Cellular Design for a Liquid Argon Time Projection Chamber

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1 Introduction

One of the major challenges in the construction and operation of massive Liquid Argon Time Projection Chambers (LArTPCs) relates to the readout planes of the TPC. The readout uses three planes of wires: two angled planes and a vertical plane – all read out at the top. There are at least five issues surrounding these long wires:

1. Electronic noise due to the capacitance and resistance of the wires.
2. The incomplete coverage of the entire tank by all three wire planes.
3. The safety, time and logistical issues of installing the wires in the tank at the correct tension.
4. The danger and consequences of wire breakage, particularly on cool-down.
5. Reconstructing events and associating signals in the different planes

This note introduces a possible solution (called a Cellular Design) to some problems caused by the long wires needed for the readout planes of a massive LArTPC. The Cellular Design could, but does not necessarily, address the first issue and may complicate the fifth, but it virtually eliminates the other three.

This note begins by discussing issues 1 through 4, then introduces the Cellular Design, showing how it remedies those issues, and then describes how the Cellular Design can be realized. A brief status is given on our work to understand the effect Cellular Design has on issue 5. We conclude by discussing a possible technique for light collection which extends the capability of the detector for non-beam associated events and may reduce the reconstruction burden.

2 Issues with Long Wires

Issue 1 is largely a result of the length of the readout wires. Using beryllium copper (BeCu) wires (resistivity of 8.62E-05 Ω-cm) with a diameter of 2.00E-04 m and pitch of 5 mm, the wires have a capacitance of $\sim$ 12 pF/m and resistance of $\sim$25 Ω/m, which, for a 30m wire is $\sim$360pF and $\sim$800Ω, adding a significant amount of capacitive and some Johnson noise.

Issue 2 (coverage of the entire tank) simply arises from the geometry of putting angled wires which are read out on the top into a tank with a rectangular cross-section. As shown in Figure 1, typically about 50 to 75% tank is covered by only one set of angled wires and only 25% of the area is covered by both angled sets.

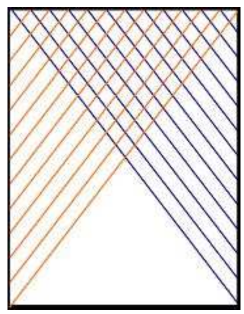

Figure 1: Drawing of angled wires showing their incomplete coverage of the tank.

Issue 3 is a result of the large size of the tank. In, for example, a 50kton detector the longest wires will span a cross-sectional square of $\sim$30m by $\sim$30m. With an angle of $\pm$30 degrees with respect to the vertical for the angled wires, the longest wire will be $\sim$41m long. Installing some hundred thousand $\sim$200μm diameter wires up to $\sim$41m long to exact tensions requires rigorous safety precautions and will be time consuming and difficult. Additionally, the stress on the wire support mechanism due to the tension of the wires must be managed with extraordinary care. Further, the first time that the wires are cold tested is in the detector when it is being filled to take data; they cannot be tested beforehand. If a wire breaks, there is no way to repair it without losing the current inventory of argon. An unbound 41m long wire could cause numerous problems in the LArTPC, including tank-wide shorts in the HV and readout.

The cooling of the tank as it is filled with liquid argon causes issue 4. As the wires have a very small volume to surface area ratio, they will cool to the temperature of the gas inside the tank (be that 273K or 87K) effectively instantaneously. The tank body itself will cool much more slowly. As a result, if the tank is filled with LAr from room temperature, the tank will remain at its room-temperature size while the wires will assume the temperature of the cold gas. If the wires are attached rigidly to the tank, or any massive structure, their tension, and the consequent probability of failure, will increase significantly.

3 The Cellular Design

The Cellular Design divides each set of sense planes into sections. Thus a 50kton tank is full of 30m long by 3m wide readout ‘panels’. A panel has three layers of wires on each face (two angled layers and one vertical layer). See Figures 2 and 3 for the configuration of the planes and how they are laid out in the detector.

