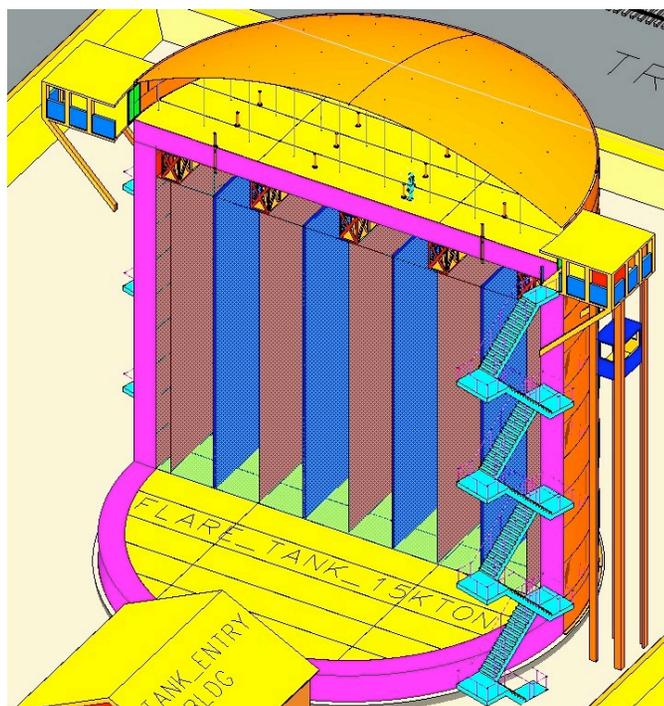




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# Liquid Argon R &D



Stephen Pordes  
Fermilab  
June 26, 2008

TANK\_ENTRY  
BLDG



# The challenge

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- Develop a plan leading to the construction of a 50 to 100 kiloton Liquid Argon TPC experiment \*.
  - Develop confidence in the construction technology
  - Develop confidence in the cost estimate
  - Develop a reasonable cost device
  - Do interesting and relevant physics on the way
- These issues need to be considered over a multi-year time frame.
- Experience in Liquid Argon TPC technology exists in Europe through ICARUS - much less in the U.S.

\* with charge and light readout

# Some LArTPC Technical Issues



- Argon Purity
  - From atmosphere to purity without evacuation
  - How to remove impurities from Argon (filter gas as well as liquid?)
  - What impurities matter and how to measure drift lifetime
  - What are the sources of contamination and how to avoid/remove them without pumping (vessel, plastics=> surface physics)
- Vessel Design
  - (Cost)
  - Design, (**Underground**) Construction, Safety
  - Cryogenics (cooling system and insulation )
  - Thermodynamics (argon temperature and flow distribution)
- Detector Design
  - (Cost)
  - HV system
  - Mechanical reliability - **TPC constructed in situ or externally**
  - Constraints from electronics (eg readout only at top?)
  - Light collection scheme; (for `triggering' and pattern recognition)
- Electronics & DAQ
  - Amplifiers, multiplexing, digitizers - **in cryostat?** Feedthroughs
  - Signal/noise (large capacitance) and constraints on TPC design
  - Zero suppression, signal processing, local event recognition capability, **100% livetime (not just beam spill)**
- Simulation & Reconstruction
  - Real and simulated signals on wires; develop signal processing
  - Event generation in argon
  - Vertex and pattern recognition; cosmic ray rejection

# The Plan

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- Use small cryostat test stands for specific issues;
    - Measure contaminant effects of TPC materials
    - Measure efficacy of contaminant removal filters
    - Provide real signals for electronics development
  - Build intermediate size detectors (1/3 ton (ArgoNeut), 200 tons (MicroBoonE) and few kilotons (LAr5))
    - Stimulates and sets schedules for technology
    - Forces integration of all aspects of experiment design
    - Stimulates development of `physics' software
    - Builds collaborations
- MicroBooNE: BNL, Columbia, FNAL, Michigan State, UTA & Yale.



# Nice words from P5

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- From the P5 report

- The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

- From C. Baltay presentation:

- Should our Long Range Vision include having a world-leading Neutrino program in the US

- If so, it is clear that we can not get there in one step but have to follow a program with a series of steps

- It might be important to realize that each step in isolation by itself may not be spectacular but is justified as a step necessary to get to our goal
      - Care should be taken that these steps not be detours or sidetracks but are the most direct and rapid steps that lead to our goal

