LArTPC Design and Cost Considerations

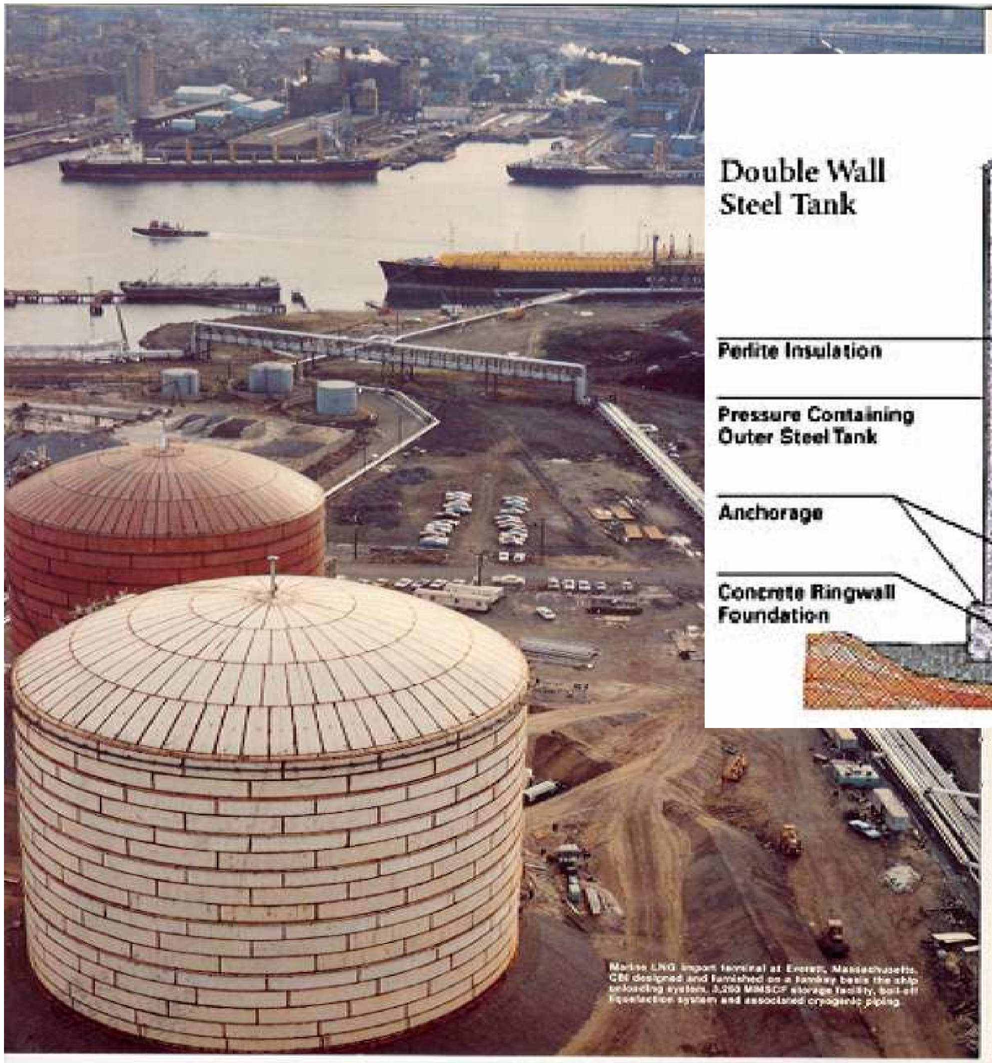
- Ultimate Step and Penultimate Step
- LArTPC Costing Methodology
- Ongoing LArTPC R&D
- Summary

