LAr1-ND Cryostat and Cryogenics

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Outline

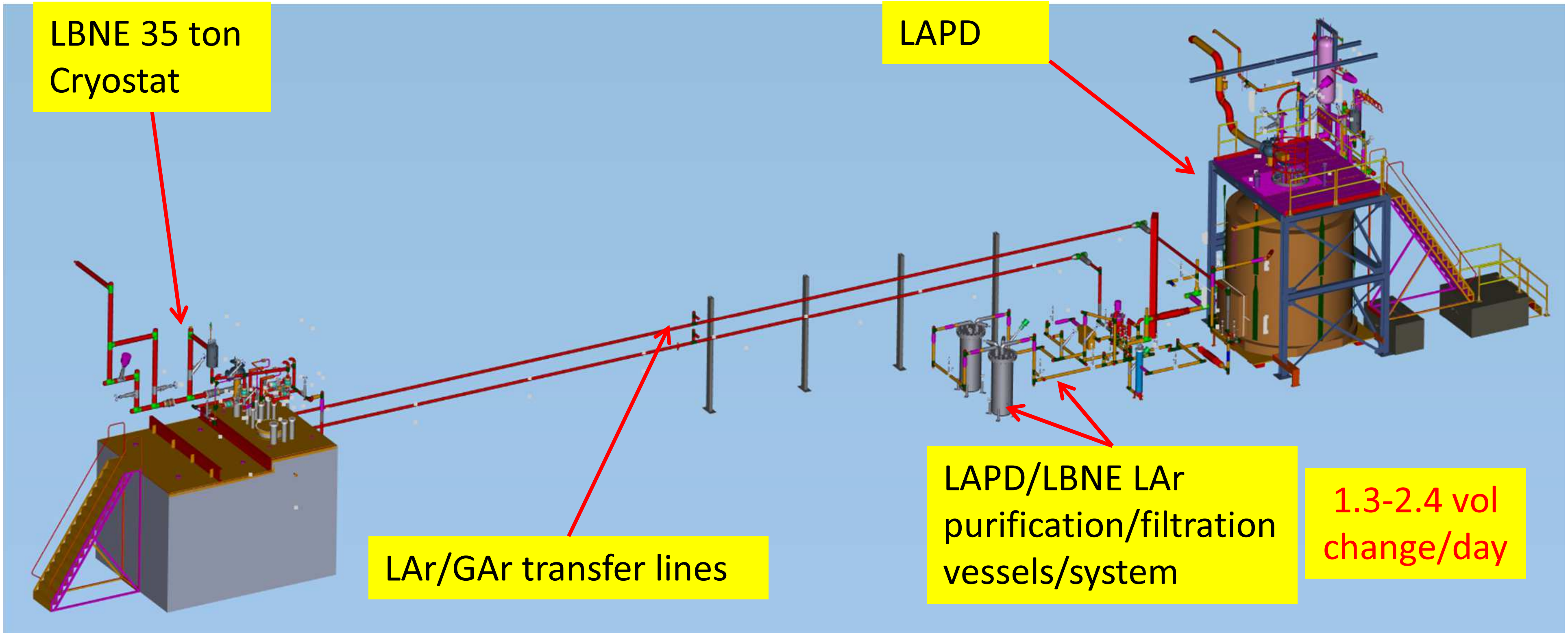
- Introduction
- Cryostat
- Cryogenic System
- Outstanding issues
- Summary

Introduction

- The Short-Baseline Neutrino Program (SBN) at Fermilab will study neutrino properties using a combination of detectors:
  - existing MicroBooNE
  - new LAr1-ND (Near Detector)
  - a refurbished ICARUS T600 (Far Detector)
- These slides described the current thoughts on the cryostat and cryogenic system for the LAr1-ND detector.
- The base design is a membrane cryostat of 129 m^3 (LAr volume) or 180 ton LAr Mass.
- The cryostat will be housed in a new dedicated building next to the SciBooNE enclosure, where the cryogenic system will be located. The two buildings will be connected with a tunnel through which interconnecting lines will connect the cryostat to the cryogenic system.
- It may be possible to increase the sensitivity by increasing the LAr volume. We have looked into extending the width to 7.9 m (from 4.4) , that is 231 m^3, or 80% more than the original one of 129 m^3.

Layout for LAr1-ND Similar to 35 Ton

(Imagine LAr1-ND as Experiment Connected to Purification/Filtration)



- This is the 3D model of PC-4 with the LBNE 35 ton and LAPD.
- We plan to do the same with LAr1-ND and the cryogenic system.

