Engineering Note
for
E906 Detector Assembly

PROJECT: E906

TITLE: Station 4X Hodoscope Assembly

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ABSTRACT: This document describes an aluminum framework designed to secure an array of scintillators/photomultipliers in E906. Once assembled this framework will also be used to hang the tubes in place in the E906 beamline. This scope of this document is limited to the detector assembly. The means of permanently hanging this detector must be addressed in separate engineering note.

DESIGN:
The scintillator bodies, light guides, and phototubes for station 4X hodoscopes are provided by Abilene Christian University. Each body is coupled to two light guides and photomultiplier tubes to produce a Scintillator Assembly as shown in Figure 1.

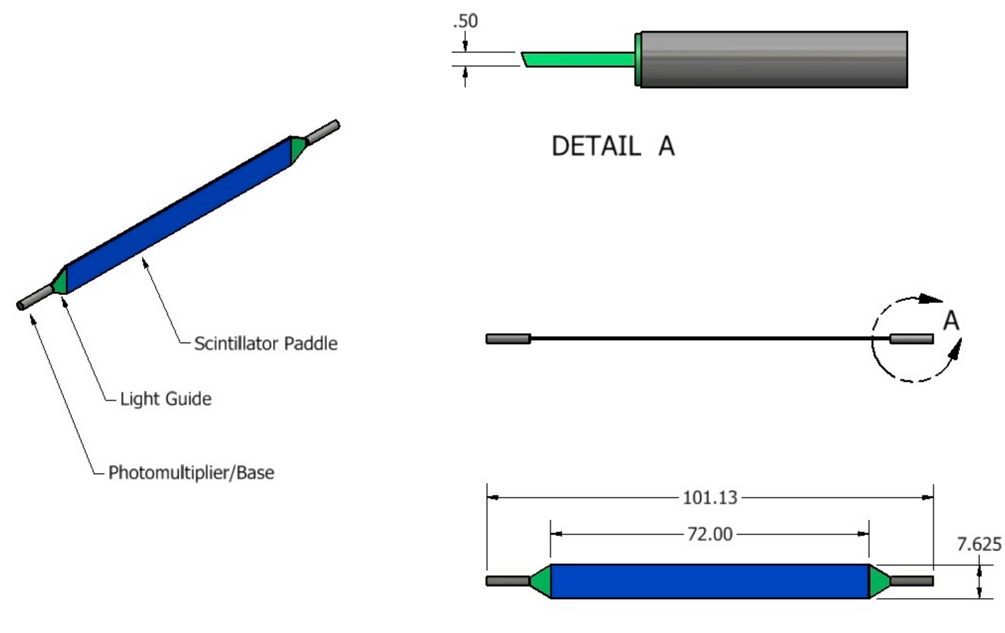

Figure 1: Station 4X Scintillator Assembly
Approximate Weight = 13 lbs.

For the Station 4X hodoscope array, 16 of these assemblies will be arranged with a slight overlap to form an array approximately 60" x 144". When placed into the beamline the scintillator assemblies will be oriented vertically. They will be held in place by a framework consisting of aluminum extrusions and fastening hardware. The extrusions are produced by 8020, Incorporated and the proposed assembly for the E906 beamline is shown in Figure 2.

The perimeter of the framework is constructed from extrusions with (1" x 2") and (2" x 2") cross sections. Within this perimeter are two additional 1" x 2" extrusions located near the midpoint of the scintillator array. These are used to mount spacer blocks in order to maintain proper separation between the scintillators and to restrict movement of the paddles. The scintillator assemblies will be secured to the framework by clamping the light guides in place with a u-bolt and mounting plate on each end.

