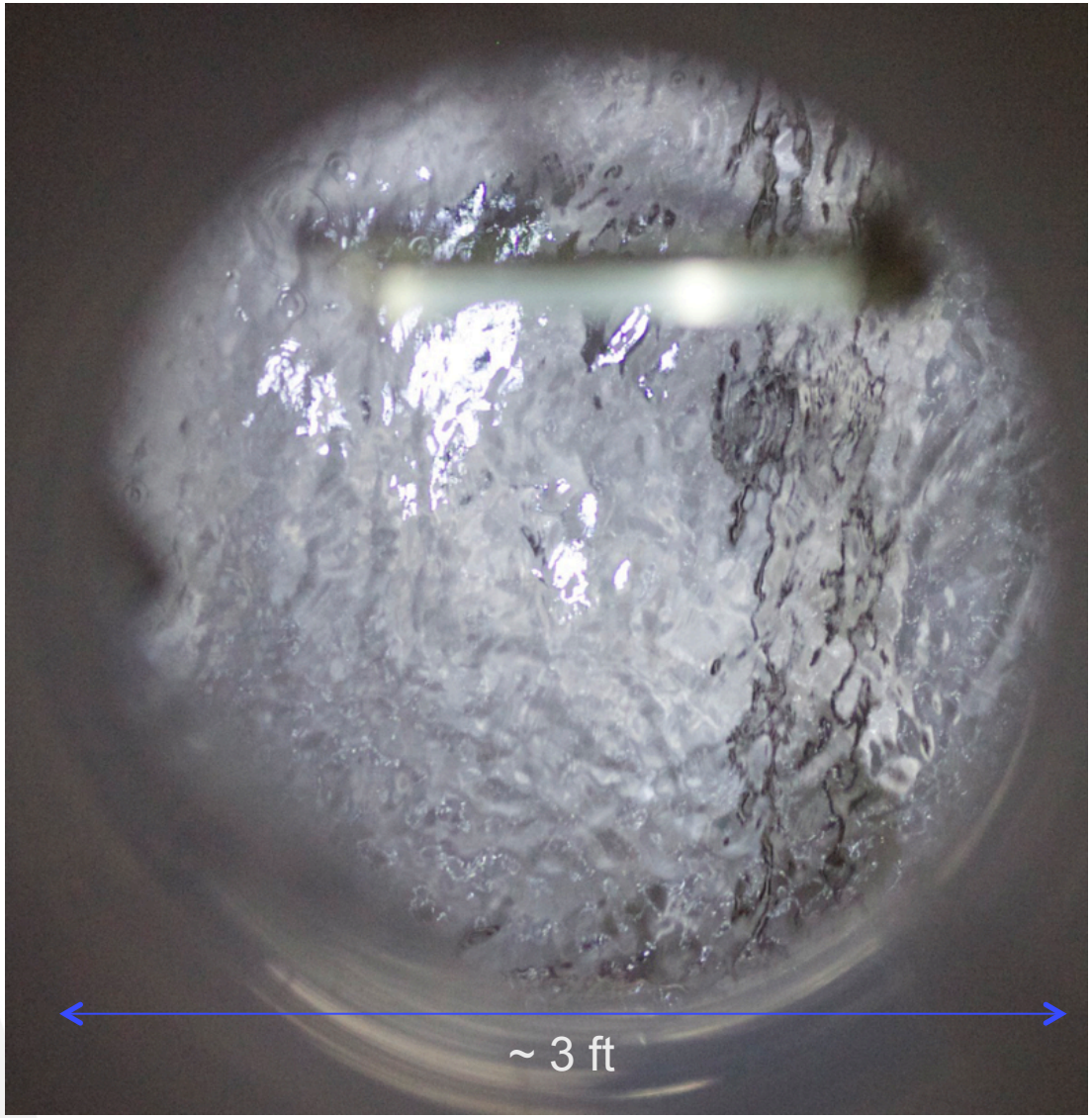
2 sets of 3 translating RTDs

Sniffer set to measure purge evolution

Inline

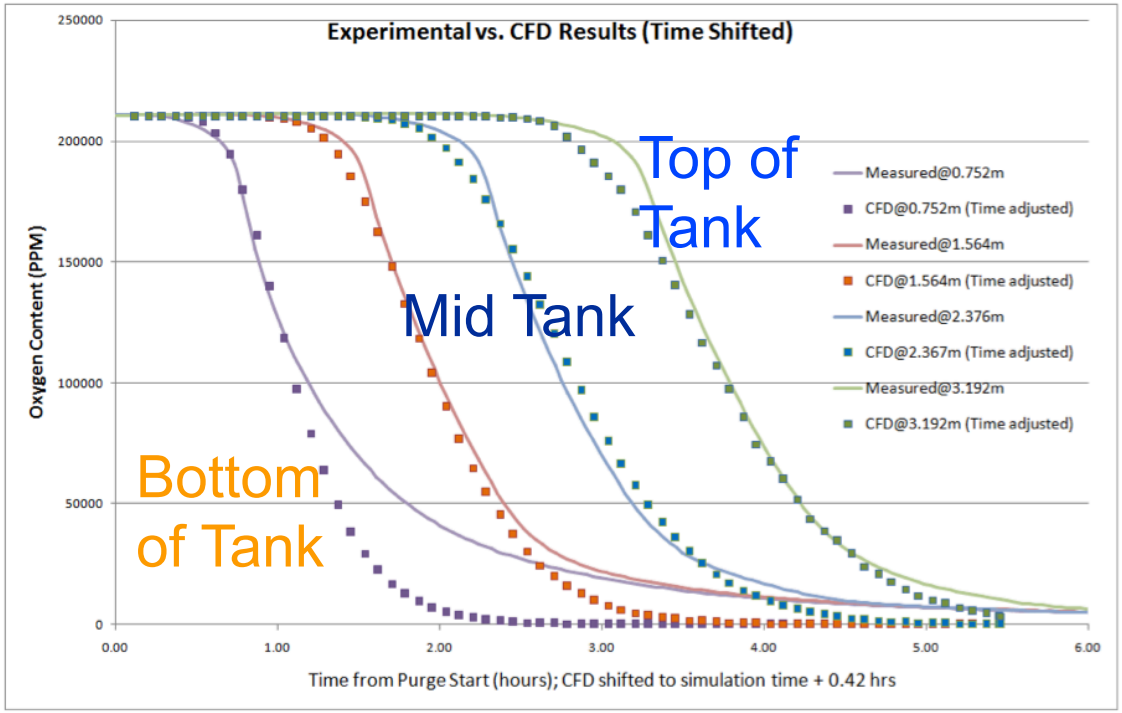
Purity Monitor

Looking through a viewport on the Argon 10 ft below

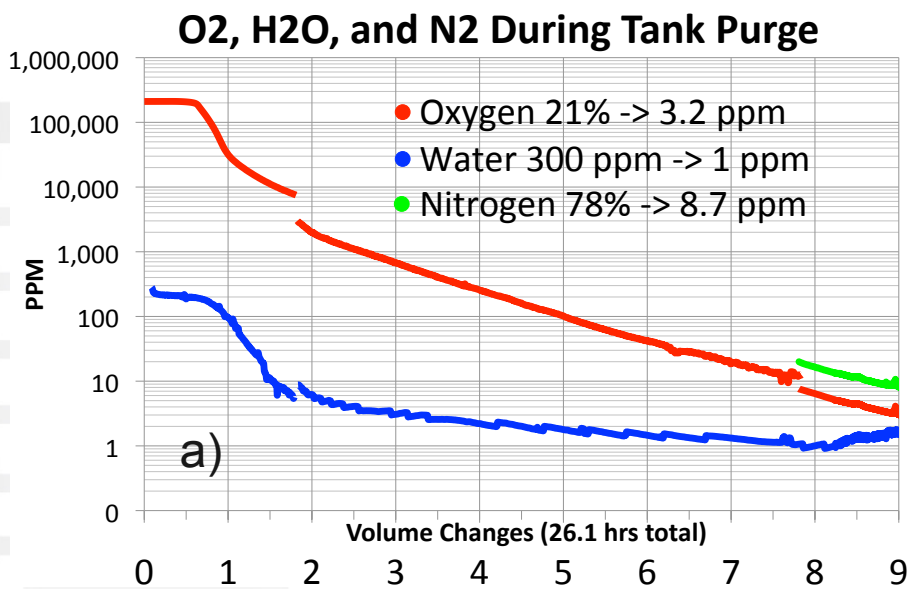


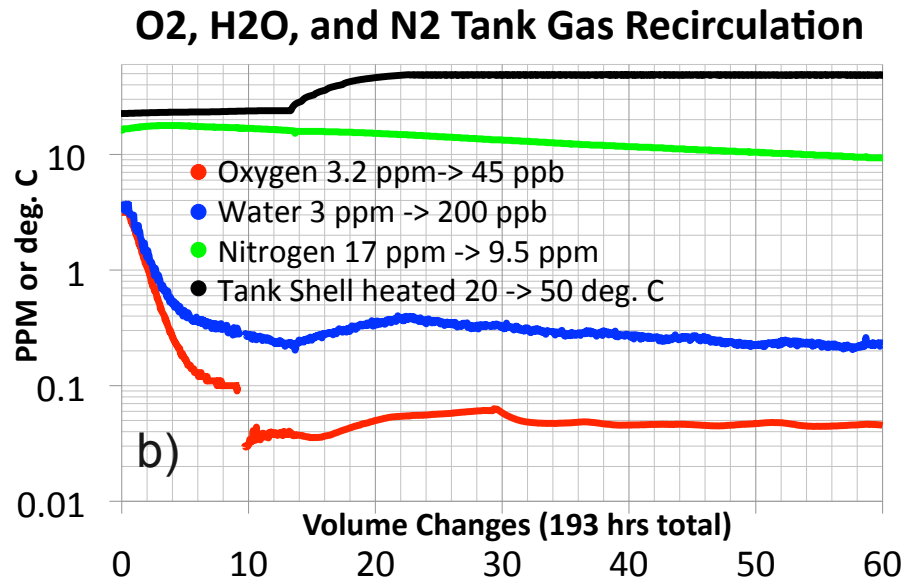
– the rippling never stopped

