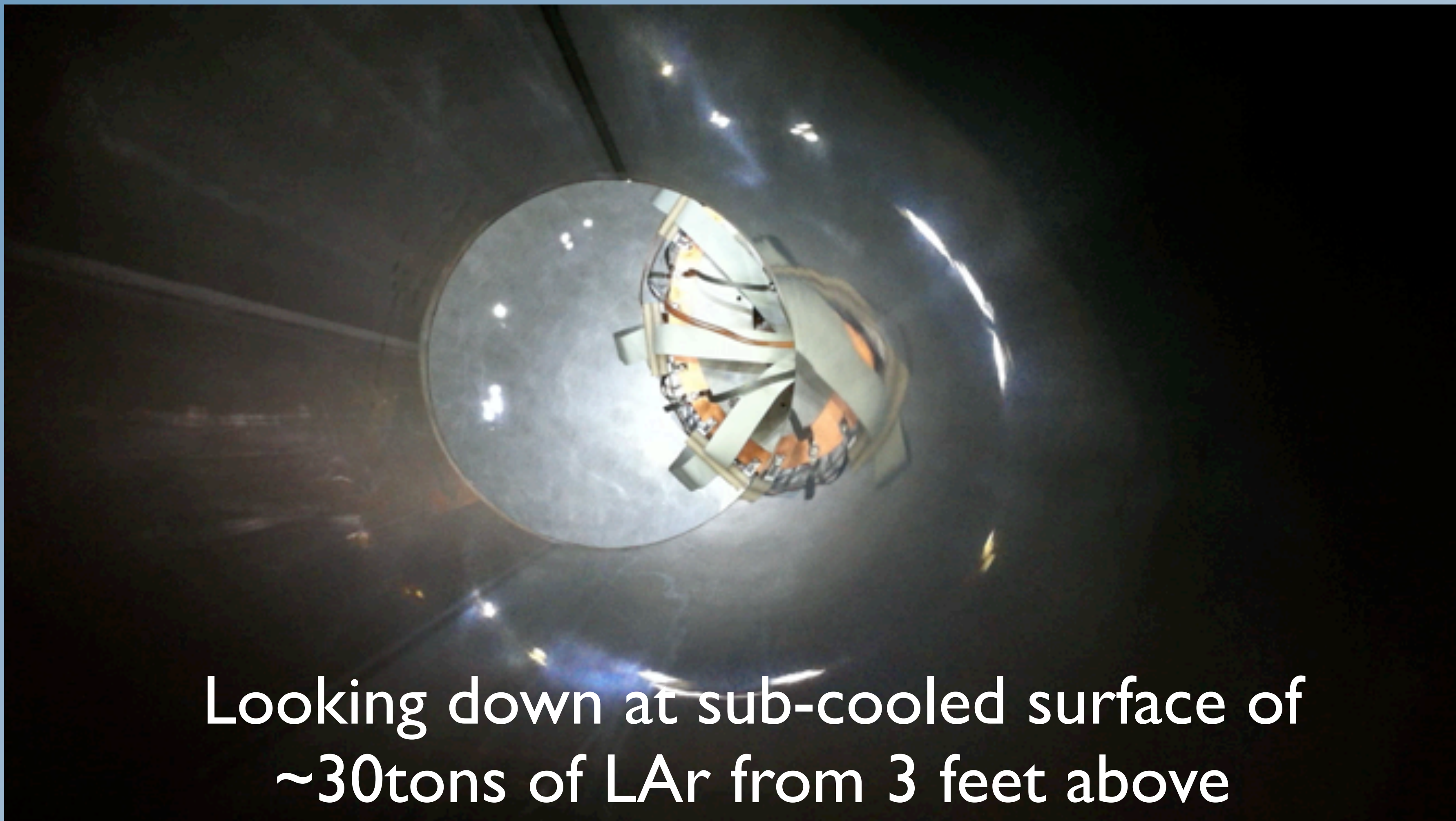
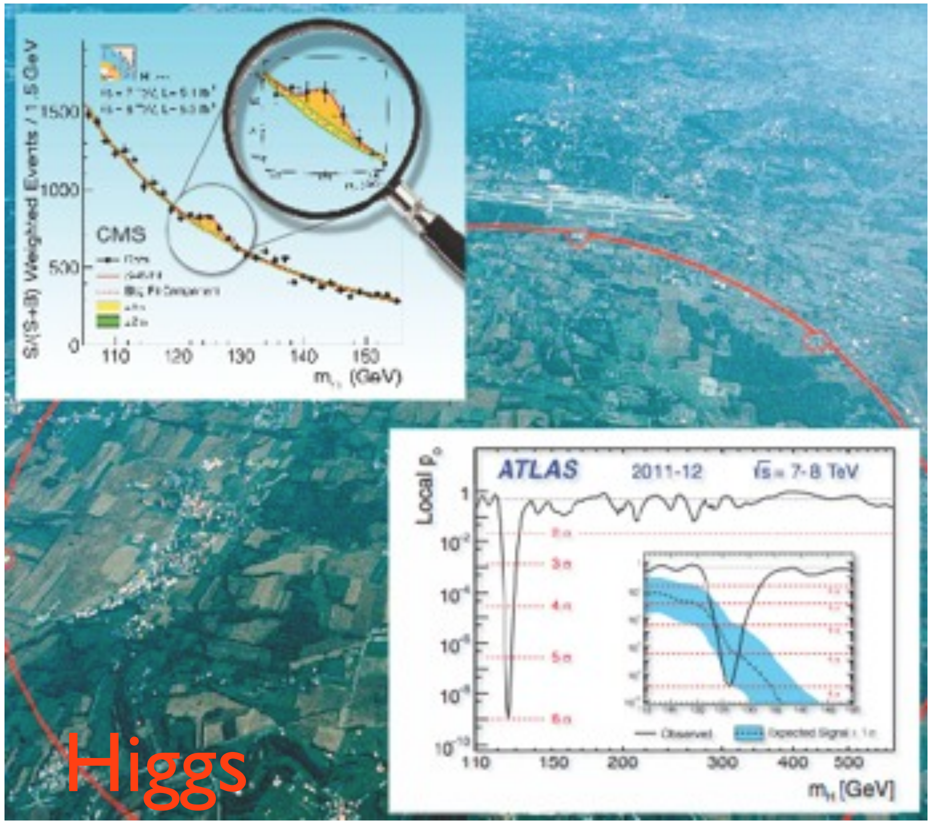
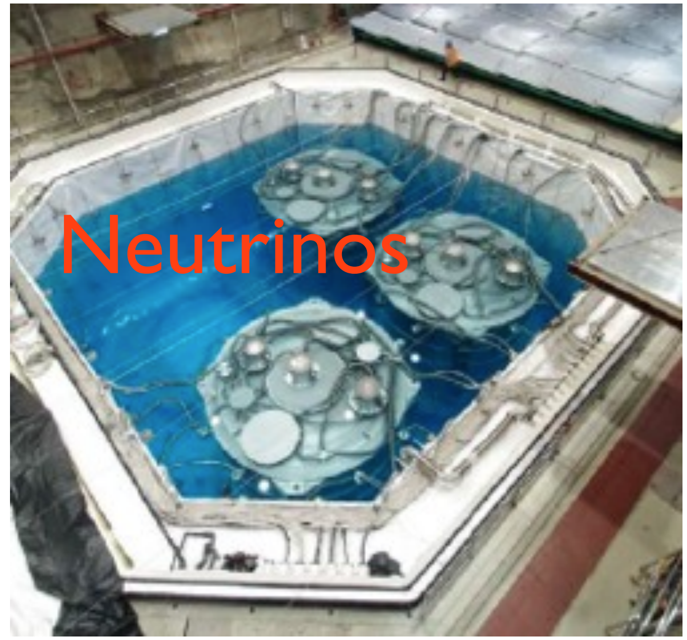
LArTPC Development and the Coordinating Panel For Advanced Detectors

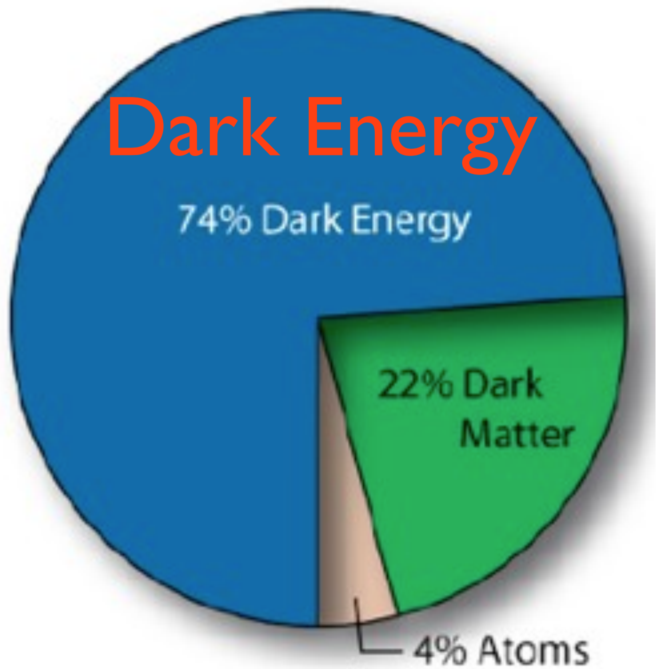


Brian Rebel
February 2, 2013

Instrumentation Makes Our Science Possible







- Exciting time of new discoveries made possible by advanced detectors
- Many questions left to answer - require new instruments and a strong program of development

Report of the DPF Taskforce on Instrumentation in Particle Physics

Instrumentation in Particle Physics

Commissioned by the Executive Committee of the Division of Particles and Fields, American Physical Society

October 2011

Prepared by the Task Force Members:

Authors: Marina Artuso (Syracuse), Ed Blucher (Chicago), Ariella Cattai (CERN), Marcel Demarteau (co-chair, ANL), Murdock Gilchriese (LBNL), Ron Lipton (FNAL), David Lissauer (BNL), David MacFarlane (SLAC), Bill Molzon (UCI), Adam Para (FNAL), Bruce Schumm (UCSC), Gabriella Sciolla (Brandeis), Ian Shipsey (co-chair, Purdue), Harry Weerts (ANL) Ex-officio: Chip Brock (Michigan State), Patricia McBride (FNAL), Howard Nicholson (Mount Holyoke).

October, 2011

CPAD formed Feb, 2012

http://www.physics.purdue.edu/dpf_instrumentation_taskforce/

The DPF Taskforce on Instrumentation

- From Universities
  - Marina Artuso, Syracuse
  - Ed Blucher, Chicago
  - Bill Molzon, Irvine
  - Gabriella Sciolla, Brandeis
  - Ian Shipsey*, Purdue
  - Andy White, UT Arlington
- From laboratories
  - Marcel Demarteau*, Argonne
  - David Lissauer, Brookhaven
  - David MacFarlane, SLAC
  - Ron Lipton, Fermilab
  - Gil Gilchriese, LBNL
  - Harry Weerts, Argonne
- Ex-officio
  - Chip Brock, DPF MSU
  - Patty McBride, DPF Fermilab
  - Howard Nicholson, DOE Emeritus

(*) co-Chair

Membership of the taskforce had a large overlap with current CPAD membership

Taskforce Charge

Charge organized in three broad areas

I. Structure for a National Instrumentation R&D strategy
   I. Need, merit and process for evaluating and promoting the national R&D program through a National Instrumentation Advisory Panel
   II. Appropriate role for a standing panel on instrumentation vis-à-vis existing and new projects
   III. Models for universities-laboratory collaborative projects
   IV. Strategic links to other scientific disciplines
   V. Strategic links to industry
II. Models for Entrepreneurial Instrumentation Science Strategy
   I. Availability of targeted resources at each of the five national laboratories to specifically support particular needs of individual researchers at the universities and the laboratories?

Taskforce Charge

III. Graduate Student and Post Doctoral Training
   I. Role of experience in instrumentation R&D in the life of US graduate students
   II. Academic, intensive, US-based instrumentation experience for graduate students with academic credits, within the context of a global program of coordinated instrumentation schools
   III. National instrumentation fellowship program for Ph.D. Students and postdoctoral scholars to encourage and support research in instrumentation.

Perspective, broad input, ownership

International Advisors

Asia: Yoshitako Kuno, Geoff Taylor, Yifang Wang,Hitoshi Yamamoto

Europe & Canada : Ariella Cattai, Joachim Mnich, Tatsuya Nakada, William Trischuk, Peter Weilhammer

National Advisors

David Asner, Daniela Bortoletto, Jim Brau, Joel Butler, Karen Byrum, Chris Bebek, Priscilla Cushman, Su Dong, Juan Estrada, Jim Fast, Bonnie Fleming, Paul O'Connor, Mike Crisler, Carl Haber, Chris Kenney, Steve Holland, Simon Kwan, Ron Lipton, Ted Liu, Hogan Nguyen, David Nygren, Paul O'Connor, Erick Ramberg, Natalie Roe, Aaron Roodman, David Saltzberg, Sally Seidel, Abe Seiden, Wesley Smith, Mani Tripathi, Jerry Va'vra, James White, Minfang Yeh

~30 provided multi-page answers to detailed questions related to the themes and scope of the charge. They continued to provide advice throughout the process, and some have also joined subgroups of the taskforce

Coordinating Panel for Advanced Detectors (CPAD)

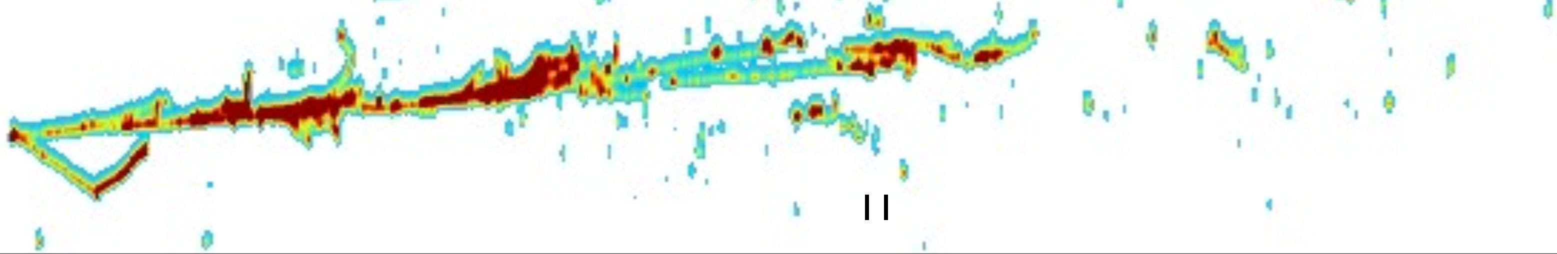
- Advisor & Community input: A coordinating panel will elevate & champion instrumentation, community voice, representative of the community ensure complete coordinated balanced program, promote cooperation across community, decadal perspective, advocate with congress and industry & other disciplines, can be used by DOE as a source of advice (when asked to do so)
- *The primary recommendation of the Taskforce report is that a standing Coordinating Panel for Detector R&D the Coordinating Panel for Advanced Detectors (CPAD) be formed, under the auspices of the DPF Executive Committee*
- Recommendations
  1. A standing body – CPAD - should be formed to promote and stimulate the national instrumentation detector R&D program.
  2. The CPAD should be largely self-organized and consist of representatives from the national HEP labs and the university community to form a representative panel of outstanding capability in detector and instrumentation R&D.
  3. The primary role of CPAD should be to promote and assist in generic detector R&D

- **Formation and function**
  - The CPAD would be initiated under the auspices of the DPF Executive Committee
  - The CPAD would not be managed by any national laboratory, the DPF or the funding agencies. (i.e. self-organized)
  - However, the CPAD would inform the laboratories, the DPF Executive Committee (or designated individuals), the funding agencies and the community at large of its work on a regular basis.
- **Membership of CPAD:**
  - One representative from each of the five HEP national laboratories (ANL, BNL, FNAL, LBNL and SLAC); appointed by the labs
  - At least an equal number of representatives from the university community; appointed by DPF
  - Observers from outside the U.S.; appointed by DPF

- Role of Panel (see longer list in Task Force Report)
  - "...promote national detector R&D and stimulate new ideas in instrumentation development.
  - Improved coordination among the national HEP laboratories and university groups engaged in detector R&D……."
  - ".... help facilitate utilization of targeted resources at the national laboratories…."
- <u>Not role of Panel</u>
  - Acting as a Program Advisory Committee ………….
  - Acting as a standing review body for proposals …. or for peer review of proposals;
  - Providing a "roadmap" for the national detector R&D program. (But would be aware of roadmap for field)

LArTPC Organization in CPAD

- David Lissauer (BNL) and Ed Blucher (Chicago) head the detector systems group of CPAD
- They decided to form a LArTPC Detector group and asked me (FNAL), Craig Thorn (BNL) and Jon Urheim (Indiana U) to convene the group
- We have identified several areas of effort related to making LArTPC detectors a standard technology (see next slide) and are in the process of asking people to lead subgroups examining those areas
- Ultimate goal is to provide a clear picture of what work is happening and what questions still need to be answered
- Topical group will convene annually to update the community and hear about new ideas



Topical Areas for LArTPC Detectors

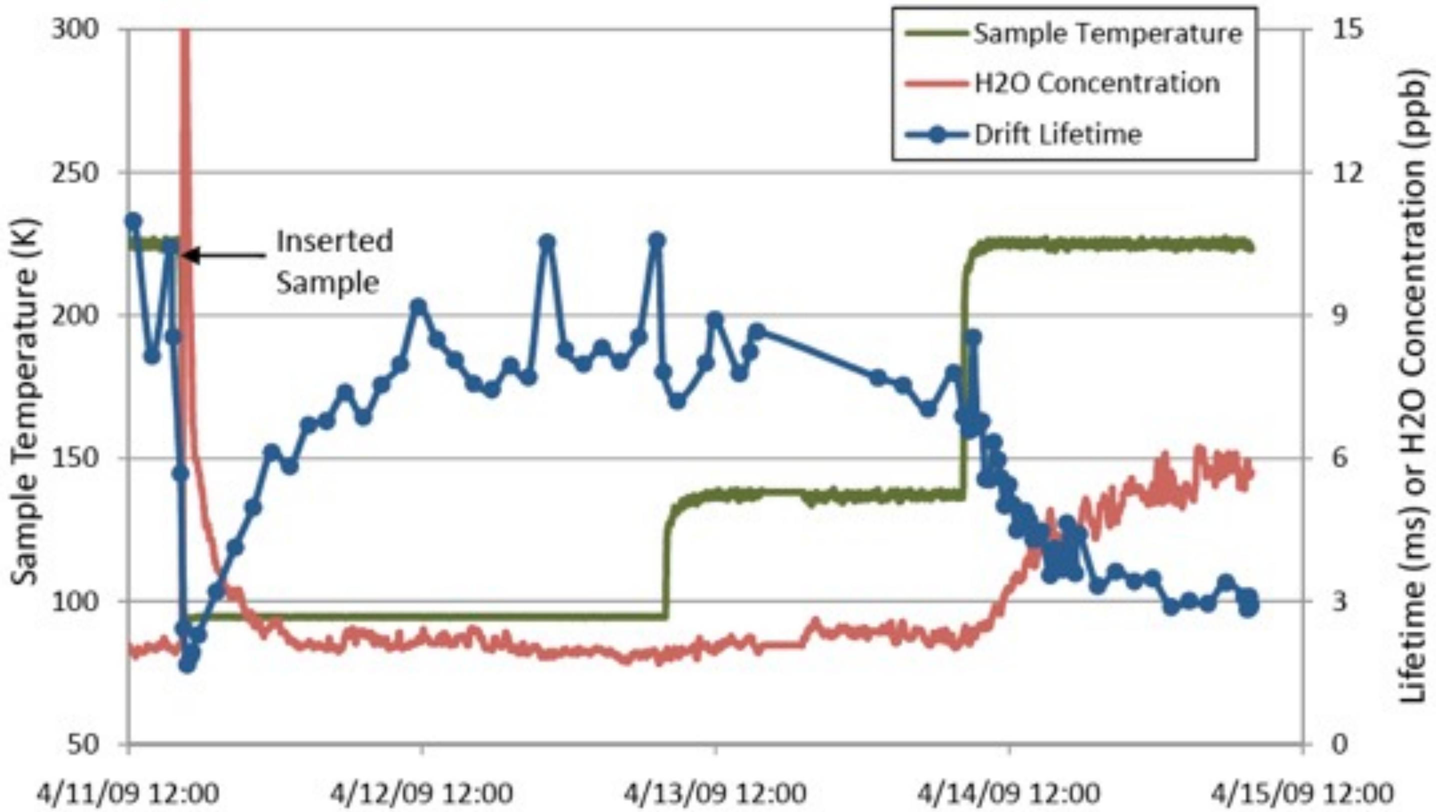
- Physics: needs of the planned experiments will drive the requirements in these areas. Interfacing with representatives from the Intensity Frontier and Cosmic Frontier to quantify those needs
- Cryogenics (Cavanna [INFN/Yale])
- Purification (Pordes [FNAL])
- TPC and High Voltage (TBD)
- Electronics,DAQ, and Triggering (Thorn [BNL], Bromberg [MSU])
- Photon Detection (Mufson [Indiana], Katori [MIT])
- Calibration and Test Beams (Raaf [FNAL], Mauger [LANL])
- Software (Junk [FNAL], Soderberg [Syracuse])

Purity

Keeping liquid argon free of electronegative impurities is crucial for operation of LArTPCs

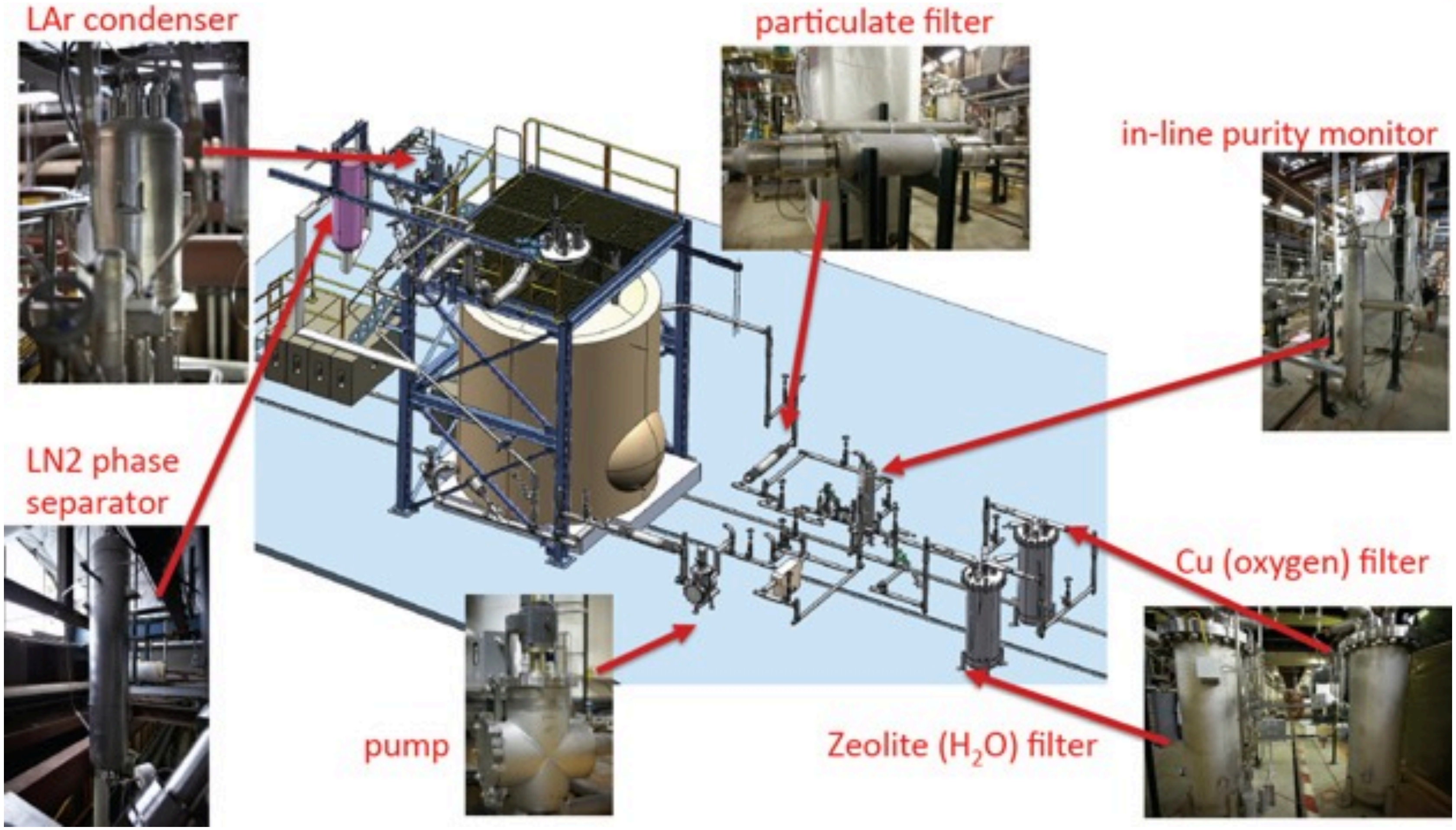
Materials Test Stand at Fermilab

Conclusions about H_2O from the MTS



- Direct relation between electron lifetime and H_2O concentration
- Water concentration in vapor space influenced by materials in vapor space
- No change in electron lifetime when materials are in liquid
- Condensed LAr should not be returned directly to the bulk liquid

