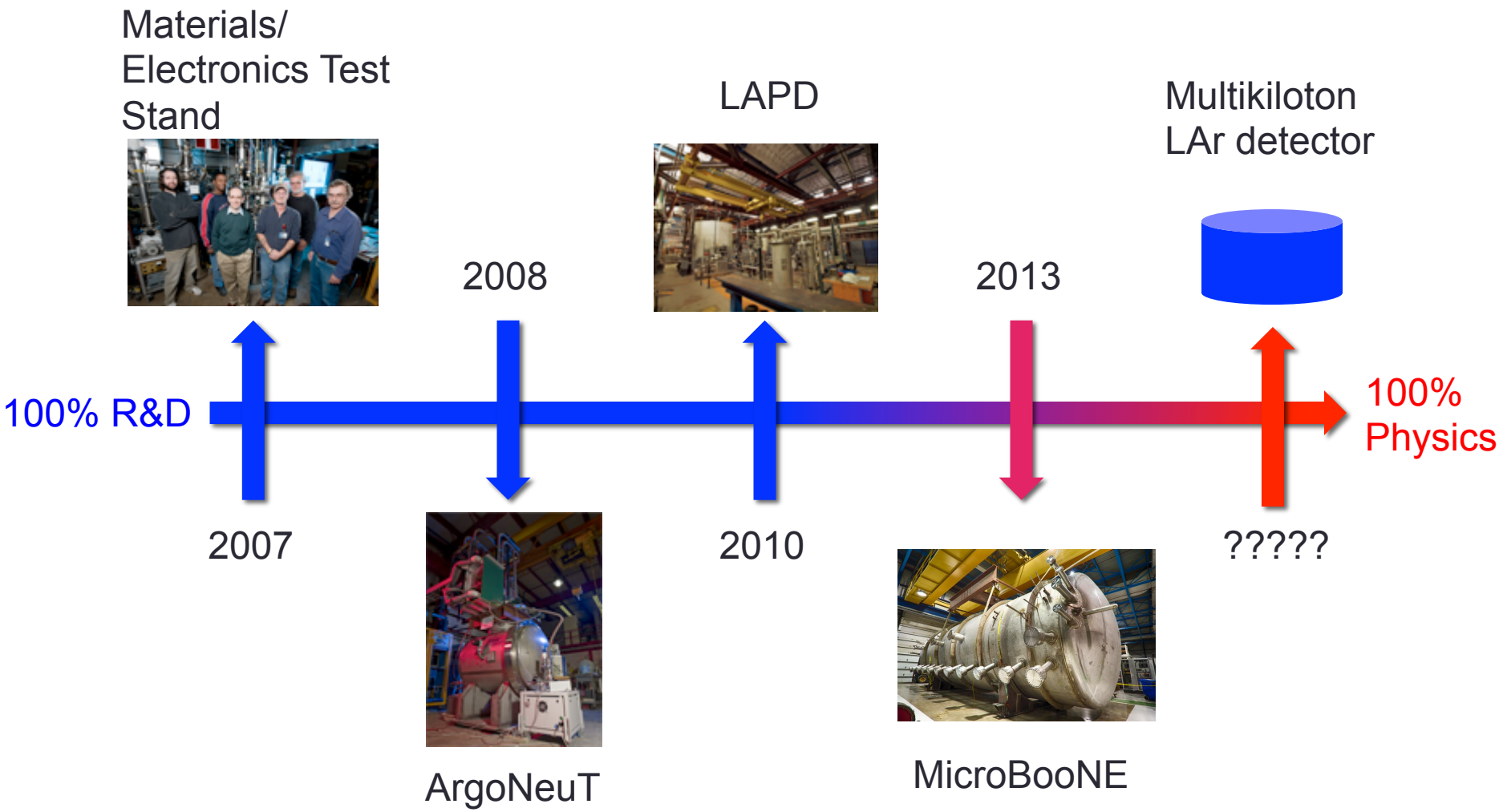
LIQUID ARGON CRYOGENICS AT FERMILAB

Ben Carls
Fermilab

LAr Work at Fermilab

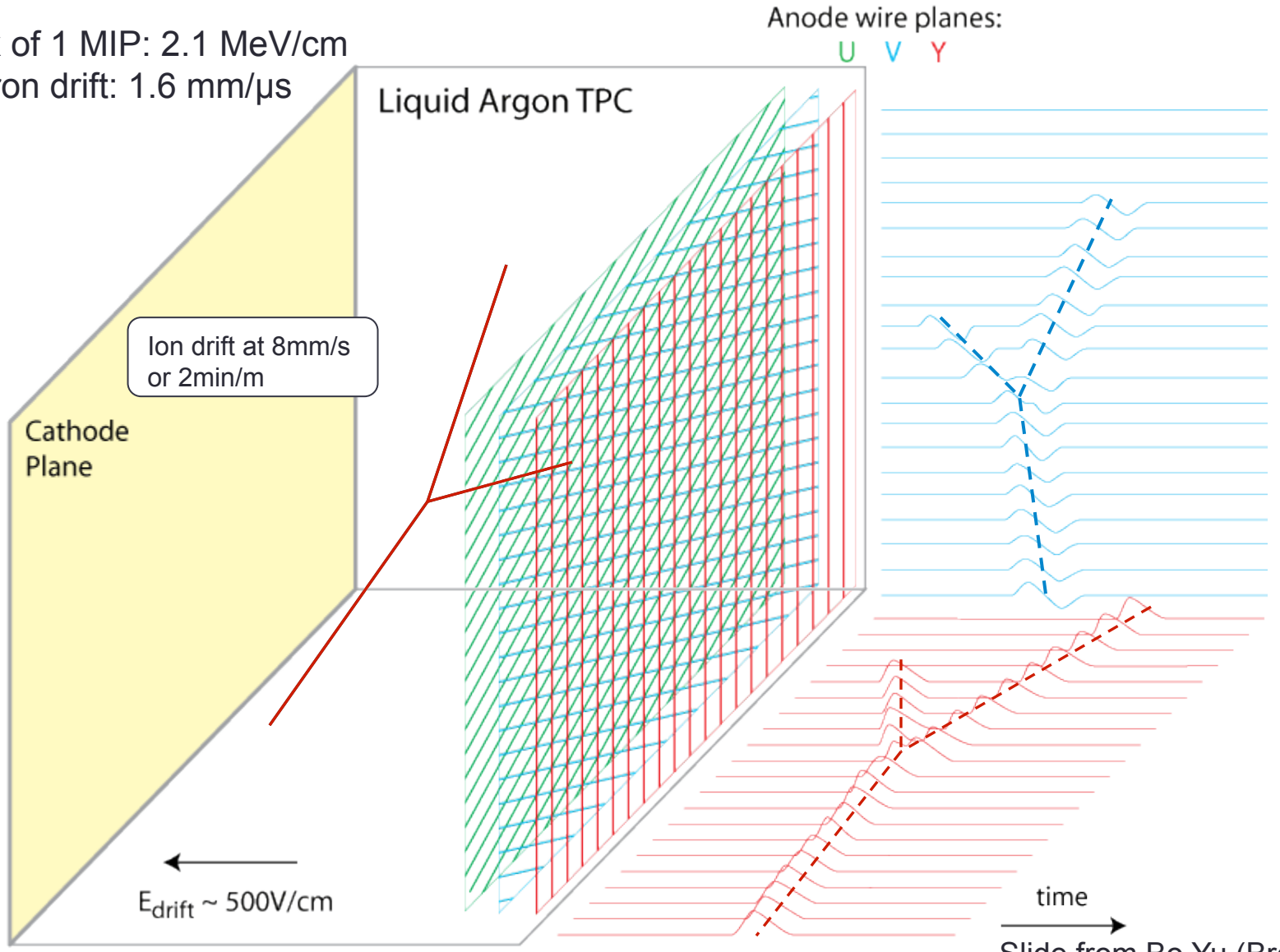


Outline

- Requirements and basic operation
- ArgoNeuT
  - First FNAL experience with LAr TPCs in a beamline
- Liquid Argon Purity Demonstrator (LAPD)
  - Walkthrough of operation
  - Purity measurements (including one coming from the TPC)
- MicroBooNE
  - The system
  - Differences from LAPD
- Towards LBNE
  - The 35 ton prototype

How does a LArTPC work?