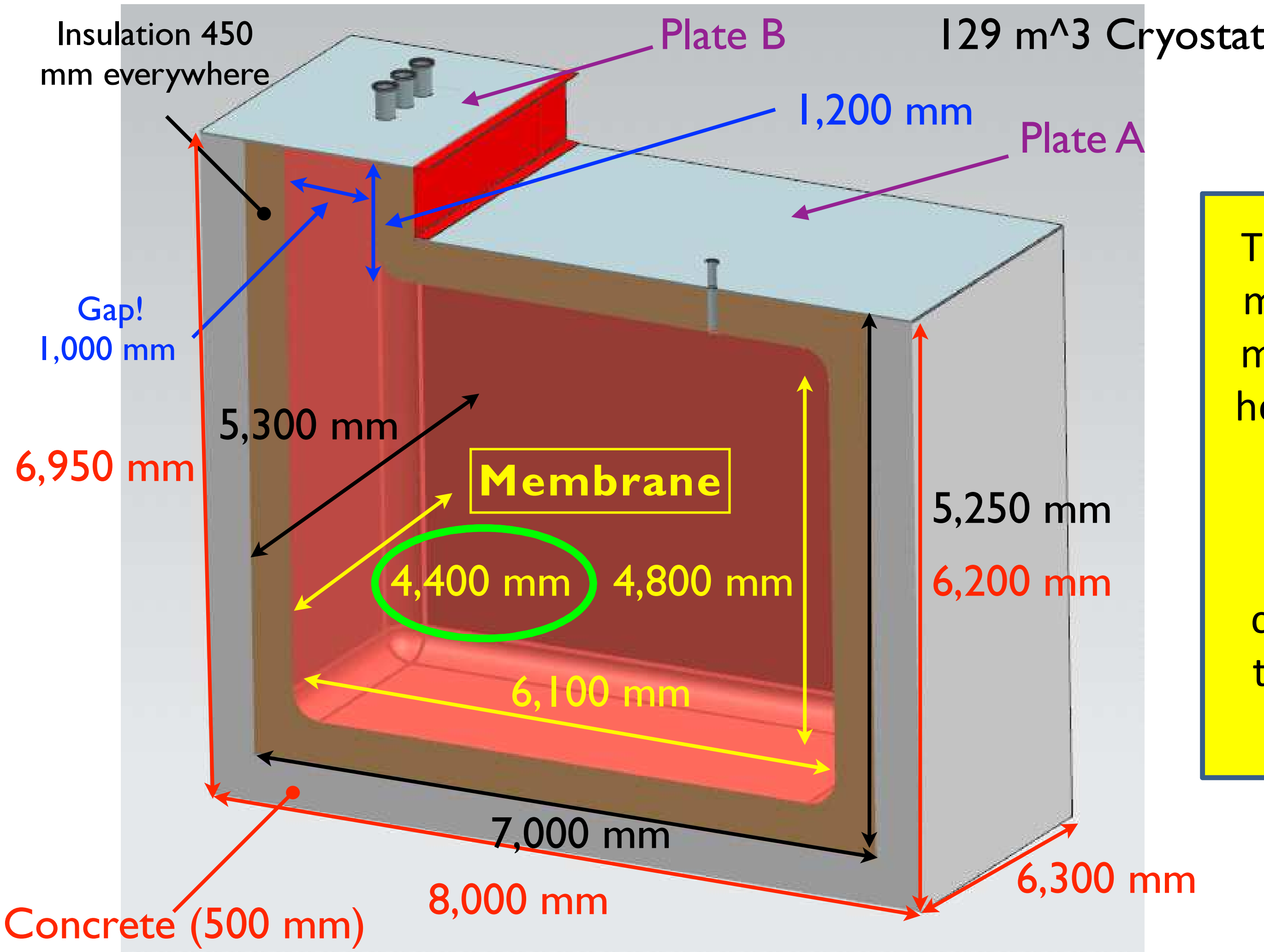
Cryostat

Cryostat Current Design Parameters

Parameter	Value
Type of structure	Membrane cryostat
Outside reinforcement	Concrete enclosure with embedded heaters (Floor + Sides)
Fluid	Liquid Argon (LAr)
LAr Volume/Mass	129 m^3 / 180 ton
Inner dimensions (flat plate to flat plate)	4.4 m (W) x 6.1 m (L) x 4.8 m (H)
Depth of liquid argon	4.8 m (All the gas in the "neck" region)
Insulation thickness	0.45 m (everywhere)
Primary membrane	SS 304/304L
Operating gas pressure	1.0 psig (~70 mbar)
Vacuum	No vacuum
Design Pressure	3.0 psig (~207 mbar)
Design Temperature	77 K (liquid Nitrogen temperature for convenience)
Metal surfaces in the ullage in ops	< 100K (to reduce outgassing)
LAr pumps for continuous purification	Outside tank
Penetrations	One (HV) through the insulation and all the others through the neck region.
Duration	10 years
Thermal cycles	20 complete cycles (cool down and total warm up)

Width varies for more mass

LAr1-ND 129 m^3 Model (based on 35 ton)

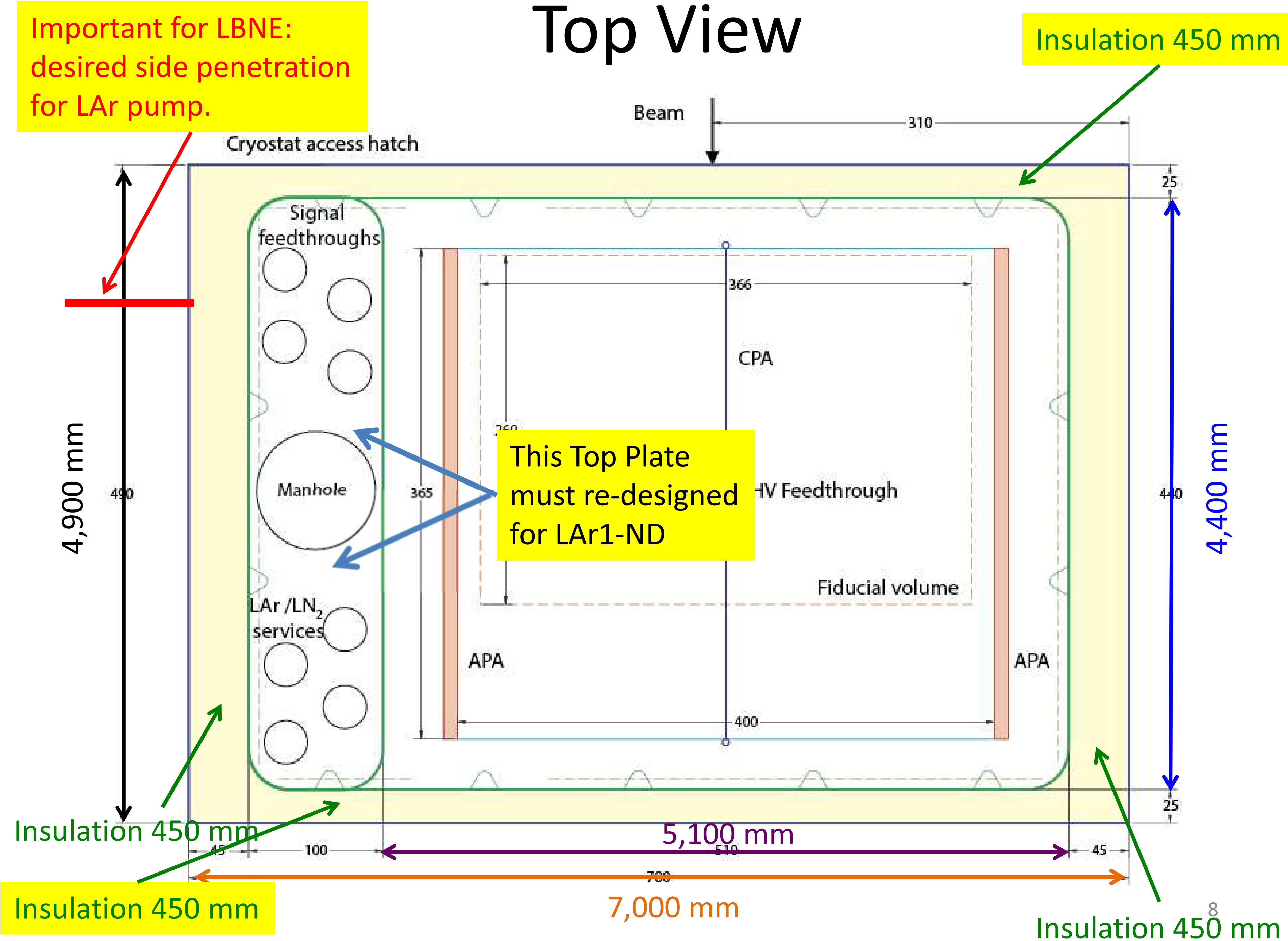


This shows model of 129 m^3 or 180 ton LAr total mass. Note the Top Plate here is just a sample with fewer penetrations.