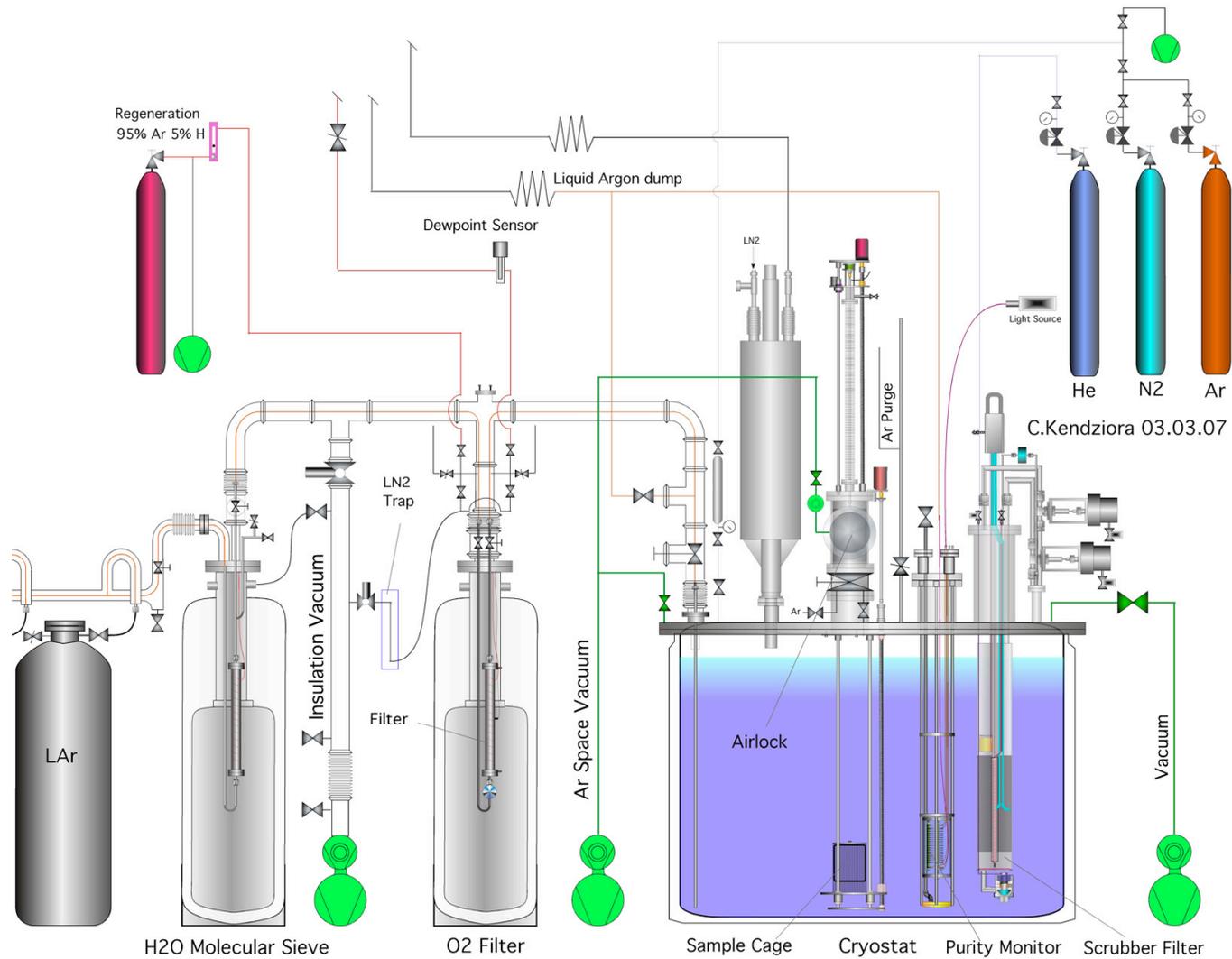


# Test Stand Work at Fermilab

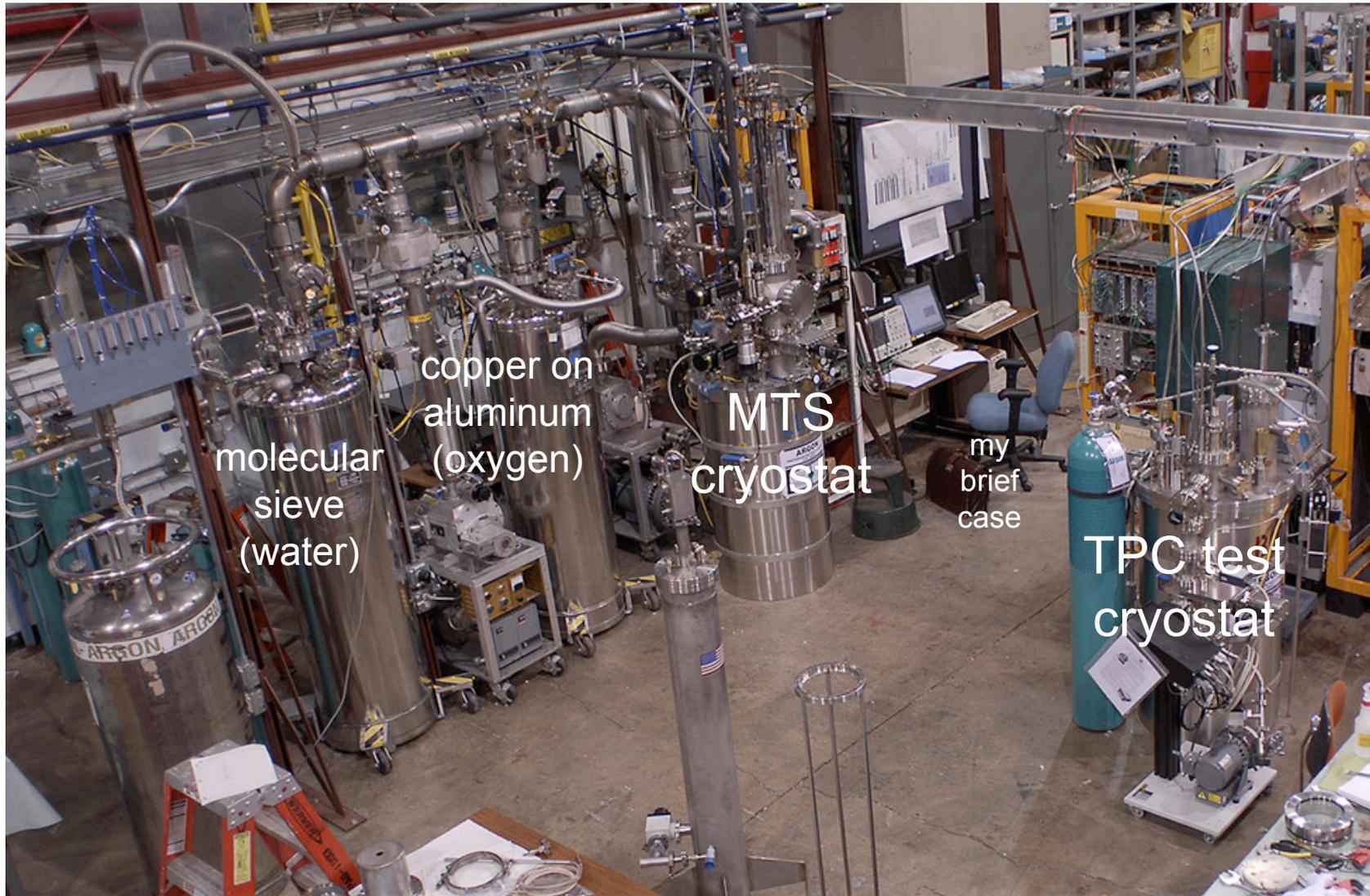
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- Materials Test System (MTS)
- TPC for electronics development - cryostat not yet in operation
- Bell-jar for photo-cathode and light-fiber testing
  
- L.A.P.D: 20 ton atmosphere to clean argon without evacuation - proposed to DOE for \$300k of DUSEL R&D funds (D. Finley) - not funded.
  
- Tests performed for atmosphere to purity without evacuation
  - Demonstration of Argon Piston (purge to few ppm)
  - Demonstration of Oxygen to few ppb and water to few ppm
  
- Infrastructure Developments
  - Single Pass clean Argon Source with Oxygen and water filters.
  - Home-made Filters that can be regenerated in-situ
  - Fermilab versions of ICARUS 'purity monitor' and readout electronics
  - Nitrogen concentration measurement (at the 0.2 ppm)

