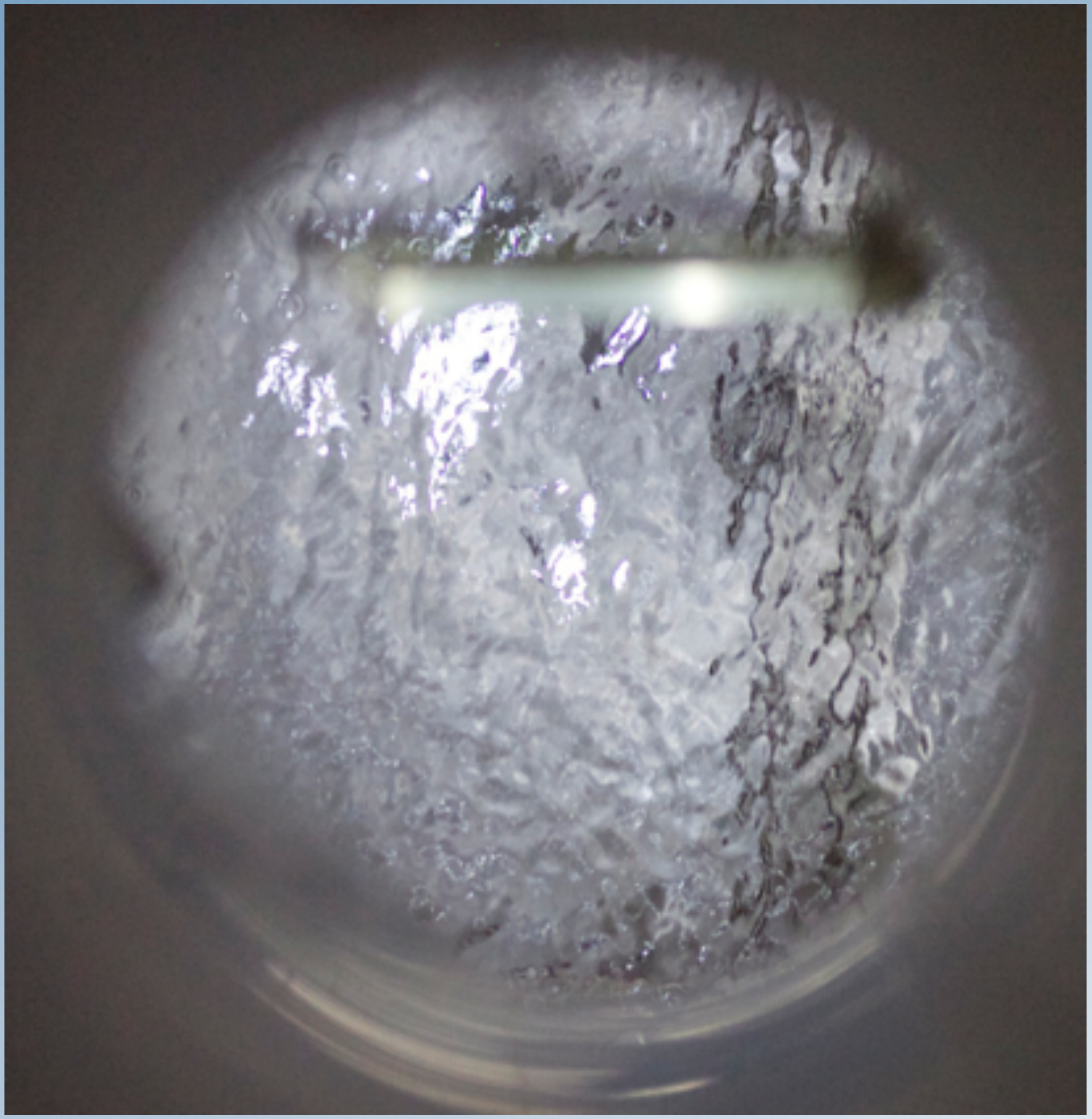
Fermilab Liquid Argon R&D Program

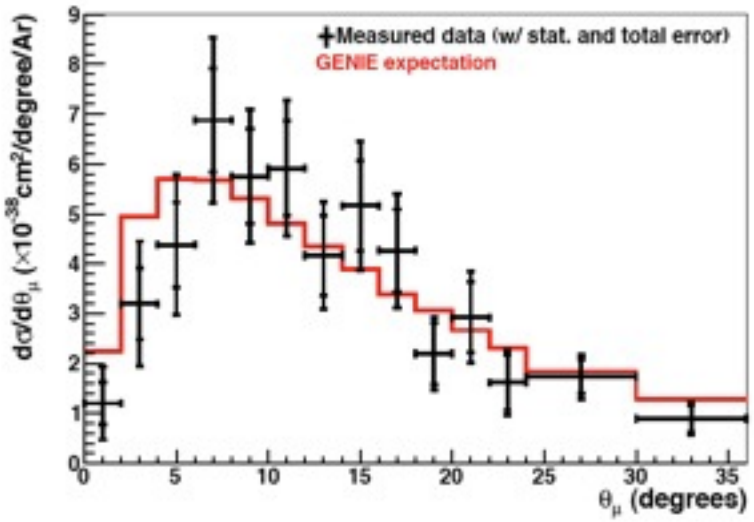


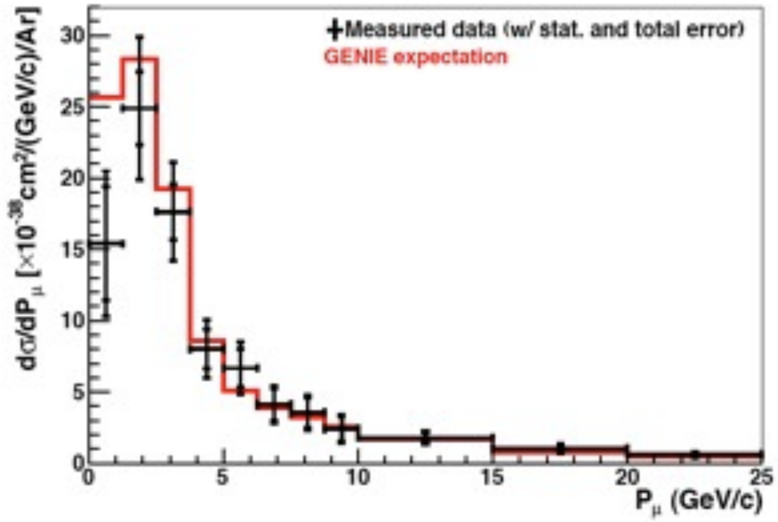
Brian Rebel
June 19, 2012

Outline

- ArgoNeuT
- Liquid Argon Purity Demonstrator (LAPD)
- Long Bo: long drift distance test and cold electronics
- 35 ton membrane cryostat prototype
- MicroBooNE contributions to R&D
- Argon Distillation Column
- Liquid Argon Detector Beam Test

ArgoNeuT: First Cross Section Measurements on Ar



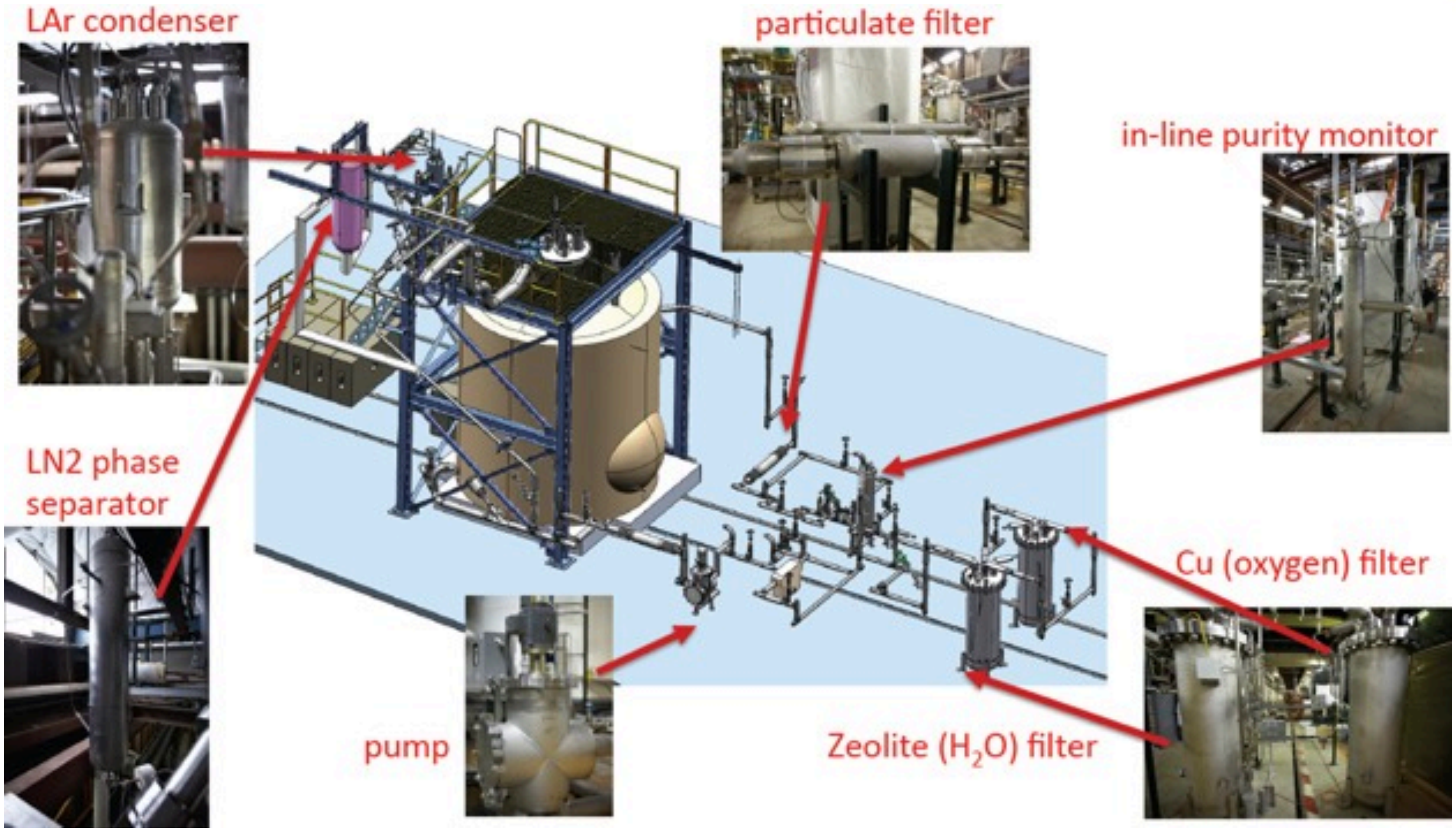


- ArgoNeuT took data in NuMI beam for 5 months in 2009-2010
- First measurements of differential cross sections for neutrino-Ar interactions made with the neutrino mode data

$$\sigma/E_{\nu}=(7.3\pm1.2)\times10^{-39}\,\frac{\mathrm{cm}^2}{\mathrm{GeV}}\quad\langle E_{\nu}\rangle = 4.3\ \mathrm{GeV}$$