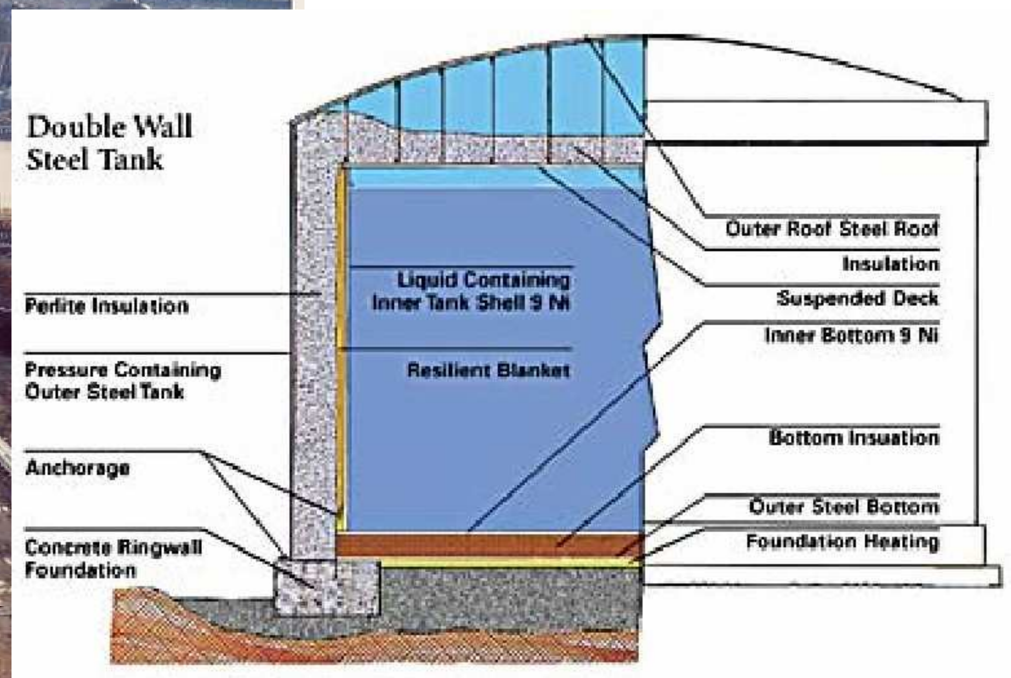
The Ultimate Neutrino Detector

Adam Para, Fermilab

Experimental Seminar,
SLAC,
March 28, 2006

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



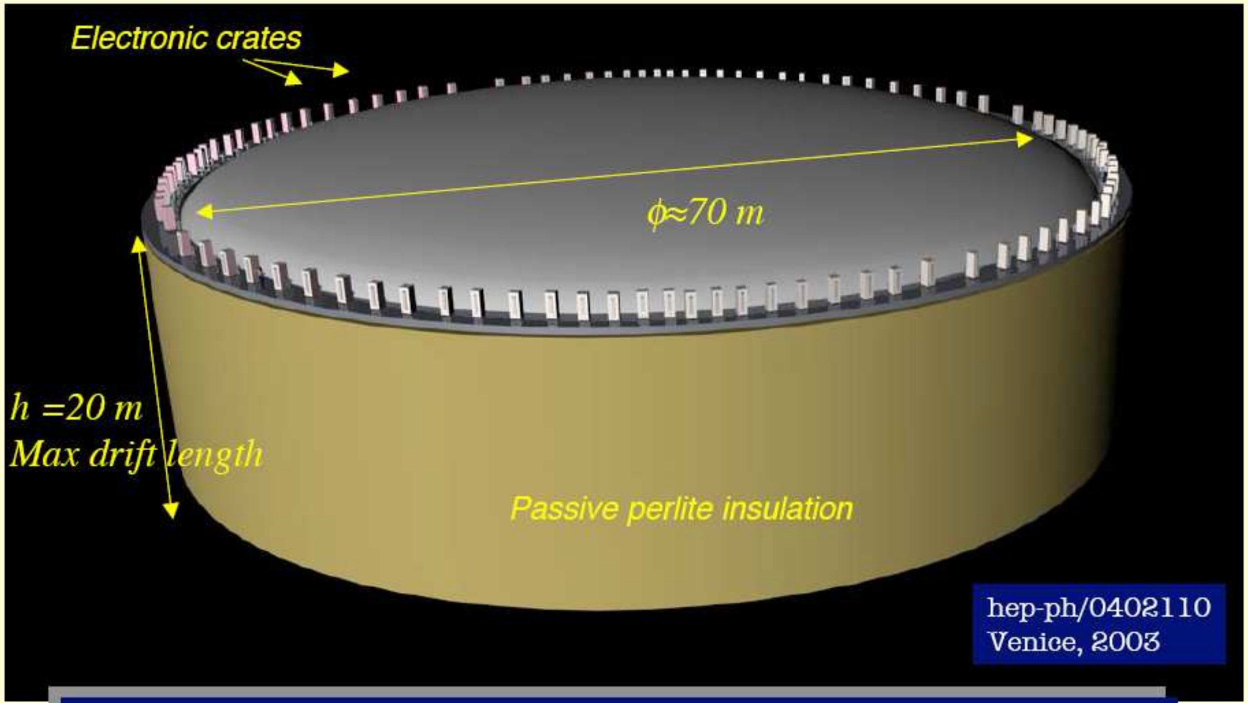


Many large LNG tanks in service. excellent safety record

André Rubbia (ETH Zürich)

http://neutrino.ethz.ch/GLACIER/

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 ν, p-decay, atm ν, …)

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 ? (~1mrad 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.)

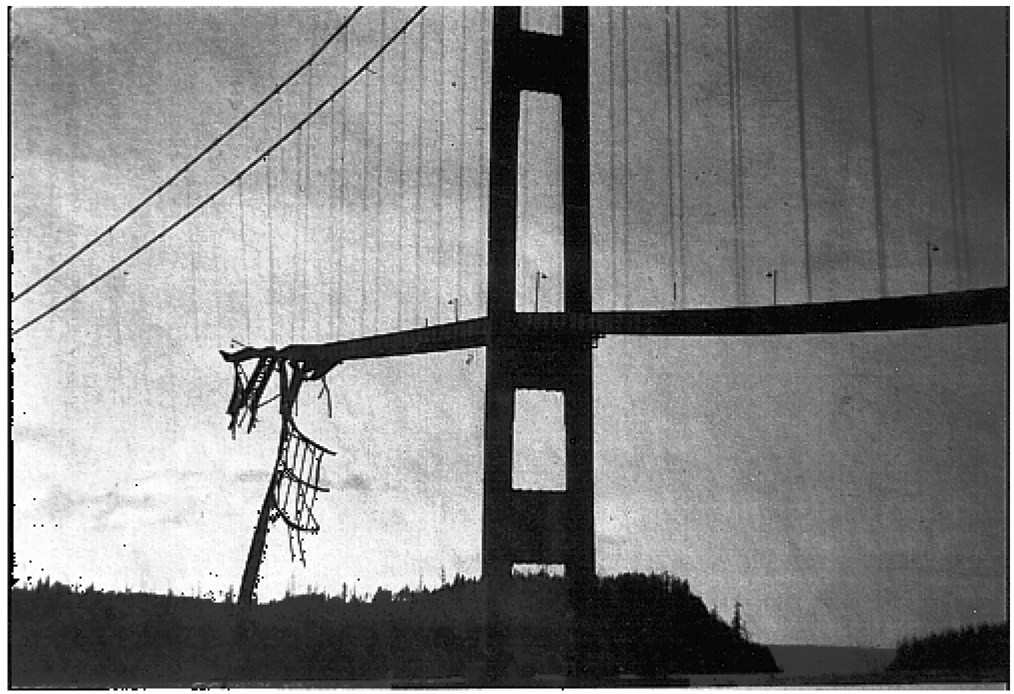
History: What has been done?

- 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

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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
Total	**35,600**	

Table 7.1: Estimate for Mechanical Infrastructure

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_2 Storage and Pumps	300	includes back-up
LN_2 Instrumentation & Controls	100	Commercial Software/Hardware
Heat Exchangers	100	eng. estimate
Total	**16,550**	