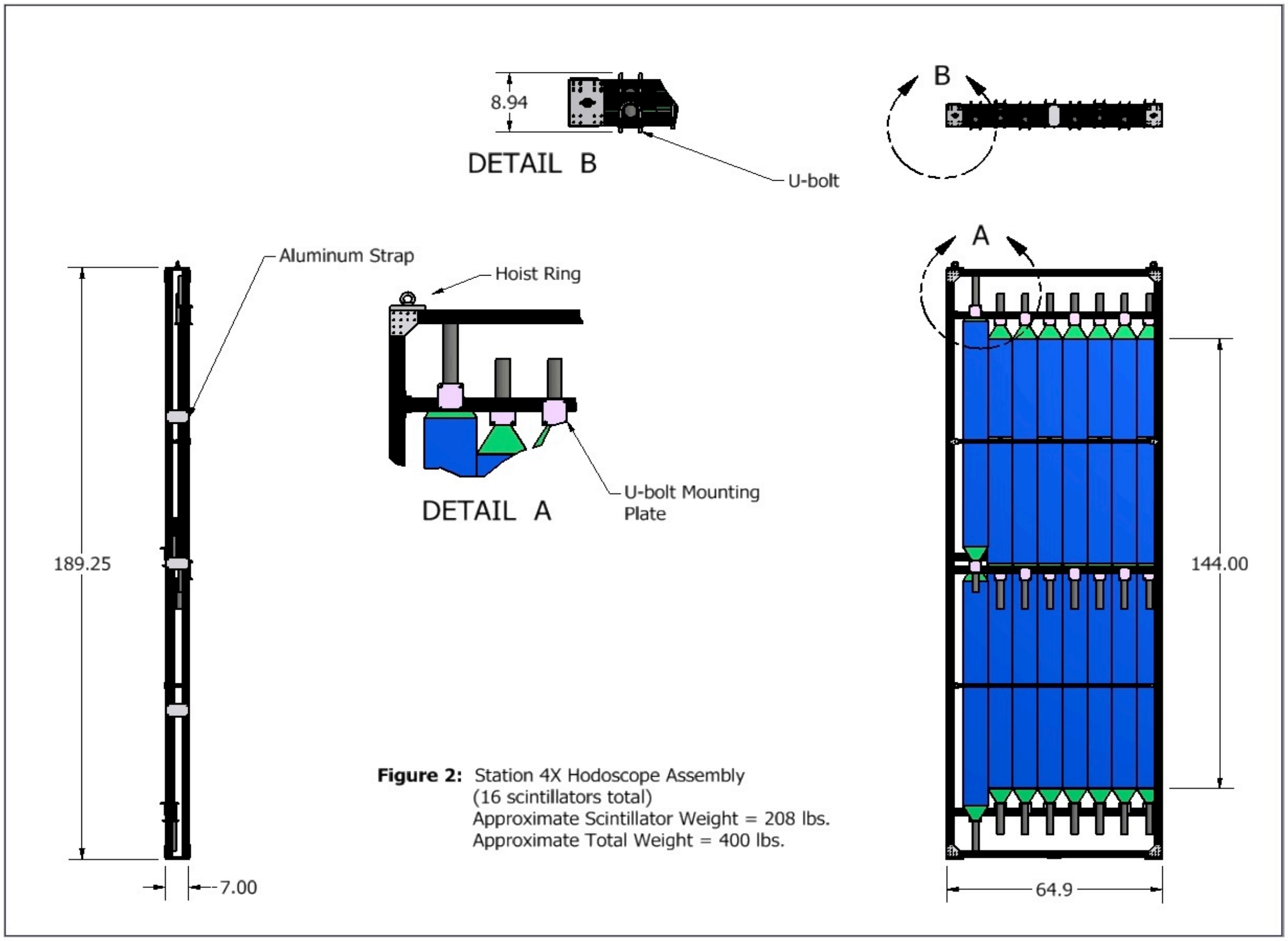

Figure 2: Station 4X Hodoscope Assembly
(16 scintillators total)
Approximate Scintillator Weight = 208 lbs.
Approximate Total Weight = 400 lbs.

The weight of the framework and mounting hardware is approximately 200 pounds and when this is added to the weight of the scintillators the total assembly weight is approximately 400 pounds. During assembly, the frames and tubes will be laid out horizontally. After assembly the entire package shown in Figure 2 will be lifted and rotated to be installed vertically into the E906 beamline. Table 1 lists the mechanical properties of the extrusion profiles relevant to this report.

Part No.	Cross Section	Area (in^2)	Material	lbs/foot	Ix (in^4)	Iy (in^4)
1020	1" x 2"	0.7914	6105-T5*	0.9212	0.3078	0.0833
2020	2" x 2"	1.2079	6105-T5*	1.4060	0.5509	0.5509

- UTS = 38ksi minimum, Yield = 35ksi minimum, Emod = 10.2e6 psi,
- Allowable Tensile Stress = 19.5ksi*

*(per Aluminum Design Manual Part IA, 1994).