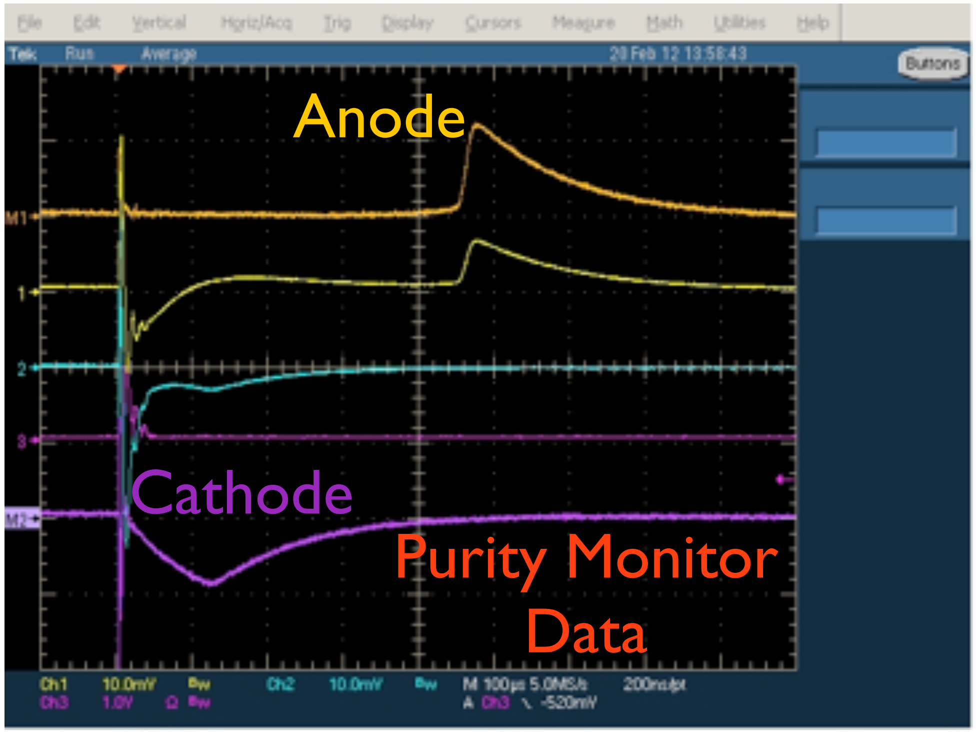
Liquid Argon Purity Demonstrator

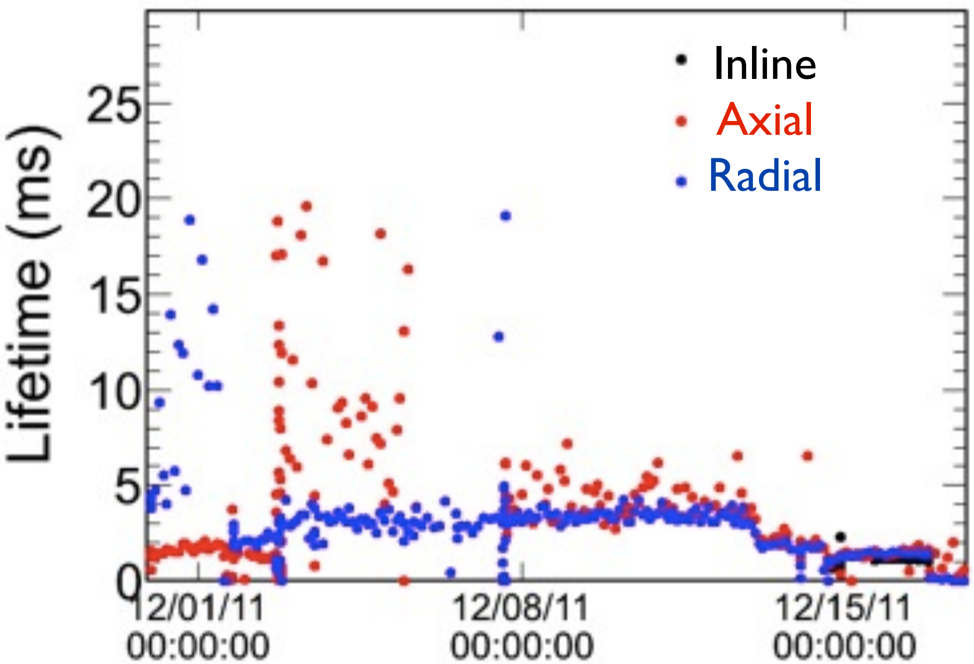


B. Rebel, T. Tope (FNAL)

- 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

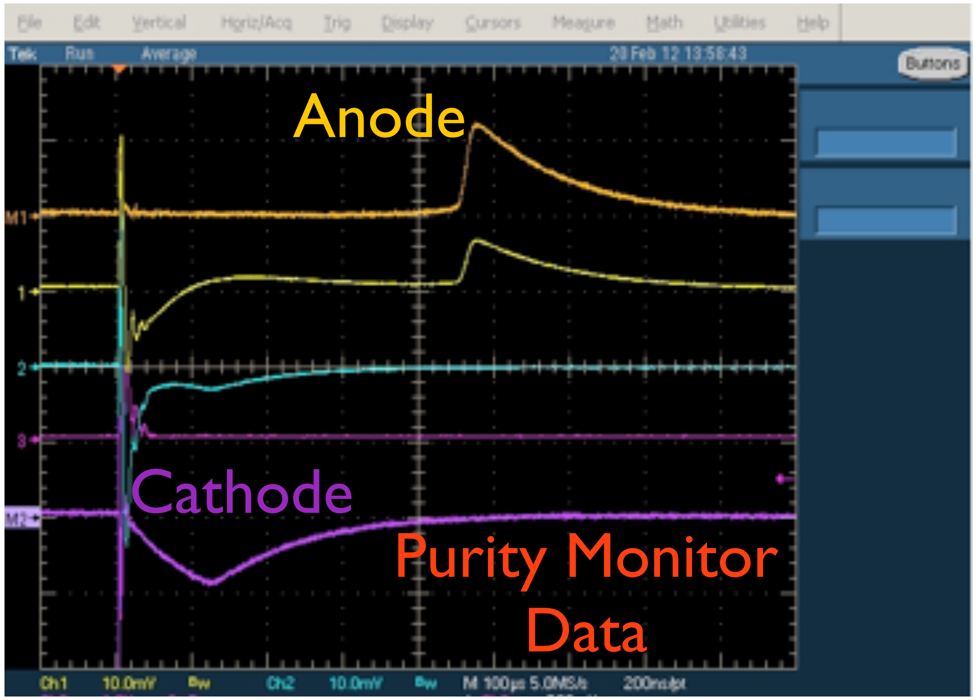
Electron Lifetime Measurement

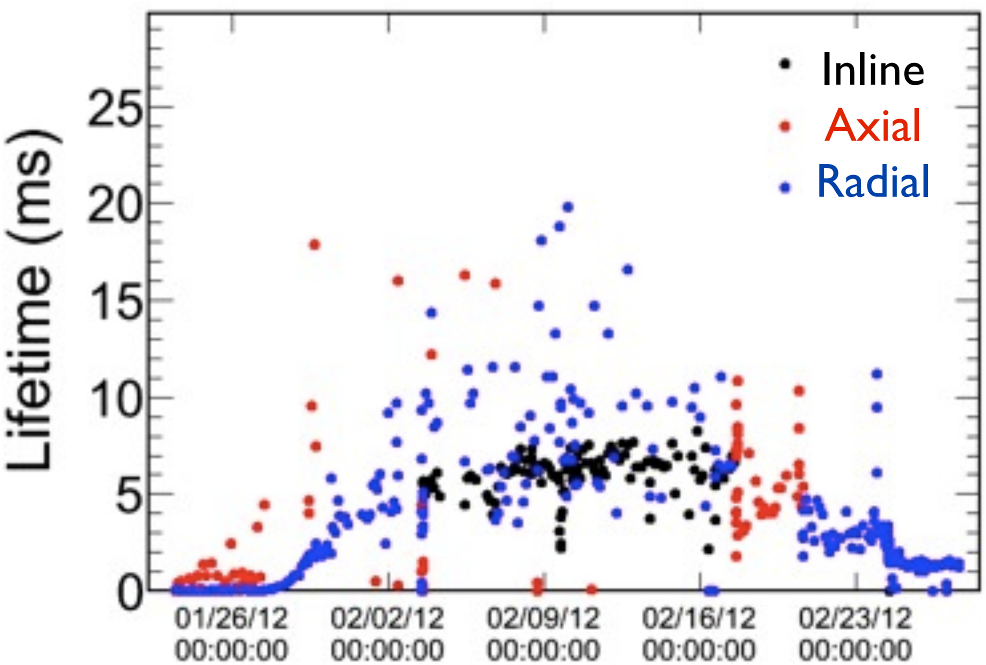




- First electron lifetime measurements made after 11 volume exchanges of liquid (66 hours)
- Lifetime during first run was stable at 3 ms or better (LBNE needs 1.4 ms)
- Lifetimes began decreasing after 2 weeks, indicating filter saturation
- Filters were regenerated and lifetimes went up to 5 ms
- Filters possibly started showing signs of saturation again, but an unplanned power outage stopped the run prematurely
- Vessel now full for the second phase run

Electron Lifetime Measurement





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Future Studies

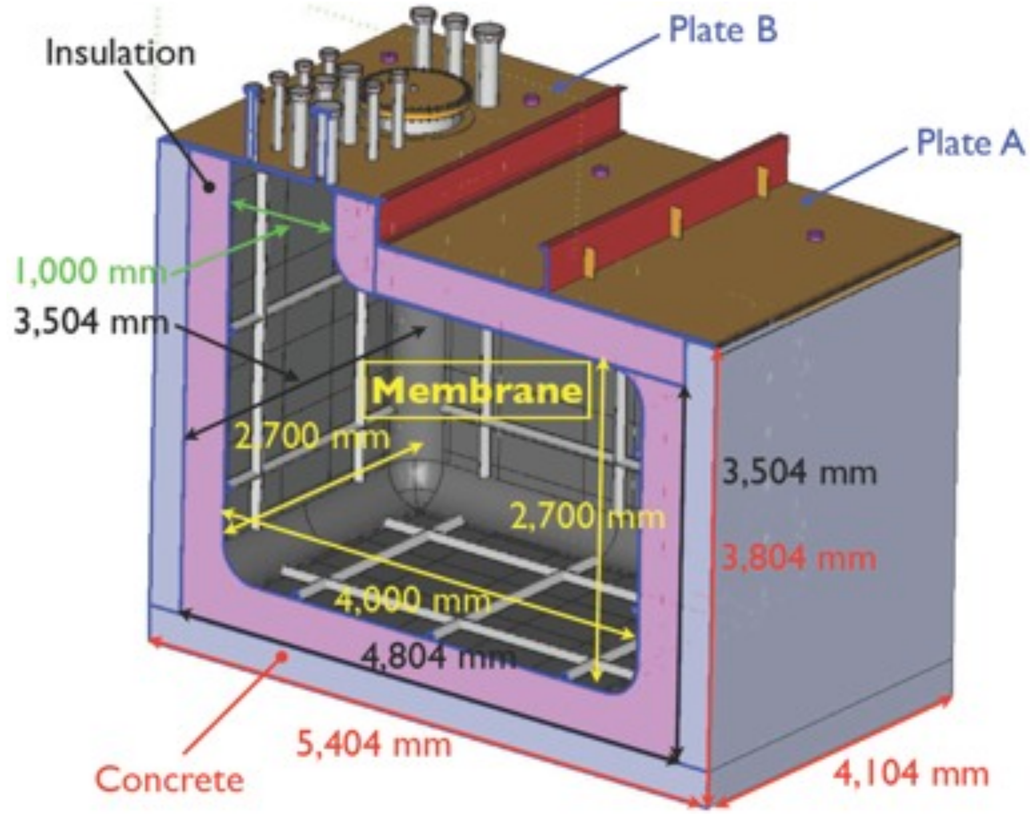
- The initial results represent a major step forward in development of liquid argon detector technologies
- We have already exceeded the design specification for electron lifetime in LBNE by more than a factor of 2!
- LAPD will continue running to
  - Test purification with a TPC in the volume - Long 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

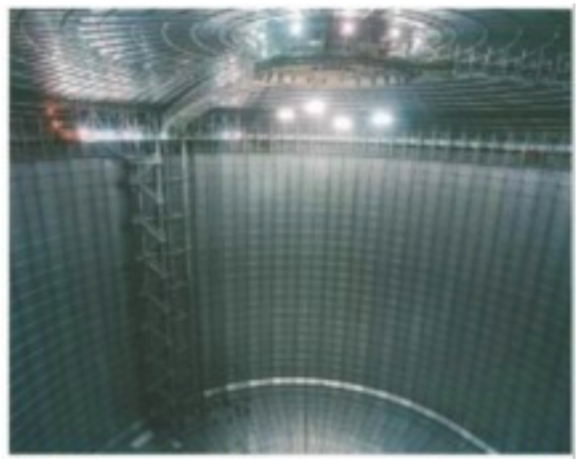
Cryogenics

How to most efficiently deliver a system that will provide stable and safe operations over a long period of time

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



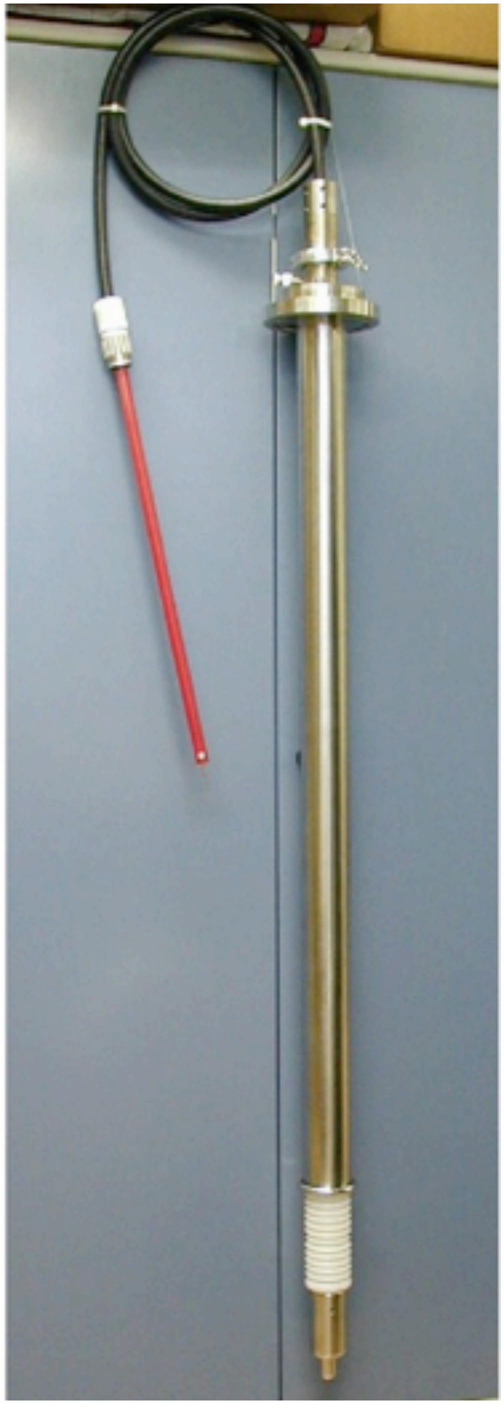


LNG Storage with Membrane from IHI

TPC and High Voltage Feed Throughs

Have to create a field of order 500 V/cm over many meters for large neutrino detectors

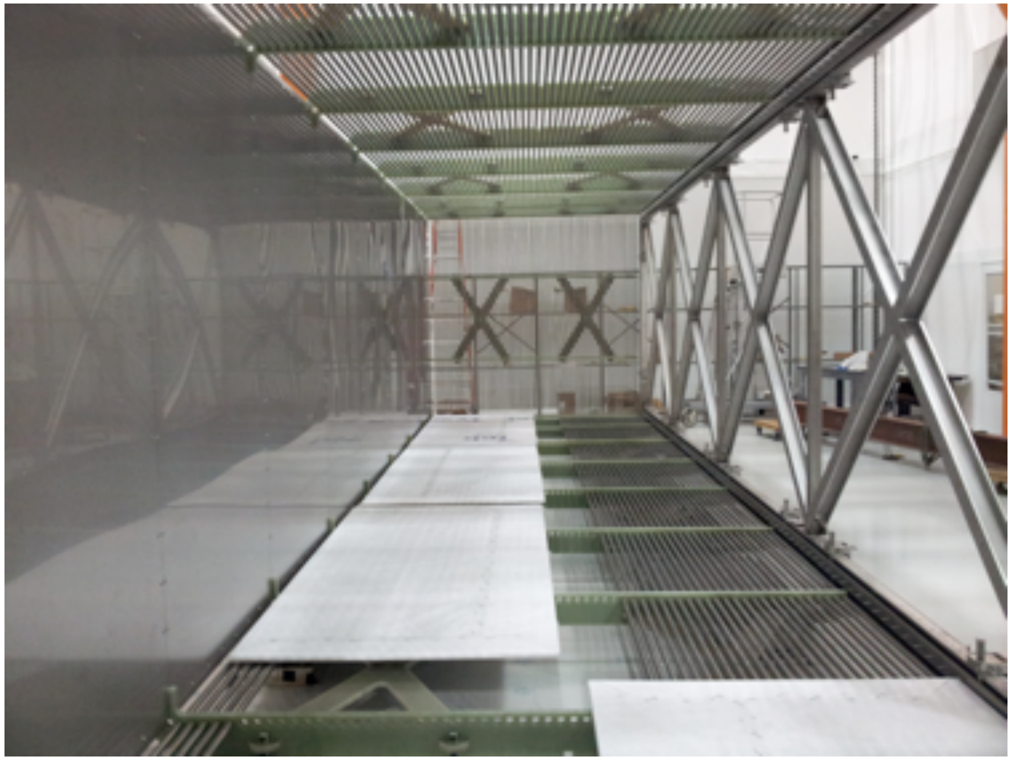
High Voltage Feed Throughs

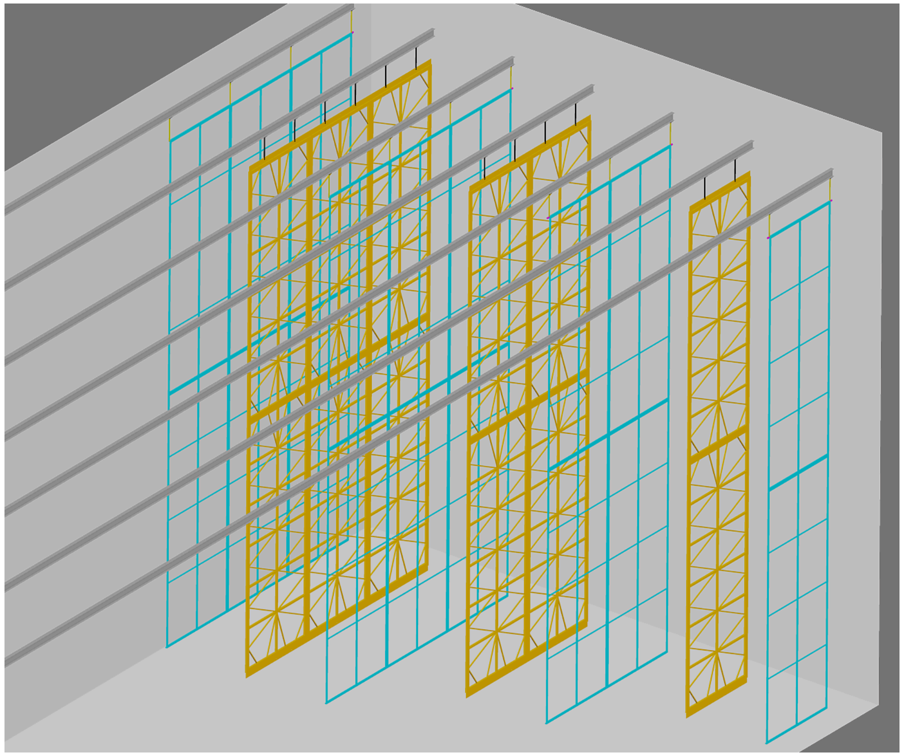


- Typical fields of 500 V/cm require voltages of 50,000 V at cathode for each meter of drift
- Several considerations when designing feed throughs
  - Commercial ceramic feedthroughs are not designed for gas applications - assumes vacuum on one side
  - Gas near the feedthrough conducive to sparking
  - Ionization near the feedthrough can cause charge build up on the insulator
  - Bubbles migrated through the field could cause sparking
- ICARUS constructed first large HV feed through for LArTPCs, operated up to -150 kV
- UCLA group working on LBNE design, Fermilab group produced prototype for Long Bo

F. Sergiempietri, UCLA

Building TPCs





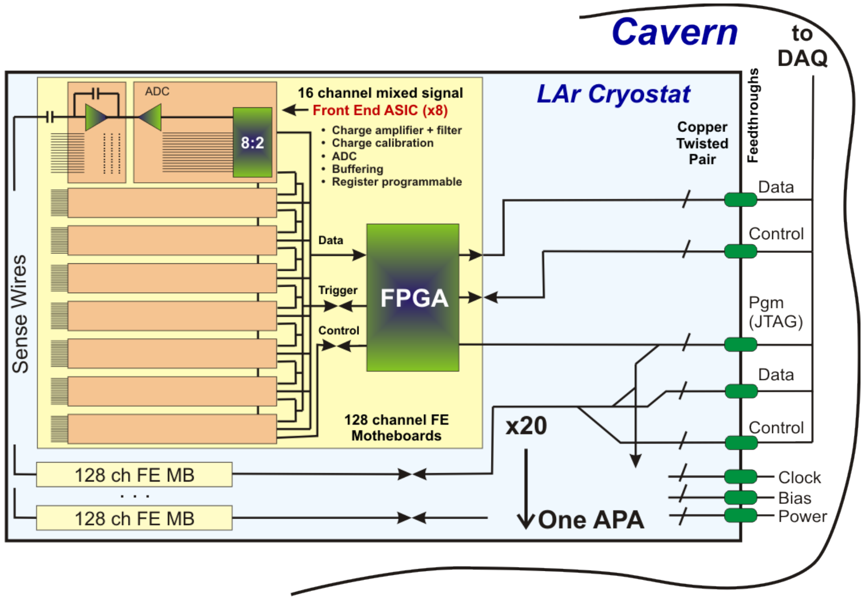
- MicroBooNE is in the process of building the largest TPC in the US - 2.5 m x 2.5 m x 10 m
- Lots of valuable experience gained in this process - understanding how to work with various materials, tolerances on things like the flatness of the cathode plane
- LBNE TPC has a different design - hanging planes for cathodes and anodes