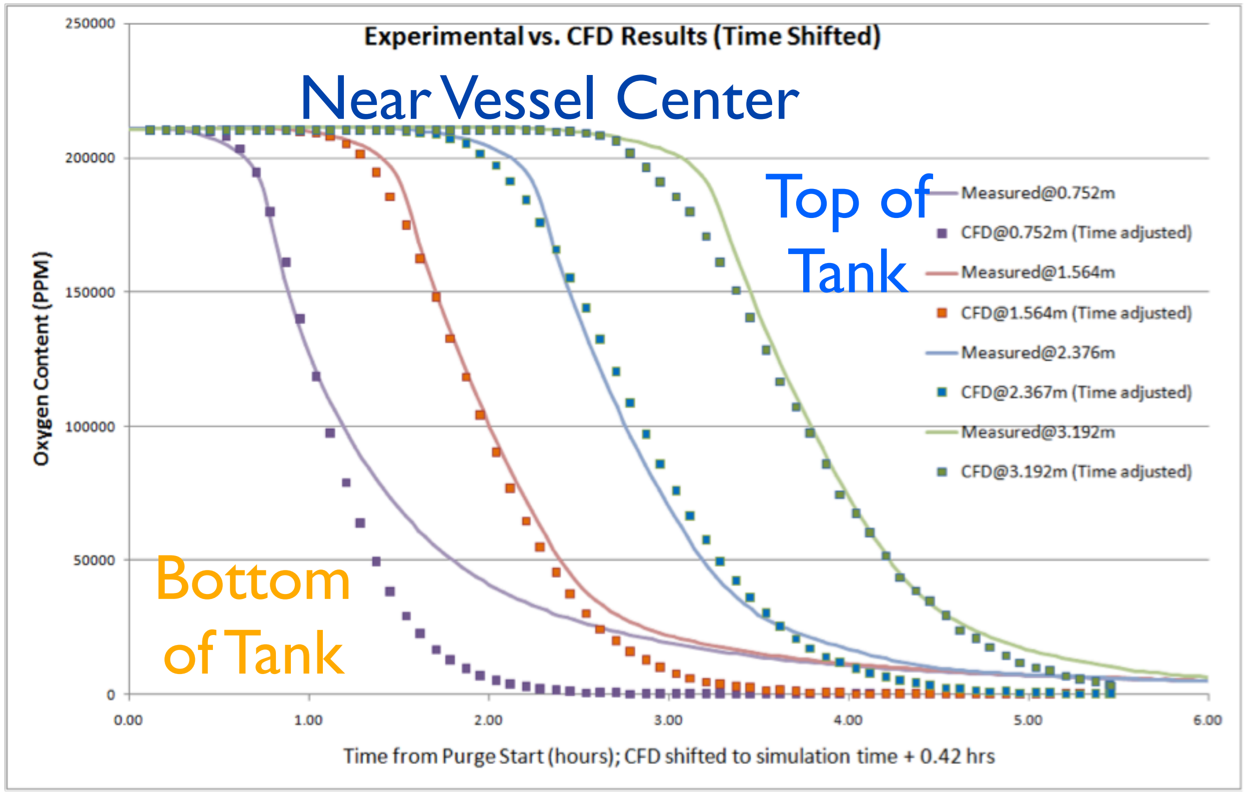
- Published in PRL 108, 161802 (2012), 2 more papers nearly ready for submission to journals (arXiv: 1205.6747 and 1205.6702)
- Collaboration between Fermilab and 8 other institutions
- Analysis was done using LArSoft reconstruction and simulation package

Liquid Argon Purity Demonstrator



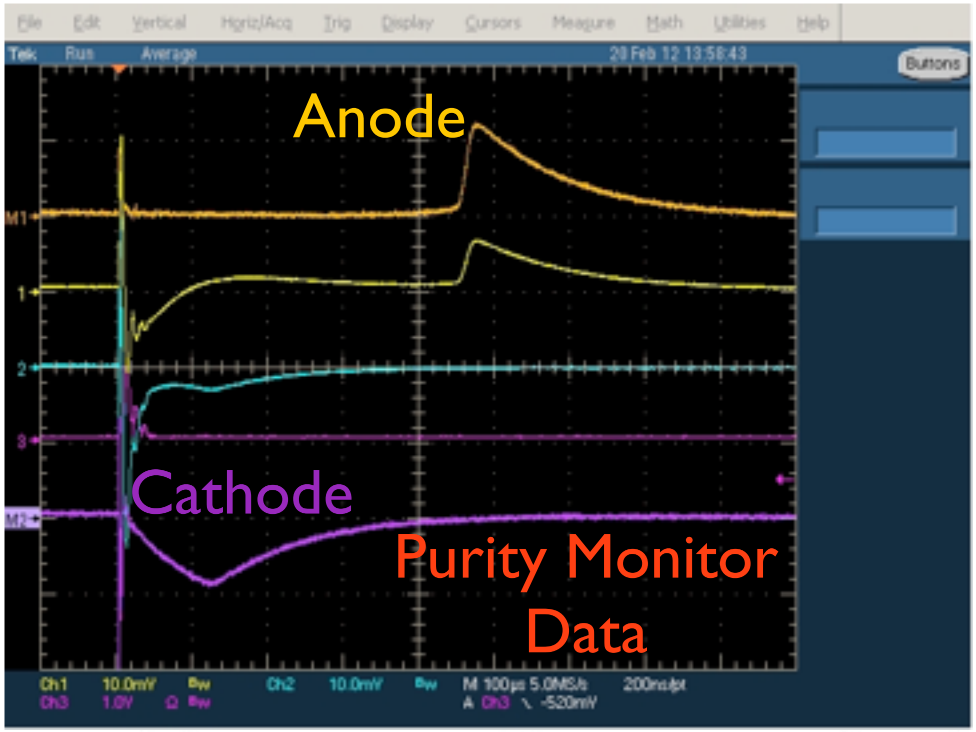
- Primary goal: show required electron lifetimes can be achieved without evacuation in an empty vessel using gaseous Ar purge, followed by gaseous Ar filtration, followed by liquid fill and filtration
- Fermilab program with contributions from Indiana University

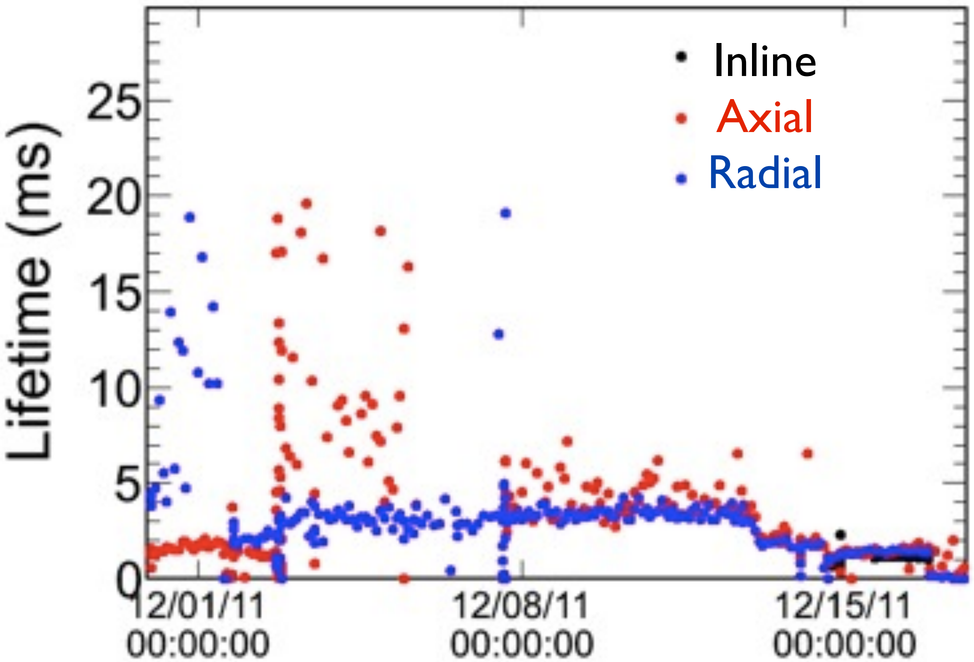
Gaseous Argon Purge



- Set of sniffer tubes monitored the oxygen content of the gas inside the vessel at various depths throughout the purge
- Plot shows the content relative to the pre-purge state of the tank in solid lines
- Clear front of argon gas moving through the vessel
- Comparison to calculations (points) shows good agreement, aside from some discrepancy in time that is likely due to 3D flow and mixing as argon gas is forced into the bottom of the tank

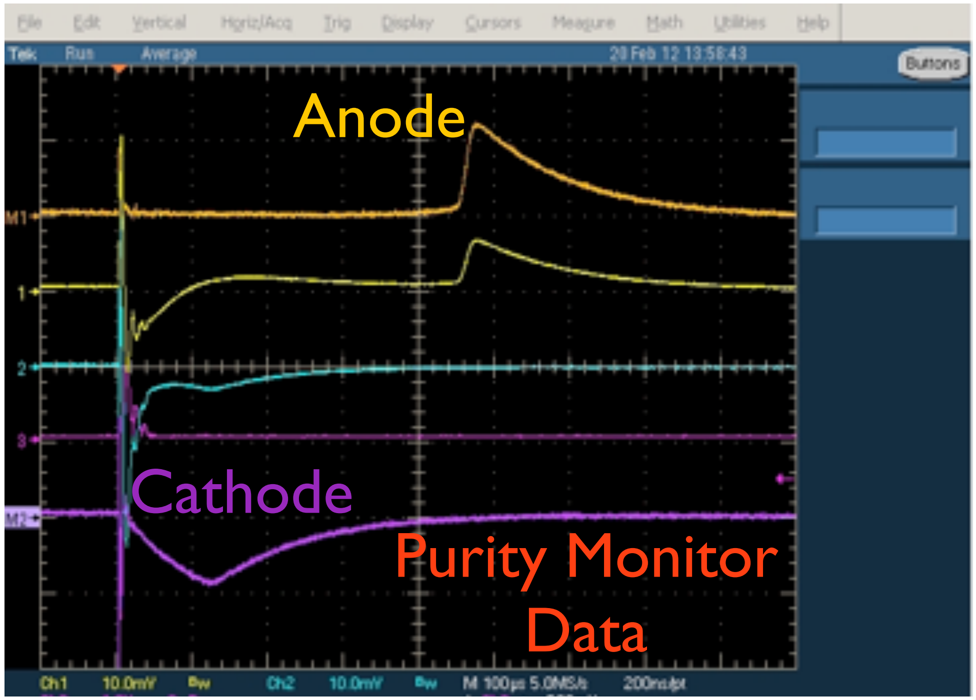
Electron Lifetime Measurement

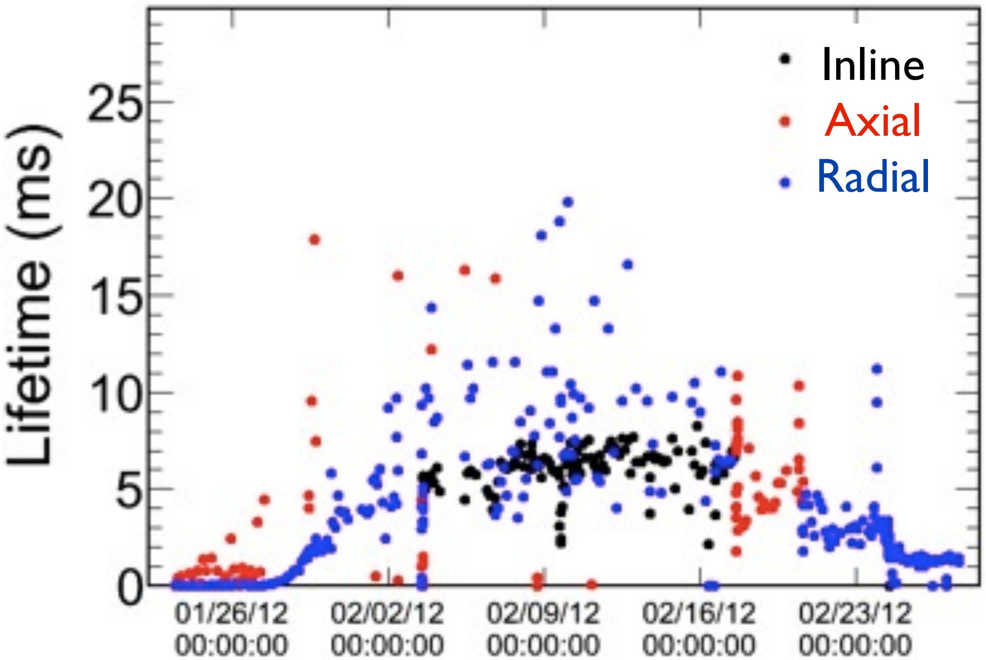




- First electron lifetime measurements made after 11 volume exchanges of liquid (66 hours)
- Lifetime during first run was stable at 3 ms or better (LBNE needs 1.4 ms)
- Lifetimes began decreasing after 2 weeks, indicating filter saturation
- Filters were regenerated and lifetimes went up to 5 ms
- Filters possibly started showing signs of saturation again, but an unplanned power outage stopped the run prematurely
- Currently repairing/upgrading filter vessels and condenser, ready to fill again at the end of the summer