dE/dx of 1 MIP: 2.1 MeV/cm
Electron drift: 1.6 mm/μs

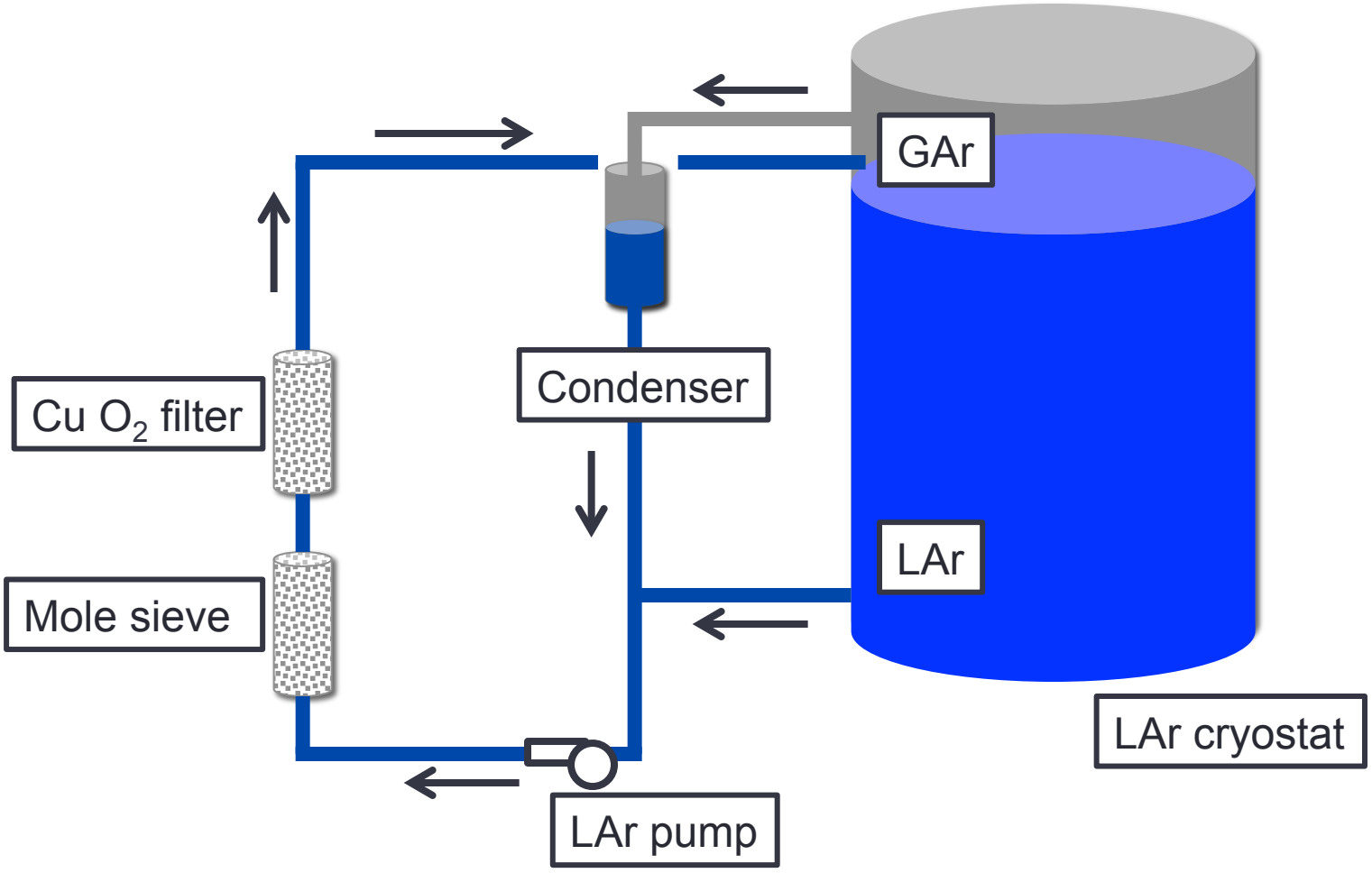


Slide from Bo Yu (Brookhaven)

System Requirements

- Liquid argon (LAr) kept at 88K
- Prevent heat leaks which produce convective flow in the cryostat and ice build up outside
- Need LN_2 for cooling and obviously LAr, places requirements on infrastructure
- Need low concentrations of electronegative contaminants (e.g. O_2 and H_2O)
- For MicroBooNE, our specs are < 100 ppt O_2 (electron lifetime requirement drives this) and < 1 ppm N_2 (contaminant for scintillation light)

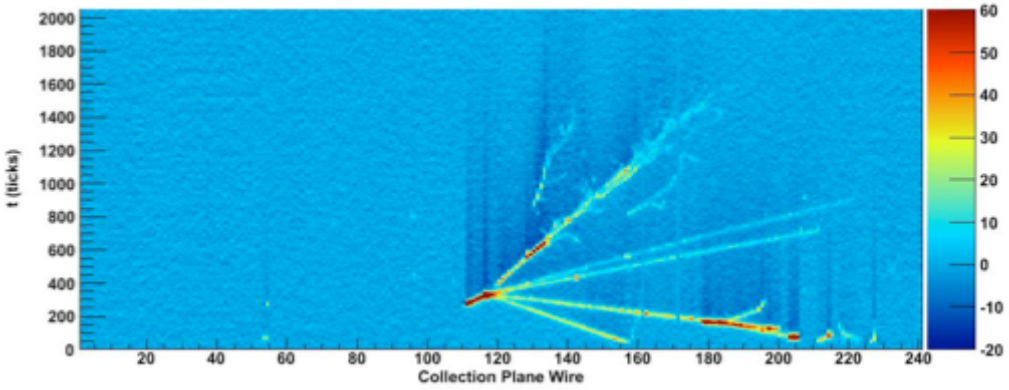
Operation of Purification



ArgoNeuT

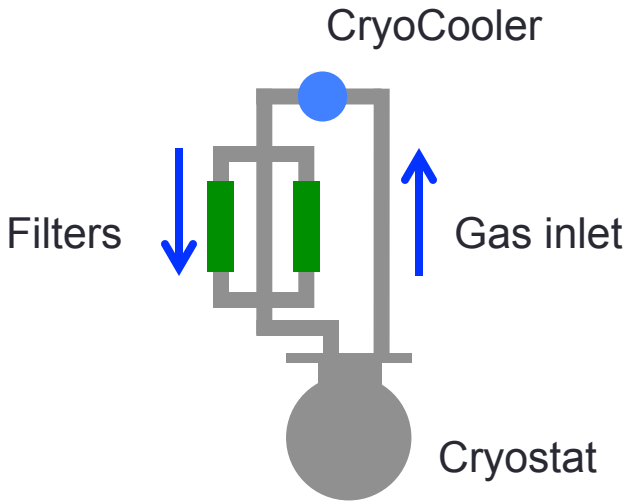
ArgoNeuT

- First experience at FNAL of having a LArTPC in a beamline (NuMI)
- Took data in the 0.1-10 GeV neutrino energy ranges, ~1.4E20 protons on target
- Inner cryostat contained 500 liters LAr, 170 liters fiducial



ArgoNeuT

- Start of operation utilized three cycles purge of vessel with GAr followed by evacuation
- Cryogenics for ArgoNeuT operated without a pump, relied on gravity
- Evacuation no longer practical though for larger cryostats, doesn't guarantee purity either