# Schematic of Materials Test System



# Setup at the Proton Assembly Building (PAB)



June 24-26, 2008

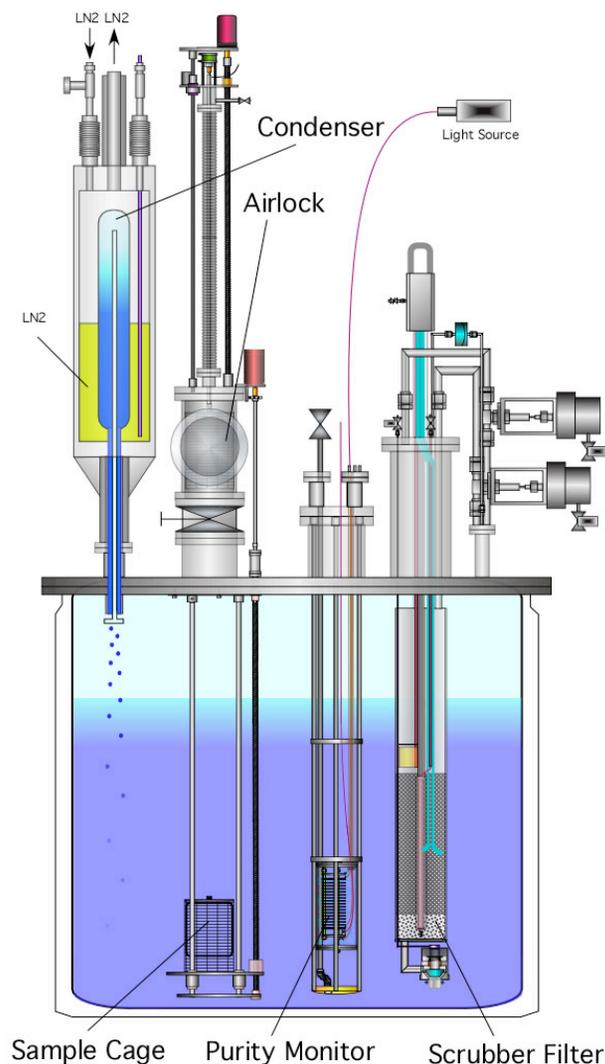
FNAL Science & Technology Review

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# The Materials Test System

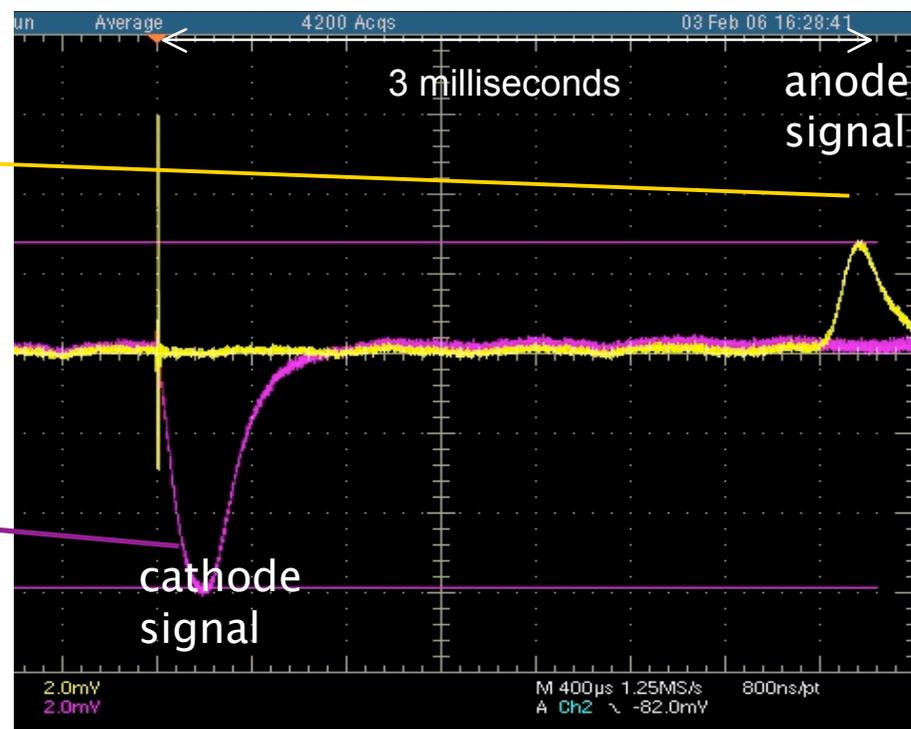
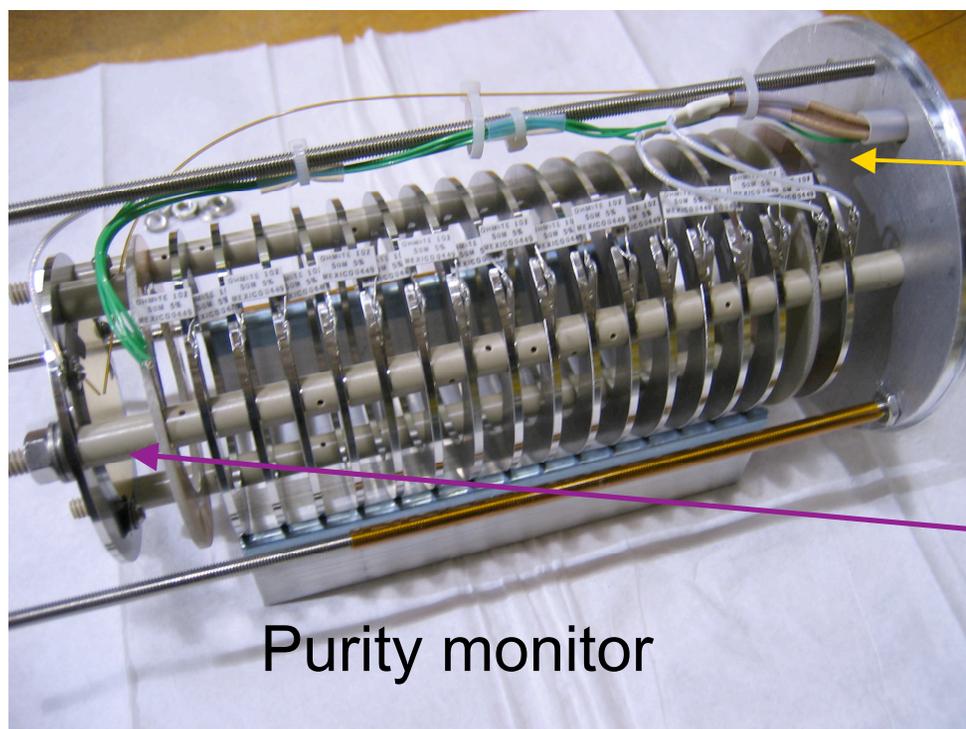
- The essentials of the MTS cryostat.
  - the Condenser (to maintain a closed system)
  - the sample insertion mechanism (allows insertion of materials without evacuation)(Airlock)
  - the lifetime monitor (Purity Monitor) (to measure the electron drift-lifetime)
  - the filter pump (Scrubber Filter) (filled with zeolite and oxygen-filter material)





## Some Zeroth order Lessons Learned

- Water from source argon and from materials outgassing is a serious challenge:
  - zeolite/molecular sieves need to complement oxygen filters.
- After that, we have achieved many millisecond lifetimes with open and closed systems.
- Nitrogen at ppm level does not affect drift-lifetime (cf ppt level for Oxygen)

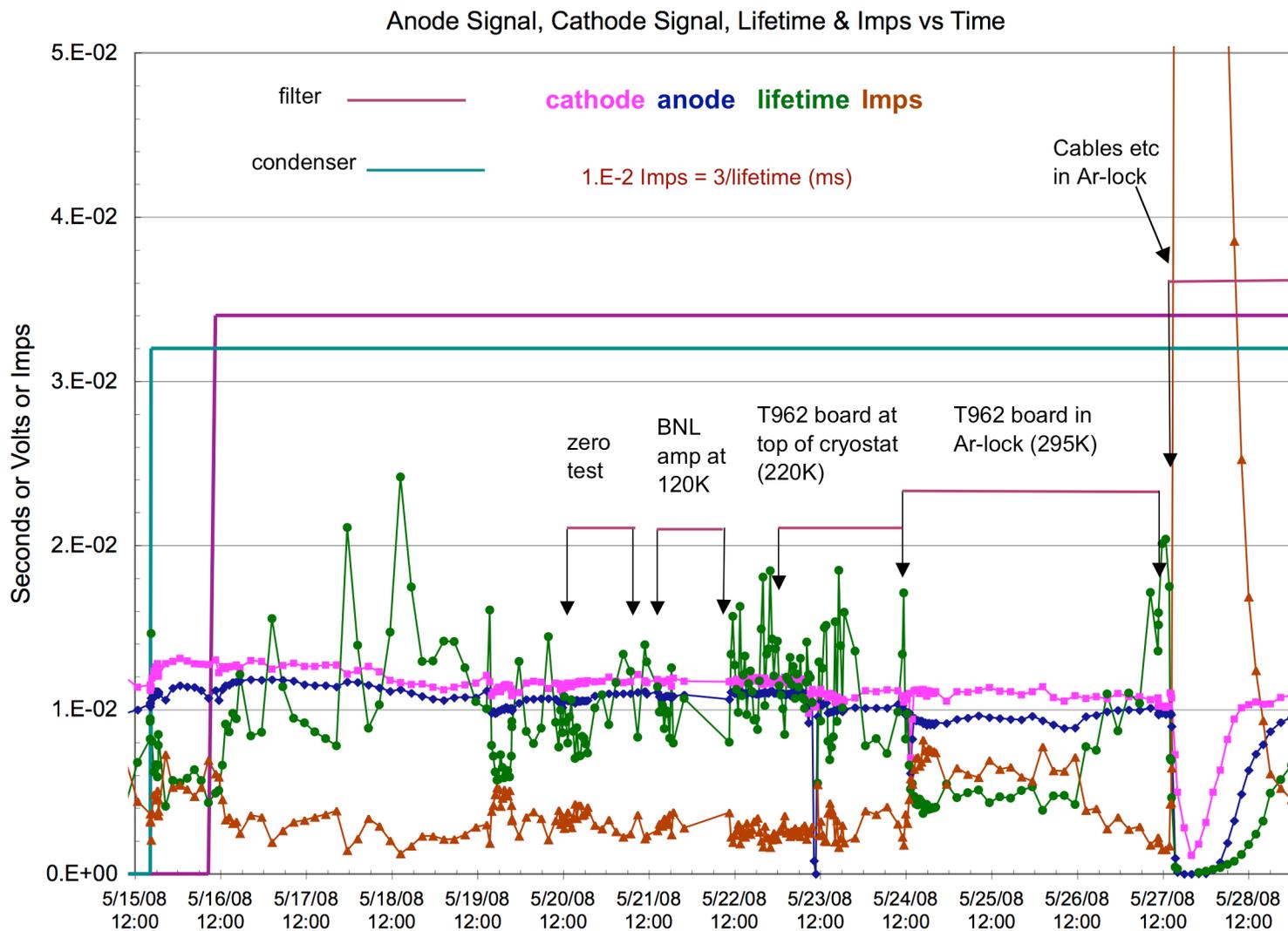


(G. Carugno et al., NIM A292 (1990))

$$Q_A/Q_C = e^{-t_{\text{drift}}/\text{lifetime}}$$



# Some data from the Materials Test System





# TPC for Electronics Development

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- Motivation:

