

# LArTPC Design and Cost Considerations

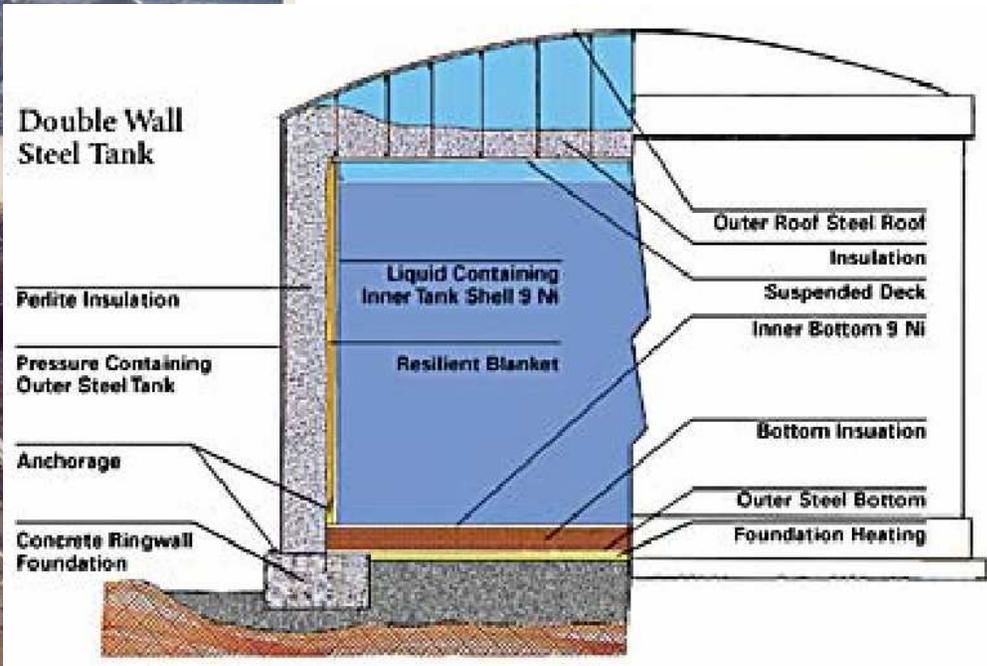
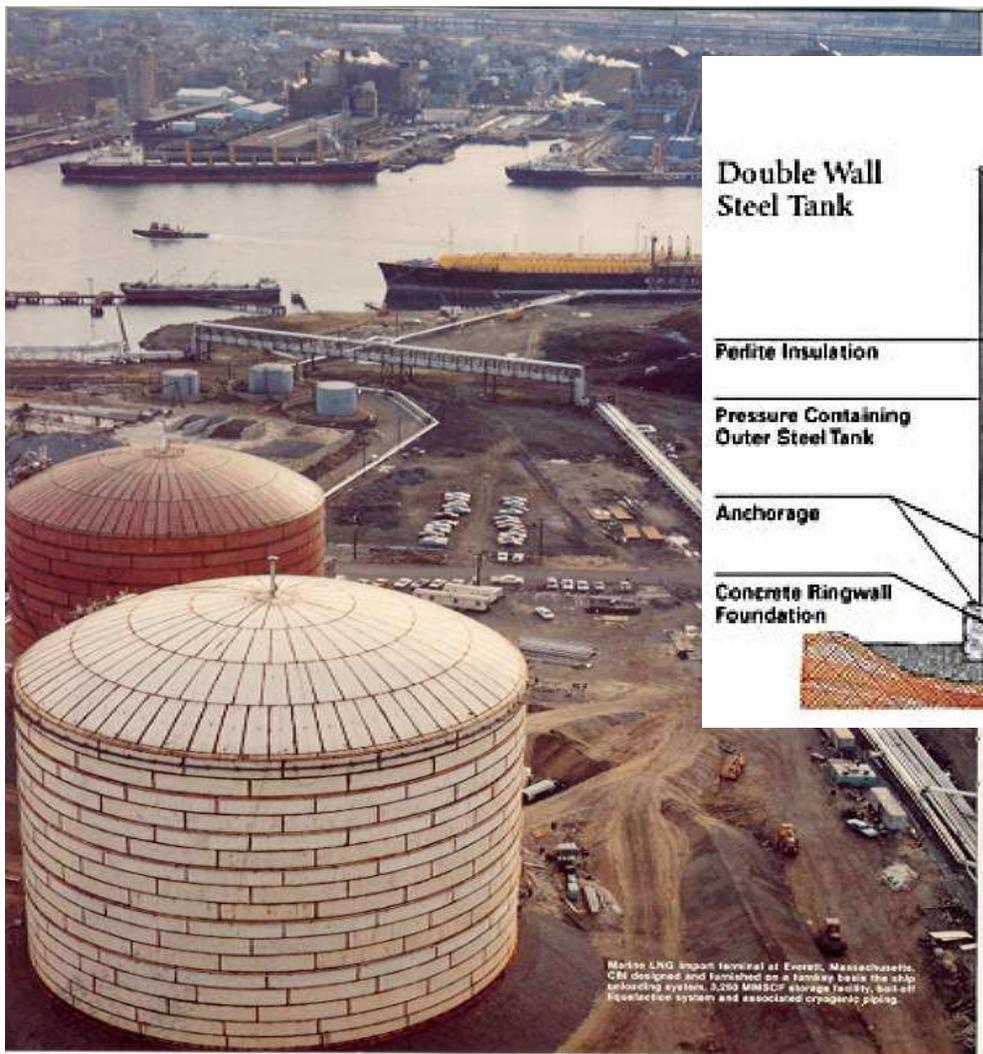
- Ultimate Step and Penultimate Step
  - LArTPC Costing Methodology
    - Ongoing LArTPC R&D
      - Summary