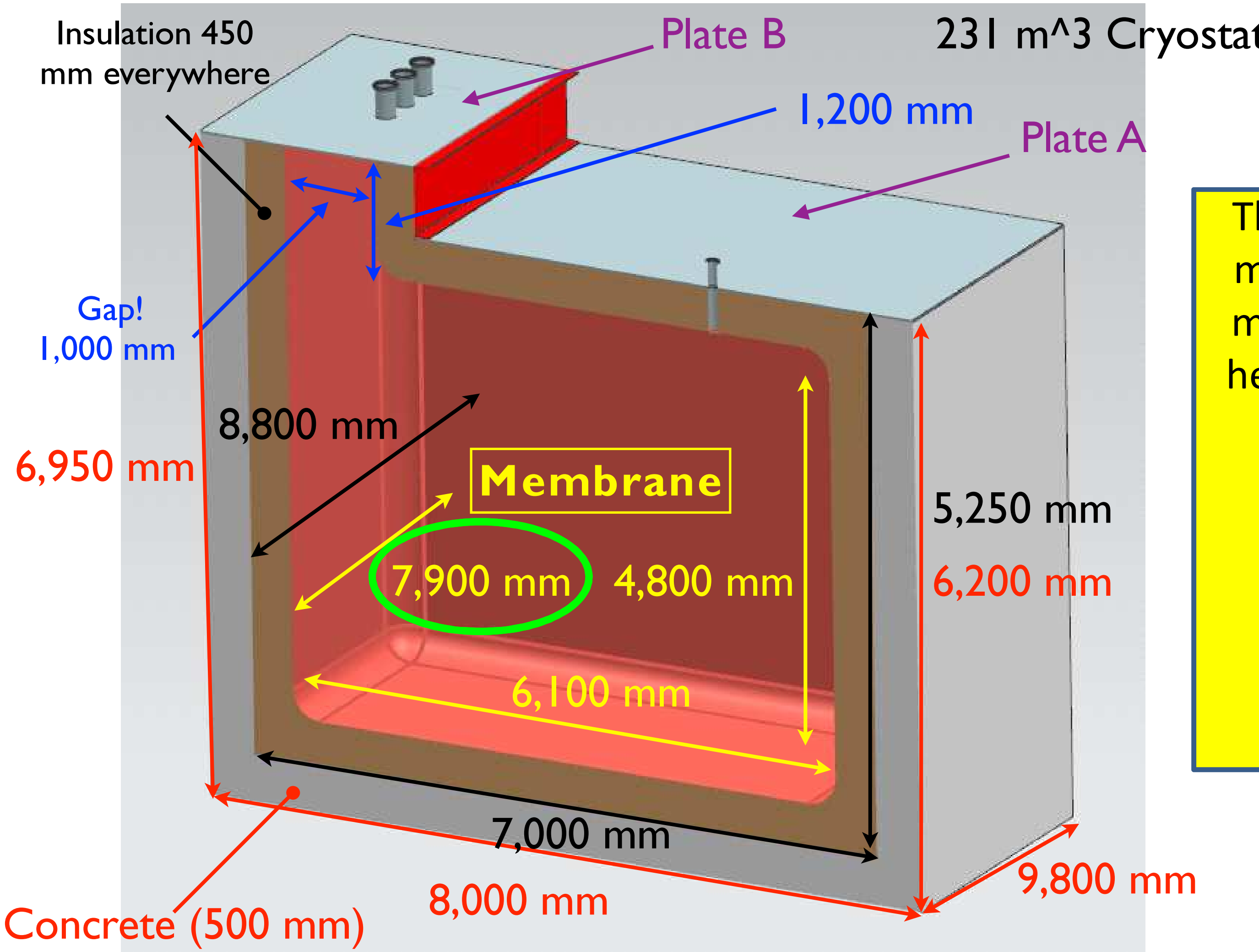
Assumption: A larger cryostat would increase the internal width from 4.4 m to 7.9 m

- This is the 3D model of LAr1-ND based on the 35 ton concept.

Top View


Important for LBNE: desired side penetration for LAr pump.
Insulation 450 mm
Beam
310
Cryostat access hatch
25
Signal feedthroughs
366
CPA
4,900 mm
490
Manhole
365
This Top Plate must re-designed for LAr1-ND
HV Feedthrough
440
4,400 mm
Fiducial volume
LAr /LN_2 services
APA
APA
400
25
Insulation 450 mm
5,100 mm
45
100
510
45
700
Insulation 450 mm
7,000 mm
Insulation 450 mm

LAr1-ND 231 m^3 Model (based on 35 ton)



This shows model of 231 m^3 or 322 ton LAr total mass. Note the Top Plate here is just a sample with fewer penetrations.

Assumption: A larger version of the base cryostat. The internal width increased from 4.4 m to 7.9 m

- This is the 3D model of LAr1-ND based on the 35 ton concept.

Heat Leak Summary

	129 m^3 Estimated Heat Leak (kW)	231 m^3 Estimated Heat Leak (kW)
Base of Cryostat	0.356	0.641
End Walls of Cryostat	0.560	1.008
Side Walls of Cryostat	0.777	0.777
Top Plate A	0.277	0.499
Radiative Heat Load through Neck of Top Plate B	~ 0.326 (from 35 ton estimate)	Assume ~ 0.587 (from 35 ton estimate)
TPC or Electronics	TBD	TBD
LAr Pumps	TBD	TBD
HV Feed through	TBD	TBD
Piping	TBD	TBD
Total	~2.2 kW + TBD	~3.5 kW + TBD