Electron Lifetime Measurement





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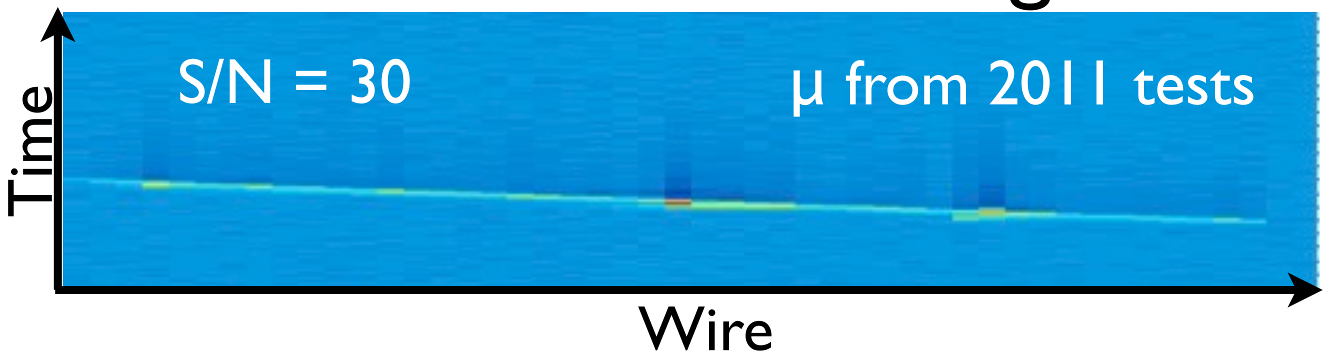
Future Studies

- The initial results represent a major step forward in development of liquid argon detector technologies
- We have already exceeded the design specification for electron lifetime in LBNE by more than a factor of 2!
- LAPD will continue running to
    - Test purification with a TPC in the volume - Long Bo
    - Fully characterize filter sizing and material performance
    - Study temperature gradients in the bulk liquid as a way to understand convection
    - Study the effect of varying the flow rate on the electron lifetimes
    - Perform studies of how quickly lifetimes can be recovered from intentional poisoning of the environment in the vessel

Long Bo



- Long Bo is a cylindrical TPC with 2m drift, it extends the previous Bo test stand TPC
- Will go into LAPD during its second phase
- Long Bo provides the first long drift distance test at Fermilab, has spurred tests of HV feed throughs (100kV) that are benefitting MicroBooNE
- Also extends tests of cold electronics mounted on the TPC, ran twice on Bo in 2011
- Effort includes Fermilab and Michigan State University

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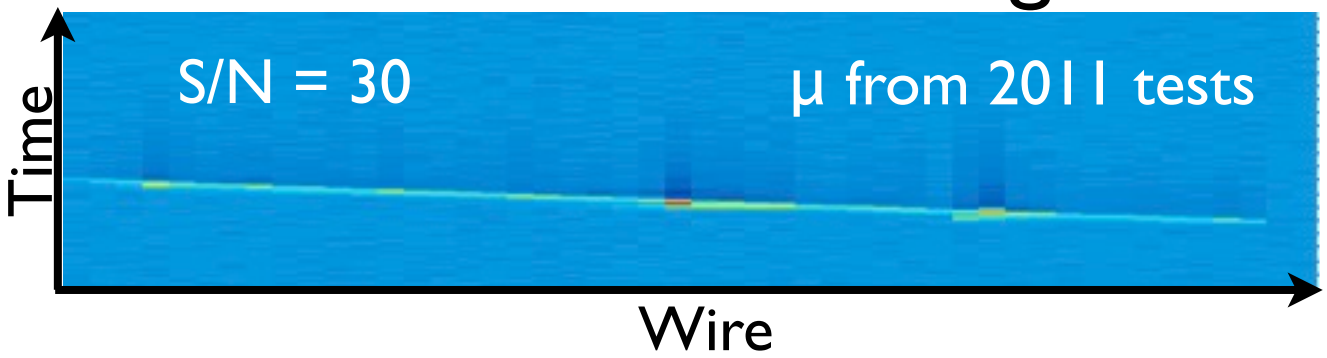

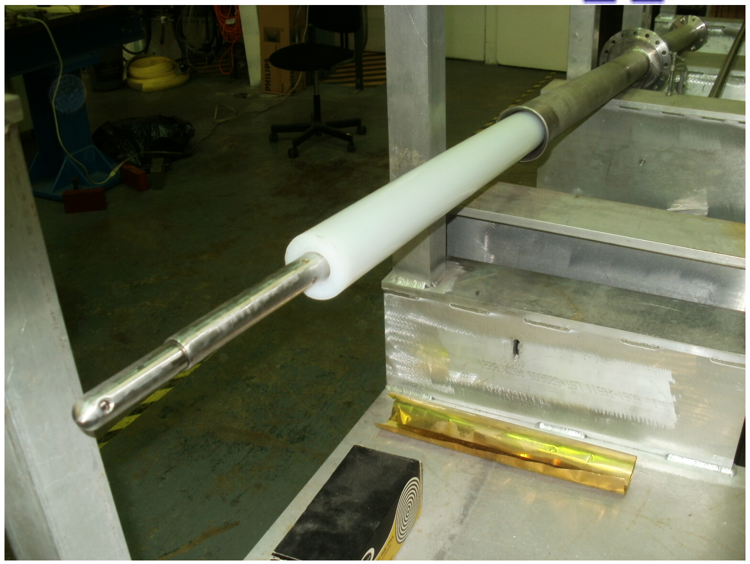

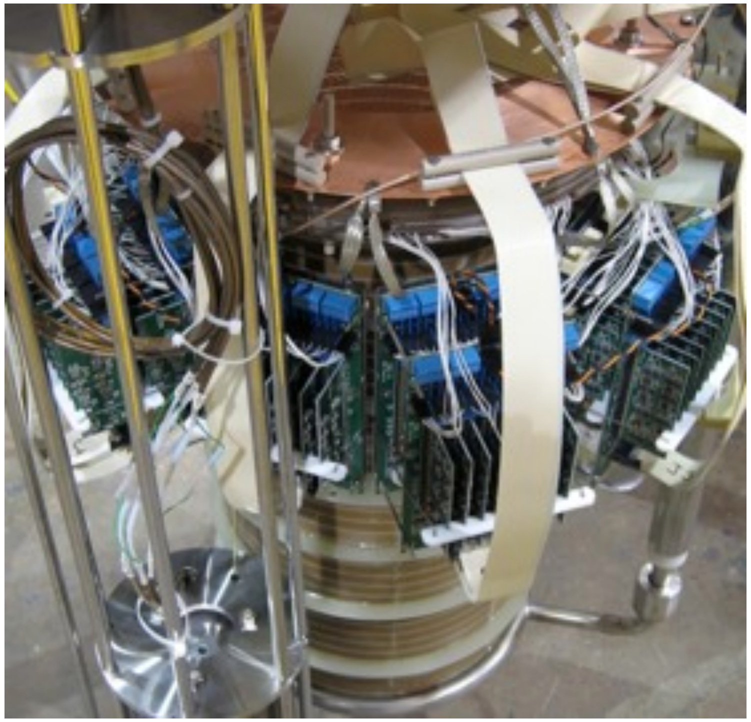

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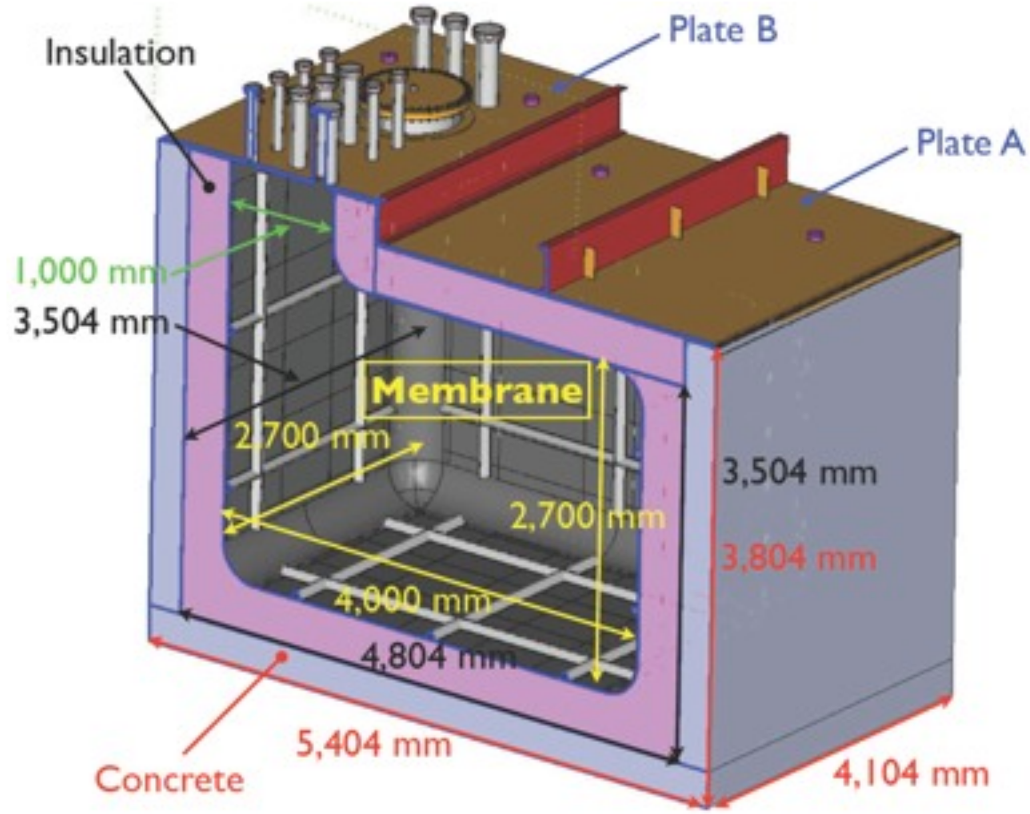
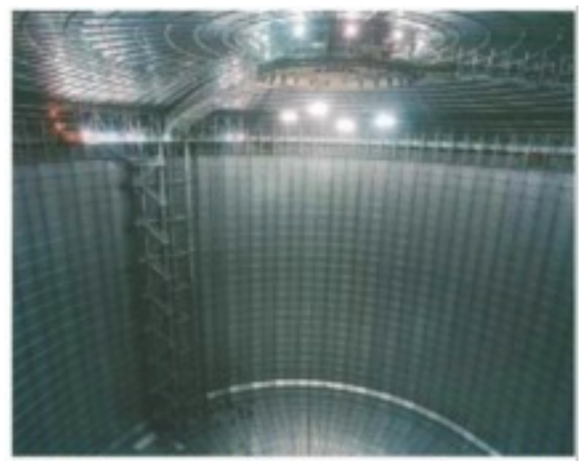
35 Ton Membrane Cryostat Prototype

- Membrane cryostats appear to be a good option for large LAr detectors
- Well understood technology with industry suppliers
- Prototype will demonstrate thermal performance, leak tightness, and use for LAr
- Will also show there are no issues related to this technology that can affect LAr purity
- Will share LAPD cryogenic filtration and pumping system
- Part of the LBNE project