# The Ultimate Neutrino Detector

Adam Para, Fermilab

Experimental Seminar,  
SLAC,  
March 28, 2006

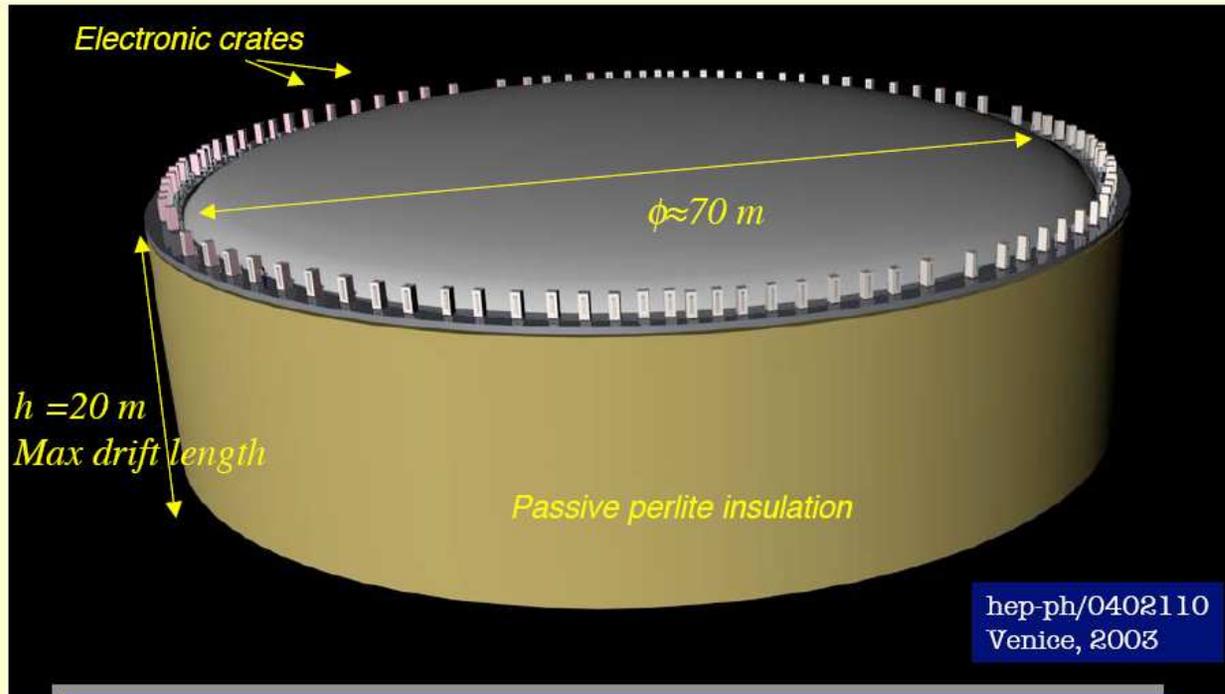
# Detector Tank based on Industrial Liquefied Natural Gas (LNG) storage tanks



Many large LNG tanks in service. excellent safety record

Marine LNG import terminal at Everett, Massachusetts. CBI designed and furnished as a turnkey basis the ship unloading system, 3,000 MMSCF storage facility, boil-off liquefaction system and associated cryogenic piping.

## A 100 kton liquid Argon TPC detector



Single module cryo-tanker based on industrial LNG technology

A “general-purpose” detector for superbeams, beta-beams and neutrino factories with broad non-accelerator physics program (SN  $\nu$ , p-decay, atm  $\nu$ , ...)

**International Neutrino Factory And Superbeam Scoping Study Meeting, CERN - 22-24 September 2005**

# The Big Question:

What is needed to take the  
Ultimate Step for Large Liquid  
Argon TPC Detectors?

This begs a smaller question:  
What is the “Penultimate Step”?

# The Ultimate Step

- Assumptions for beginning the ultimate step:
  - A timely, cutting edge **physics justification**
    - Examples may be:
      - Neutrino oscillations, proton decay, supernovae, etc
  - A **project** with well-understood technical capabilities and costs for a 50 to 100 kton TPC liquid argon detector
  - An **international collaboration** which proposes to **international funding** agencies locating one or more detectors:
    - Under rock/dirt in Europe, the Americas, Asia or elsewhere
    - On the surface anywhere on the planet (including in a neutrino beam)

# The Penultimate Step – Part 1

- Making the penultimate step assumes completion of:
  - A compelling **physics case** for the penultimate step and perhaps the ultimate step
    - In the context of a globally coordinated neutrino physics program, which in turn requires
    - An international collaboration in place with possible, but unapproved, funding sources for the ultimate detector, and
  - A credible **schedule**, which requires (see next slides):
  - A credible **cost estimate**, which requires (see next slides):
  - A **demonstration of the engineering/technology** (ICARUS / T600 is an existence proof of one approach) and the plausibility of the experimental physics capability for the Penultimate Detector

# The Penultimate Detector(s)

- There may be many examples of a penultimate detector, but they all have these criteria:
  - A compelling physics experiment justifies the penultimate detector
  - The relationship of the penultimate detector to determining the costs and scalability of the technology to the ultimate detector must be clear.
  - The penultimate detector is part of a global neutrino physics program and likely requires international coordination and funding
- One example: **3 kton\* LArTPC (nearly) on-axis in NuMI beam.**
  - Physics Case ??
  - $\theta_{13}$ ,  $\theta_{23}$ , mass hierarchy, other ? ...
  - complementary to NOvA ???
  - On the surface at Soudan ? ( $\sim 1$  mrad off axis = “near on-axis”)

\* active mass

# The Penultimate Step – Part 2

- Making the penultimate step requires completion of:
  - A credible **schedule**, which includes:
    - Time for peer reviews, lab reviews, and government approvals
    - Completion of R&D for the engineering/technology and physics capability required for the penultimate detector
    - Time for construction and operation of the penultimate detector
  - A credible **cost** estimate, which requires:
    - A **technical design** to accomplish the physics
    - A credible schedule
    - Engineers and **project management** techniques
    - Perhaps a clear cost scaling to the ultimate detector

# Cost methodology ...

## – Any cost estimate ...

- Can be used to identify large costs (and cost uncertainties) which might be reduced by
  - technical R&D including more detailed engineering designs or
  - getting information which is closer to firm quotes from vendors
- Can be used to increase costs to reduce risk or improve technical performance, or to advance/stretch the schedule (for whatever reasons)
- Can be used to help identify all tasks (i.e., costs) by using a WBS
- Can be used to compare to other techniques and approaches (e.g. Water Cherenkov, surface vs. below ground, etc.)

# History: What has been done?

- ICARUS

- Allocated ~\$20M for 1.2 kton (actually 20M Euros)
  - Math gives: ~17M\$/kton or ~830M\$/50 kton
  - And math gives: a factor of ten cheaper would be ~83M\$/50kton
  - This is an “experience based” cost estimate.
  - This is not a cost done by DOE accounting.

# History: What has been done?

Caution: Bridge Out

November 7, 1940, at  
approximately 11:00  
AM, Tacoma  
Washington



There is much more to this than “math”.

Use of cost numbers in this talk without contextual protection may reduce your credibility

# History: What has been done?

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    - This is not a cost done by DOE accounting.
- **LArTPC NuSAG submission**
  - \$57.45M for 15 kton
    - Math gives: 3.8M\$/kton or ~190M\$/50kton
    - This is not an “experience based” cost estimate.
    - This is not a cost done by DOE accounting.
- **NuSAG response**
  - See next slide

# NuSAG February 28, 2006

- 6.2.3 The U.S. R&D program in Liquid Argon TPC's should be supported at a level that can establish if the technology is scalable to the 10-30 kiloton range. If workable, this technology will come into its own in the later phases of the long-baseline program.

NuSAG's charge suggested that we consider this technology as an alternative to NOvA. This was not the case presented to NuSAG by the proponents or by Fermilab. Instead, use of a liquid argon neutrino detector in later phases of the program is contemplated, possibly for a second detector in the NOvA program.

Besides dealing with longer wires, higher voltage, and longer drift times than the existing Icarus modules, cost reduction by about an order of magnitude will be required to make a 10-30 kiloton detector feasible.