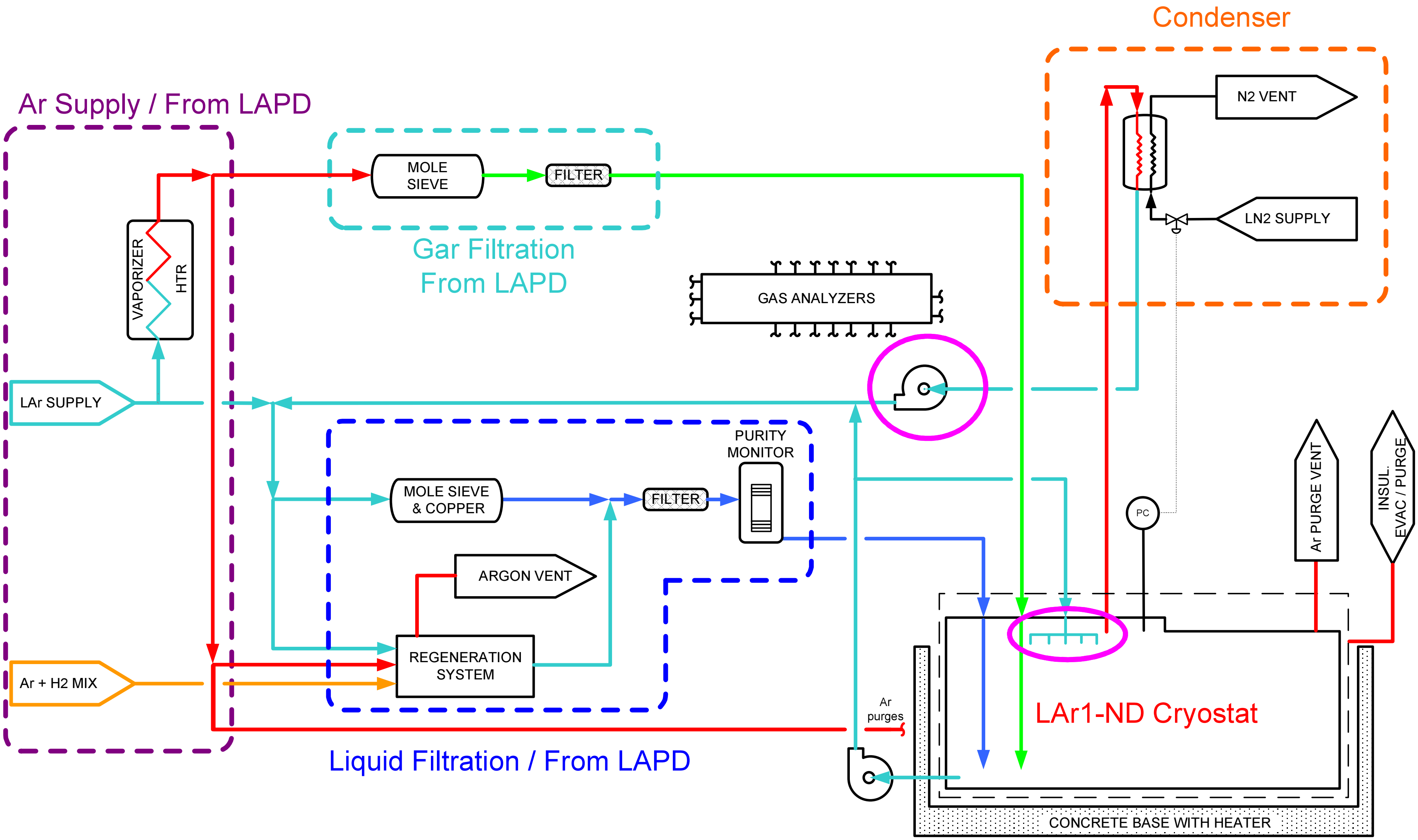
Cryogenic System

Cryogenic System Design Requirements

Parameter	Value
LAr purity	6 ms electron lifetime (~50 ppt O2 equivalent)
Piston purge rate of rise	1.2 m/hr
Membrane cool-down flow rate	< 10-15 K/hr (vendor's specifications)
GAr purification flow rate	Value to come from boil off gas and outgassing flow rate
LAr purification flow rate (filling/ops)	1 volume change/day: - 5.4 m^3/hr = 24 gpm (129 m^3) - 9.7 m^3/hr = 43 gpm (231 m^3)
Convective currents inside the tank	< 10 cm/s
Cooling power	Cool-down: 14 kW (129 m^3) / 22 kW (231 m^3) for cool down. Operations: 2.2 kw (129 m^3) + TBD / 3.5 + TBD (231 m^3).

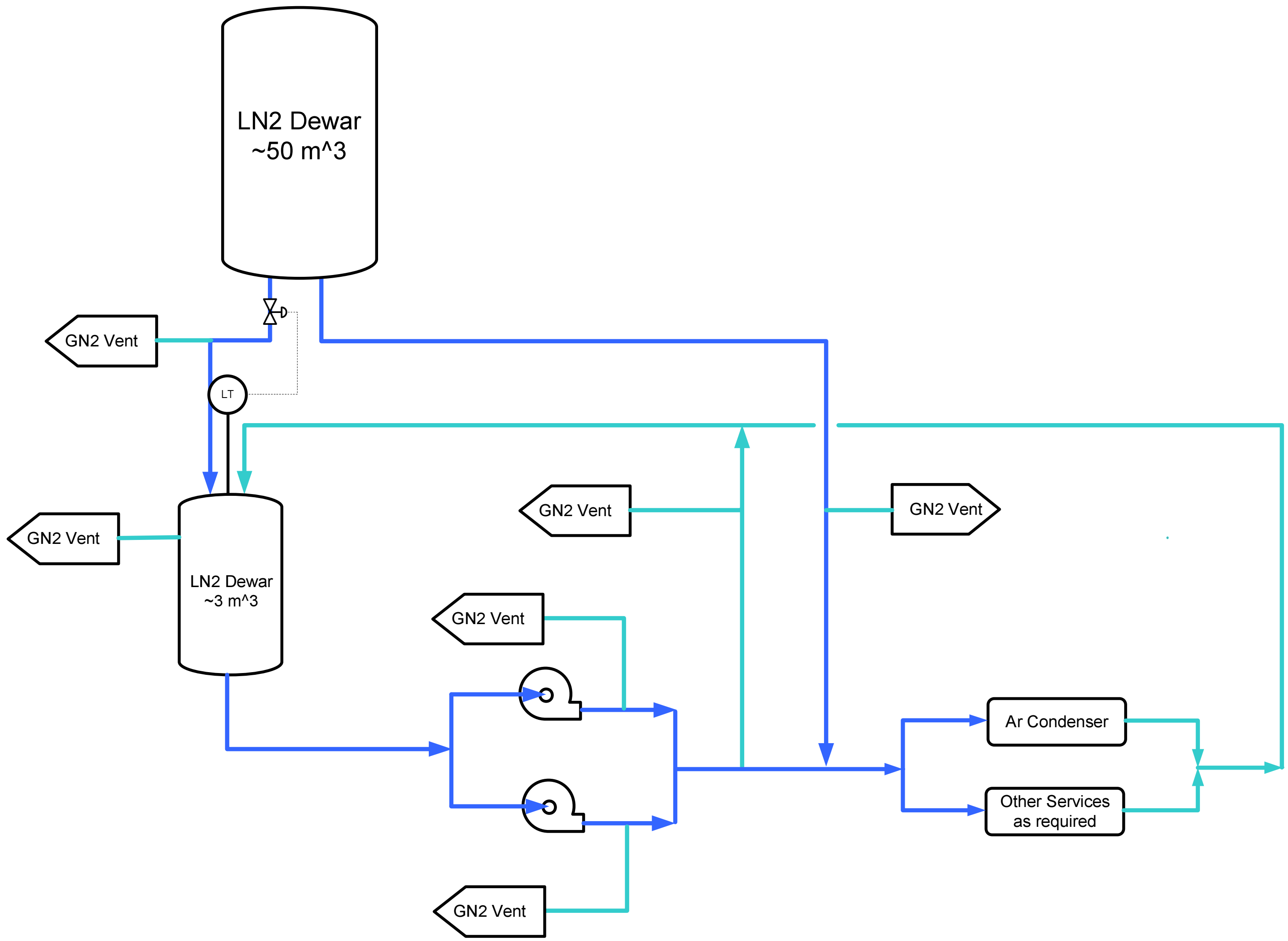
- Portable system(s) lowered through the top in the SciBooNE hall, with quick connections to/from the cryostat.
- Cryogenic and GAr/LAr purification systems to LBNE design (where possible).
- LN2 refrigeration based on LBNE design is not cost effective.
- GAr purge within the cryostat insulation.
- Cryostat overpressure protection
- Cryostat vacuum protection

