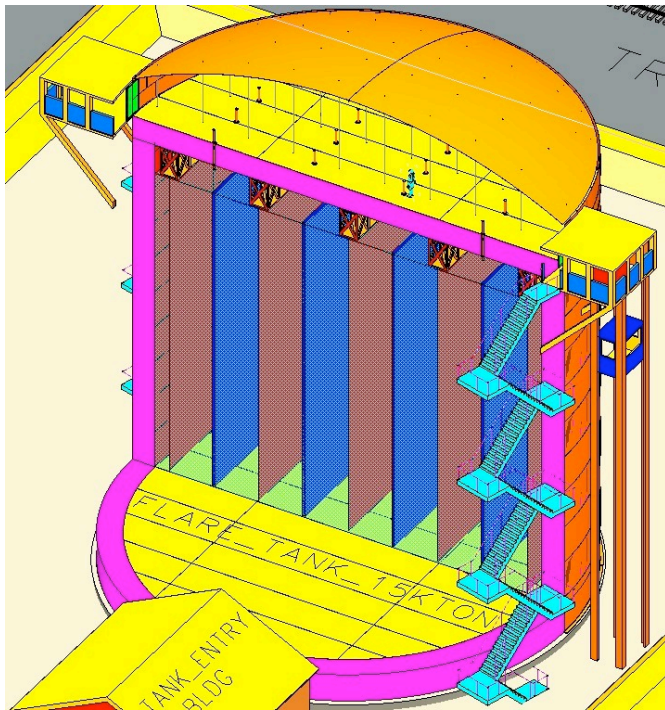


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# Liquid Argon R&D

(A few small steps toward multi-kiloton detectors)



15-kiloton LArTPC

Carl Bromberg  
Michigan State University  
November 18, 2008

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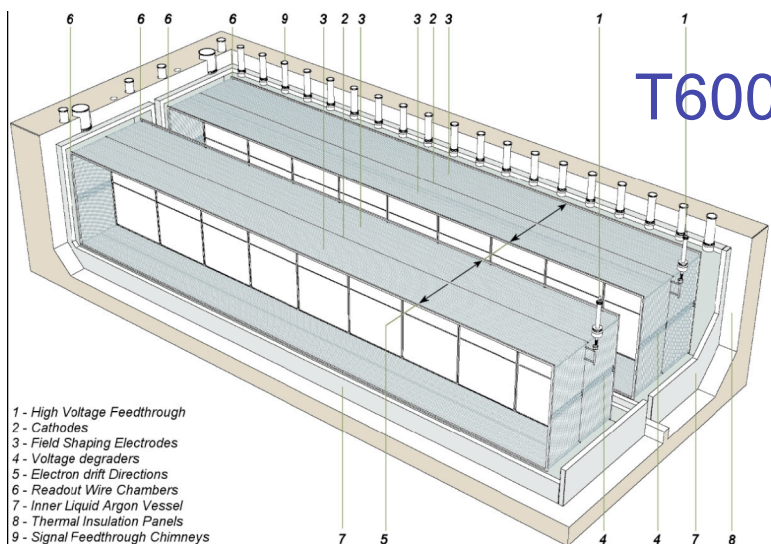
# The challenge

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- 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  $\nu$  beams and NO $\nu$ A. 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

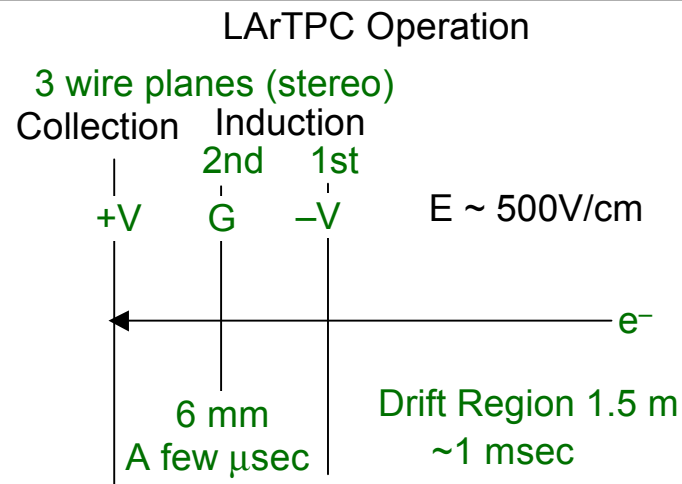
- Twenty years of detector development (50L • 3T • 300T)
  - Successful surface test of T300
  - T600 (2 x T300) in Grand Sasso Lab
  - Pioneering LAr underground
  - UV light trigger with PMTs
  - Fill after winter shutdown



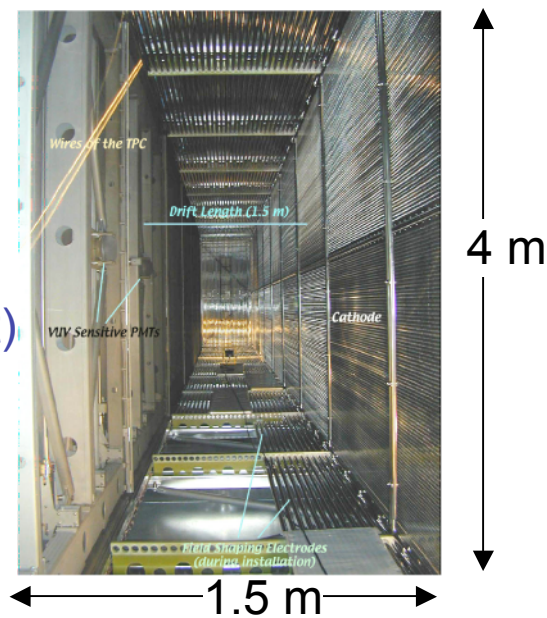
- 1 - High Voltage Feedthrough
- 2 - Cathodes
- 3 - Field Shaping Electrodes
- 4 - Voltage degraders
- 5 - Electron drift Directions
- 6 - Readout Wire Chambers
- 7 - Inner Liquid Argon Vessel
- 8 - Thermal Insulation Panels
- 9 - Signal Feedthrough Chimneys

Nucl. Inst. Meth., A527 (2004)

T600



T300  
(left drift)