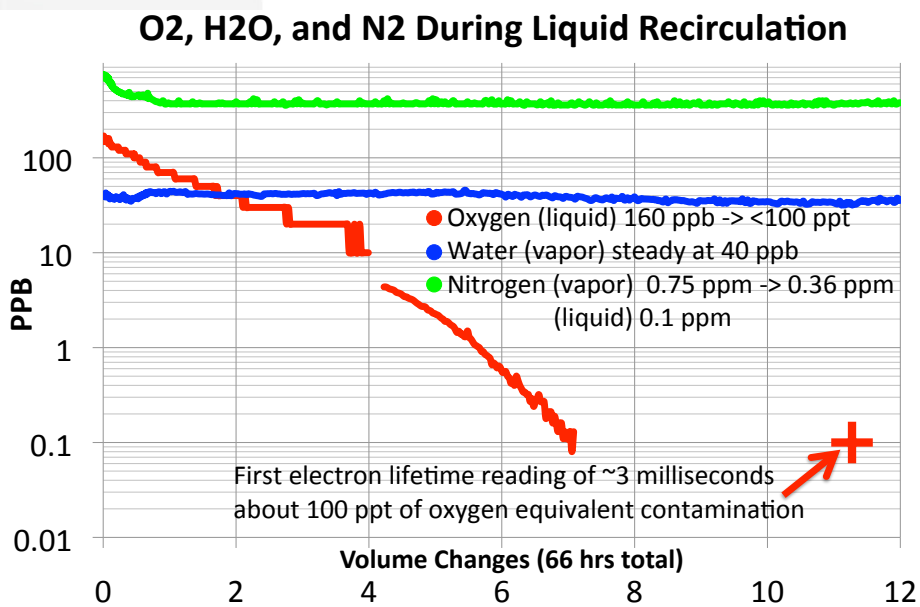
Gaseous Argon Purge



- Set of sniffer tubes monitored the oxygen content of the gas inside the vessel at various depths throughout the purge
- Lines are measurements, dots are simulation (no free parameters)
- Comparison to calculation is reasonable – some issue about mixing near the bottom