LNG Storage with Membrane from IHI

35 Ton Membrane Cryostat Prototype

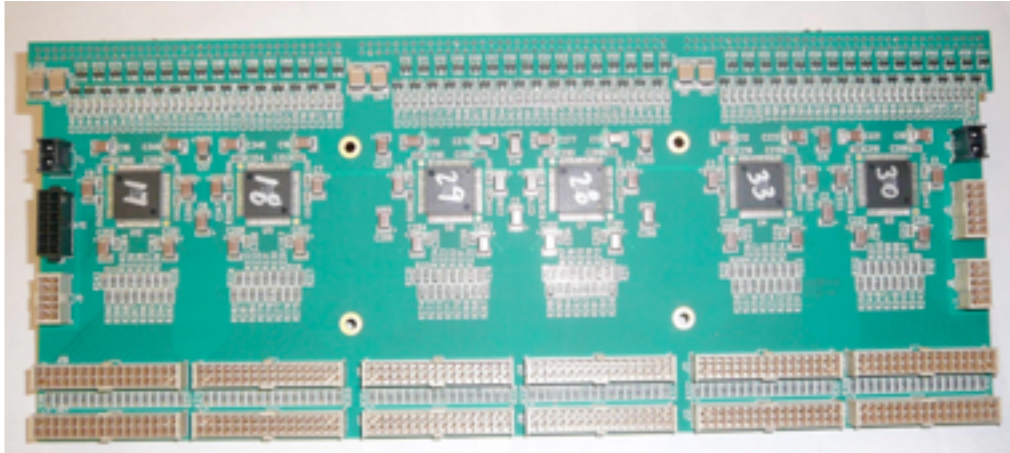


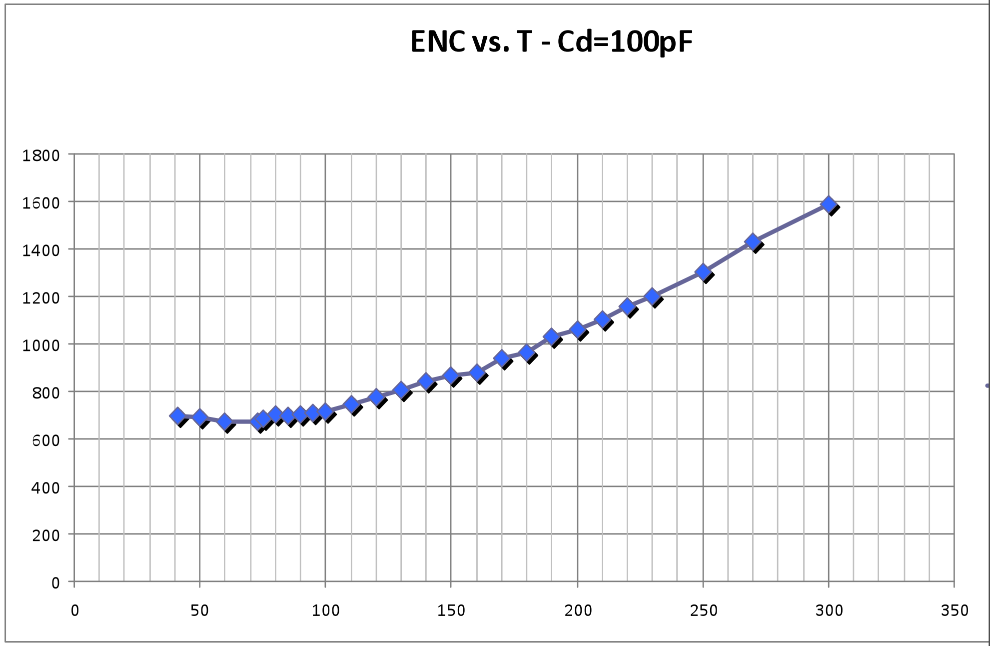
- The concrete bathtub has been constructed
- IHI, the provider of the membrane is at Fermilab teaching technicians and welders how to work with the material

Parameter	Value
LAr Temperature	89K ± 1K
Operating Gas Pressure	70 mBar (~ 1 psig)
Vacuum	No Vacuum, we will SLOWLY purge it with GAr (See LAPD)
Design Pressure	207 mBar (~ 3 psig)
Leak tightness	10^{-6} mBar*l/sec (with NH3 leak check, ASTM standard)
Heat Leak	< 13 W/m^2 (~11.5 W/m^2)
Design Code	Applicable parts of JGA Recommended Practice for LNG In ground storage tanks FESHM 5031.5

μBooNE: Cold Electronics

- A primary goal of μBooNE is to contribute to understanding of running cold electronics in a LArTPC
- Electronics are being designed primarily by BNL, will be used in LBNE too
- Tests show
  - Noise at 87k is half that at 300k
  - crosstalk and gain variations are each < 0.3%
- Stress tests also performed show no problems after many immersions in LN_2
- ATLAS and NA48 calorimeters show very low failure rate over many years
- μBooNE has 16 institutions, including international collaborators





Noise vs Temperature

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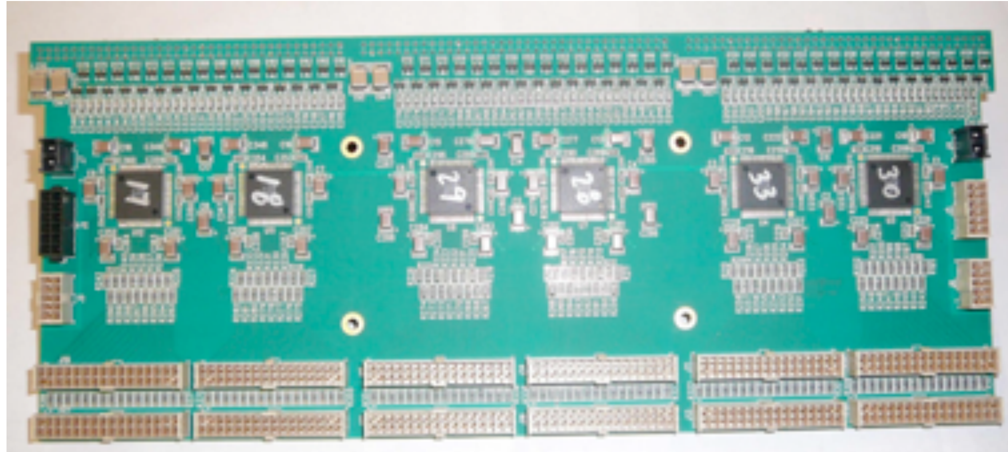
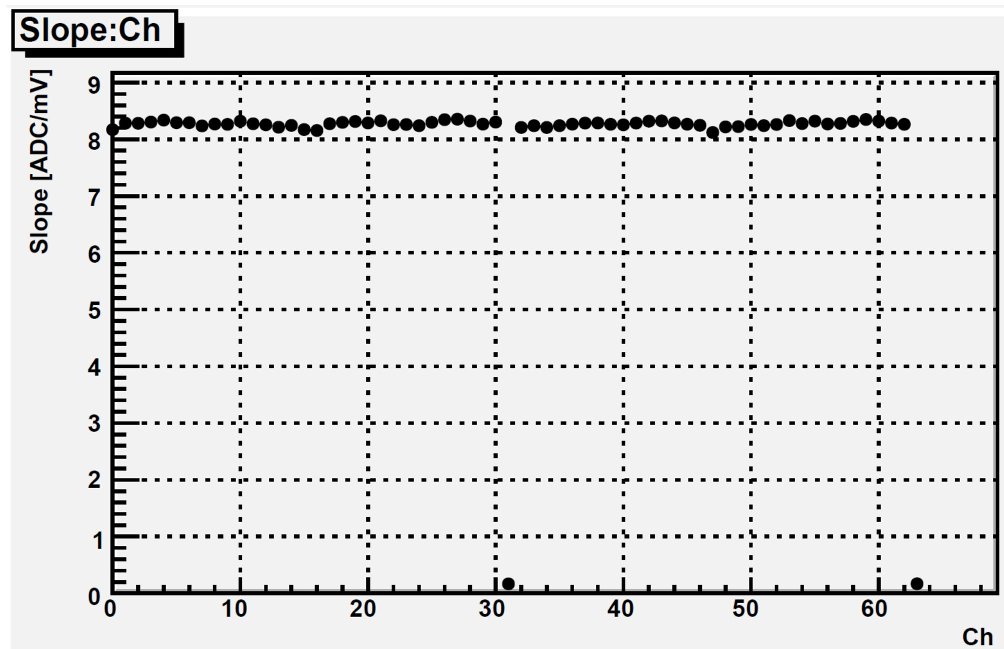
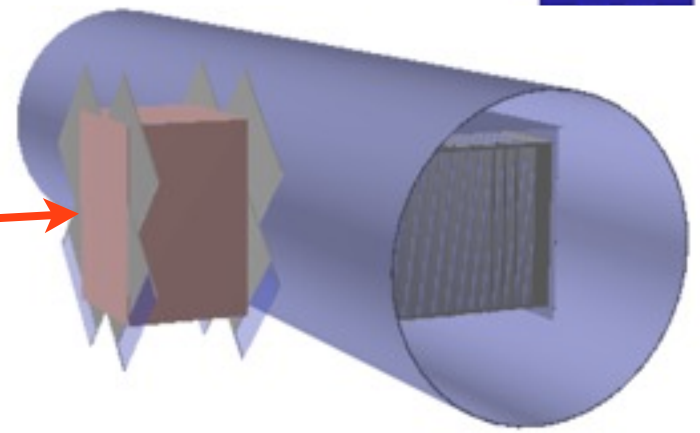


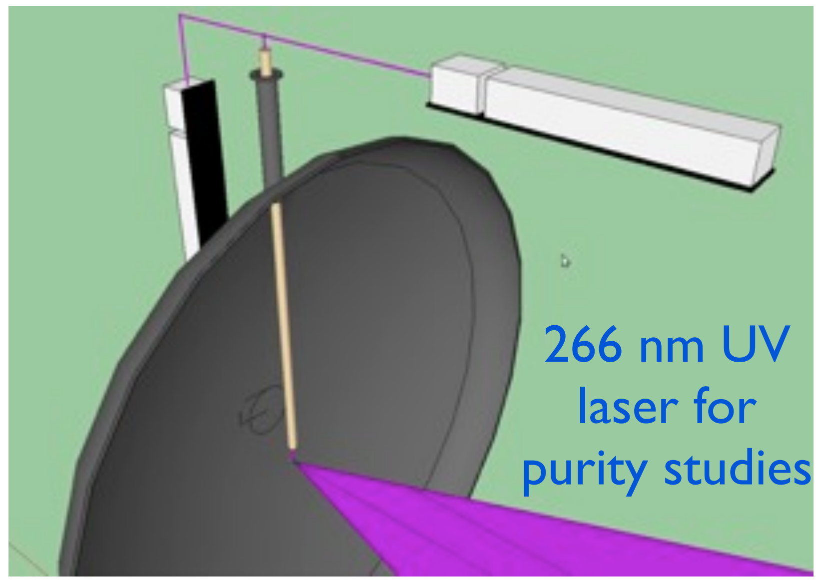


Gain Variation

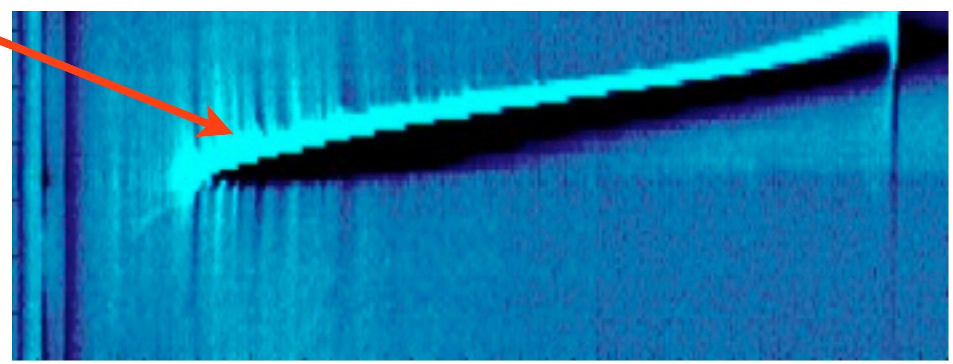
μBooNE: Proton Decay and Purity



- Would like to measure the K^0_L backgrounds to proton decay (from charge exchange to K^+) by placing a large granite block next to the detector
- Studies led by Columbia/Nevis group
- Use Double Chooz veto paddles on either side of the block to tag neutrons and charged particles



- Looking at including a UV laser system to study purity and drift field in the TPC
- Laser already tested in 5 m drift test ARGONTUBE in Bern



