Large Liquid Argon Detector R&D in the US

David Finley / Fermilab

NNN07: Workshop on Next generation Nucleon decay and Neutrino detectors

October 2-5, 2007
Hamamatsu Japan

Association with ICARUS

- ICARUS is the world leader in large liquid argon TPC R&D.

- Much of the US work on using liquid argon TPCs intended for use in neutrino beams, particularly the recent work, started with crucial help from the people associated with ICARUS.

Outline

- Recent Reports in the US
  - Long Baseline Study: Fermilab/Brookhaven
  - NuSAG = Neutrino Science Assessment Group:
    - US DOE/NSF HEPAP
  - Fermilab Steering Group

- Large Liquid Argon Detector R&D in the US
  - Materials Test Stand at Fermilab: Initial Use
  - Electronics
  - Purity Demonstration: 20 ton
  - Cellular TPC Design and construction techniques
  - Tracks at Yale
  - LANND and DUSEL

- Physics Efforts based on LArTPCs in the US
  - T962 Status
  - MicroBooNE

The Future US Long Baseline Study

(excerpted from R. Rameika September 2007 report to DOE)

The charge to the Study participants
by Montgomery of Fermilab and Dawson of BNL

Compare the neutrino oscillation physics potential of:

- Broadband beam to a DUSEL site
- Next Generation Off-Axis options

- Liquid Argon Detector
  - At DUSEL or
  - As a second NOνA detector

- Proton options
  - ~1 MW from existing accelerator complex
  - 1 - 2 MW
  - Proton Driver (~2MW)

Duration: March 2006 - May 2007; arXiv:0705.4396 (May 2007)

The NuSAG Report (July 13, 2007)

(excerpted from R. Rameika September 2007 report to DOE)

- **Simultaneous with the FNAL/BNL Study, NuSAG was also charged to explore the options for future US long baseline experiments.**
- **Focused on experiments to determine the neutrino mass hierarchy and δCP**
- **Knowledge that $\sin^2 2\theta_{13}$ > 0.01 is REQUIRED before considering future options that use conventional neutrino beams (~ 1 MW beam power)**
  - **1st results around 2012**
- **Main Conclusion : in the interim, focus on R&D towards intense beams and large detectors**

NuSAG = Neutrino Science Assessment Group
Reports to a DOE/NSF advisory panel

Available at: http://www.science.doe.gov/hep/hepap_reports.shtm

NuSAG Report
… in particular….

Recommendation 4. A phased R&D program with milestones …
[a] 50-100 kton detector is recommended for the liquid [argon] detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.

… and of course …

… it should be 10 times less expensive per kton than today's LArTPC costs …

Liquid Argon TPC Overview for NuSAG

Note: At this point in time …

"15" could be "50"

"1" could be "3"

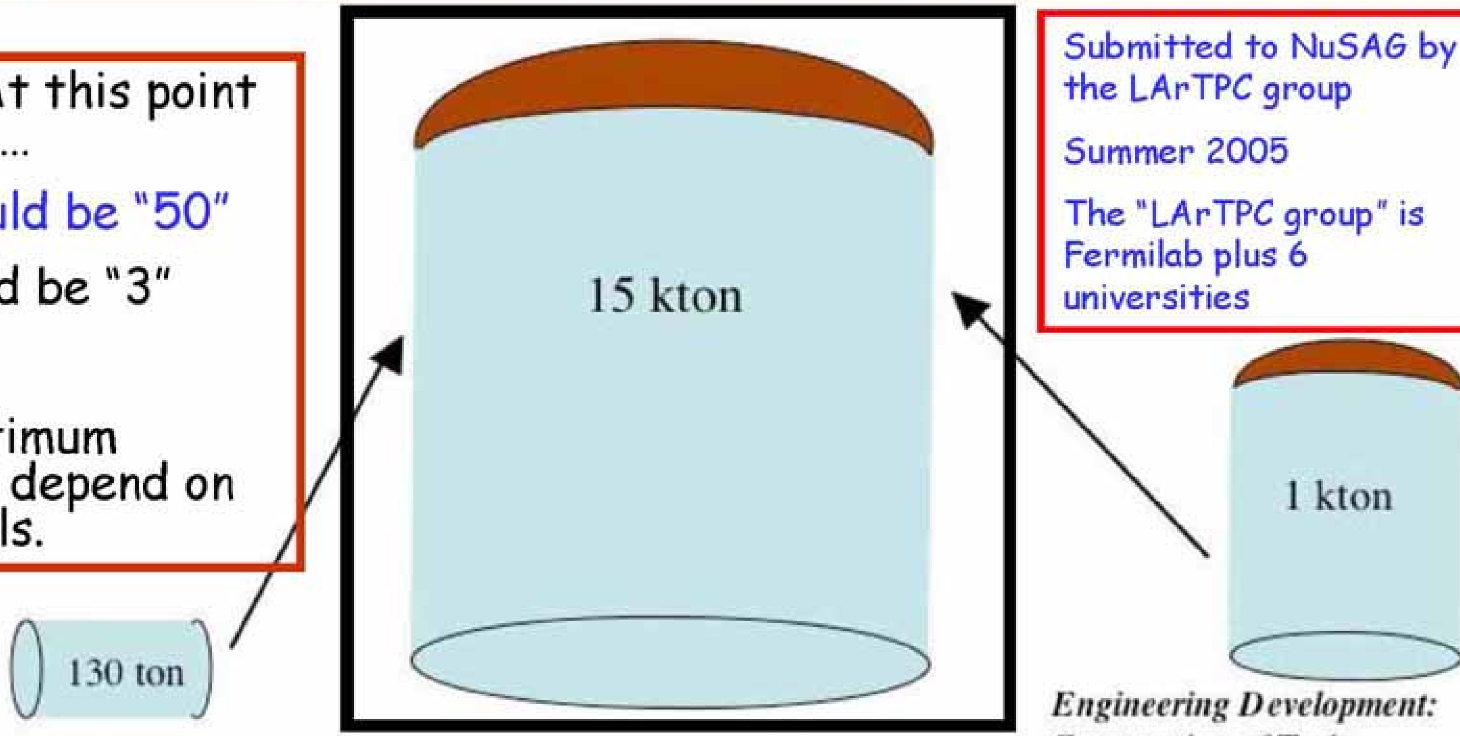
etc

The optimum choices depend on the goals.

Submitted to NuSAG by the LArTPC group

Summer 2005

The "LArTPC group" is Fermilab plus 6 universities



Physics Development *using* ***existing*** *technology*

Record **complete neutrino interactions**: (ν_e & ν_μ)

Establish **Physics Collaboration**

Develop **Event Identification**,

Develop **Reconstruction**,

Develop **Analysis**,

Establish successful **Technology transfer**

Engineering Development:

Construction of Tank

Argon Purity

Mechanical Integrity of TPC

Readout S/N

Microphonics due to Argon Flow

Technical Setups

Purity Monitor Development	Materials Tests	5 m Drift Demonstration	Long Wires Tests	Electronics Development

Fermilab Steering Group

develop roadmap
for accelerator-based HEP program at Fermilab

http://www.fnal.gov/directorate/Longrange/Steering_Public/

Young-Kee Kim

P5 Meeting, Fermilab
September 24, 2007

Letters and Proposals from the Community

- ## Letters from the Community

1. John Marriner (May 5, 2007)
2. Norman Gelfand (May 8, 2007)
3. Stanley Brodsky (May 31, 2007)
4. Steve Geer et al. (June 8, 2007)
5. Buck Field (June 12, 2007)
6. Chuck Ankenbrandt et al (June 12, 2007)
7. Maury Goodman (July 7, 2007)

- ## One Page Proposals from the community

1. 6GeV ILC Test Linac - Giorgio Apollinari and Bob Webber (May 7, 2007)
2. LAr TPC in FNAL's Neutrino Beams - David Finley (May 29, 2007)
3. Precision Neutrino Scattering at Tevatron - Janet Conrad and Peter Fisher (May 29, 2007)
4. Very Large Cherenkov Detector - Milind Diwan et al (June 5, 2007)
5. From Tevatron to Muon Storage Ring - Terry Goldman (June 6, 2007)
6. Antimatter Gravity Experiment - Thomas Phillips (June 7, 2007)
7. Neutrino Oscillation with high energy/intensity beam - Henryk Piekarz (June 10, 2007)
8. Space-Time Ripples Study - Nikolai Andreev (June 11, 2007)
9. Fixed Targer Charm Expt - Jeff Appel and Alan Schwartz (June 11, 2007)
10. Stopped Pion Neutrino Source - Kate Scholberg (June 11, 2007)
11. UNO Experiment - Change Kee Jung (June 11, 2007)
12. n-nbar Transition Search at DUSEL - Yuri Kamyshkov (June 11, 2007)
13. 8GeV cw Superconducting Linac - Ankenbrandt et al. (June 12, 2007)
14. Neutrino Expt with 5kton LAr TPC - Fleming and Rameika (June 12, 2007)
15. MicroBooNE - Fleming and Willis (June 12, 2007)
16. delta_s - Rex Tayloe (June 14, 2007)

Very similar physics as MODULAr

- ## Expression of Interest (EOI)

1. mu to e conversion - William Molzon (May, 2007)
2. me to e conversion - E.J. Prebys, J.P. Miller et al (May, 2007)
3. Klong to pi0 nu nu - D. Bryman et al (June 11, 2007)

- ## Letter of Intent (LOI)

1. Low- and Medium-Energy Anti-Proton Physics - D. Kaplan et al (June 1, 2007)

(from Y.K. Kim talk to P5 September 24, 2007)

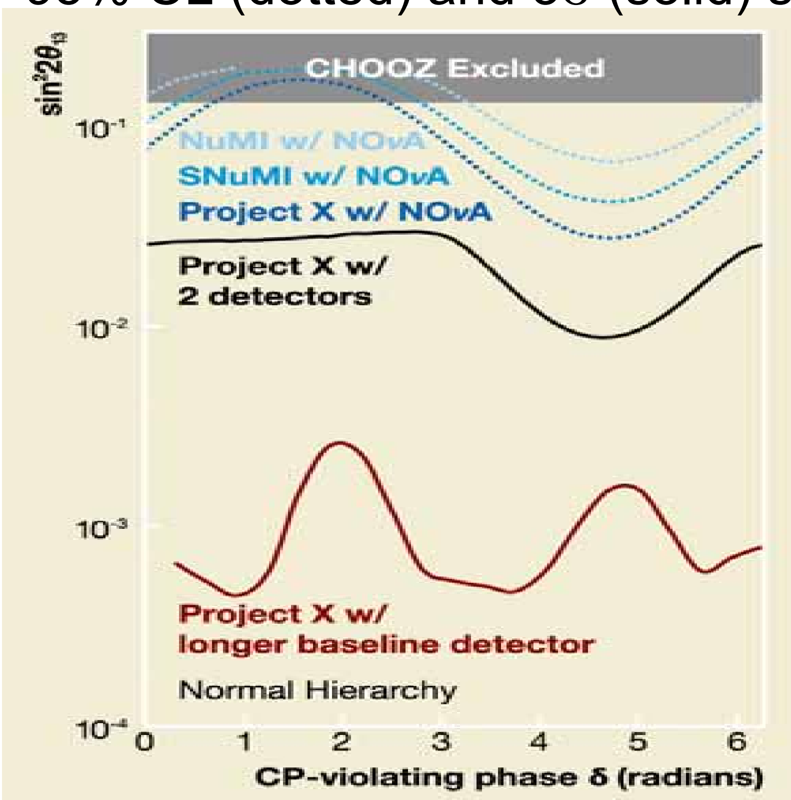
Liquid argon is mentioned on 3 of the 55 slides of the full talk … this is Slide 35.