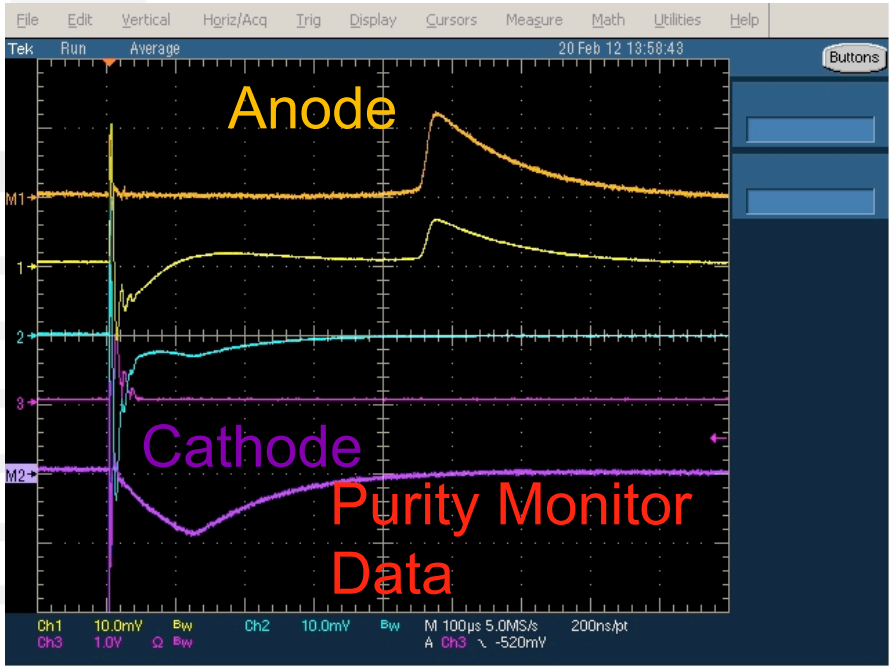




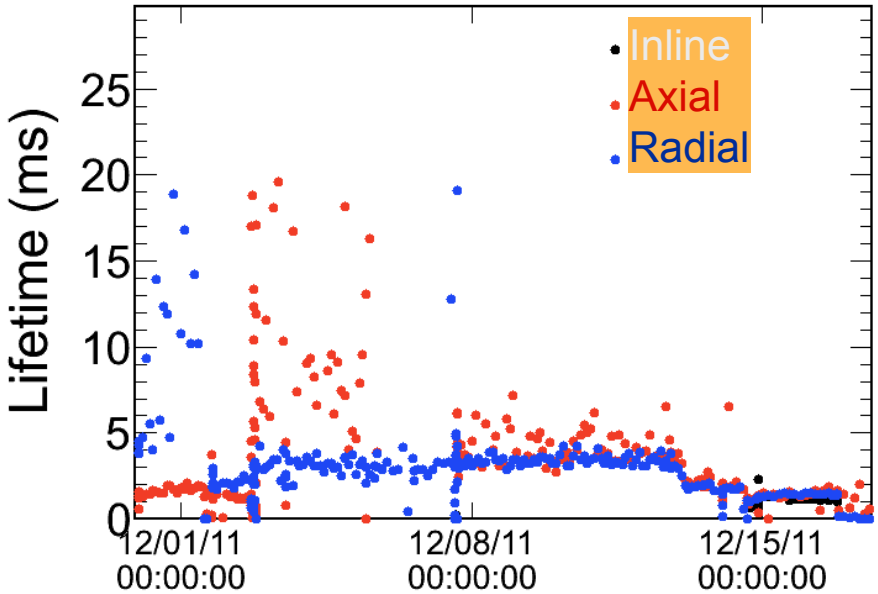
Concentrations of O_2, N_2 & H_20 during
a) purge,
b) gas recirculation through filters, and
c) liquid recirculation.

Note: **constant level of H_20** (in vapor)* and **the removal of N_2** (which affects light production at 1 ppm level)

*H_20 in liquid below measurable levels



Drift Lifetime Measurement



First drift lifetime measurements made after 11 volume exchanges of liquid (66 hours)

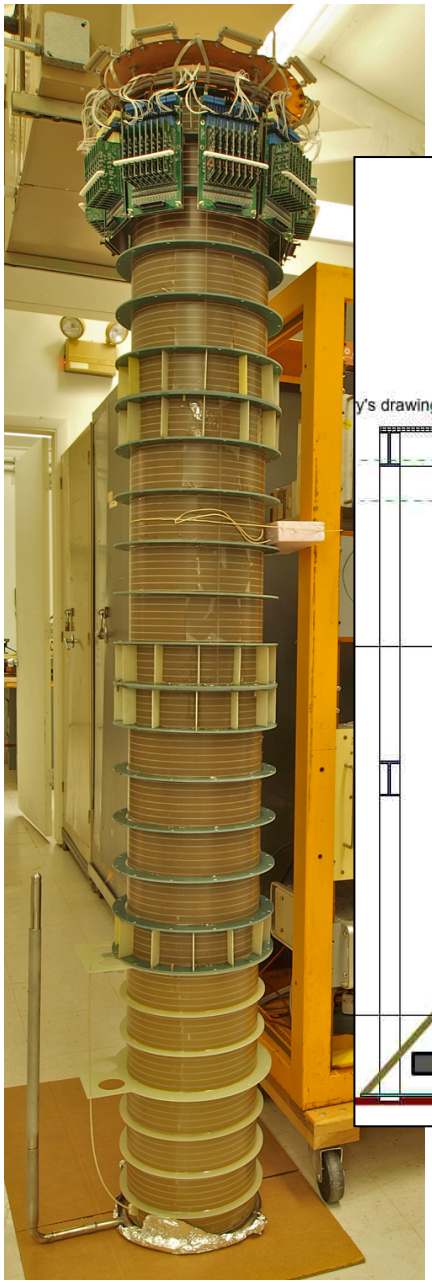
Lifetime stable at 3 ms or better (LBNE drift is 1.4 ms) for 2 weeks