# NuSAG Submission Costs

Item (15 kton)	cost (k\$)	Comment
Site Preparation	5,300	same as NOvA
Buildings	2,000	support buildings only
Tank	13,300	e-mail quote
Habitable Deck	2,500	\$300/sq ft.
Tank Top Structure	4,000	Wire Load/Tank Pressure
Cathode and Field Cage	3,000	Eng. Estimate
Signal Planes	3,000	Eng. Estimate
Access to Deck	1,500	Elevator and Stairways
Assembly Platforms	1,000	Installation of TPC
<b>Total</b>	<b>35,600</b>	

Table 7.1: Estimate for Mechanical Infrastructure

Item (15 kton)	cost (k\$)	Comment
Front-End ASIC	1,000	ASIC development & production
Commercial Components	500	ADC, FPGA and Data Link
Connectors, cable, PC Boards	1,100	Parts & similar boards
Feedthroughs	300	Purchasable Devices
Power Supplies	200	
<b>Total</b>	<b>3,100</b>	

Table 7.3: Estimate for Electronics

**15 kton**

The costs presented in this chapter add up to a total of 57.45 Million dollars. This is a preliminary cost estimate which does not include EDIA or contingency.

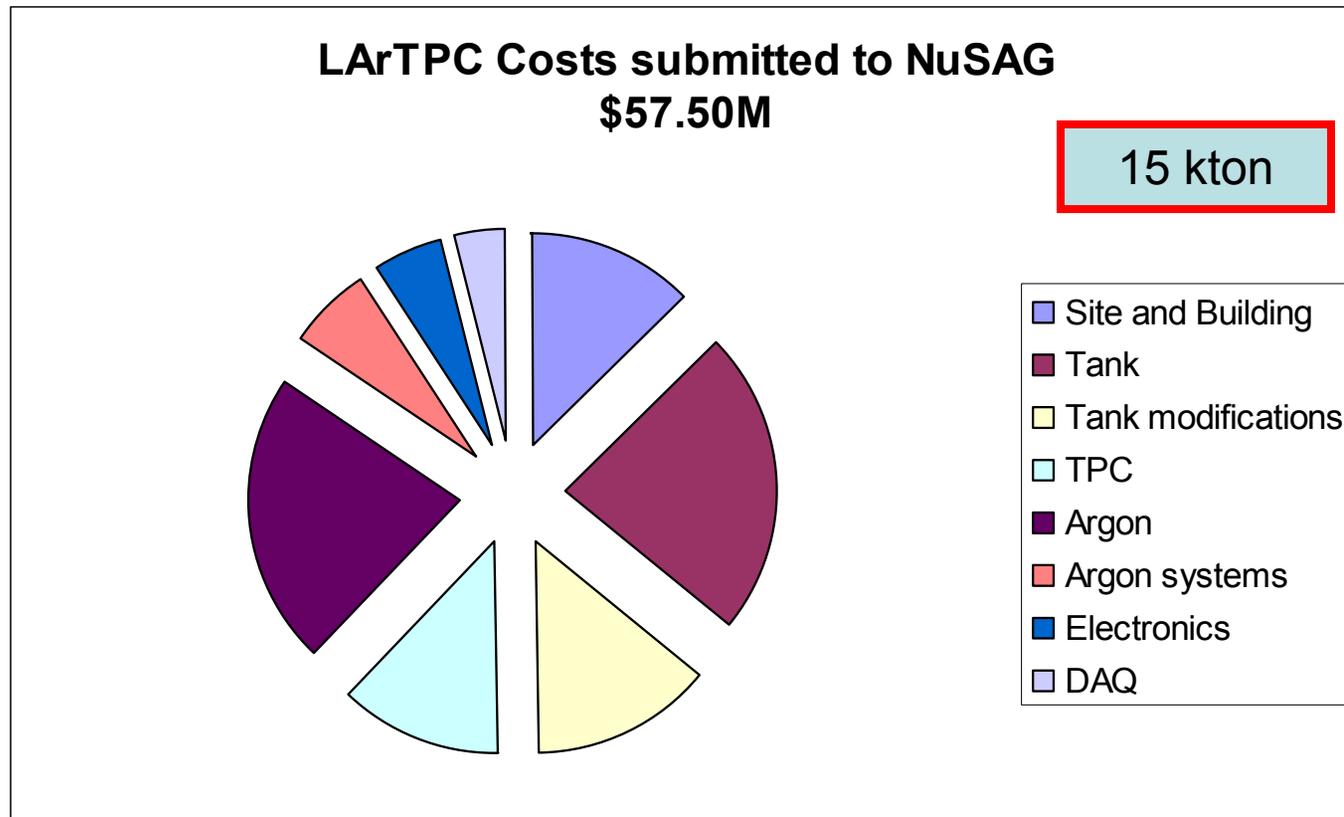
Item (15 kton)	cost (k\$)	comment
Argon	13,000	2004 quote
LAr purifiers	800	Commercial (includes spare)
Tank atmos. purification	500	eng. estimate
LAr Receiving & Transfer	1,500	3 stations
LAr Instrumentation & Controls	250	Commercial Software/Hardware
LN <sub>2</sub> Storage and Pumps	300	includes back-up
LN <sub>2</sub> Instrumentation & Controls	100	Commercial Software/Hardware
Heat Exchangers	100	eng. estimate
<b>Total</b>	<b>16,550</b>	

Table 7.2: Estimate for Cryogenics Material and Systems

Item (15 kton)	cost (k\$)	Comment
Switches & cable	50	Commercial Product
Computers	500	200 PCs
Slow Controls	200	Eng. Estimate
Timing System	100	Eng. Estimate
Data Storage	1200	2 Pbytes <sup>1</sup>
Development Systems	200	Eng. Estimate
<b>Total</b>	<b>2,250</b>	

Table 7.4: Estimate for Data Acquisition

# NuSAG LArTPC Cost Pie



The costs presented in this chapter add up to a total of 57.45 Million dollars. This is a preliminary cost estimate which does not include EDIA or contingency.

# Schedule

- The LArTPC schedule in the NuSAG submission allowed our Director a moment of levity.
  - The DOE approval process was not included.
- The work on the schedule for the (Pen)Ultimate detector is just starting

# Next cost steps (1)

- Methodology and archeology
  - “Include project management” items so that the Directorate can compare LArTPC costs to other DOE-costed competitors for the funds.
  - “Get ICARUS costs directly from INFN”
    - so we can benefit from their experience
    - and relate “Italian cost accounting” to “DOE cost accounting”
    - so one can better specify what NuSAG meant by “about an order of magnitude” less
- What does “cost” mean? It means:
  - DOE defensible

## Next cost steps (2)

- **Some informative specific design choices**
  - 3 kton ... three 15 kton ... 30 ktons ... 50 kton ... 100 ktons ...
    - what else? ...
    - and what experiments drive these choices?