# Multi-kT LArTPC technical & cost issues

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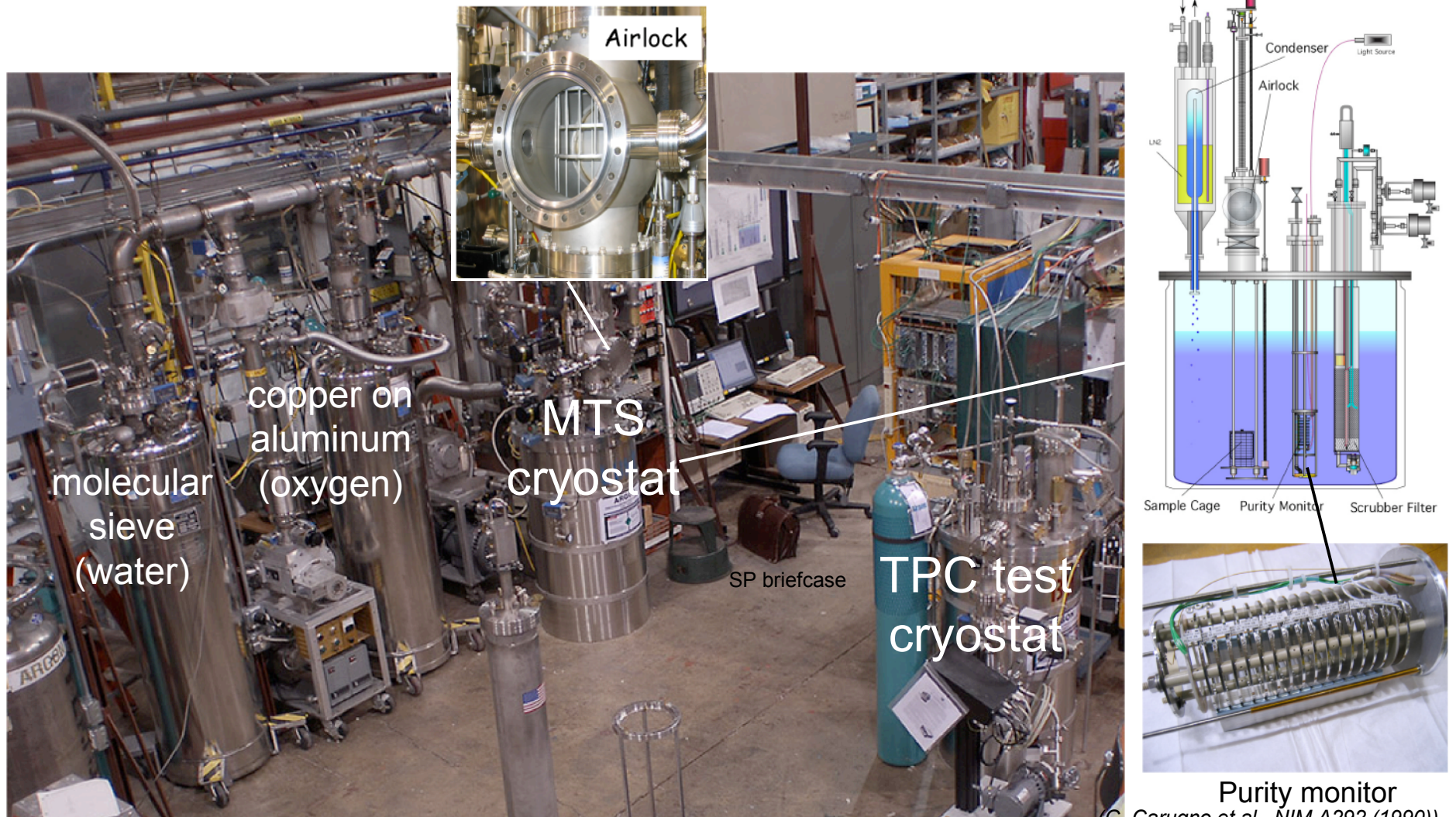
- Argon purity
  - Reduce O<sub>2</sub> fraction from 0.2 to  $< 10^{-10}$  *without evacuation*, Ar gas “piston”
  - Filter technologies for continuous purification of liquid and gas
  - Identify safe detector materials in liquid and gas. Large tanks are easier?
- Vessel design & cost
  - Shape, safety (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 preamp, feedthrough, RF shielding, cables
  - Live hit/track finding, zero suppression, 100% live (for p-decay, supernova)
  - Implement PMTs for triggering in a large tank
- Software
  - Event simulation and reconstruction, digital signal processing (DSP)
  - Pattern recognition, automated scanning, trigger, cosmic rays (surface)
- Cost scaling from 0.1 kT -> 1.0 kT -> 10 kT -> 100 kT
  - Economies of scale require *design stability*. Ideas to lower cost - test now

# 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 filters in-house design
  - 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 (evaluate noise) to normalize MC software development
- Build intermediate size detectors & do some  $\nu$  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
- US goal is to have “a world-class neutrino program” (P5 report)

# Test Stands (FNAL): Materials Test System

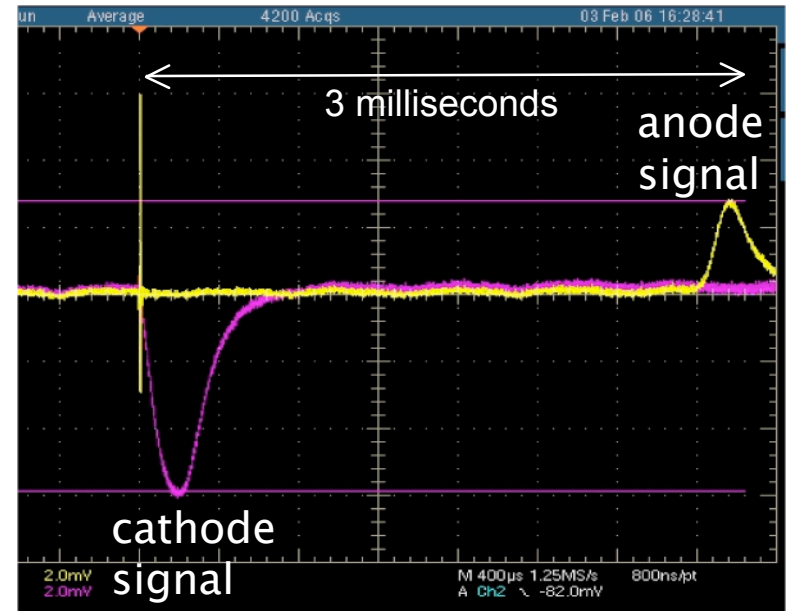


Purity monitor  
(G. Carugno et al., NIM A292 (1990))

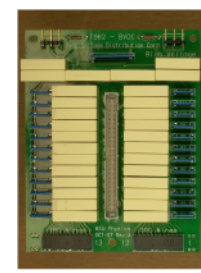
# Observations with the MTS

- 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 (need  $O_2$  at ppt levels)
- Most materials in 87K liquid or 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