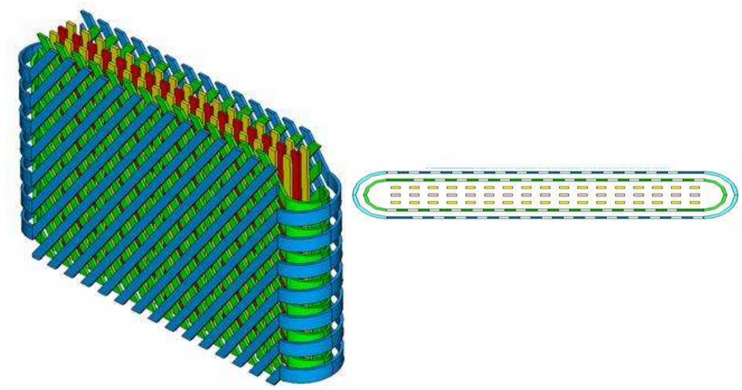

Figure 2: *Left:* 3-Dimensional view of one panel. *Right:* top view of one panel. The yellow layers are the vertical wires on each side; both the blue and green planes are angled.

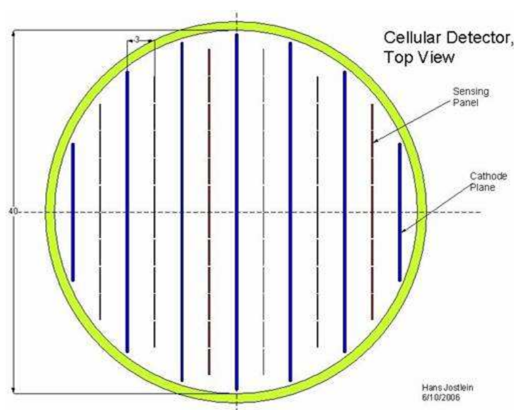

Figure 3: A top view of an entire Cellular Design detector with many panels inside.

(We note in passing that issue 1 can be much improved if we were able to put the preamps and/or multiplexers in the LAr. This would significantly reduce cable capacitance, thereby improving the signal to noise ratio. The panel structure provides a natural place to mount such electronics.)

The Cellular Design resolves issue 2: the panels effectively span the entire height and breadth of the tank. There is minimal dead space between adjacent panels and between the last panels in each row and the wall of the tank. Thus we achieve a high fiducial to total volume ratio while still reading all signals out at the top of the tank.

The Cellular Design also alleviates issue 3. The panels can be mass produced off-site at the same time as the tank is prepared, saving considerable time and making the installation much simpler. They can be cold-shocked and fully tested at the factory to ensure that there are no wire breakage problems. This is a major advantage over our previous concepts. Further, the wires are attached to

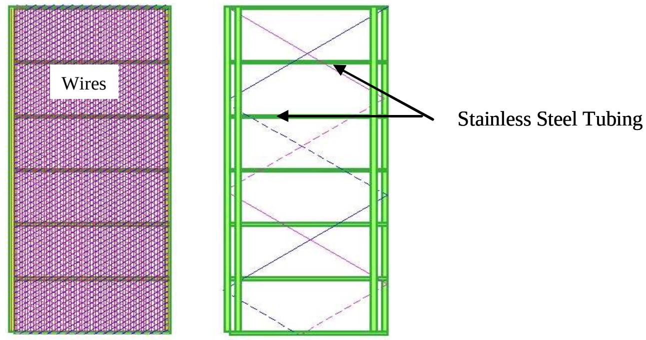

Figure 4: A panel with and without wires, showing the stainless steel structural tubing with two stiles on each side.

the panel at periodic intervals, limiting the maximum length of wire which could become free in case of breakage.

The Cellular Design largely removes Issue 4 since the changes in dimension of the tank will not affect the tension in the wires. The tension is only affected by the differences in thermal coefficients of the panel structure (stainless steel) and the wire.

4 Panel Construction

The 'panels' are designed as ladder structures (see Fig. 4). A detailed design has been produced which addresses the two main engineering issues which are:

A. Eliminating strain on the panels and tank arising from the stress of the wire tension (both bending and buckling strains) and mass of the panels

B. Maintaining exact wire alignment

A cross-section of the sensing panel is shown in Fig. 5. Table 1 lists the parameters used in the calculations.

The wires spacing is controlled by the equivalent of a guitar bridge, made of notched G-10 strips, parallel to the rungs of the ladder. The wires are secured with epoxy thus limiting the length of free wire in the case a wire breaks. The angled wires are insulated from the stiles by G-10 half-tubes (see Fig. 5) which also serve to control the wire spacing.