Table 7.2: Estimate for Cryogenics Material and Systems

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	
Total	**3,100**	

Table 7.3: Estimate for Electronics

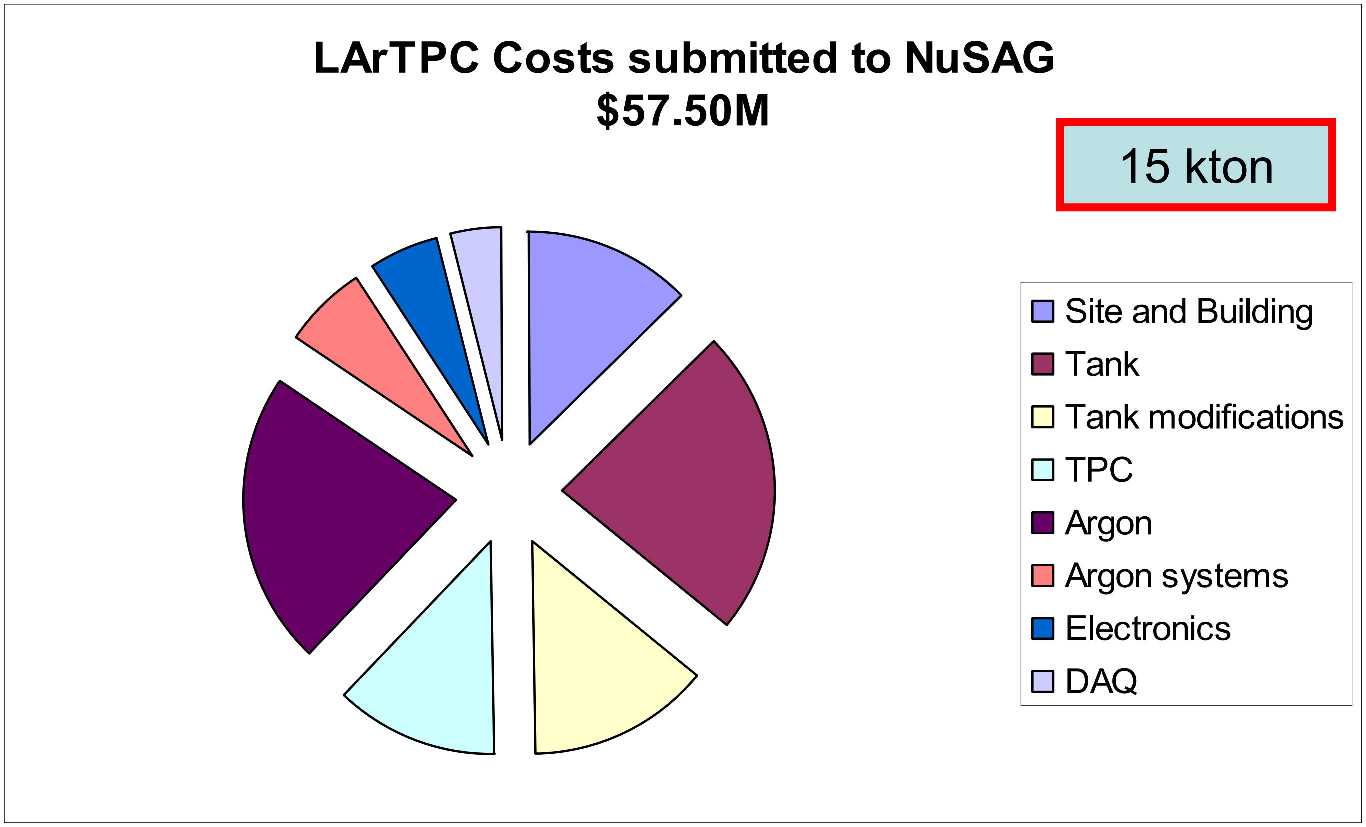
Item (15 kton)	cost (k$)	Comment
Switches & cable	50	Commercial Product
Computers	500	200 PCs
Slow Controls	200	Eng. Estimate
Timing System	100	Eng. Estimate
Data Storage	1200	2 Pbytes[1]
Development Systems	200	Eng. Estimate
Total	**2,250**	

Table 7.4: Estimate for Data Acquisition

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.

NuSAG LArTPC Cost Pie



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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 ~1,000 tons of liquid argon (1.40 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.

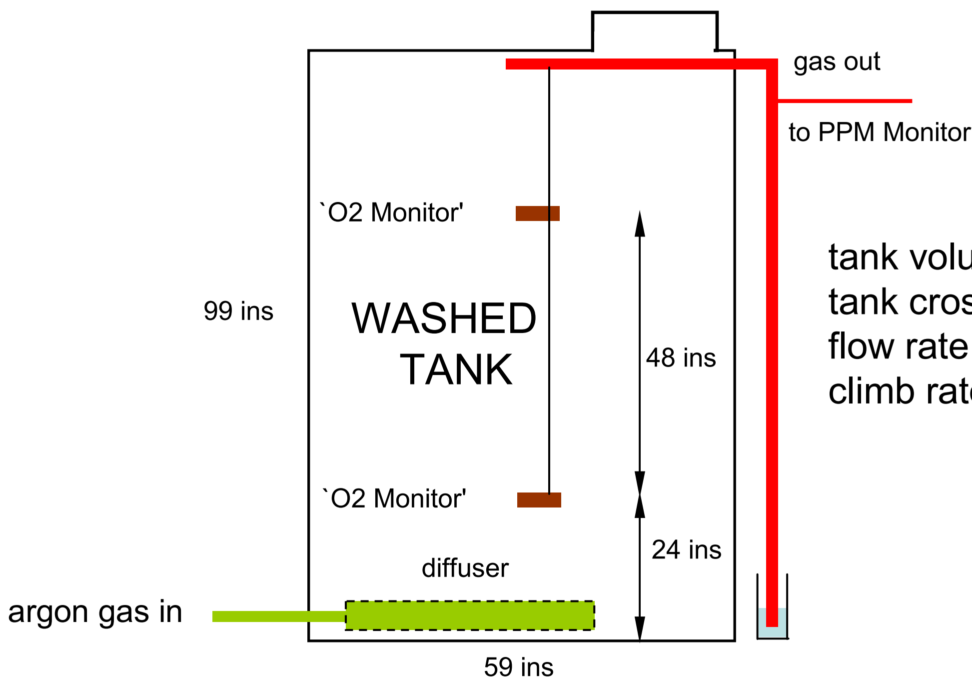
LArTPC: Purging a tiny tank

Test of purging a volume from atmosphere:

insert Argon gas at bottom of tank over large area at low velocity;