LAr1-ND PFD of LAr systems (based on 35 ton)



- This is the PFD of the LAr system of LAr1-ND based on the 35 ton concept (but with an **external LAr pump** and a system to **spray clean LAr/GAr** on the top to keep the ullage cold).
- Assumption: 129 m^3 tank (base option).

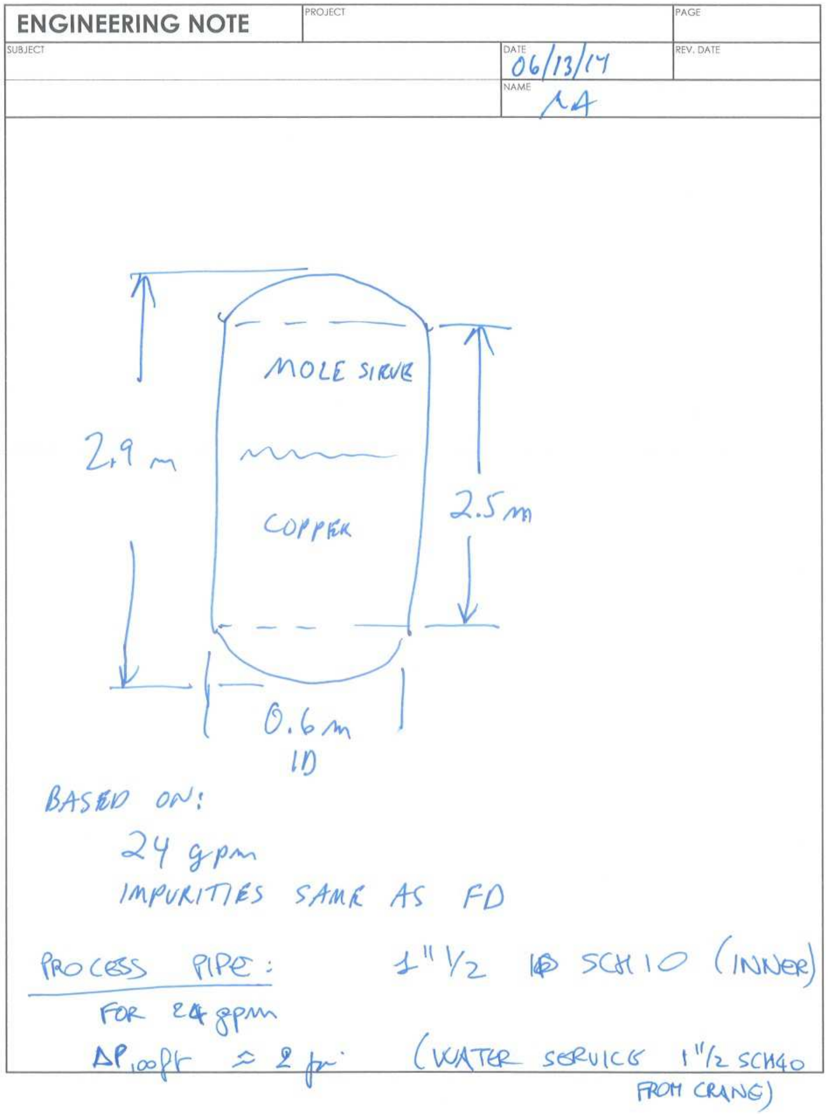
LAr1-ND PFD of LN2 systems (based on 35 ton)



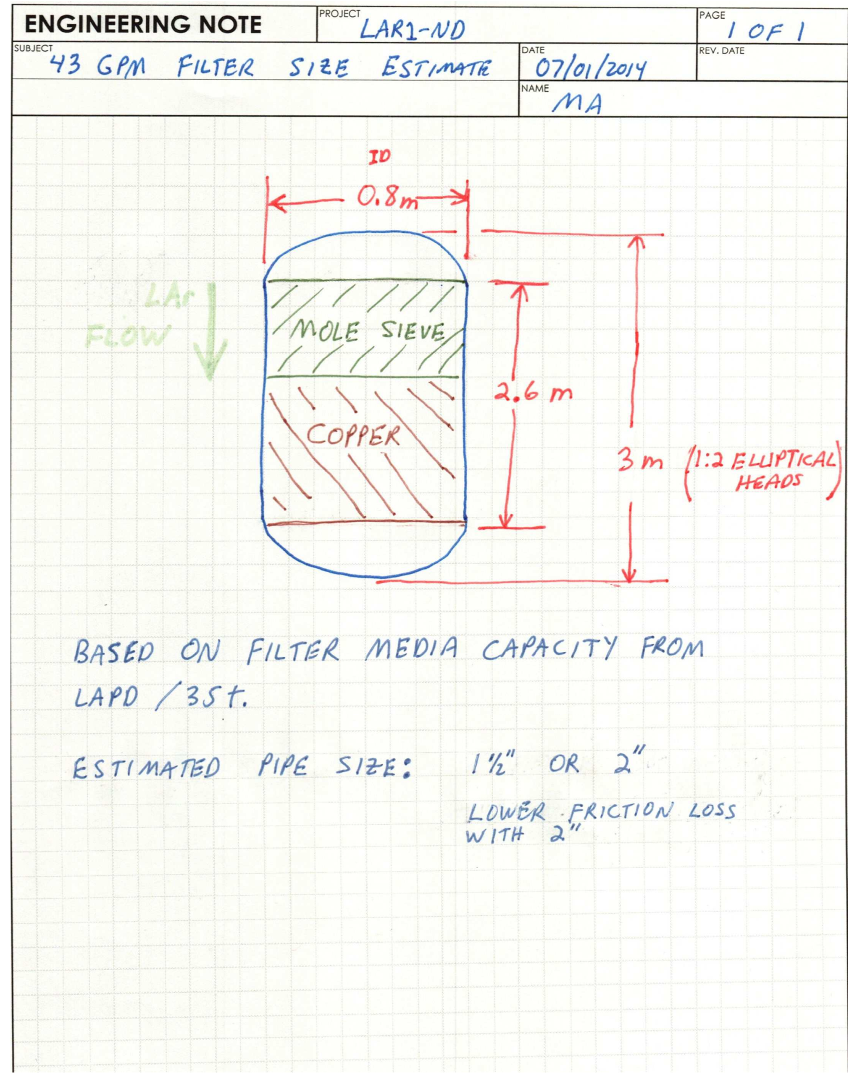
- This is the PFD of the LN2 system of LAr1-ND based on the 35 ton concept and CERN initial idea as presented on Jun 18, 2014.
- Assumption: 129 m^3 tank (base option).