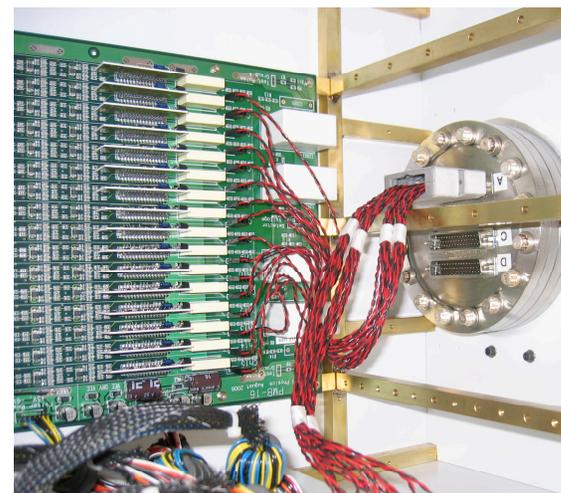
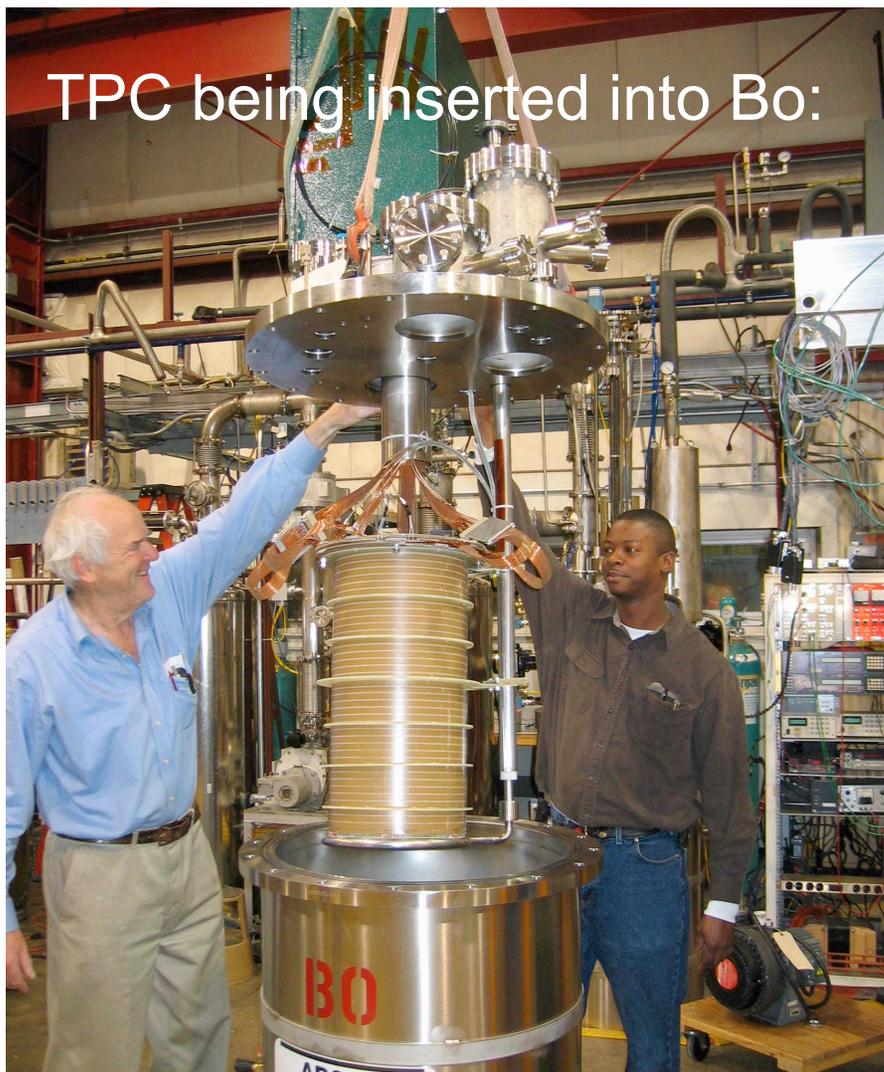
- Provide a system with signals from an actual TPC in LAr to test performance of front-end electronics (as developed at MSU and BNL).

- Features:

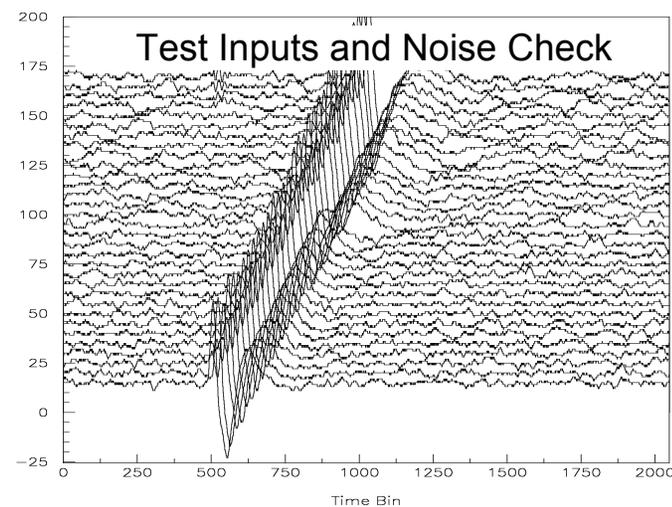
- Cylindrical TPC, 96 channels in 3 planes, with 50 cm drift and 24 cm diameter; separate purity monitor (PrM); there is space for electronics in the cryostat when we come to test `cold' electronics.
  - Present front-end electronics designed and built at Michigan State; MSU has provided DAQ, using DZero ADC and memory boards, and trigger.



# Status of test TPC system

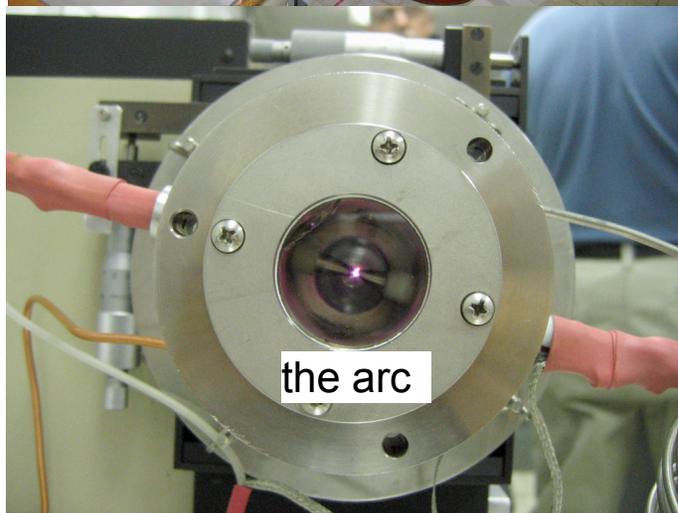
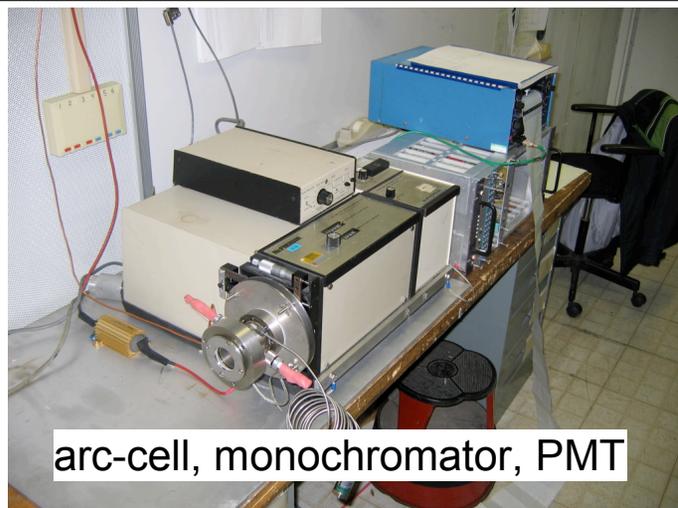


Electronics Installation (Michigan State)