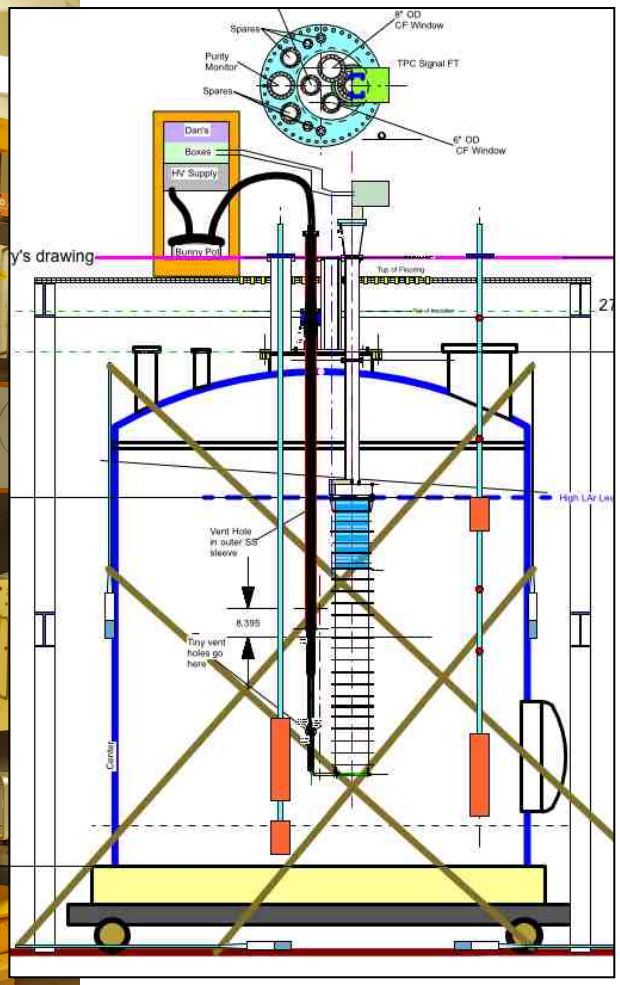
Filters regenerated and lifetimes went up to 5 ms

Unplanned power outage stopped the run (prematurely)

Present: repairing/upgrading filter vessels and condenser, ready to fill with Ar (from DZero) at the end of the summer

- LAPD will continue running for the next year – sharing the purification system with the 35 ton Membrane Cryostat (LBNE style cryostat)
- Challenge purification with a TPC in the volume – 2 m drift, 100 kV
- Fully characterize filter sizing and material performance
- Study the effect of varying the recirculation rate on the drift lifetime
- Perform studies of how quickly lifetimes can be recovered from (intentional) poisoning of the Argon





Atmospheric argon ~ 1Bq/kg from ^{39}Ar;

This background limits the size of dual-phase Argon TPCs to < 1 tonne for dark matter searches because of pile up.

Ar (600 ppm) from certain CO_2 wells in Co has < 0.01 Bq/kg (arXiv:1204.6011)

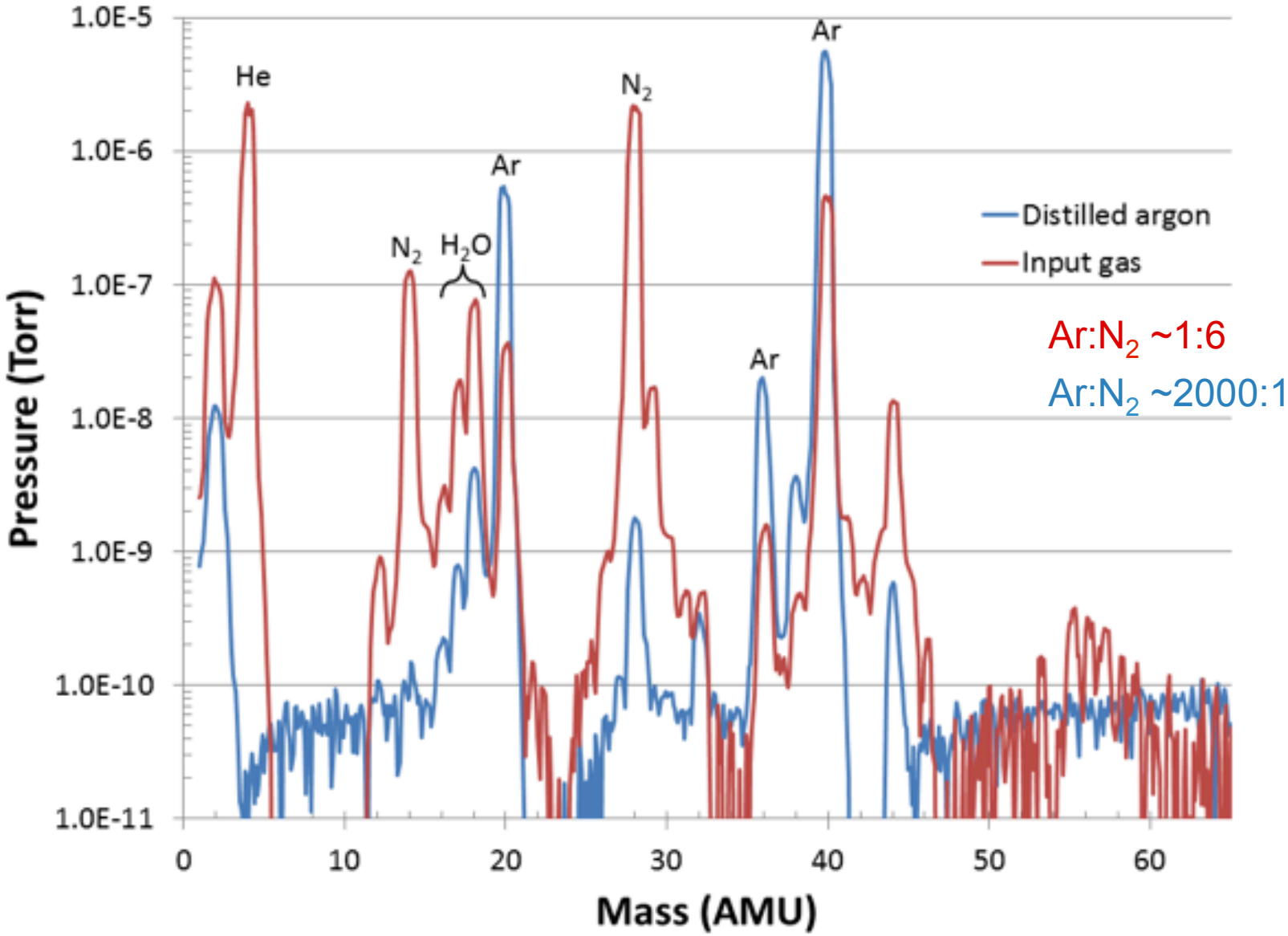
Mixture of ~4% Ar, 25% N_2, 71% He comes to Fermilab; have to distill the N_2 off.