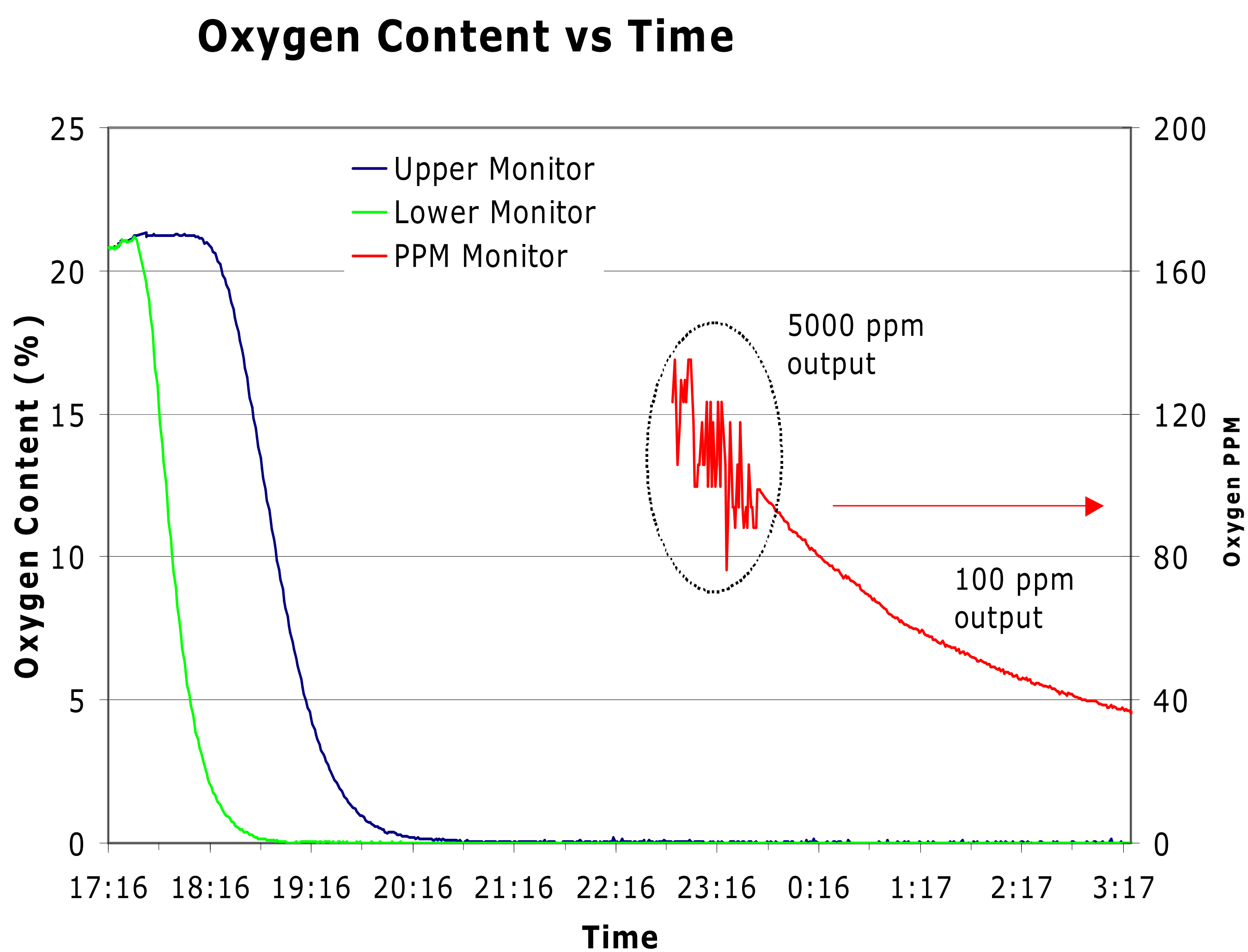
the Argon introduced being heavier than air will act as a piston and drive the air out of the tank at the top;

fewer volume changes than simple mixing model will achieve a given reduction in air concentration.



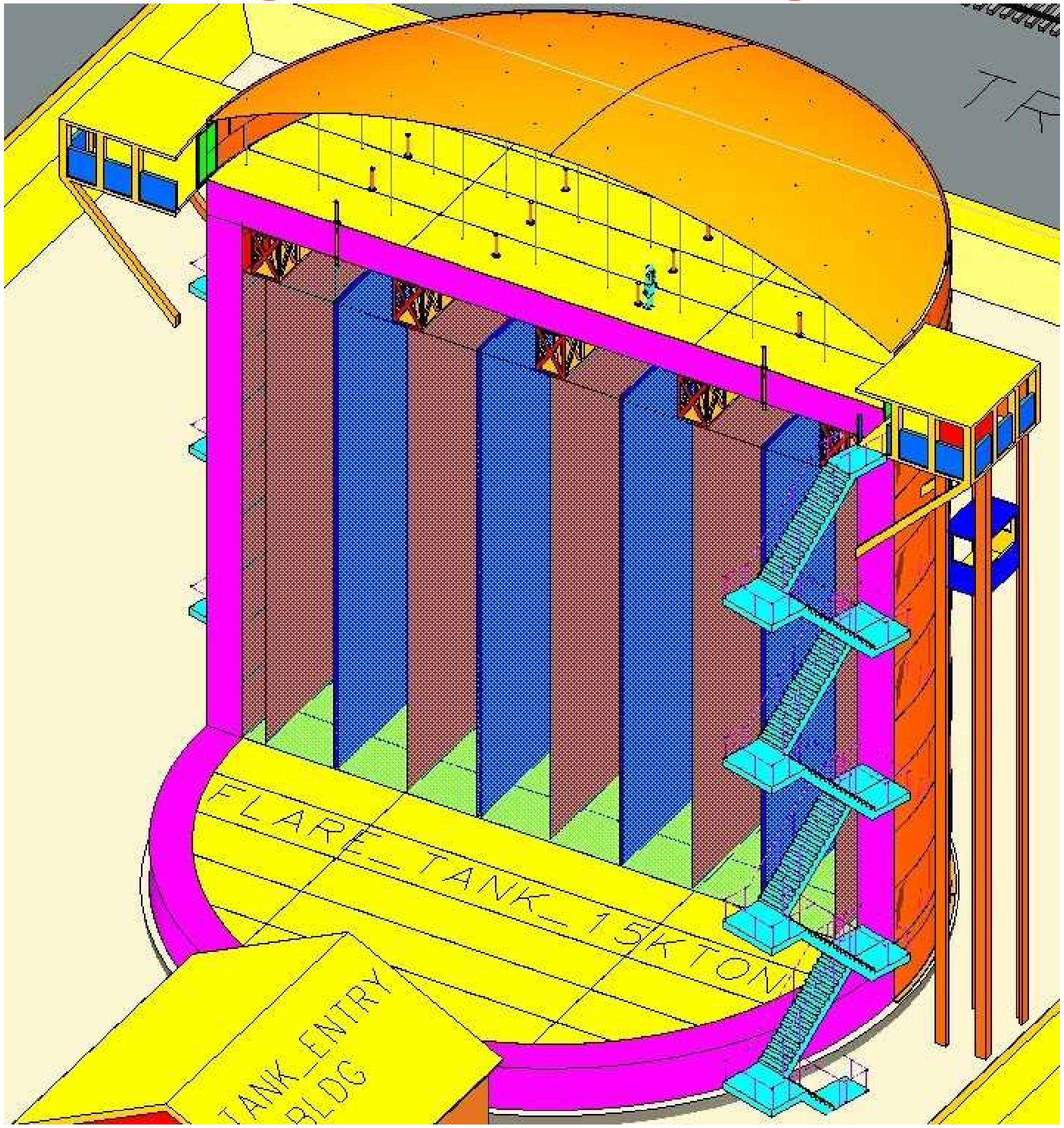
tank volume = 157 cf
tank cross section = 19 sf
flow rate ~ 73.2 cf/h (reading for air was 86 scfh)
climb rate ~ 3.8 f/h


