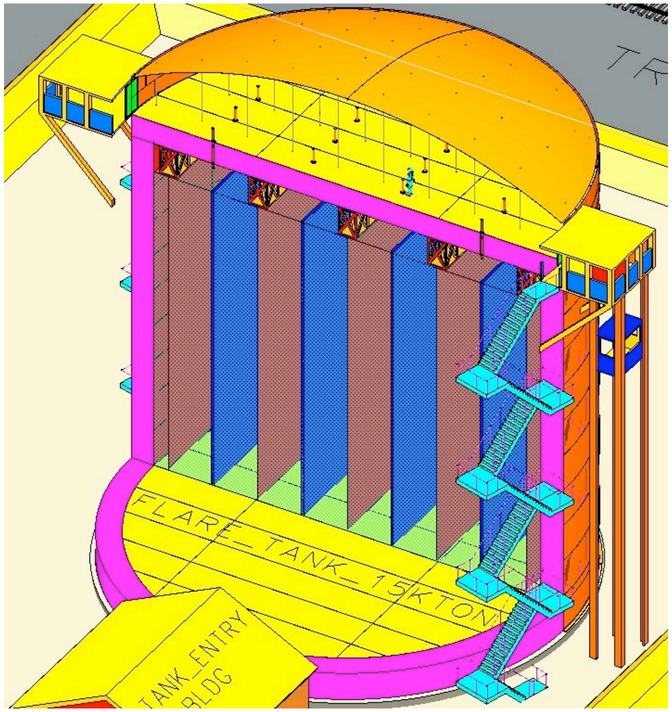
Liquid Argon R&D

(A few small steps toward multi-kiloton detectors)



15-kiloton LArTPC

Carl Bromberg

Michigan State University

October 23, 2008

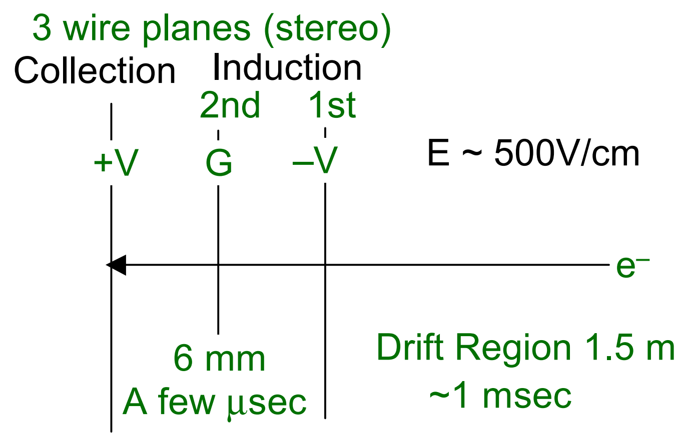
The challenge

- A plan leading to the construction of a multi-kiloton Liquid Argon TPC neutrino experiment in the U.S.
  - Develop confidence in the construction technology
  - Develop a design with a reasonable cost (innovative solutions)
  - Develop confidence in a cost estimate (+ contingency)
  - Do some interesting and relevant physics along the way
- Will require a multi-year time frame
- The U.S. is investing in ν beams and NOνA. To maximize the physics reach, a next-generation detector should be close behind
- Little past experience with LArTPC in the US
- Experience in LArTPC technology exists mostly in Europe through the work of the ICARUS collaboration

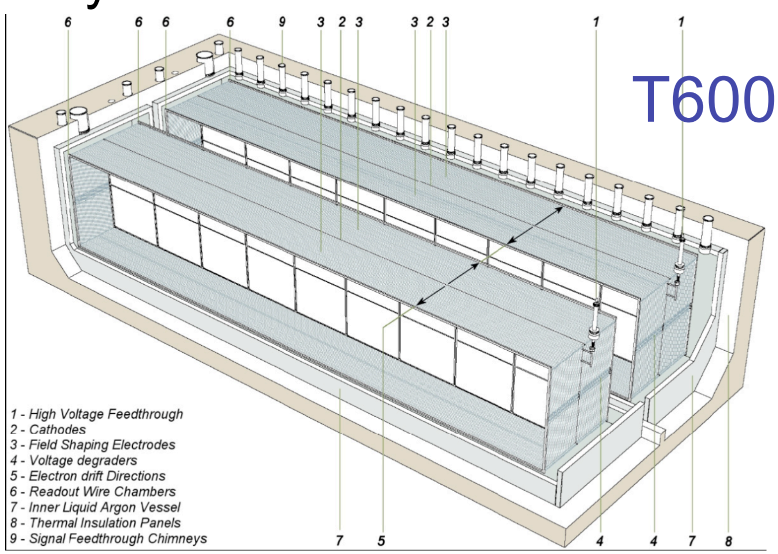
ICARUS

- Twenty years of detector development (50L • 3T • 300T)
  - Successful surface test of T300
  - T600 (2 x T300) in Grand Sasso Lab
  - Pioneering LAr underground
  - Triggers with UV light from PMTs
  - May fill before CERN winter shutdown

LArTPC Operation

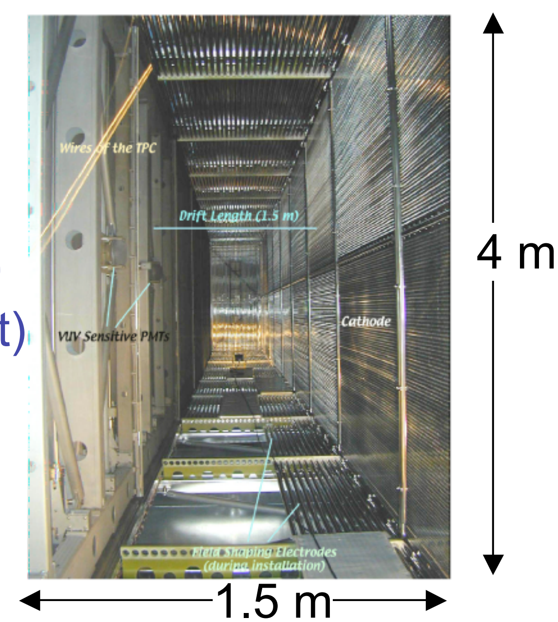


T600



Nucl. Inst. Meth., A527 (2004)

T300
(left drift)