Cryogenic System Conceptual (from Mark A.)

129 m^3



231 m^3



Purification/Filtration systems needs

- Gas purge/recirculation: GAr purification during initial cleaning.
- Filling: LAr purification.
- Operations: LAr + GAr boil off purification.
- GAr purge inside the insulation.

- LN2 tanker delivery to onsite LN2 dewar (10,000 gal available from D0):
  - Five (5) year usage based on estimated heat leak
- LN2 Refrigerator based on LBNE cycle (NOT cost effective):
  - Estimated Cost of LN2 plant (Design, Procure, Install)
  - Power + GN2 costs

Cryogenic System Capabilities

- To purify the LAr (filling and operations).
- To re-condense and purify the boil off gas.
  - LAr condenser and LN2 phase separator.
  - LAr circulation pump to send LAr to purification system
- To handle the LAr/GAr and LN2/GN2 flows:
  - Initial cleaning → GAr purging and venting, GAr recirculation and purification.
  - Ops → cool down, LAr filling, GAr boil off purification and re-condensation, LAr purification, LAr return to the tank.
  - Make-up GAr.
- Pressure control/Vacuum protection (inside the tank):
  - PSV, VSV, Auto/Manual venting.
- To handle the GAr purge inside the insulation.
- Instrumentation and diagnostics: T and P sensors, flow meters, liquid level sensors, etc., analytical instruments to measure the contamination, in-line Purity Monitors (??), etc.
- To develop the control system.

Current list of penetrations

- Liquid level probe(s).
- LAr Out (to LAr pump through the side of the tank)
- LAr In (from pump discharge through purification system)
- Cool-down ports (depending on cool down method)
- GAr purge inlet
- GAr purge outlet
- GAr to condenser and vent valves
- Low P make-up GAr
- PSV
- VSV
- LAr cool-down
- T sensors
- T sensors Feedthrough
- Miscellaneous Feedthrough (LED lights, etc.)
- TPC Signal Feedthroughs (warm or cold ??)
- TPC HV feedthroughs (on center of cryostat)
- Purity Monitor(s)?
- Glass window view port ??
- Sampling ports
- LN2/GN2 heat exchanger ports
- Instrumentation & Diagnostics ??
- Spare ports

Feedthroughs

- <u>TPC HV FT:</u>
  - warm FT right on top of the Cathode plane with its c own nozzle.
  - Ullage region of the HV needs to be connected to the ullage region in the "chimney" to maintain stable liquid level in the HV nozzle.
- <u>Signal Baseline:</u>
  - Warm FT. "MicroBooNe" Style.
  - Option: Long "Cold" FT dipping into the liquid. Eliminates the exposed cables in the gas region. Needs to be designed.

Outstanding issues

- **Installation:**
  - How will the TPCs be installed?
  - Do the cryostat dimensions need to be revised to account for the installation of the TPCs?
  - Does the location of the openings (feedthroughs and installation hatch) need to be modified?
  - How do we connect the cables to the Feedthroughs?
  - How do we test the APAs during installation?
- **Integration of TPC** in cryostat
- Studies on how to keep **all surfaces at a Temperature lower than 100 K**.
- Studies on how to minimize **noise** in the vicinity of the wires.
- **LAr Pump (Outside):**
  - Need to see how to isolate the pump electrically and mechanically from the TPC. Issues with electronic noise and microphonics.
  - Check with Fermilab safety that cryogenic review panel is ok. We believe it it ok.
  - This is related to the overall grounding plan. Need to update MicroBooNE's grounding plan.
- Ability to make modifications after run for x years ??
  - Replace the electronics ??

Summary

- Preliminary thinking has been done on layout of LAr1-ND for two different sizes: base option (129 m^3) and enlarged (80% more) version (231 m^3).
- Cryogenically the system 'feels like' the 35 ton system at Fermilab's PC-4 but placed in separate facility detector.
- LAr cryogenic system is thought to be a scaled-up version of that of 35 ton/LAPD.
- Need to decide on LN2 system design "common" to T600 (FD).

<u>Closing statements:</u>

- Fundamentally there are no foreseen issues related to increasing the cryostat size. There are increased costs for the cryostat as well as the cryogenic system. They will scale with heat leak and the purification flow rate.
- The two design issues which are key:
  1) How does the TPC installation/integration happen ?
  2) How do we keep the surfaces of the ullage at T <= 100 K ?

Backup

Current Schedule

- The goal is to have the detector ready for commissioning in the fall of 2017 and to take beam data in Apr 2018.

LN2 refrigeration conceptual from MA

From: Mark Adamowski madamski@fnal.gov
Subject: rough 14kw LN2 cost
Date: June 13, 2014 at 9:36 AM
To: David Montanari dmontana@fnal.gov

David,
Rough estimate of 14 kW LN2 refrig based on the best available cost data (CTS). Numbers from Cosmodyne have some built in development costs that make it difficult to use or scale.

Mark

13 Jun 2014 09:31:33 - LAR1-ND 14kW refrig cost est rev 140613.sm

LN2 refrig cost scaling

Previously CTS stated that a cost scaling exponent of 0.8 would be appropriate for rough cost scaling of the LN2 refrigeration unit type proposed by CTS.