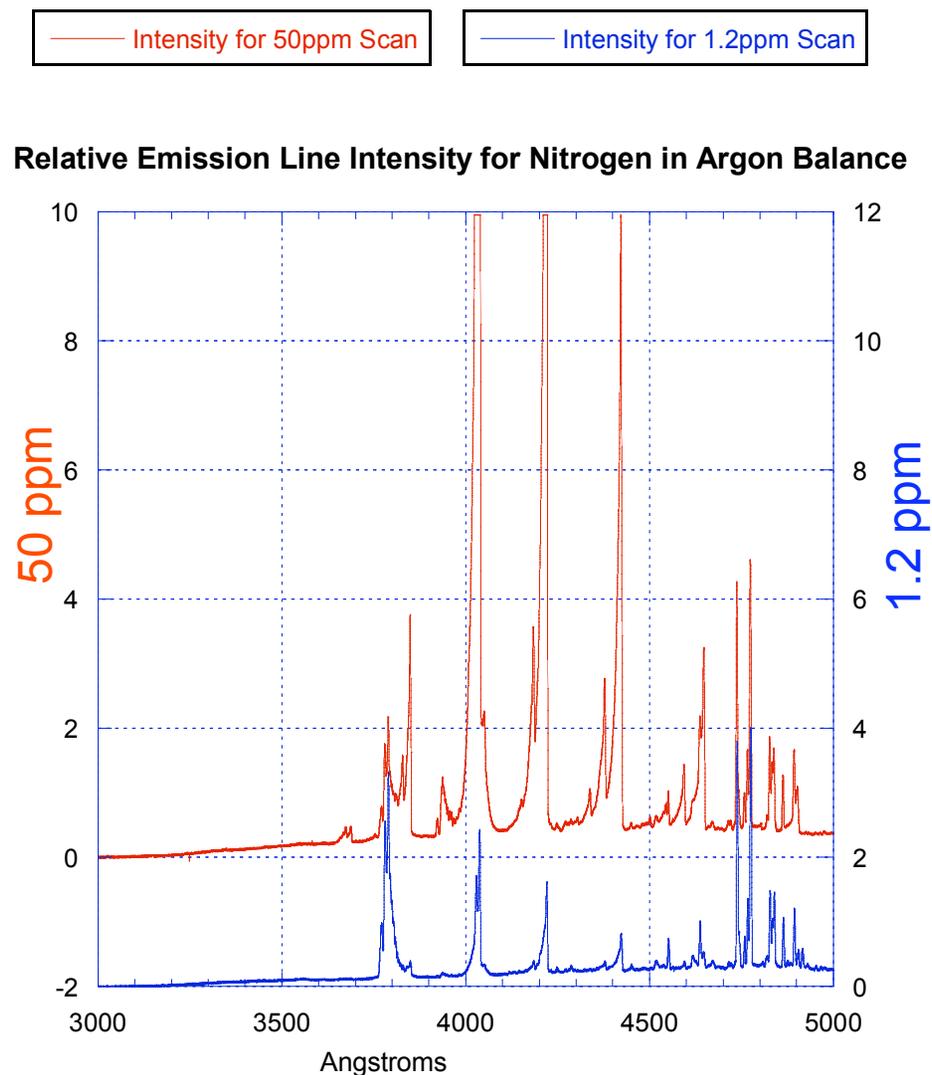




# Measurement of Nitrogen in Argon



Based on Tevatron measurement of Nitrogen in Helium

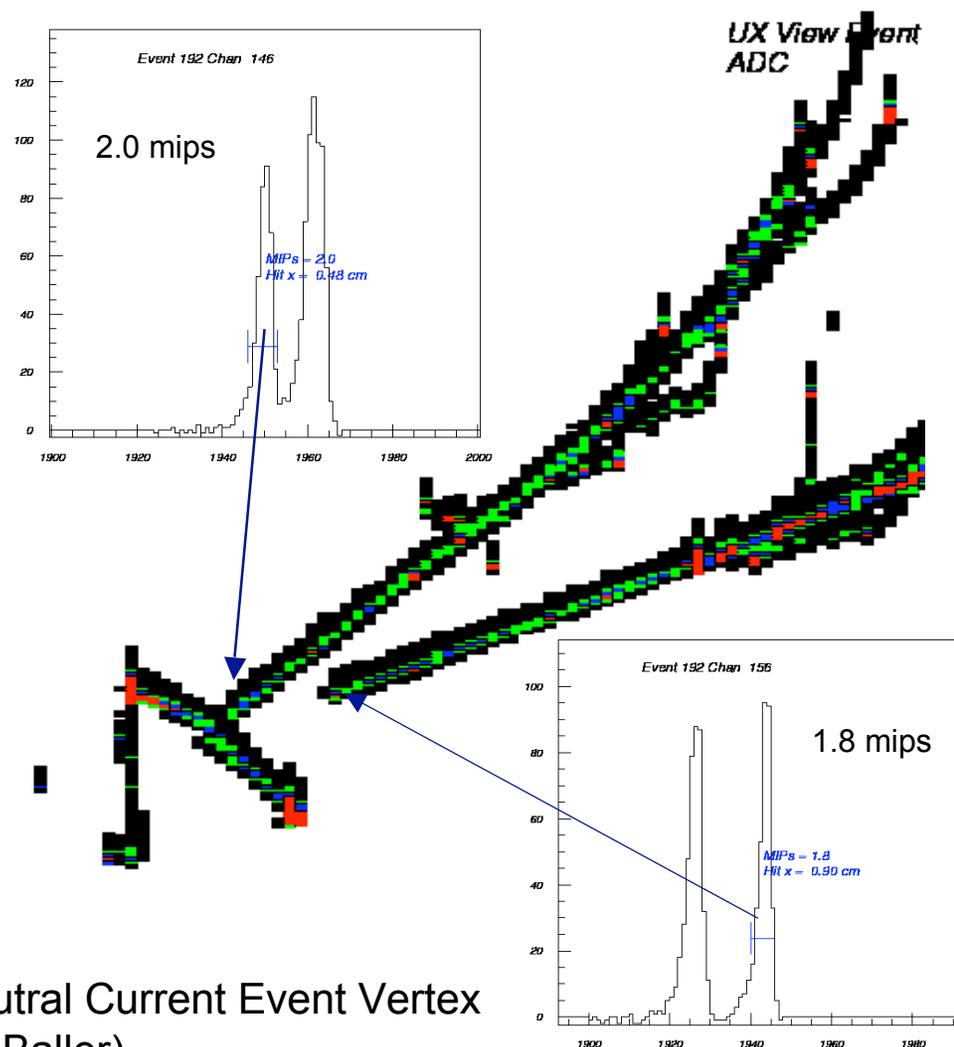




# Simulation Software:

- Full Simulation of events in the detector starting from ionization through signals induced on wires through amplifier shaping and Fourier deconvolution etc

- know what to expect using 'typical' parameters
- investigate alternatives (wire spacing, wire angles)
- develop pattern recognition and event ID algorithms

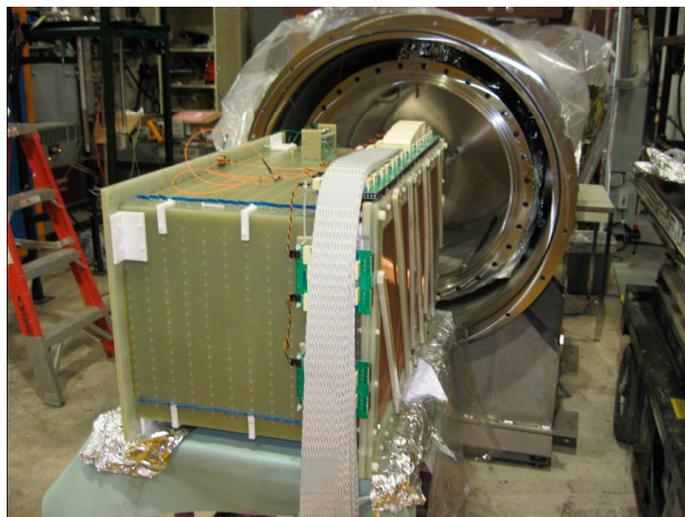


Neutral Current Event Vertex  
(B. Baller)

# ArgoNeuT (T-962) (Yale-FNAL-MSU-LNGS-UTA)



- 0.25 ton LAr TPC in NuMI beam u/s of MINOS ND;
  - FNAL cryogenics & purification, MSU electronics & DAQ
  - FNAL/YALE/LNGS simulation
  - dealt with underground safety issues
- 800  $\nu_\mu$  CC, 15  $\nu_e$  CC, 250 NC per week
  - more than 20,000 events in 6 month run
  - demonstrate electron/gamma separation