# A sampling of LArTPC R&D paths

- **Big Tank R&D (see next slides)**
  - Purity Test Station to qualify materials for big tank
  - Achieving required argon purity without vacuum and clean room techniques
- **Cellular TPC design (see next slides)**
- **Cold electronics (see next slides)**
  - Allows one to use shorter wires
  - Costs money
- **D > H Tanks (like GLACIER)**
  - Allows use of shorter wires
  - Less efficient use of argon, more electronic channels needed
- **Design Against Cosmic Rays**
  - Go underground!
  - Use plane spacing less than 3 meters, use shorter wires (see above)
  - Is this really an issue, or just a worry?

# LArTPC: Purity Test Station

## Setup at PAB (Proton Assembly Building) at Fermilab

A test station to study (a) the contamination of LAr by various materials and (b) the efficacy of various 'filters' for the removal of oxygen (and other electronegative species)



In May 2006, we achieved a purity which scales to a 3 meter drift with a 20% loss of electrons, meeting our goal for electron lifetime.

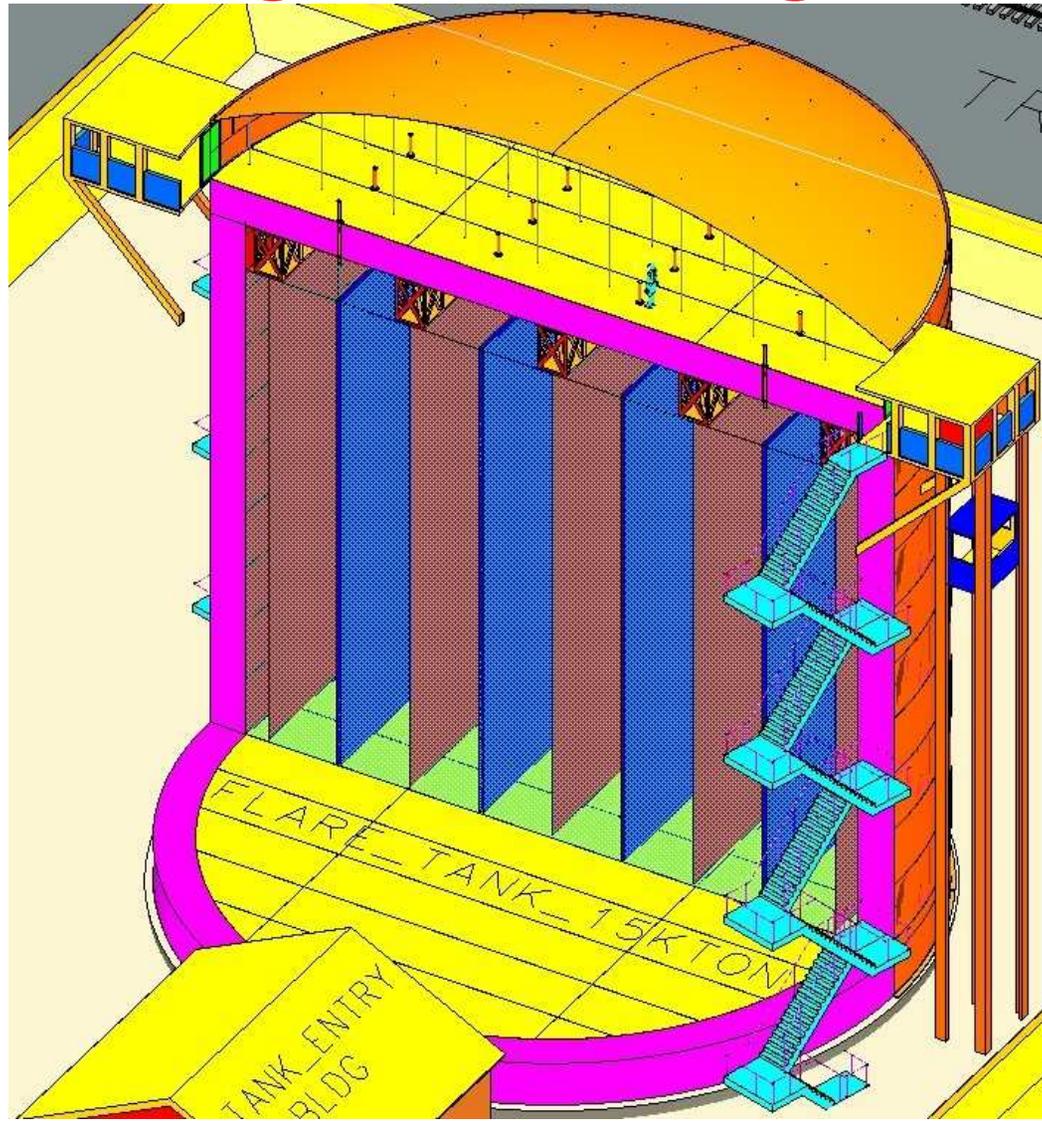
Mostly recycled equipment

# LArTPC: Purging a “big” tank

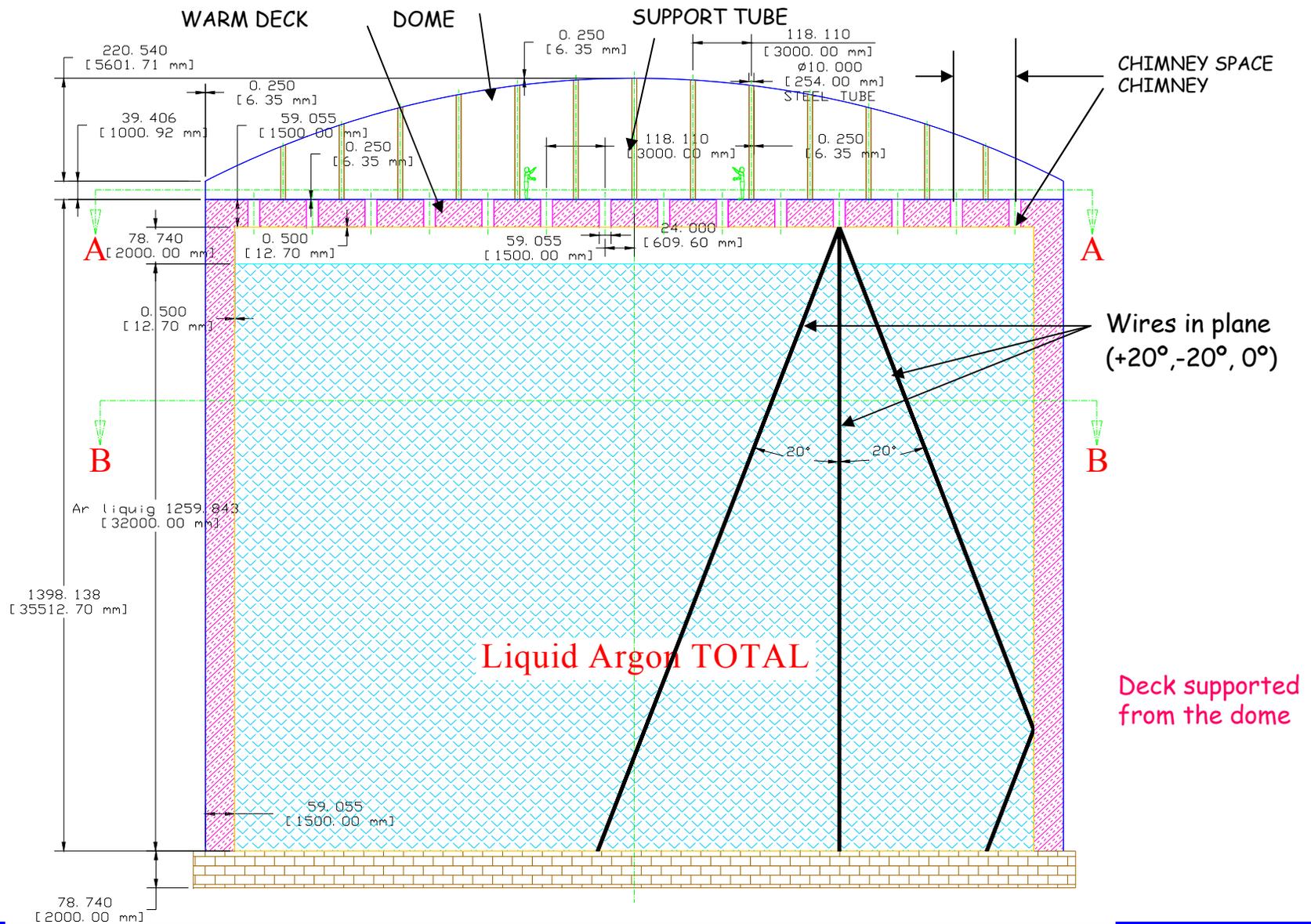
- The “Village water tank” has a volume the same as  $\sim 1,000$  tons of liquid argon ( $1.40 \text{ g/cm}^3$ ).
- It was part of the village of Weston.
- The intention is to use it to challenge models of purging tanks with a “piston” of argon gas.