Table 1: Summary of the stress and strain on the frames due to the wire tension and the tank due to the mass of the panels.

Whole Ladder Properties		
Frame (stainless steel)		
	Modulus of Elasticity	2.00E+11 Pa
	Density	7.90E+03 kg/m^3
	Length	30 m
	Width	3 m
	Rung Spacing	1 m
Wires (BeCu)		
	Tension (cold)	2.82 N
	Density	8778.56 kg/m^3
	Diameter	2.00E-04 m
	Cross-sectional area	3.14E-08 m^2
	Perpendicular Wire Spacing	5.00E-03 m
	Wire angle to Vertical	60 degrees
	Wire Spacing on vertical parts of frame	5.77E-03 m
	Wire Spacing on horizontal parts of frame	1.00E-02 m
	Total Wire Mass	29.78 kg
	Effective weight from tension	977.19 N
Ladder Stile Deflection		
	Outer Radius (of stile tubing)	0.0127 m
	Inner Radius	0.0117 m
	Wall thickness	0.001 m
	Separation of Tube Centers	0.06 m
	Thickness of strips connecting Tubes	0.001 m
	Mass of Stiles	86.89 kg
	Second moment of inertia	1.85E-07 m^4
	Boundary condition factor	5
	Maximum Deflection	-3.43E-04 m
Ladder Rung Failure		
	Outer Radius	0.0127 m
	Inner Radius	0.0107 m
	Wall thickness	0.002 m
	Length of Rung	2.8292 m
	Number of Rungs	32
	Mass of Rungs	105.16 kg
	Second moment of inertia	1.01E-08 m^4
	Boundary condition factor	4
	Maximum Load	9999.1 N
	Factor of Safety against Buckling	5.12
Mass Totals		
	Total mass of one panel	221.83 kg
	Diameter of tank	30 m
	Drift region	3 m
	# of panels (approximate)	39
	Total mass of all Panels	8651.4 kg

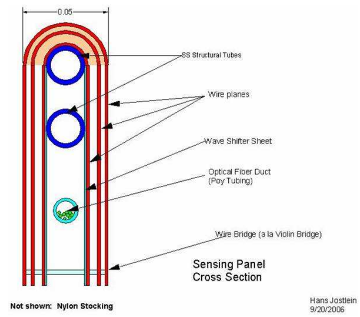

Figure 5: A cross-sectional view of the sensing panel, highlighting the dual-stile design to minimize deflection due to wire tension.

5 Reconstruction Issues

The 'panel' design has immediate implications for the reconstruction. Since the wires of the angled planes wrap around both sides of the panel, one cannot tell on which side of the panel a track passed from the angled wire data alone. While the vertical wires resolve this ambiguity, the vertical position of a track is only known modulo the vertical wrap spacing.

A two dimensional view of the 'front' side of a panel is shown in Fig. 6.

