Cryostats for a Liquid Argon "Near Detector" in a Neutrino Beam

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This note sketches some preliminary specifications for the cryostats for liquid argon (density $\rho = 1.396$ g/cm^3, $T = 87$ K) time projection chambers of active mass in the range 40-333 metric tons, as would be suitable for use as "near detectors" in a neutrino beam such as the NuMI beam now under construction at Fermilab.

A major cost driver of such a detector is its cryostat, which will have to be delivered in pieces to the underground site, and welded together *in situ*.

An important constraint on the assembly of the detector is the size of the access shaft through which the parts must be delivered. Here, we use the dimensions of the vertical access shaft, shown in Fig. 1, to the NuMI/MINOS Near Detector Hall which is about 350′ underground, as shown in Fig. 2. Nominally, the largest rectangular aperture in the shaft is 1.75×6.4 m^2. In this note, we suppose that this restricts components to have a maximum cross section (in the horizontal plane) of 1.5×6 m^2.

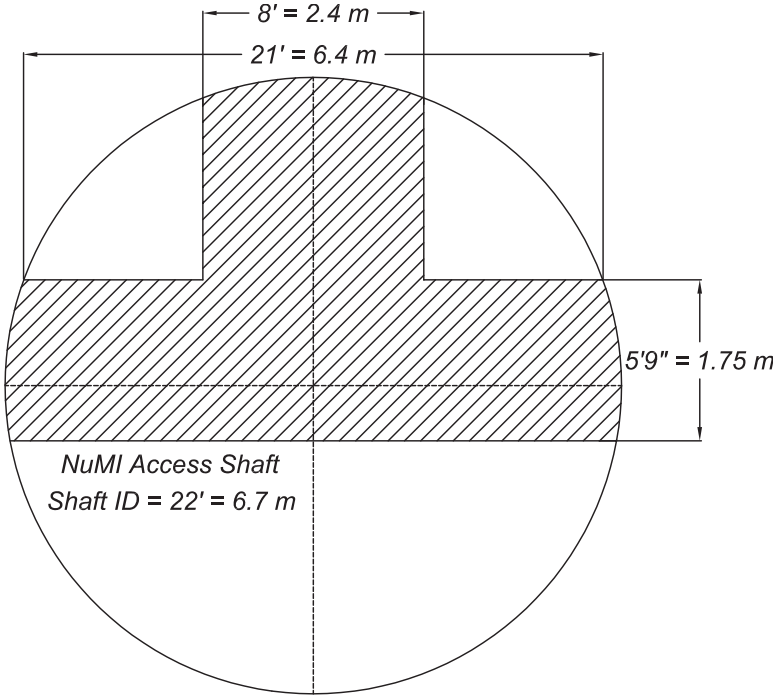


Figure 1: A vertical cross section of the NuMI access shaft.

Simplicity of construction (and hence cost effectiveness) suggest that the detector cryostat be in the form of a right circular cylinder, with axis along the beam (*i.e.*, horizontal or nearly so), with oblate spheroidal endcaps. The active volumes are right circular cylinders, of radius 0.3 m less than that of the inner shell of the cryostat. The electric field of the detector is