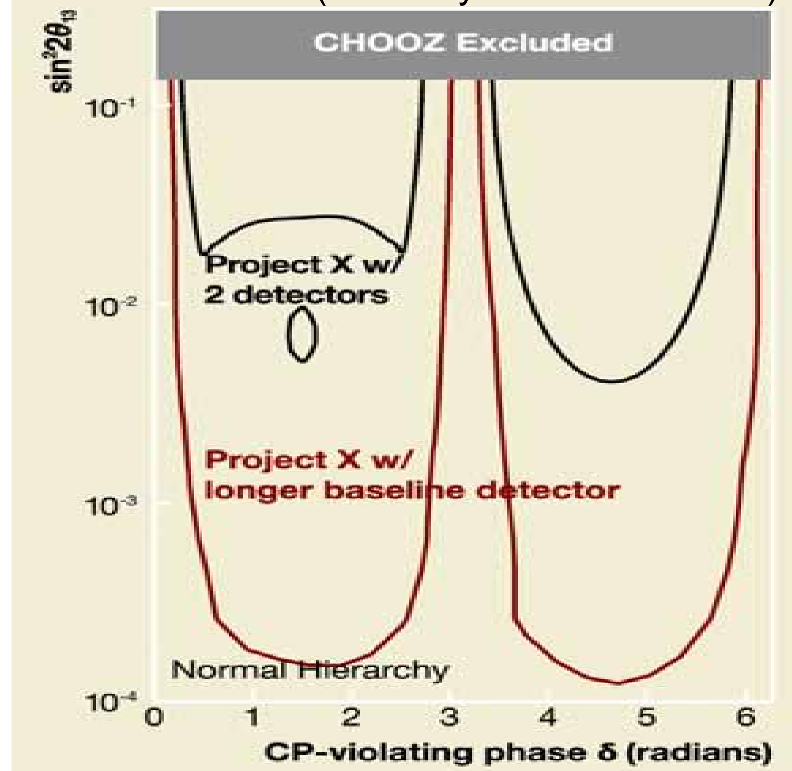
Neutrino Oscillation

Mass Ordering CP Violation

95% CL (dotted) and 3σ (solid) sensitivity with 3 years of each ν and $\bar{\nu}$

(Courtesy of Niki Saoulidou)





2 100kt LAr detectors at 1st(700 km) & 2nd(810 km) oscillation maxima w/ NuMI beamline

One 100 kt LAr (or 300 kt water Cerenkov) at 1300 km using a wide-band ν beam

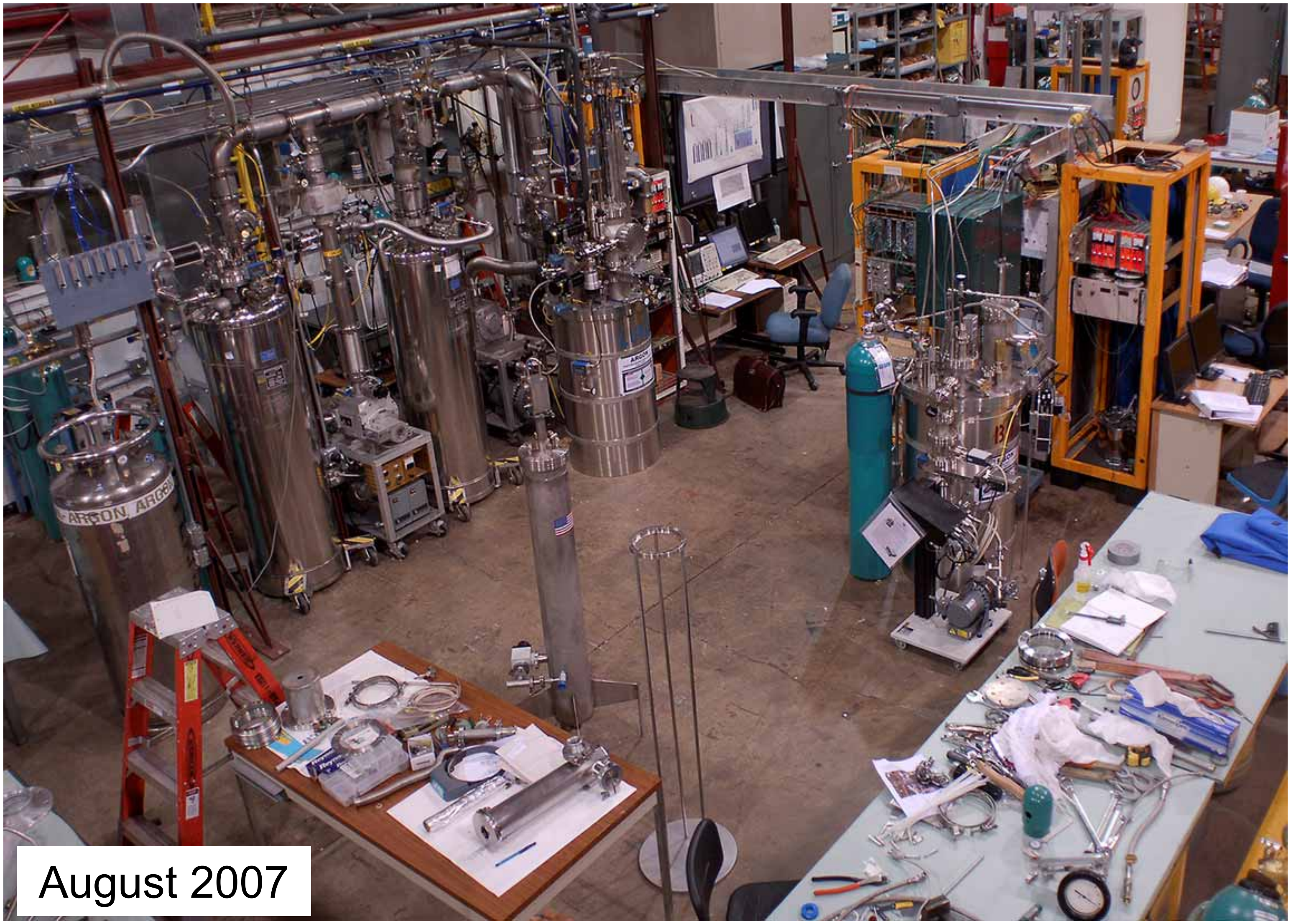
A large ν detector in DUSEL would also be a world-class proton decay detector, addressing *"Do all the forces become one?"*

(from Y.K. Kim talk to P5 September 24, 2007)

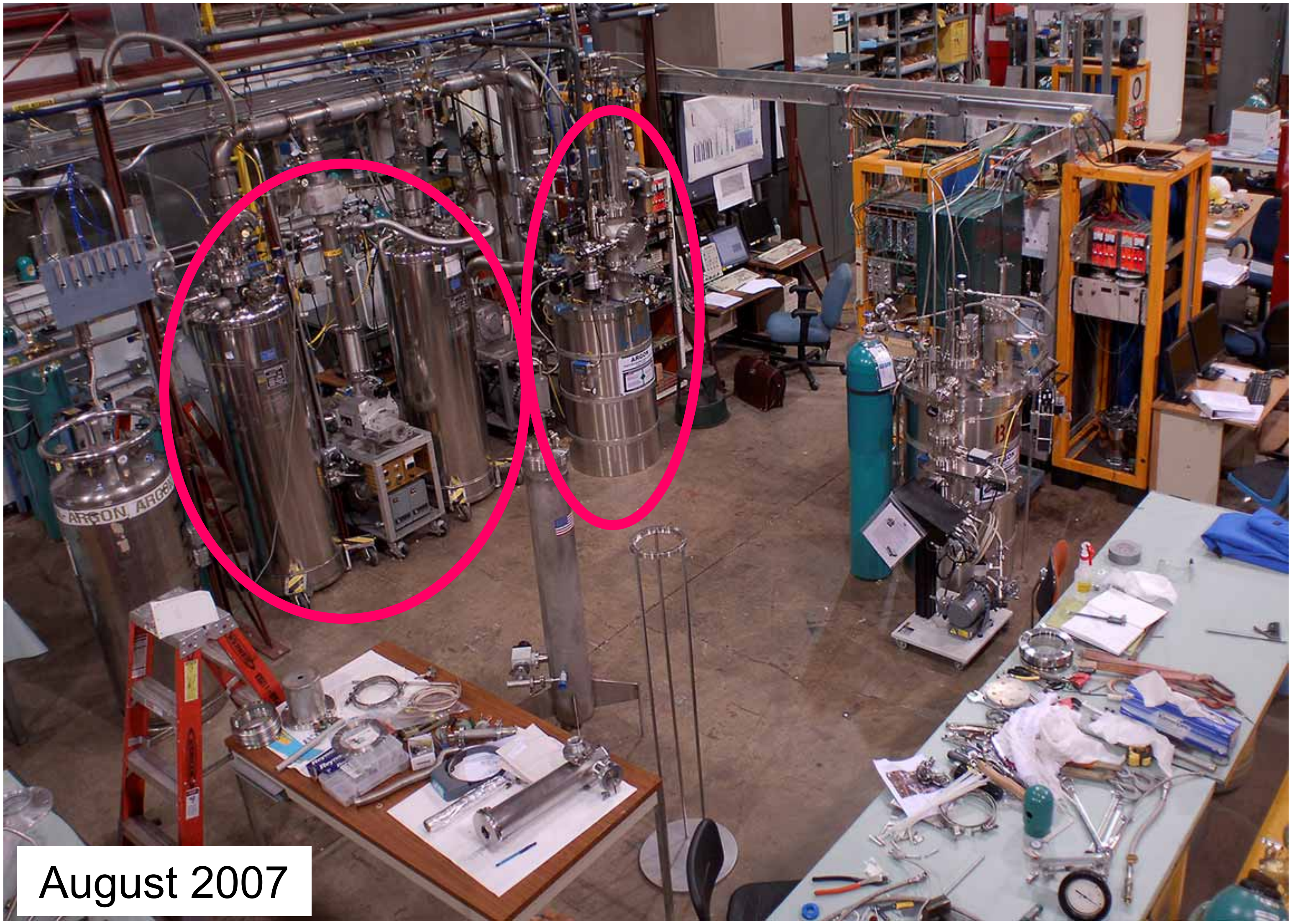
Outline

- Recent Reports in the US
  - Long Baseline Study: Fermilab/Brookhaven
  - NuSAG = Neutrino Science Assessment Group:
    - US DOE/NSF HEPAP
  - Fermilab Steering Group
- Large Liquid Argon Detector R&D in the US
  - Materials Test Stand at Fermilab: Initial Use
  - Electronics
  - Purity Demonstration: 20 ton
  - Cellular TPC Design and construction techniques
  - Tracks at Yale
  - LANND and DUSEL
- Physics Efforts based on LArTPCs in the US
  - T962 Status
  - MicroBooNE

One of Fermilab's R&D areas (PAB)