$N := 0.8 \qquad \frac{C}{C_0} = \left(\frac{S}{S_0}\right)^N$

The CTS proposal price for a 50 kW LN2 refrig unit can be scaled to 75 kW nominal (85+ peak kW), by using the following cost ratio multiplier.

$S_0 := 55\ kW \qquad S := 14\ kW$

$cost_{ratio} := \left(\frac{S}{S_0}\right)^N \qquad cost_{ratio} = 0.3347$

$LN2cost := 1.75 \cdot cost_{ratio} + 0.350 + 0.250$

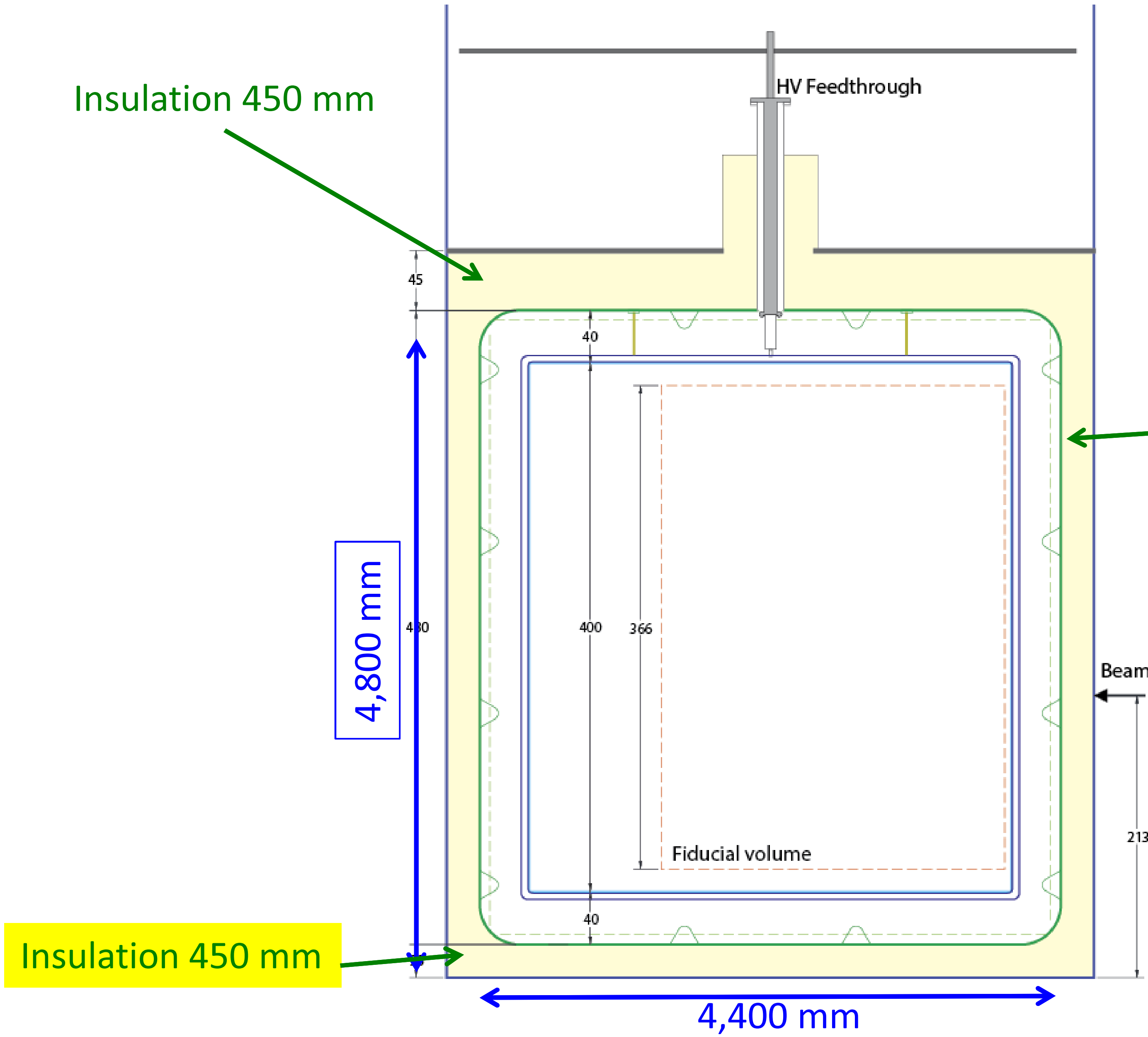
Engineering and support charges assumed to remain the same.

$LN2cost = 1.1857$ in million \$ (yr 2010)