COLTS
XXI
FOOTBALL

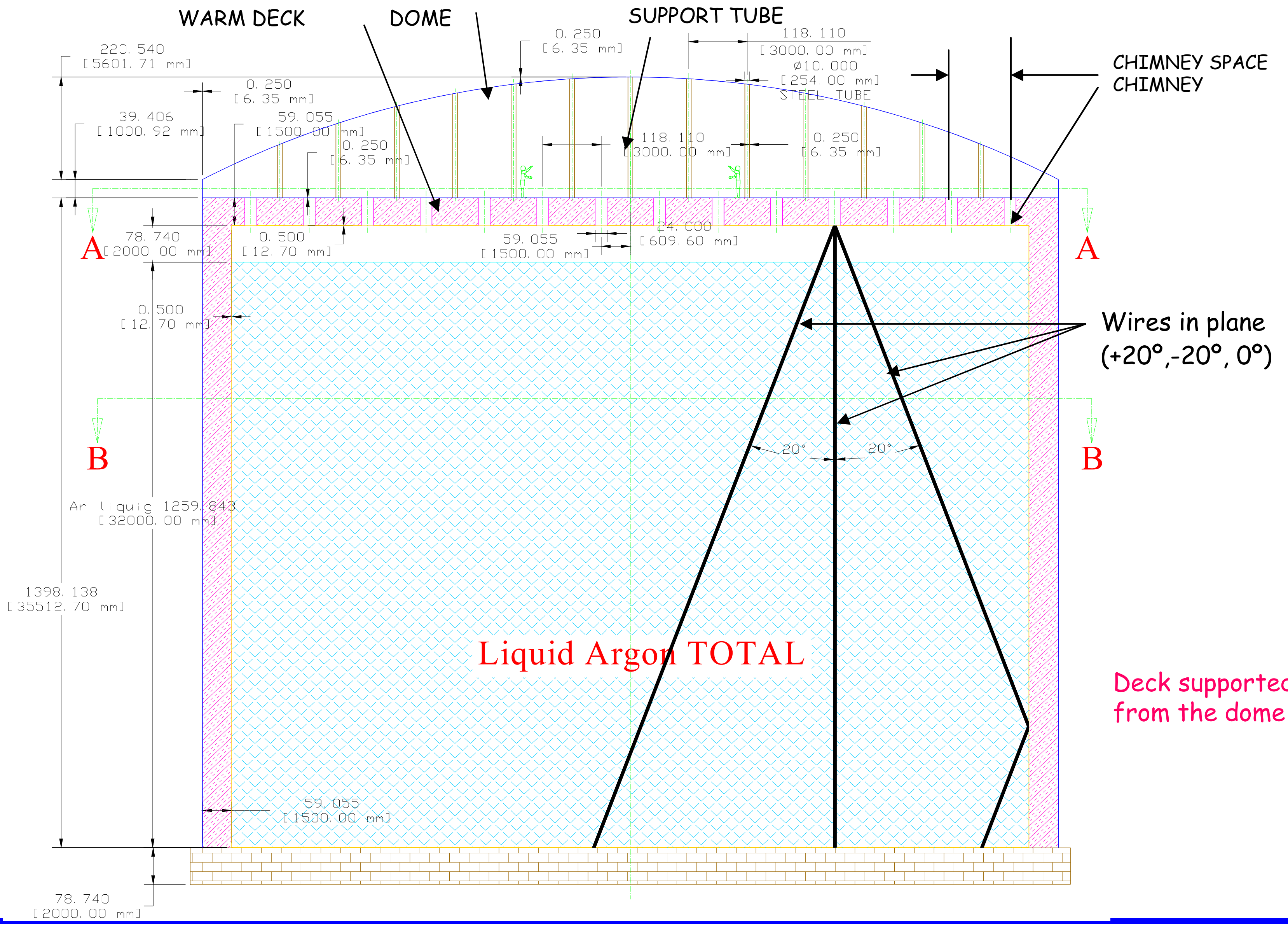


to 100 ppm (reduction of 2,000) takes 6 hrs = 2.6 volume changes
(cf simple mixing, which predicts ln(2000) = 7.6 volume changes)