Materials Test Station



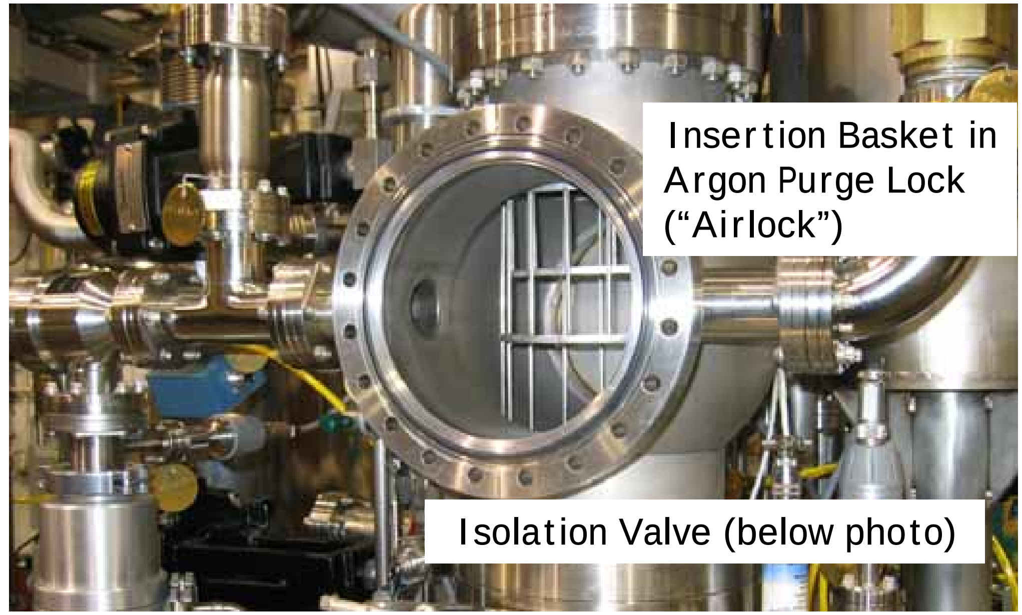
August 2007

Have tested two items and are developing systematic discipline.

Stay tuned … and feel free to suggest materials to be tested

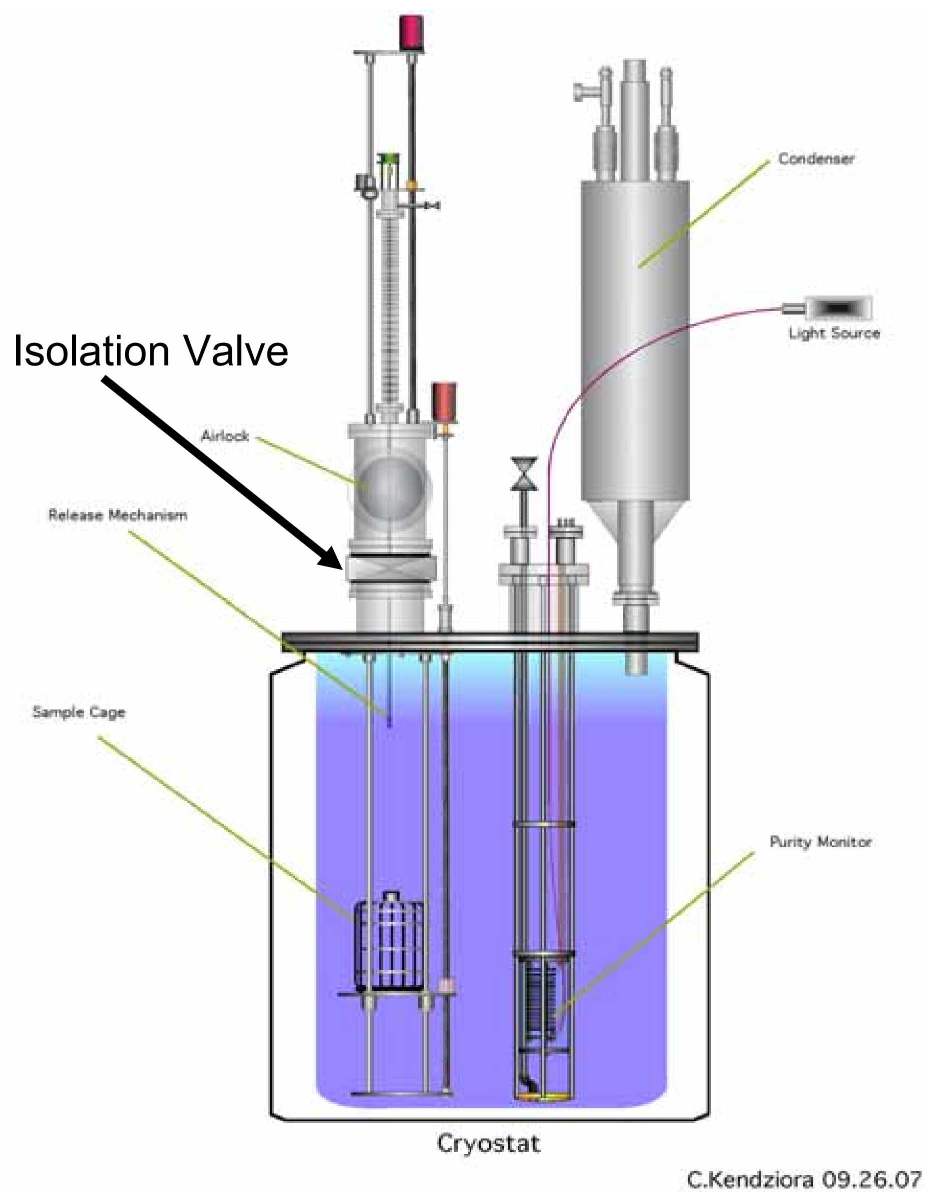
Using the Materials Test Station (1)

Insertion Basket ("Sample Cage")

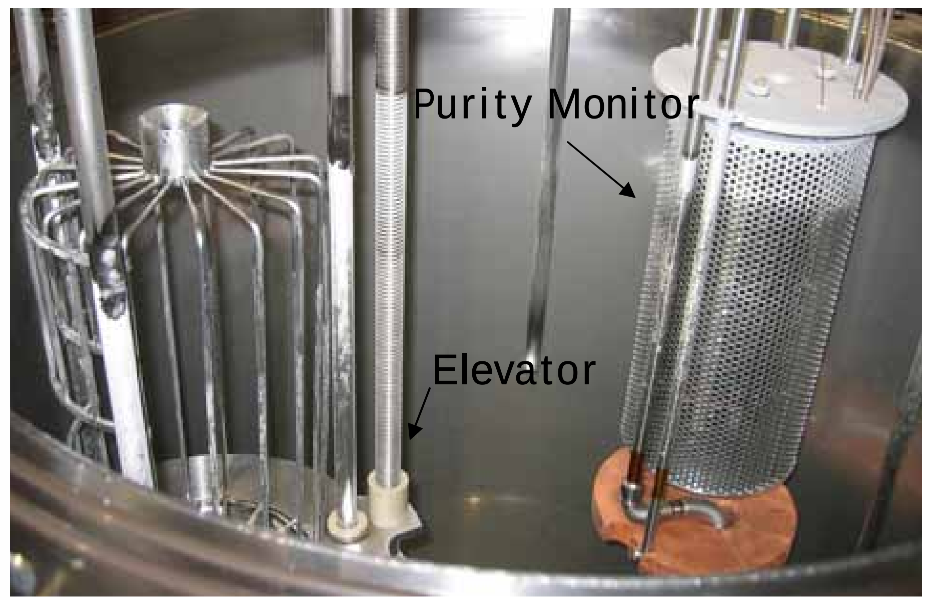


- Put materials in the Insertion Basket.
- Seal the Purge Lock with window (not shown).
- Choose to evacuate the Purge Lock (or not).
- Purge with pure argon gas (available above the pure liquid in the dewar).
- Continue on next slide

Using the Materials Test Station (2)



- Open the Isolation Valve.
- Lower the Elevator into the liquid, or into the gas above the liquid.
- Monitor lifetime with Purity Monitor.
- Understand results.



The Purity Monitor is an ICARUS clone.

Materials Test Station: Sample # 1

PAB Materials Test System **Sample #** 1

Date 08/28/07 **Logbook Page** 118

Sample Description Kapton clad conductor

Sample Composition Kapton and Copper

Sample Weight

Sample Exposed Area 16.5 ins^2

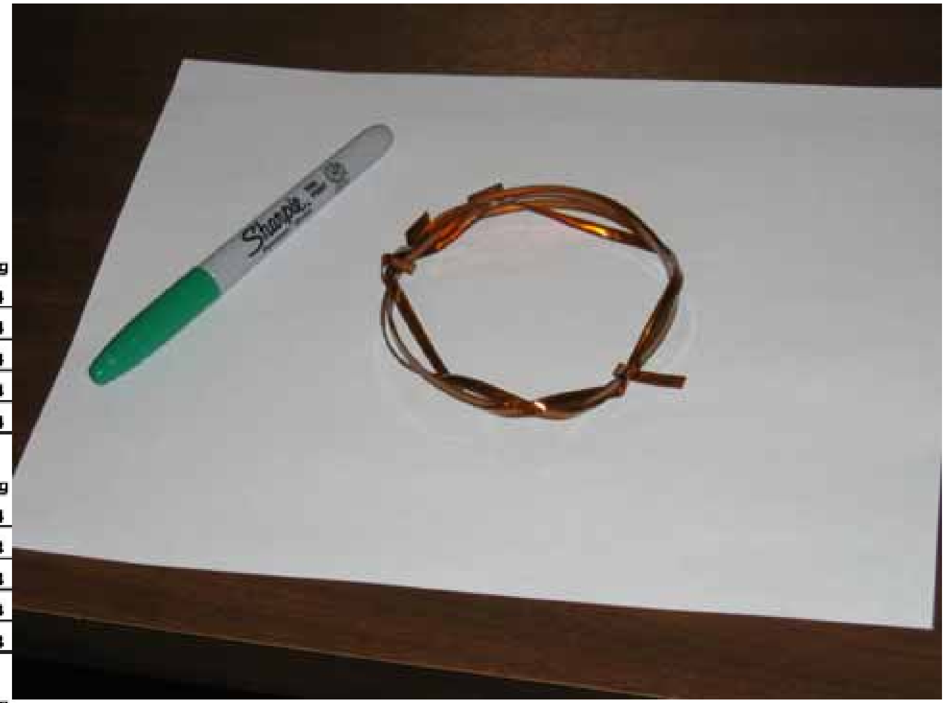
Verifiers S.Pordes, D. Finley

Source of Sample A. Rubbia

Sample Prep. Wipe with alcohol

Results to: A. Rubbia, S. Pordes

Purge Duration (hrs) 16 **Purge 02 Reading(ppm)** 0.02



Before Dunk:

CV	AV	CS	AS	DT	Lifetime	Level	T_m	Psig
150	3000	18.4	18.8	276	1628	18.4	93.5	6.4
100	2000	12.4	13.6	390	2263	18.4	93.5	6.4
67	1350	7.8	9	556	2461	18.4	93.5	6.4
45	880	4.6	5.6	826	2647	18.4	93.5	6.4
30	600	2.6	3.5	1192	2954	18.4	93.5	6.4
					2391			

Valve Open

CV	AV	CS	AS	DT	Lifetime	Level	T_m	Psig
150	3000	16.9	18	276	2157	18.4	93.4	6.4
100	2000	12	13.2	384	2319	18.4	93.4	6.3
66	1350	7.6	8.9	554	2577	18.4	93.4	6.3
45	880	4.6	5.6	816	2660	18.4	93.4	6.3
30	600	2.7	3.4	1192	2535	18.4	93.4	6.3
					2450			