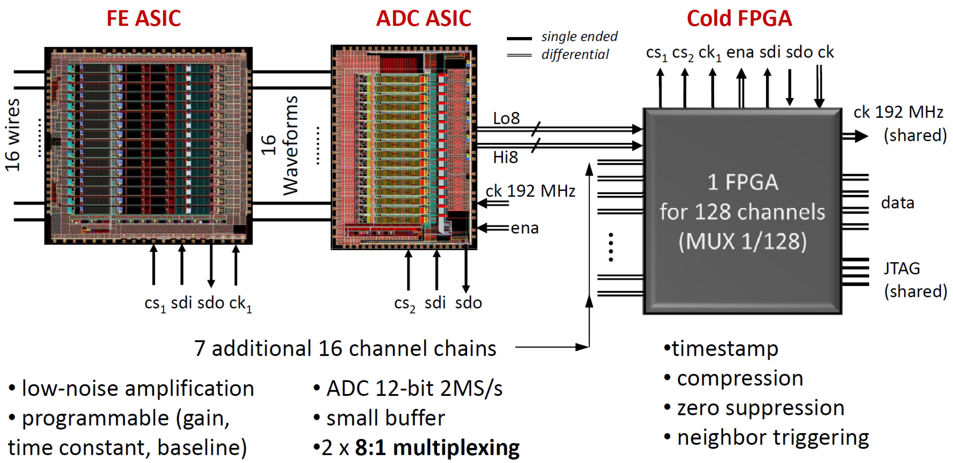
Electronics, DAQ, and Triggering

Keeping noise levels low, dealing with large amounts of data and picking out the interesting signals

Cold Electronics

- Placing front end chips directly in the LAr minimizes capacitance and noise
- On chip digitization converts analog to digital inside the cryostat
- Multiplex signals to high speed serial link - reduces number of cables and minimizes out-gassing. This approach is important to scaling to large detectors
- Cold FPGA houses flexible algorithms for data processing and reduction
- Can use industry standard serial link to connect directly to back end system, minimizes conventional DAQ hardware

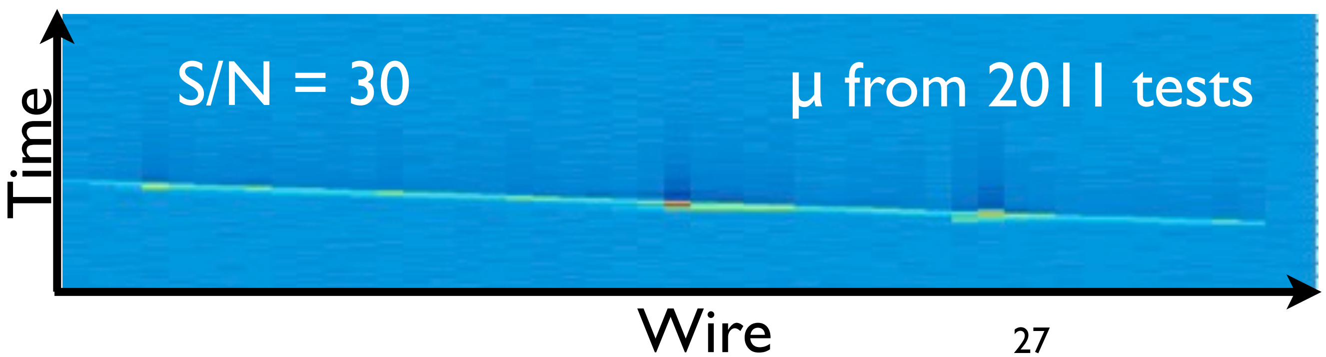




BNL work for LBNE and Dark Side

Cold Electronics

- Two main approaches in US
- Long Bo is a cylindrical TPC with 2m drift, uses off the shelf components for its electronics (MSU)
- Tests show S/N = 30 and currently running in LAPD
- µBooNE and LBNE use specially designed ASICs and boards (BNL)
- BNL electronics have low noise, cross talk and gain variations



FNAL, MSU

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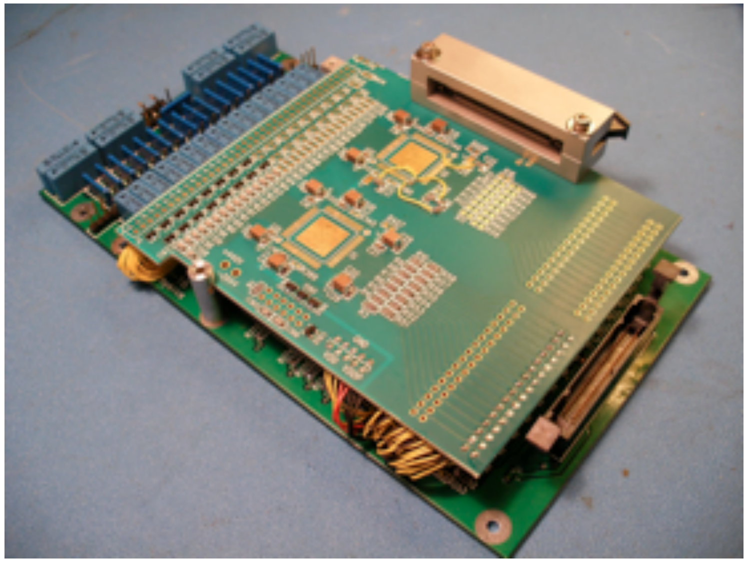

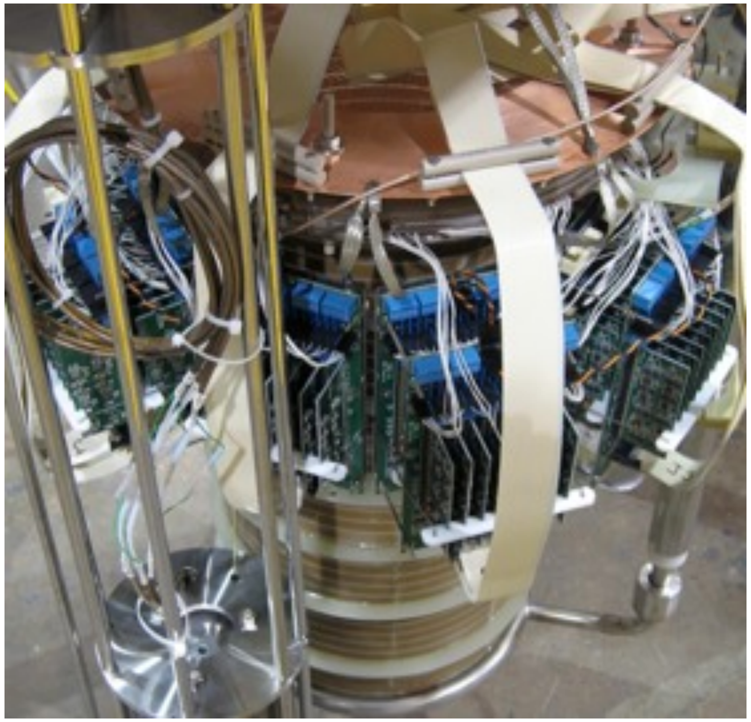

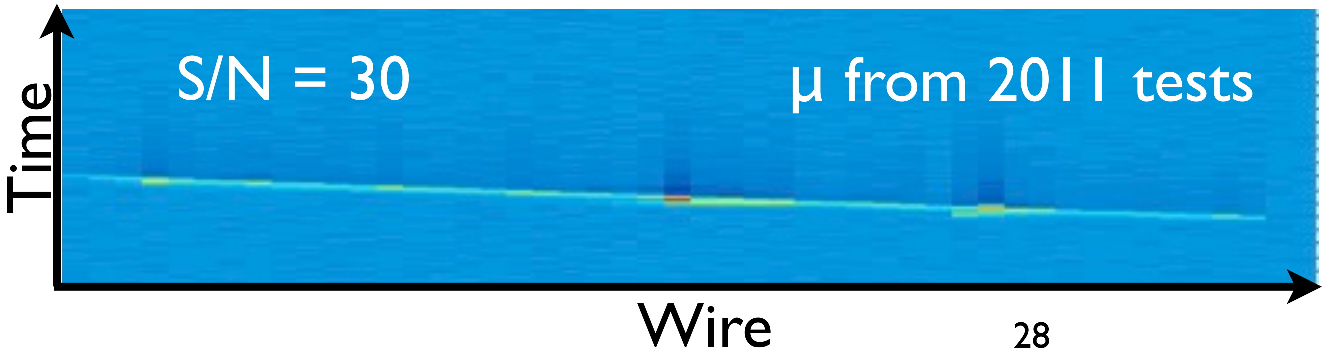

C. Bromberg, D. Edmunds (MSU)

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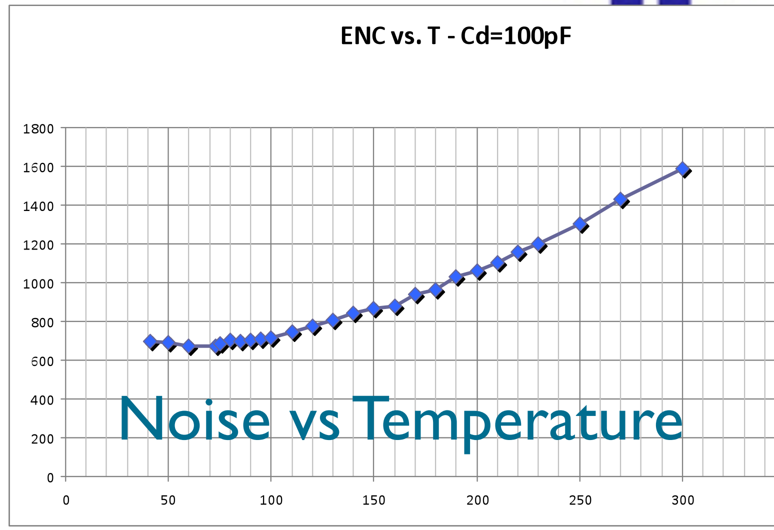
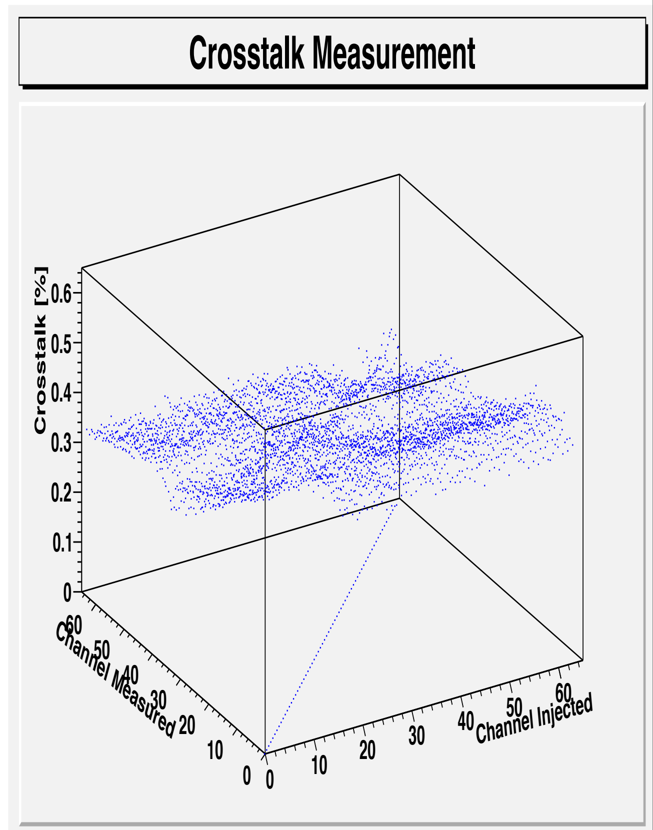
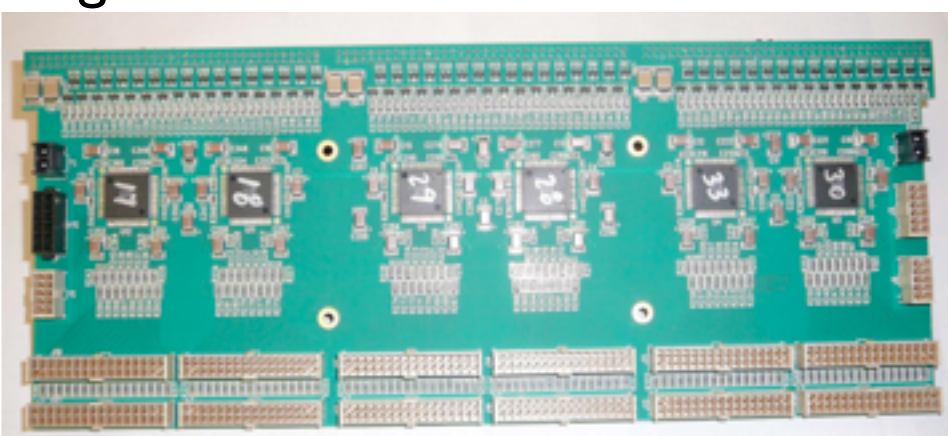


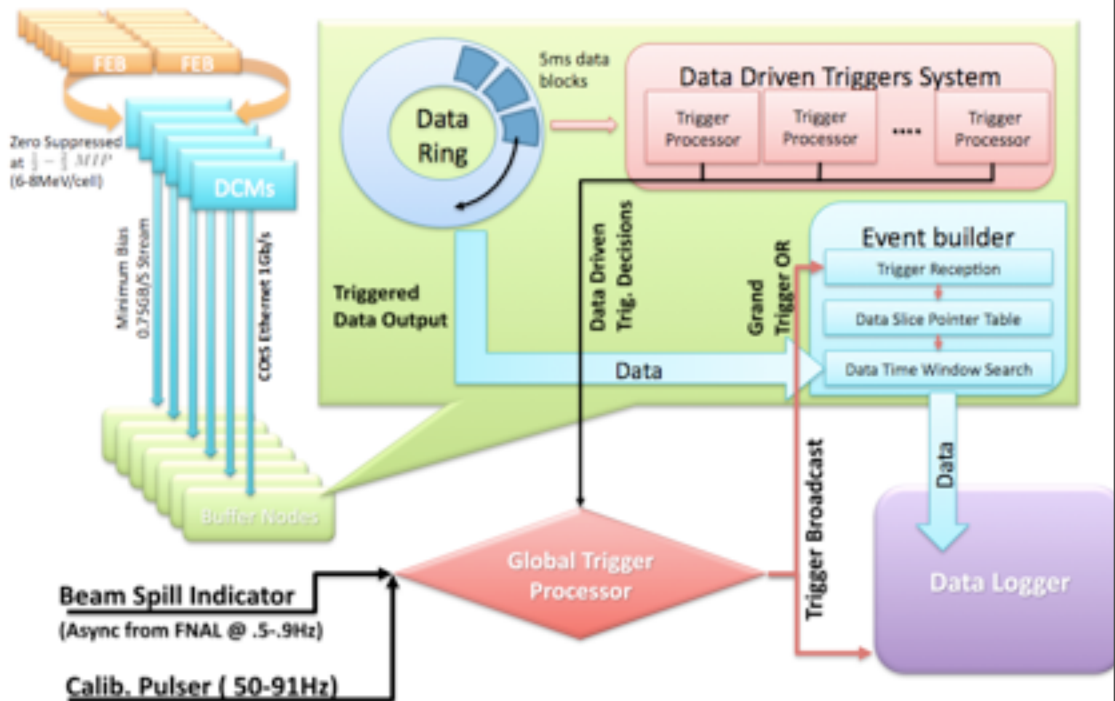




Heat dissipation of 5 mW/channel

DAQ and Triggering

- Clearly each experiment will have different requirements, but there are common things to consider
- Data rates - not only the signal events, but also cosmic ray and radioactivity backgrounds
- How to trigger on signal - GPS clock and accelerator spill timestamps, photon detection, etc
- Data quantity - longer the drift distance, the more clock ticks to read out and store. Need to understand compression algorithms
- LBNE and MicroBooNE making use of NOvA experience



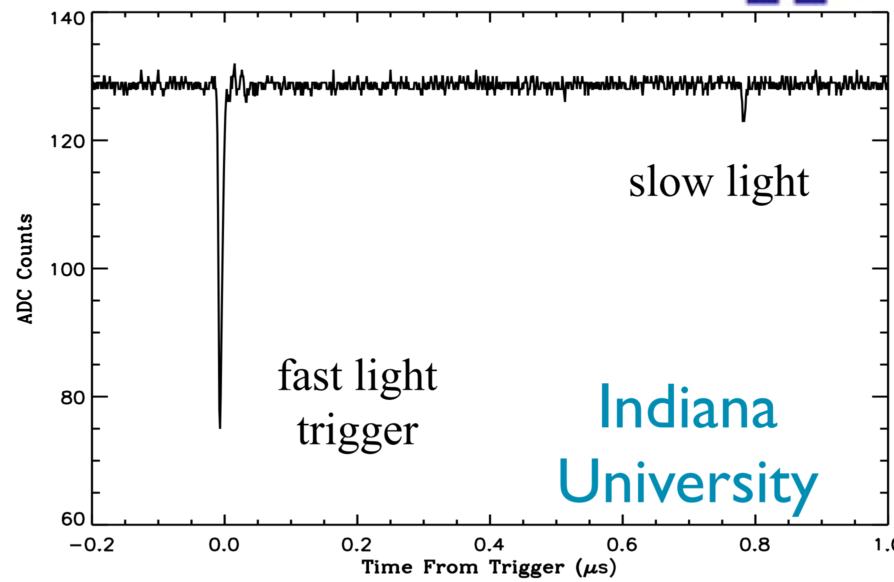
Photon Detection

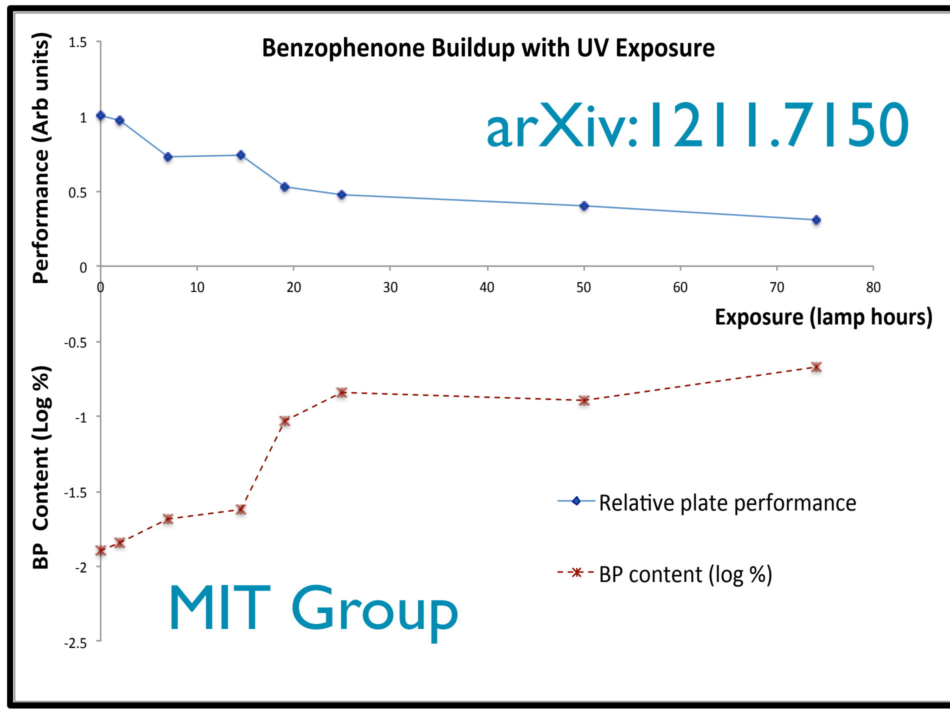
LAr produces scintillation light that can be used for triggering and possibly calorimetric reconstruction

Very useful in the absence of an accelerator signal

Wavelength Shifting

- The emitted light (128 nm) has to be shifted to a wavelength where light detectors have high quantum efficiency
- Options for light collection include placing Tetraphenyl Butadiene (TPB) coated plates in front of PMTs and coated bars as light guides to SiPMs
- TPB degrades when exposed to UV light - handling TPB requires care to ensure it still works when installed
- Another option explored by CSU is using WLS fibers coupled to SiPMs

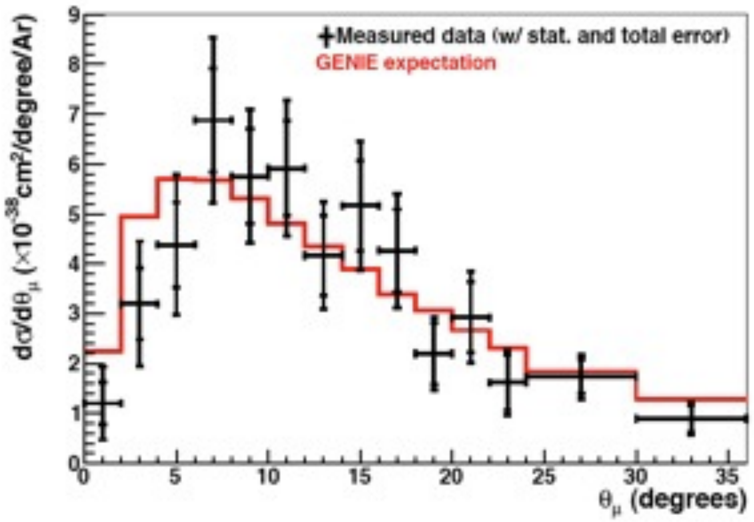


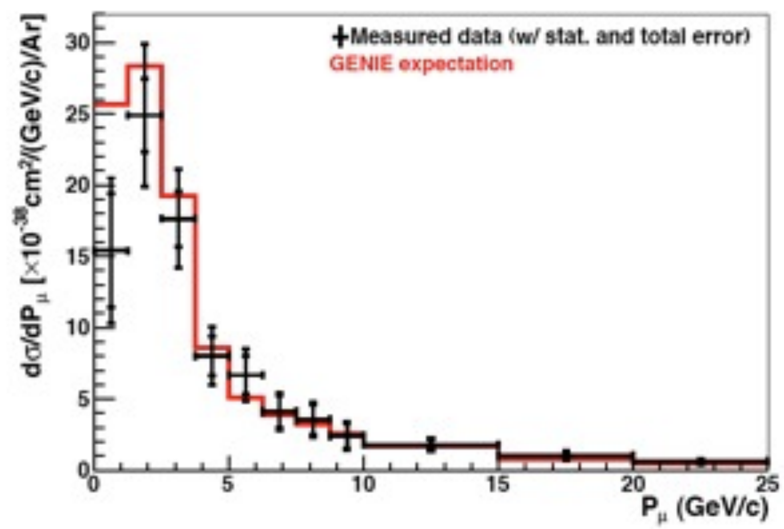


Test Beam Efforts

Understanding the performance of LArTPCs

ArgoNeuT: First Cross Section Measurements on Ar





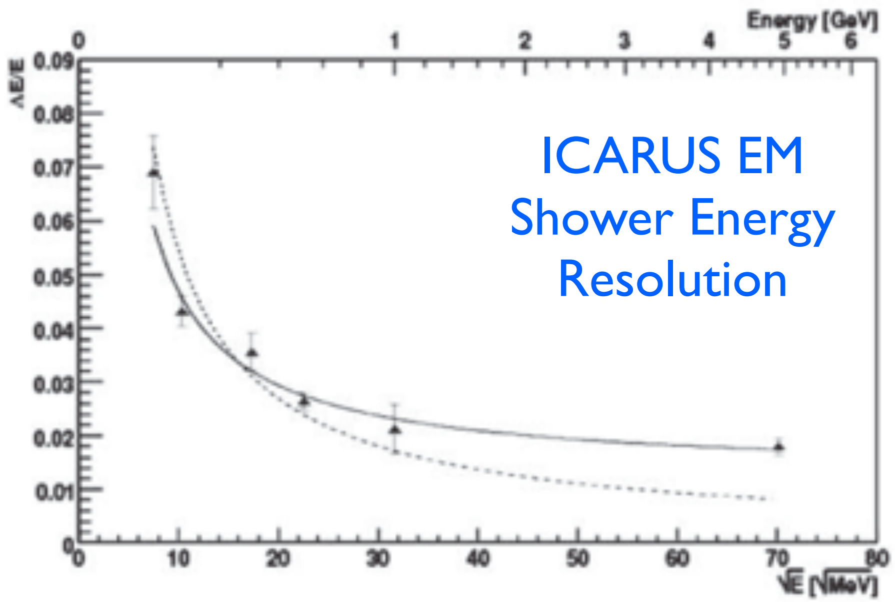
- ArgoNeuT took data in NuMI beam for 5 months in 2009-2010
- First measurements of differential cross sections for neutrino-Ar interactions made with the neutrino mode data