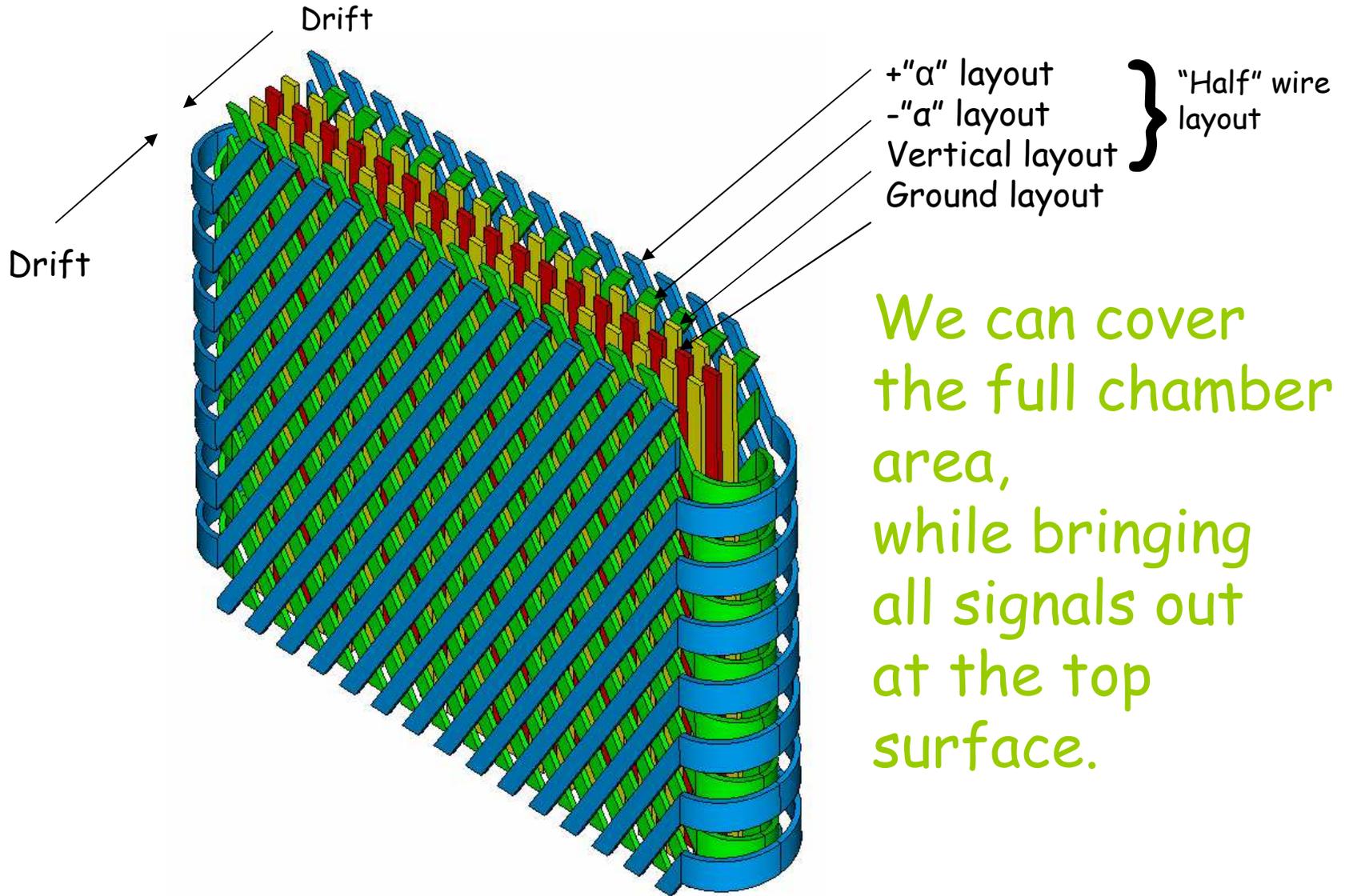
# Large Tank Design



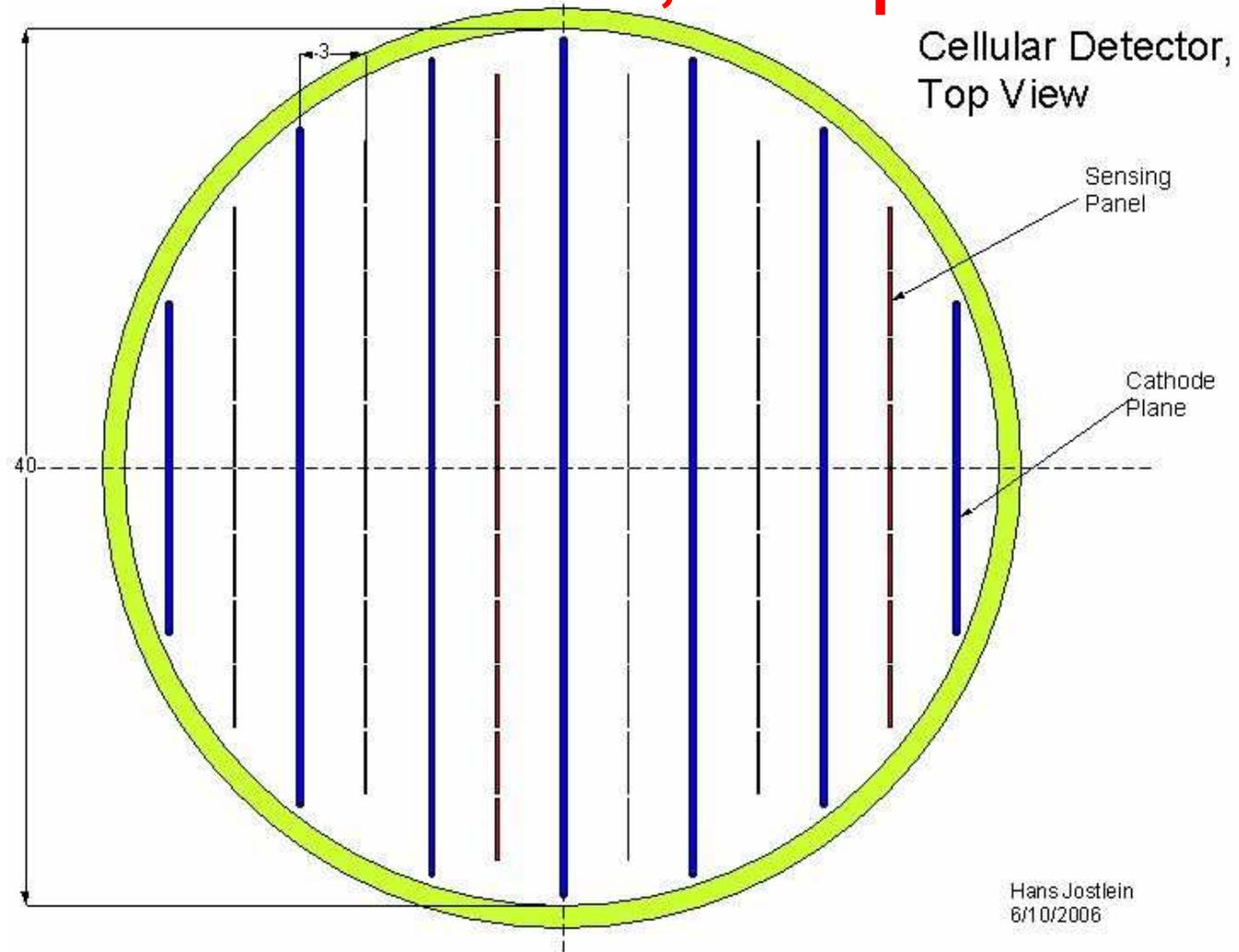
# LArTPC 50KT (wire plane section)



# A Clever Wire Layout



# Cellular Detector, Top View



# Cellular TPC design

- Cellular TPC design
  - Allows construction of TPC modules away from detector location
  - Allows for construction of much of TPC in parallel with tank construction
  - Still requires assembly of the cells into the TPC at the site, of course
  - And may or may not cost more to the project

# Cold Preamplifiers for the next LArTPC?\*

- Signal to noise (S/N) is a major challenge for a large LArTPC.
- Preamps in the cryostat promise significant improvements in S/N
- For **cold preamps** in the **next large LArTPC**, R&D must start soon !
- A few of the R&D issues:
  - Address Argon contamination by design and testing of hermetic seals, and tests of individual components (for additional insurance)
  - Investigate compromises between cost and complexity of high density packaging for LArTPC wire pitch/plane spacing = 5 mm/5 mm
  - Find practical limit of increased power dissipation to yield lower S/N
  - Design specific preamplifier mounting, wire mechanical fixtures and electrical connections
  - Find and test solutions for distribution of power, bias voltage, and test pulses, and routing of output signal cables to feed-through ports
