The Geometry of the CLAS12 Pre-shower Calorimeter

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Abstract

In this note, the geometry of the CLAS12 Pre-shower Calorimeter (PCAL) is described. The description includes the basic geometry of the detector and the internal structure of the detector, the average scintillator width and thickness in each layer, the space between the scintillator strips and the walls of the PCAL box, the thickness of the lead sheets, readout arrangement and the readout fiber lengths. The location of the PCAL active region in the Hall-B coordinate system has been defined based on available survey data.

Contents

I. INTRODUCTION

One of the main goals of the CLAS12 physics program is to study the internal nucleon dynamics by accessing the nucleon's Generalized Parton Distributions (GPDs), which can be accomplished through measurements of cross sections and spin asymmetries in Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP) processes. These experiments depend on the ability to detect neutral and charged particles at high momentum. Every CLAS12 electroproduction experiment requires the reliable detection and identification of high energy electrons, where the electron identification will use shower energy in the electromagnetic calorimeter.

High-energy particles will be produced in the interaction of up to 11 GeV electron beams with a variety of targets for the proposed CLAS12 experiments. The electron identification will use shower energy in the electromagnetic calorimeter and, hence, requires good energy resolution for the full range of energies. The separation of a single high energy photon from the photons from π^0 decay is very important for the DVCS experiment. A single high energy photon is produced in the reaction $ep \to ep\gamma$ and the largest background to this process is from single π^0 production, $ep \to ep\pi^0$. In addition, direct π^0 production complements the DVCS measurements by accessing GPDs at low and high momentum transfer $|t|$. Clearly, good π^0 detection is crucial to separate these two processes.

High energy electron and neutral pion detection presents a challenge to the CLAS Electromagnetic Calorimeters (EC) that will be reused for CLAS12. Due to limited radiation length thickness, 15 r.l., a significant part of the electromagnetic shower from high energy electrons (> 7 GeV) will leak out from the back of the EC and will not be accounted for. This will result in a worsening of the energy resolution for high energy electrons. Neutral pions decay immediately into two photons with an opening angle that decreases as the π^0 momentum increases. The two photons from π^0 decay could not be distinguished from a single high energy photon by the EC for pion energies above 5 GeV. For full reconstruction of the high-energy showers and to separate high energy π^0's and photons, a Pre-shower Calorimeter detector (PCAL) was built and installed in front of the EC for the CLAS12 detector [1]. In the following sections, we describe the general geometrical properties of the PCAL.

II. GEOMETRY OF THE PCAL

The PCAL has a geometry similar to the CLAS EC. The PCAL active area is an isosceles triangle with a base length of 394 cm and a base angle $\alpha = 62.9^o$ (we will refer to the base as the back side). The PCAL active area is slightly larger than the acceptance of the EC projected towards the CLAS target to the location of the last layer of the PCAL, see Figure 1. Each PCAL module is composed of 15 scintillator layers sandwiched with 14 layers of lead, similar to the inner calorimeter of the CLAS EC. Each scintillator and lead layer is separated by a 50 μm Teflon sheet and the entire scintillator/lead volume is confined within a triangular shaped box that has composite front and rear windows and aluminum side plates as shown in Figure 2. Each window consists of 2 inch thick foam (FR-3715 Last-A-Foam, density 0.24 g cm^{-3}) sandwiched between a pair of 2 mm thick stainless steel sheets and supported by a stainless steel frame on the perimeter. Particles passing through the active area of the PCAL towards EC will pass through the forward entrance window, layers of lead and scintillaptor, and the rear exit window (as well as the entrance window of the EC). The full list of materials, their thicknesses and their densities are presented in Table I. These materials must be taken into account in the simulations.

All lead and scintillator layers inside the box are held in position by a retaining system attached to two of the sidewalls. This system also allows a space between the sidewall and the end of the scintillator strips in order to route light readout fibers out of the box to the PMTs, see Figure 3. The scintillator layers have three alternating stereo readout planes named U, V and W. Scintillator strips of varying lengths but with a fixed cross-sectional area of 4.5×1 cm^2 (design values), see Figure 4, are used to construct each U, V or W readout layer. In each stereo readout layer the strips are oriented parallel to one of the sides of the triangle. For the U-view, the strips are parallel to the back side (the base of the isosceles triangle, farthest from the beamline). For the W-view, the strips are parallel to the side on which the U readout is located, the PMTs are mounted. For the V view, the strips are parallel to the last remaining side. Light generated in the strips by ionizing radiation is transported to photomultiplier tubes (Hamamatsu R6095) mounted outside of the box via Kururay Y-11 1 mm diameter multi-clad wave-length shifting fibers inserted inside holes along the strips. There are 2 holes per strip and 2 fibers per hole are used to transport the

TABLE I: PCAL materials on the way of particles as seen from the target. Note: scintillators have ≤ 0.25 mm thick titanium dioxide (TiO_2) coating with density of 4.23 g/cm^3.