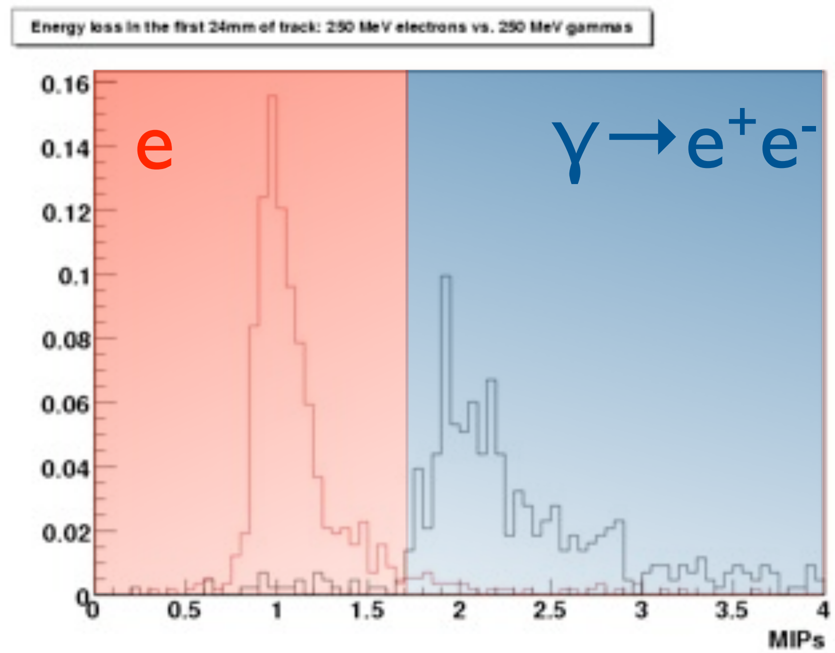
$$\sigma/E_\nu = (7.3 \pm 1.2) \times 10^{-39} \frac{\text{cm}^2}{\text{GeV}} \quad \langle E_\nu \rangle = 4.3 \text{ GeV}$$

- Published in PRL 108, 161802 (2012), 2 more papers recently accepted - JINST 7, P10019 (2012) and JINST 7, P10020 (2012)
- Collaboration between Fermilab and 8 other institutions
- Analysis was done using LArSoft reconstruction and simulation package

LAr Detector Beam Test

- A major question from the 2009 Fermilab LAr R&D review was *How well known are the energy resolution and particle identification capabilities of a LArTPC?*
- Previous estimates 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
- Need data from particles and energies expected in neutrino experiments: e, p, π, μ
- LArIAT and LDRD efforts clearly important components to LArTPC R&D



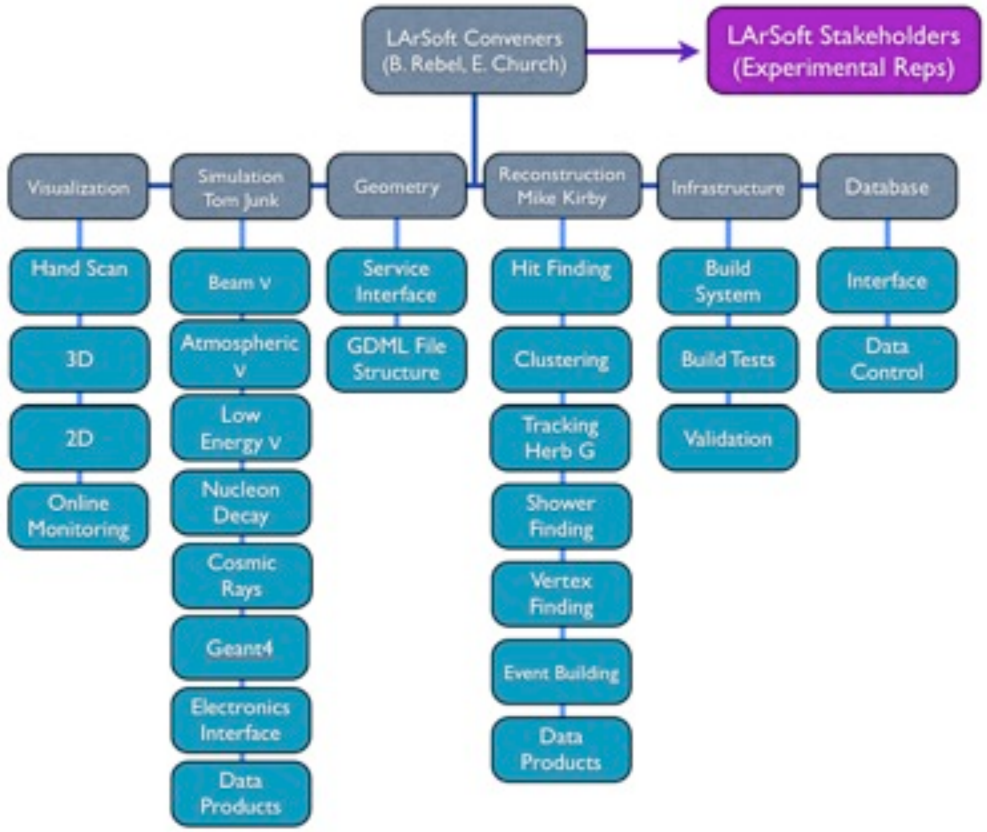


Software

Simulation, Reconstruction, and Analysis

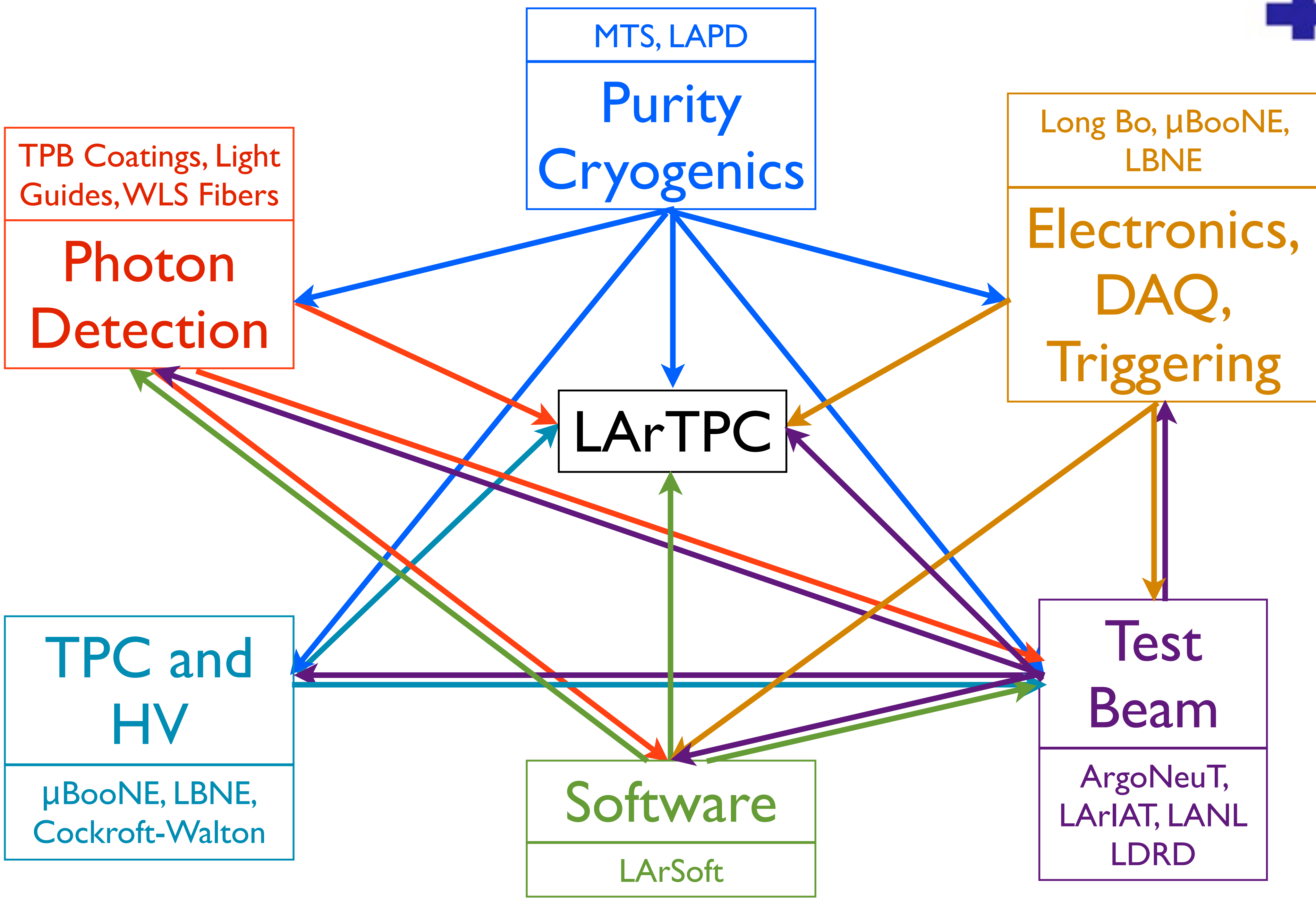
LArSoft

- 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



LArSoft Documentation at https://cdcvs.fnal.gov/redmine/projects/larsoftsvn/wiki

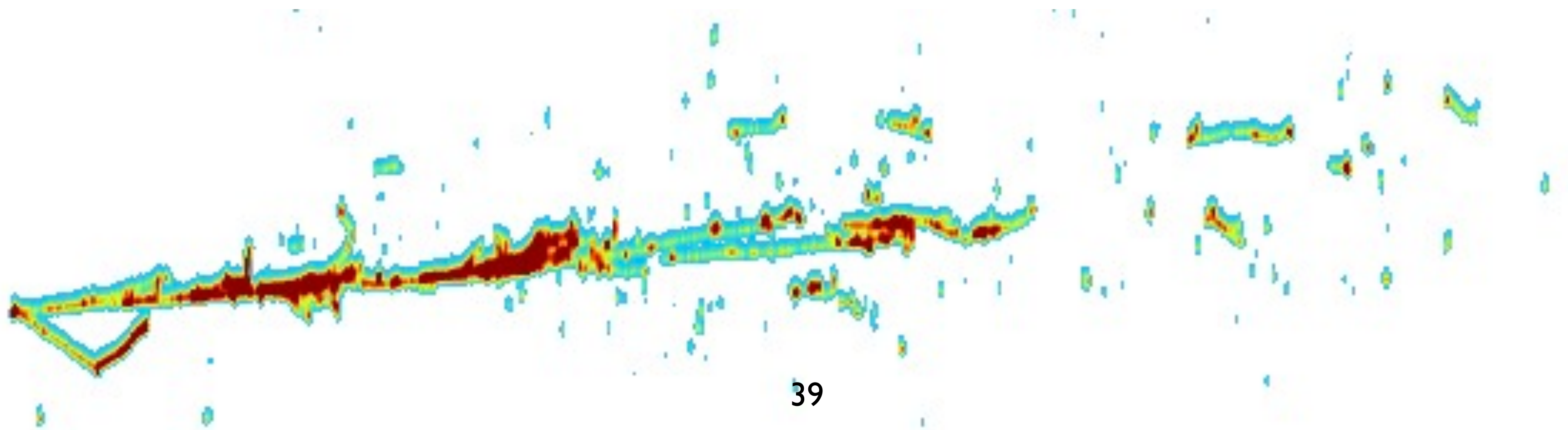
Bringing It All Together



Next Steps

- Organizing a workshop to go through these areas in depth
- To be held at Fermilab March 20-21, 2013, website will be live soon
- Email list created to foster communication in the community - cpad_lartpc@fnal.gov
- Subscribe by sending email to listserve@fnal.gov with no subject line and body should have

  SUBSCRIBE cpad_lartpc FIRSTNAME LASTNAME

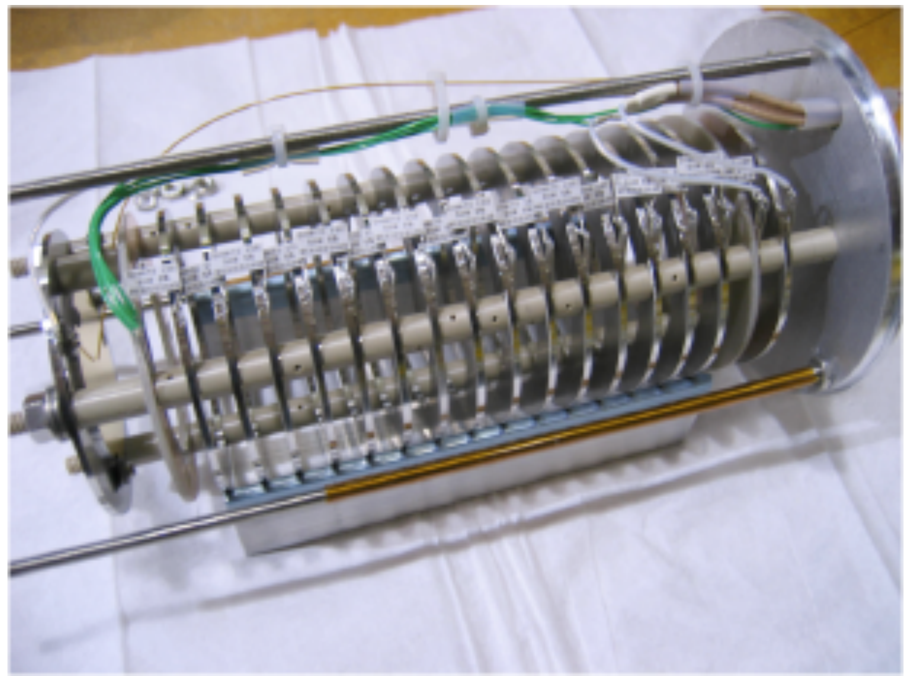


Fermilab Program for Understanding Purity

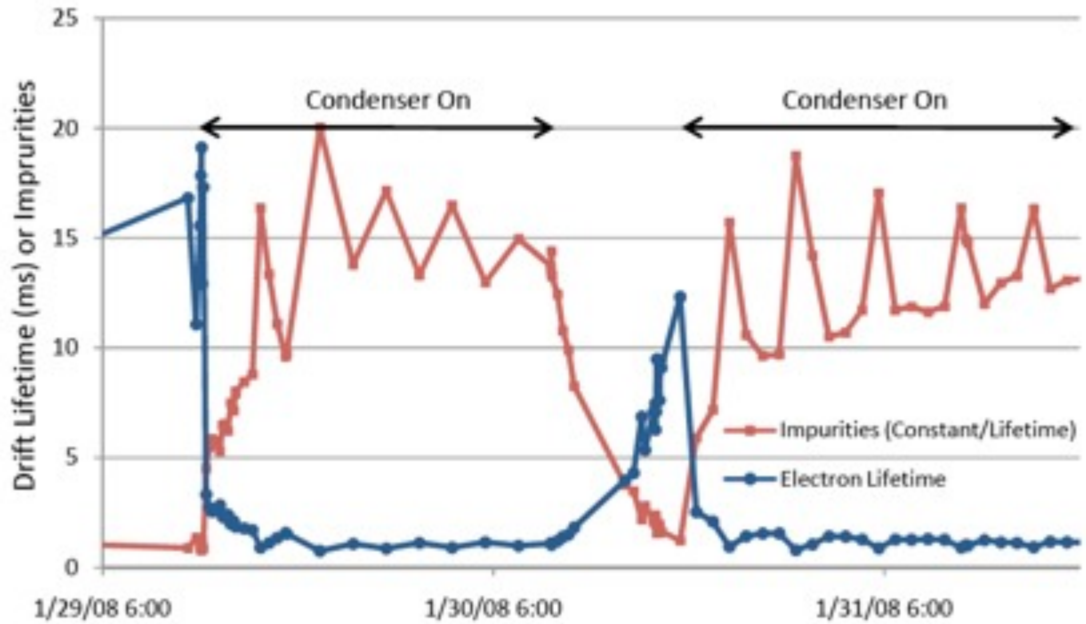
- The mantra is to learn and keep learning from existing systems, like ICARUS
- In addition, we want to develop experience with filters, cryogenics, pumps and electronics
- Use home grown test stands to get the experience and push the development
- Test stands allow us to judge suitability of materials to use in a LArTPC (MTS), and understand how to achieve large drift lifetime without evacuation

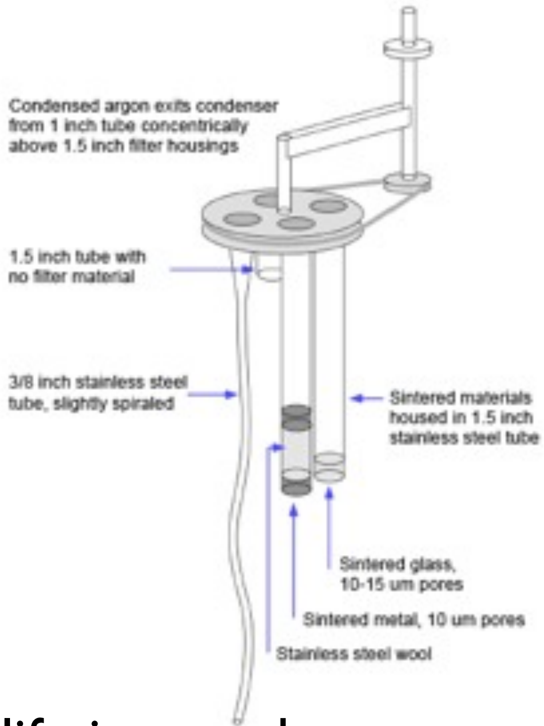
Program for Understanding Purity

- Sample cage volume is 10 cm x 10 cm x 10 cm
- Argonlock can be purged with either external argon or argon from the cryostat
- Can also be evacuated
- Electron lifetime is measured using an ICARUS style purity monitor



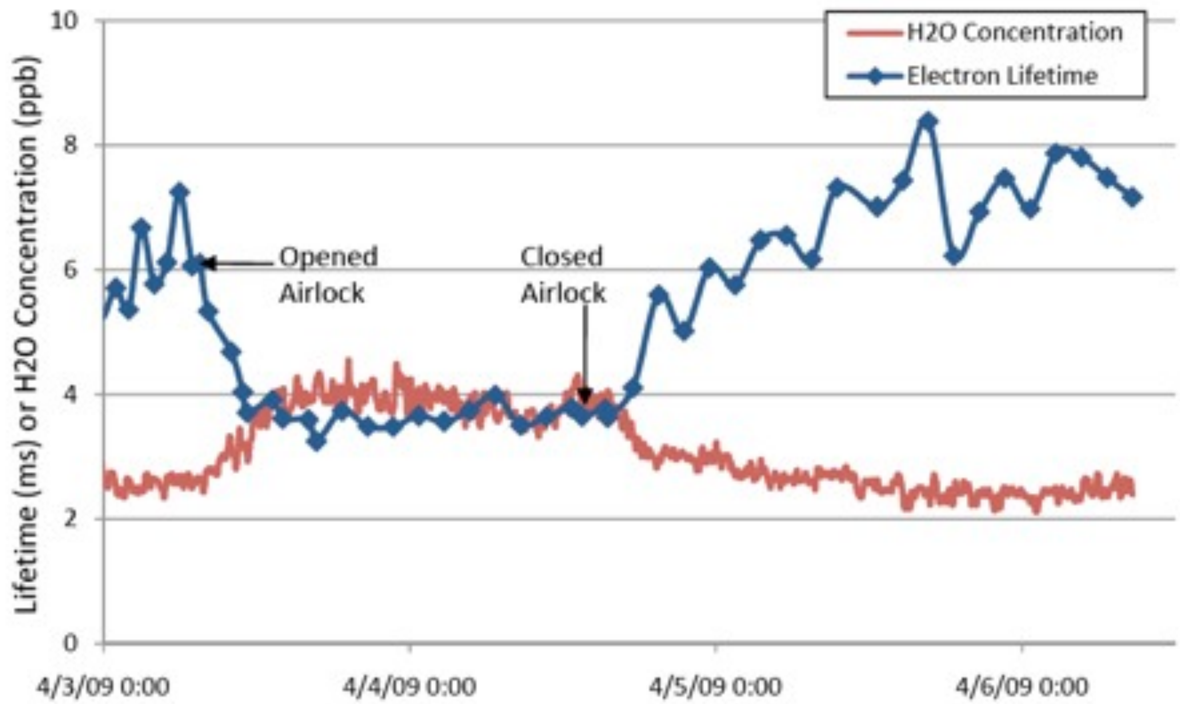
Condenser Surprises





- Initially, operation of the condenser caused electron lifetime to drop
- Condensed liquid rained directly into the bulk liquid
- Several tests through various return paths showed that increasing cold metal surface area on return to liquid improved lifetime
- Hypothesis: impurity desorbs from warm surfaces, gets mixed into liquid in condenser
- Depending on return path, impurity can adsorb to cold metal on return to liquid and be removed

What is the Impurity?