Column commissioned with atmospheric Ar in November 2011 99.95% pure;

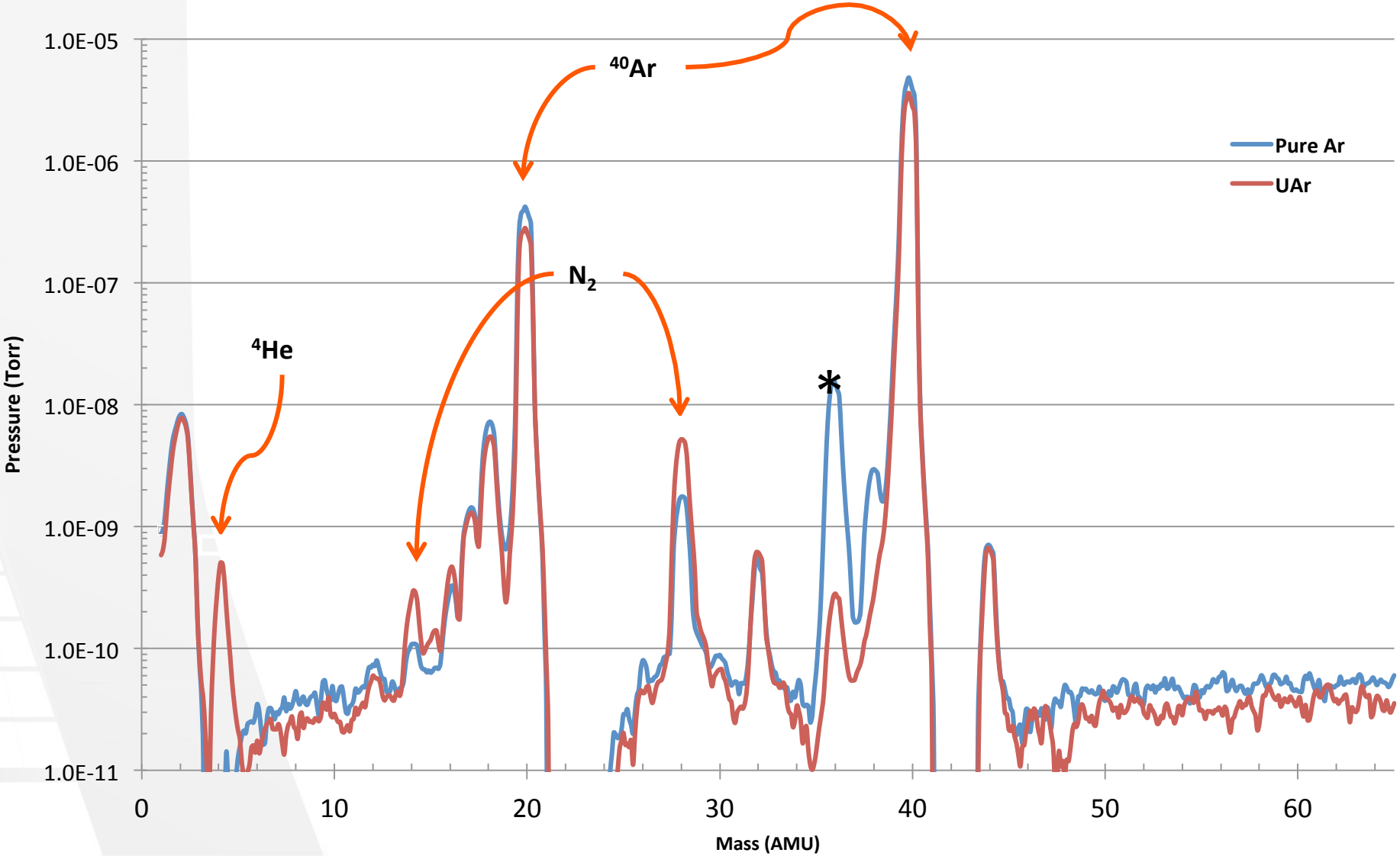
Processing underground Ar since April 2012 – 15 kg processed;

Aimed at DarkSide and DEAP

Before and After Distillation (Atmospheric Argon)