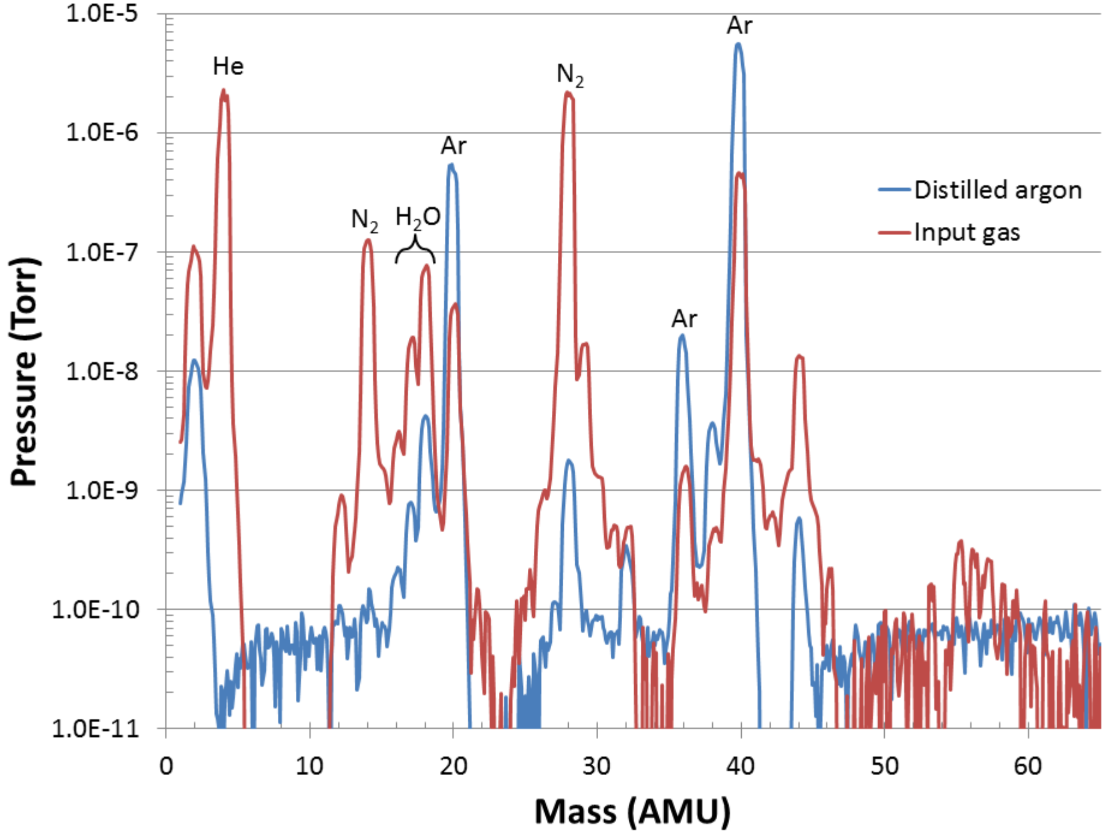
- Will also learn a lot through construction and operation of the detector

Distillation Column

- Atmospheric argon emits ~ 1Bq/kg from ^{39}Ar, while mantle argon has < 0.01 Bq/kg (measured)
- Background limits the size of dual-phase TPCs for dark matter searches because of pile up
- Get mantle Ar from CO_2 wells, extracts 3% Ar, 27% N_2, 70% He; have to distill the N_2 off He just goes away
- Column commissioned with atmospheric Ar in November 2011
- Princeton, SNOLab and Fermilab collaborating on this effort

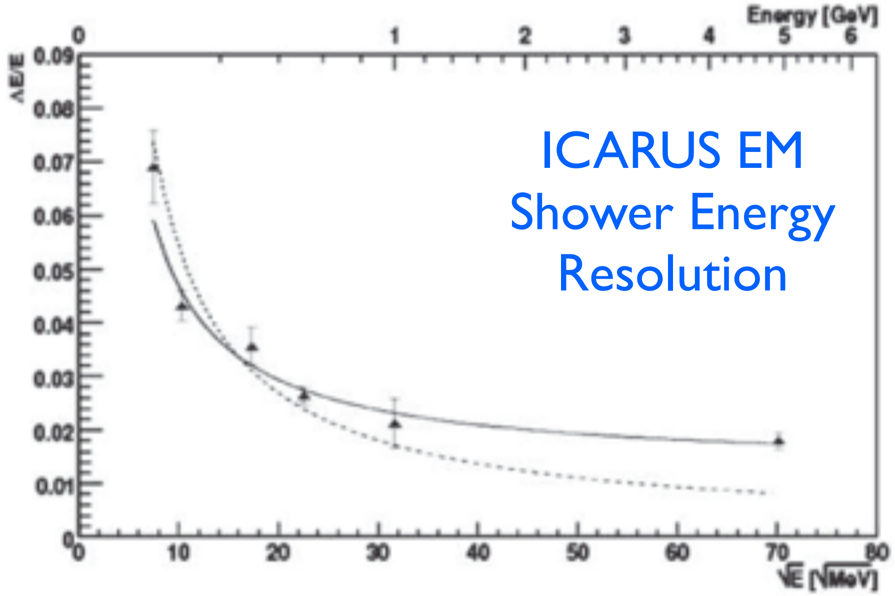
Distillation Column

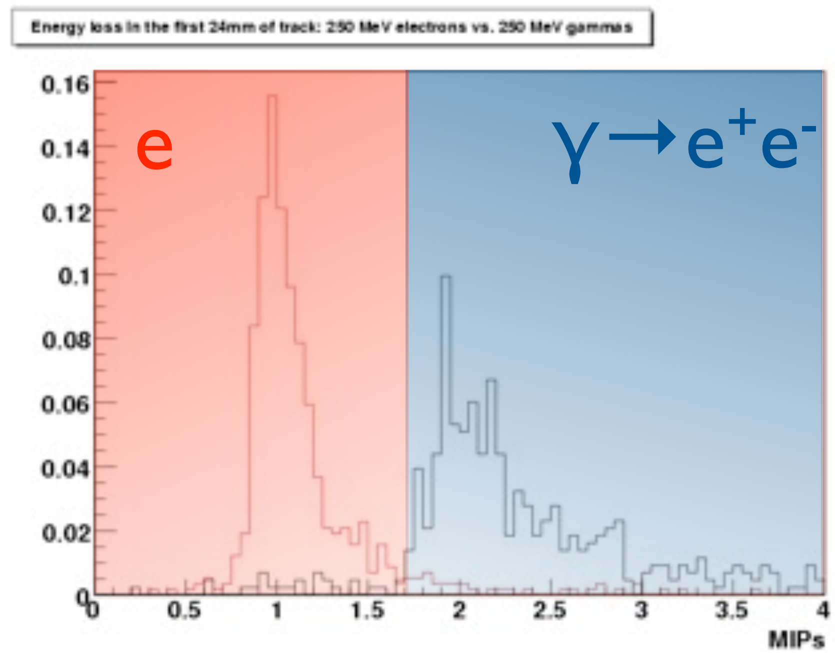
- Efforts of distillation column are aimed at the Darkside and DEAP experiments
- Notice the distilled mixture has the Ar enhanced by a factor of 10 compared to the input
- The N_2 is suppressed by a factor of 1000
- Distilling underground Ar since March 2012
- 15 kg total distilled, storing in gas cylinders under a berm to prevent reactivation



LAr Detector Beam Test

- A major question to come out of the 2009 LAr R&D review was *How well known are the energy resolution and particle identification capabilities of a LArTPC?*
- Previous estimates of energy resolution from the 50L WARP test stand and ICARUS T600 run on the surface with cosmic rays
- T32 at JPARC run to understand charged particles in ArgoNeuT sized TPC (arXiv: 1206.1181)
- Need data from particles and energies expected in neutrino experiments: e, p, π, μ
- Want to build a beam test experiment to study these issues





Beam Test Participants

13 Institutions
30 physicists

College of William & Mary 1693

Imperial College London

Syracuse

UCL

Texas

Argonne National Laboratory

The University of Chicago

Yale

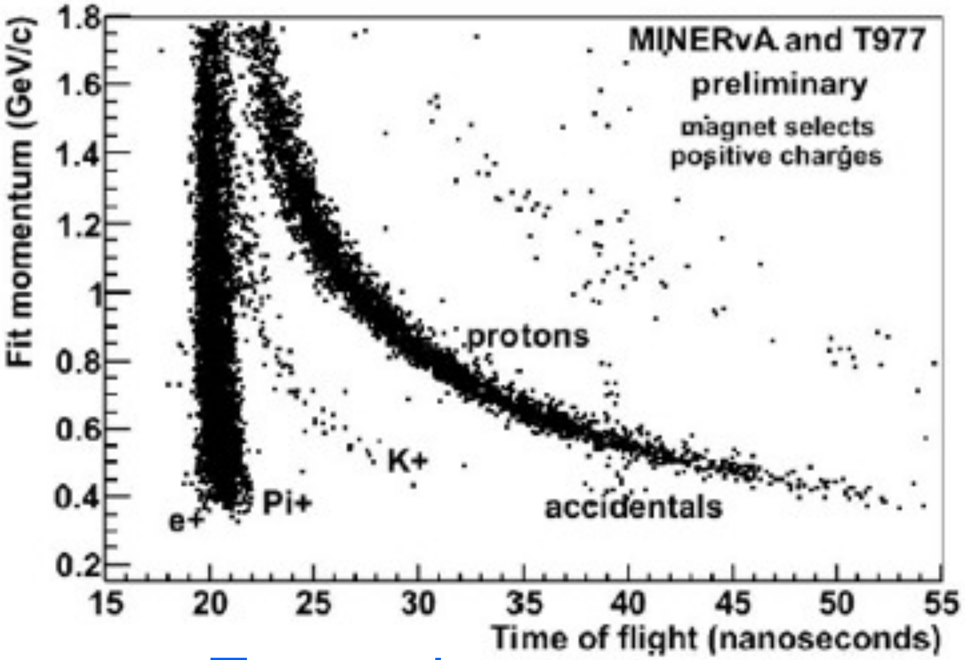
UMD Duluth

Michigan State University

Manchester 1824
The University of Manchester

The Plan

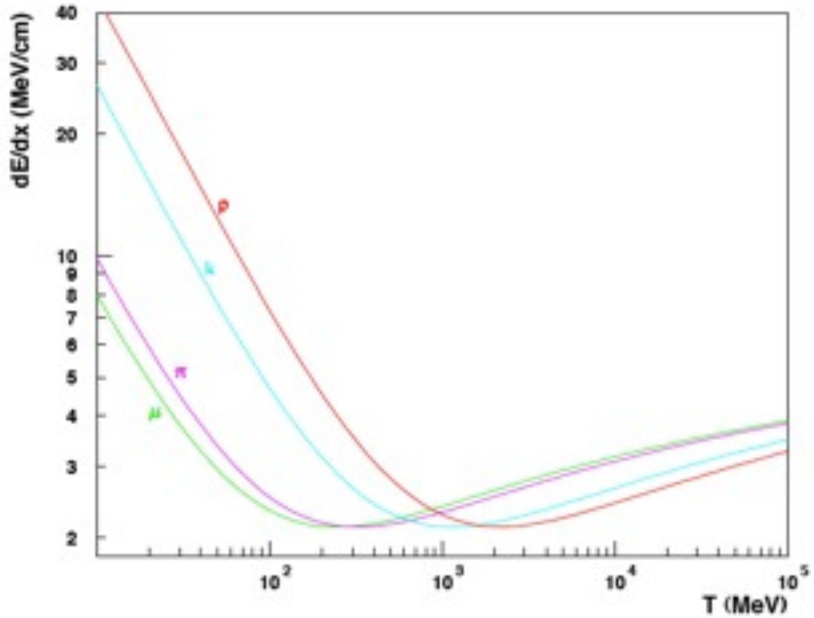
- Create a facility for long term use where we can have the most flexible program both in terms of calibration tests and R&D related tests
- We have examined both the M-Test and M-Center areas in the Fermilab Test Beam Facility
- M-Center appears to be the better of the two locations for both size and availability over extended time periods
- Make use of the tertiary beam setup that was first used in the MINERνA test beam program