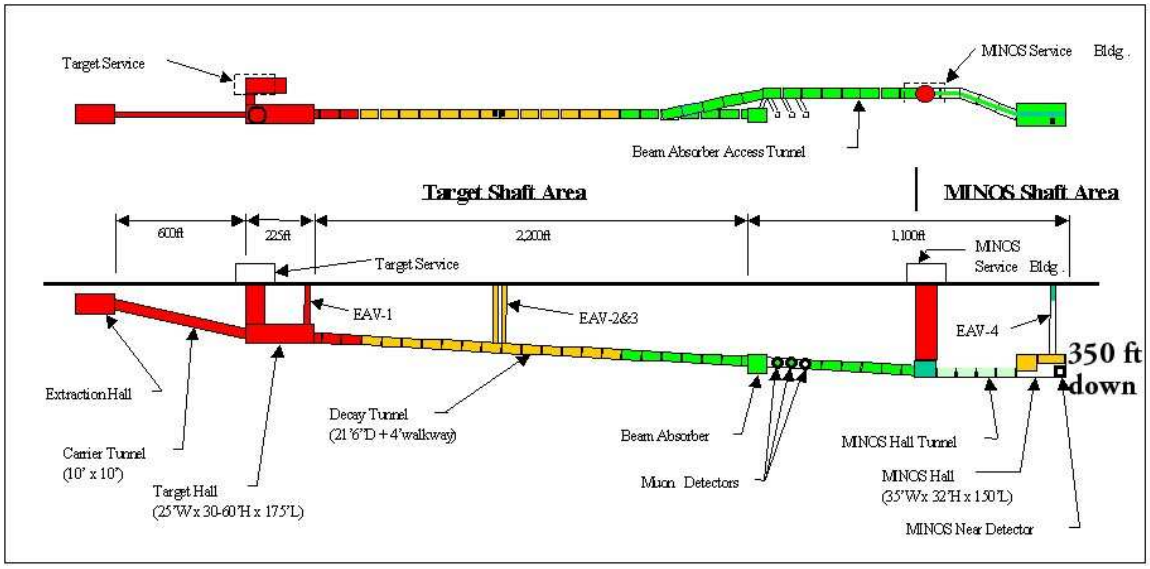


Figure 2: Plan and elevation views of the NuMI beamline, including the MINOS near detector hall 350′ underground.

parallel to the cylinder axis, with the readout planes at ground on the two flat end surfaces of the active region. (This avoids the very high fields that would occur just outside the ends of the active region if the readout planes were at the middle of the detector.)

Four possible detectors based on this concept are shown in Figs. 3-6. The detectors are to be built from 4-7 sections that are 1.5-m-long cylindrical hoops, plus a pair of endcaps. These detectors span the range from the smallest (T40) that has non-zero fiducial mass, to the largest (T333) that could be made of parts that fit down the NuMI access shaft and have at most a 5-meter drift of ionized electrons to the readout planes. Parameters of these detectors are given in Table 1.

In estimating the fiducial volume of the detector, I suppose that the hadronic shower due to a neutrino interaction should be at least 90% contained, which implies (roughly) that the fiducial radius is $R_F = R_A - \lambda_{\rm int} = R_A - 0.8$ m, and that the fiducial length is $L_F = L_A - 5\lambda_{\rm int} = L_A - 4$ m.

Not shown in the figures are the various cryogenic feedthroughs that will be needed: argon gas and liquid inlets and outlets, a high voltage feedthrough, and the readout signal feedthroughs. The latter will be via 6″ diameter pipes, serving about 600 channels each, for a total of 8, 12, 16 and 18 readout feedthroughs for the T40, T100, T250 and T333 detectors, respectively.

Table 1: Parameters of the four candidate liquid argon detectors. Subscripts A, F and T refer to the active, fiducial and total regions, respectively. The heat leak is calculated as $\epsilon\sigma(\Delta T)^4 A$ for $\Delta T = 297 - 87 = 210$ K, supposing superinsulation reduces emissivity ϵ to 0.02. The Stefan-Boltzmann constant is $\sigma = 5.67 \times 10^{-8}$ W/m^2-K. The surface area is given by $A_T = 2\pi R_T(L_A + 3)$, assuming that all endcaps have axial extent of 1.5 m. The boiloff fraction per day is based on the heat of vaporization of liquid argon of 162 MJ/ton. The readout channel count assumes the detector is divided into two sections of length $L_A/2$, each with x, y and $u = 45°$ readout planes of wires on a 3-mm pitch.