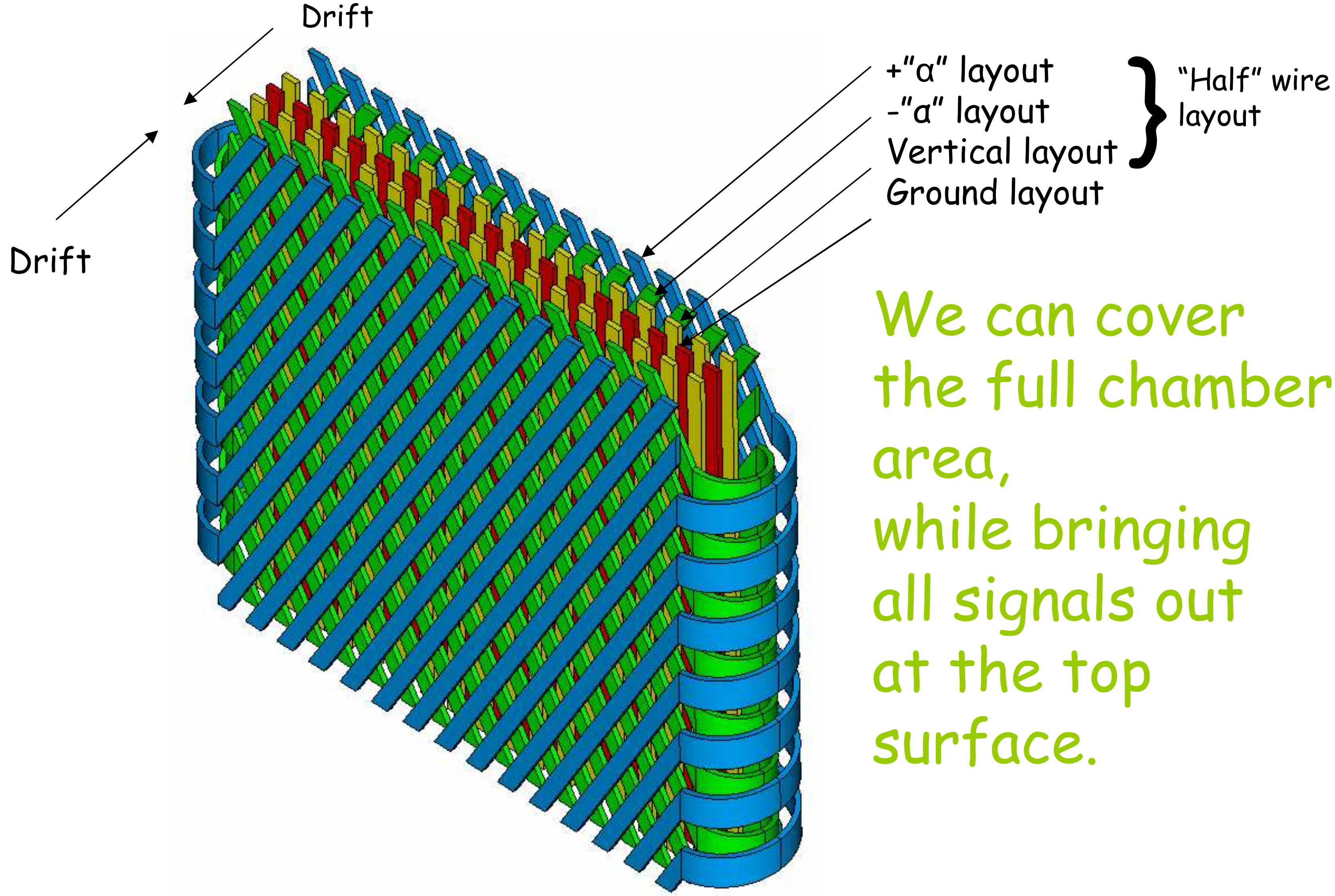
Large Tank Design



LArTPC 50KT (wire plane section)



A Clever Wire Layout

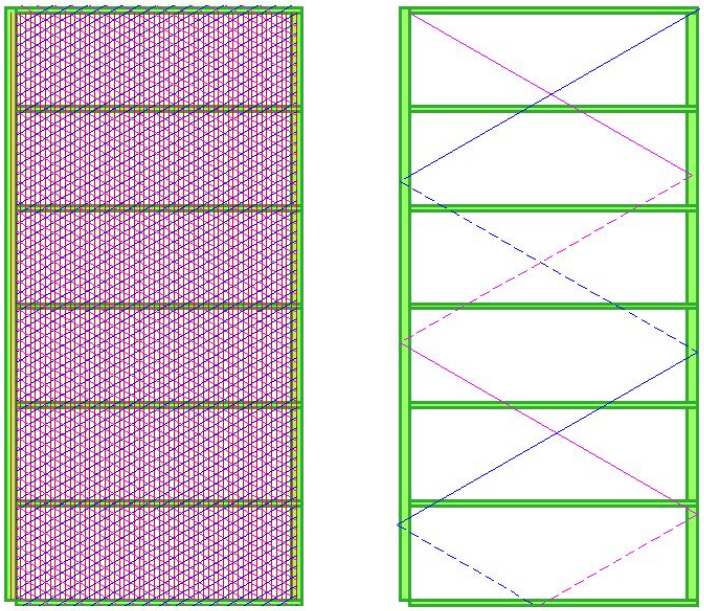


We can cover the full chamber area, while bringing all signals out at the top surface.

Cellular Concept

Many wires displayed

Only two wires displayed



3 meters wide

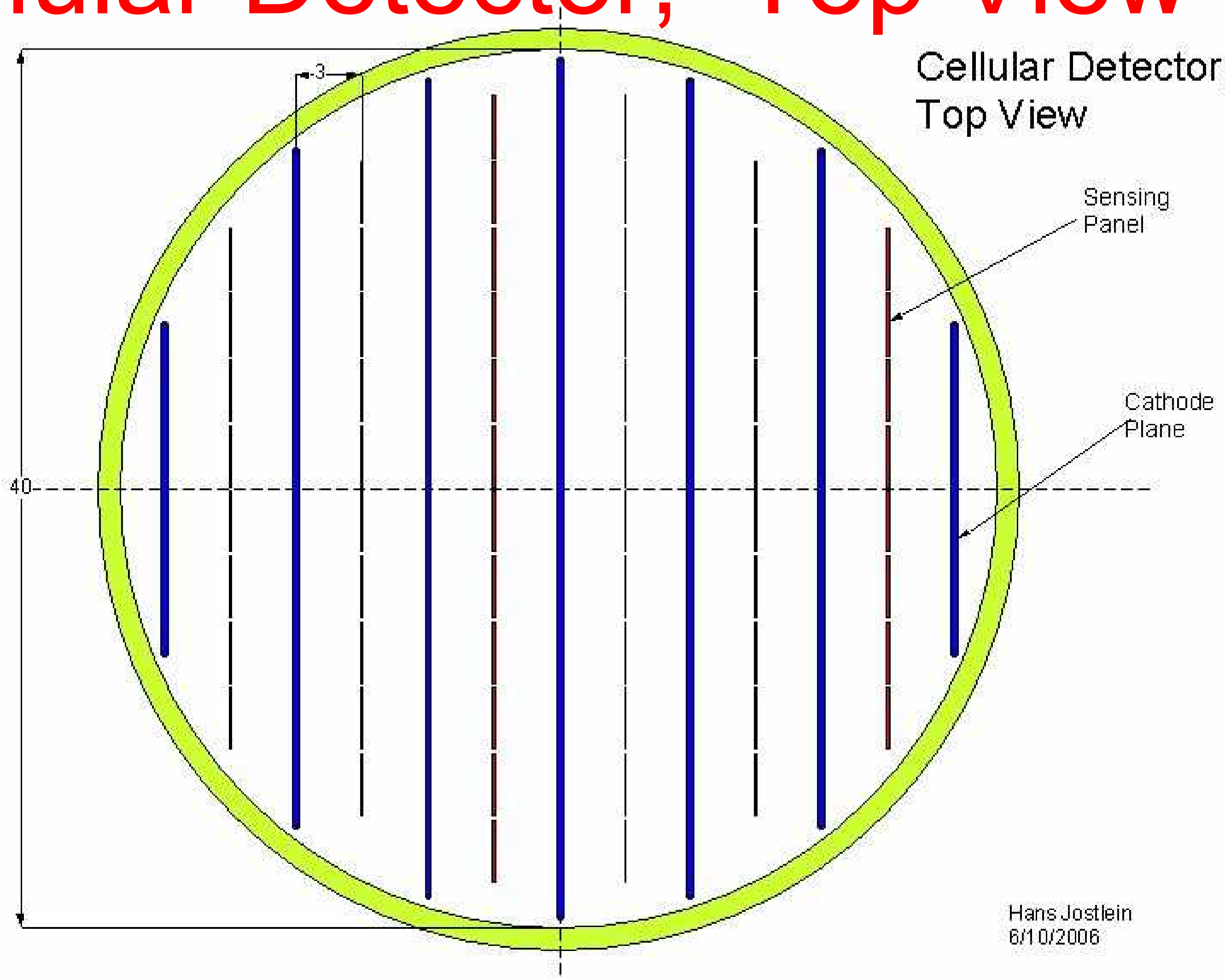
+- 60 degree

Solid lines on this side,

Dotted lines on the other side

Hans Jostlein 6/27/06

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 the major challenge for a LArTPC
- S/N improved by cold preamps in the cryostat.
- Cold preamp R&D must start soon !
  - Decision to use must precede design of LArTPC components
  - Argon purity: hermetic seals & component testing
  - Highest practical preamp packaging density to reduce costs
  - Highest practical power dissipation to lower S/N
  - Secure mounting and reliable electrical connections
  - Power, bias voltage, and test pulse distribution
  - Output signal cable routing
  - Testing in-situ before closing the cryostat
- In general, establish confidence in cold preamps