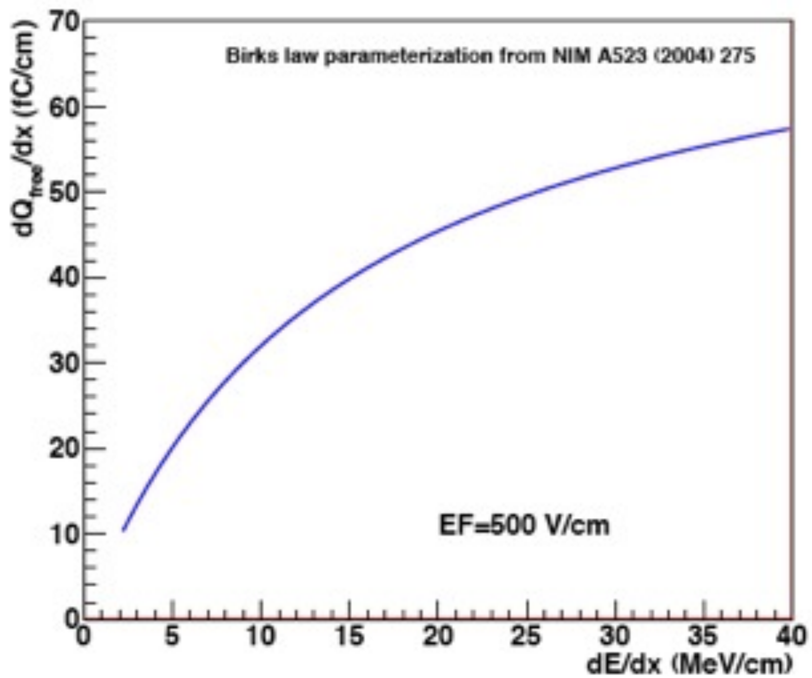


Tertiary beam composition

Phase 1: Upgraded ArgoNeuT

- We would like to get started on understanding the calibration as quickly as possible
- Yale and Syracuse have submitted a NSF proposal to upgrade ArgoNeuT
  - PMT to detect scintillation light
  - Cold window to minimize amount of steel between the beam and LAr
  - Upgraded filtration system
  - Possible upgrade of the TPC to use cold electronics
- Will be used to study charge to energy conversion with single track topologies
- Also will study initial ionization in EM showers to understand e/γ separation





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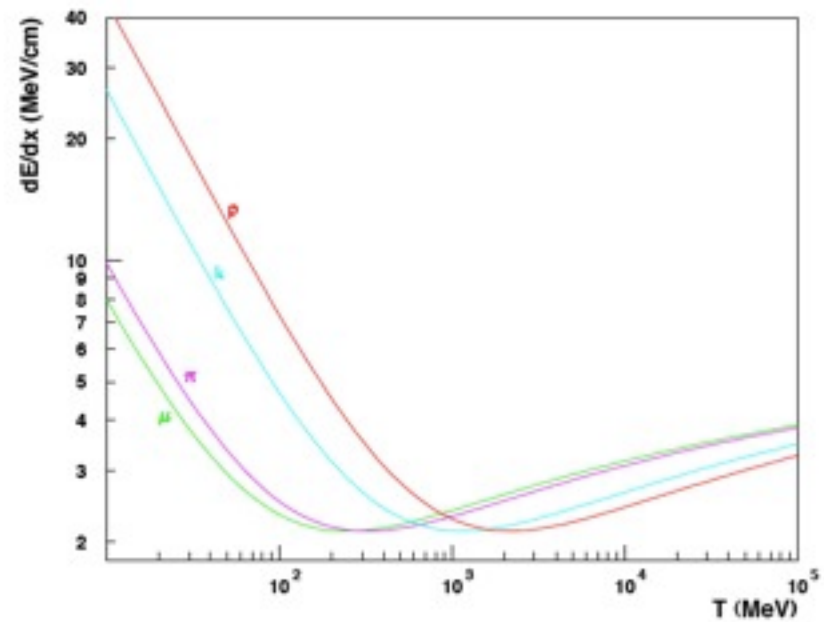
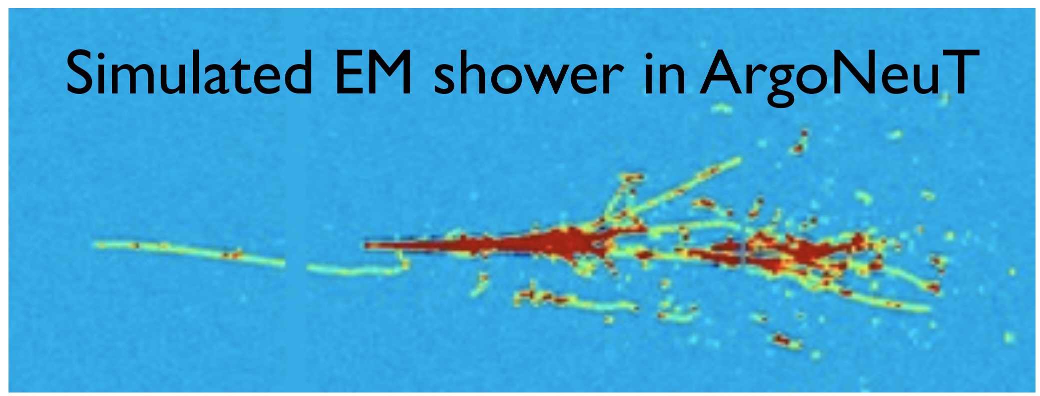


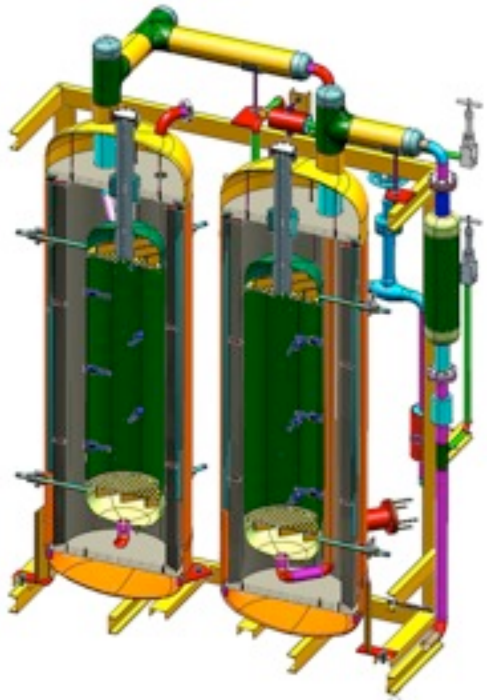

Simulated EM shower in ArgoNeuT

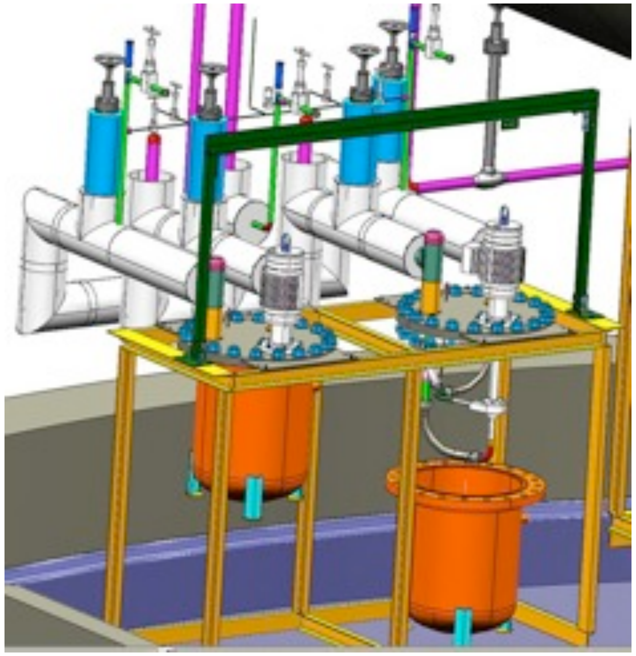
Phase 2: TPC Size

- ArgoNeuT is a good start to understanding the calibration, but it is too small to fully contain showers
- Hadronic interaction length is 80 cm, need 240 cm of LAr longitudinally and up to 160 cm transversely
- Radiation length is 14 cm, need at least 190 cm of LAr in longitudinal direction and 30 cm transverse to contain 95% of the energy
- Muons lose 2.2 MeV/cm, so a 5m long active volume will range out a 1 GeV muon
- TPC should have active volume on the scale of 1m x 1m x 5m
- Studies to optimize the size are underway
- M-Center large enough to accommodate at least 5m long TPC, cannot go much over 1m transversely

Phase 2: The Facility

MicroBooNE
Filter Skid





MicroBooNE
Pump Skid

- Fermilab would provide the facilities, other groups would provide the active detectors
- Use experience from LAPD and MicroBooNE for cryogenic system design
- The facility will provide a filtration and pumping system that is appropriately sized to the volume of LAr
- Build cryostat to allow convenient access to inside of vessel
- Imagine exchanging electronics, light collection systems, TPCs, etc during several year program

Phase 2: The Program

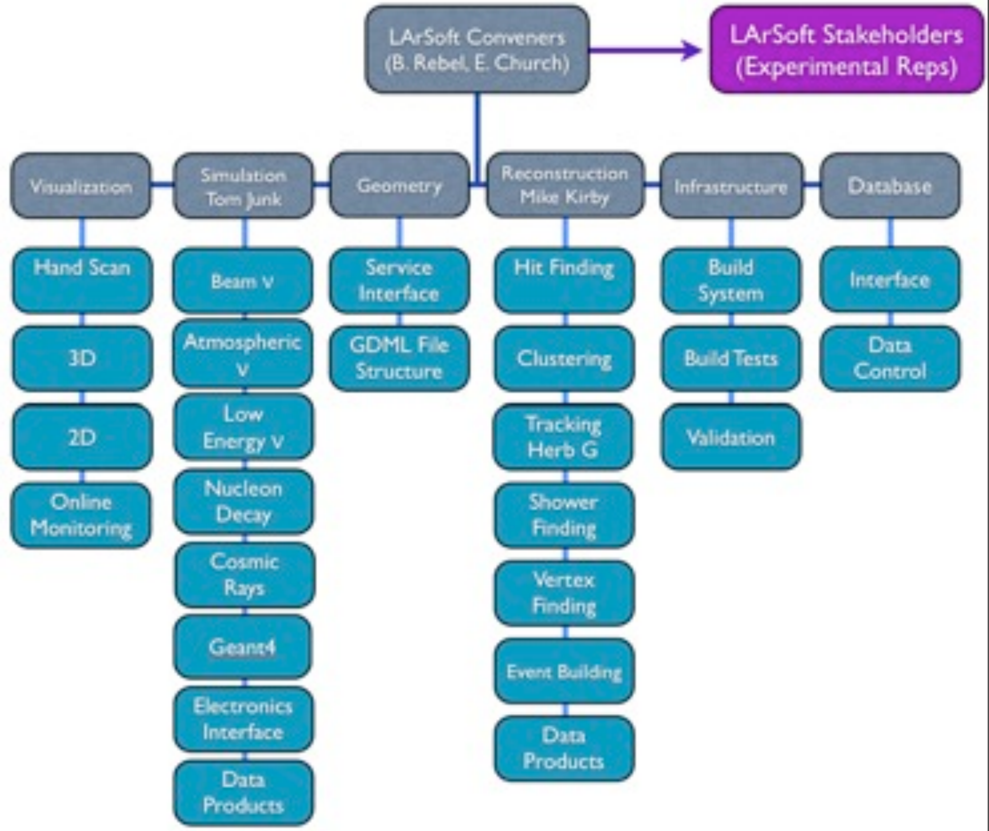
- Measurements to be made include
  - EM shower energy resolution
  - Hadronic shower energy resolution, visible vs invisible energy
  - E_{had}/E_{EM} ratio
  - Directionality of through going particles using delta rays
  - Particle identification
  - dE/dx for several particle species
  - Light collection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

Summary

- ArgoNeuT is producing physics papers with its data set
- LAPD showed for the first time that an electron lifetime well above that needed for LBNE can be achieved without evacuating the vessel
- The Long Bo test of large drift distance TPCs and cold electronics will go into LAPD for its next run
- The 35 ton membrane cryostat prototype is currently under construction with help from IHI to develop institutional knowledge at Fermilab
- MicroBooNE is contributing to understanding cold electronics as well as purity measurements and proton decay backgrounds
- The distillation column is successfully enhancing the amount of low background argon in gas taken from CO_2 wells
- The liquid argon detector beam test effort is underway and has good collaboration between Fermilab, university groups and other national labs