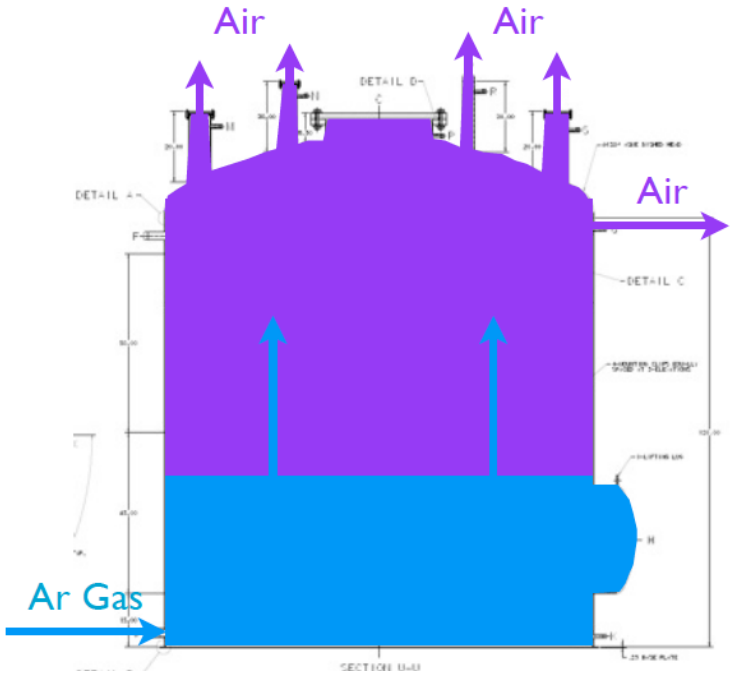
LAPD

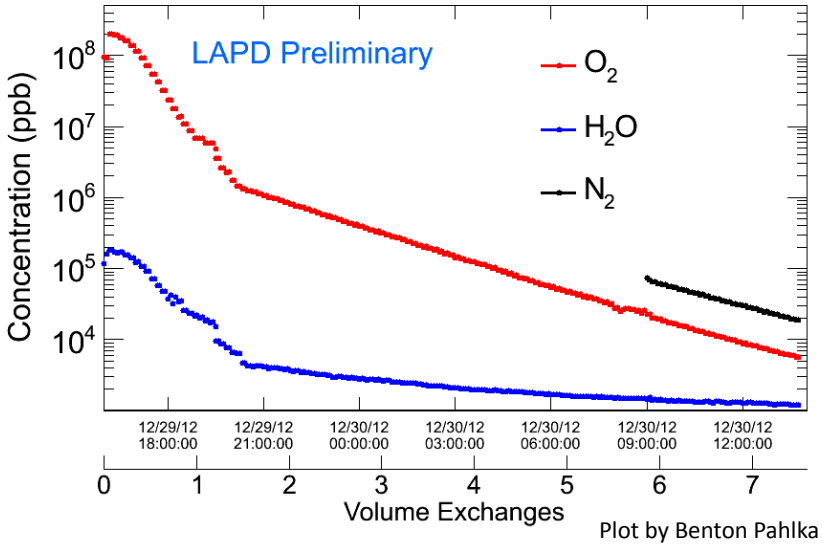
Liquid Argon Purity Demonstrator

- The Liquid Argon Purity Demonstrator (LAPD) serves as a workhorse test bed for liquid argon R&D at FNAL
- First large scale system at FNAL, invaluable experience
- Demonstrated purification without evacuation of a 30 ton cryostat for the first time
- High electron lifetimes have been achieved, on the order of 5 ms

The Purge

- Pump warm argon gas into the tank
- Argon gas acts as a piston pushing ambient air out
  - O_2 from 21% to 6 ppm
  - N_2 from 78% to 18 ppm
  - H_2O from 200 ppm to 1.2 ppm

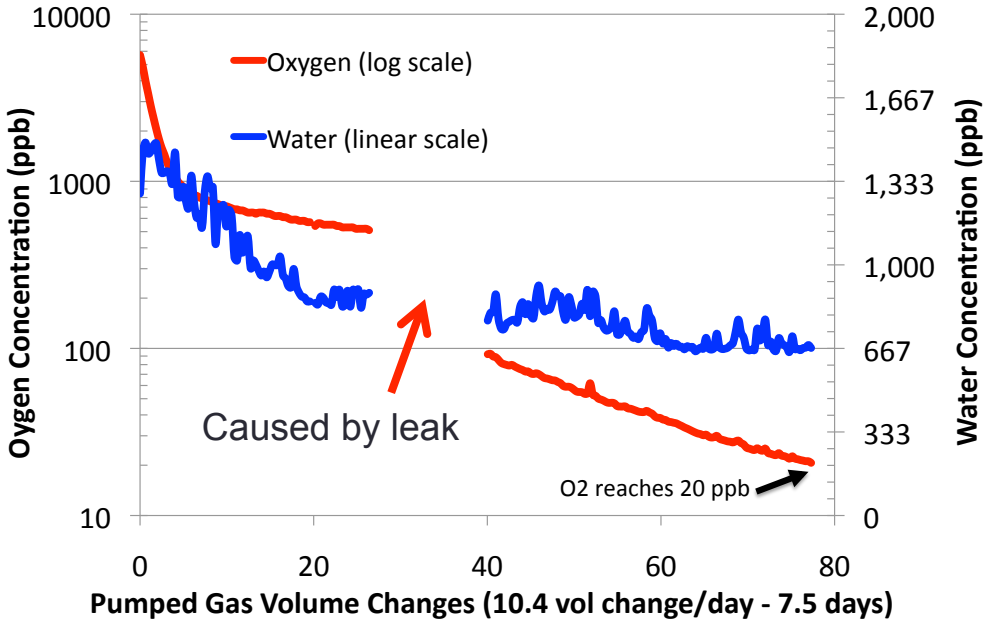




Plot by Benton Pahlka

Gas Recirculation

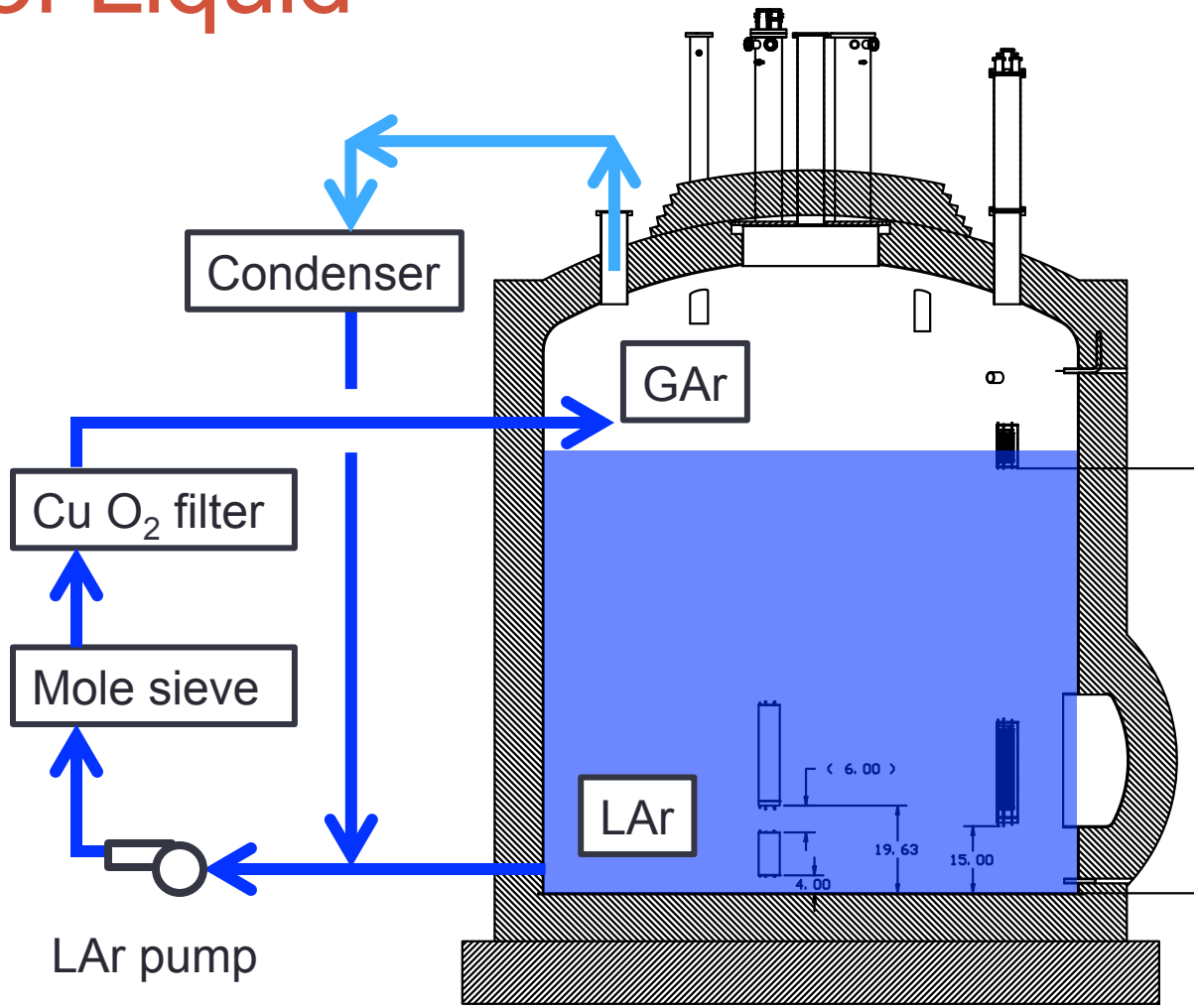
- Run gas through filters, same as for the liquid
- Useful for debugging
- Aim to bring H_2O outgassing rate to match filtration rate



Plot by Terry Tope

Introduction of Liquid

- Have used liquid from both a commercial vendor (first phase) and D0 (second phase)
- The D0 argon was exceptionally clean (could not actually measure H_2O in it)
- A pump circulates gas through a condenser and filters