- Source must be something that remains on metal surfaces in vacuum and has an affinity for cold surfaces: Water is a clear suspect

- Moisture analyzer with 2 ppb detection limit used to monitor water concentration in cryostat

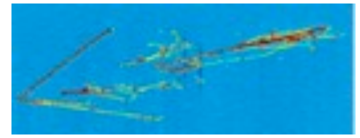
- Water concentration increases when airlock is open to cryostat, electron lifetime decreases

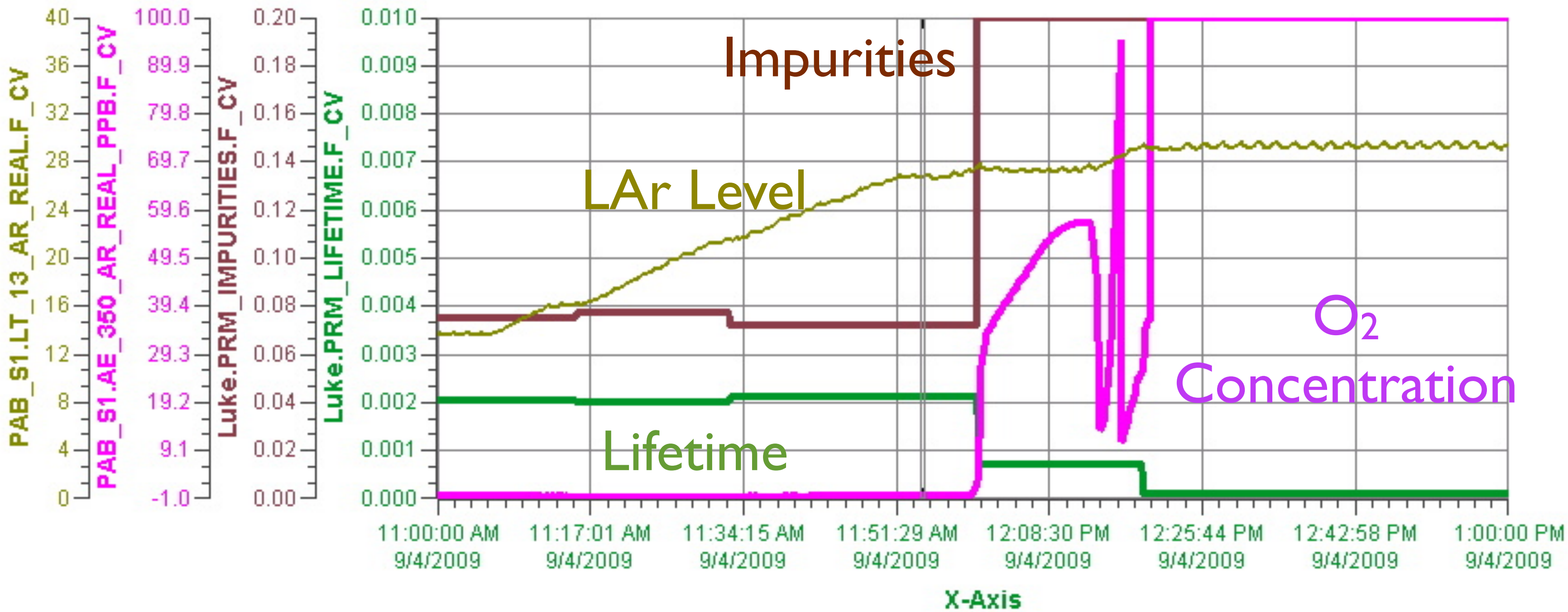
Data from Various Materials

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

- Significant correlation with data in water-content database at outgassing.nasa.gov
- FR4 is fine to use in the liquid, don't place it in warm gas
- Teflon tubing is far superior to polyethylene tubing

Filter Capacity Tests



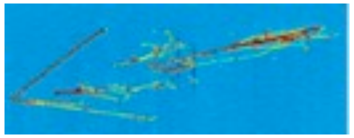


Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
Luke.PRM_LIFETIME....	Luke.PRM_LIFETIME.F_CV	0.00210	sec	0.00210	0.00005
Luke.PRM_IMPURITIE...	Luke.PRM_IMPURITIES.F_...	0.0715	Imps	2.7750	0.0715
PAB_S1.AE_350_AR_...	ppb version for plotting (F_...	-0.80	ppb	463.06	-1.01
PAB_S1.LT_13_AR_R...	Luke Argon Level Probe	26.6	inches	29.7	13.5

9/4/2009 11:00:00 AM — 9/4/2009 1:00:00 PM

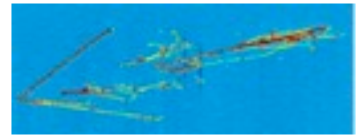
- This figure shows an example of filter 'Break Through'
- Argon level is nearly constant, but impurity levels spike as does the oxygen concentration
- Break through is happening during filling

Summary



- Detector Materials
  - Materials immersed in the liquid have no effect on electron lifetime
  - Materials in the ullage have no effect on lifetime if the gas is venting at a large enough rate to prevent diffusion into the liquid
  - Materials in the ullage have a significant effect if the warm gas mixes with the liquid argon or if metal surfaces outgas water vapor at a significant rate
- Filters
  - Industrial materials are capable of removing all electronegative materials (water, oxygen) and producing liquid with lifetimes greater than 10 ms
  - Filters can be regenerated many times using a non-flammable Ar-H mixture
  - Filter regeneration will happen during initial fill and purification, not necessary during maintenance running

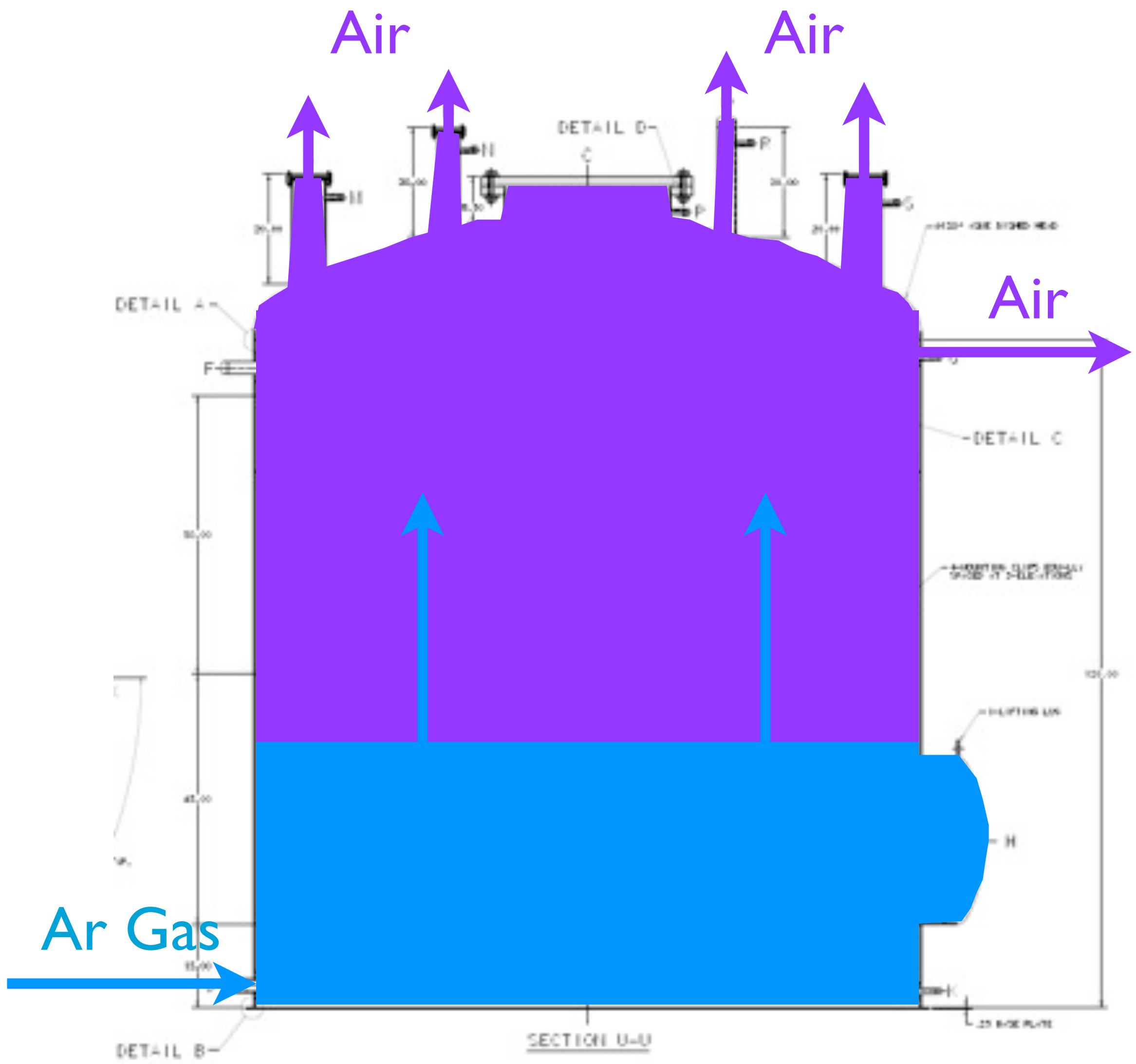
Summary



- Contaminants: absent leaks, water is the primary concern as it comes from detector materials and the cryostat walls in the warm gas
- Considerations for any LArTPC
  - Cold surfaces in the ullage that will condense contaminant-laden gas directly into the liquid must be eliminated
  - Materials in the ullage should have minimum water content, ie use teflon instead of nylon
  - The amount of material in the warm ullage should be minimized, ie reduce the number of cables passing out of the TPC
  - Adequate flow of argon gas away from the liquid should be maintained, as done in ICARUS
  - Pass all argon through filters before allowing it to return to the bulk

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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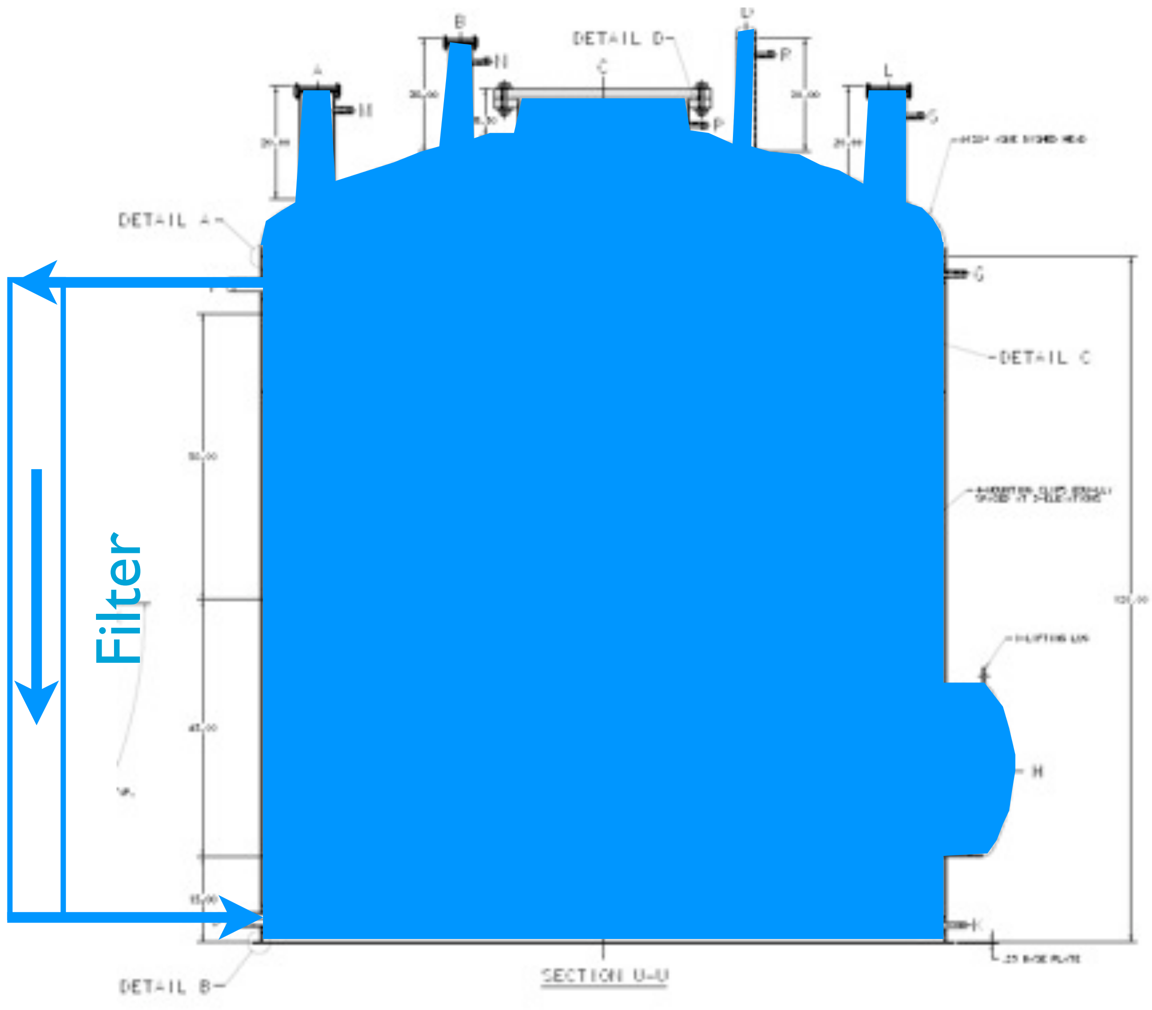
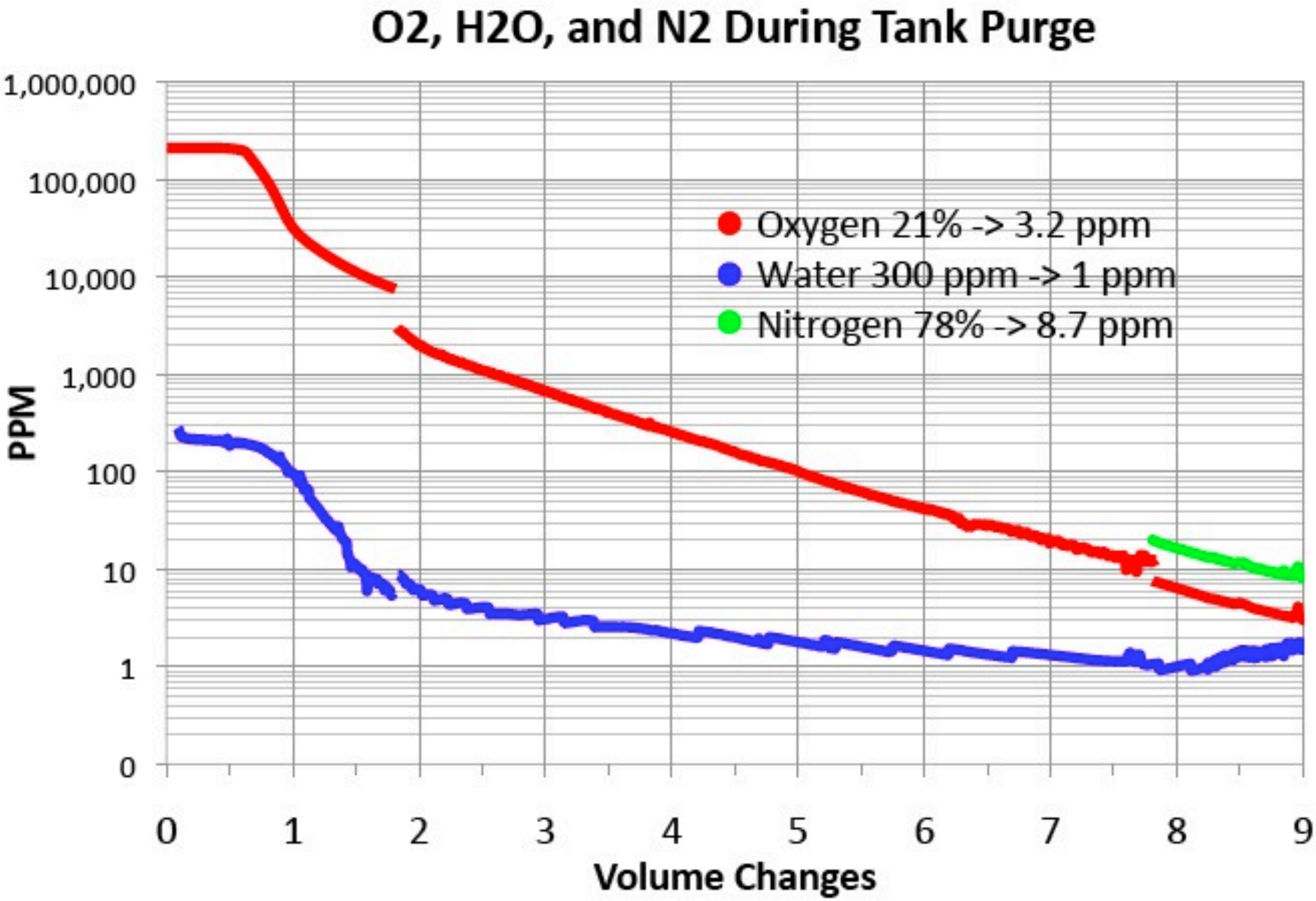
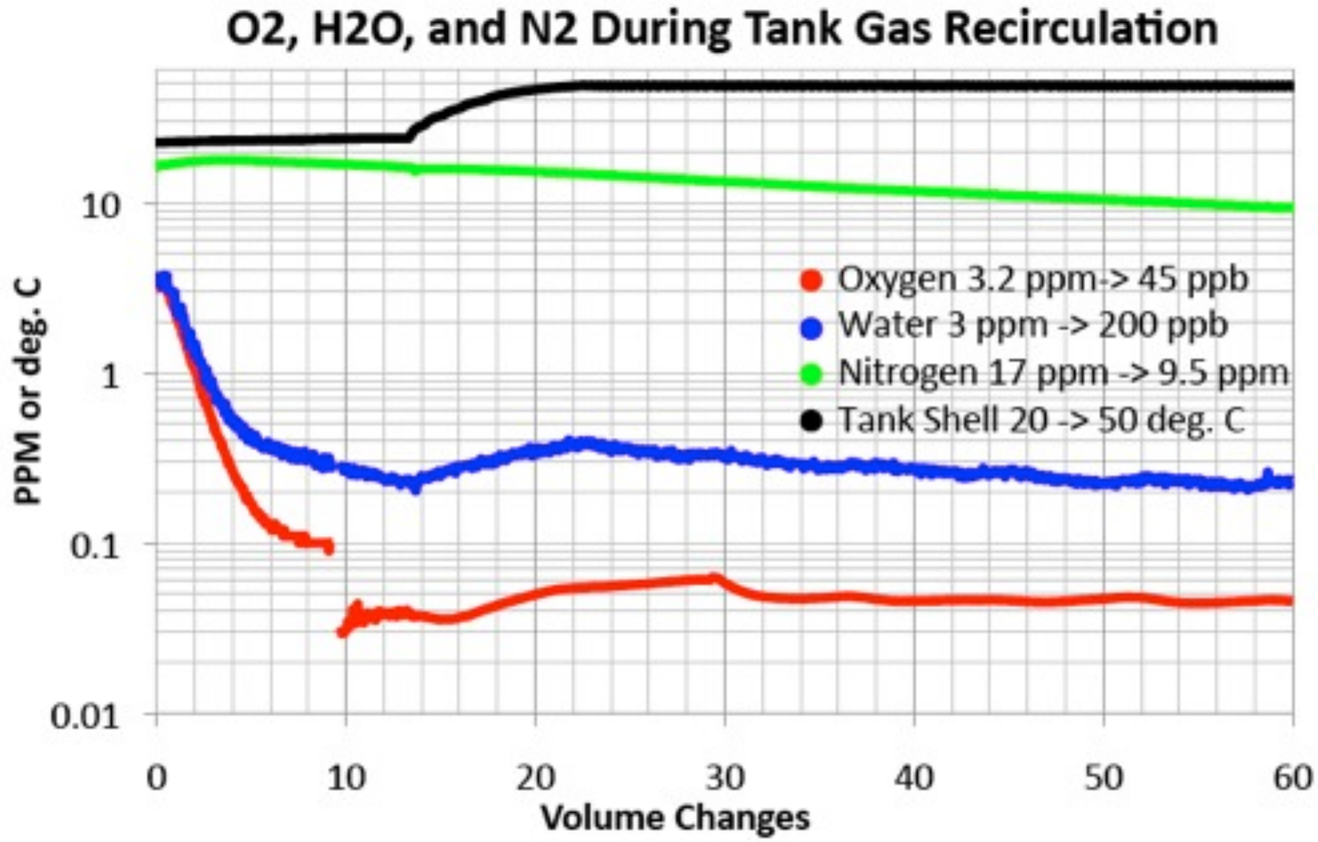


Gaseous Argon Purge

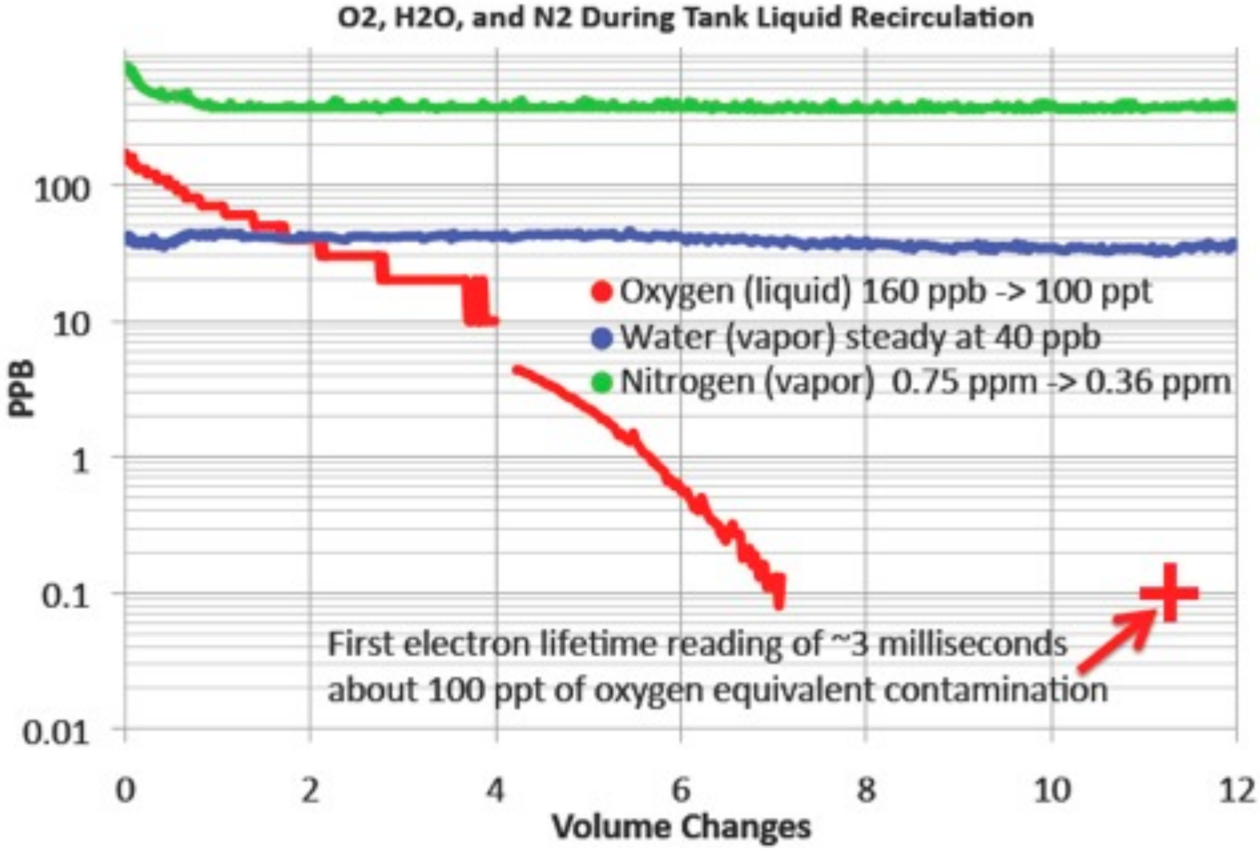


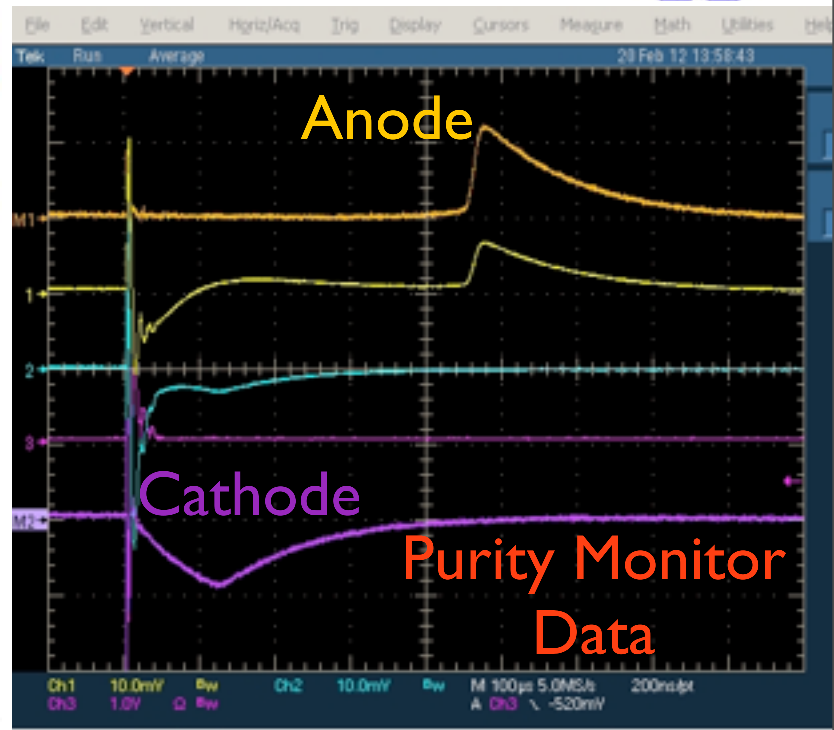
Gaseous Argon Recirculation



- 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





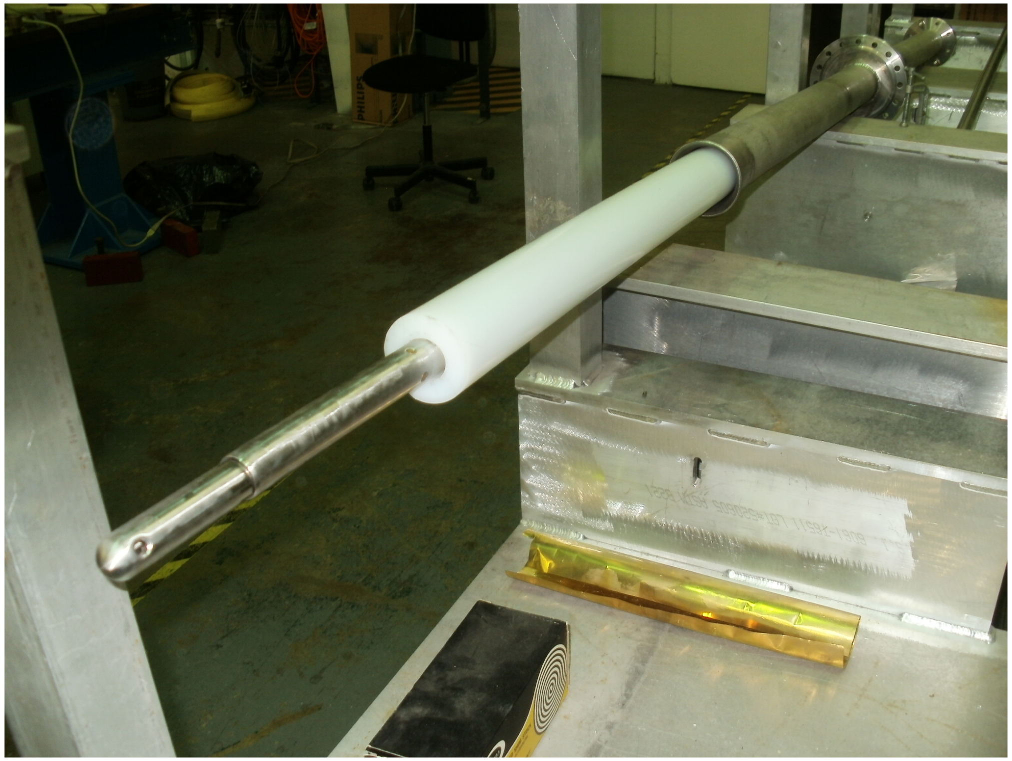
- Liquid filtration began after the flow through the O_2 filter was reversed to prevent clogging of the particulate filters
- Filtration progressed at the rate of about 1 volume exchange every 6 hours
- First electron lifetime measurements made after 11 volume exchanges
- Electron lifetimes were determined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