TPC  
insertion

Vessel  
closed



## Purification from Atmosphere without evacuation

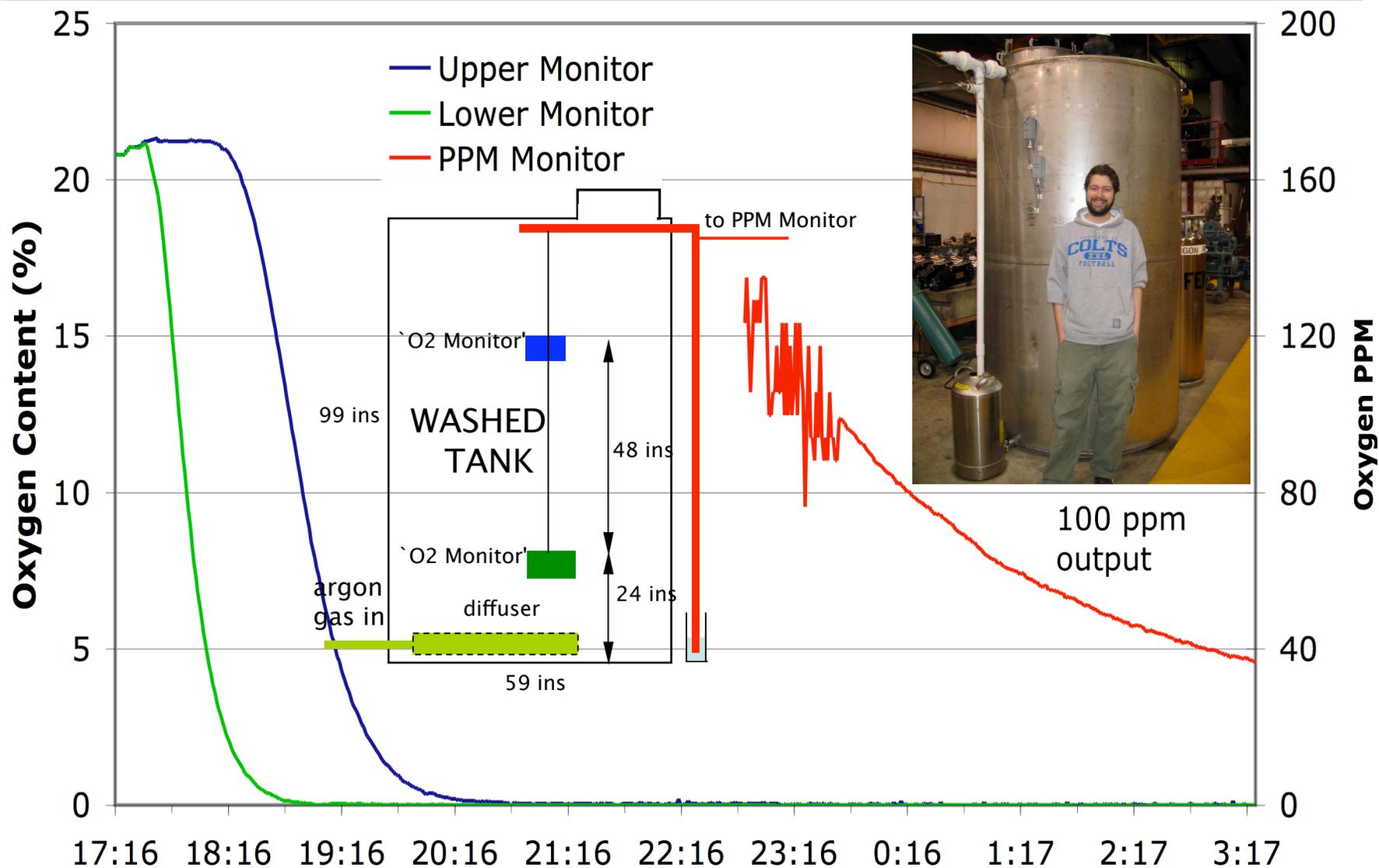
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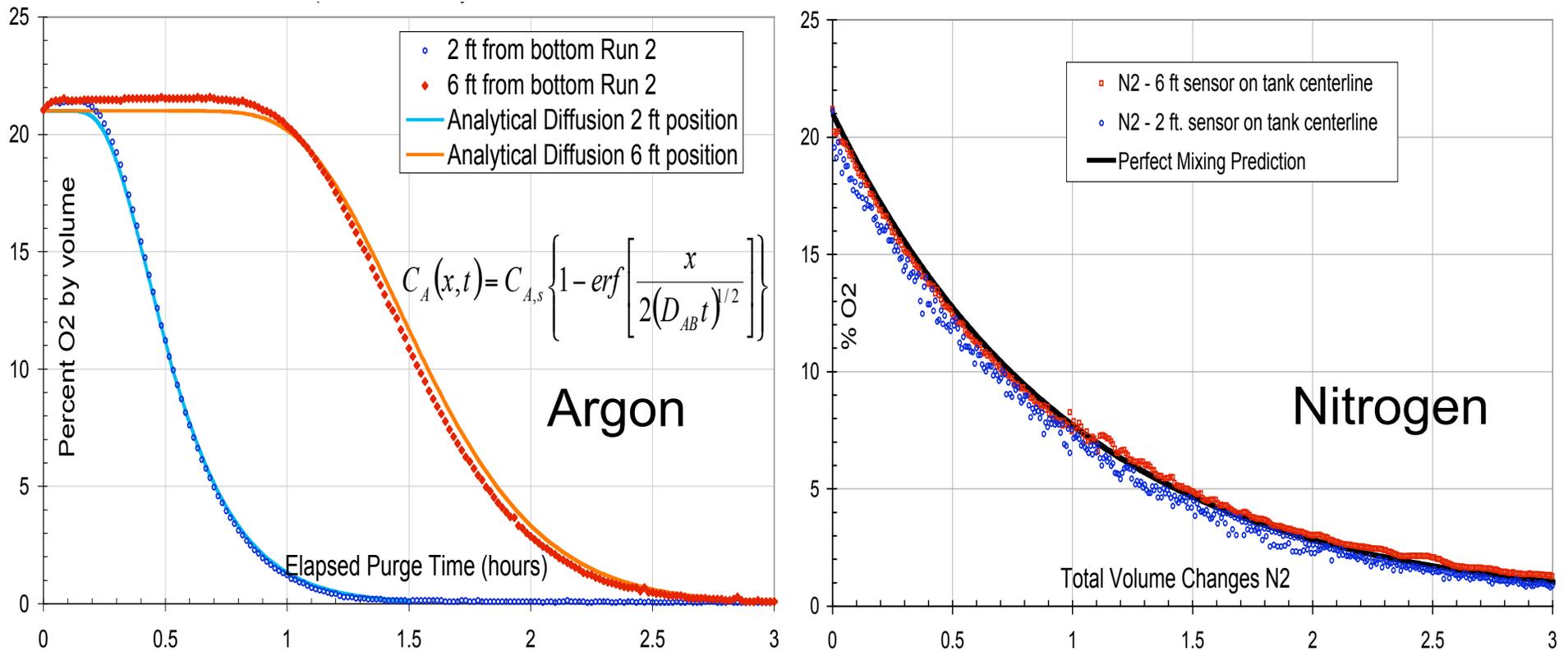
- The air in the cryostat has ~200 times as much Oxygen (20%) as the source Liquid Argon (1 ppm)
  - Need 10's of ppt Oxygen in Liquid => 10's of ppb in gas
  - Purging should be able to reduce Oxygen level to ppm
  - In an industrial vessel circulation through filters will achieve ??
- Tests of purging and ultimate Oxygen concentration
  - Argon piston - introduce Argon at bottom and push air out
  - What level is achieved in an industrial tank with recirculation filters