In Liquid Argon

CV	AV	CS	AS	DT	Lifetime	Level	T_m	Psig							
150	3000	17.1	18.1	276	2057	18.1	93.3	6.3	83.80	186.34	0.0728	54.71	1.25	8.30	1.04
100	2000	11.9	12.7	386	1959	18.1	93.3	6.3	55.87	124.22	0.0520	76.51	1.37	11.60	1.05
67	1350	7.7	8.4	554	1973	18.1	93.3	6.3	37.43	83.85	0.0363	110.47	1.55	16.63	1.07
45	880	4.6	5.4	824	2372	18.1	93.3	6.3	25.14	54.66	0.0243	160.41	1.85	24.87	1.11
30	600	2.5	3.1	1184	2457	18.1	93.3	6.3	16.76	37.27	0.0170	234.69	2.33	35.58	1.16
					2163										

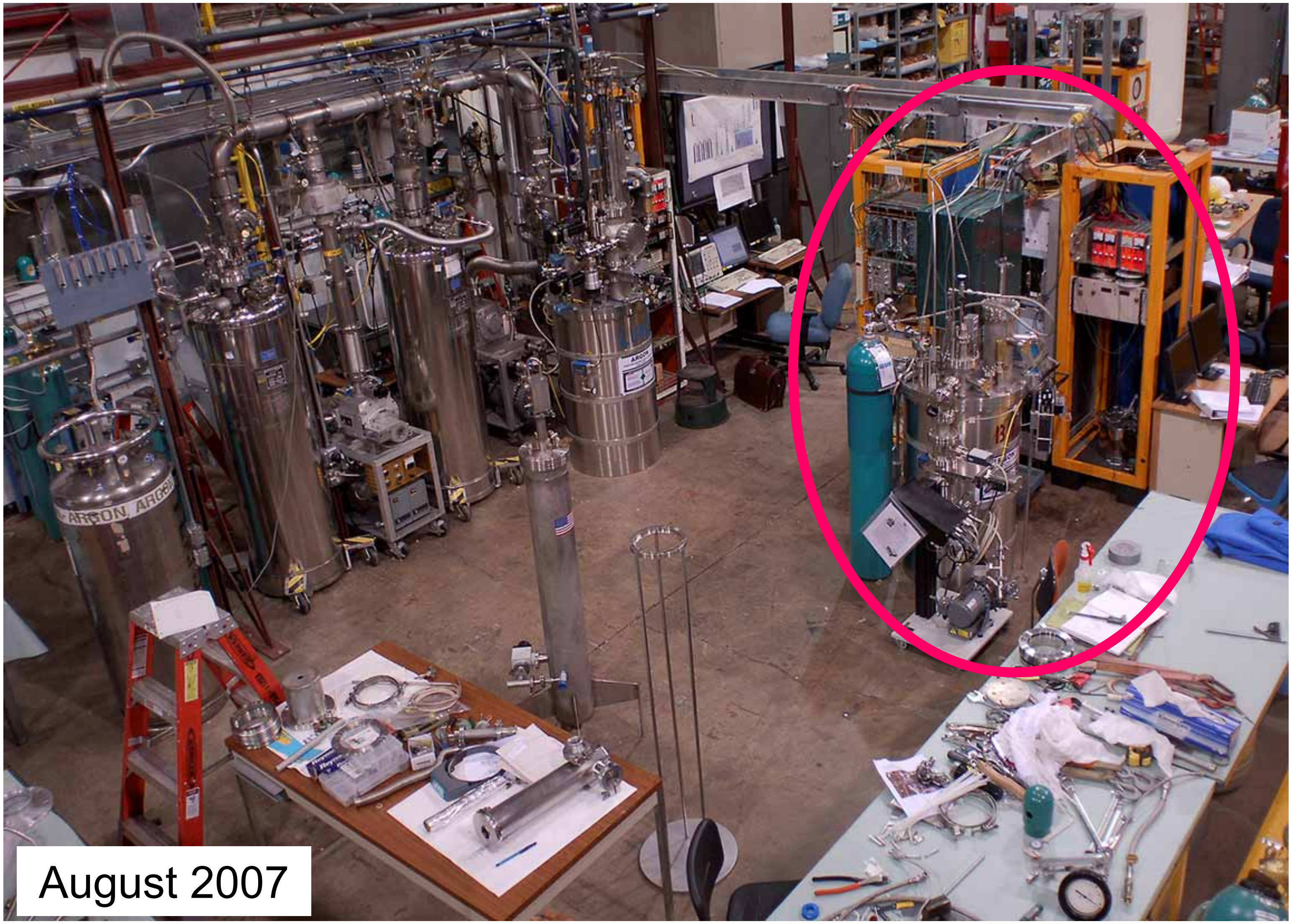
Name S. Pordes **Date** 08/28/07

Comments A possible change in lifetime from 2.4 ms to 2.15 ms .. This is typical of what happens when we lower the elevator. At face value, this corresponds to adding an impurity with a lifetime of (1/2.15 - 1/2.4)^-1 = 20 ms

Please suggest other interesting tests

A possible change in lifetime from 2.4 ms to 2.15 ms .. This is typical of what happens when we lower the elevator. At face value, this corresponds to adding an impurity with a lifetime of (1/2.15 - 1/2.4)^-1 = 20 ms

… and Electronics Development Station



With Michigan State University

Developing T962 electronics, intend to do cold electronics, etc

However: Has not seen liquid argon yet.

Demonstrating purity without evacuation

- The purpose is to demonstrate the feasibility of achieving the purity of liquid argon required for a 5kton TPC detector, explicitly without evacuation of the containment tank, and to estimate the costs associated with the required purification system.

- A suitable demonstration, or a true prototype, could:
  - be at least ~150tons,
  - use a scaled down version of the proposed 5kton purification system,
  - have a fully functioning TPC,
  - be located in a neutrino beam (at Fermilab for example),
  - be on the surface (to understand impact of cosmic rays on the 5kton),
  - and measure all that neutrinos do in liquid argon.

- But (to be as cheap as possible), a first step can use a 20ton vessel.
  - Still must use a scaled down version of the purification required for 5ktons.
  - But: can be single wall containment vessel, constructed by industry, small enough to be delivered by highway, with the ability to put TPC materials in it, but without a functioning TPC (at least initially).

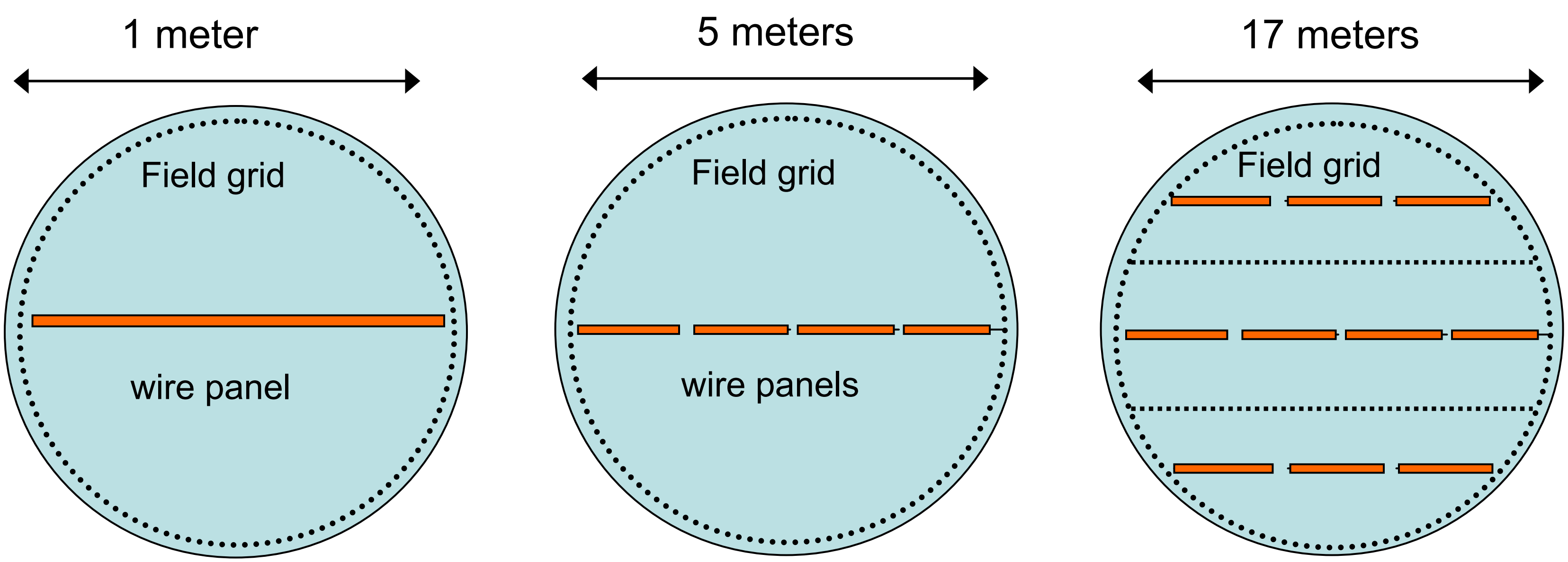
- The cost of this first step (at 20tons) is about $310,000 to buy the equipment, assemble it and do the demonstration. It can be done in less than a year.

Cellular TPC Design Concept: Scaling

A 5 ton detector is a cylinder 5 meters high with diameter 1 meter.

A 150 ton detector is a cylinder 5 meters high with diameter 5 meters.

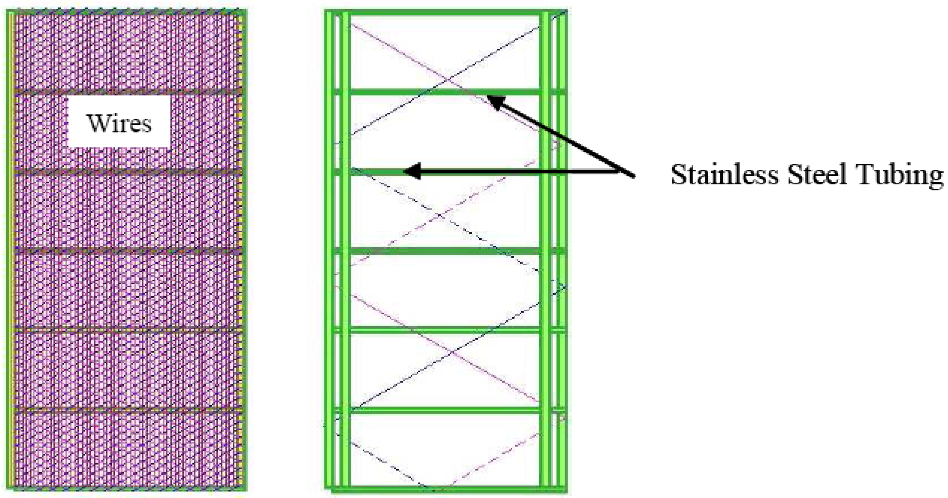
A 5 kton detector is a cylinder 17 meters high with diameter 17 meters



The transverse dimension is partly modular - more panels, similar drift distances;