	Component name	Material type	Thickness	Density
Entrance Window	Entrance window skin	Stainless steel	0.2 cm	8 g cm^{-3}
	Window foam	FR-3715 Last-A-Foam	5.02 cm	0.24 g cm^{-3}
	Entrance window skin	Stainless steel	0.2 cm	8 g cm^{-3}
Repets 4 times	U-layer	Scnitillator	1 cm	1.03 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	Lead layer	Lead	0.22 cm	11.34 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	V-layer	Scnitillator	1 cm	1.03 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	Lead layer	Lead	0.22 cm	11.34 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	W-layer	Scnitillator	1 cm	1.03 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	Lead layer	Lead	0.22 cm	11.34 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
Last 3 layers	U-layer	Scnitillator	1 cm	1.03 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	Lead layer	Lead	0.22 cm	11.34 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	V-layer	Scnitillator	1 cm	1.03 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	Lead layer	Lead	0.22 cm	11.34 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
	W-layer	Scnitillator	1 cm	1.03 g cm^{-3}
	Teflon cover	Teflon	0.005 cm	2.2 g cm^{-3}
Exit Window	Exit window skin	Stainless steel	0.2 cm	8 g cm^{-3}
	Window foam	FR-3715 Last-A-Foam	5.02 cm	0.24 g cm^{-3}
	Exit window skin	Stainless steel	0.2 cm	8 g cm^{-3}

light to the photomultiplier, see Figure 4. The readout ends of the fibers are attached to the PMTs using optical grease, the opposite ends of the fibers stick out from the far end of the strips by ~ 1 mm and are spot glued to the scintillator.

There are 84 strips in the U-view, and 77 strips in the V- and W-views. In order to optimize the number of readout channels, pair of strips at large scattering angles were combined into a single readout channel (fibers from two adjacent strips were routed to a single PMT). For the U-view only the shortest 52 strips are read out individually with a single PMT. The longest 32 strips are paired into 16 channels, making a total of 68 readout channels for U-redout view (see Table II.) For the V- and W-views, the 47 longest strips are read out individually, while the 30 shortest strips are paired into 15 readout channels, bringing the total number of PMTs per view to 62 (Table III.) The overall readout arrangement is shown in Figure 5. The U-strips are read out from the left-side of the triangle as seen from the target looking to the middle of the sector. PMTs for the V- and W-views are located on the back-side of the triangle (farthest from the beamline).