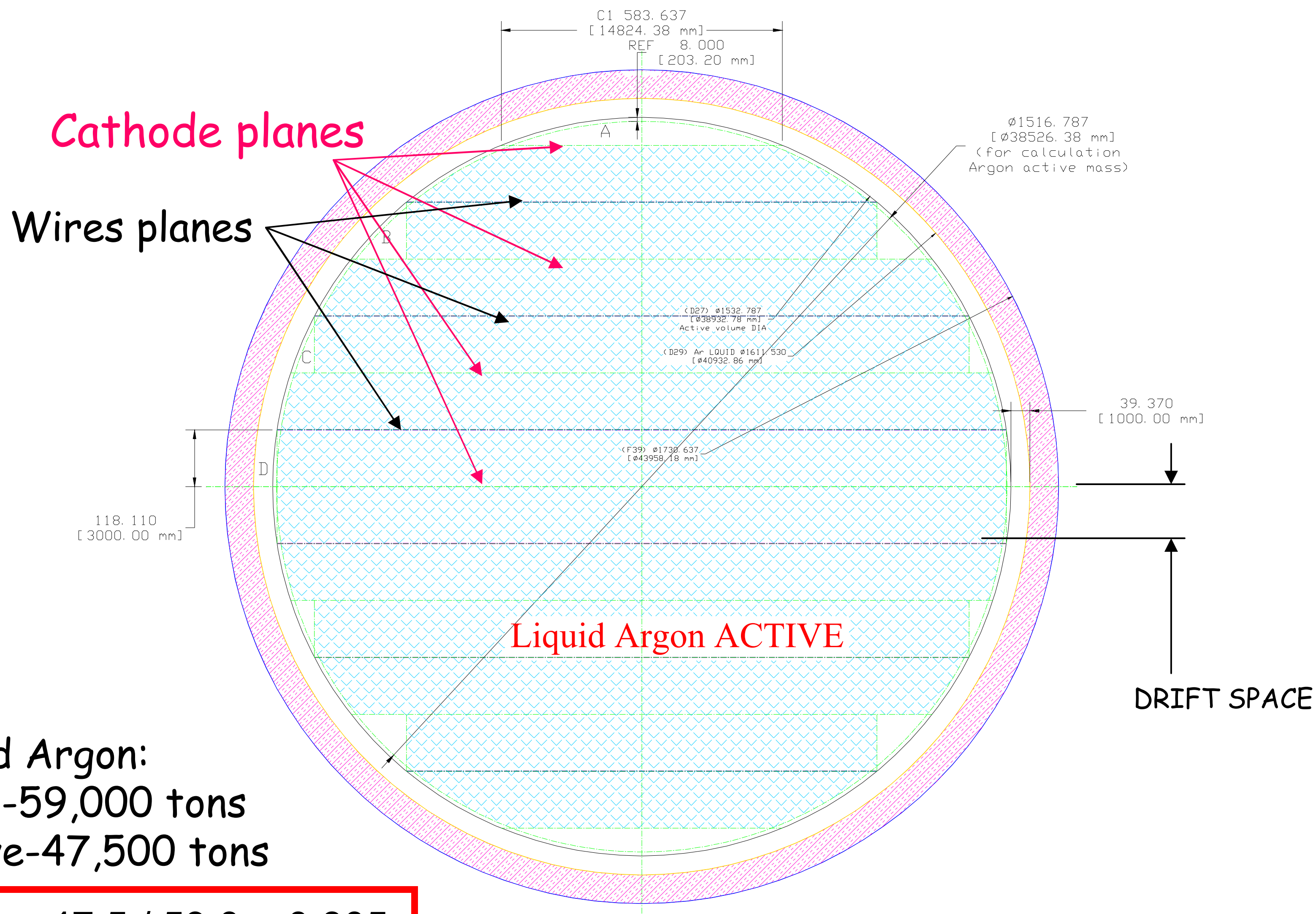
Building confidence in cold preamps

- HEP use of cold preamps
  - ATLAS (LAr hadronic endcap calorimeter, and purity monitors)
  - NA48 (LKr calorimeter)
  - but LArTPC has different freq. response, S/N, purity demands
- University expertise from IR Astronomy and CMP experiments
- Commercial resources exist
  - www.extremetemperatureelectronics.com (consulting engineers)
  - www.cryocircuits.com , www.cryoconnect.com (companies doing cold electronics)
- A LArTPC test facility being built at Fermilab
  - Commission with a few hundred channels of warm electronics
  - Build and test a few hundred channels of cold preamps
  - Obtain a defensible cold preamp cost estimate
- Note: 50 kT LArTPC may not be possible without cold preamps
- Time to start development is NOW.

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)