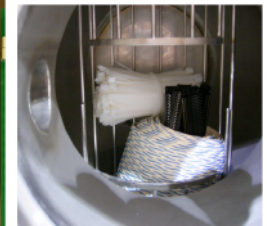
Purity monitor signals



Hybrid preamp



Bias Voltage  
Dist. Card



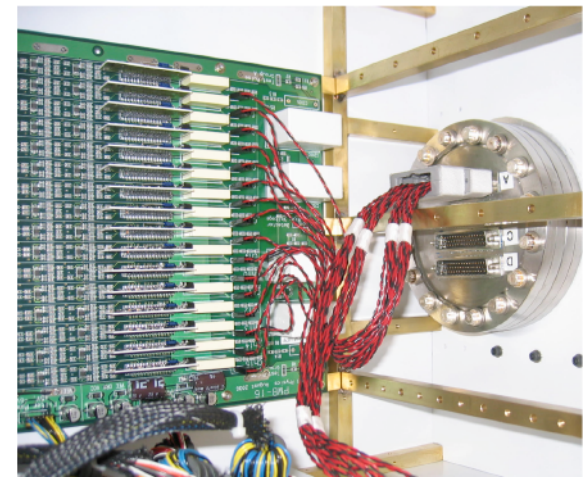
Cables &  
Cable-ties

# Small TPC “laboratory bench”

- 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
  - Dual FET front-end preamp (hybrids\*)
  - Bias voltage (~400V) on signal cables
  - Minimal noise filtering to optimize S/N
  - Over sampled at 5 MHz for offline DSP
  - ADC/FPGA\* (MSU), 2048 samples/channel, 5MHz (modern approach for LArTPC DAQ)
  - Careful grounding, RF shielding, LV supplies  
\*borrowed from D0
- Electronics filter optimization for ArgoNeuT
- Platform for future electronics development

As in  
ICARUS

TPC being lowered into its cryostat

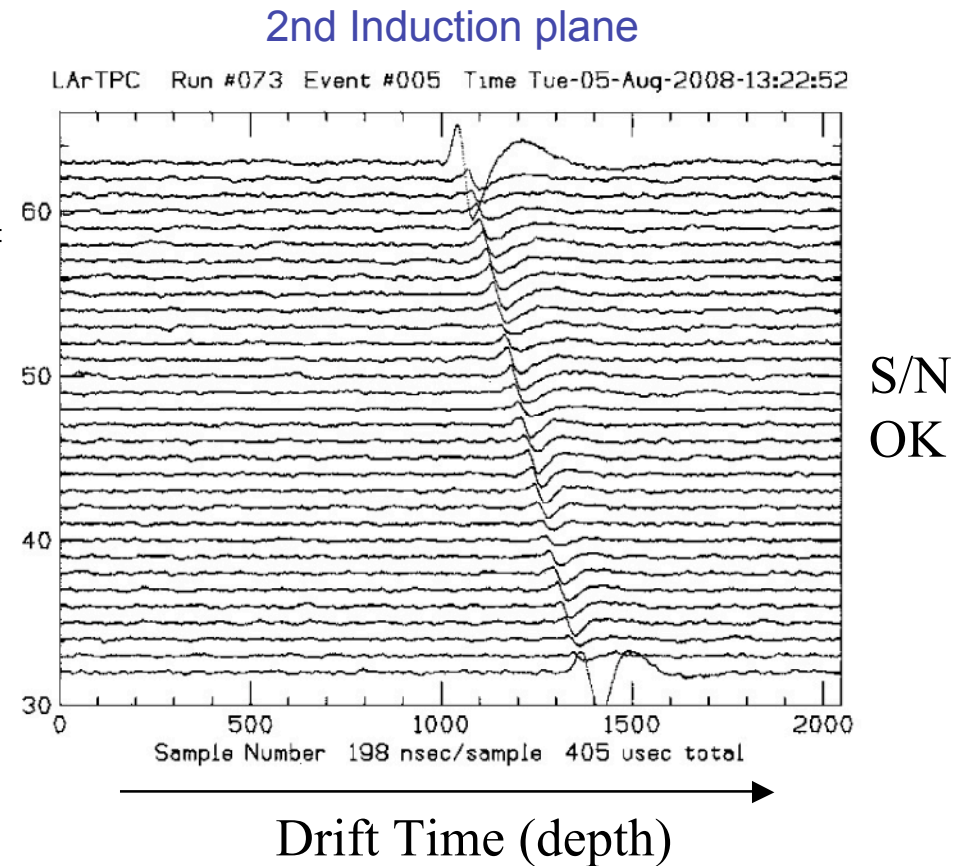
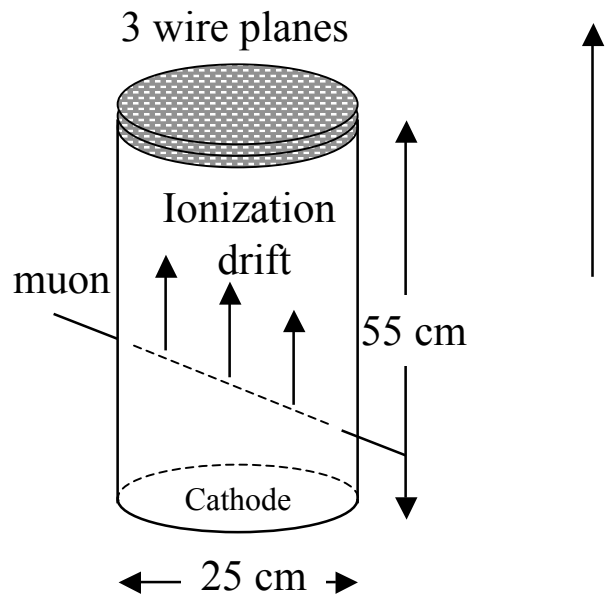


Installing preamp motherboards



# Right out of the box

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

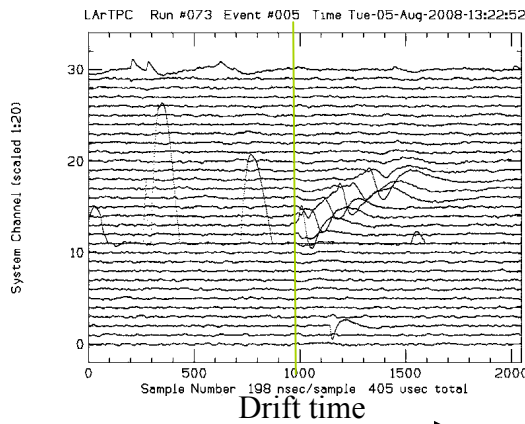


- Looks like our “calibration track” -- ionization fluctuations give it away.