35 Ton Membrane Cryostat Prototype

- Cryostat is now complete
- Working on the process piping to connect to the LAPD filtration system

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

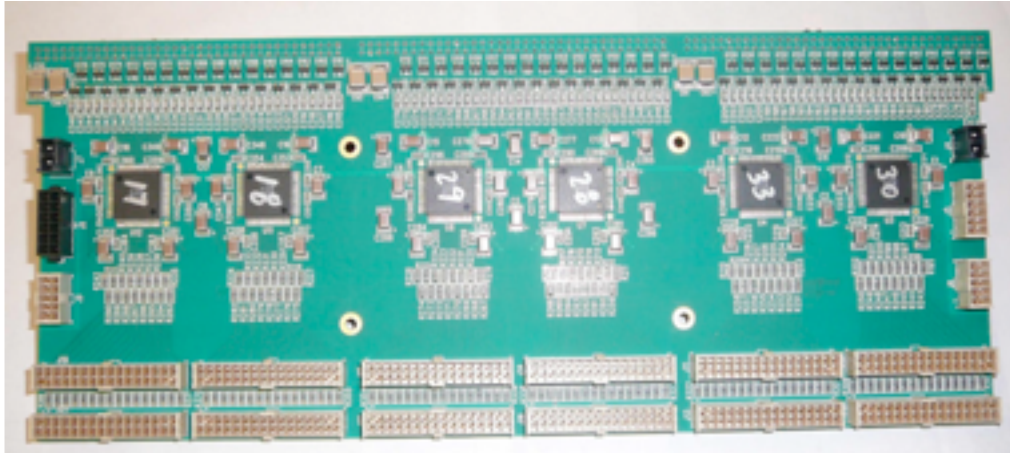
Current Efforts to Design Feedthroughs



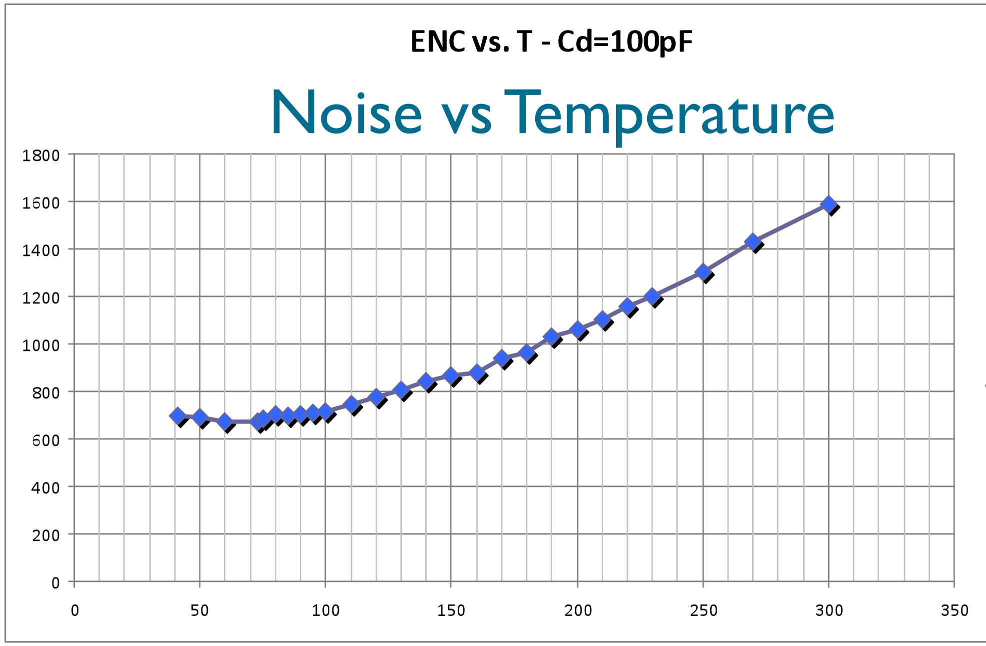
- UCLA group working on design for LBNE
- Fermilab group working on design for MicroBooNE, being tested with Long Bo
- Successfully held 60 kV in Long Bo for last couple of days

μBooNE: Cold Electronics

- A primary goal of μBooNE is to understand 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 is < 0.3%, gain variations are 7%
- 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, designed for > 30 year lifetime



Heat dissipation of 5 mW/channel



Saturday, February 2, 13

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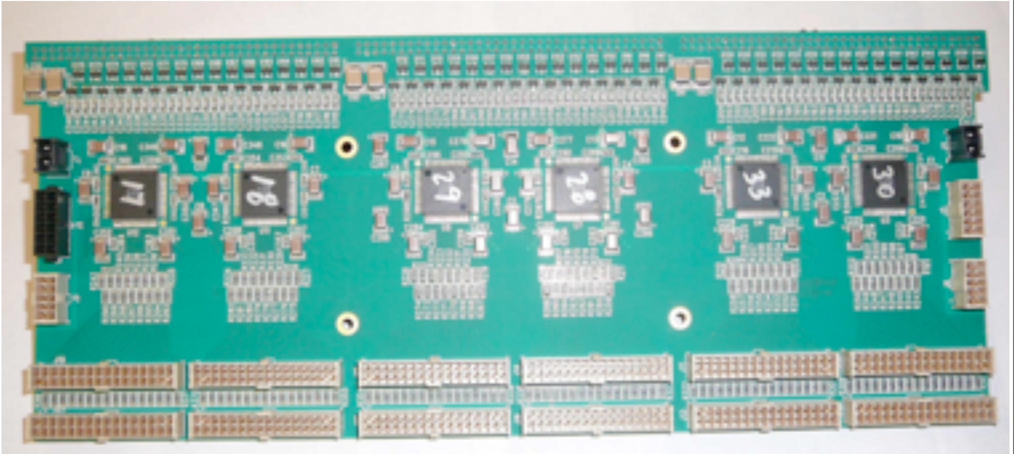
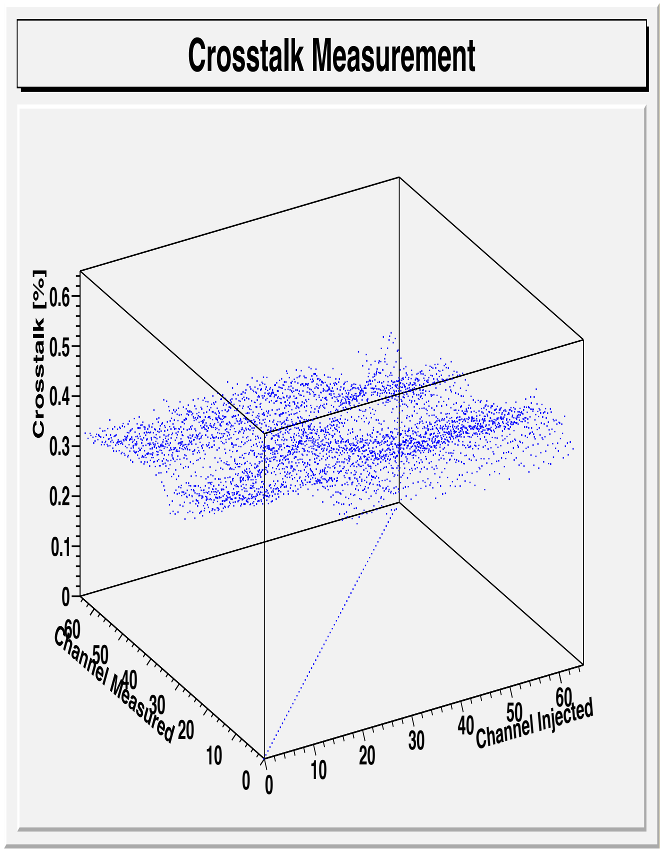




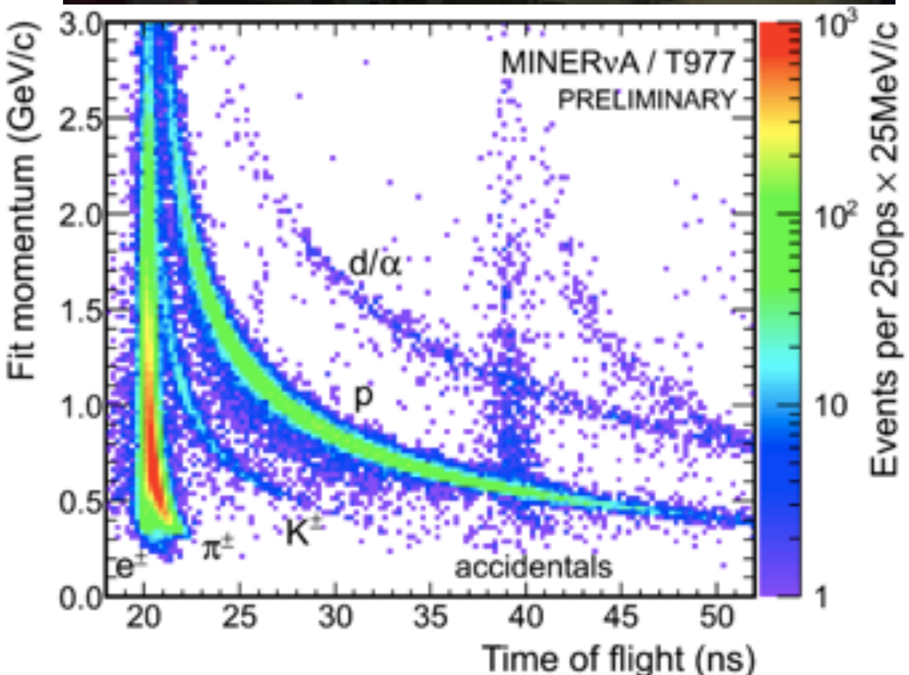
ArgoNeuT

- First LArTPC in a low energy neutrino beam - mostly R&D, but with some Physics thrown in
- Cryostat went into the MINOS hall in December 2008
- Filled with LAr May 8, 2009
- Ran through February, 2010

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330μs)
Light Collection	None

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

Cockroft-Walton High Voltage

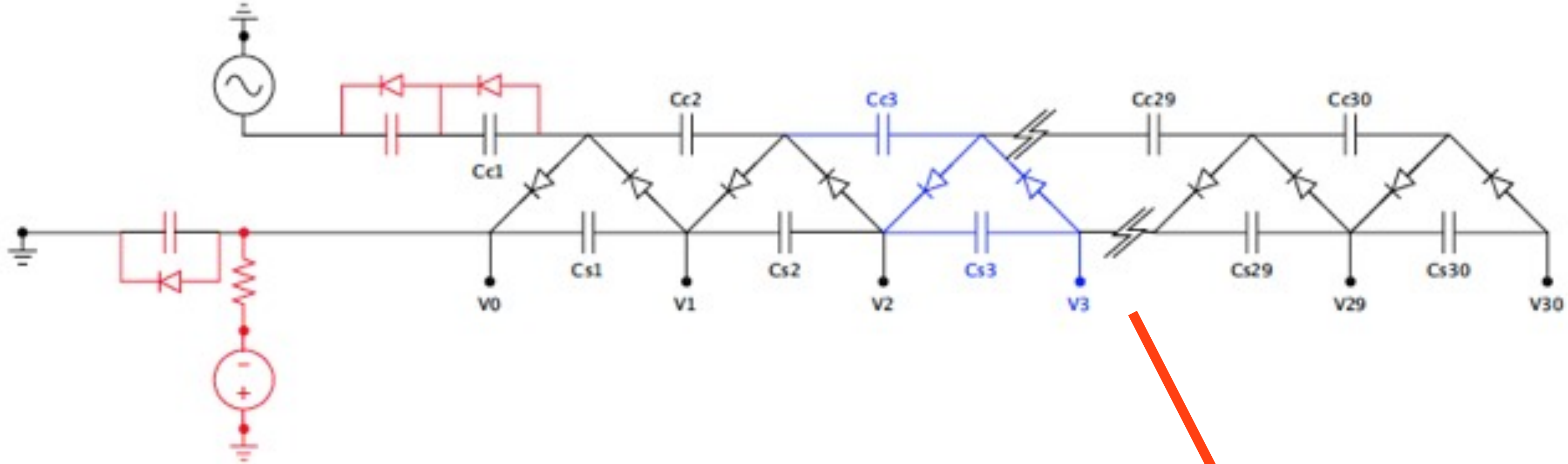
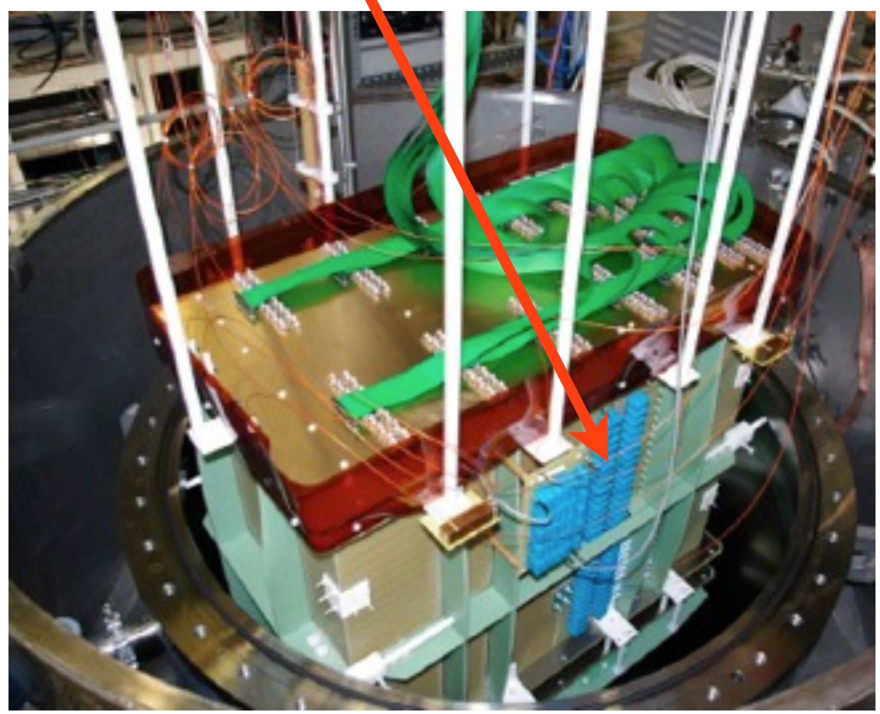
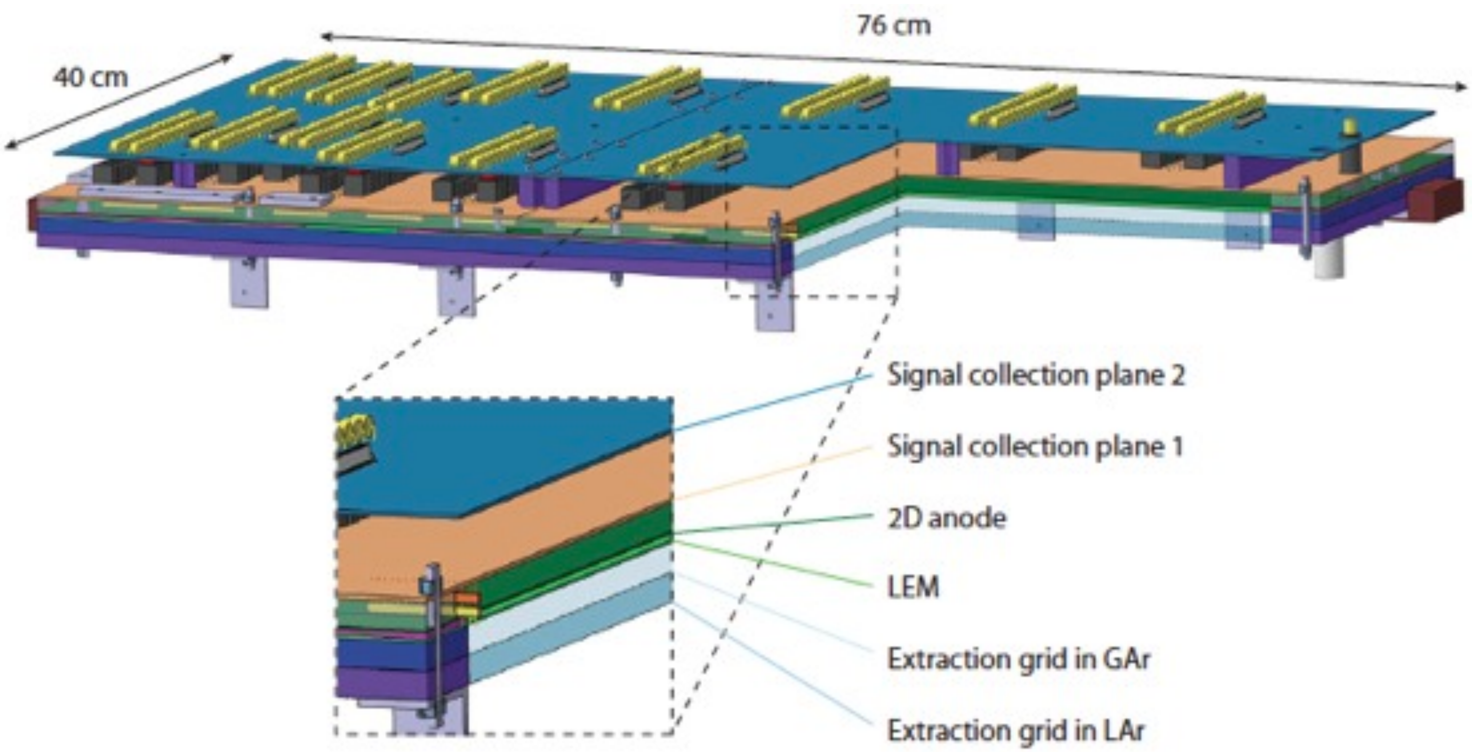


Figure 5. Diagram of a 30-stage negative Greinacher circuit. The stage No. 3 is colored in blue to visualize the structure of a single stage. The DC voltage source, the capacitors and the diodes shown in red are used to shift the potential of the whole circuit by a certain value with respect to the ground.

- Used in T32 test beam experiment in Japan, not used currently in US
- Advantages include requiring much smaller HV input to achieve the required field in the TPC
- Disadvantages include having to wait for the circuit to charge, frequency of recharge has to be low



Dual Phase TPCs



- One way to improve signal to noise is to drift electrons through liquid into gas phase and then drive them through thick GEMS aka LEMS
- Gain of size 27 was reported by ETH Zurich group, S/N > 200, compare to values in the range of 10 - 30 for single phase detectors
- Used in T32 test beam experiment in Japan, not used currently in US

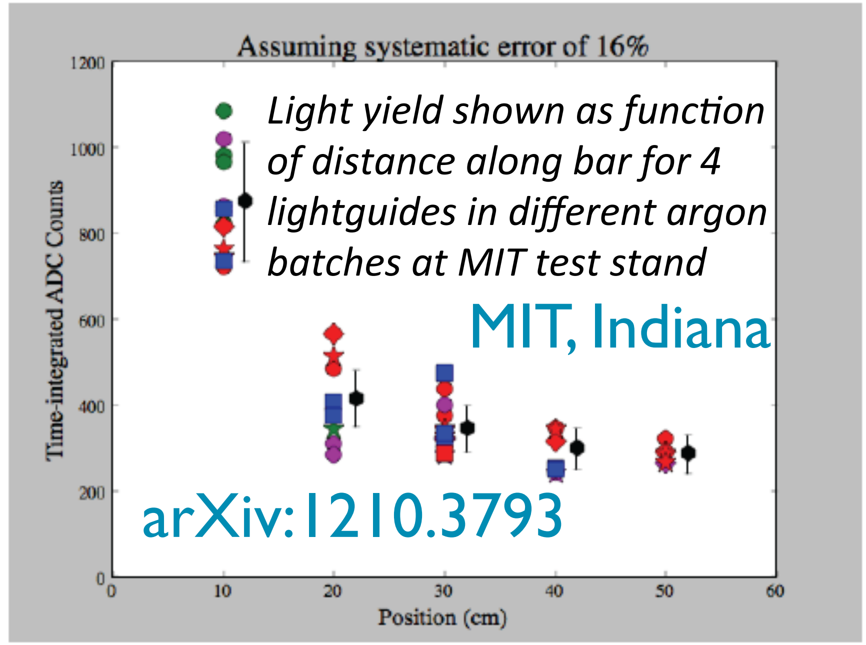
Light Guides

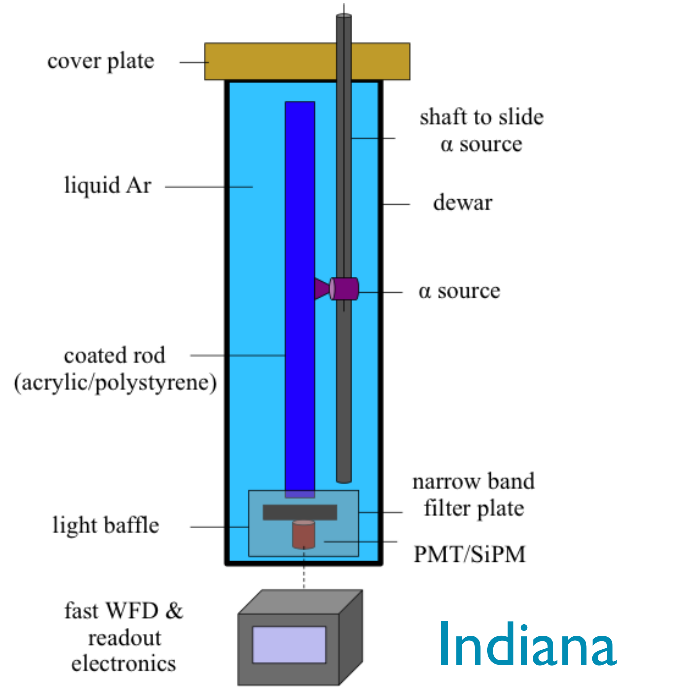
- Options for light collection include placing TBP coated plates in front of PMTs and coated bars as light guides to SiPMs

- Fermilab will be constructing a facility for testing various light collection techniques - cryostat with 48 inch diameter and 60 inch height with argon delivery and filtration