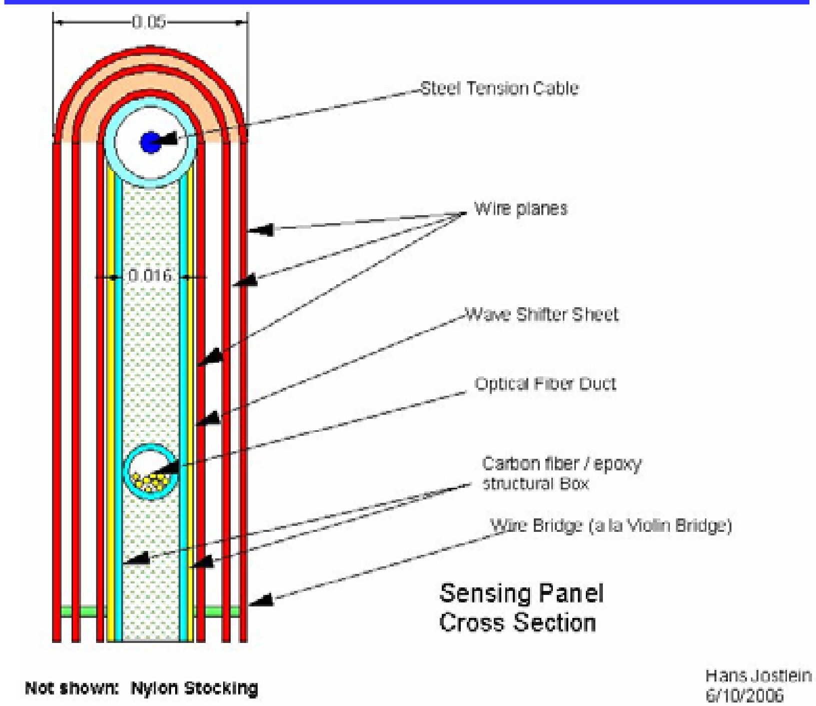
Once the 150 ton detector works, the design of the 17 meter panel is probably the key technical challenge.

Cellular TPC Design Concept:
Wire Panel and Light Collection Panel



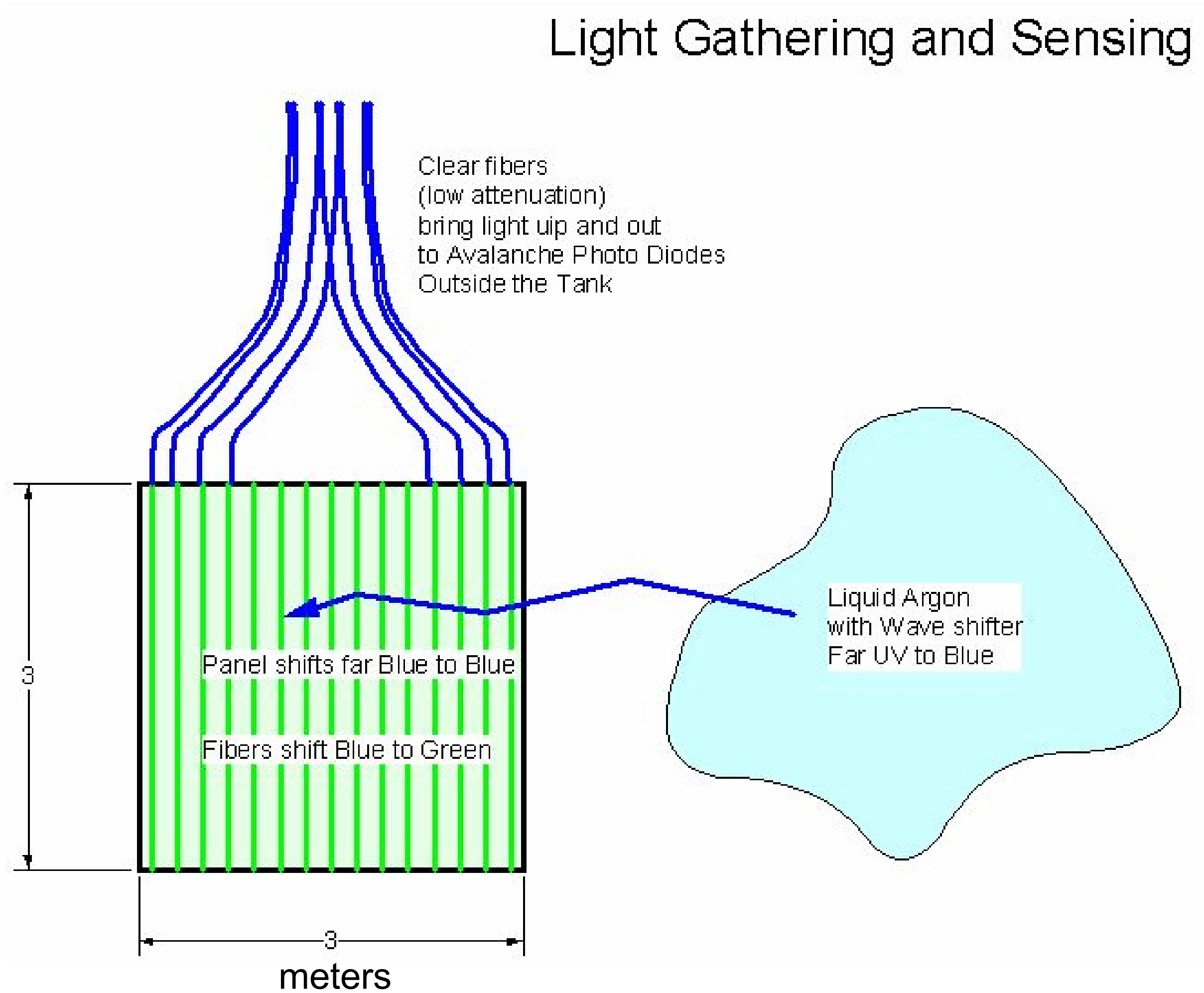
The spaces between adjacent stainless steel tubes are used for the scintillator panels ("wave shifter sheets") as shown below.

The stainless steel tubing as shown above provides structural support for the wires.



Real materials will serve in the 20ton purity demonstration.

Cellular TPC Design Concept:
Light Collection Using Sheets of Plastic Scintillator



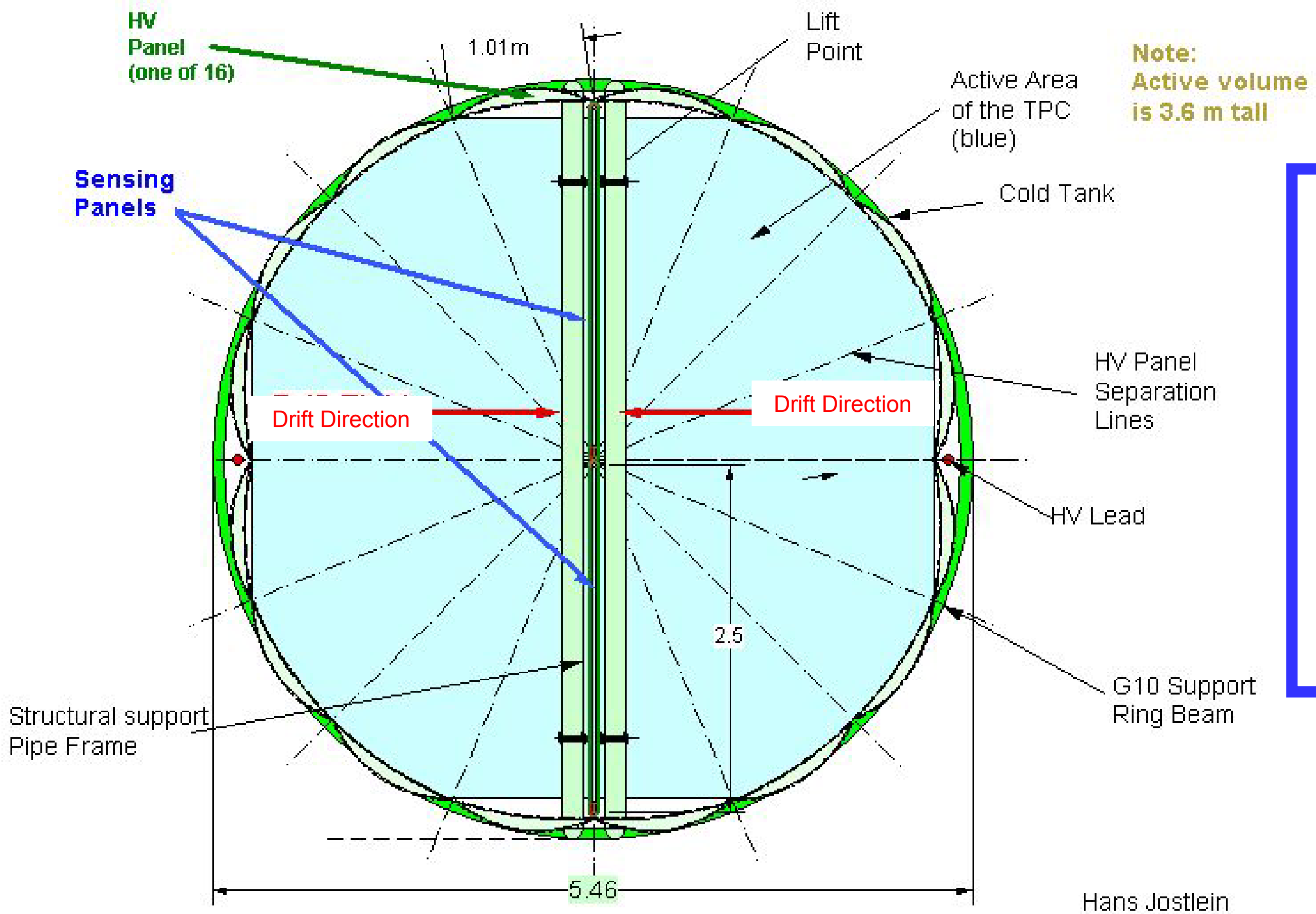
Need to understand:

- Effects of nitrogen on light propagation in the liquid argon

- Wavelength shifter appropriate for large area panel

- Etc.

Cellular TPC Design Concept: High Voltage distribution



150 ton LAr TPC Top View

The drift field will be uniform if the voltage is distributed as cos(theta) on a surface located at a constant distance from the center.