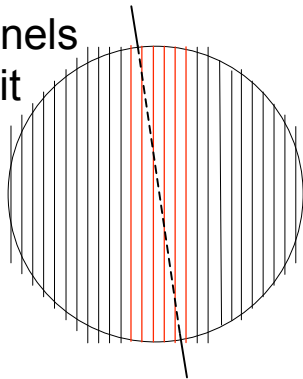
# More track details

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

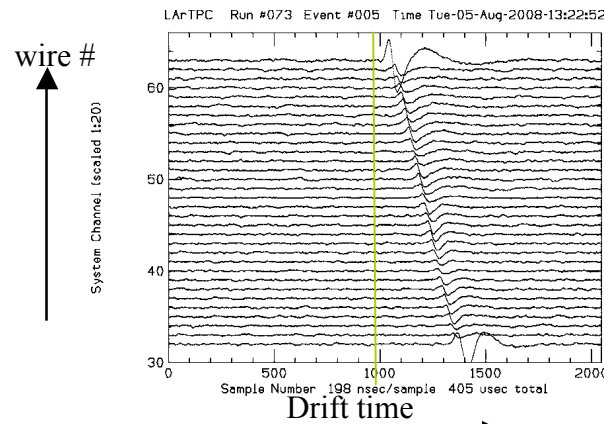
**Plane 1**  
(Induction,  $0^\circ$ )



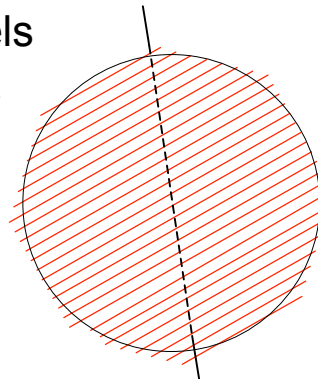
few channels  
show a hit



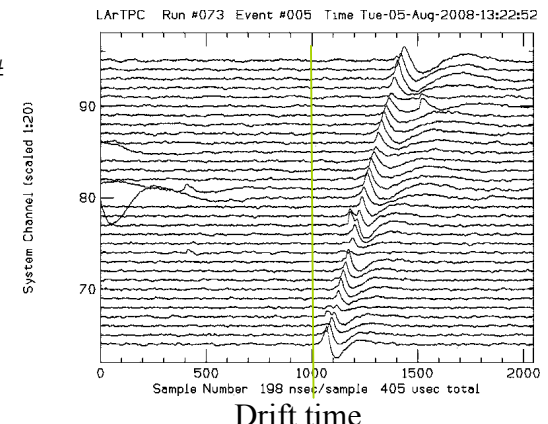
**Plane 2**  
(Induction,  $+60^\circ$ )