Det.	R_A (m)	L_A (m)	M_A (ton)	R_F (m)	L_F (m)	M_F (ton)	R_T (m)	M_T (ton)	A_T (m^2)	Heat (W)	Boiloff (day^{-1})	Readout Ch.
T40	1.2	6.0	38	0.4	2.0	1.4	1.5	79	85	187	0.0013	4,800
T100	1.75	7.5	101	0.95	3.5	14	2.05	176	135	298	0.0009	7,000
T250	2.5	9	247	1.7	5.0	64	2.8	380	211	466	0.0007	10,000
T333	2.7	10.5	337	1.9	6.5	103	3.0	495	254	560	0.0006	10,800

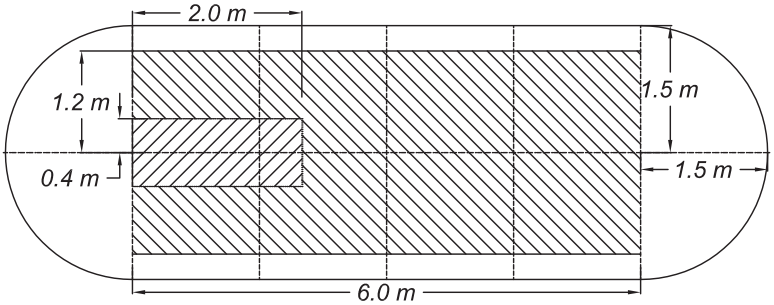
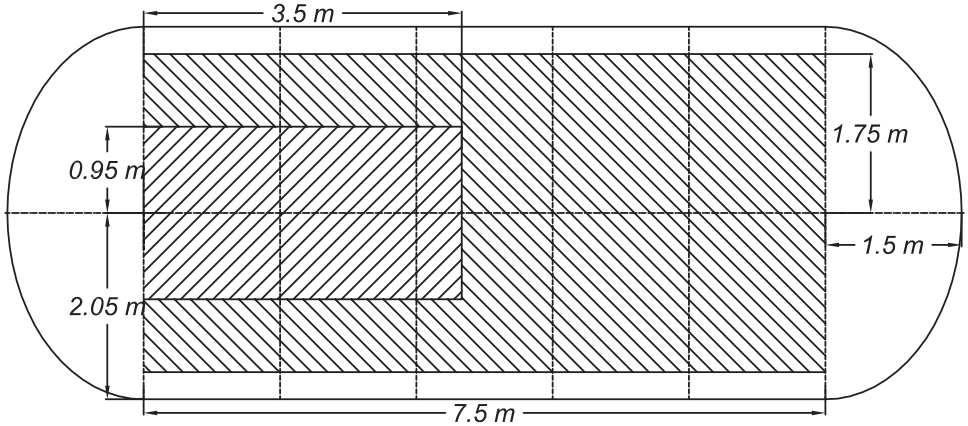
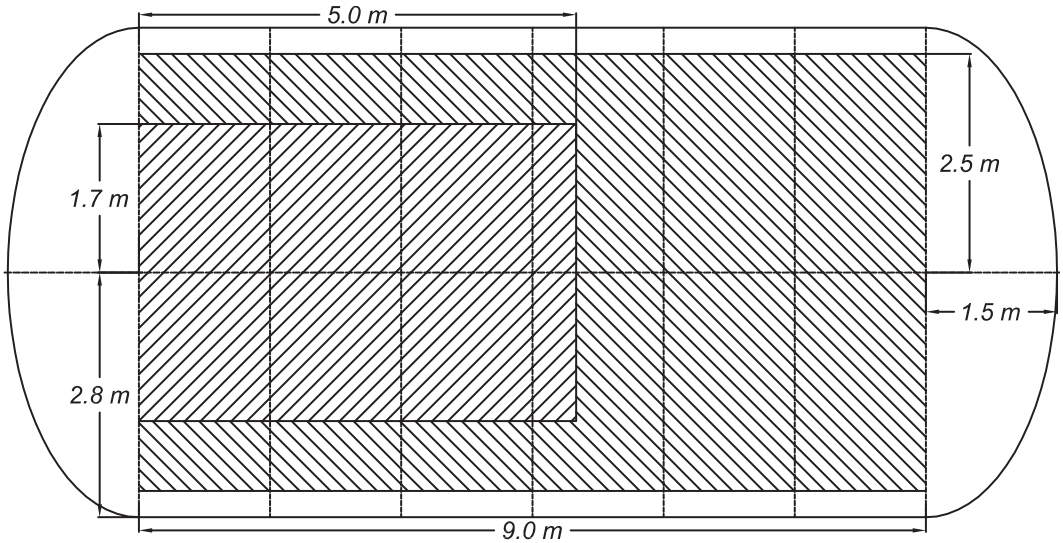


Figure 3: Dimensions of the inner cryostat shell for a liquid argon detector with 79 tons total mass or liquid argon, 40 tons active mass, and 1.4 tons fiducial mass.