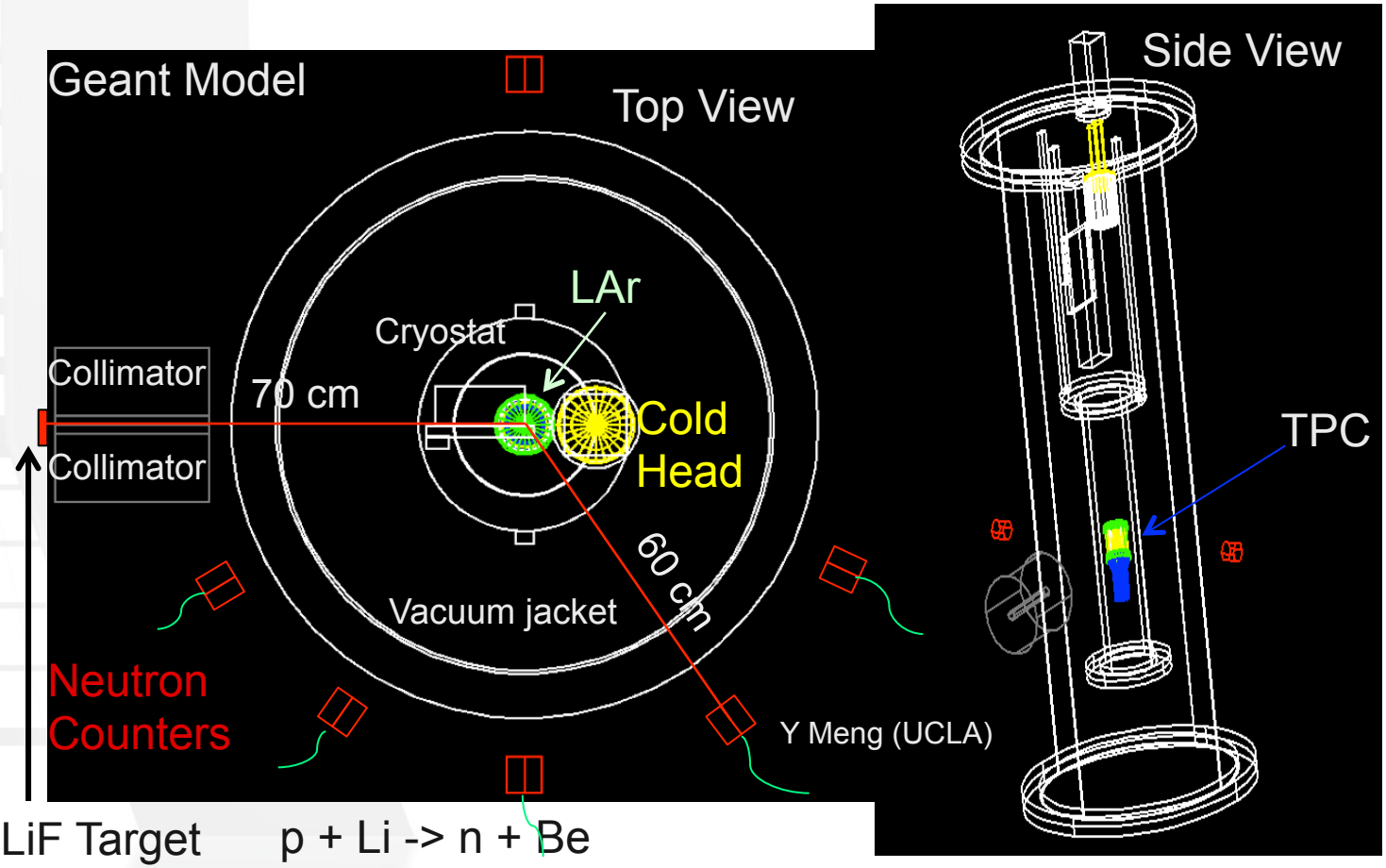


Comparison of Darkside Ar and Airgas (atmospheric) pure Ar



SCENE – Scintillation Efficiency of Noble Elements

Precision measurement of light output of Argon nuclear recoils up to ~ 50 keV in a dual-phase LArTPC using pulsed Neutron Beam at Notre Dame (Fermilab, Princeton, Naples, Notre Dame, Temple, UCLA)