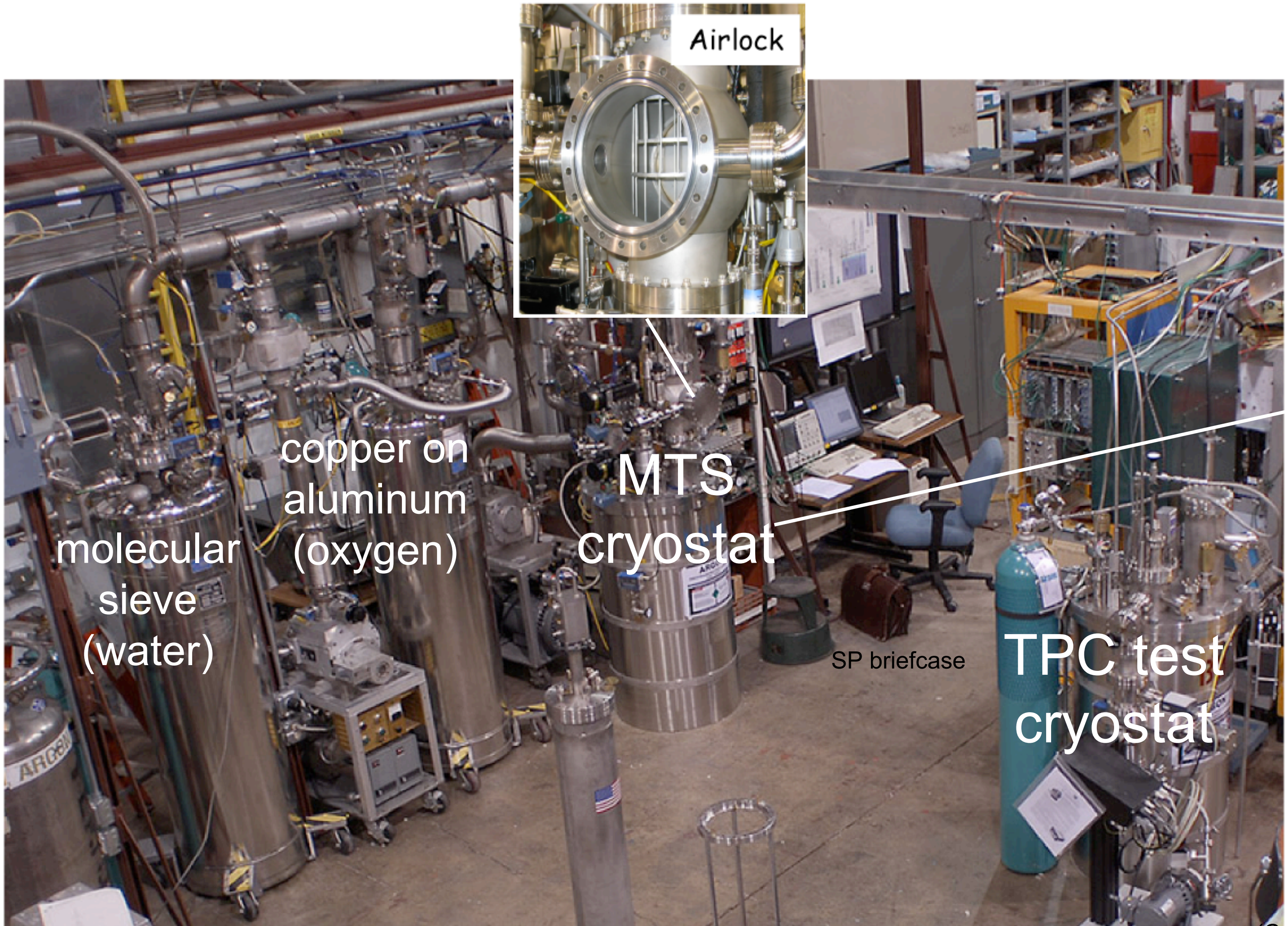
Multi-kT LArTPC technical & cost issues

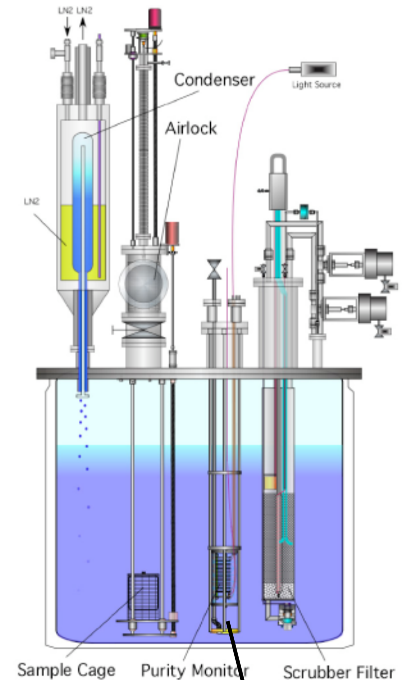
- Argon purity
  - Reduce O_2 fraction from 0.2 to $<10^{-10}$ *without evacuation*, initial gas flush
  - Filter technology for continuous purification of liquid and gas
  - Identify safe detector materials in liquid and gas. Large tanks are easier?
- Vessel design *& cost*
  - Shape, safety (underground?), cryogenics, temperature control, convection
- Detector design *& cost*
  - HV(50kV/m), >100k wires, assembly, electronics integration, UV light
- Electronics/DAQ technology *& cost*
  - Cold or warm preamps, feedthroughs, RF shielding, cables
  - Live hit/track finding, zero suppression, 100% live (for p-decay, supernova)
  - Implement PMTs for triggering
- Software
  - Event simulation and reconstruction, digital signal processing (DSP)
  - Pattern recognition, automated scanning, trigger, cosmic rays (surface)
- Cost scaling from 0.1 kT to 10 kT to 100 kT
  - Economies of scale require *design stability*. New ideas must be cheaper

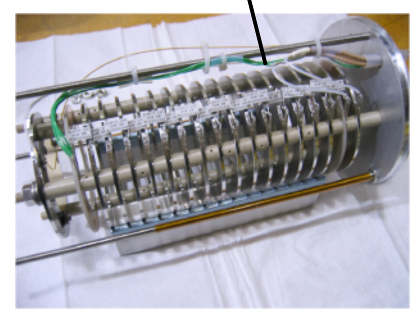
Local R&D

- Use small cryostat test stands for specific issues
  - Measure contamination effects of TPC materials & tank construction
  - Measure efficacy of contaminant removal with custom filters
  - Detect muon tracks in a small TPC to gain credibility and
    - find economical solutions for signal & HV feedthrough, cabling, RF shielding, readout electronics & TPC construction
    - Obtain track data (i.e., with noise) to normalize MC software development
- Build intermediate size detectors & do some ν physics:
  0.25T (ArgoNeut), 100T (MicroBooNE), & proposed >5kT (LAr5)
  - Stimulates and sets schedules for the technology
  - Forces integration of all aspects of experimental design
  - Stimulates development of analysis software for physics
  - Builds collaborations:
    - ArgoNeuT: L'Aquila, FNAL, LNGS, MSU, UTA, Yale
    - MicroBooNE: BNL,Columbia, FNAL, MSU, UTA, Yale
- Keep in mind the goal: "a world-class neutrino program" (P5 report)