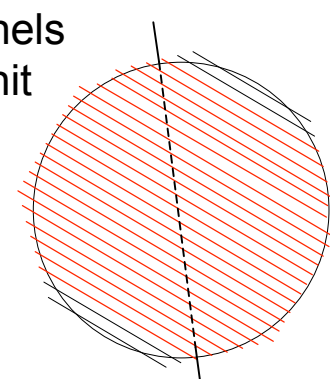
all channels  
show a hit



**Plane 3**  
(Collection,  $-60^\circ$ )

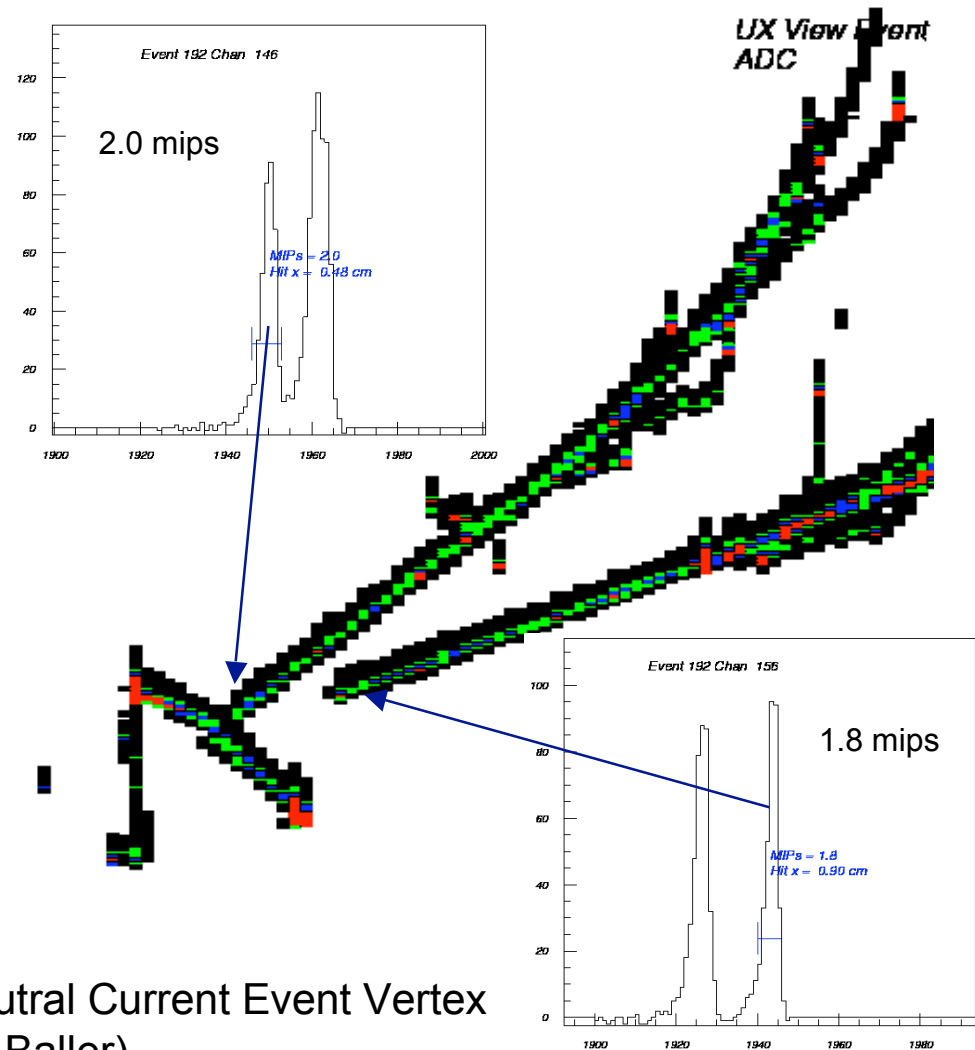


all channels  
show a hit



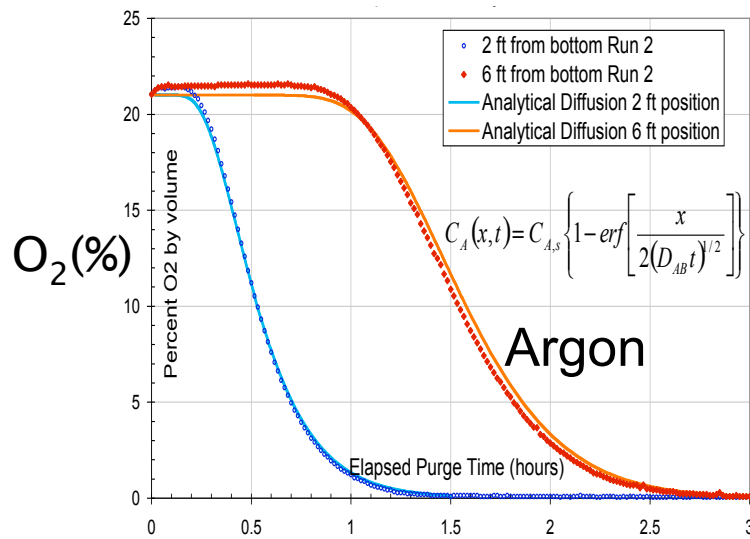
# Simulation software

- 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 DSP deconvolution, etc.
  - Investigate effects of wire pitch and plane spacing
  - Develop pattern recognition and event ID algorithms

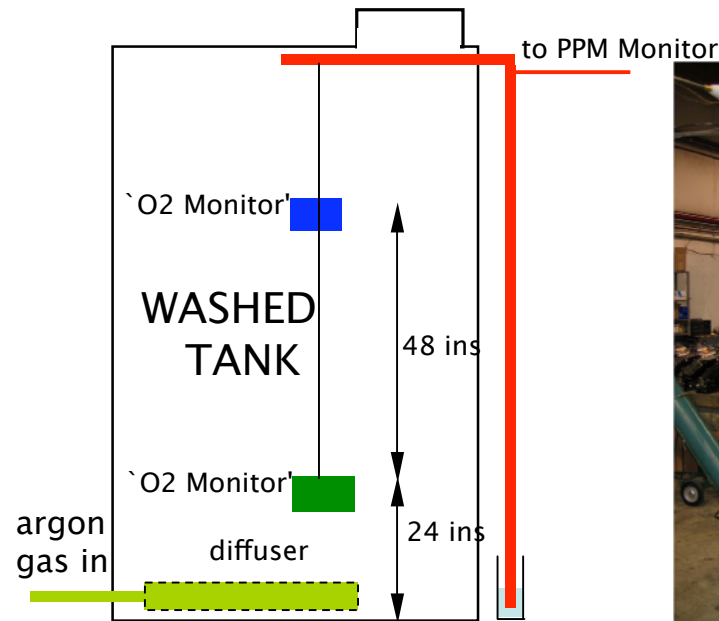


Neutral Current Event Vertex  
(B. Baller)

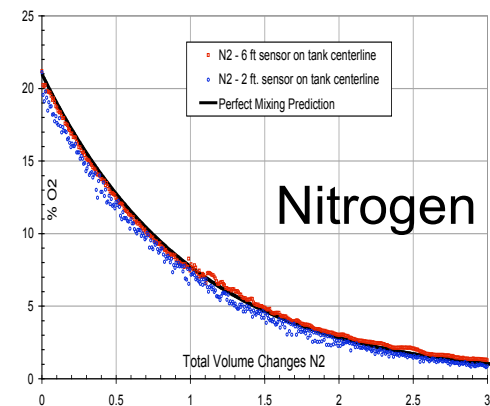
# Purification: Argon gas “piston” to a few ppm O<sub>2</sub>



2.6 volume changes  
to reach 100 ppm O<sub>2</sub>

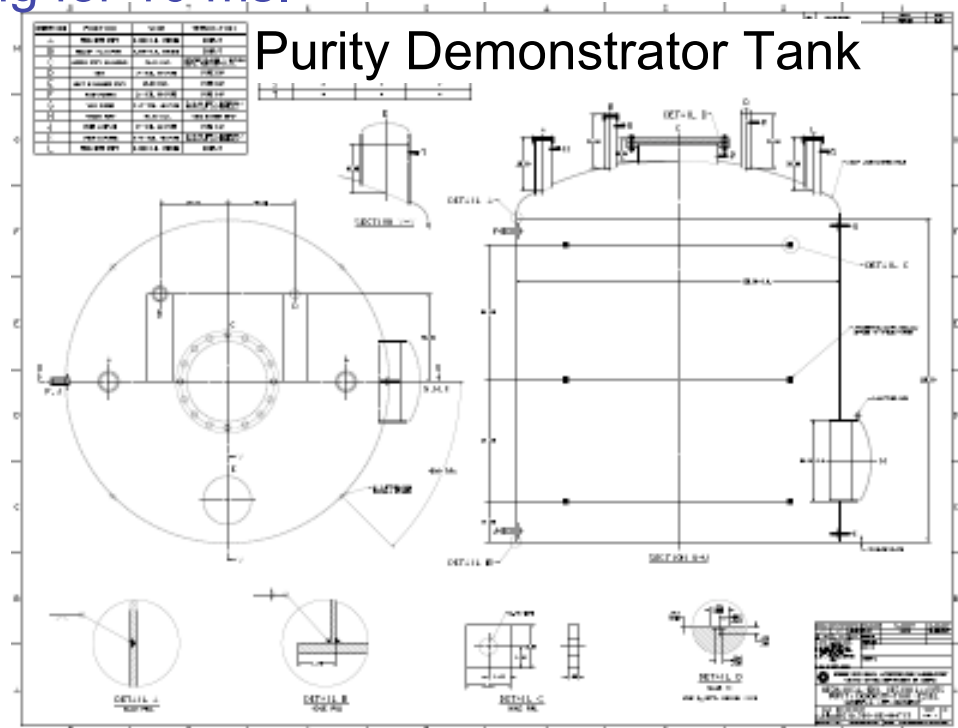


Simple mixing with  
N<sub>2</sub> takes 7.6 volume  
changes to reach  
100 ppm O<sub>2</sub>



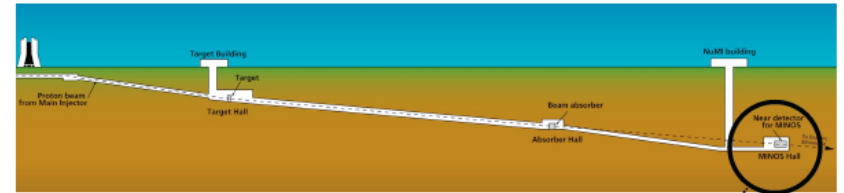
# Purity Demonstrator

- 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
- First with just tank, then with TPC materials, cables, PC boards, etc.
- Purify gas and then liquid from atmosphere to  $< 0.1$  ppb and test electron lifetime with purity monitor, aiming for 10 ms.
- Tank & cryogenics purchased
- Progress toward the big tank solution should accelerate after 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*; muon momentum analysis with MINOS ND