T100 Liquid Argon Time Projection Chamber
Total mass = 176 metric tons, Active mass = 101 metric tons
Fiducial mass = 14 metric tons
Readout: 6 planes (2 x X, Y, U), 3 mm pitch, 7,000 ch

Figure 4: Dimensions of the inner cryostat shell for a liquid argon detector with 176 tons total mass, 101 tons active mass, and 14 tons fiducial mass.



T250 Liquid Argon Time Projection Chamber
Total mass = 362 metric tons, Active mass = 247 metric tons
Fiducial mass = 64 metric tons
Readout: 6 planes (2 x X, Y, U), 3 mm pitch, 10,000 ch

Figure 5: Dimensions of the inner cryostat shell for a liquid argon detector with 360 tons total mass, 250 tons active mass, and 64 tons fiducial mass.

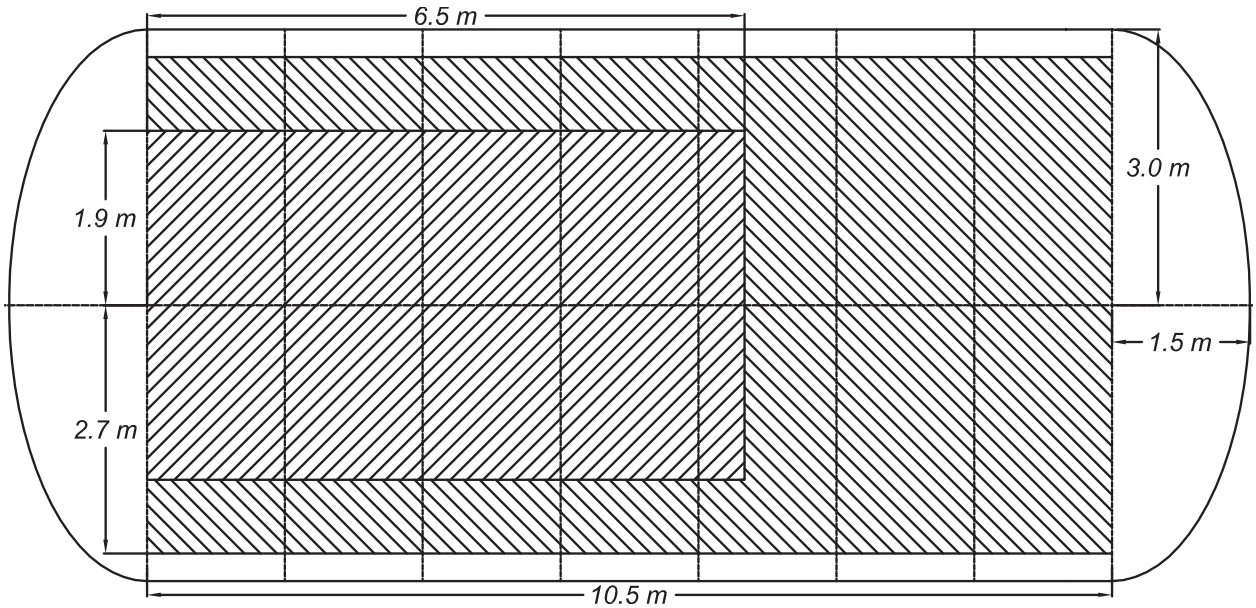


Figure 6: Dimensions of the inner cryostat shell for a liquid argon detector with 475 tons total mass, 337 tons active mass, and 103 tons fiducial mass.