  - Invent a way to perform tests before closing the cryostat
- In general, establish confidence that cold preamps will be successful

\*Slide Provided by Carl Bromberg, MSU

## Building confidence in cold preamps\*

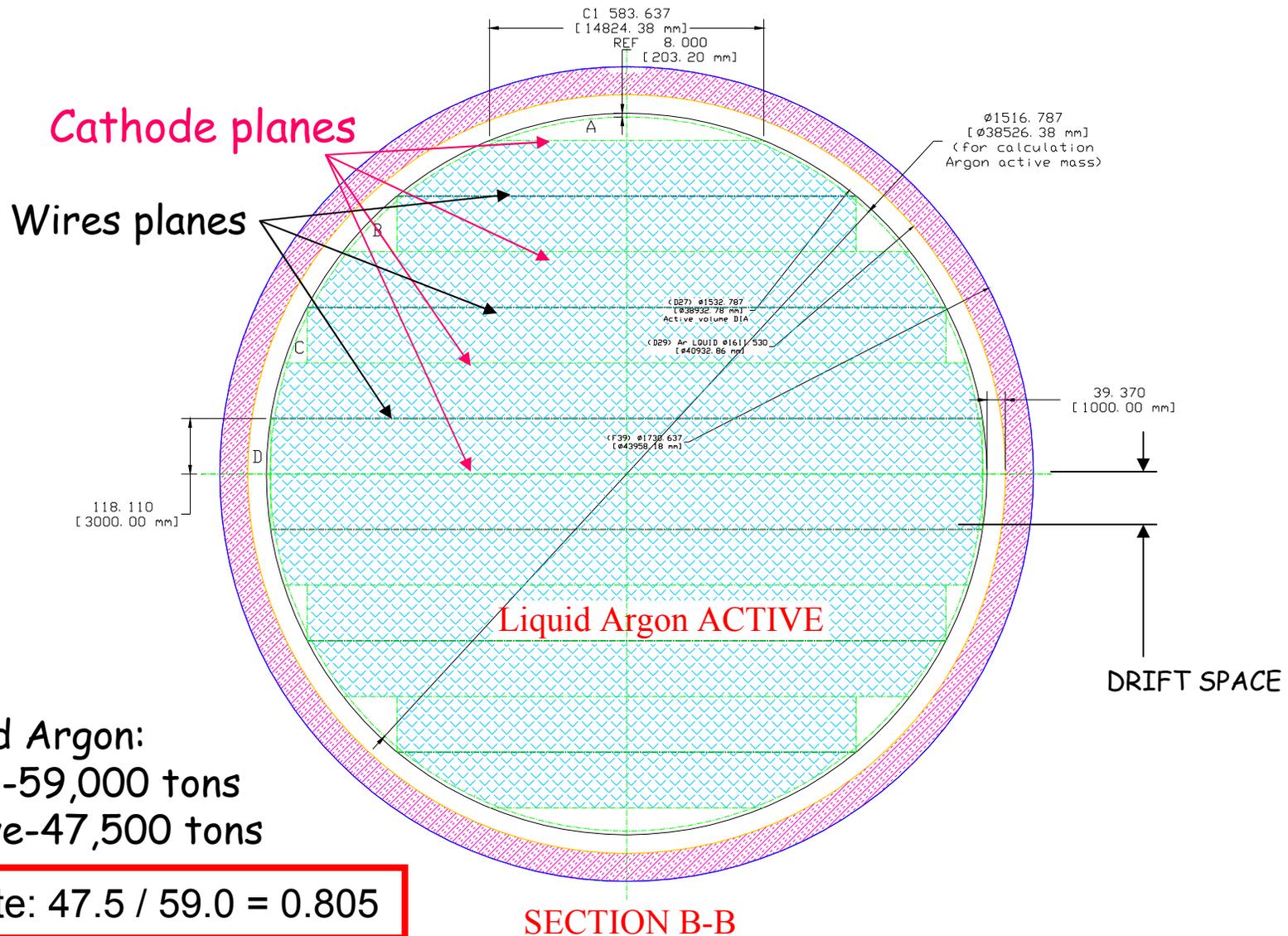
- Cold preamps used in ATLAS (LAr endcap hadronic calorimeter, and purity monitors), NA48 (LKr calorimeter), and considered for others. Obvious differences in freq. response, S/N, purity requirements
- Some University electronics groups (e.g., MSU) have cold preamp expertise from work for IR Astronomy and CMP experiments
- Commercial resources exist:
  - [www.extremetemperatureelectronics.com](http://www.extremetemperatureelectronics.com) (consulting engineers)
  - [www.cryocircuits.com](http://www.cryocircuits.com) , [www.cryoconnect.com](http://www.cryoconnect.com) (companies doing cold electronics)
- Need to design, build and test a few hundred channels of cold preamps and obtain a defensible cost estimate
- A **LArTPC test facility** is being constructed at Fermilab. It will be commissioned with a few hundred channels of warm electronics with tests of cold preamps to follow
- Acceptance of cold preamps must precede final design of LArTPC refrigeration, signal/power ports, cable choice, wire planes, etc.
- Very large LArTPC (50 kT) may not be possible without cold preamps