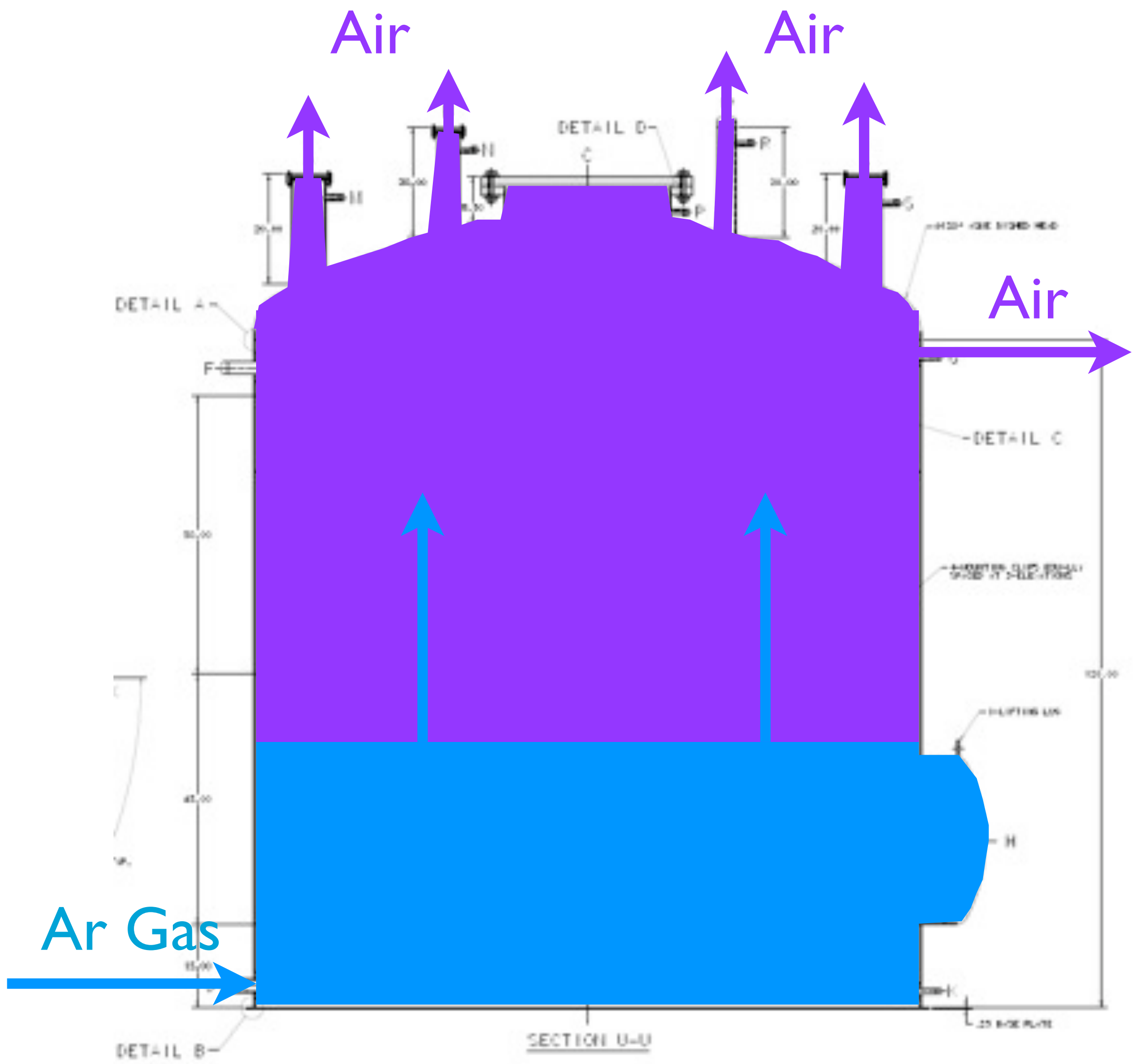
LArSoft

- LArSoft is a simulation, reconstruction and analysis framework for any LArTPC
  - Goal is to have a fully automated simulation and reconstruction for any LArTPC
  - Previous experiments have developed individual simulation and reconstruction software
- LArSoft takes this effort further by leveraging the efforts of a variety of experiments into a single product
- Accreting a lot of new effort thanks to the LBNE technology decision and µBooNE successfully passing CD-3 reviews
- Organizing new effort in specific working groups to maximize impact



Phase I - Purification without Evacuation

- Basic idea is to use an argon piston for initial purification, followed by a few more volume exchanges
- Cycle a few volumes of clean, warm Ar gas through the volume to push out ambient air and dry out surfaces
- Then recirculate the gas through filter system when contamination is < 50 ppm



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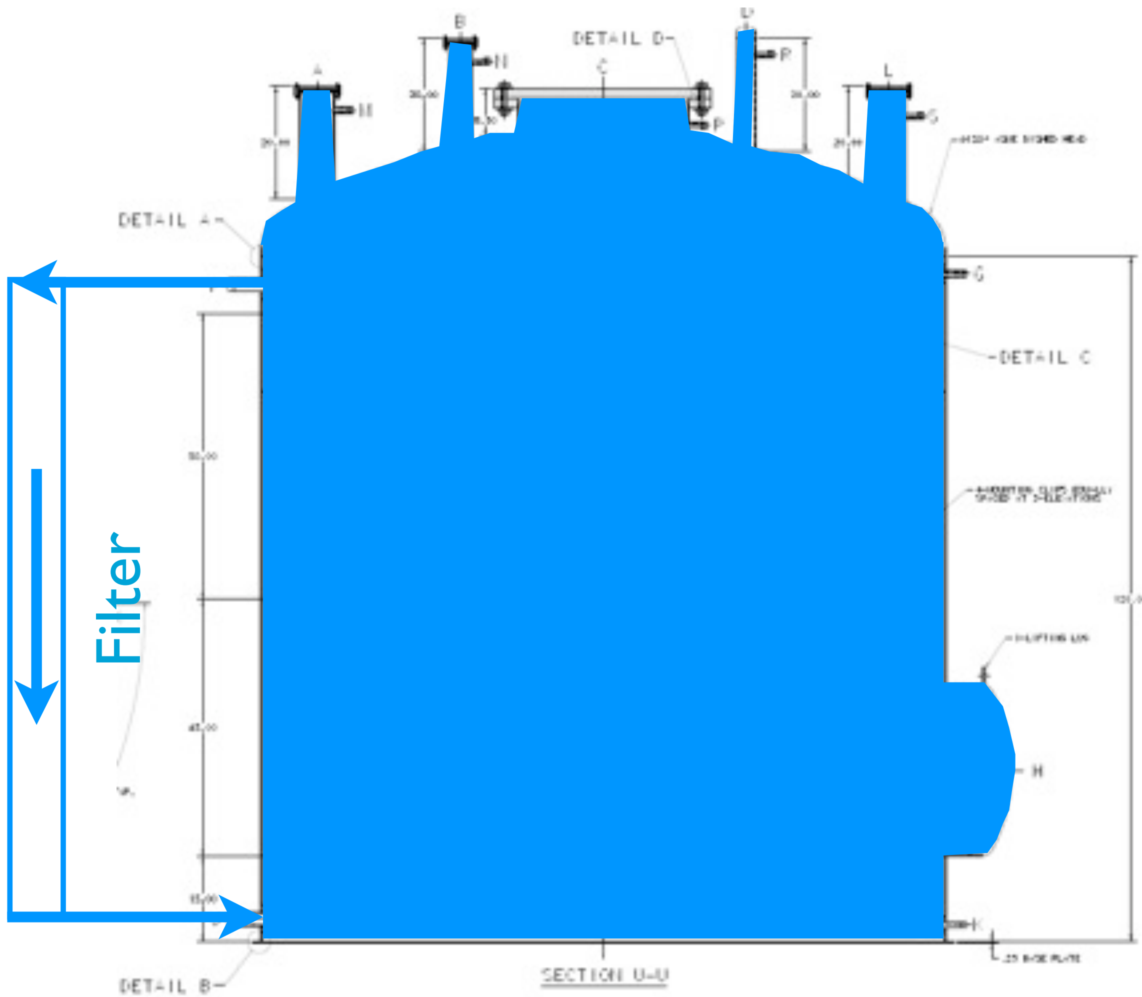
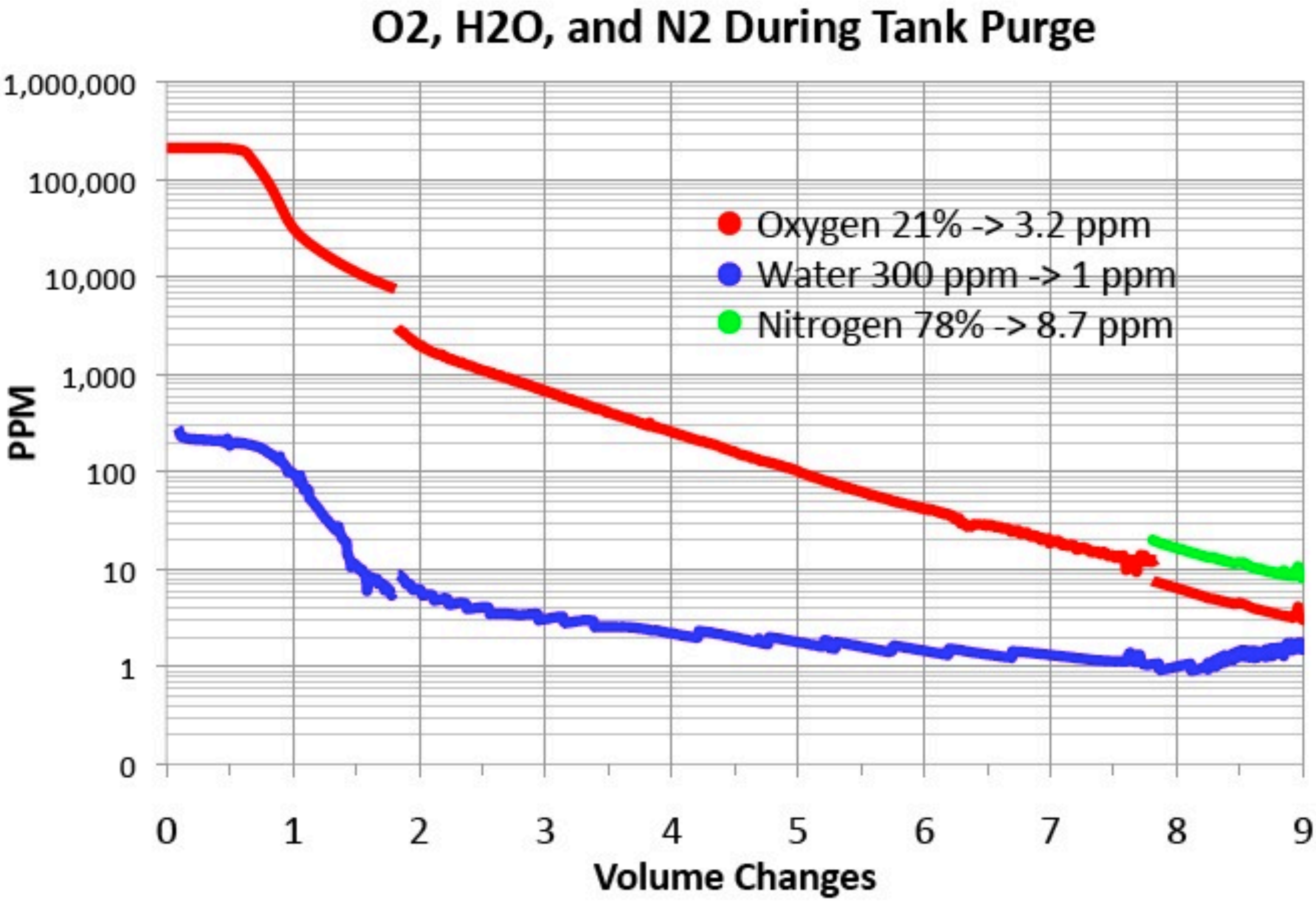
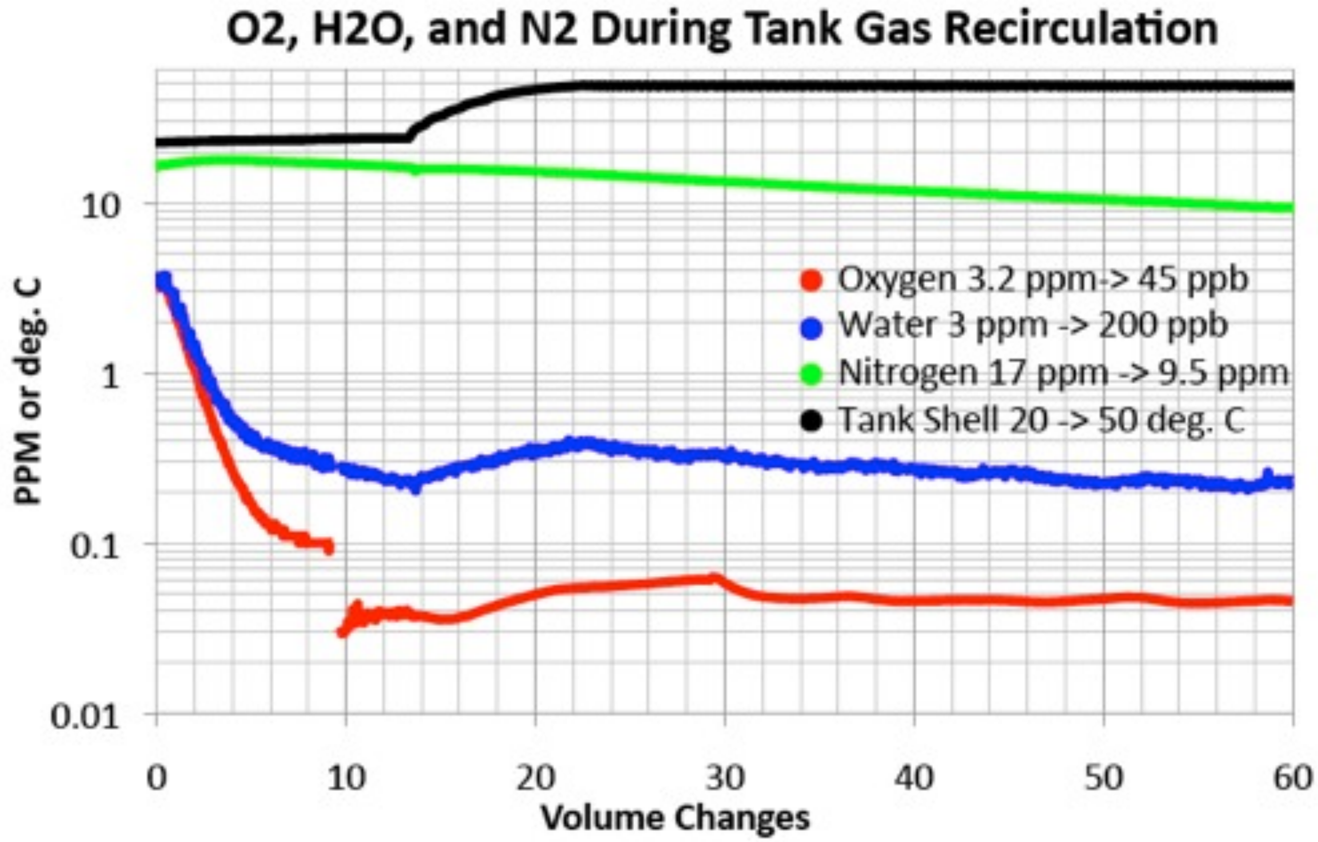