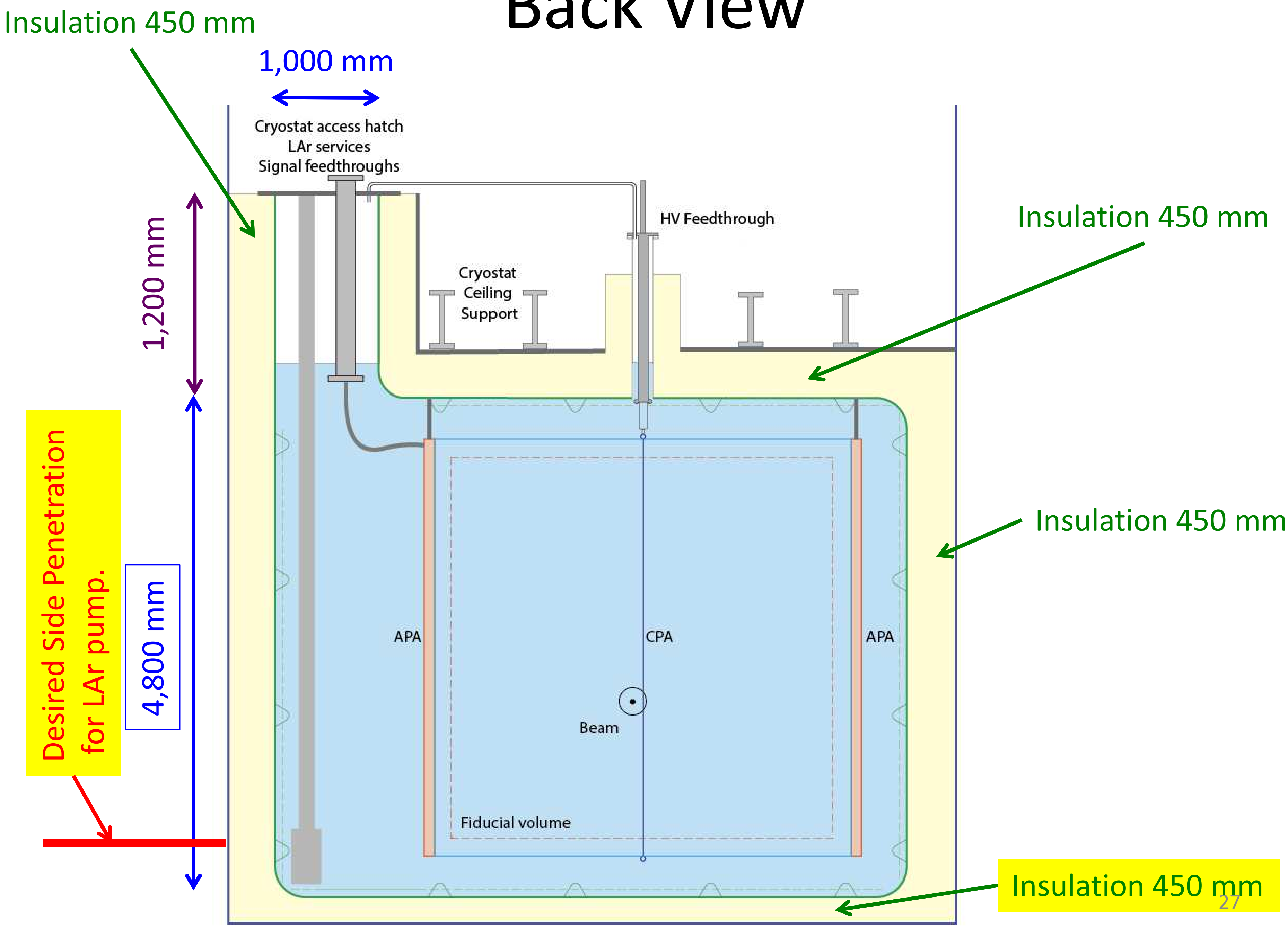
Side View

CHANGE: Note that in new building we request to Have 450 mm insulation On all six planes

The HV feedthrough does not have to be in the center of the CPA in this view

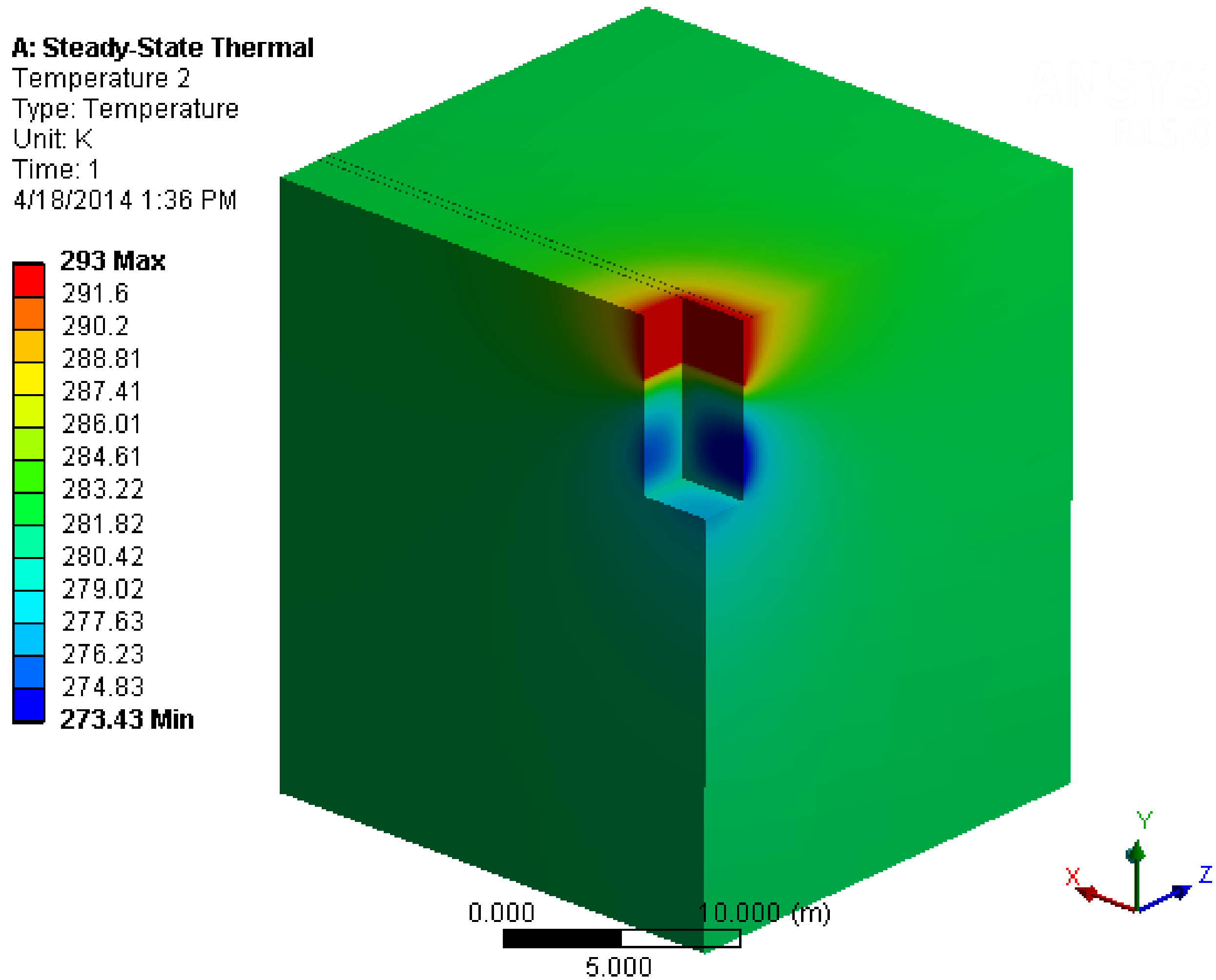


Back View



Insulation 450 mm
1,000 mm
Cryostat access hatch
LAr services
Signal feedthroughs
HV Feedthrough
Insulation 450 mm
Cryostat Ceiling Support
1,200 mm
Desired Side Penetration for LAr pump.
4,800 mm
Insulation 450 mm
APA
CPA
APA
Beam
Fiducial volume
Insulation 450 mm

Temperature Profile in Concrete/Soil with heaters



With 400W Floor Heater and 200W Large Side Heaters (800W Total) the concrete along the sides reaches a minimum temperature of ~273K. If the structure if free standing and is does not lay against the soil, the temperatures will be even higher.