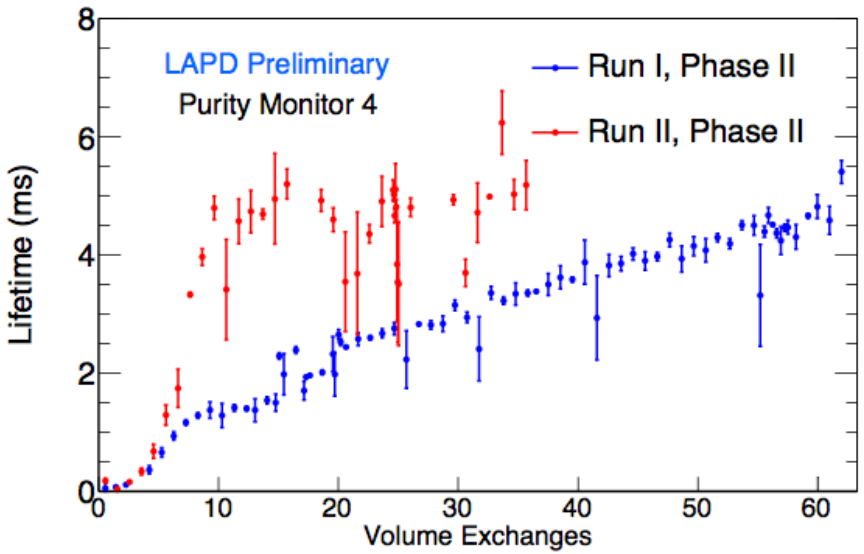


Measuring purity

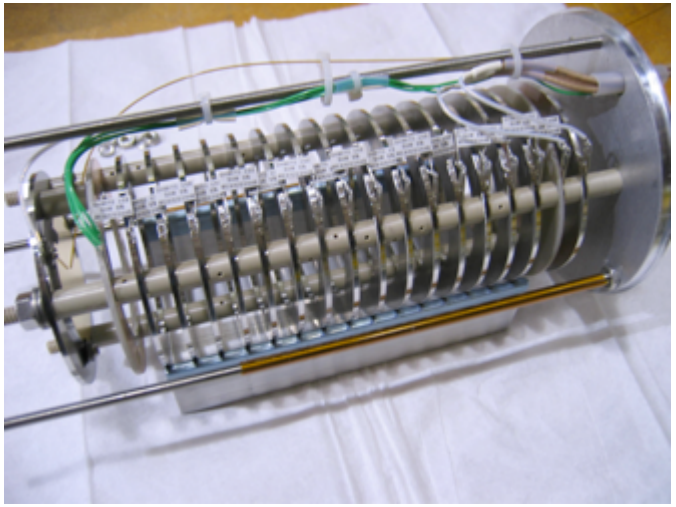
- Use purity monitors, consisting of a field cage, photocathode and anode
- Measure electron signal loss from cathode to anode to find lifetime:

$$Q_{anode} = Q_{cathode} \times \exp(-t_{drift} / \tau)$$

- Observed lifetimes on the order of 5 ms, consistent with TPC



Error bars do not include systematics
One volume exchange takes ~8 hours



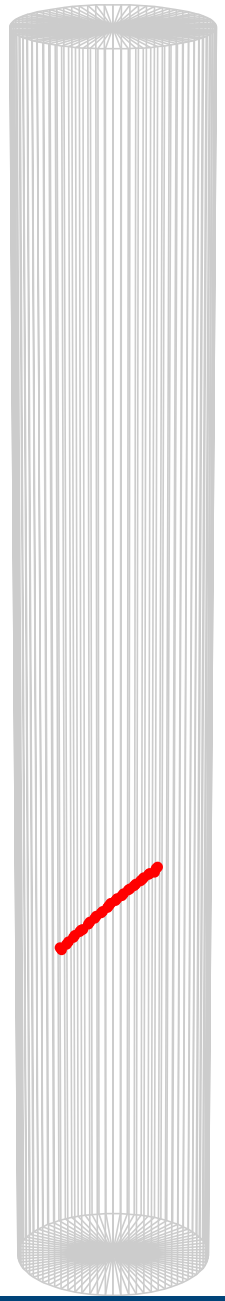
Based on the ICARUS design

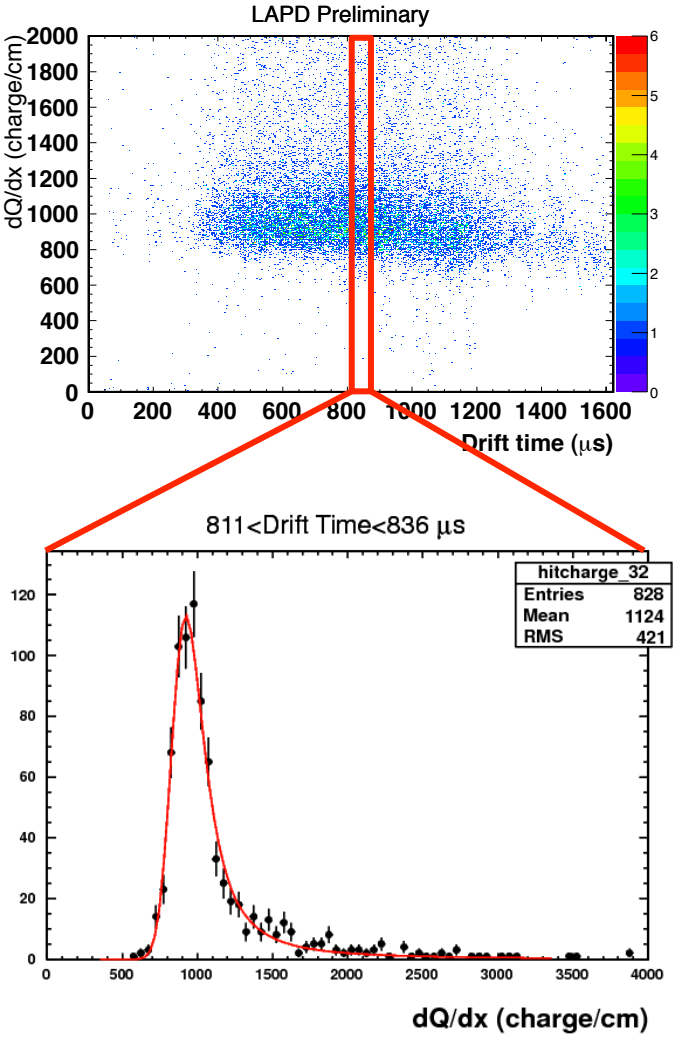
Long Bo TPC

- Phase II of LAPD saw the introduction of a TPC, Long Bo
- Set out to see cosmic rays and measure LAr purity (the ultimate purity monitor)
- Also check if introduction of TPC altered purity through outgassing
- Opportunity to test cold electronics for MicroBooNE