\*Slide Provided by Carl Bromberg, MSU

# What about “many, small” tanks?

- Is it not obvious that there are added costs for the “many small” approach?
- Yes ... (see next slides) ... but
  - How much is not used efficiently and
  - What does the increased cost buy?

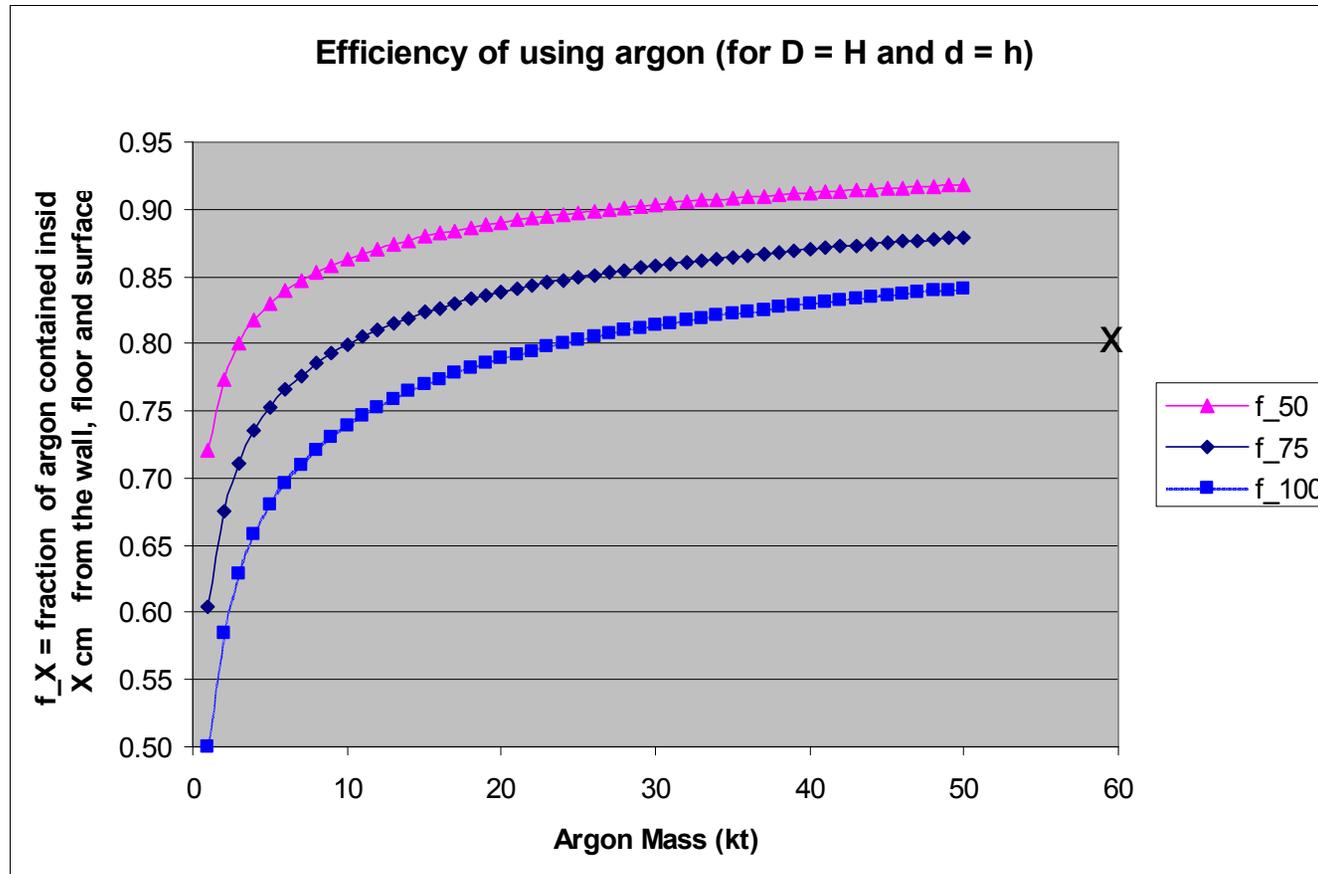
# LArTPC 50KT. (section B-B)



Liquid Argon:  
 Total-59,000 tons  
 Active-47,500 tons

Note:  $47.5 / 59.0 = 0.805$

# Fraction left after removing $d = h$



$$\text{fraction} = [1 - 2d/D]^3$$

Note: X marks  $47.5 / 59.0 = 0.805$

# “Many, Smaller” Tanks

- What does the increased cost buy?
  - Reduction in risk by having **shorter wires** ... but how short is short enough?
  - “Obvious” **control of systematics** ... but how well does a single large detector need to control systematics and how does it control systematics?
  - Allows for **staging** of data taking ... and reducing technical risks by proving / improving the capability of the prototype
  - **Reduces catastrophic risks** by not having all the “eggs in one basket” (i.e., the one TPC in one Tank).