Table 1 – Mechanical Properties of 8020 Extrusions in 4Y Prop Tube Assembly per 8020 Fractional Parts Catalog – 16th edition

ANALYSIS:
The hodoscope array will be built horizontally and then lifted/rotated and installed vertically in the E906 beamline with the tubes oriented vertically. The assembly must be strong enough to withstand the rotation from horizontal to vertical and also be strong enough to hang vertically for the duration of the experiment. Each of these cases is treated separately as follows:

Lifting/Rotating:
When the array assembly is horizontal it can be lifted at one edge and re-oriented to the vertical. If the assembly is supported along the top and bottom edges then the weight of the scintillators is essentially borne by four 2020 extrusions. If treated as beams supported on both ends subject to uniform loading then the stress and deflection can be calculated using standard formulas:

Stress at center of constant cross section: $s = \frac{-Wl}{8Z}$ **(1)**

Maximum deflection at center: $y = \frac{5}{384}\frac{Wl^3}{EI}$ **(2)**

Where:
- W is the weight supported by the beam (100-lb)
- l is the length (189.25 inches)
- I is the moment of inertia
- Z is the section modulus
- E is the modulus of elasticity

Substituting the values from Table 1 into equation (1) yields:

$$s = -\frac{1}{8}\left[\frac{100lb \times 189in}{\left(.5509in^4 \big/ 1in\right)}\right] = -4294lb/in^2$$

Likewise, substituting the values into equation (2) yields:

$$y = \frac{5}{384}\frac{100lb \times (189in)^3}{10.2e6psi \times 0.5509in^4} = 1.6in$$

The Allowable Bending Stress for a 2020 extrusion with a length of 189" (per Aluminum Design Manual Part IA, 1994) is 20,360psi. The maximum stress of 4294psi, when compared to this value for Allowable Bending Stress, provides a safety factor of 20360/4294 = 4.74. The maximum deflection of 1.6" occurs at the start of the rotation and will fall to zero as the array is made vertical.

Ultimately the weight of the entire array/framework assembly is held by two swivel-action hoist rings with 1/2-13 threads. These are bolted to steel plates which are in turn fastened to the framework using a total of twelve ¼-20 screws per plate (See Figure 2, Detail A, B). At the start of rotation all of these fasteners will experience a stress due to shear and this stress will vanish as the array is rotated. The maximum shear applied to the eyebolts and screws is calculated as follows:

> Each hoist ring supports approximately 200-lbs. The area of a ½-13 bolt, based on a minor diameter of 0.4041-in^2, is 0.128-in^2 and the resulting shear stress in each eyebolt is 200/0.128 = 1563psi. We have identified swivel eyebolts made from forged alloy steel type AISA-SAE 4140 (American Drill Bushing, part number 33515) with a minimum tensile strength of 180ksi, which is well in excess of the actual values stated above. These bolts are certified for a work load limit of work load limit of 2500-lbs with a pivot range of 180 degrees and a swivel range of 360 degrees and are suitable for this application.
>
> Also, each ¼-20 screw experiences a shear force of roughly 16.7-lbs. With a minor diameter of 0.1887 and an area of 0.0280in^2, the resulting shear stress in each ¼-20 screw is 595psi. Grade 5 screws with yield strength of 92ksi (per SAE J429) are readily available. Assuming shear strength is 60% of yield strength results in shear strength of 55ksi which is far in excess of the expected actual value.

Placement in E906 Beamline:
Once the detector assembly is vertical the weight of the scintillators is borne by two 2020 extrusion that run vertically along the edges of the framework. With an area of 1.2079in^2 (Table 1) and a weight per column of 200-lbs the tensile stress on each vertical extrusion is 200/1.2079 = 166psi and is not a cause for concern when compared to the allowable tensile stress of 19.5ksi.

The steel plates shown in Figure 3 (Detail A) will also experience stress and deflection as a result of the same 200-lb load. Assume the plate is made from 18-8 stainless steel with yield strength of 40ksi. If the plate is 7" long and 0.5" thick then the moment of inertia is 0.073-in^4, and the section modulus is 0.292-in^3. Under these conditions this plate will experience a stress of 599psi, which is well below the yield strength, and the deflection will be negligible.

Finally, in the beam line the weight of the entire array/framework assembly is held by the hoist rings and ¼-20 screws in tension (See Figure 2, Detail A). The tension in these components is calculated as follows:

> Each hoist ring experiences a tensile force of approximately 200-lbs which is well below the work load limit of 2500-lbs for the swivel eyebolts identified above.

Likewise, each ¼-20 screw experiences a tensile force of roughly 16.7-lbs. With a tensile stress area of $0.0318in^2$, the resulting tensile stress in each ¼-20 screw is 525.2, which is acceptable for Grade 5 screws per SAE J429.