NuMI  $\nu$  beamline

MINOS ND

ArgoNeuT cryostat  
with preamp RF  
shield box above

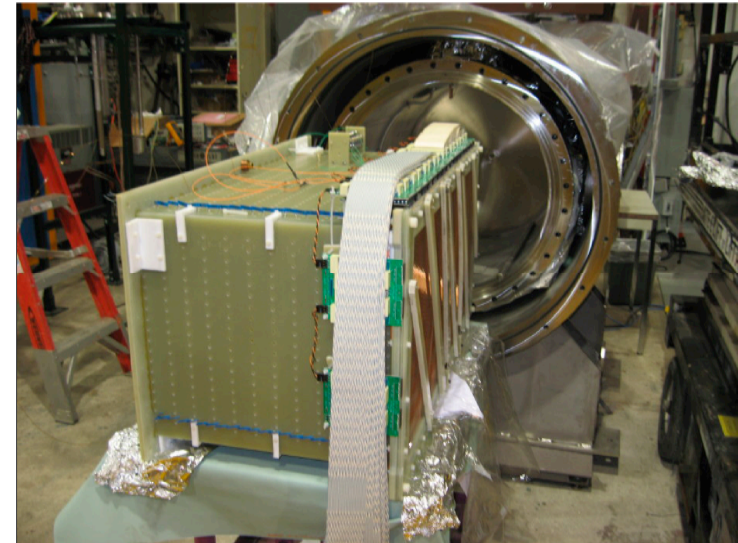
- Goals

- LArTPC construction experience
- Obtain sample of  $\sim 10,000$  *low-energy* 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  $\nu_e$  signal ( $< 5\%$ ) from NC



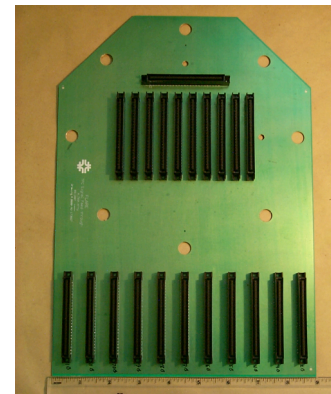
# ArgoNeuT TPC

- 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*
  - PC board will be *captured* between pipe flange and a *blanking plate*

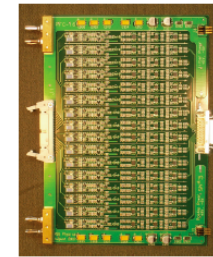


Interior connectors for TPC cables

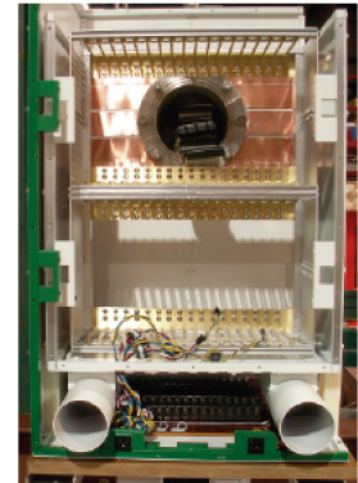
Exterior connectors for preamp cables

# ArgoNeuT electronics

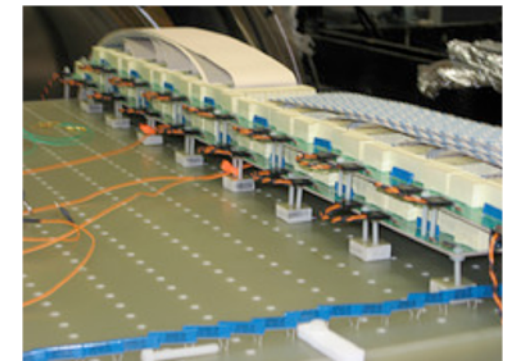
- Readout electronics and DAQ (MSU)
  - New preamplifier with onboard FET front-end, bias voltage distribution moved to TPC
  - RF shielding, cooling, and LV PS solution similar to the smaller TPC
  - 15 additional ADC/FPGA modules borrowed, 2048 samples/channel, 5 MHz sampling
  - DAQ readout via slow path, but OK for  $< 0.5$  Hz
- Bias voltage distribution card at 87K (MSU)
  - Cards plug into matching connectors on TPC, signal cables plug into the card
  - Card has isolation resistor to each wire and DC bias decoupling capacitor to the signal connector



Preamp board



RF shielding & Preamp cooling



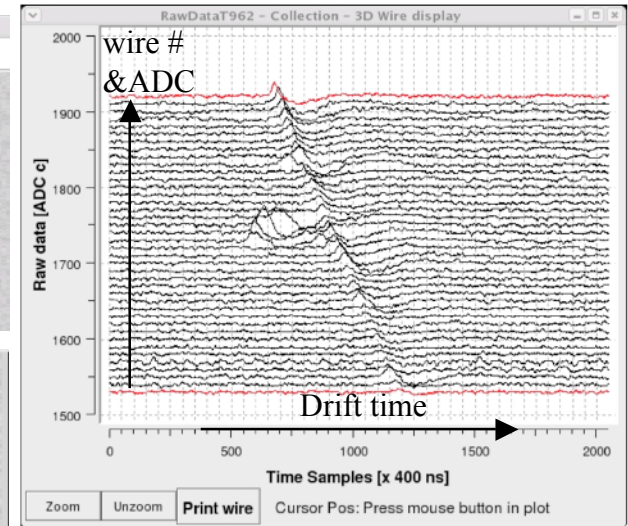
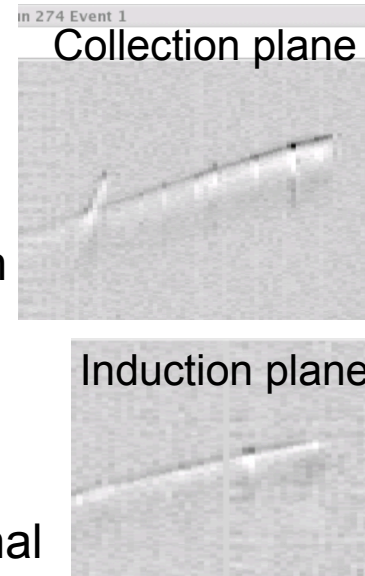
Two layers of bias voltage distribution cards on top of TPC



# ArgoNeuT commissioning

- Initial commissioning steps

- 50% of electronics installed
- Initial fill through O<sub>2</sub> 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)