Test Stands (FNAL): Materials Test System





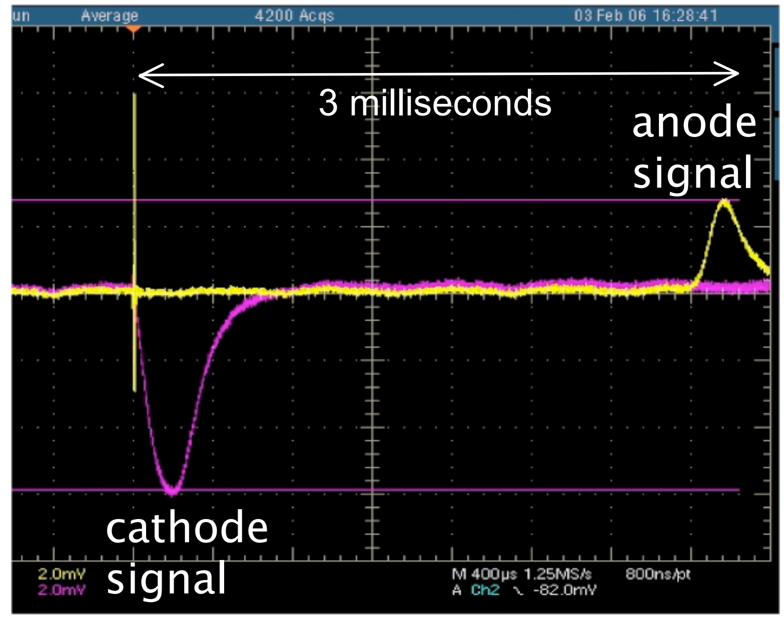


Purity monitor
(G. Carugno et al., NIM A292 (1990))

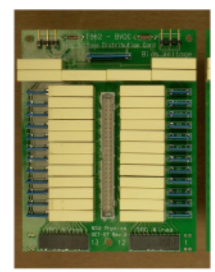
Observations with the MTS

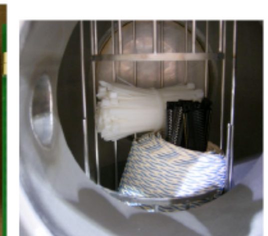
- Molecular sieve needed to remove water before the oxygen filter.
- Many millisecond e⁻ lifetimes achieved with closed and open (venting) systems
- Nitrogen at ppm levels does not affect drift-lifetime (O_2 levels in ppt)
- Most materials in 87K liquid and gas at <200K do not contaminate liquid Argon
  - Hybrid preamplifier circuit boards
  - PC boards with many C's and R's
  - Cables & cable ties
- In 295K gas, many materials contaminate the liquid Argon via the gas.
- Must purify the Argon gas and liquid

Purity monitor signals




Hybrid preamp


Bias Voltage Dist. Card


Cables & Cable-ties

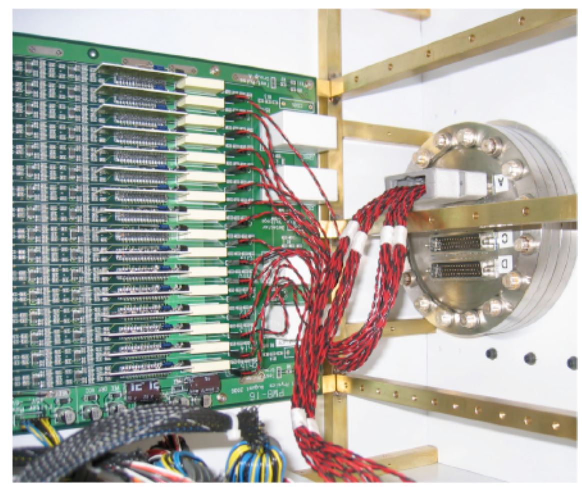
Small TPC "laboratory bench"

TPC being lowered into its cryostat

- Simple TPC construction (FNAL)
  - Cryostat with no purification (vented)
  - Copper clad thin G10 for cylindrical drift-field electrodes, resistor chain is soldered.
  - PC boards for 3 wire planes, CuBe wires soldered to Cu pads, 60° stereo, ~4 mm pitch and plane spacing
- Electronics (MSU) 96 channels

  As in ICARUS {
  - Dual FET front-end preamp hybrids*
  - Bias voltage (~400V) on signal cables
  - Noise filtering to optimize S/N (not shape)
  - Over sampled at 5 MHz for offline DSP
  - ADC/FPGA* (MSU), 2048 samples/channel (modern approach for LArTPC DAQ)
  - Careful grounding, RF shielding, LV supplies

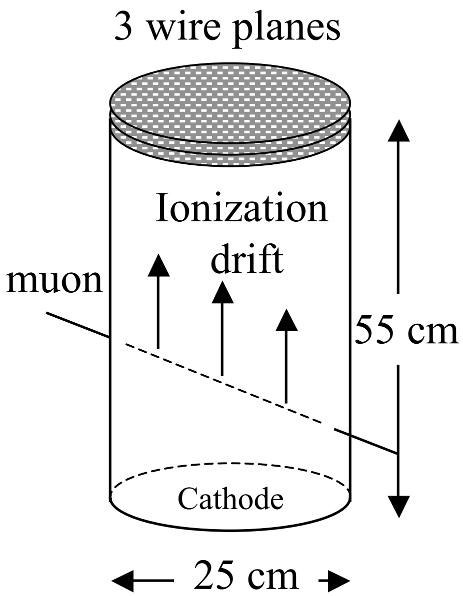
  *borrowed from D0
- Filter and shaper optimization for ArgoNeuT
- Platform for future electronics development