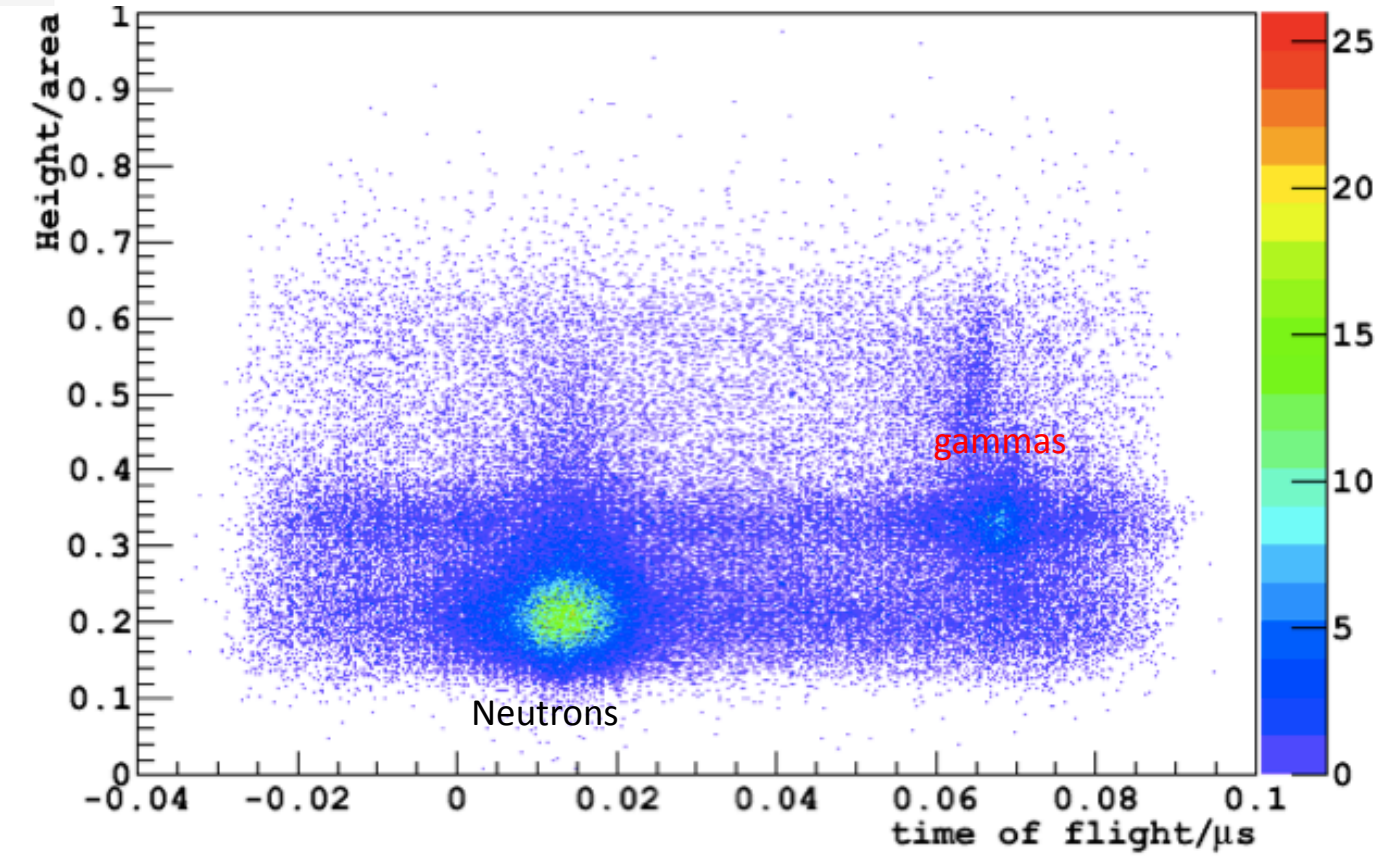
LiF Target p + Li -> n + Be

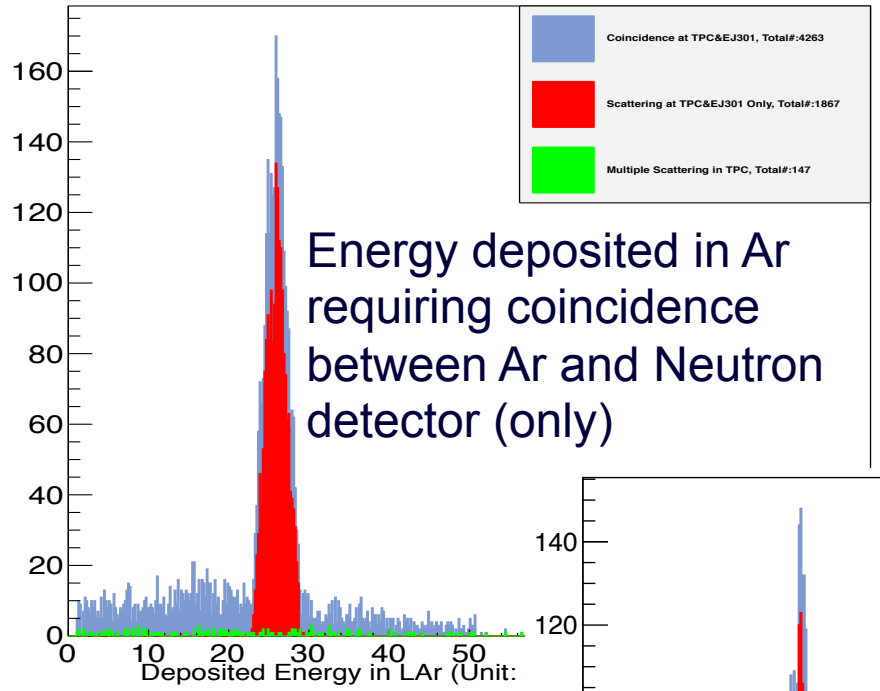
SCENE – Scintillation Efficiency of Noble Elements

Data from Beam Test at Notre Dame - no active argon

Clean photon/neutron discrimination

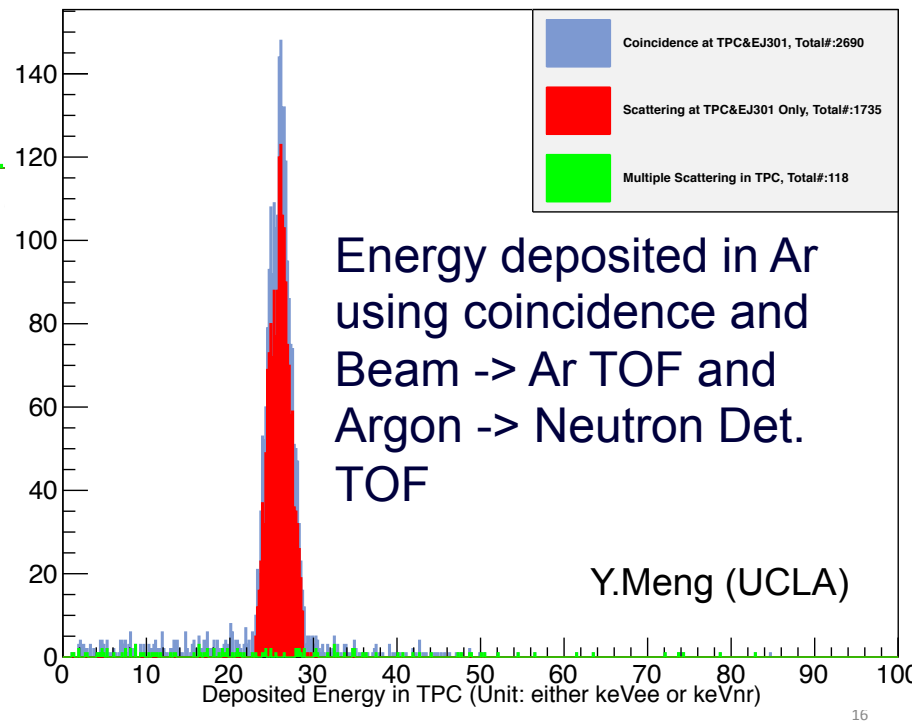
Liquid Scintillation Counter Pulse Shape Discriminant (y axis) vs TOF (x axis)





Energy deposited in Ar requiring coincidence between Ar and Neutron detector (only)

SCENE Simulations

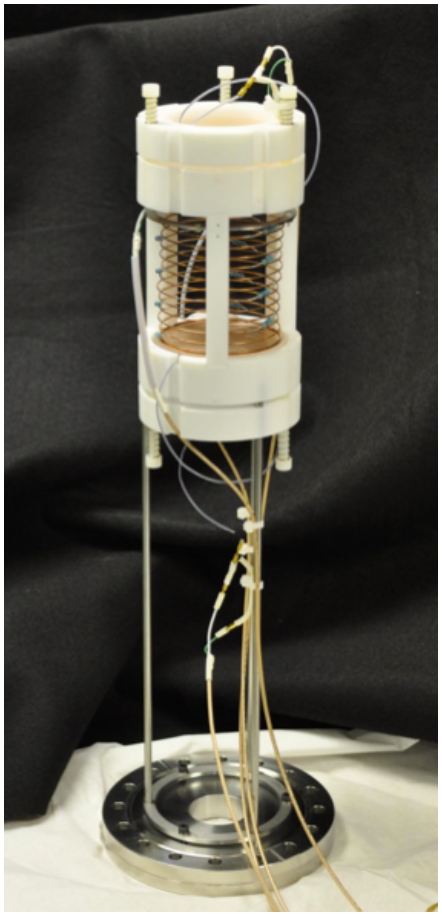


Energy deposited in Ar using coincidence and Beam -> Ar TOF and Argon -> Neutron Det. TOF

Y.Meng (UCLA)

The advantage of the pulsed beam (3 ns every 100 ns).