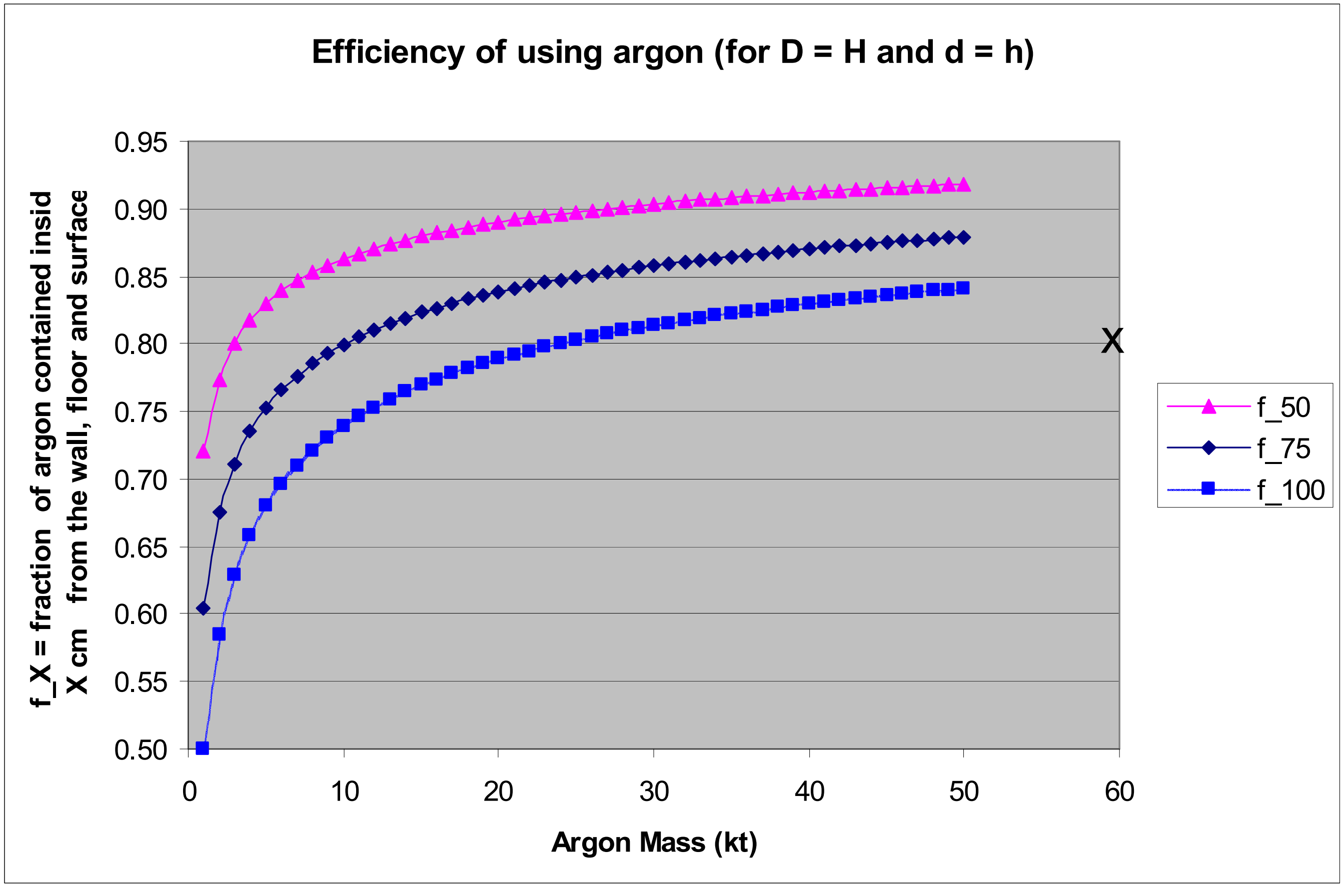


SECTION B-B

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

Note: 47.5 / 59.0 = 0.805

Fraction left after removing d = h



fraction = $[1 - 2 d / D]^3$

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

Issued By: JMH	Project: Large Underground Argon Storage Tank
	Document Title
Date:	

A feasibility study mandated to Technodyne LtD (UK)

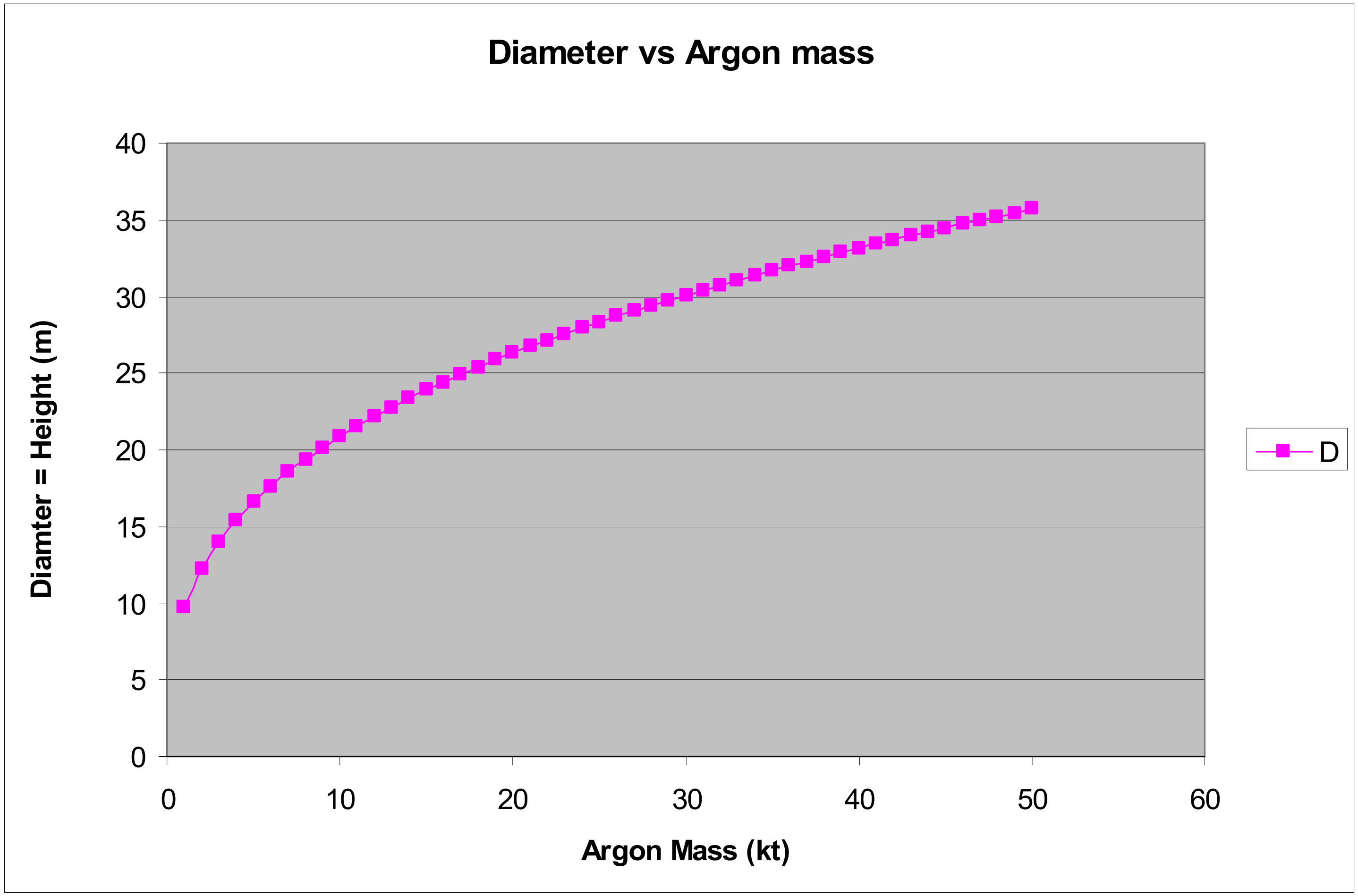
Study duration:

February - December 2004

Funded by ETHZ

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