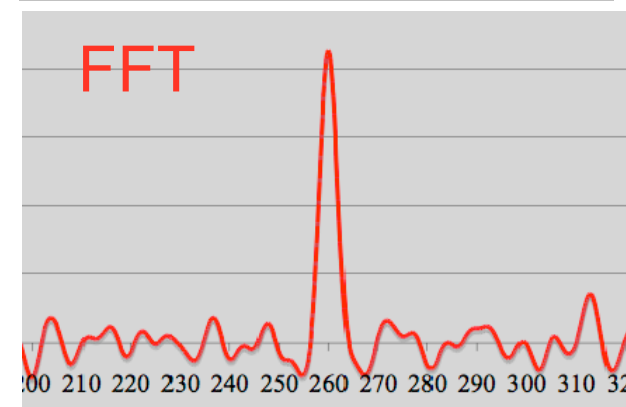
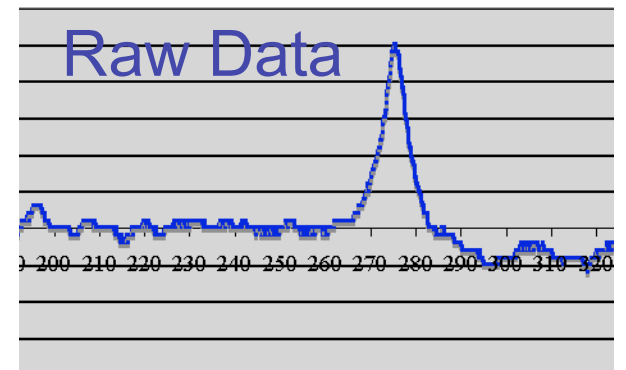
- Cryocooler & closed loop O<sub>2</sub> purifier
- LNGS display and analysis software
- Electron lifetime obtained by analysis of muon tracks
- With purifier, electron lifetime improved from 0.1 to 0.4 ms. Investigating!

- Dismantled for inspection, repairs, and to move underground

# ArgoNeuT digital signal processing

- LAr signal width depends on angles relative to wire planes
- Electronics imposes *no explicit signal shaping*
- High/low pass filters accept  $200 \text{ kHz} > f > 10 \text{ kHz}$

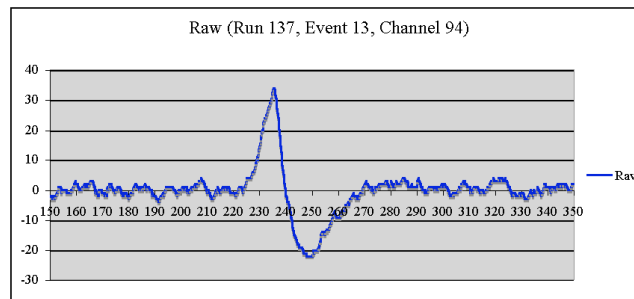
- Fourier Transform w/“flat track” signal
  - Decouple electronic signal shaping
    - Bipolar signals transformed to unipolar
    - Baseline shifts removed
  - Select frequency components of interest
    - Low-f for hit finding, ionization (best S/N)
    - High-f for pair-resolution



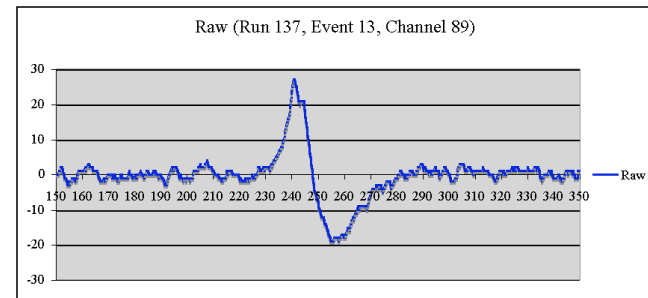
# ArgoNeuT pair-resolution (muon data)

Raw Data

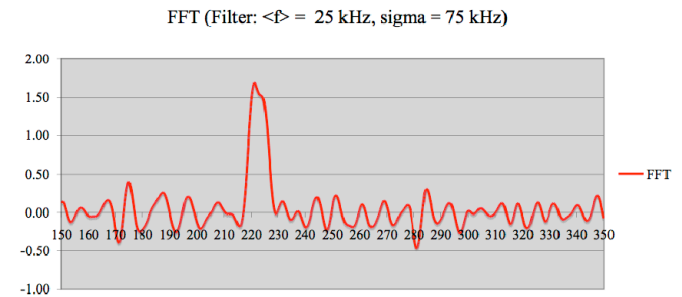
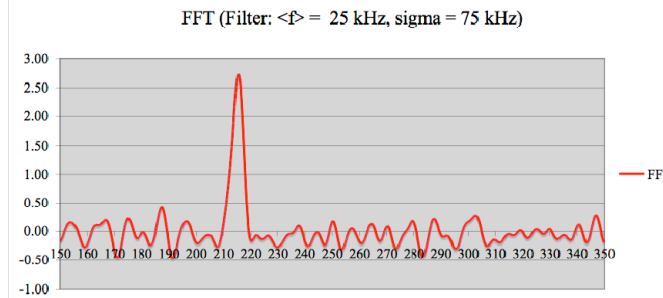
Overlapped delta-ray



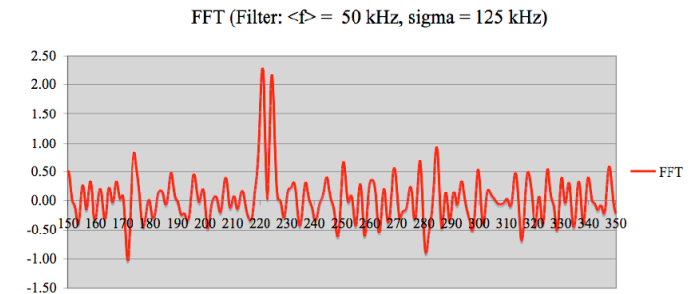
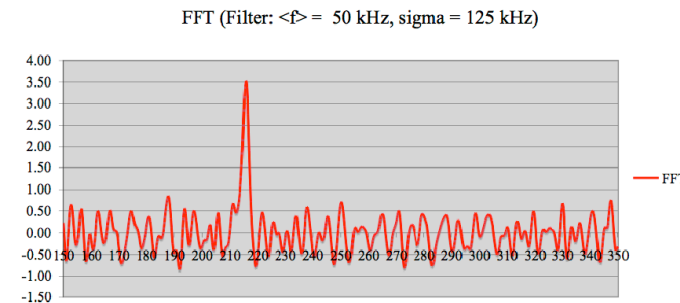
5 wires later