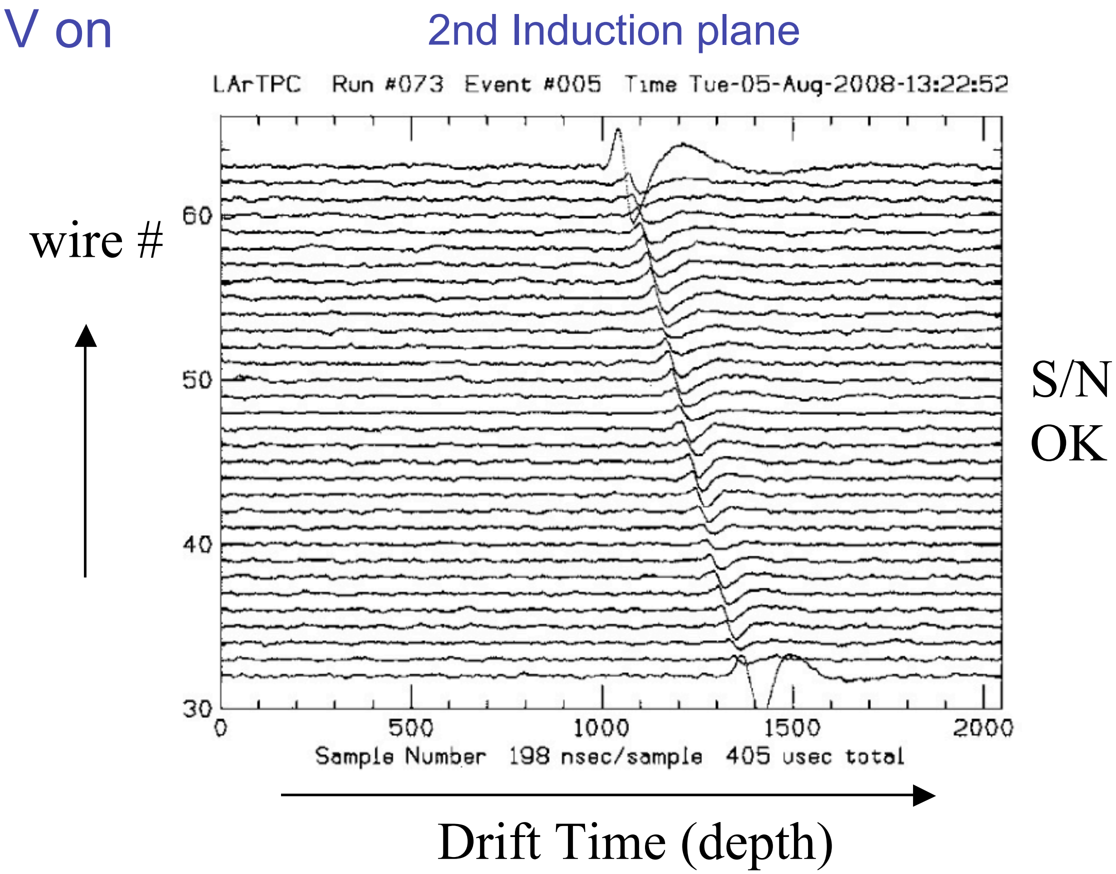


Installing preamp motherboards

Right out of the box

- Setup 2 + 2 counter trigger
- Cathode to 25 kV, bias V on
- Take a few triggers
- Muon tracks!
- Stable for 3 weeks



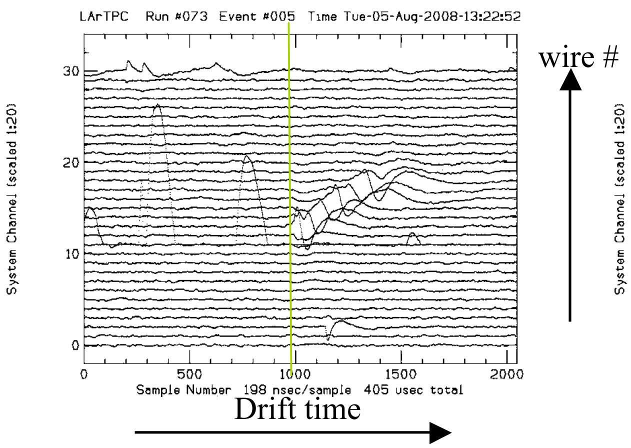


- This is not our calibration pulser -- ionization fluctuations give it away.

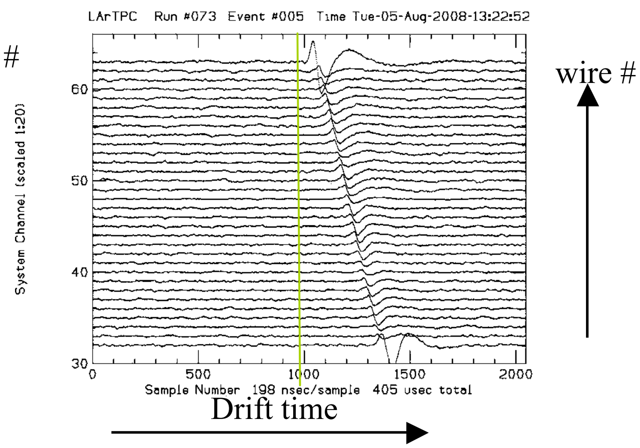
More track details

- Number of hits depend on the track orientation relative to wires
- Track orientation affects pulse height and width, issue for electronics

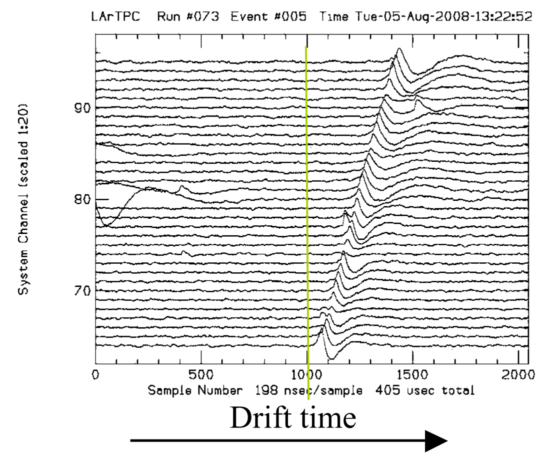
Plane 1
(Induction, 0°)



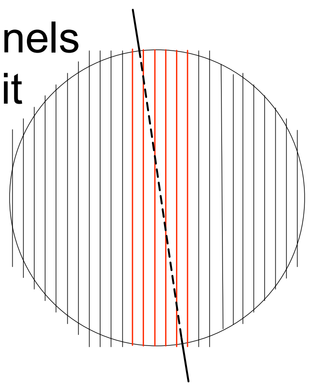
Plane 2
(Induction, +60°)



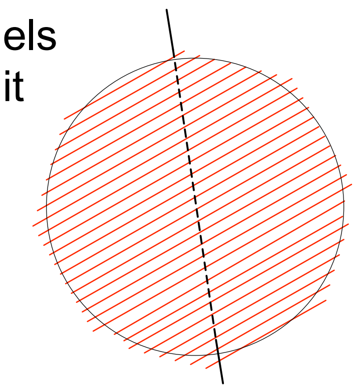
Plane 3
(Collection, –60°)