Long Bo TPC, equipped with electronics from MSU

Attenuation with Long Bo

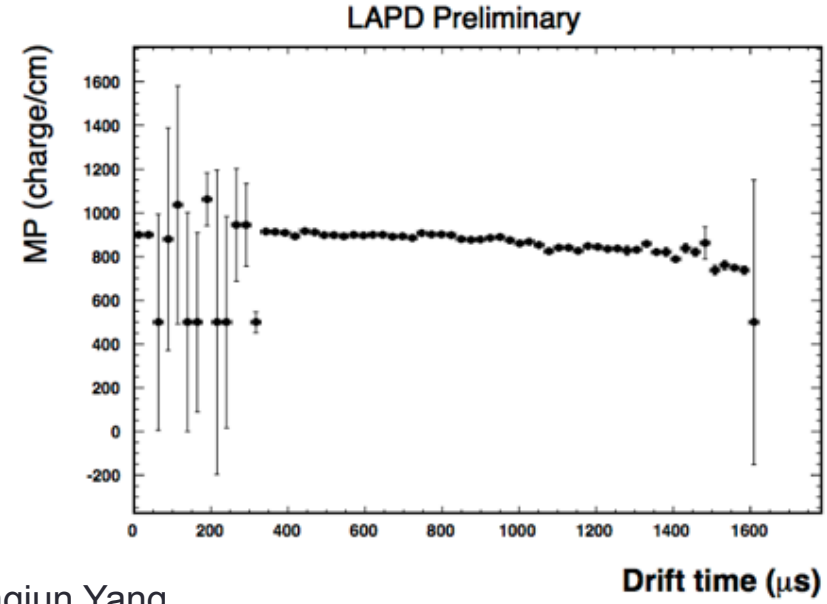




— Select single muon events between 50° < θ < 70° and remove δ rays

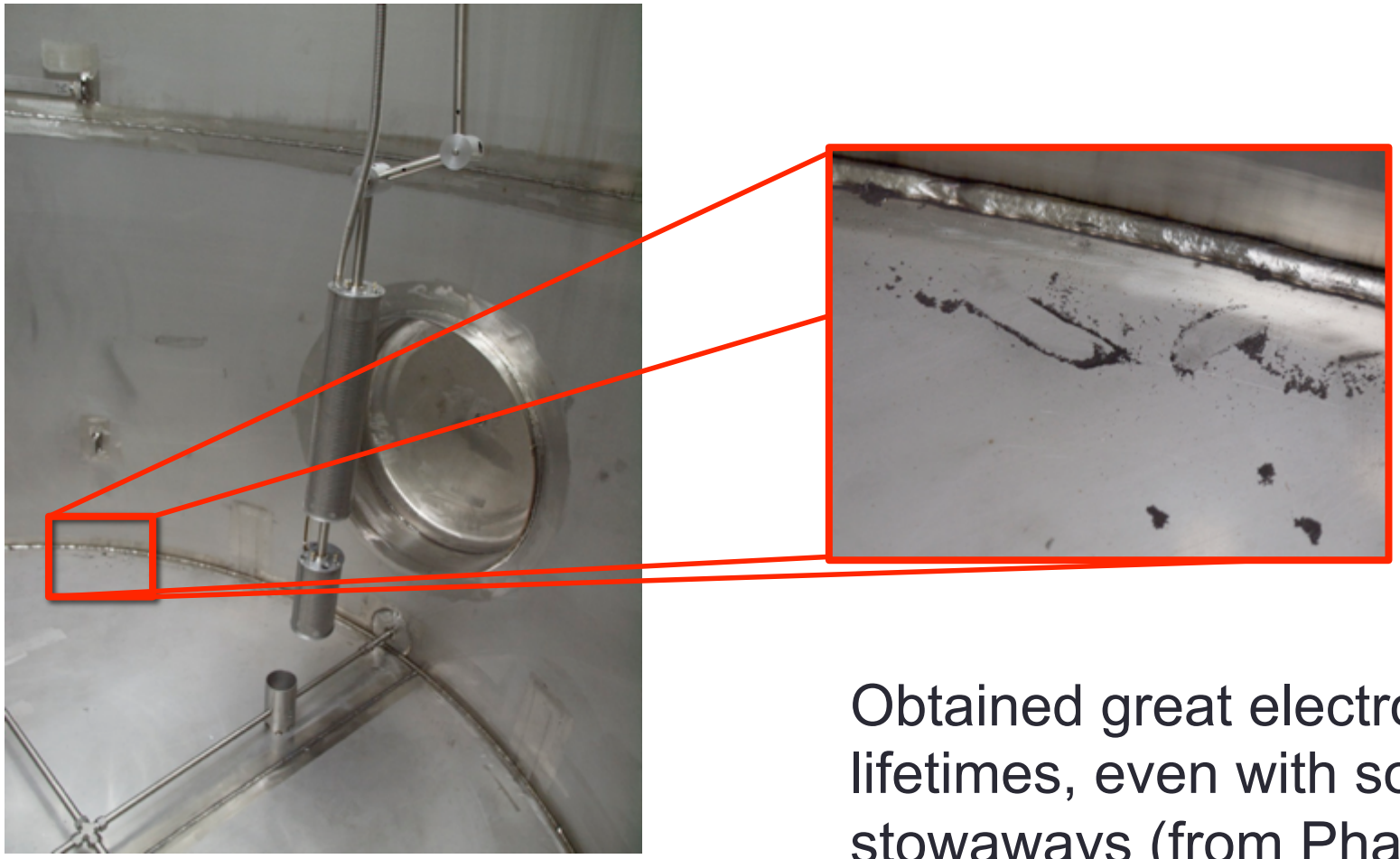
— Use dQ/dx of muon hits as a function of drift time to measure charge attenuation

— Less than 20% attenuation over 1 m



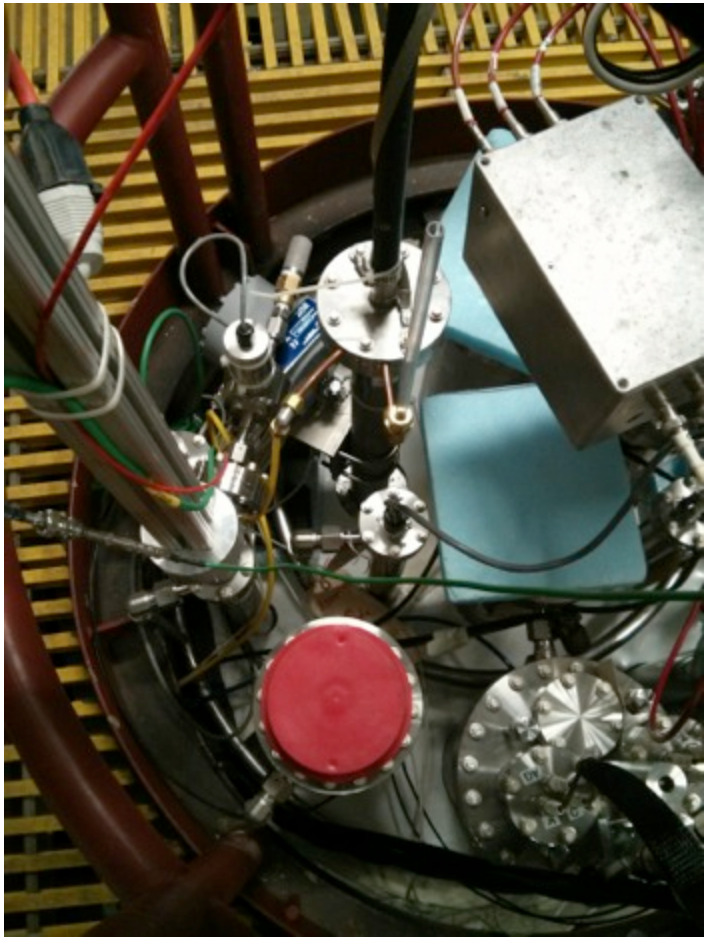
Work done by Michelle Stancari and Tingjun Yang

Robustness



Obtained great electron lifetimes, even with some stowaways (from Phase I), system is robust