FFT  
Position Filter



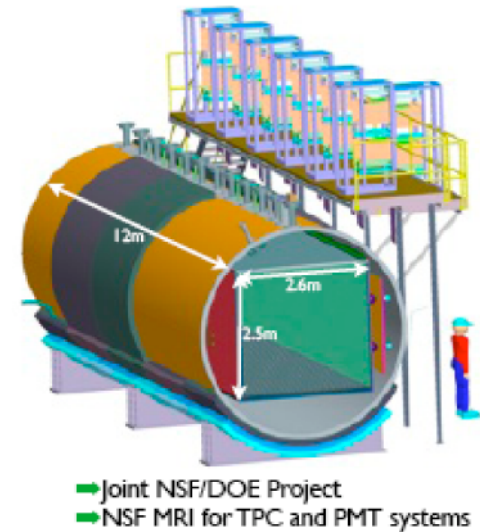
FFT  
Pair Filter



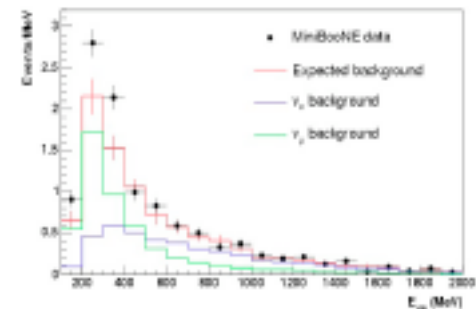
# MicroBooNE experiment

- 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
  - $5 \sigma$  significance for an electron neutrino source
  - $3.3 \sigma$  significance for a photon source
  - $K^+$  decay efficiency/background for p-decay

MicroBooNE detector

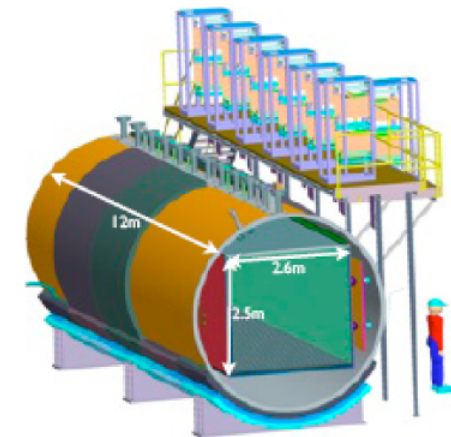


MiniBooNE Result Excess  
200-300MeV:  $45.2 \pm 26.0$  events  
300-475MeV:  $83.7 \pm 24.5$  events

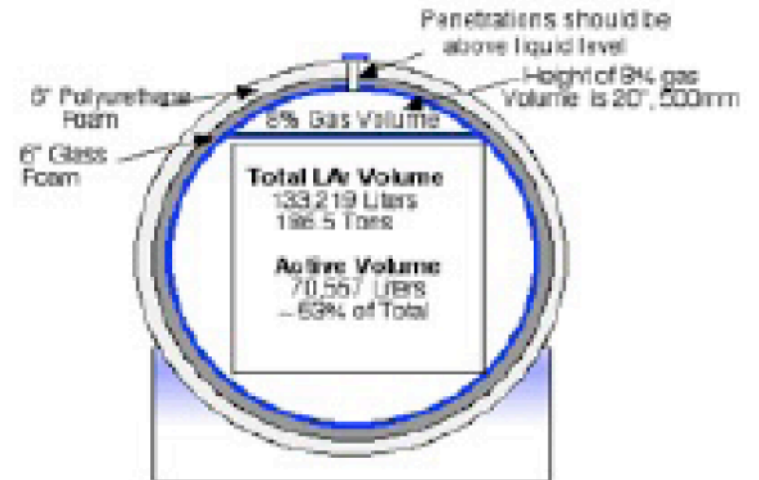


# MicroBooNE detector

- Cryostat (180T cap.) built commercially offsite
- Evacuatable 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 ( $\pm 60^\circ$  Induction,  $90^\circ$  Collection)
  - 10,000 channels of cold preamplifiers
- 30 PMTs for triggering
- New purification & recirculation system

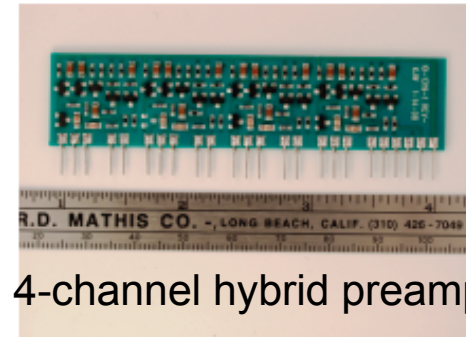


→ Joint NSF/DOE Project  
→ NSF MRI for TPC and PMT systems

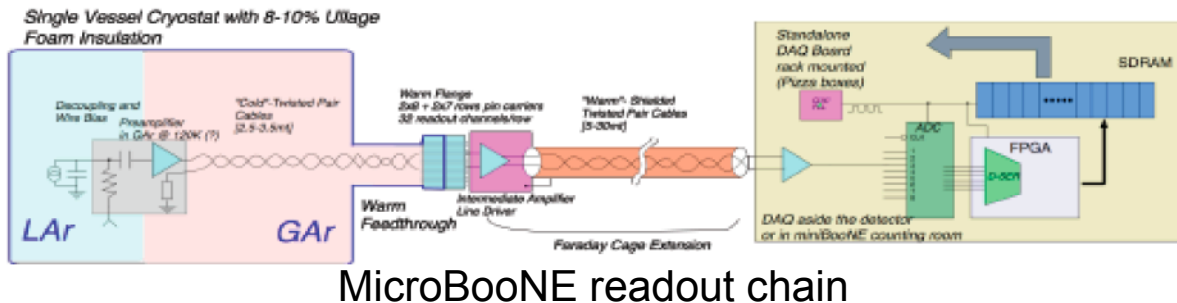


# MicroBooNE R&D

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

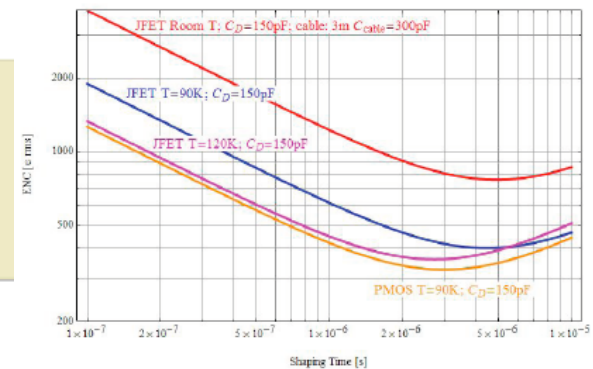


4-channel hybrid preamp



MicroBooNE readout chain

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



Noise vs. shaping time at various temperatures and cable lengths

# 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<sub>2</sub> in an LNG-type tank
  - DC 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