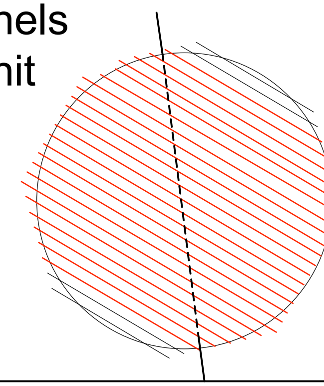
few channels show a hit



all channels show a hit

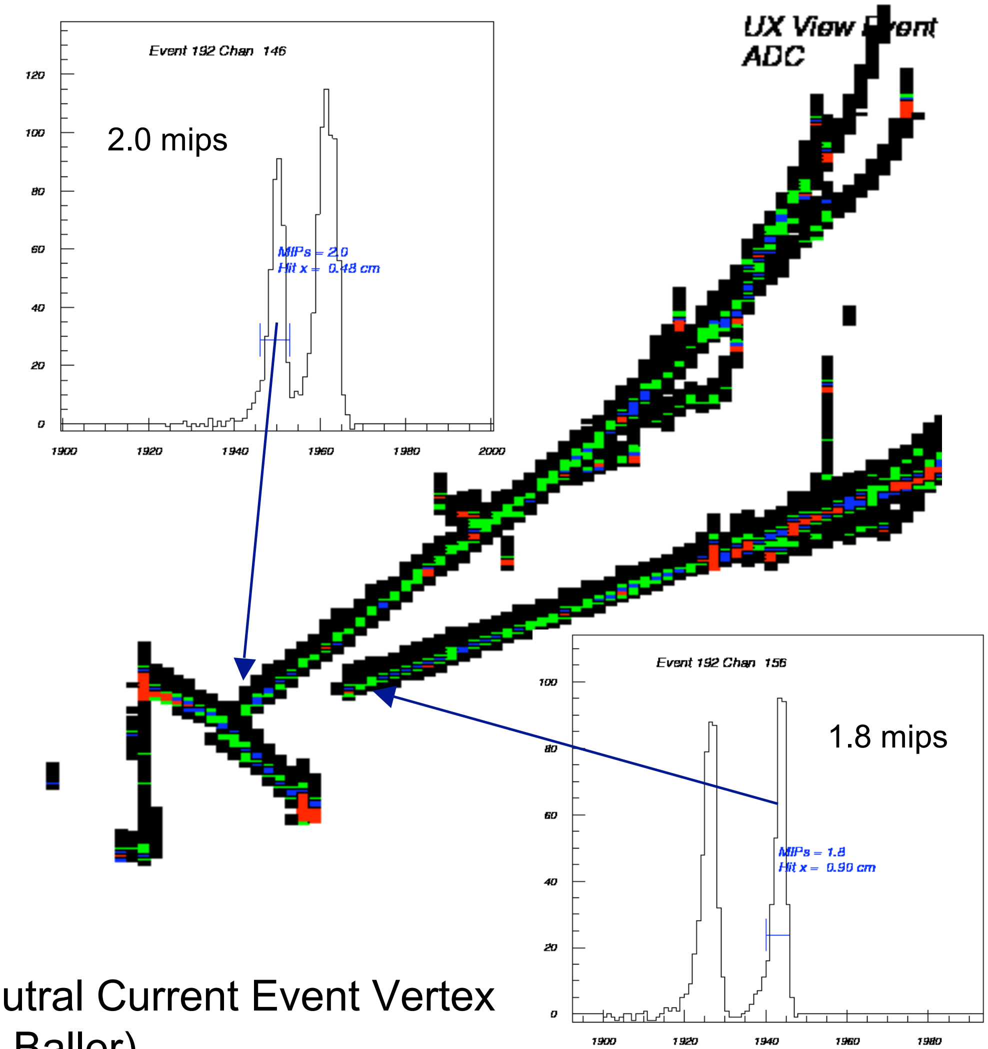


all channels show a hit



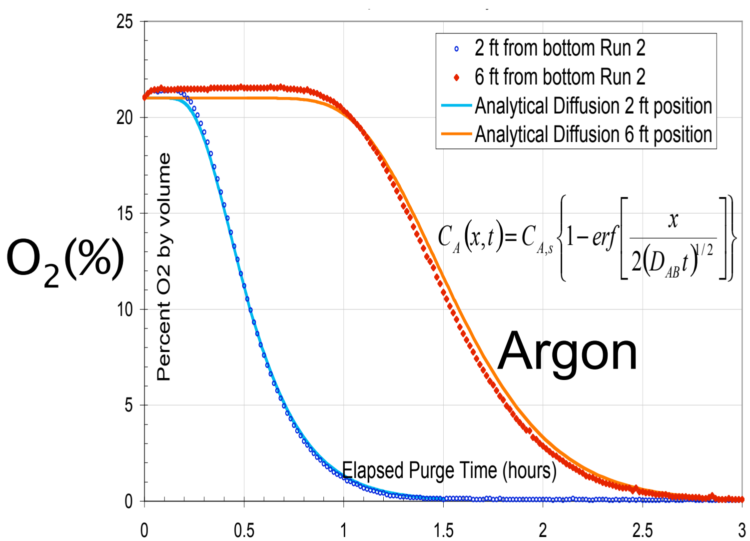
Simulation software

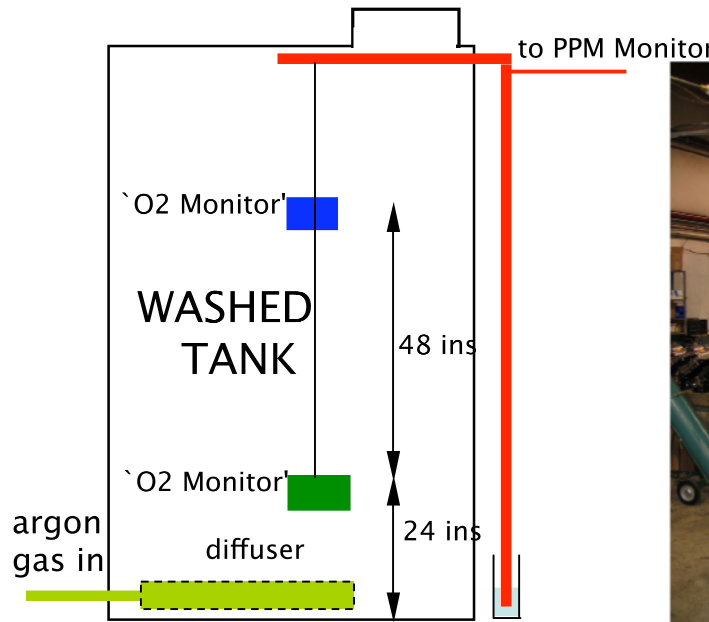
- Muon data allows simulation software to be normalized to reality - MC must include noise
- Full simulation starting from ionization to signals induced on wires to amplifier shaping and DSP deconvolution, etc.
  - Investigate effects of wire pitch and plane spacing
  - Develop pattern recognition and event ID algorithms



Neutral Current Event Vertex (B. Baller)