Cellular TPC Development: High Voltage “stave”

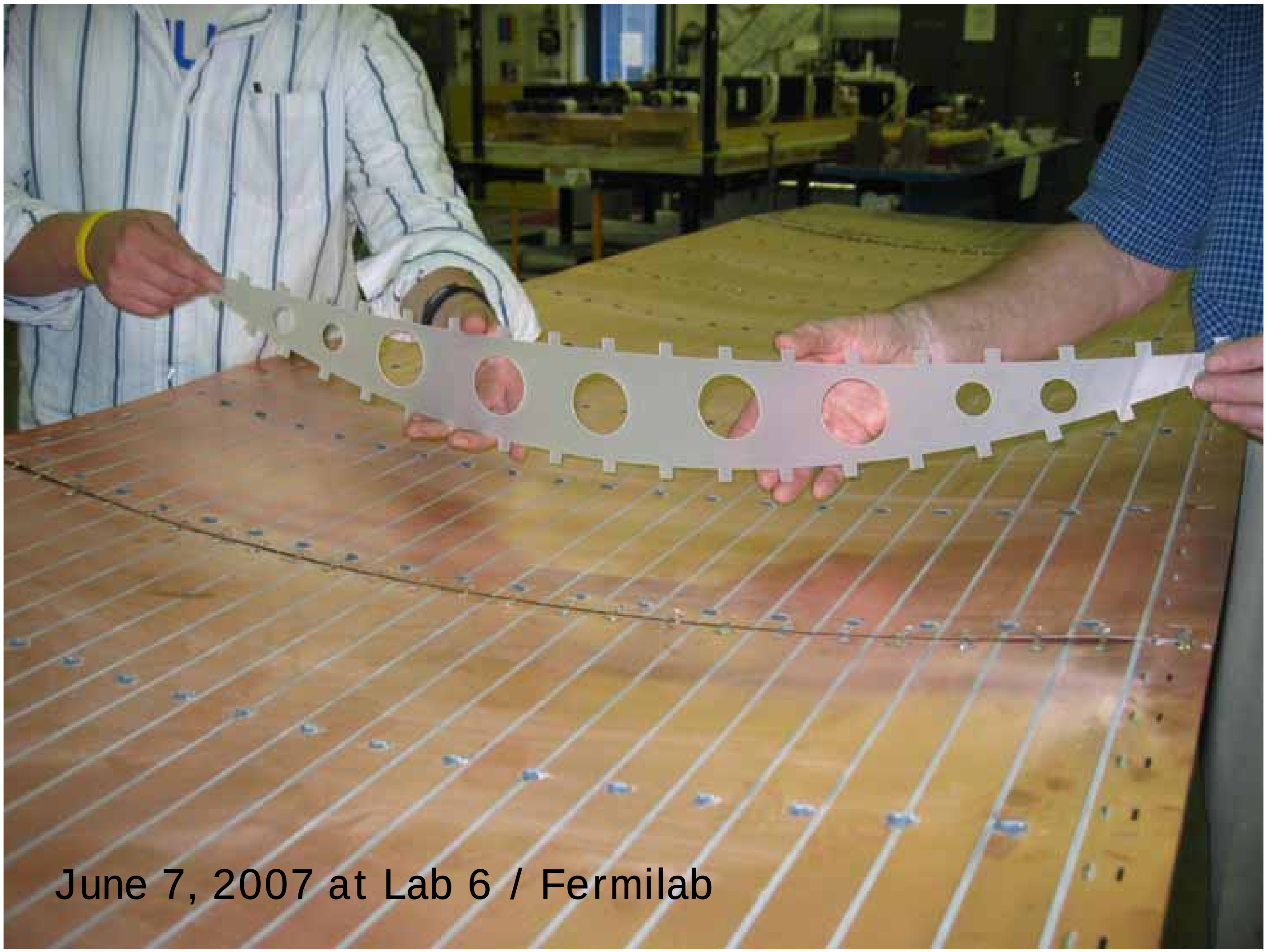
- This HV stave is for a tank with 150 tons of total LAr mass
- 16 HV staves, each 3.6 m tall and 1.04 m wide are made of G10, copper, resistors, etc
- The copper strips face the inside of the tank and provide a cos (theta) distribution of voltage
- Parts of these (plus parts from the wire panels and light panels) could serve as TPC materials for the Material Test Station as well as the purity demonstration.

Hans Jostlein and the summer student who built this first stave are shown

Cellular TPC Development: HV distribution

The resistor chain gives an ~cos(theta) voltage distribution which in turn provides a (very nearly) uniform electric field throughout the TPC volume, thus allowing full use of (nearly) all the liquid argon.

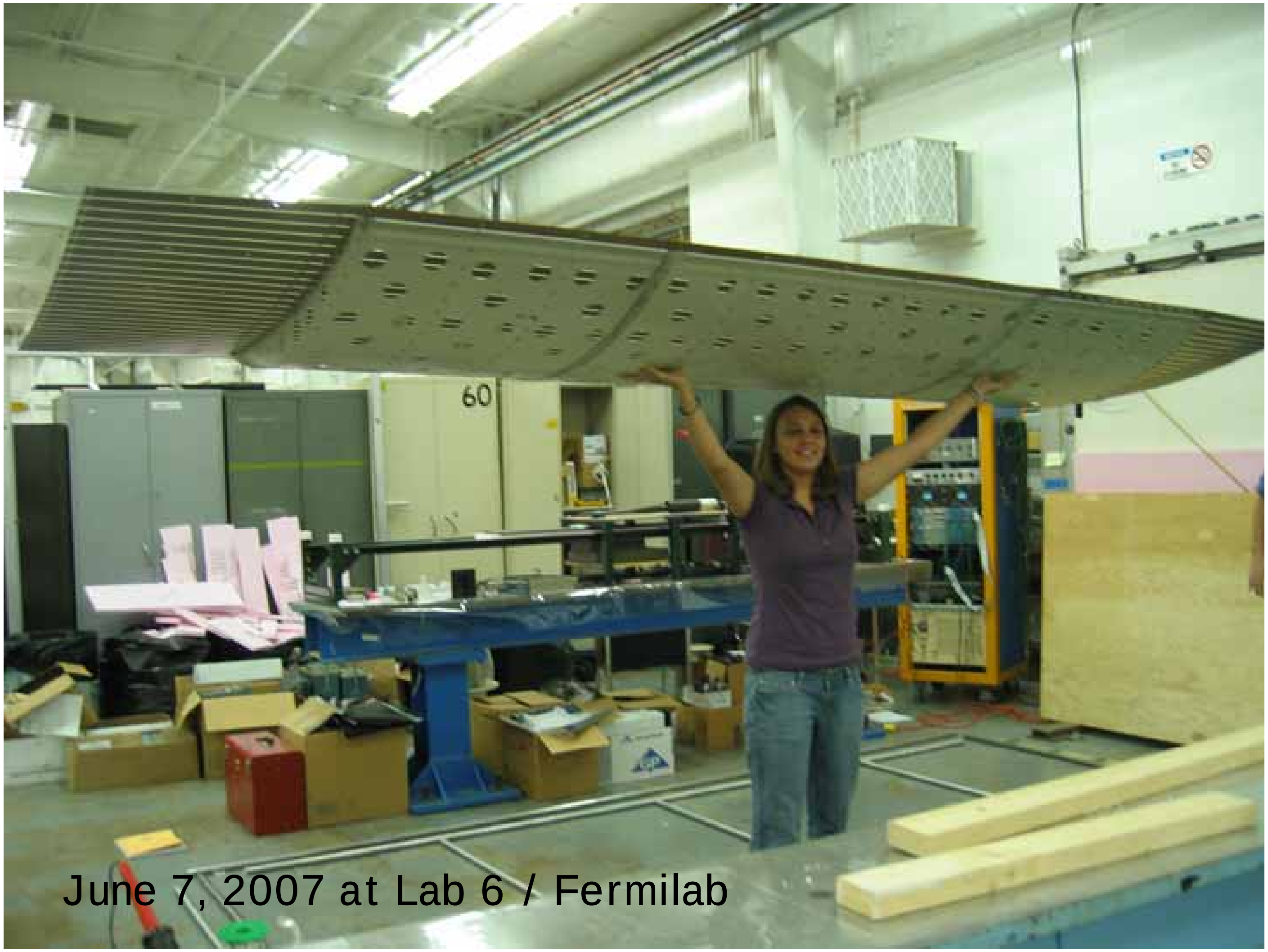
Cellular TPC Development: Ribs give proper curvature



June 7, 2007 at Lab 6 / Fermilab

Hans and a student are holding a rib. The top of the rib shown in the picture has the curvature needed for the copper strips on the inside of the HV stave. A set of these ribs is installed underneath the stave and are hidden in this photo.

Cellular TPC Development: Light weight “stave”

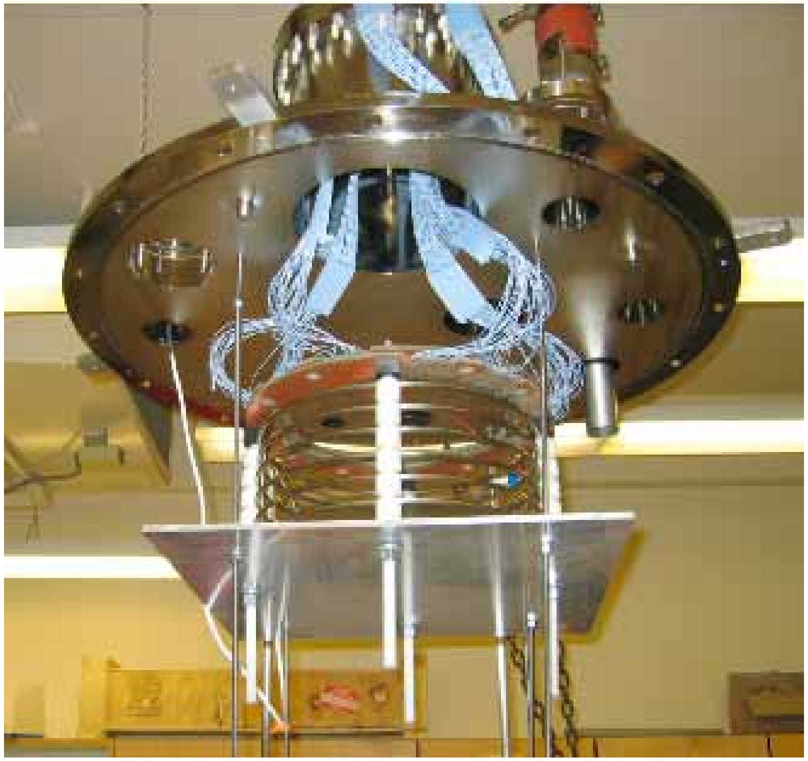


The support structure which provides the curvature shows one rib at the left end. The structure has holes in it to allow the argon to flow freely.

One complete stave is lightweight.