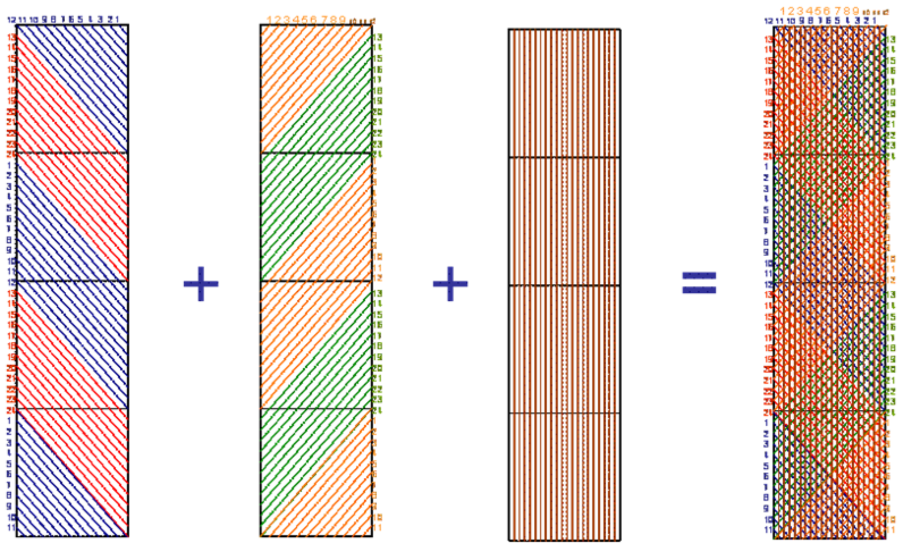

Figure 6: Graphically constructing one 'front' side of a panel – not to scale

The blue and red wires form the outermost layer, the orange and green wires the middle layer, and the brown wires are the inside vertical layer of one side of a panel. The two colors in each angled layer distinguish on which side ('front' or 'back') of the panel the wires reach the top and thus the side from which they are read out. In this case, the blue and orange angled wires and the brown vertical wires are read out on the 'front' side; the red and green angled wires are read out on the 'back' side. The numbering system is arbitrary, but convenient.

We are developing a simulation of the cellular design readout to study the pattern recognition issues. Preliminary investigations using GEANT3 to simulate cosmic muon tracks have shown that it is in fact fairly easy to reconstruct the muon topologies from simulated wire readouts. An example of the simulation is shown below in Figures 7 and 8, where 15 cosmic muons are incident on the detector.

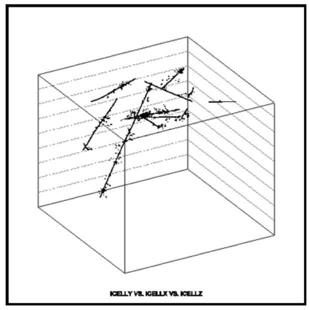

Figure 7: The 15 cosmic muons are shown as they occur in the liquid argon.

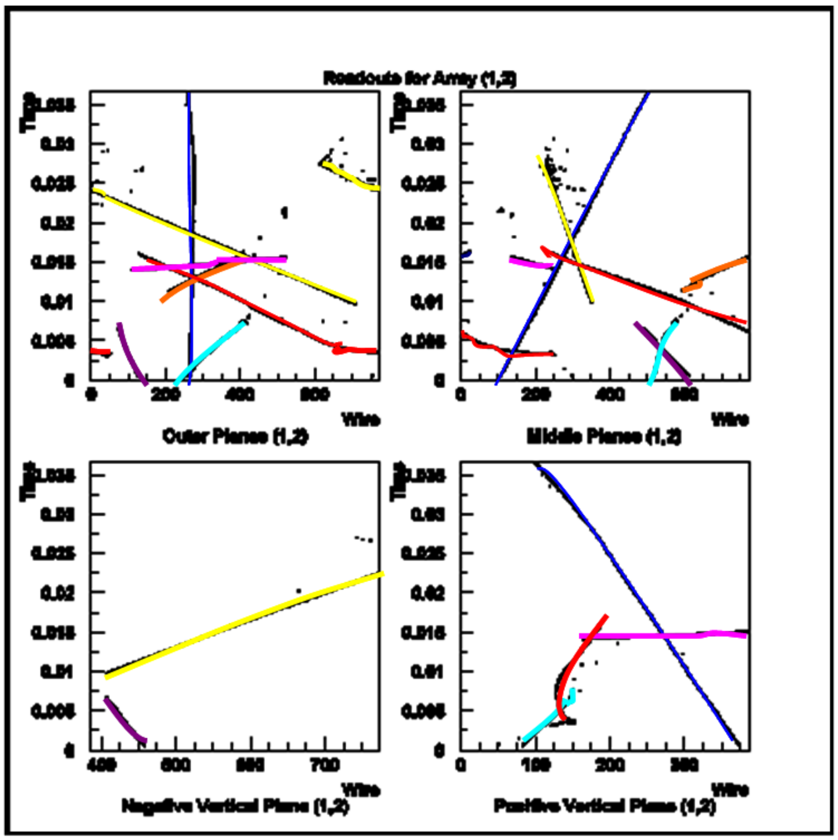

Figure 8: The simulated electronics readout for one sense panel. Time is on the vertical axis and wire number on the horizontal axis. The 'Outer' and 'Middle' planes are angled planes, with opposite angles. The projections have been hand-scanned and associated as shown in the color coding.

These studies will continue beyond cosmic muons to simulate neutrino interactions but we are encouraged at this stage to find simple effective and rules for associating projections to determine the full event topology.