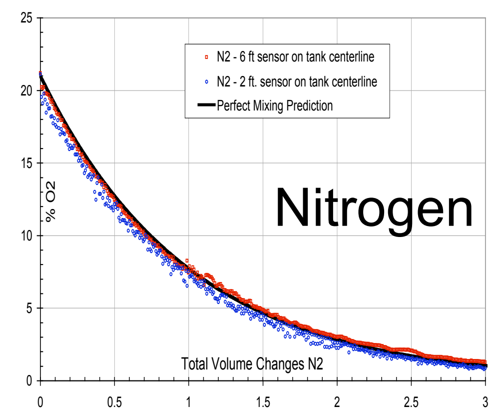
Purification: Argon gas “piston” to a few ppm O_2





2.6 volume changes to reach 100 ppm O_2

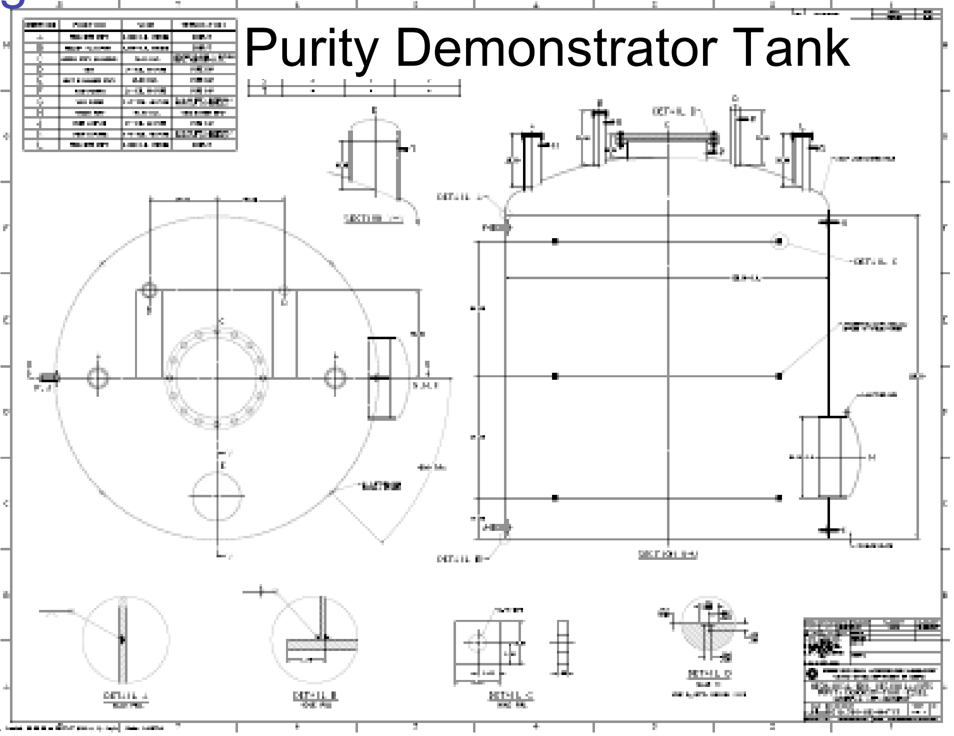
Simple mixing with N_2 takes 7.6 volume changes to reach 100 ppm O_2



Proposed Purity Demonstrator

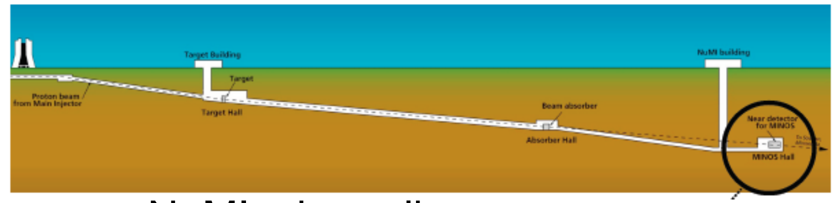
- A flat bottomed (20T) tank, as proposed for the multi-kT detector
- Commercially welded tank, foam insulated. Cannot be evacuated.
- New gas and liquid purification system reusable for future LAr experiments
- Load up with TPC materials, cables, PC boards
- Purify gas and then liquid from atmosphere to < 0.1 ppb and test electron lifetime with purity monitor, aiming for 10 ms.
- M&S costs are $300k

- Progress toward the big tank solution will be slow without this test



ArgoNeuT(T962) (jointly funded by NSF/DOE)

- Collaborating Institutions: L'Aquila, FNAL, LNGS, MSU, UTA, Yale
- 175 liter LAr TPC in NuMI beam
- Installing *underground* with muon momentum analysis by MINOS ND



NuMI ν beamline

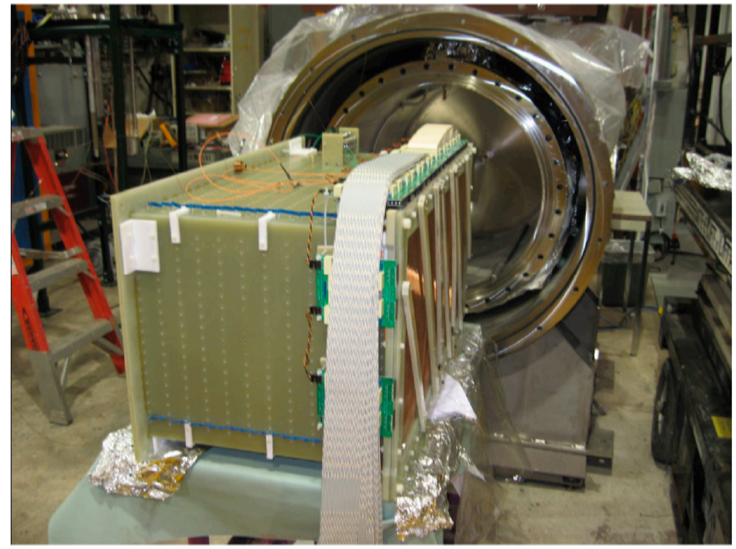
MINOS ND

ArgoNeuT cryostat with preamp RF shield box above

- Goals
  - LArTPC construction experience
  - Obtain sample of ~20,000 neutrino interactions in 6 month run
  - Confront some underground safety issues - readiness reviews in progress
  - Reconstruction & simulation software
  - Measure CC QE cross-section
  - Separate beam ν_e signal (< 5%) from NC

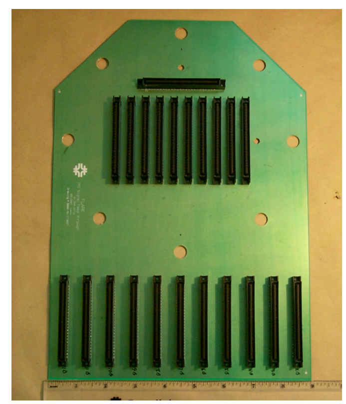
ArgoNeuT TPC

- TPC, cryostat and filters (Yale)
  - 175 L active volume, 480 signal wires
  - 2 active wire planes plus a shield plane
  - 4 mm wire pitch, 4 mm plane spacing
  - CuBe wires are soldered to readout boards
  - Field cage is Cu-clad G10 and epoxy
  - Bias voltage distributed on the TPC