Element extraction

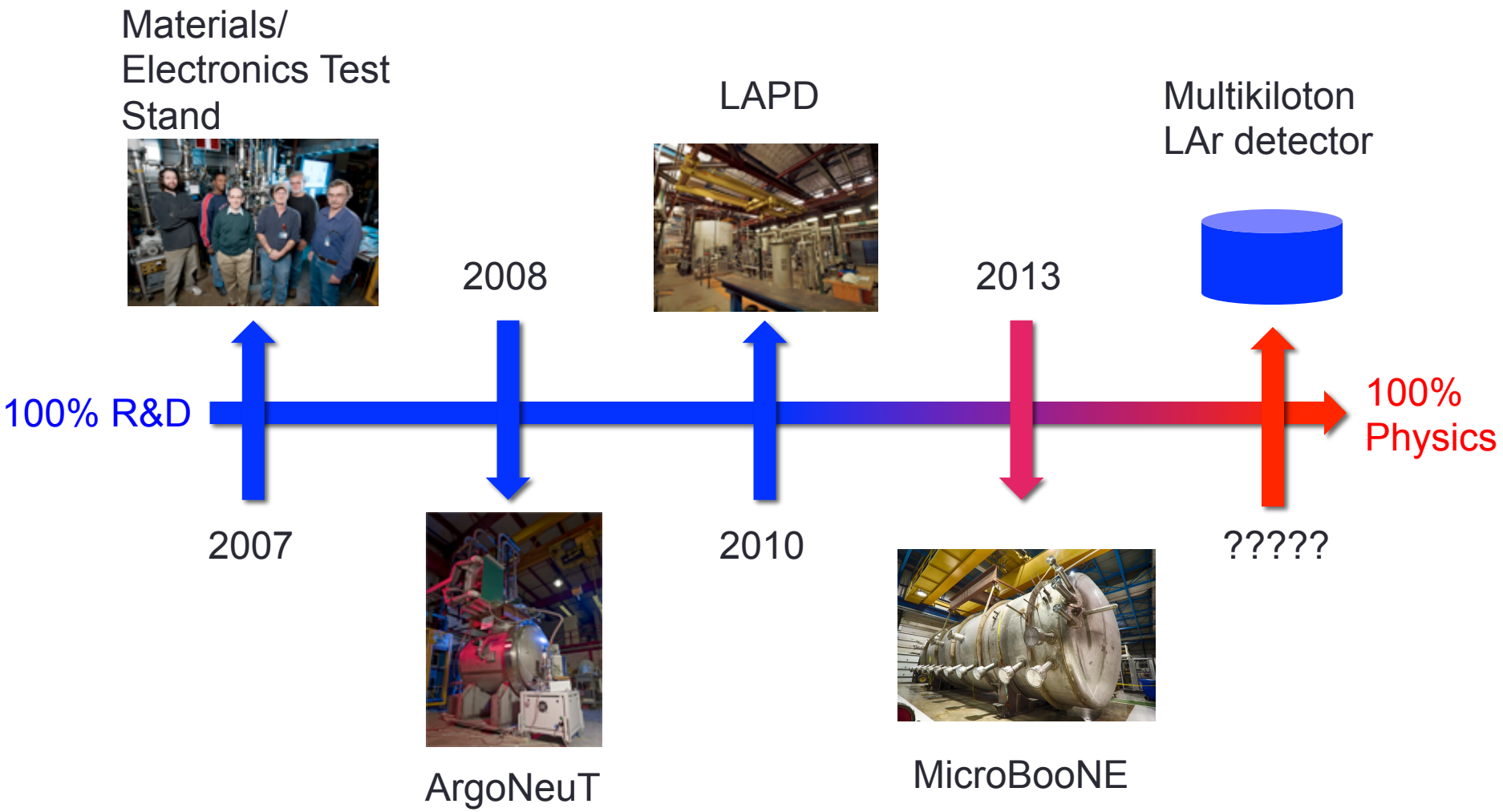


Extraction of an temperature detector had no noticeable effect on purity

From LAPD Onward

- Evacuation not needed to meet purity requirements, simplifies design of later cryostats
- Learned how to build and operate a robust, large scale system
- Introduction of a TPC did not affect purity, facilitated powerful purity measurements

LAr Work at Fermilab



MicroBooNE

MicroBooNE Cryogenics

- MicroBooNE cryogenics system based heavily on LAPD
- Few differences, such as using insulated piping instead of vacuum jacketed
- Carries out similar procedure of purge, gas recirculation, and liquid filling

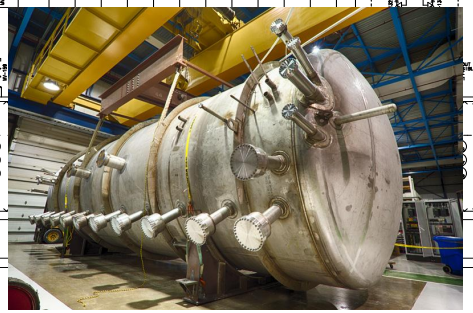
- MicroBooNE cryostat has a 150” diameter and is 40 ft long and 6/17” thick
- Will be insulated with spray on Polyurethane
- Will hold 170 t of LAr, fiducial volume of 60 t

MicroBooNE Evacuation?

- The MicroBooNE cryostat was designed to be evacuated
- However, after the success of LAPD we will proceed with only the purge
- Evacuation does not guarantee purity, as learned from ArgoNeuT

Note, the cryostat is on it's side here

MicroBooNE Cryogenics



REV	DESCRIPTION	DRAWN / APPROVED	DATE
E	SMALL MISC. CHANGES MADE.	J.CATALANELLO	02-MAR-2011
		R.SCHMITT	13-MAY-2011
F	SMALL MISC. CHANGES MADE.	J.CATALANELLO	13-JUN-2011
		M.ZUCKERBROT	28-JUL-2011
G	LARGE MISC. CHANGES MADE.	J.CATALANELLO	28-SEP-2011
		M.ZUCKERBROT	03-OCT-2011
H	LARGE MISC. CHANGES MADE.	J.CATALANELLO	29-NOV-2011
		M.ZUCKERBROT	30-MAY-2012
J	MISC. CHANGES MADE.	J.CATALANELLO	12-SEP-2012
		M.ZUCKERBROT	19-SEP-2012
K	LARGE MISC. CHANGES MADE.	J.CATALANELLO	29-JAN-2013
		M.ZUCKERBROT	06-FEB-2013

NOMENCLATURE	
CV-670	TOP FILL CHECK VALVE
MV-671	LIQUID VALVE
MV-672	GAS USE VALVE
MV-673	VENT/FULL TRYCOCK VALVE
MV-674	PRESS. BLOWDOWN VALVE
MV-676	3-WAY VALVE
MV-675	REG. 150 VALVE PB
MV-677	REG. 150 VALVE COOND REG.
MV-678	FILL BALL VALVE
LI-679	LEVEL INDICATOR
PI-680	PRESSURE 150-CV-150
PCV-681	PRESS. BLOWDOWN/COOND REG.
PSV-682	RELIEF VALVE
PSV-683	LINE RELIEF
PSE-684	BURST SYNC
PIPING	
A	TOP FILL
B	LIQUID WITHDRAWAL
C	PRESSURE BUILDING INLET
D	PRESSURE BUILDING OUTLET
E	LIQUID PHASE
F	VAPOR PHASE
G	VENT/FULL TRYCOCK
H	SAFETY EXHAUST

UNLESS OTHERWISE SPECIFIED	ORIGINATOR	R.SCHMITT	28-NOV-2006
	DRAWN	J.CATALANELLO	06-DEC-2006
± ± ±	CHECKED	R.SCHMITT	06-JAN-2009
1. BREAK ALL SHARP EDGES	APPROVED	R.SCHMITT	06-JAN-2009
2. DO NOT SCALE DRAWING. DIMENSIONS ARE GIVEN UPON REQUEST ONLY.	USED ON		
3. MFG. ALL MACH. SURFACES	MATERIAL		
4. DIMENSIONS UNITS U.S. INCH			

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

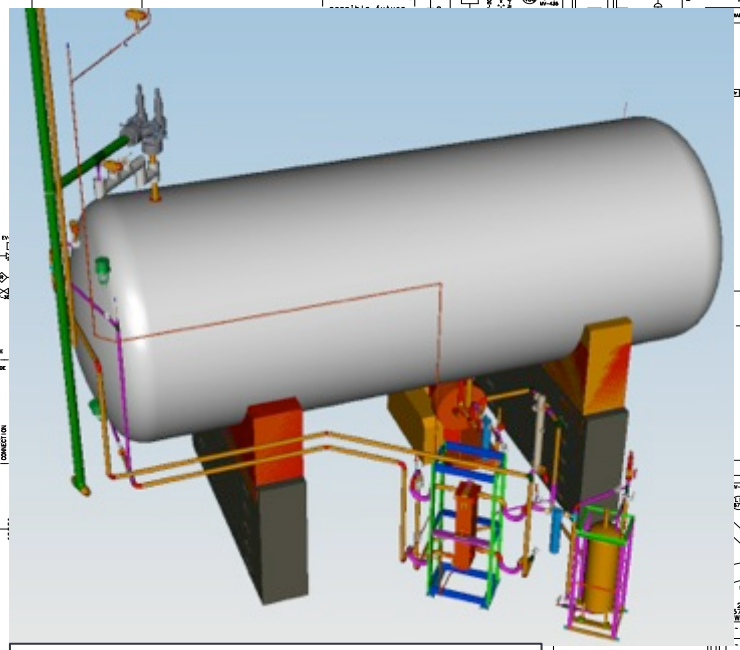
MICROBOONE LAR TPC
PIPING AND INSTRUMENT DIAGRAM
CRYOGENIC SYSTEM

SCALE	DRAWING NUMBER	SHEET	REV
NONE	3974.200-ME-466281	1 OF 1	K

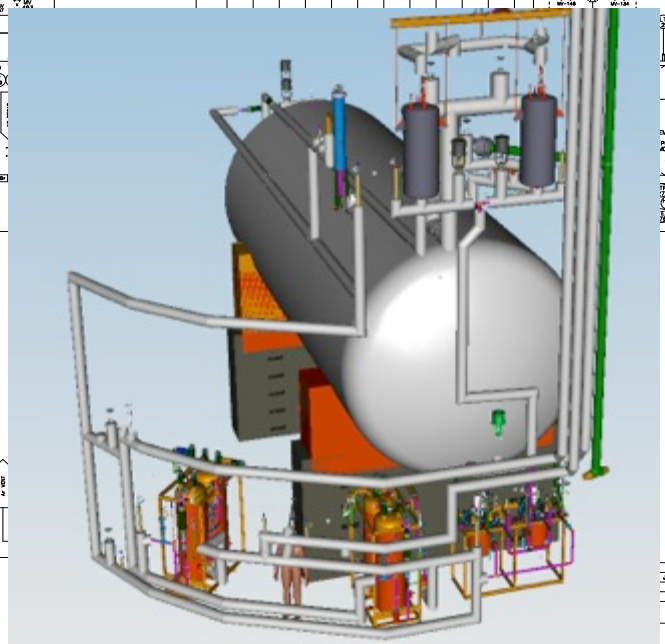
CREATED WITH: Ideas12NXSeries GROUP: PPD/MECHANICAL DEPARTMENT