The vertical position of the event, however, is still uncertain modulo the wrap spacing – and the transverse position for an event not associated with the neutrino beam spill is not known without some external timing reference.

6 Light Detection

Charged particles in liquid argon produce a substantial amount ($\sim 10^6$ photons/m) of far-ultraviolet (~128nm) scintillation light. Detecting this light would be a significant improvement in the capability of our detector to deal with non-beam associated events. It may also simplify the reconstruction effort. The scheme for light detection involves TBP coated or doped plastic – we have made samples of both – to shift the UV light into a range where the plastic is transparent (the visible) followed by wave-shifting fibers embedded in the plastic to capture this light and bring it out of the vessel. A drawing of such a structure is shown in Fig. 9.

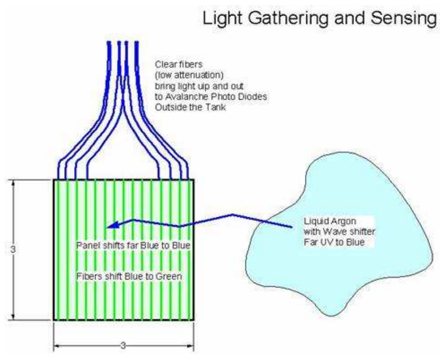

Figure 9: 3m × 3m scintillator panels bring light up and out of the tank.

Since each plastic sheet need be no more than 2mm thick and is effectively opaque to the 128nm scintillation light of LAr, we can put two sheets inside the panels, feeding the optic fibers up through a duct, as depicted in Fig. 10.

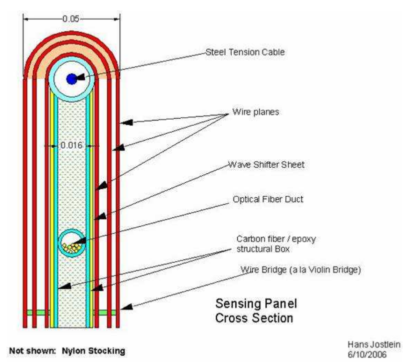

Figure 10: Cross-section of an array with two scintillator sheets and an optical fiber duct for light collection.

A single highly energetic cosmic muon which travels completely through the detector will appear as depicted in Fig. 11.

7 Summary

The Cellular Design for a LArTPC provides a solution to some of the construction, installation and coverage problems associated with the long wires in our previous massive LArTPC designs. It

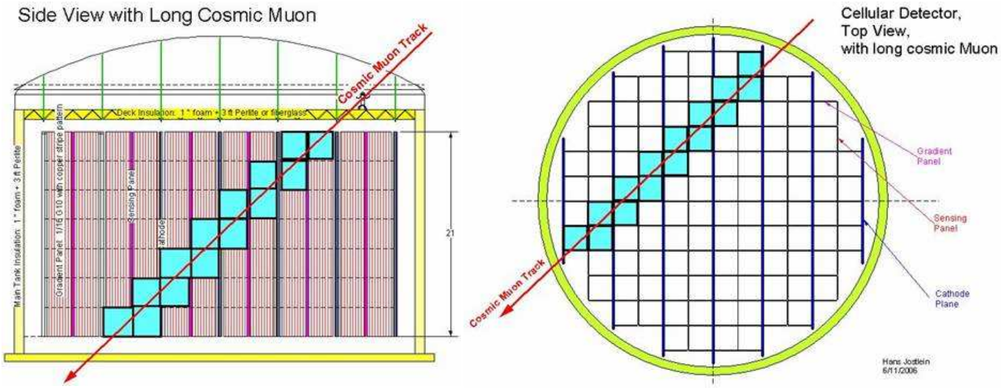

Figure 11: Left: Side view of the detector with a long cosmic muon. The detector has been segmented into cubes by the light detection panels. The squares in teal are those which register a hit from the cosmic muon. Right: Top view of the detector with the same long cosmic muon. Again, the detector is segmented, and only those cubes which are teal have a light signal from the muon.

presents new challenges for reconstruction which we are investigating with encouraging results. The possibility of putting light-collecting devices inside the Cellular Design panels is very attractive and we are studying both coated and doped plastic as converter from UV. We are planning to construct a small wire-panel this summer.