Inserting TPC into the cryostat

- Novel signal feedthrough (FNAL)
  - Standard connectors and cables!
  - Multilayer PC board routes signals from inside the flange to outside the flange
  - Connectors are *not leak tight*
    Note: PC board will be *captured* between pipe flange and a *blanking plate*

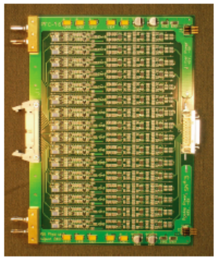


Interior connectors for TPC cables

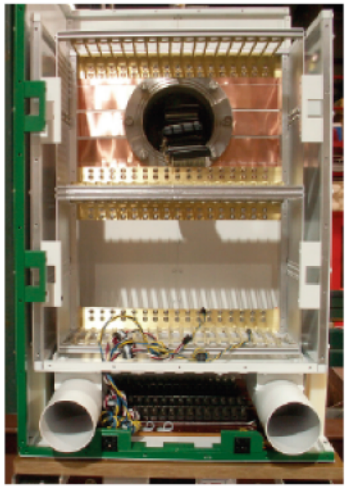
Exterior connectors for preamp cables

ArgoNeuT electronics

- Readout electronics and DAQ (MSU)
  - New preamplifier with onboard FET front-end, bias voltage distribution moved to TPC
  - RF shielding, cooling, and LV PS solution similar to the earlier small TPC
  - 15 additional ADC/FPGA cards, 2048 samples/channel
  - DAQ readout via slow path, but OK for < 0.5 Hz

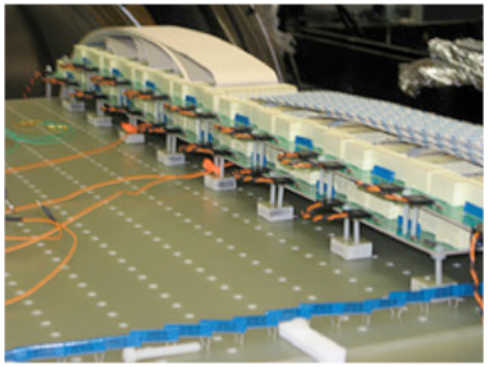


Preamp board



RF shielding & Preamp cooling

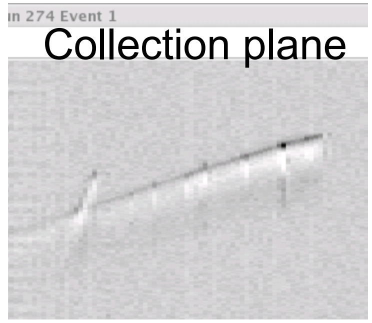
- Bias voltage distribution card at 87K (MSU)
  - Cards plug into matching TPC connectors, signal cables plug into the card
  - Card has isolation resistor to each wire and DC bias decoupling capacitor to the signal connector

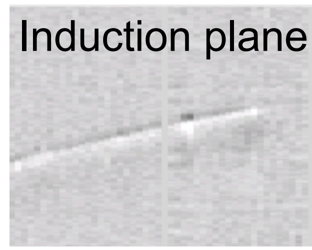


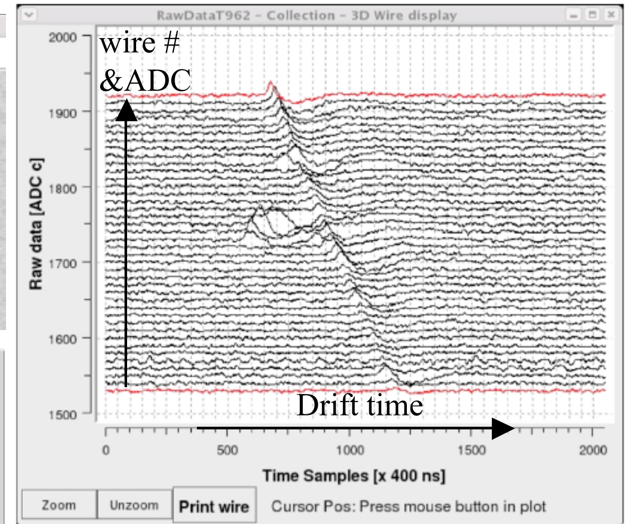
Two layers of bias voltage distribution cards on top of TPC

ArgoNeut commissioning

- Initial commissioning steps
  - 50% of electronics installed
  - Initial fill through O_2 purifier
  - HV to 5 kV & bias voltages on
  - Take a few random triggers
  - Muon tracks!
  - Signal to noise "comfortable"
  - 100% of electronics operational





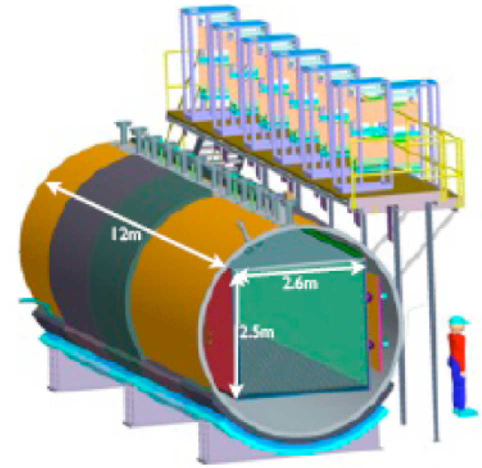


- Cryogenics & purification (with L'Aquila, LNGS expertise)
  - Cryocooler & closed loop O_2 purifier
  - LNGS display and analysis software
  - Electron lifetime obtained by analysis of muon tracks
  - Electron lifetime improved with purifier from 0.1 to 0.4 ms. Investigating!
- Dismantled for inspection, repairs, and to move underground

MicroBooNE experiment

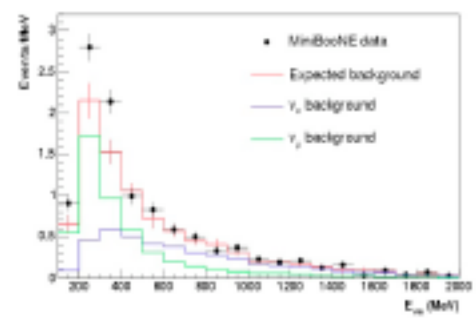
- MicroBooNE LArTPC will observe on-axis Booster and off-axis NuMI neutrino interactions
- Stage 1 approval June 2008.
- Combines timely physics with R&D for LArTPC technology
  - Cold (120K) preamplifiers for improved S/N
  - Long (2.5m) drift reduces electronics cost
- Obtain LE cross sections and check MiniBooNE anomaly below 400 MeV.
- MicroBooNE capabilities
  - Excellent electron - gamma discrimination
  - Low energy cross sections (CC, NC, Res)
  - Resonance identification, K-production
  - UV-trigger, automate cosmic muon rejection
  - 5 σ significance for an electron neutrino source
  - 3.3 σ significance for a photon source
  - K^+ decay efficiency/background for p-decay