MicroBooNE Cryogenics

Complex, but can be divided into two primary systems, cool-down and purification



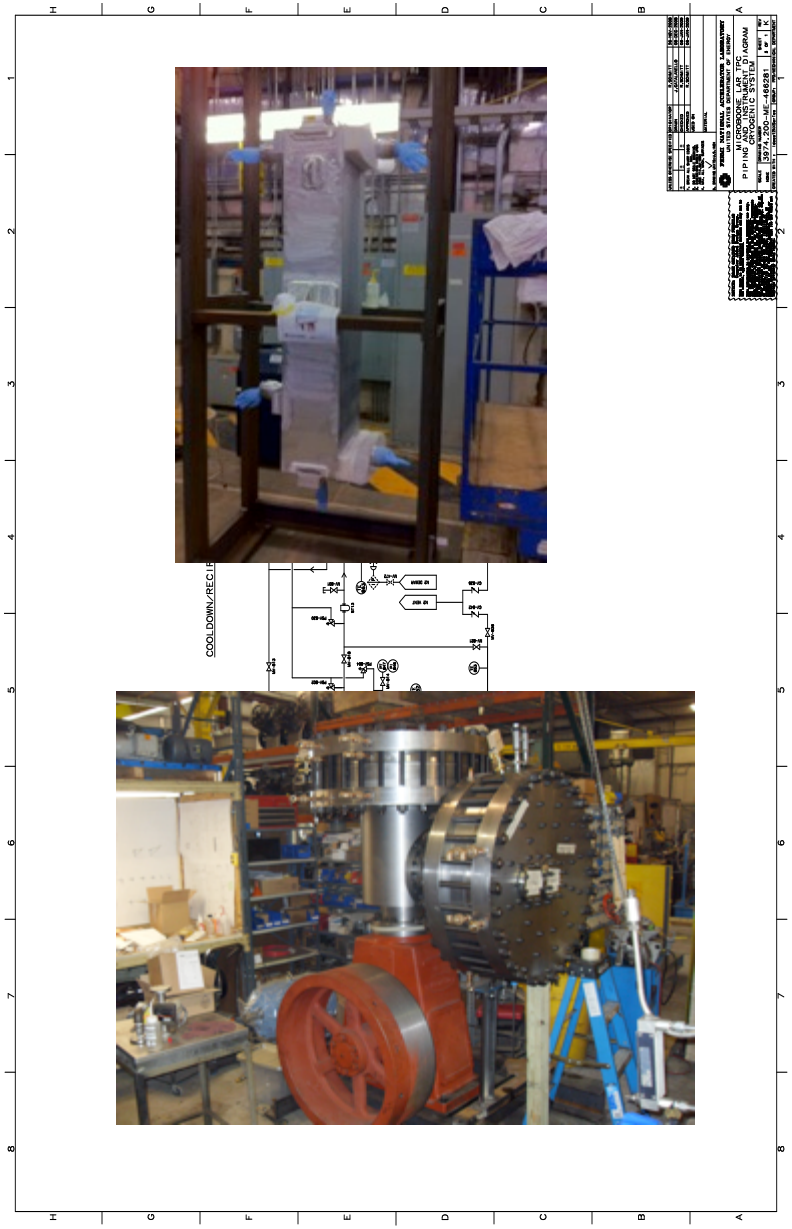
Cool-down system



Purification system

Cool-Down System

- After the purge and gas recirculation, we cool down the gaseous argon to prevent mechanical stress
- A plate fin heat exchanger delivers cooling
- The circuit is powered by a compressor
- Hope to use the circuit once, will run for a few weeks

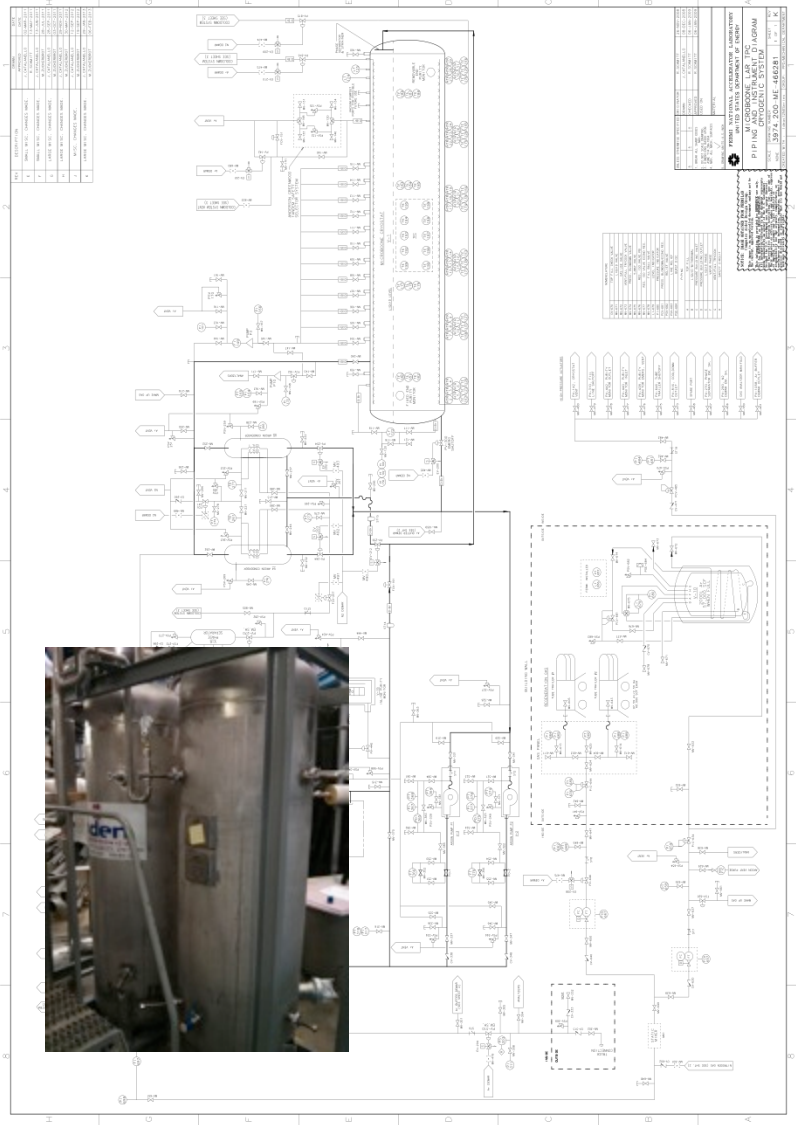


Testing delivered LAr

- Our spec for delivered LAr is 1 ppm O_2 and H_2O, 3 ppm N_2
- We test if the argon is up to spec using a series of sensors operating via a gas manifold
- We have the ability to store up to two trucks worth of LAr in a buffer dewar

Purification System

- The purification system removes contaminants from both delivered Ar and Ar coming from the cryostat vessel
- Two types of filters used
  - —Molecular sieve, based on 208604-5KG Type 4A material, removes H_2O
  - —Another copper based filter, CU-0226 S 14 X 28, removes O_2
- Filters designed at FNAL