# Purification: The Argon Piston



# Comparison of Oxygen displacement by Argon and by Nitrogen (Argon Piston)

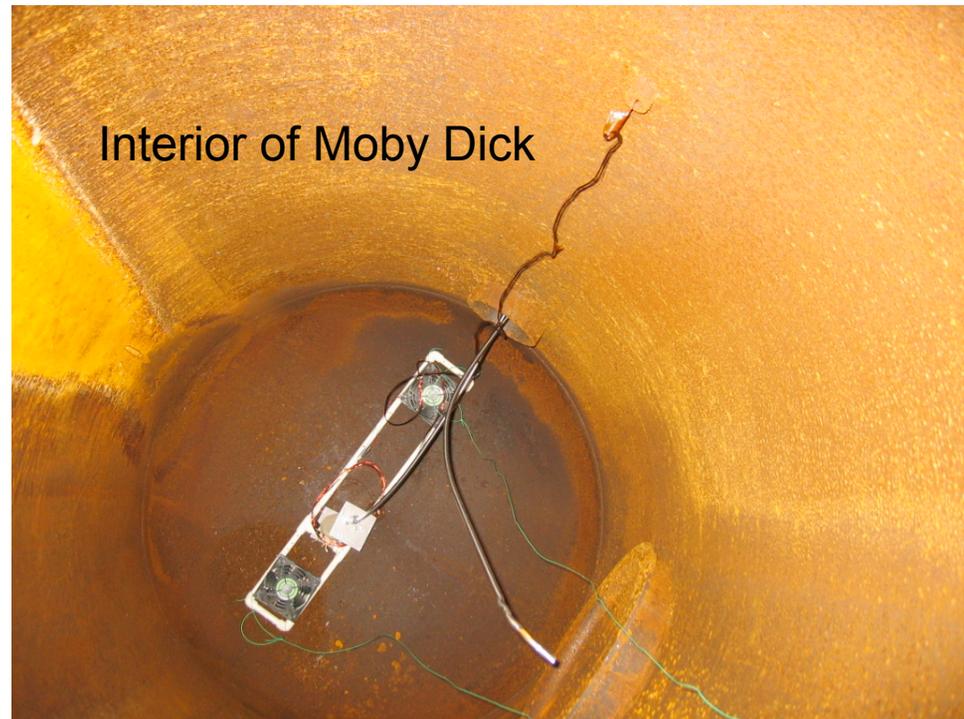


T. Tope

- to 100 ppm (reduction of 2,000) takes 2.6 volume changes (cf simple mixing, which predicts  $\ln(2000) = 7.6$  volume changes)

# Purification: From atmosphere without evacuation

## Purge Test of a 'dirty' vessel - Moby Dick

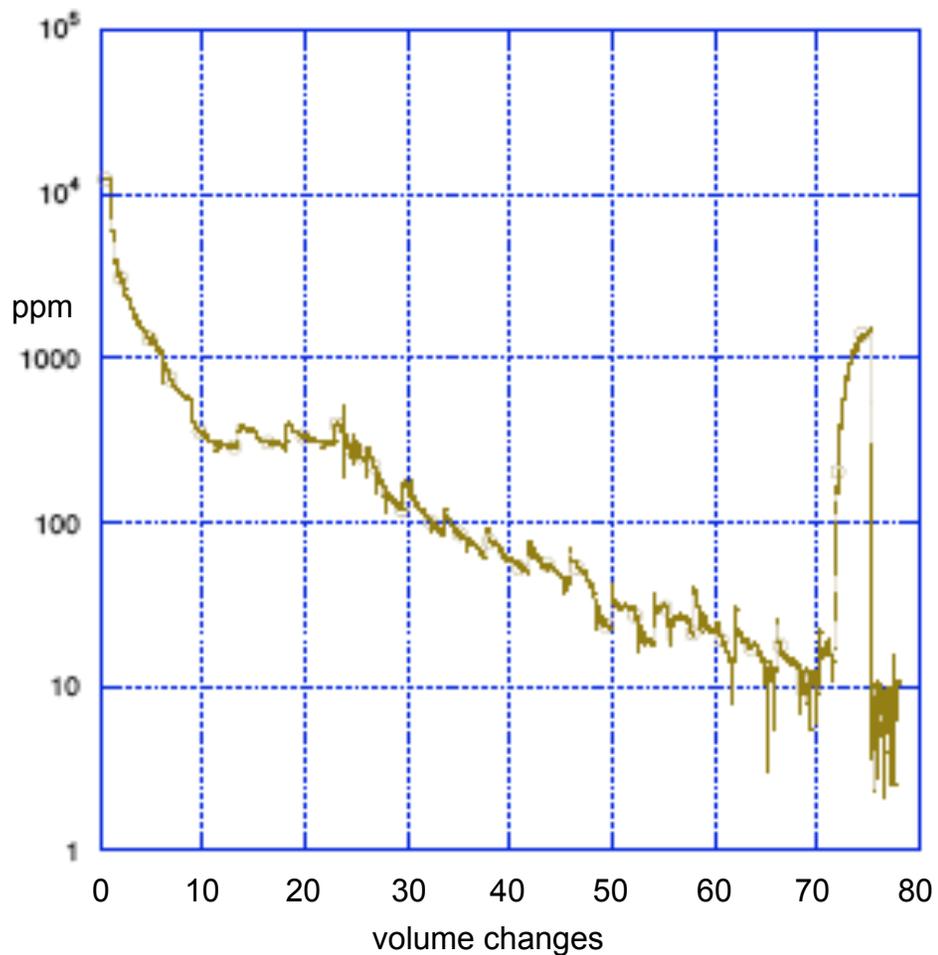


No attempt to clean after hydrostatic pressure test;  
The vessel was previously used for compressed air storage.

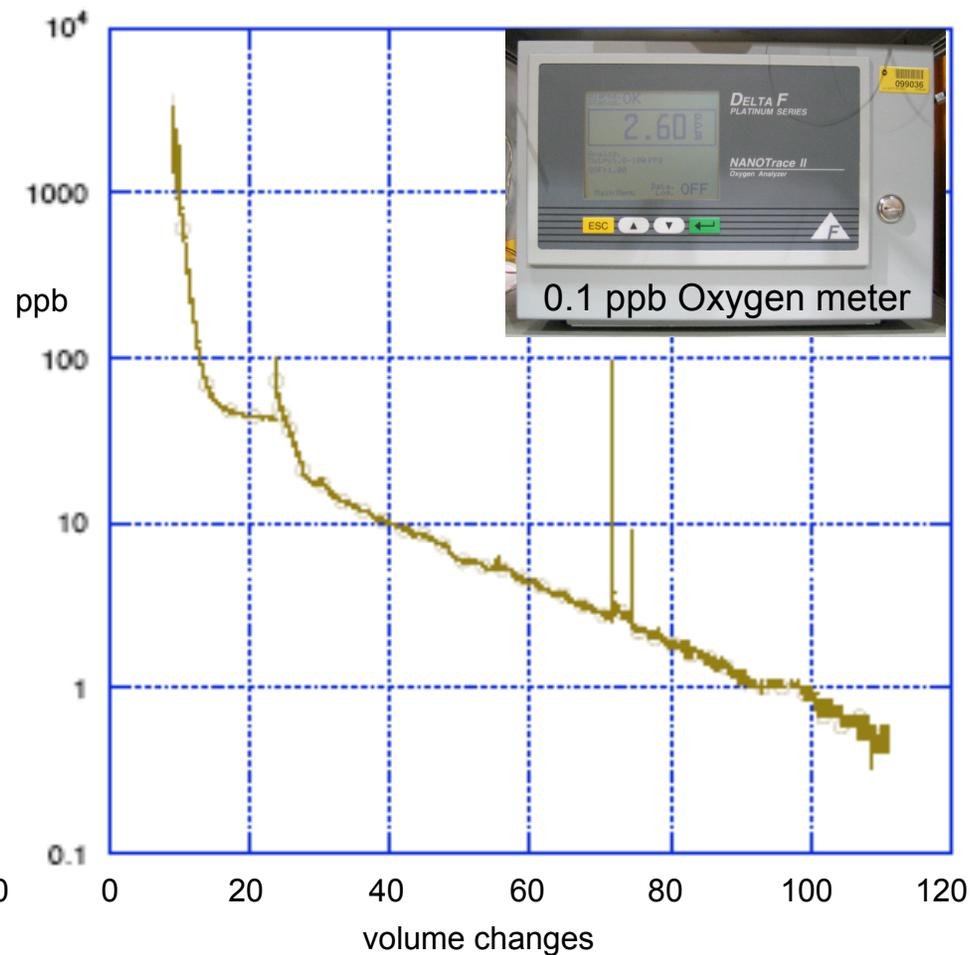


# Water and Oxygen concentrations through purging and filtering

Water Concentration in MD outflow - ppm



Oxygen Concentration in MD outflow - ppb





## Purification without evacuation:

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- MicroBooNE plan:

Devote two months to achieve clean argon without evacuation; purge with warm Argon-gas to the ~ppm Oxygen level, recirculate gas through water and oxygen filters, then introduce liquid and recirculate through liquid filtration system.