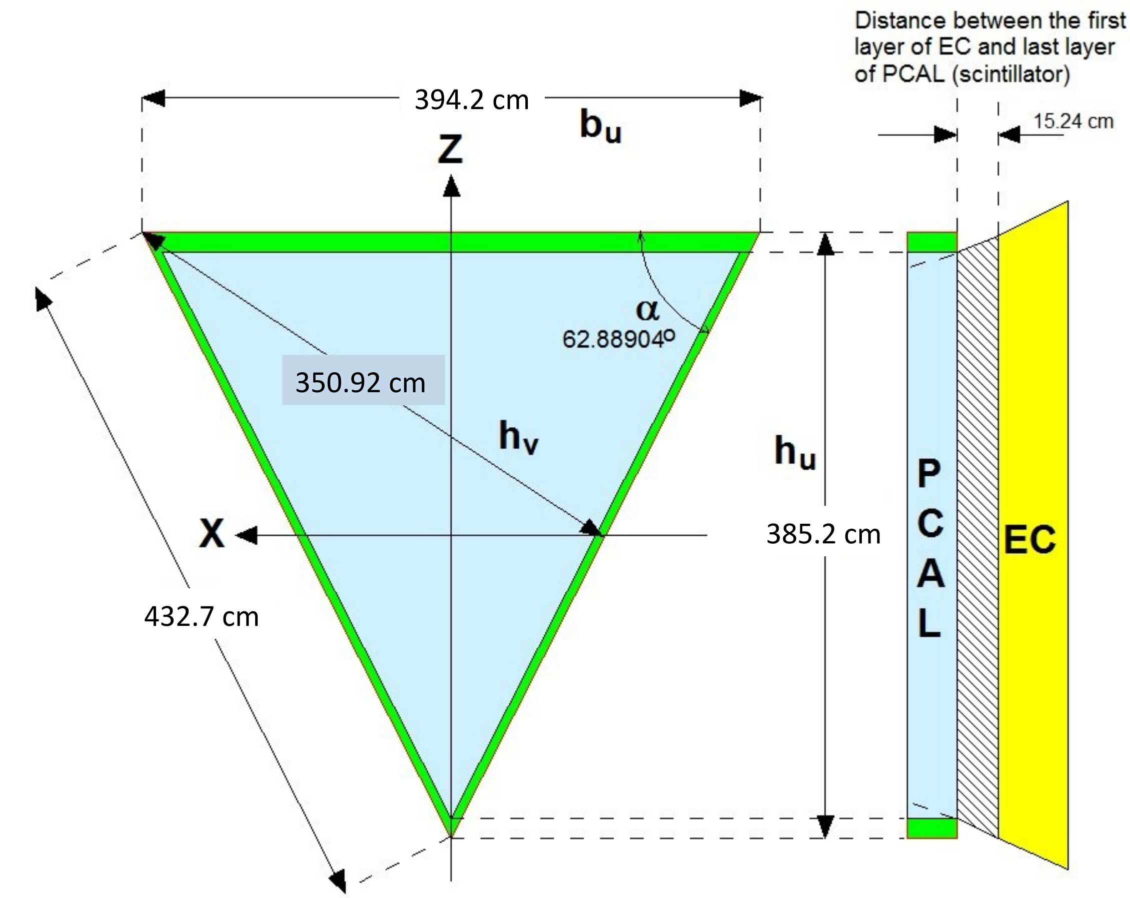

FIG. 1: A schematic plot showing the dimensions of a PCAL module. The design length L_1 of the longest scintillator strips are $L_1 = 394.2$ cm for the U strips and $L_1 = 432.7$ cm for the V and W strips.

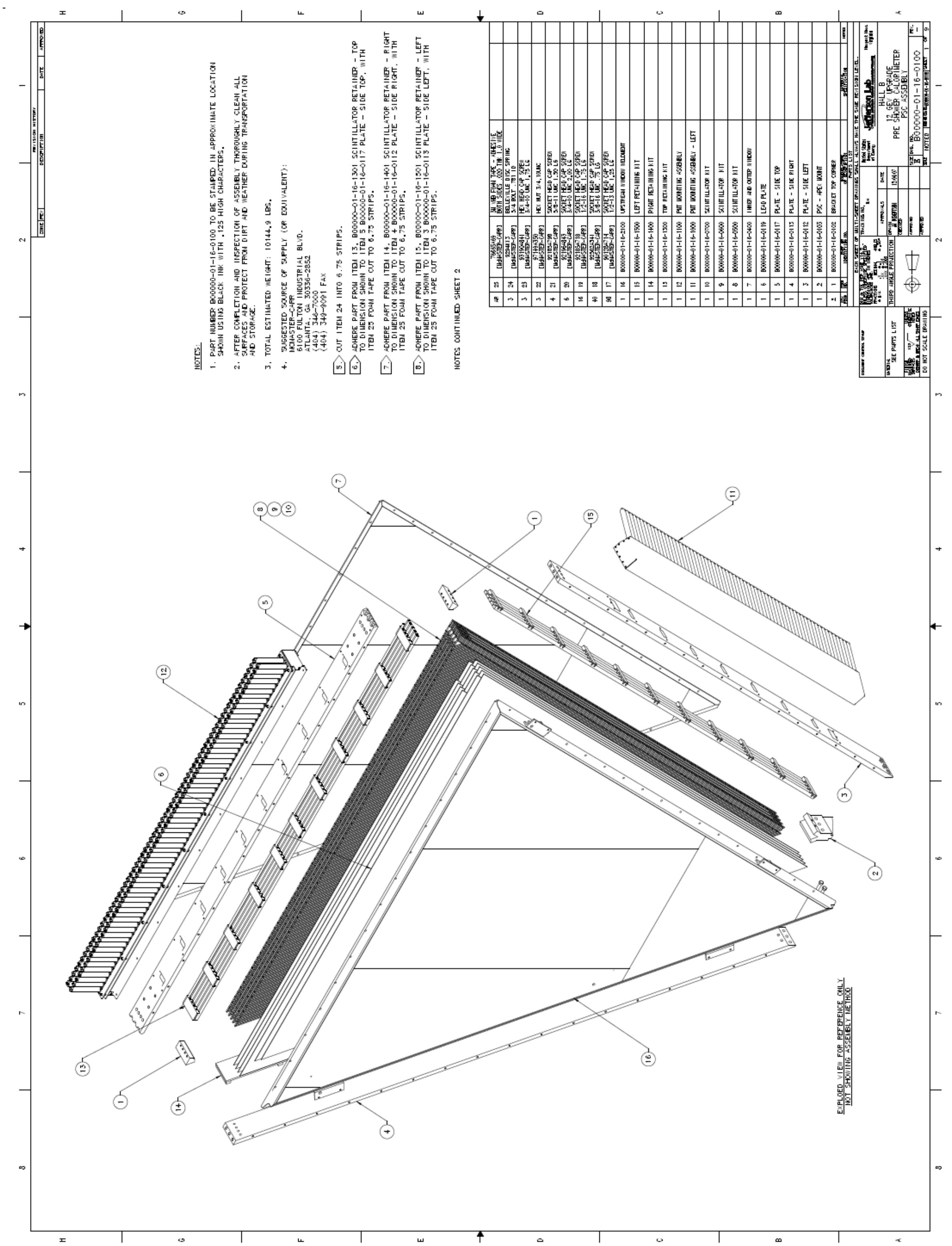

FIG. 2: Assembly drawing of the CLAS12 PCAL.