# Summary

- **LArTPC Detector Designs and Costing**
  - Ultimate ... Penultimate ... on going R&D
- **Reasons for the Penultimate Detector:**
  - Physics case(s) for Penultimate and Ultimate Detectors
  - Demonstrate scaling of costs and technology to Ultimate Detector
  - Development of international collaboration and funding sources required for Ultimate Detector
- **LArTPC group is in an R&D stage**

# Backup

## (6) Study of large underground storage tank

	Project: Large <b>Underground</b> Argon Storage Tank
Issued By: JMH	Document Title
Date:	

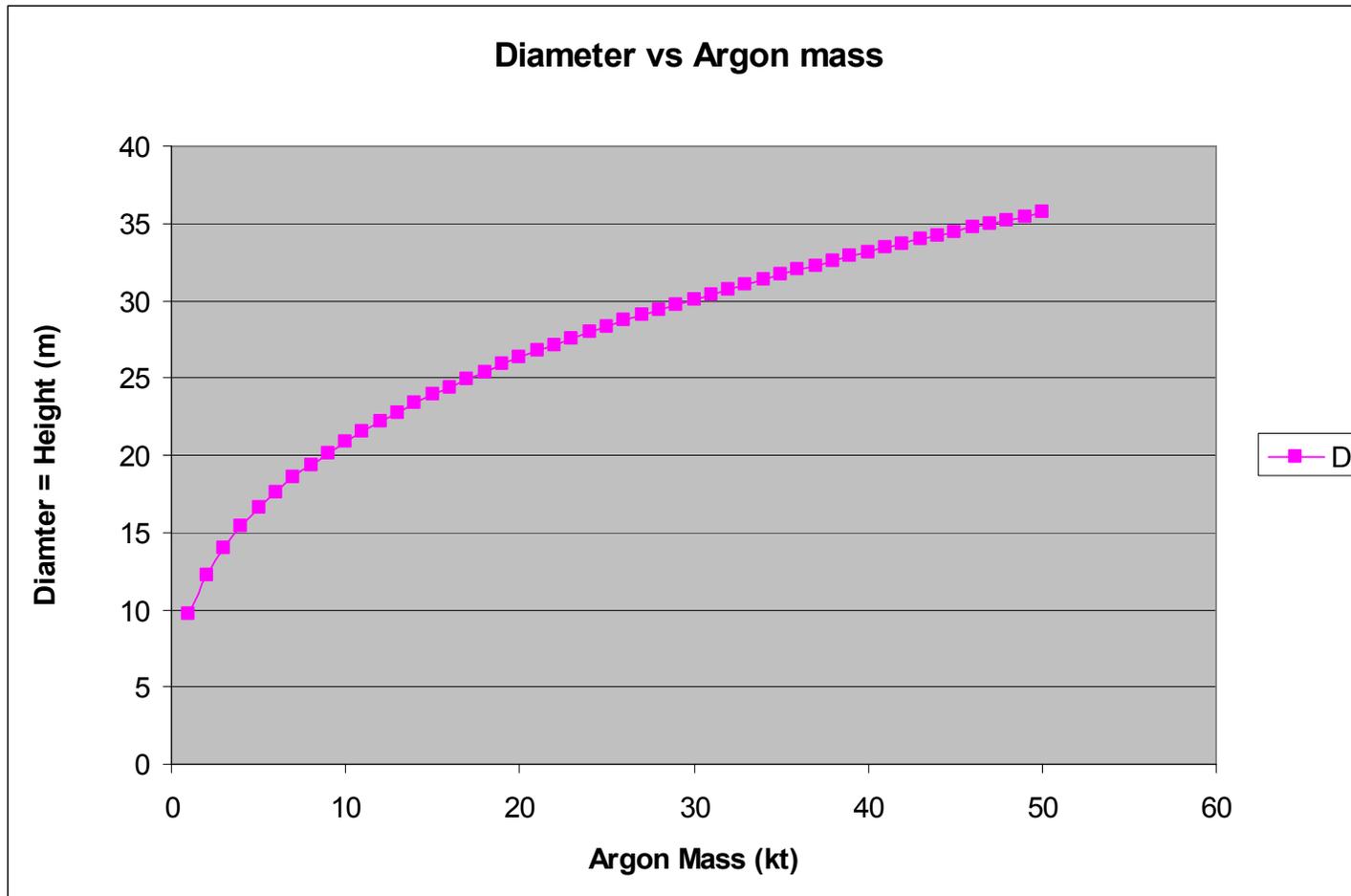
*A feasibility study mandated to Technodyne Ltd (UK)*

Study duration:  
February - December 2004  
Funded by ETHZ

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**International Neutrino Factory And Superbeam Scoping Study Meeting, CERN - 22-24 September 2005**

# Diameter (= Height) vs. Argon Mass



# Liquid Argon TPC Overview for NuSAG

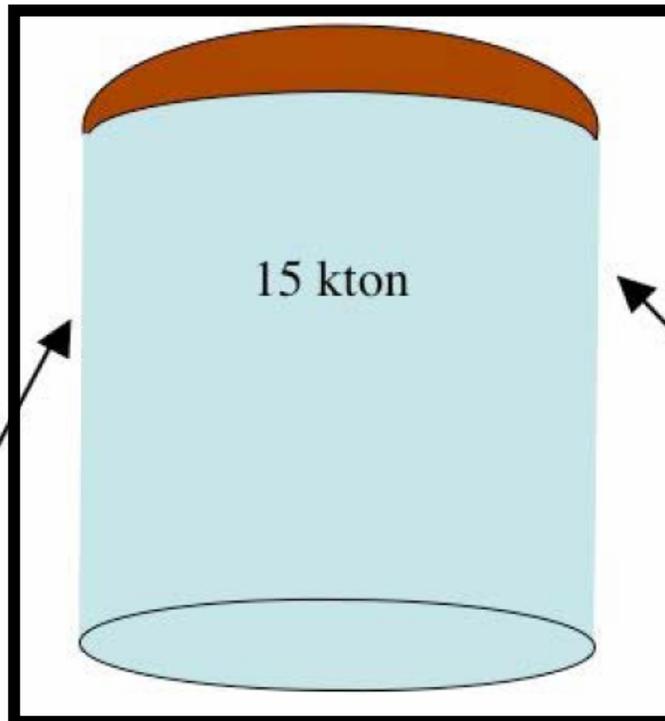
Note: At this point in time ...

"15" could be "50"

"1" could be "3"

etc

The optimum choices depend on the goals.



Submitted to NuSAG

Summer 2005

Fermilab plus 6 universities



*Physics Development using existing technology*

Record complete neutrino interactions: ( $\nu_e$  &  $\nu_\mu$ )

Establish **Physics Collaboration**

Develop **Event Identification**,

Develop **Reconstruction**,

Develop **Analysis**,

Establish successful **Technology transfer**

*Engineering Development:*

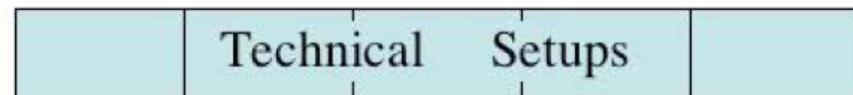
Construction of Tank

Argon Purity

Mechanical Integrity of TPC

Readout S/N

Microphonics due to Argon Flow



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