MicroBooNE detector



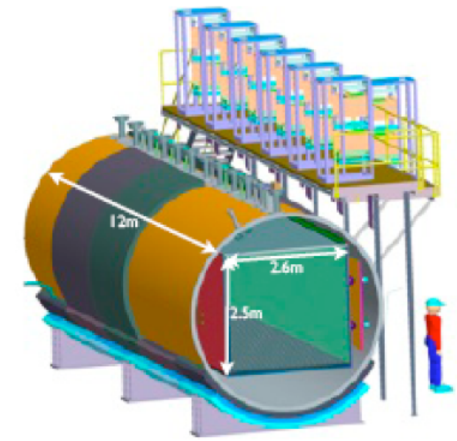
➡Joint NSF/DOE Project
➡NSF MRI for TPC and PMT systems

MiniBooNE Result Excess
200-300MeV: 45.2±26.0 events
300-475MeV: 83.7±24.5 events

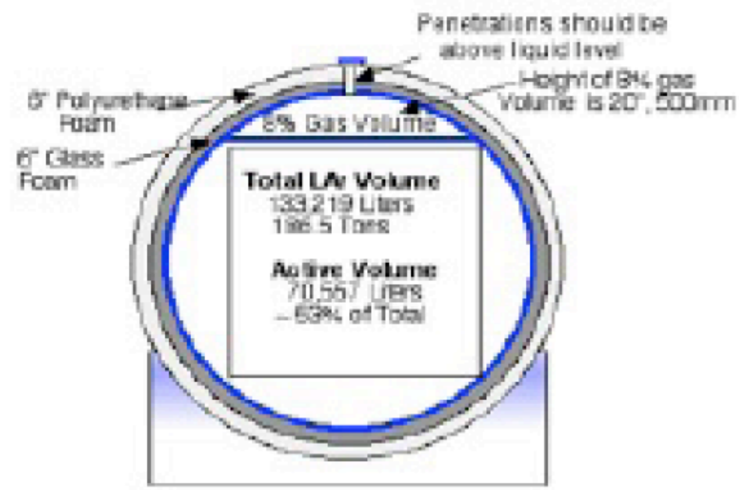


MicroBooNE detector

- Cryostat (180T cap.) built commercially offsite
- Evacuable vessel with foam insulation
  (may not need to evacuate before purification)
- On the surface near MiniBooNE location
- TPC parameters
  - 100T fiducial mass
  - 2.5 m drift, drift field 500 V/cm
  - 3 readout planes (±60° Induction, 90° Collection)
  - 10,000 channels of cold preamplifiers
- 30 PMTs for triggering
- New purification & recirculation system

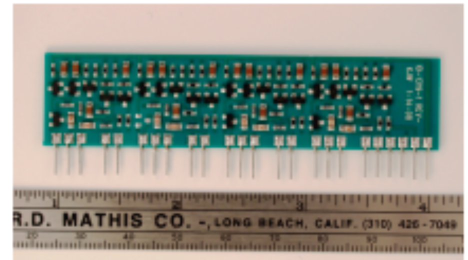


➡Joint NSF/DOE Project
➡NSF MRI for TPC and PMT systems

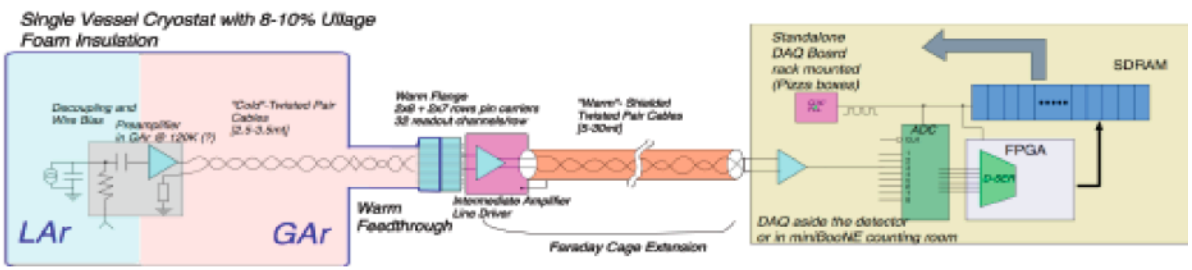


MicroBooNE R&D

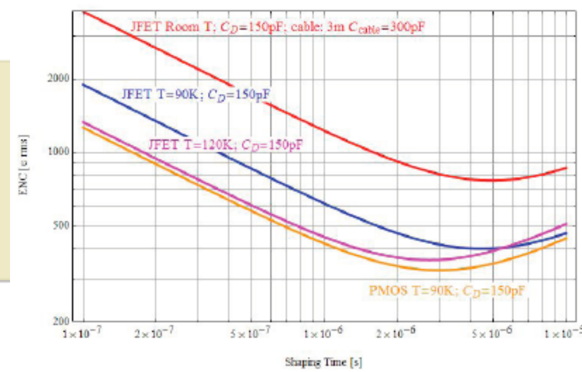
- Preamps in the cryostat gas at 120K
  - Lower capacitance and therefore lower noise
  - 120K is optimum for FET Preamp noise performance
  - Post Amplifiers at the feedthrough
  - Remote ADC/FPGA and Ram buffer



4-channel hybrid preamp



MicroBooNE readout chain



Noise vs. shaping time at various temperatures and cable lengths

- Long term R&D: move into the 87K liquid
  - Use pMos on TPC
  - ADC, hit finding on TPC
  - multiplexed readout
  - Fewer systems -> lower cost

Summary - toward a multi-kiloton LArTPC

- Progress
  - Obtained filter performance required, and Argon "piston" successful
  - Testing materials for safety in liquid and gas
  - Simulations indicate that temperature uniformity in a tank is good
  - New feedthrough allows standard cable and connectors to be used
  - RF shielding design yields good S/N; good tracks on small TPC devices
  - Event simulation and reconstruction making good progress
  - Developing digital signal processing techniques for on & offline data
- To do list
  - Without evacuation, purify gas and liquid to 10^{-10} O_2 in an LNG-type tank
  - Develop online hit finding & zero suppression in ADC/FPGA combination
  - System tests with cold electronics: preamps, ideally ADC / multiplexing
  - Devise and test realistic TPC assembly procedures, modular if possible
  - Find cost effective implementation of UV light triggering
  - Test automated scanning and cosmic ray rejection algorithms
  - Many details …
- Obtain physics with ArgoNeuT and complete design of MicroBooNE