If successful, this will be a significant demonstration that one can indeed achieve clean argon without evacuation.

# Some LArTPC Technical Progress



- Argon Purity
  - From atmosphere to purity without evacuation**
  - How to remove impurities from Argon (filter gas as well as liquid?)
  - What impurities matter and how to measure drift lifetime
  - What are the sources of contamination and how to avoid/remove them without pumping (vessel, plastics=> surface physics)
- Vessel Design
  - (Cost)
  - Design, **(Underground) Construction**, Safety
  - Cryogenics (cooling system and insulation )
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  - Mechanical reliability - **TPC constructed in situ or externally**
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# A caveat

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- From the P5 report:

- The panel recommends support for a vigorous R&D program on liquid argon detectors and water Cerenkov detectors in any funding scenario considered by the panel.

- From the recent (June 3) Director's Review: ( bold Finding)

- The proposed R&D plan, while necessary, is insufficient as a plan to prepare for an eventual 100 kTon LAr detector. The program would need to be substantially enhanced with strong engineering support

- Ibid Concern 5)

- The team currently engaged in this work is capable but too small for the planned activities. To achieve the stated goals the workforce will have to be expanded considerably, especially in the area of engineering support.

- Ibid Recommendation 3)

- While necessary, the proposed R&D program is insufficient as a plan to prepare for an eventual 100 kton LAr detector. The program needs to be substantially enhanced with strong engineering support.



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backups



The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

The panel recommends support for R&D on the technology for a large detector at DUSEL. The nature of such a large detector is not yet clear. The two contending technologies are water Cerenkov and liquid argon. Large-scale water Cerenkov detectors are a mature technology, although at a smaller scale than is envisioned for DUSEL. The panel recommends support for a vigorous R&D program on liquid argon detectors and water Cerenkov detectors in any funding scenario considered by the panel. The panel recommends designing the detector in a fashion that allows an evolving capability to measure neutrino oscillations and to search for proton decays and supernovae neutrinos.

# From Director's Review ..

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## Director's Review of Liquid Argon TPC R&D Towards a ~ 100 KT Detector

June 3, 2008

Reviewers:

Bob Kephart, Fermilab (Chair)  
Daniel Fournier, LAL/IN2P3  
Taka Kondo, KEK  
Alberto Marchionni, ETH-Zurich  
Harry Weerts, Argonne

Charge:

Liquid Argon TPCs show promise as scalable devices for the large detectors needed for long-baseline neutrino oscillation physics. Over the last several years a staged approach to developing the technology for large detectors has been developed. A specific plan with the ~200 ton MicroBooNE detector and the ~5000 ton LAr5 detector as the key elements emerged with the presentations of these detectors to the Fermilab Physics Advisory Committee.

Please evaluate this specific approach as a path to a ~100 kton LAr TPC detector mass. In particular, are the proposed R&D programs, in the context of other initiatives worldwide, effective steps towards large detectors?

Review presentations:

The committee heard presentations from proponents on the morning of June 3, 2008. The agenda, link to talks, and links to supporting documents can be found at the following web site:  
[http://www.fnal.gov/directorate/program\\_planning/LArReviewJune2008/Dirs\\_LAr\\_TPC\\_Rev.html](http://www.fnal.gov/directorate/program_planning/LArReviewJune2008/Dirs_LAr_TPC_Rev.html)



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## Findings:

The proponents are to be commended for significant progress in assembling a materials test dewar, Ar purification and monitoring systems, two small LAr TPC's, etc. and for completing a variety of smaller scale R&D activities.

The proponents presented plans for a series of additional R&D activities ranging from small prototypes and materials studies through intermediate scale detector and electronics (MicroBoone) leading to a 5 KT detector at Soudan with physics reach comparable to NovA and that would serve as a engineering prototypes for an eventual 100 KT LAr detector.

The plan for developing LAr electronics as presented seems well motivated and achievable.

The committee finds that the plan to study neutrino interactions in the ArgoNeut detector is well motivated and likely to contribute to the understanding of both neutrino cross sections and feasibility of future large LAr detectors in particular information gained about reconstruction techniques, efficiencies, etc. should be particularly valuable.

The committee notes that that MicroBooNE program is driven both by Physics and R&D goals. For reasons of expediency and cost the LAr vessel construction and electronics readout envisioned for MicroBooNE would not be the same as one would use on a larger scale detector. If one removes the physics motivation, it is not obvious that MicroBooNE is the optimal engineering step if the goal is to head towards a 100 KT detector as soon as possible. That said, the committee does feel that a large scale demonstration of a scalable LAr TPC in a neutrino beam that demonstrates stable operation and good physics capability is a key ingredient for success of any future 100 KT LAr proposal. MicroBooNE will test some features of the planned larger detector, and as a result, the committee expects that much will be learned about a 100 KT detector if MicroBooNE is constructed.



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**The committee finds that the overall LAr TPC R&D program as presented to be well motivated and effective in the near term. We recommend that the proponents be supported to proceed.**

**The proposed R&D plan, while necessary, is insufficient as a plan to prepare for an eventual 100 KT LAr detector. The program would need to be substantially enhanced with strong engineering support.**

**Comments/Concerns:**

- 1) The civil engineering design for the underground enclosure at DUSEL and the LAr vessel design and modularity are closely related and should be studied as a whole. These studies may lead to modified designs with issues that should be explored in during the R&D phase.
- 2) Construction of 10 KT modules each 15 M x 15 M x 50 M deep underground at DUSEL (4850 ft) as described requires welded assembly of the vessel from kit made up of thousands of plates sized to fit in the existing elevator. There will be important cost and schedule implications due to this constraint. This requires serious engineering study, and practical experience, etc. Alternative assembly techniques or modified methods of access to DUSEL may result in changes to the basic detector design. Assembly at depth of the entire detector represents a huge construction activity, all at depth. We were not presented with a plan for carrying out more general engineering studies of these issues. This seems to a necessary part of any program leading to 100 KT scale detector.
- 3) Safety for such a large LAr vessel will be an important consideration if located at depth in DUSEL or Soudan, we did not hear a plan for engineering to be performed in this area.
- 4) More refined cost scaling studies will be a necessary part of demonstrating feasibility of a 100 KT detector and should be part of the proposed program
- 5) The team currently engaged in this work is capable but too small for the planned activities. To achieve the stated goals the workforce will have to be expanded considerably, especially in the area of engineering support.
- 6) It seems the 5 KT detector at Soudan is driven by physics considerations while a smaller module located elsewhere might achieve all the engineering goals regardless of location. Once LAr5 becomes driven by physics its design may drift away from that optimal to demonstrate techniques for an eventual 100 KT detector at DUSEL.



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### **Recommendations:**

In general the committee finds that the overall program is effective in the near term.

- 1) We find the proposed R&D program to be well motivated and recommend that the program be supported to proceed.**
  
- 2) The Laboratory/proponents need to examine the goals of MicroBooNE and understand clearly what it realistically will and will not contribute to preparations for an eventual 100 KT LAr detector. The goal should be to insure that the areas not covered by MicroBooNE are covered elsewhere in the planned program.**
  
- 3) While necessary, the proposed R&D plan is insufficient as a plan to prepare for an eventual 100 KT LAr detector. The program needs to be substantially enhanced with strong engineering support. These studies may lead to other conclusions about the next steps on the way to a 100 KT detector.**
  - a. Create a plan and propose engineering resources to explore the cryogenics design of the LAr Vessel
  - b. Propose a plan and estimate engineering resources to explore civil engineering-LAr vessel design tradeoffs
  - c. Propose a plan for engineering resources to further explore safety and cost issues for a 100 KT detector.