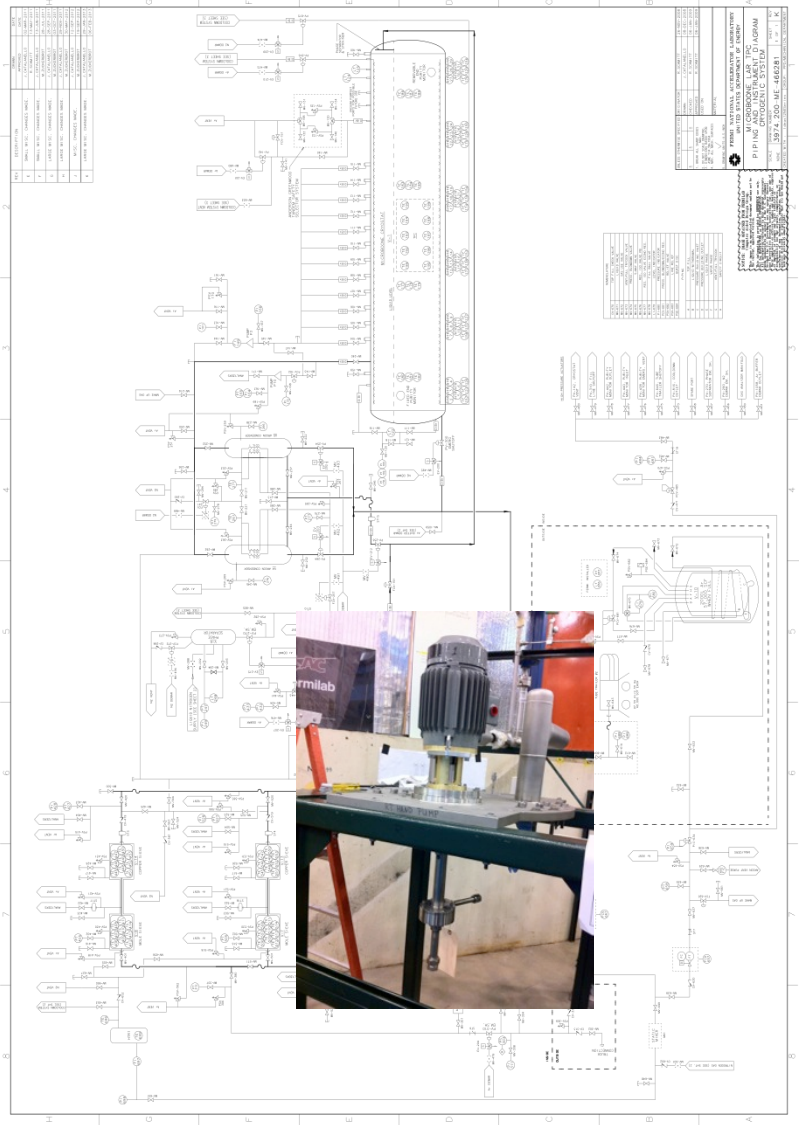


Purification System

- The filters will eventually get saturated with H_2O and O_2
- Fortunately, the filters can be regenerated in place
  - —We will supply a combination of H_2 and argon at 200° C to remove contaminants
- The filter material can be removed if necessary

Purification System

- The system is powered by two Barber-Nichols centrifugal pumps
- Capable of 10-12 gallons a minute, each
- Recycle the LAr in the cryostat once a day



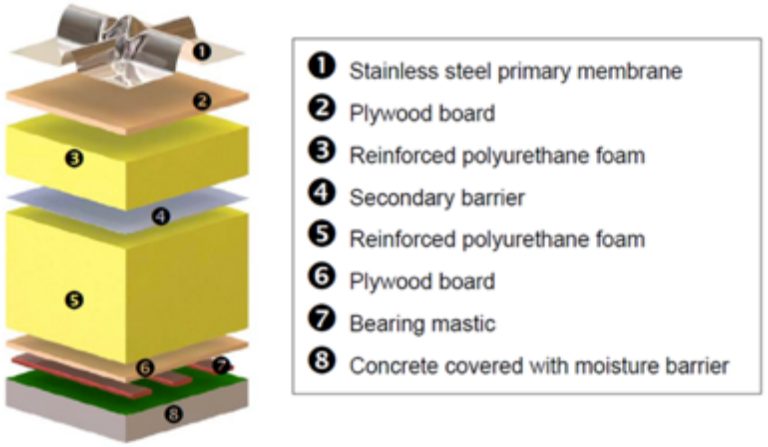
Purification System

- The system is powered by two Barber-Nichols centrifugal pumps
- Capable of 10-12 gallons a minute, each
- Recycle the LAr in the cryostat once a day

LBNE

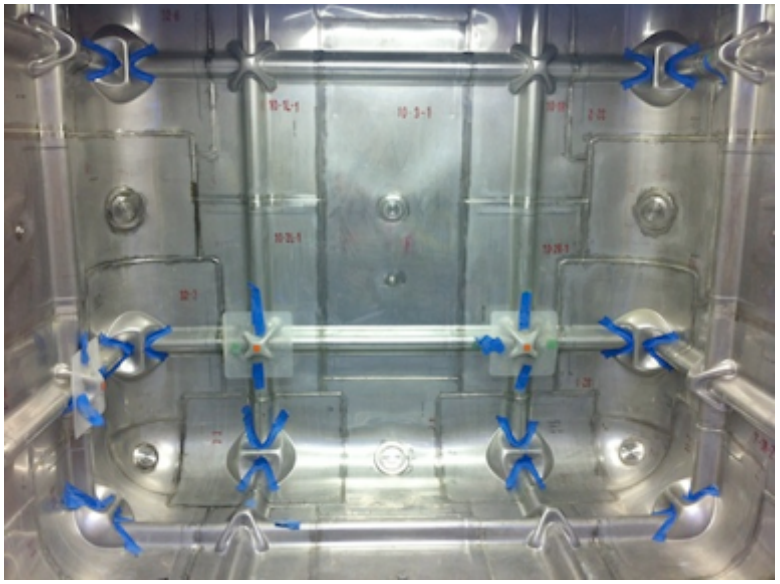
LBNE Cryostat

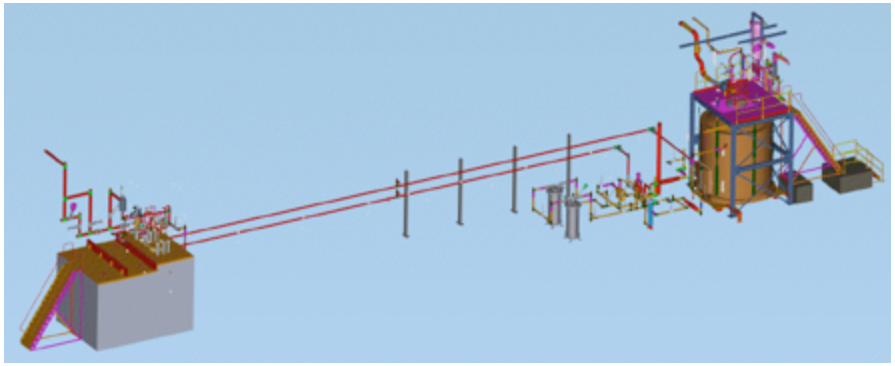
- First difference from LAPD and MicroBooNE is that LBNE will utilize a membrane cryostat
- Widely used for tanker vessels and reliable, easy to install underground
- LBNE will use more than 20 kton LAr
- LBNE will use similar approach as LAPD and MicroBooNE: purge and purify



35 Ton Prototype

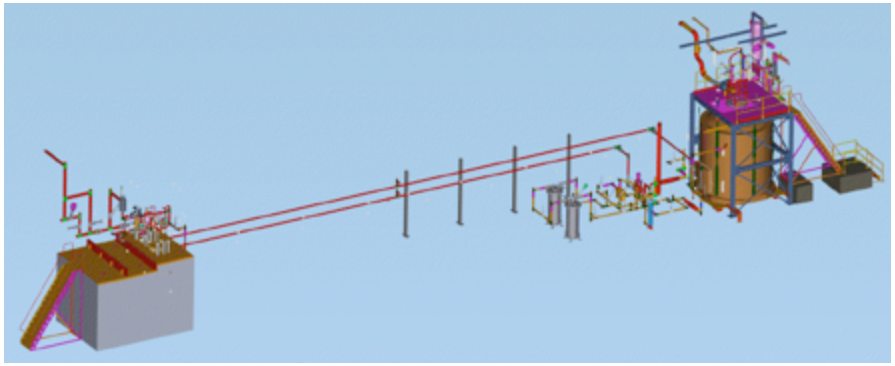
- A prototype of the membrane cryostat for LBNE exists right next to LAPD
- Capitalize on existing infrastructure at LAPD
- Two runs in mind:
  - —Phase 1 is to prove required purity can be achieved (> 1.4 ms)
  - —Phase 2 will introduce two TPCs





35 Ton Prototype

- A prototype of the membrane cryostat for LBNE exists right next to LAPD
- Capitalize on existing infrastructure at LAPD
- Two runs in mind:
  - —Phase 1 is to prove required purity can be achieved (> 1.4 ms)
  - —Phase 2 will introduce two TPCs



Conclusions

- Each step builds off of the last, from ArgoNeuT to LBNE
- LAPD has been widely successful
  - Electron lifetimes on the order of 5 ms have been achieved
  - Purity without evacuation successful, that combined with experience with ArgoNeuT indicates evacuation not necessarily critical
- MicroBooNE will soon run, giving us even more experience with cryogenics and purification
- 35 ton LBNE prototype will run this summer

Backup

Importance of the Purge

- Liquid argon is 871 times more dense than gaseous argon
  - —6 ppm O_2 vapor contamination adds only 7 ppb O_2 to the equivalent liquid volume
  - —18 ppm N_2 vapor contamination adds 21 ppb to the equivalent liquid volume
- Also helps to limit contamination from volumes connected to the tank that cannot be evacuated