Summer student from Minnesota with the first HV stave

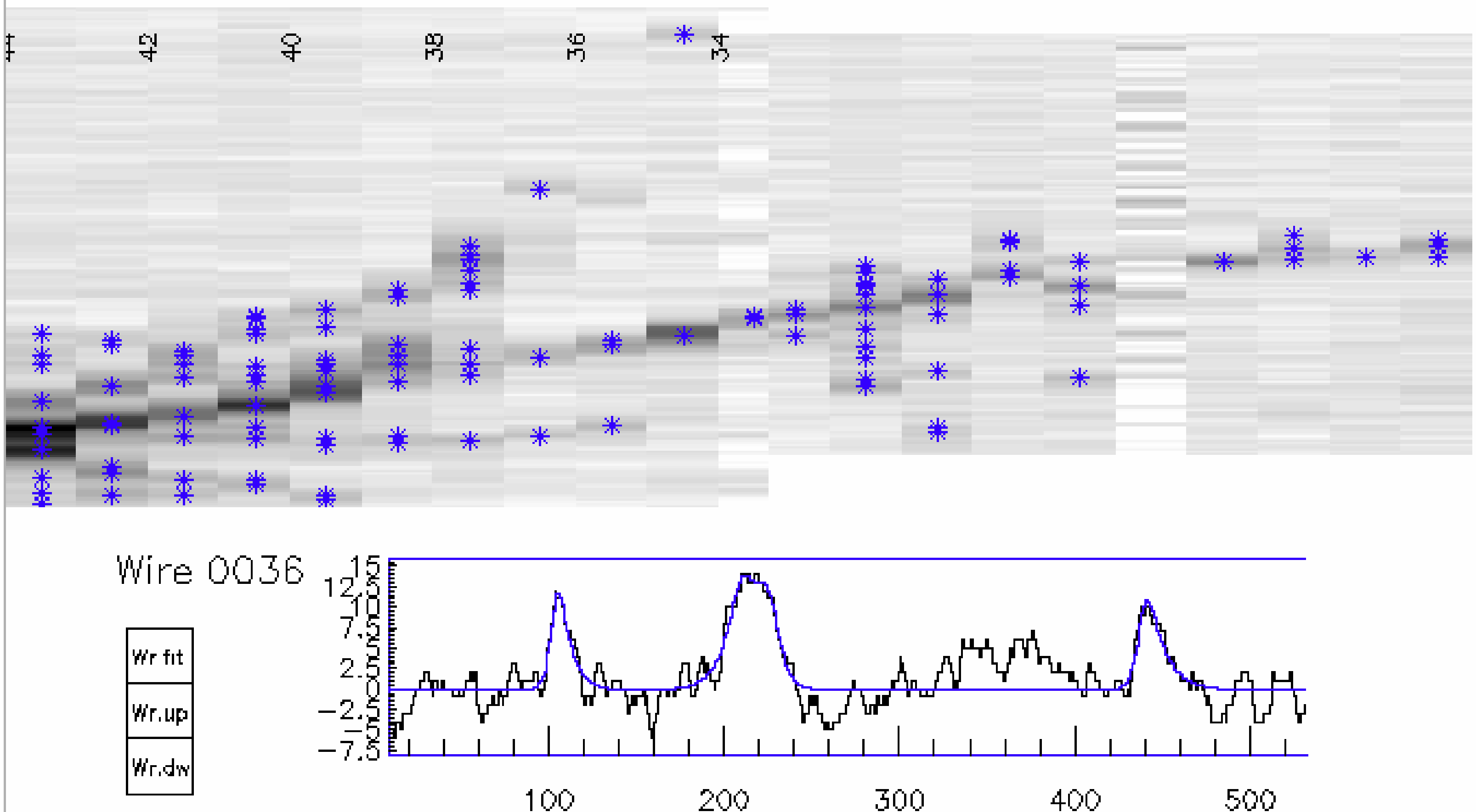
Tracks at Yale



TPC test setup at Yale with filters and TPC from Fermilab and electronics from Padova

Courtesy Alessandro Curioni / Yale

Track Display from Yale TPC
First tracks seen in Spring 2007



time (400 ns bins)

Wire 36 signal

Courtesy Alessandro Curioni / Yale

LANNDD

A LINE OF LIQUID ARGON TPC DETECTORS SCALABLE IN MASS FROM 200 TONS TO 100 KTONS

David B. Cline [1], Fabrizio Raffaelli [2] and Franco Sergiampietri [1,2]

[1] Astrophysics Division, Department of Physics & Astronomy, University of California, Los Angeles, CA 90095 USA

[2] INFN-Sezione di Pisa, Largo B. Pontecorvo 3, 56127 Pisa, ITALY

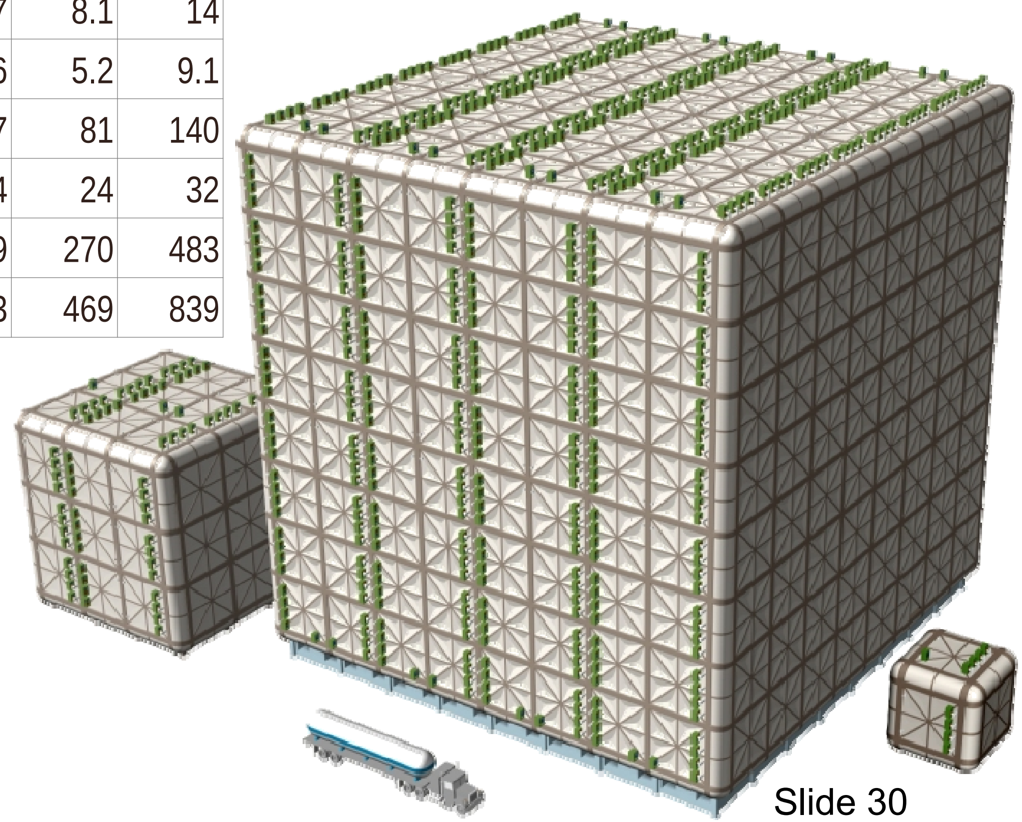
Designed with DUSEL in mind

Large Liquid Argon Neutrino and Nucleon Decay Detector

Slide 29

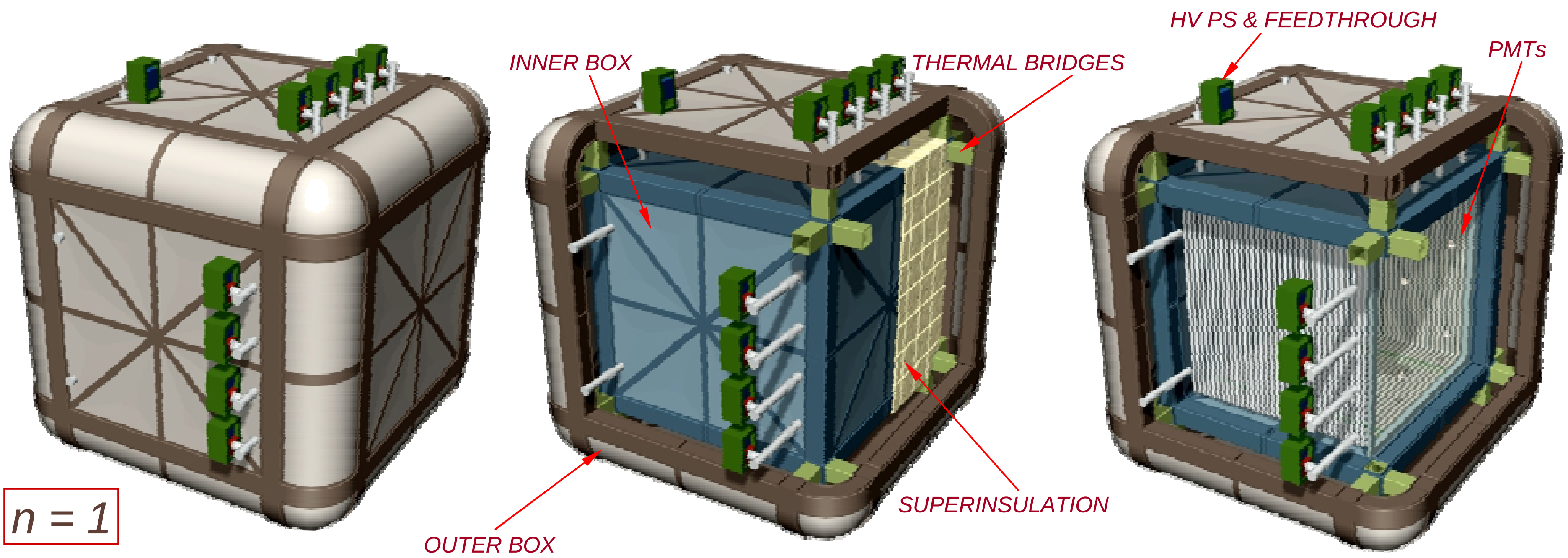
LANNDD: SCALING

N. of cells/side	1	2	3	4	6	8
Total N. of cells	1	8	27	64	216	512
Total LAr volume [10^3 m^3]	0.14	1.36	4.93	12.1	42.4	102
Active LAr volume [10^3 m^3]	0.14	1.27	4.49	10.9	35.9	86.9
Active LAr mass [KTon]	0.19	1.78	6.28	15.2	50.3	122
Total inner beam length [Km]	0.08	0.34	0.89	1.83	5.37	11.8
Total heat input [KW]	0.3	1.0	2.1	3.7	8.1	14
Equiv. LN_2 consumption [m^3/d]	0.18	0.63	1.36	2.36	5.2	9.1
Equiv. El. Power-Cooling [KW]	2.8	9.8	21	37	81	140
N. of wire chambers	1	2	3	4	24	32
N. of channels [10^3]	3.3	14	33	59	270	483
El. Power-Electronics [KW]	6	25	57	103	469	839



Slide 30

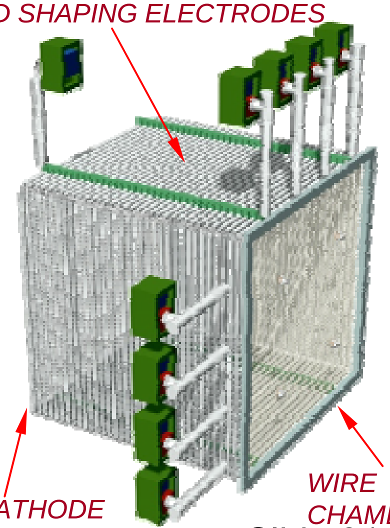
Structural tests: LANNDD - 001



A single cell detector is proposed as study prototype to analyze the ***mechanical stiffness*** *of the inbox-outbox complex at room and at low temperature and in condition to simulate a 7bar + 1bar (vacuum) head pressure for the extension to n=8 (LAr depth = 48m).*

The detector is useful for ***developing*** *and* ***testing*** *the HV system, the readout electronics, the purification and cooling systems, the acquisition and reconstruction software and all the* ***repetitive details*** *and solutions to adopt for the full scale detector.*

The instrumented LAr has a volume of ***125 m^3*** *and a mass of* ***175 Ton***



LANNDD: CONSTRAINTS AND GENERAL LINES - 4

In order to reach and maintain during years the required level of purity we consider as inalienable the following construction criteria and conditions:

- *Possibility of generating vacuum inside the inner vessel and of checking its tightness*
- *Wise choice of construction materials (use of stainless steel for the inner vessel walls, for cathodes, for wire chamber frame and for electrical field shaping electrodes; possible use of alternative and cheaper alloys, as CORTEN, for the outer vessel)*
- *Continuous, adiabatic argon purification in liquid phase*
- *UHP and UHV standards for any device and cryogenic detail (flanges, valves, pipes, welding) in contact with the argon*

Running costs are mainly related to the efficiency of the thermal insulation. Vacuum insulation, joint to the use of superinsulation jacket around the cold vessel, should be considered as the primary choice.