[Assuming 3M Foil Reflector around TPC]



TPC Structure

LAr TPC in the Fermilab Test Beam 14 Institutions

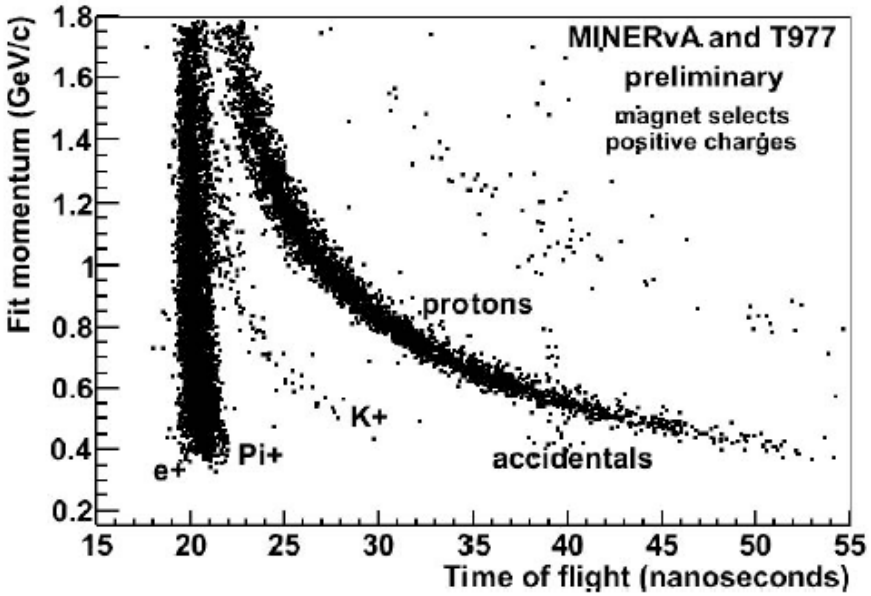
Beam Test Collaboration

L'Aquila

The Vision

- Create a facility for: physics of interactions in Argon, for detector response calibration, and for detector R&D
- Use the Tertiary beam of the Fermilab Test Beam facility.

Tertiary beam composition



The Plan - Phase 1

- Start work on understanding single particle issues as quickly as possible - using the ArgoNeuT detector and cryo system.
  - Yale and Syracuse have submitted a NSF proposal to upgrade ArgoNeuT
    - Cold window to minimize amount of steel between the beam and LAr
    - Upgraded purification system
    - Upgrade of the TPC to use cold electronics
- Study energy to charge (dE/dx -> dQ/dx) conversion for single tracks of different particle types
- Study EM showers to demonstrate and measure e/γ separation

The Plan - Phase 2

- Develop a TPC large enough to contain a hadronic (and electromagnetic) shower (~ 2 meters transverse,~ 5 meters long).
- Fermilab provides the cryogenics and cryostat; other groups provide the active detectors.
- Cryostat designed to allow convenient access to interior for detector development.

  Allows for complete characterization of hadronic and electromagnetic interactions in liquid argon TPC.

  Test bed for new electronics, light collection systems, and TPC designs for multi-year program of studies and development

One Slide on Software

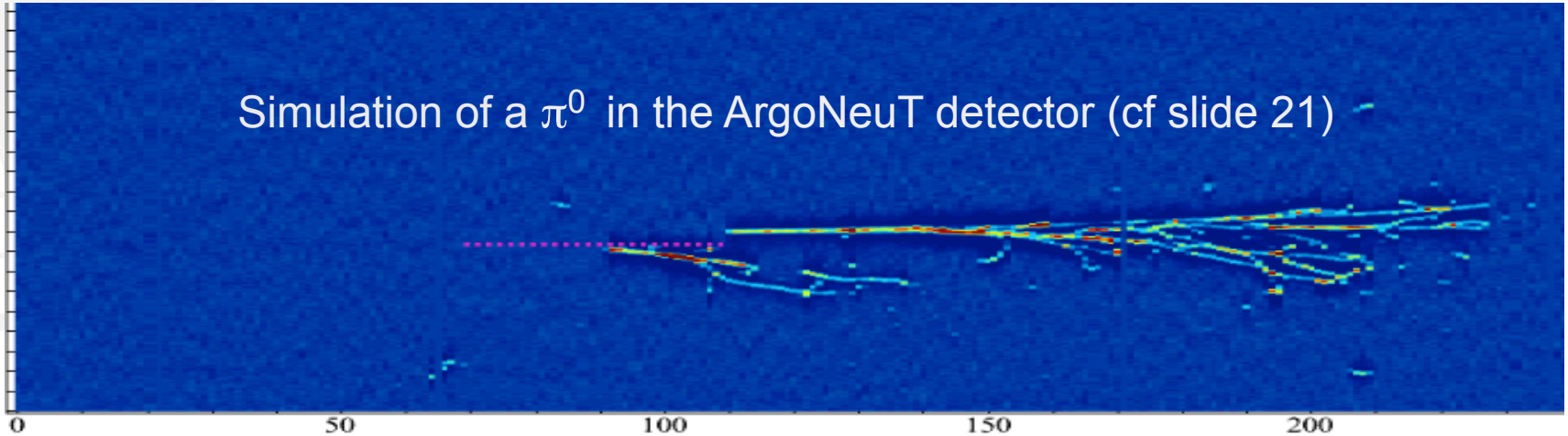
Detector simulations and event reconstruction software are important for the success of the LAr technology, and present a significant challenge given the wealth of data the detector provides.

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

Uses the Fermilab Art Framework: provides event-types (neutrino interaction, single particle, cosmic rays) propagates the charge and light to user-defined detectors

LArSoft has contributors from:

Bern (CH), Colorado State, Columbia, Duke, Fermilab, LNGS (It), Kansas State, L.A.N.L., M.I.T., Michigan State, New Mexico, U. Penn, S.M.U., Syracuse, and Yale.



Summary

I - Argon is attractive material

F - In use – provide broad service – want to expand with a cryostat for `light' work

A - Generating physics papers, stimulating software development

LP - Demonstrating good lifetime without evacuation – testbed for long drift TPC

DM - Important and unique contributions to LAr for Dark Matter searches

LB - Exciting project for high quality information on interactions in LAr

LS - Appropriate focus and coherence for work on software for reconstruction ..

Plus ..maintain close contact/direct relevance to approved LAr projects

Phase 2: The Program

Partial list of measurements:

- EM shower energy resolution
- Hadronic shower energy resolution
- E_{had}/E_{EM} ratio
- Directionality of through going particles using delta rays
- Particle identification
- dE/dx for several particle species
- Light collection efficiency
- Surface operation in a high cosmic ray rate environment
- Studies of proton decay backgrounds
- Diffusion studies over long drift times