- First customer will be Indiana University to test paddle system for LBNE

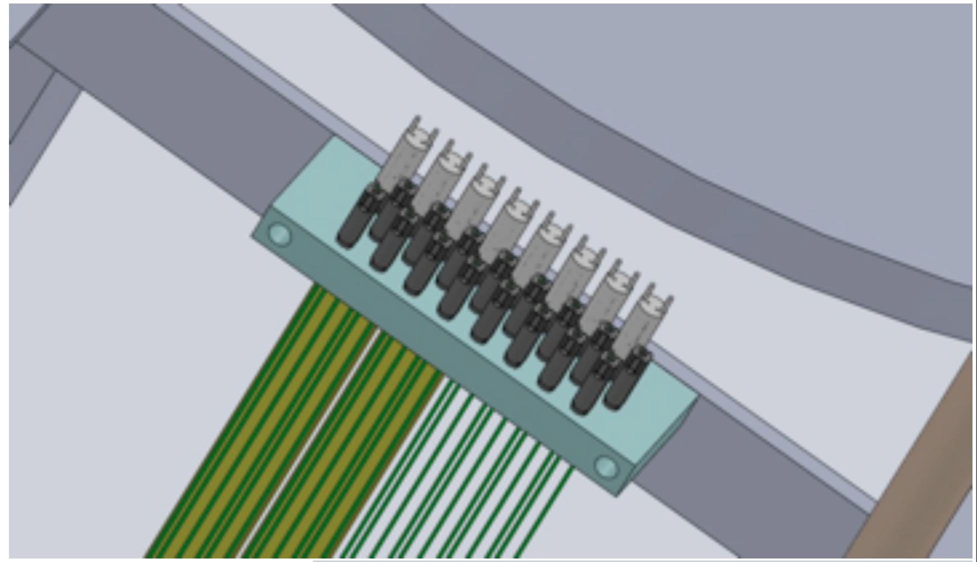
- Can be used to test other techniques like LAPPDs

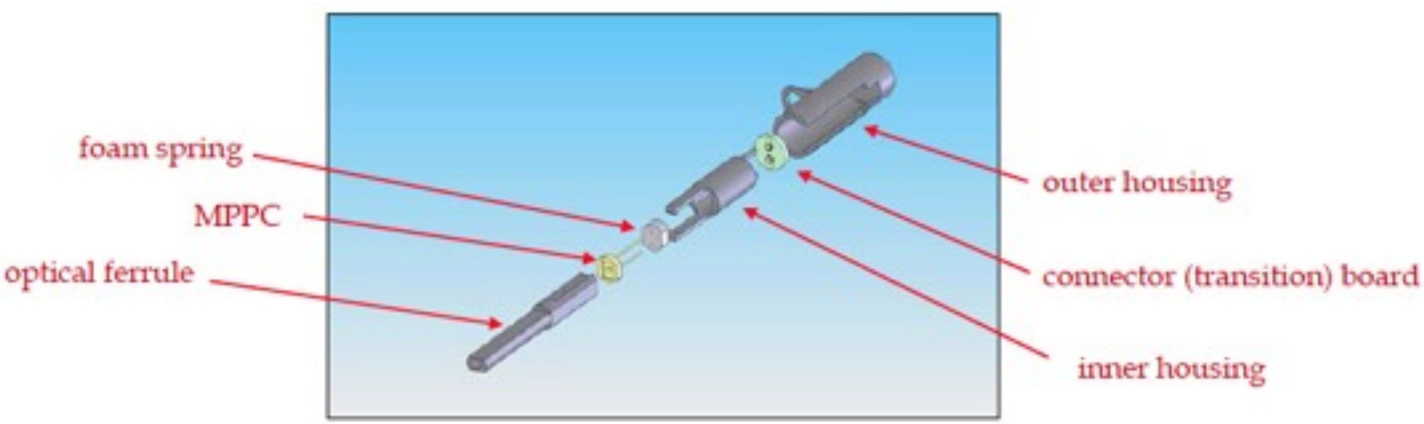




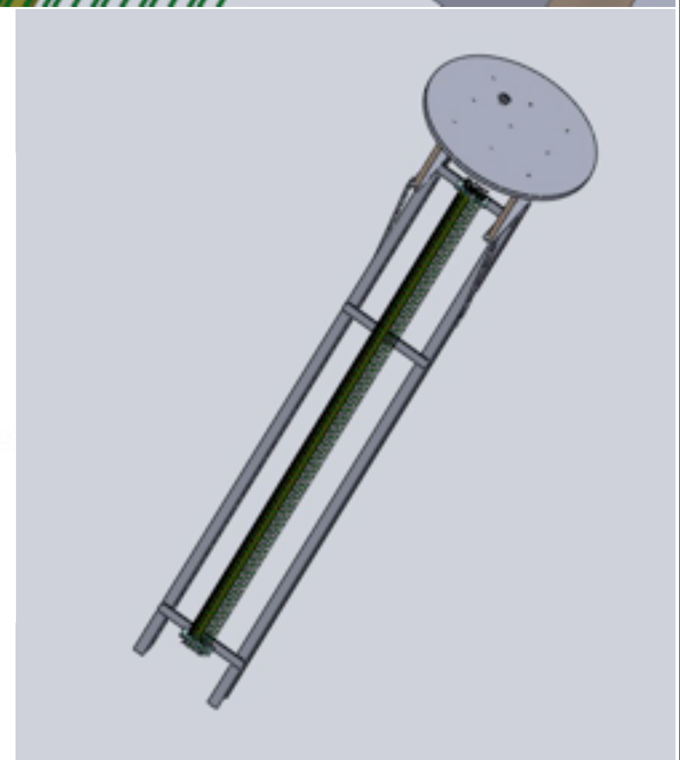
Fiber Based Photon Detection

- Colorado State looking at using wavelength shifting fibers to collect the photons
- Uses SiPMs as active detector
- Coupling of fiber to SiPM based on T2K near detector experience



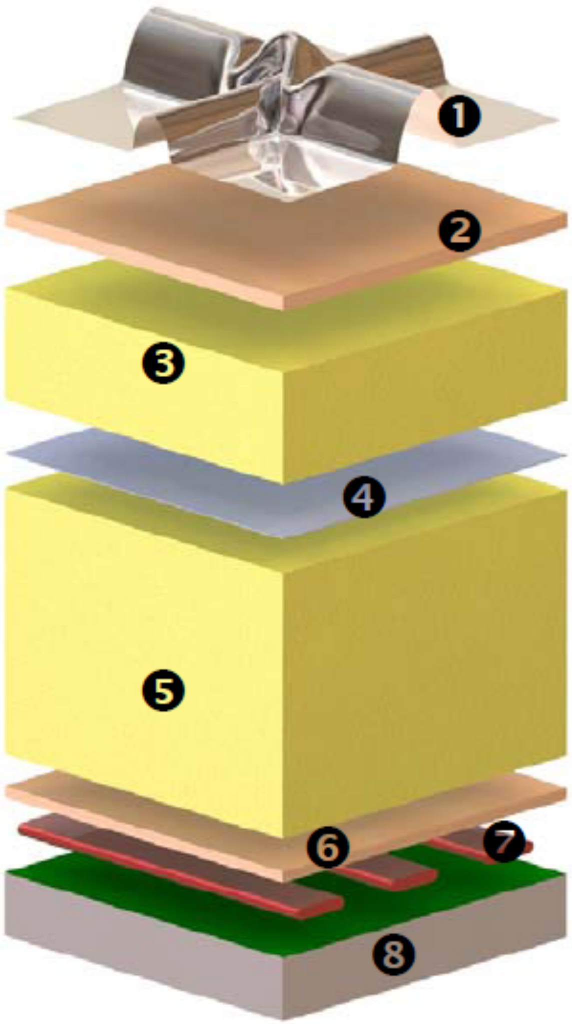


Exploded view showing all components




MT1 Target: 25cm Al
MT4 Target: 30cm Al
MT6 Absorbers: 1.5m
MTest Beamline
MCenter Beamline
M01
M02
M03
M04
M05
MS1
MS2
MS3
MS4
MS5
MS6
MS7
MT6 Sect 2
MC6
MB6
MC7
MB7
MC8
PK045
PK066
PK067
MW7
MW8
MP7
MP8
M West Cryo Area
Cryo offices
M Polarized
MEast
ILC
Meson Detector Bui (MDB)

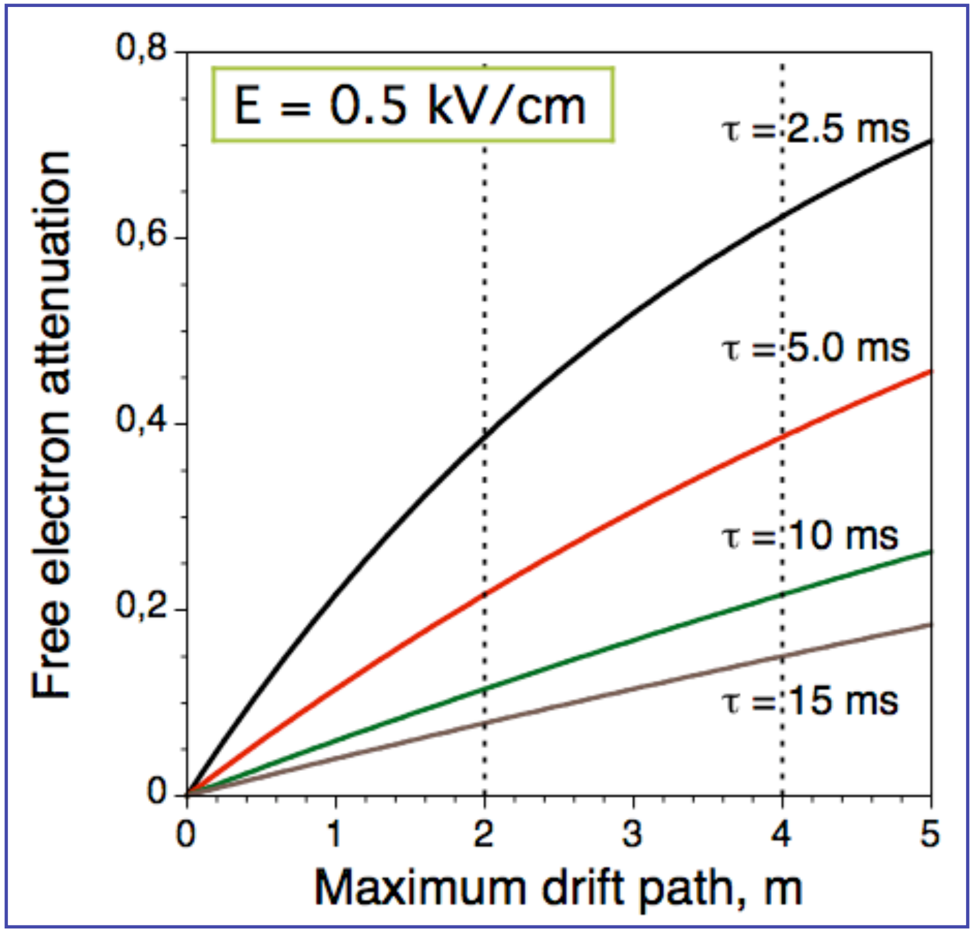
Membrane Cryostat



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

LAr Purity - How Pure?

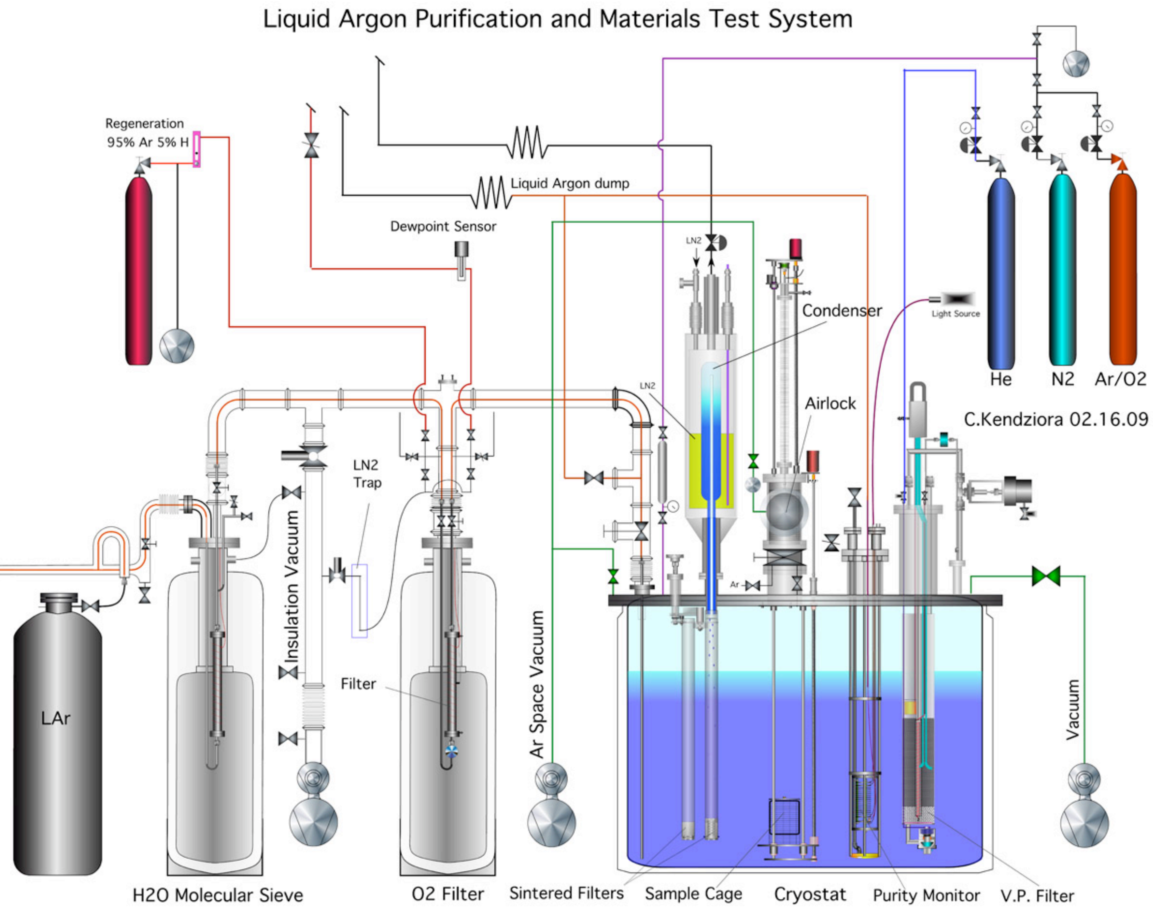
- Poor lifetime reduces the dynamic range and strains electronics
- 100 parts per trillion (ppt) O_2 equivalent corresponds to an electron lifetime of 3 ms
- The product of the contamination and the lifetime is a constant, so for a 10 ms lifetime you need 30 ppt O_2 equivalent
- In a field of 500 V/cm the drift time for 1 m is then 0.63 ms



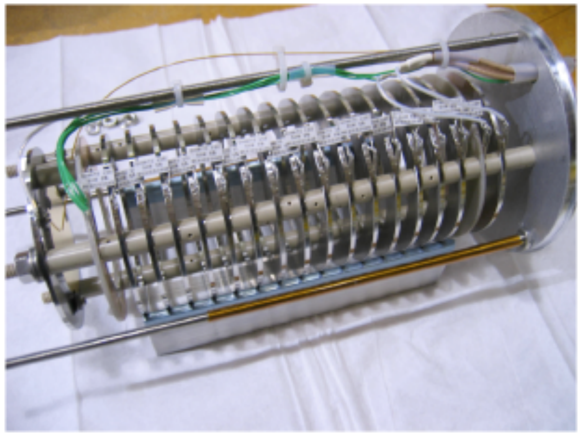
From C. Montanari, June 2007

MTS Schematic

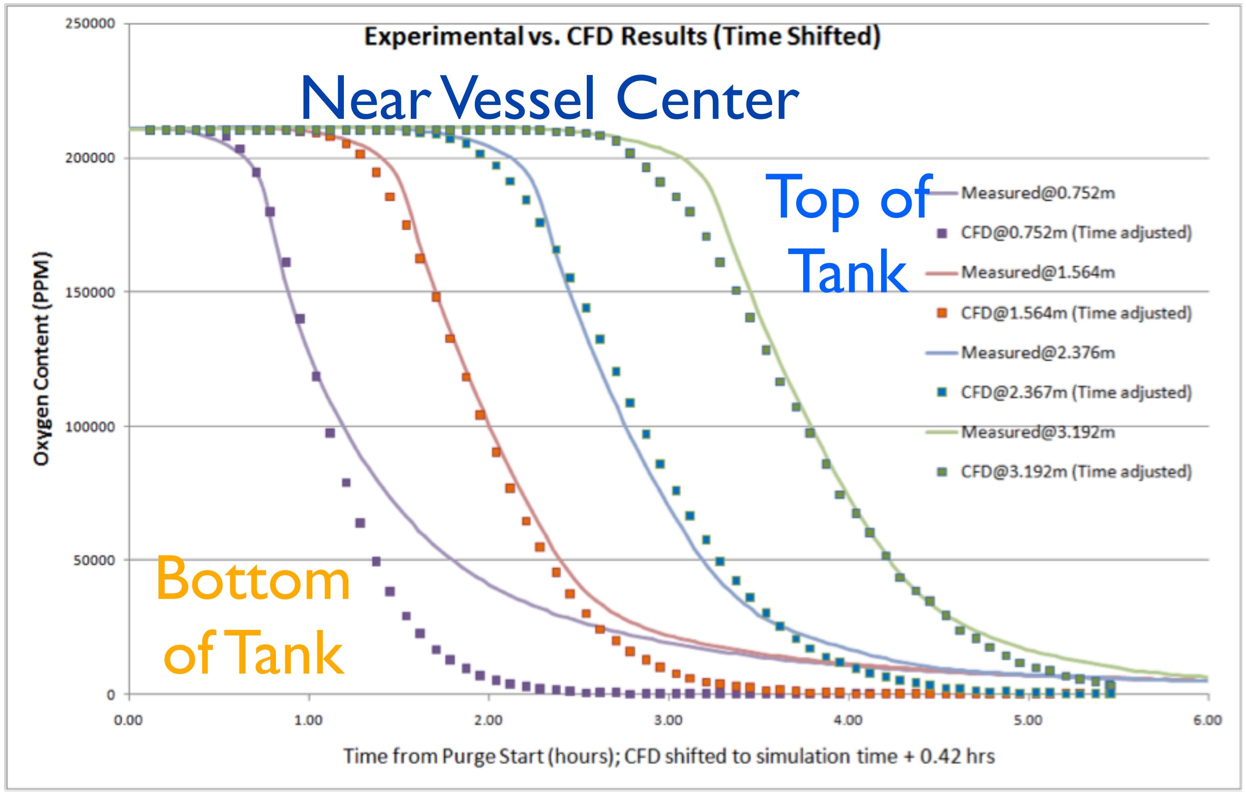
- Commercial LAr is passed through molecular sieve to remove water and copper to remove O_2
- Cryostat has airlock to allow insertion of materials, sample cage (1000 cm^3) can be placed at any depth
- LN_2 condenser used to liquify Ar boil off gas, in situ filter used to remove contaminants
- Measure H_2O and O_2 concentrations to 0.5 ppb, e lifetimes 0.3 - 10 ms
- Several locations where samples can be taken/tested for contamination
- Can inject known contamination of gases



S. Pordes, C. Kendziora, T. Tope (FNAL)



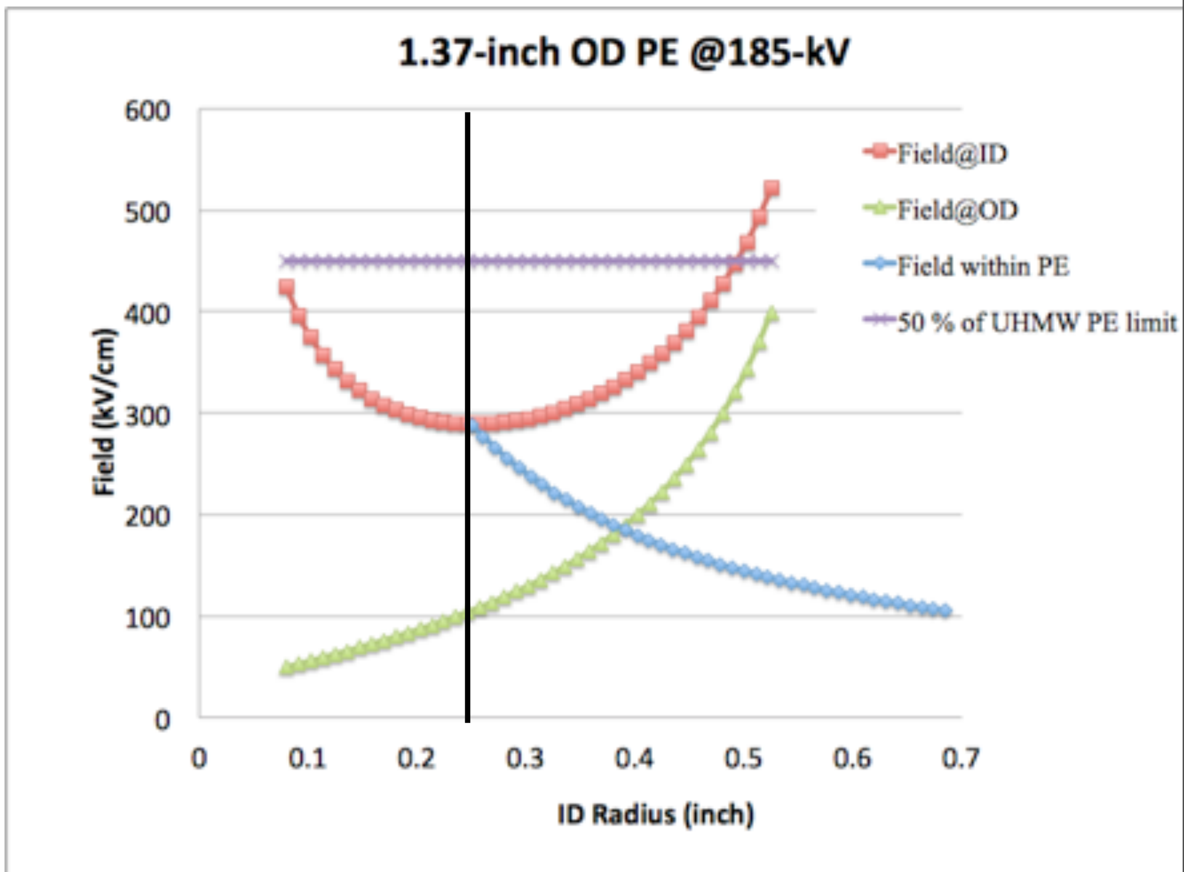
Gaseous Argon Purge



- 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

Geometry Design Considerations

- At a given outer diameter, (OD) there is an optimum inner diameter (ID) to minimize field strength on the ID surface
- Optimal ID for a 1.37 inch OD is 0.5 inch
- Blue points show field within the polyethylene (PE)
- Purple line shows 50% of dielectric strength for ultra-high molecular weight PE
- Tip geometry, TPC design and connection details also important to determining limiting HV for feedthrough



H. Wang, A. Teymourian (UCLA)

Filtering

- Ripples from the HV power supply will induce charge pick up by the readout electronics
- Electronics and TPC geometry will determine requirements on allowed level of ripple
- Plot shows voltage ripple for different load resistors, 0.001% peak to peak ripple
- MicroBooNE design 0.03% ripple

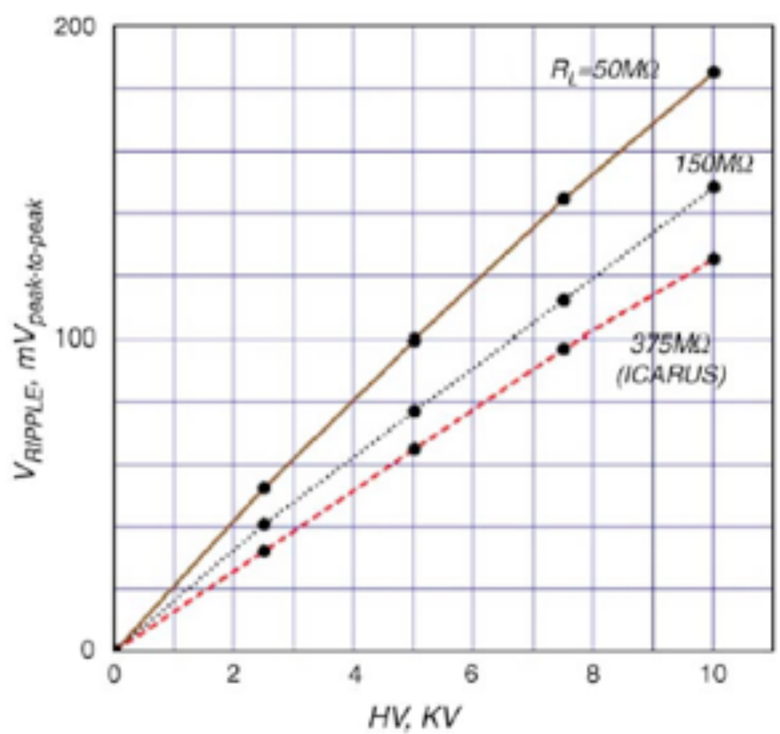


Fig. 41. Dependence of the voltage ripple (peak-to-peak) on the HV for different load resistors. (a) Solid line: $R_L = 50$ MΩ; (b) dotted line: $R_L = 150$ MΩ; (c) dashed line: $R_L = 375$ MΩ (T600 working conditions).