An optimized thermal insulation, with a low rate evaporation for LAr and low electric power involvement for cryogenerators, is also a must to safely operate the detector underground during tenths of years

LAN Comparison by speaker (from Fermilab) ES - 4

In order to reach and maintain during years the required level of purity we consider as inalienable the following construction criteria and conditions:

- *Possibility of generating vacuum inside the inner vessel and of checking its tightness* ?
- *Wise choice of construction materials (use of stainless steel for the inner vessel walls, for cathodes, for wire chamber frame and for electrical field shaping electrodes; possible use of alternative and cheaper alloys, as CORTEN, for the outer vessel)* Yes
- *Continuous, adiabatic argon purification in liquid phase* Yes
- *UHP and UHV standards for any device and cryogenic detail (flanges, valves, pipes, welding) in contact with the argon* ?

Running costs are mainly related to the efficiency of the thermal insulation. Vacuum insulation, joint to the use of superinsulation jacket around the cold vessel, should be considered as the primary choice. Partly Yes

An optimized thermal insulation, with a low rate evaporation for LAr and low electric power involvement for cryogenerators, is also a must to safely operate the detector underground during tenths of years Partially Yes

Outline

- Recent Reports in the US
  - Long Baseline Study: Fermilab/Brookhaven
  - NuSAG = Neutrino Science Assessment Group:
    - US DOE/NSF HEPAP
  - Fermilab Steering Group

- Large Liquid Argon Detector R&D in the US
  - Materials Test Stand at Fermilab: Initial Use
  - Electronics
  - Purity Demonstration: 20 ton
  - Cellular TPC Design and construction techniques
  - Tracks at Yale
  - LANND and DUSEL

- Physics Efforts based on LArTPCs in the US
  - T962 Status
  - MicroBooNE

ArgoNeuT (T962): Argon Neutrino Test

Expose a small (~250 liter active volume)
LArTPC to the NuMI neutrino beam

- See low energy (1-3 GeV) neutrino interactions in a LArTPC
  - specifically NCπ°s and ν_e
- gain experience operating stabily over months

These are firsts:

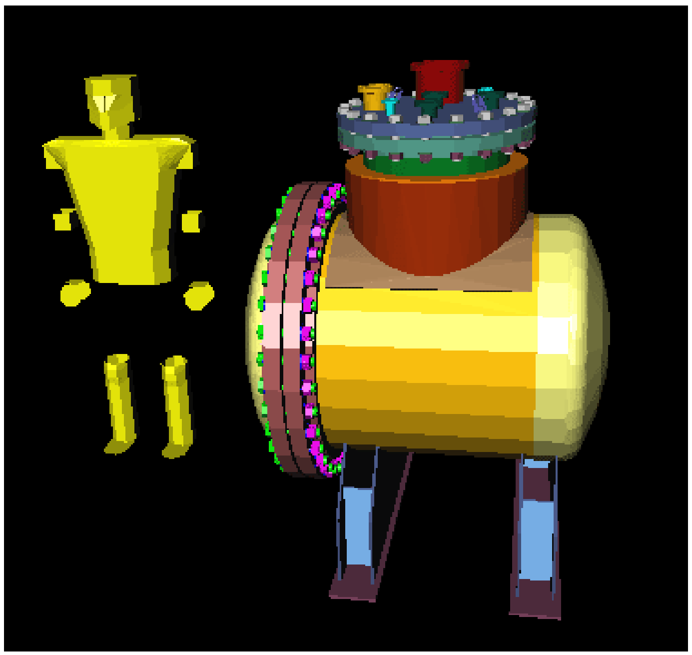
- only other TPC to see neutrinos was ICARUS 50l
  - 50 liter volume
  - 24 GeV beam
  - published ~100 ν_μ CCQE events

Neither the 50 liter nor other TPCs (including T600) has operated continuously, for months, underground.

Courtesy Bonnie Fleming / Yale

funded via NSF CAREER grant

Cryostat:
- ~500 liters total volume
- ~250 liters active volume
- .5 x .5 x 1m TPC



sit just upstream of the MINOS near detector (as PEANUT has done)

use MINOS as muon catcher

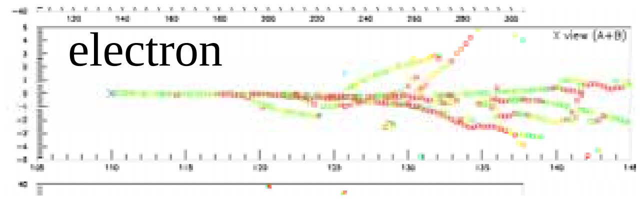
~300 ν_e CC events/day → Scheduled run: Jan '08 to August '08

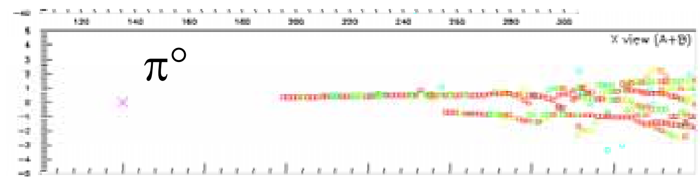
Courtesy Bonnie Fleming / Yale

MiniBooNE follow-on:
~~Boone~~

microBooNE

Brookhaven, Columbia, Fermilab, Michigan State, St, Mary's, Yale, UTAustin





Ideal detector to understand miniBooNE low energy excess:
Liquid Argon TPC

- sensitive at low energies
- e/gamma separation
- high efficiency for “signal
- low background

- 70 ton fiducial volume TPC
- 170 ton total volume
- 3 years at 2E20 pot/year

-> resolve miniBooNE excess

Courtesy Bonnie Fleming / Yale

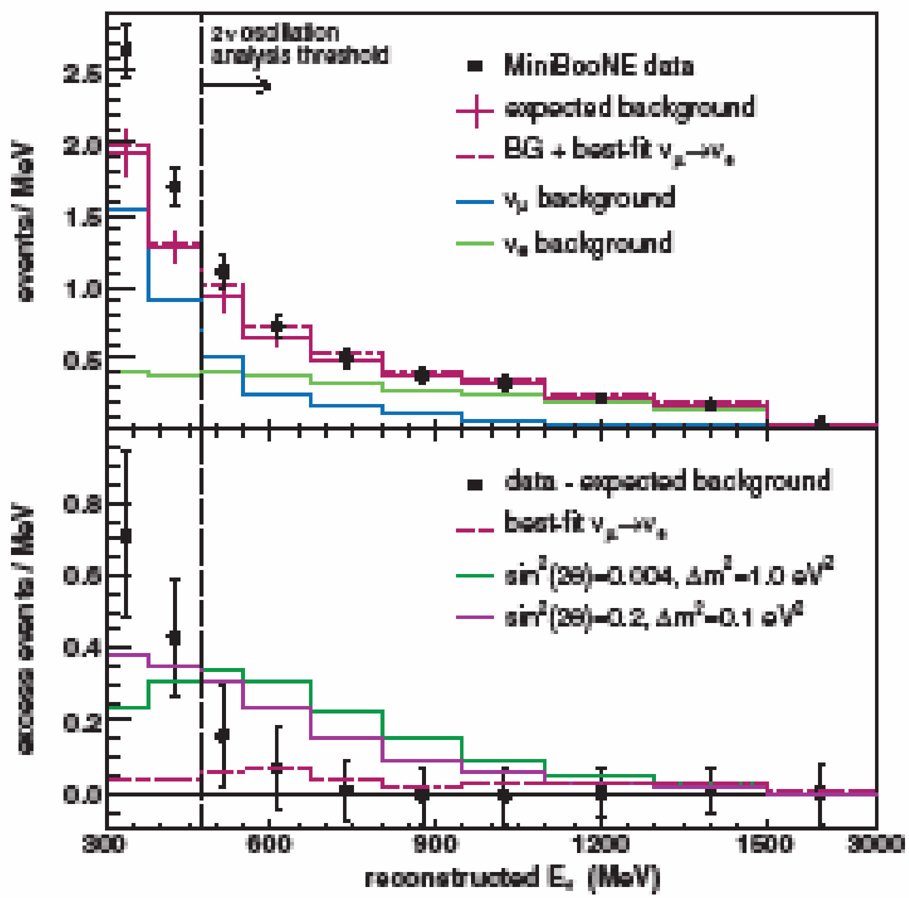
- Thank you!

PRL 98, 231801 (2007) PHYSICAL REVIEW LETTERS week ending 8 JUNE 2007

Search for Electron Neutrino Appearance at the $\Delta m^2 \sim 1$ eV^2 Scale

A. A. Aguilar-Arevalo,[5] A. O. Bazarko,[12] S. J. Brice,[7] B. C. Brown,[7] L. Bugel,[5] J. Cao,[11] L. Coney,[5] J. M. Conrad,[5] D. C. Cox,[8] A. Curioni,[16] Z. Djurcic,[5] D. A. Finley,[7] B. T. Fleming,[16] R. Ford,[7] F. G. Garcia,[7] G. T. Garvey,[9] C. Green,[7,9] J. A. Green,[8,9] T. L. Hart,[4] E. Hawker,[15] R. Imlay,[10] R. A. Johnson,[3] P. Kasper,[7] T. Katori,[8] T. Kobilarcik,[7] I. Kourbanis,[7] S. Koutsoliotas,[2] E. M. Laird,[12] J. M. Link,[14] Y. Liu,[11] Y. Liu,[1] W. C. Louis,[9] K. B. M. Mahn,[5] W. Marsh,[7] P. S. Martin,[7] G. McGregor,[9] W. Metcalf,[10] P. D. Meyers,[12] F. Mills,[7] G. B. Mills,[9] J. Monroe,[5] C. D. Moore,[7] R. H. Nelson,[4] P. Nienaber,[13] S. Ouedraogo,[10] R. B. Patterson,[12] D. Perevalov,[1] C. C. Polly,[8] E. Prebys,[7] J. L. Raaf,[3] H. Ray,[9] B. P. Roe,[11] A. D. Russell,[7] V. Sandberg,[9] R. Schirato,[9] D. Schmitz,[5] M. H. Shaevitz,[5] F. C. Shoemaker,[12] D. Smith,[6] M. Sorel,[5] P. Spentzouris,[7] I. Stancu,[1] R. J. Stefanski,[7] M. Sung,[10] H. A. Tanaka,[12] R. Tayloe,[8] M. Tzanov,[4] R. Van de Water,[9] M. O. Wascko,[10] D. H. White,[9] M. J. Wilking,[4] H. J. Yang,[11] G. P. Zeller,[5] and E. D. Zimmerman[4]

(MiniBooNE Collaboration)



The top plot in Fig. 2 shows candidate ν_e events as a function of E_ν^{QE}. The vertical dashed line indicates the minimum E_ν^{QE} used in the two-neutrino oscillation analysis. There is no significant excess of events ($22 \pm 19 \pm 35$ events) for $475 < E_\nu^{QE} < 1250$ MeV; however, an excess of events ($96 \pm 17 \pm 20$ events) is observed below 475 MeV. This low-energy excess cannot be explained by a two-neutrino oscillation model, and its source is under investigation. The dashed histogram in Fig. 2