Monday, June 18, 2012

Gaseous Argon Purge

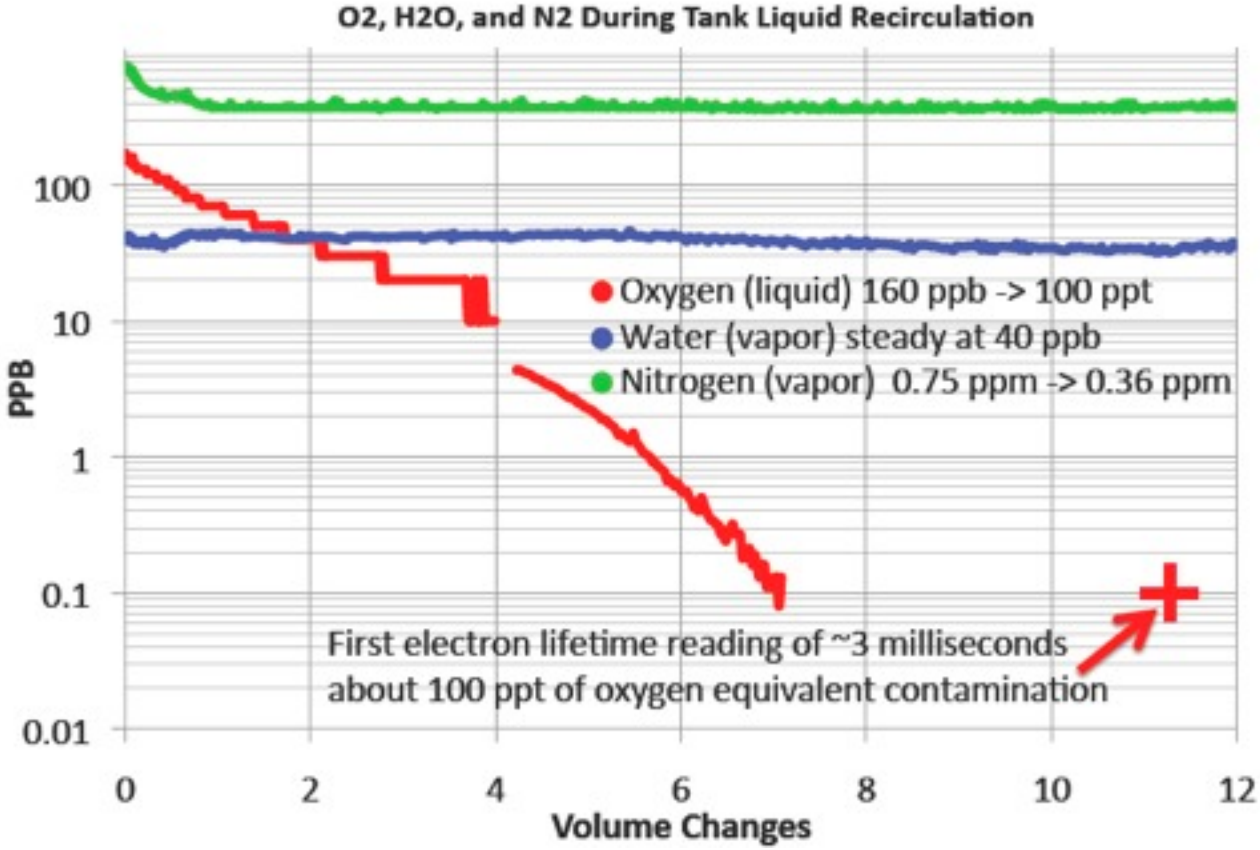


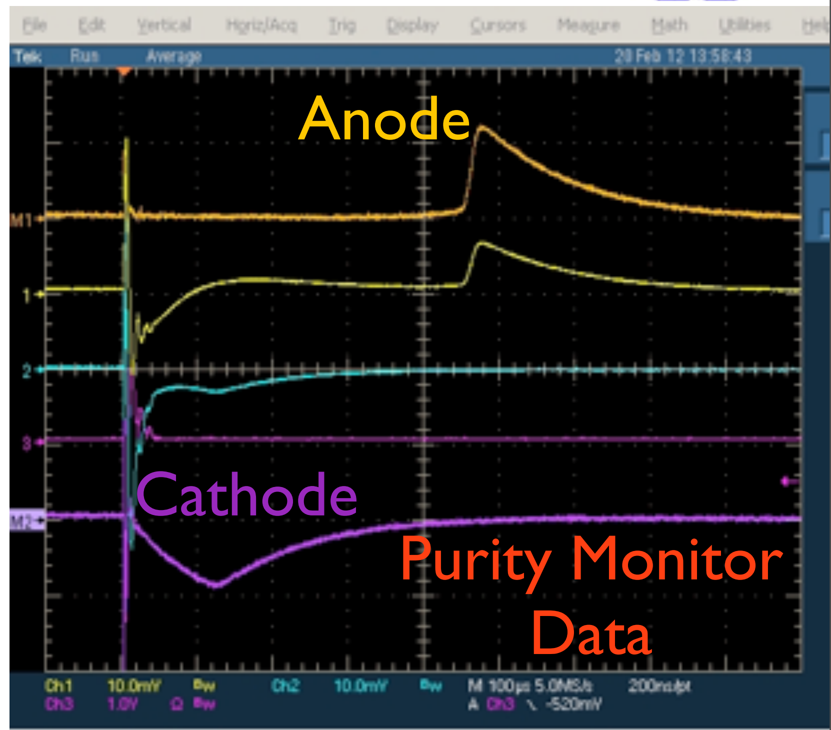
Gaseous Argon Recirculation



- The purge was very successful and brought the vapor in the tank to a contamination level that was below the specifications for the delivered liquid
- Both O_2 and H_2O contamination were well below 1 ppm after 3 volume exchanges
- Maintained sub-ppm levels in the gas for over 20 days
- Heating the tank shell allowed more contamination to be “baked” out

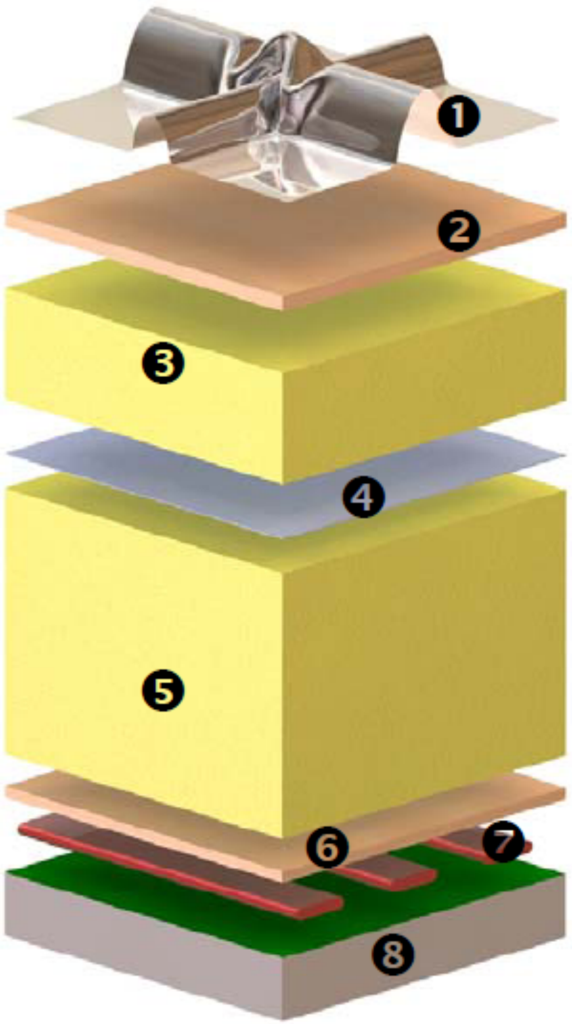
Liquid Argon Recirculation





- Liquid filtration began after the flow through the O_2 filter was reversed to prevent clogging of the particulate filters
- Filtration progressed at the rate of about 1 volume exchange every 6 hours
- First electron lifetime measurements made after 11 volume exchanges
- Electron lifetimes were determined to be at least 3 ms, LBNE needs 1.4 ms

Membrane Cryostat



1. Stainless steel primary membrane
2. Plywood board
3. Reinforced polyurethane foam
4. Secondary barrier
5. Reinforced polyurethane foam
6. Plywood board
7. Bearing mastic
8. Concrete covered with moisture barrier


MT4 Target: 30cm Al
MT6 Absorbers: 1.5m
MT1 Target: 25cm Al
MTest Beamline
MCenter Beamline
M01
M02
M03
M04
M05
MS1
MS2
MS3
MS4
MS5
MS6
MS7
MT6 Sect 2
MW7
MW8
MC7
MC8
MB7
PK045
PK066
PK067
MP7
MP8
M West Cryo Area
M Polarized
MEast
ILC
Cryo offices
Meson Detector Bui (MDB)