ICARUS

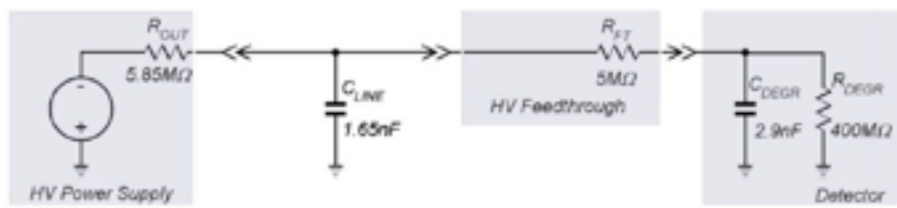
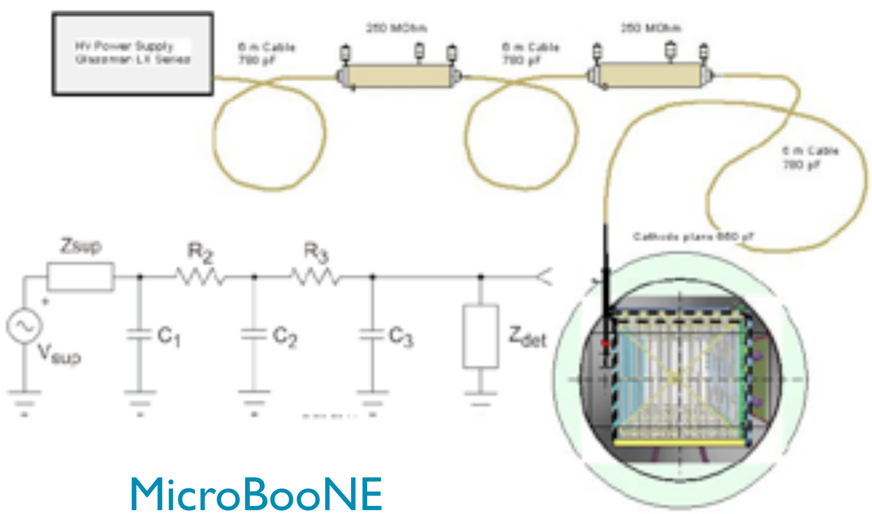


Fig. 42. Electric scheme of the external ripple rejection filter.

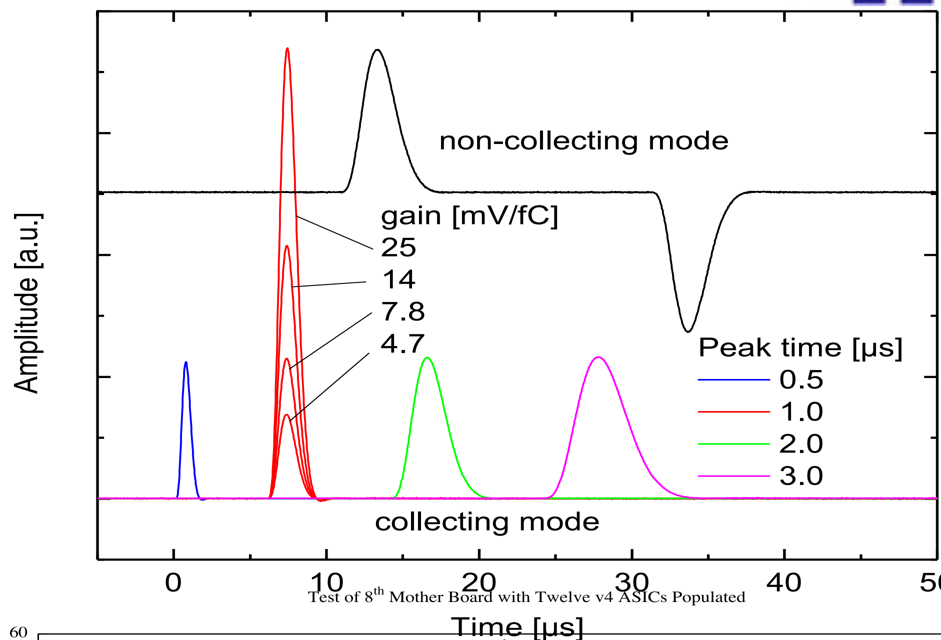


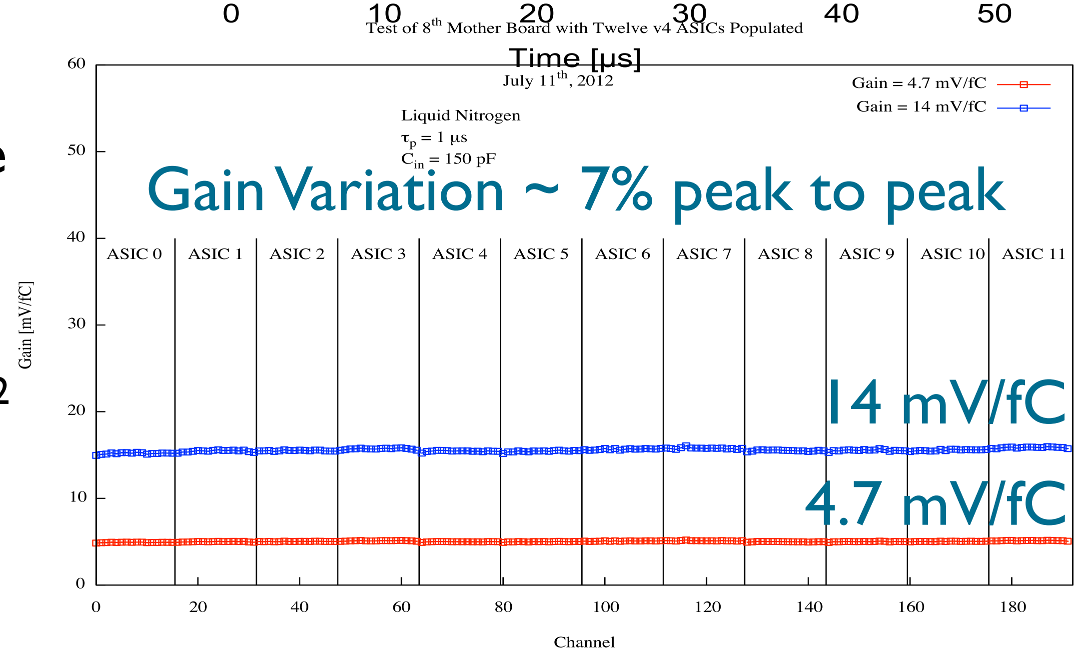
MicroBooNE

Figure 6. The circuit for the HV power supply and filter with the field cage as a load.

μBooNE: Cold Electronics

- A primary goal of μBooNE is to understand 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 is < 0.3%, gain variations are 7%
- 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, designed for > 30 year lifetime





LAr In a Test Beam (LArIAT) Participants

14 Institutions
30+ physicists

College of William & Mary 1693

Imperial College London

Syracuse

UCL

Texas

Argonne National Laboratory

The University of Chicago

Yale

The University of Texas Arlington

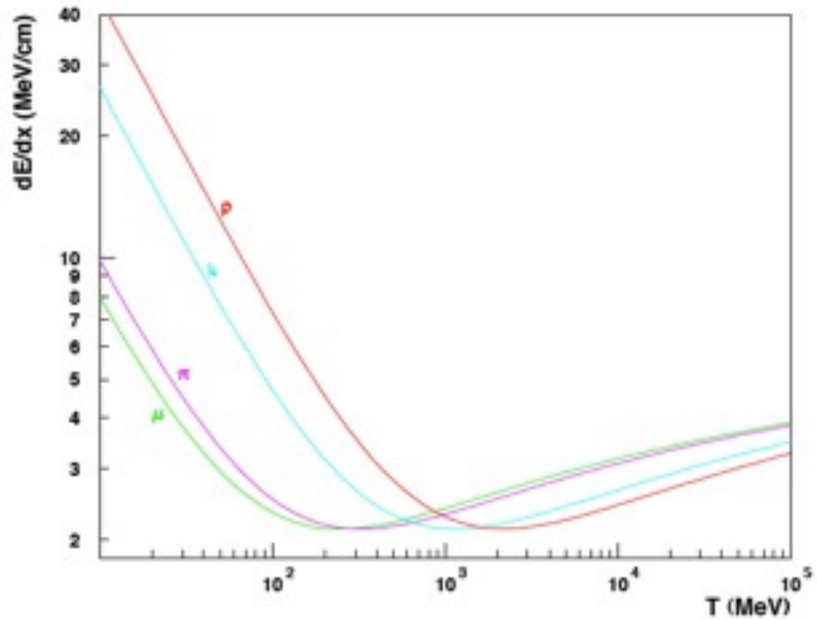
Michigan State University

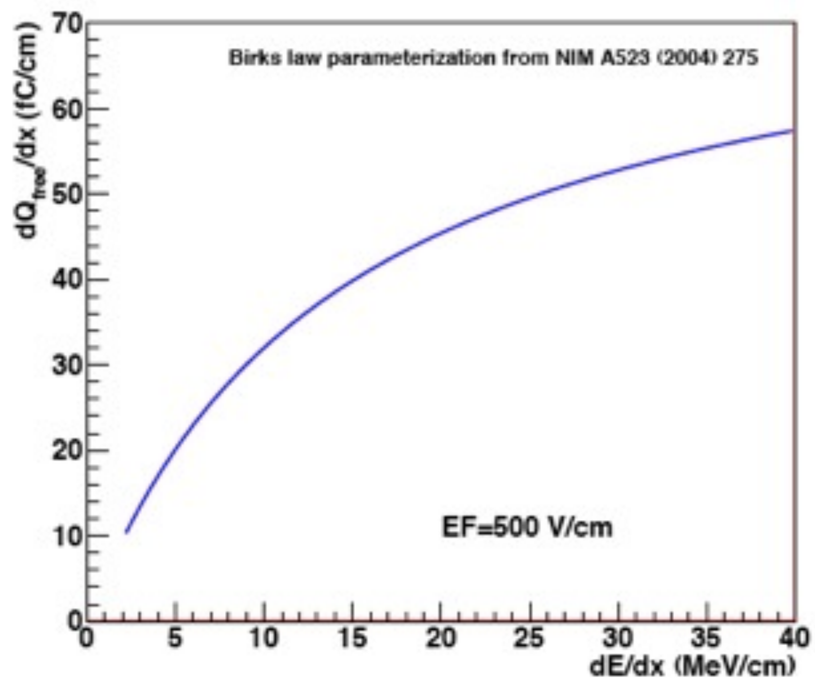
Manchester 1824
The University of Manchester

UMD Duluth

Phase 1: Upgraded ArgoNeuT

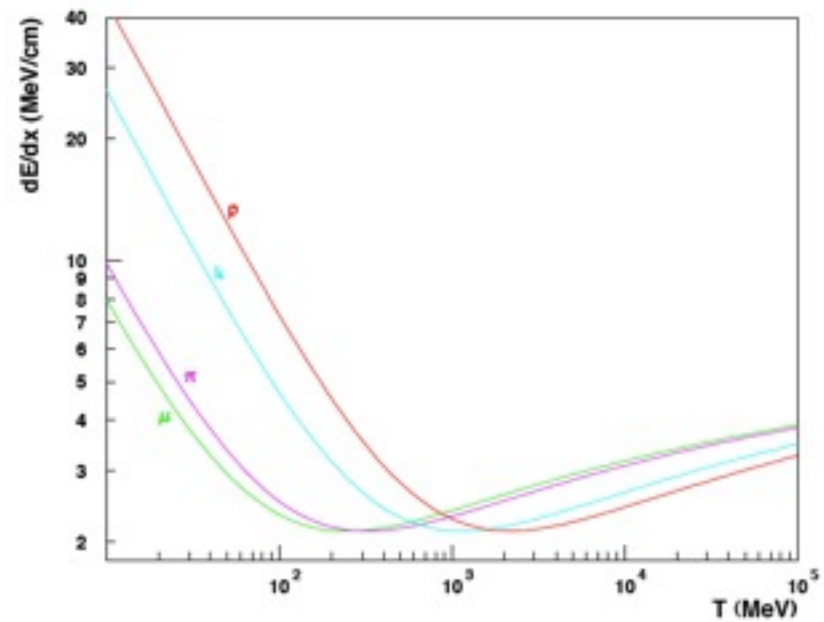
- We would like to get started on understanding the calibration as quickly as possible
- Upgrade of ArgoNeuT to start
  - PMT to detect scintillation light
  - Cold window to minimize amount of steel between the beam and LAr
  - Upgraded filtration system
  - Possible upgrade of the TPC to use cold electronics
- 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

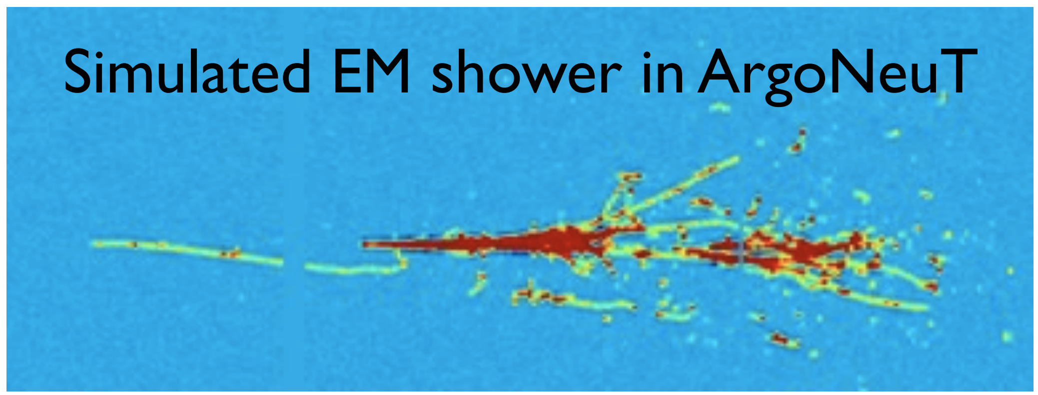




Phase 1: Upgraded ArgoNeuT

- 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

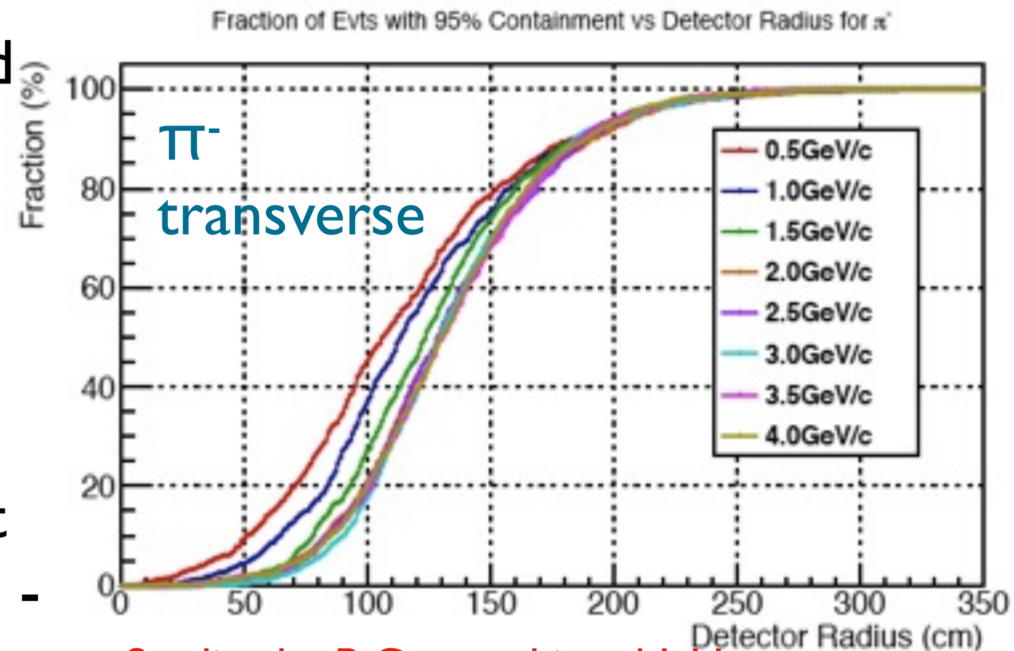




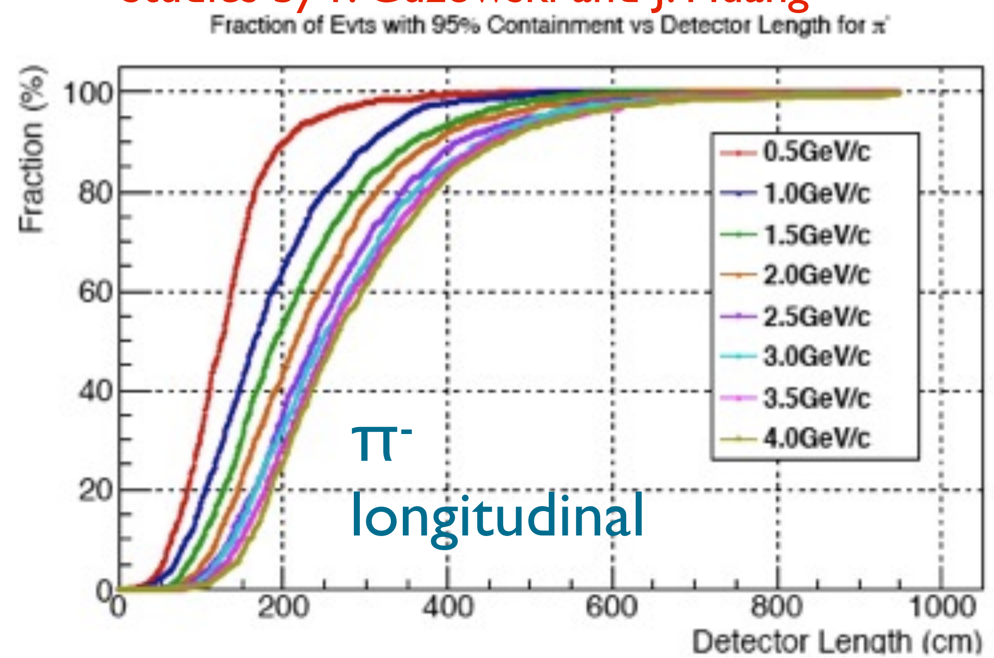
Simulated EM shower in ArgoNeuT

Phase 2: TPC Size

- Muons lose 2.2 MeV/cm, hadronic interaction length in LAr is 80 cm, and radiation length is 14 cm
- Hadron containment determines the scale of the detector
- MC studies show that ~2 m diameter will contain 95% of total energy for at least 20% of the interactions from 0.5 - 4 GeV pions
- Length should be ≥3 m for same containment requirement
- Costs and hall size combined with containment indicates TPC be on the scale of 2m x 2m x 3m
- Would make cryostat longer for upgrades

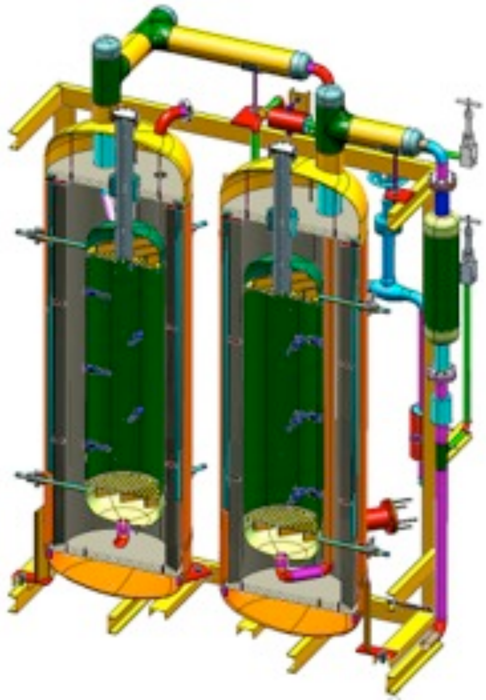


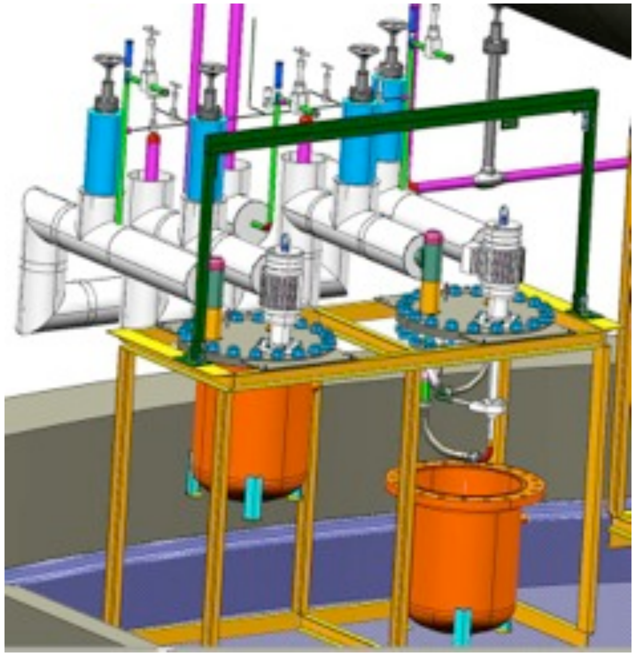
Studies by P. Guzowski and J. Huang



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

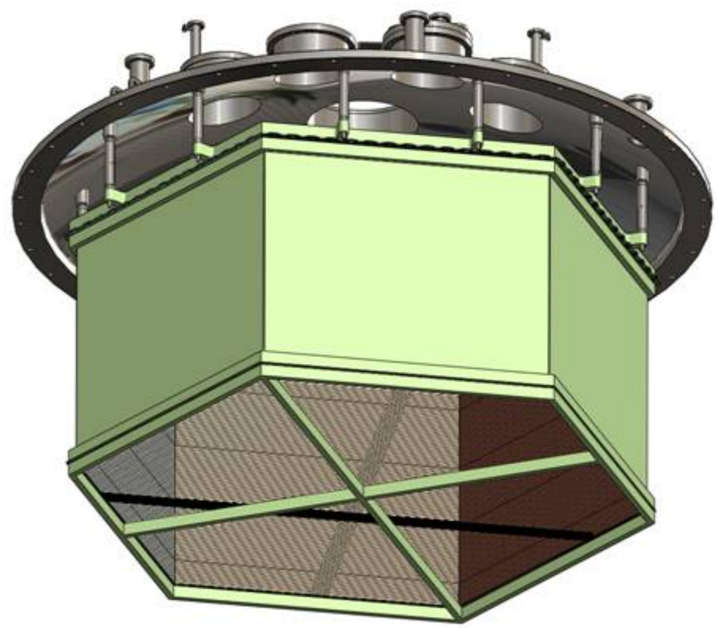
Phase 2 Physics Program

- Measurements to be made include
  - EM shower energy resolution
  - Hadronic shower energy resolution, visible vs invisible energy
  - 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

LANL LDRD TPC

- Vertically oriented cryostat/TPC
- TPC hexagonal: apothem: 1.1 m, height: 1m
- Designed to be portable
- 2000 wires instrumented using µBooNE electronics/DAQ
- Many ports for charged particle beams and laser calibration
- PMTs for photon detection
- Laser already in hand – ex-situ set up in process

C. Mauger, G. Sinnis



LANL LDRD TPC - Physics Goals

- Successfully, build, commission and run the liquid argon TPC, reconstruct cosmic-ray muons
- Empirical muon capture signals
- Spallation backgrounds, low energy particle identification, optical photons vs. ionization
- Calibration development – laser calibration
- Future possibilities (after LDRD period):
  - spallation studies using LANL neutron beam
  - running in charged particle beam
  - running in neutrino beam at ORNL (SN neutrino energies) or FNAL (NuMI medium energy tune)