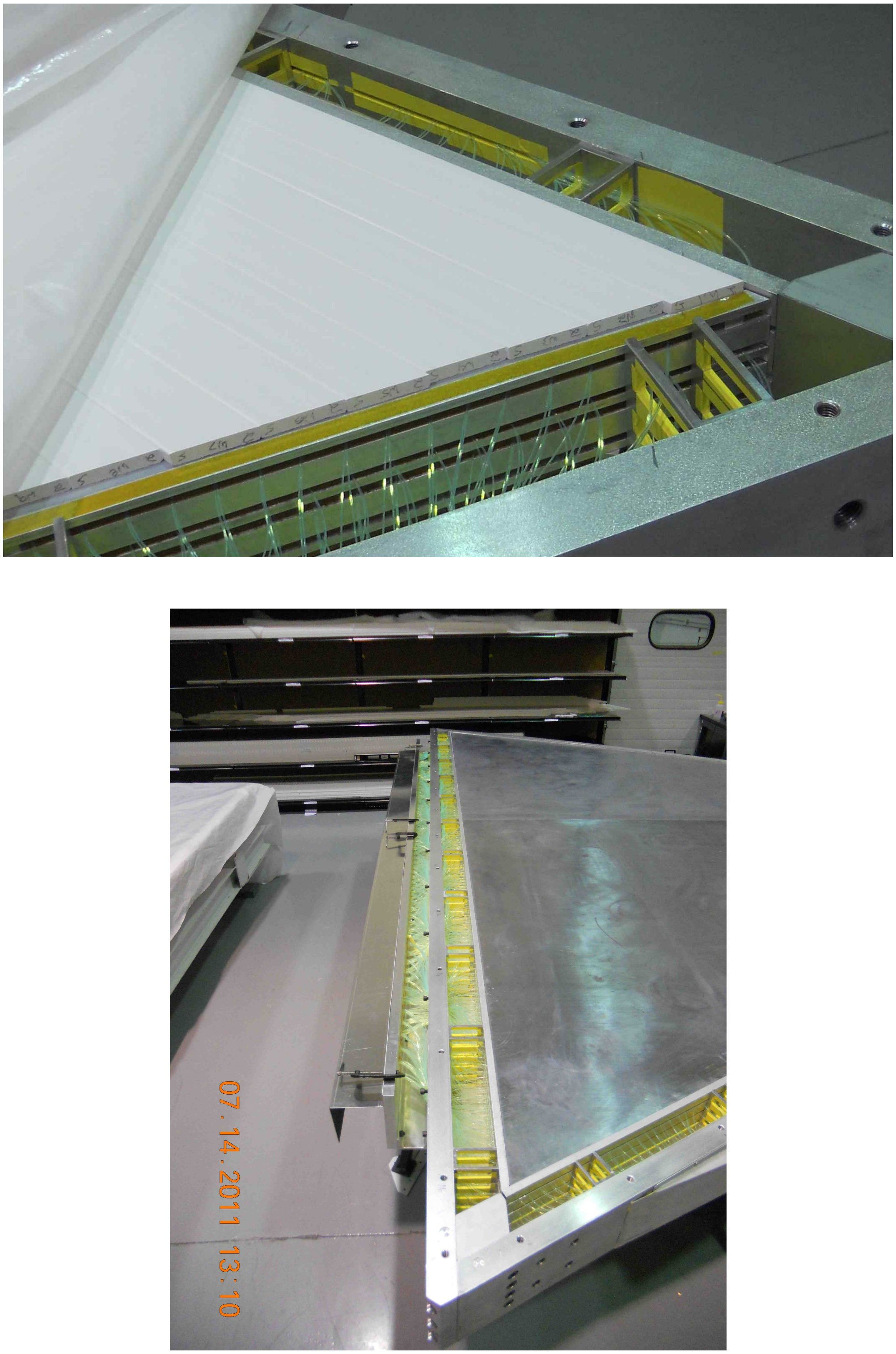

FIG. 3: Retainer assembly at the corner of the back-side and U-PMT readout side.

TABLE II: Correspondence between strips and PMTs for U strips. U1 is the shortest strip.

Strip	PMT	Strip	PMT	Strip	PMT	Strip	PMT	Strip	PMT	Strip	PMT
U1	U1	U15	U15	U29	U29	U43	U43	U57	U55	U71	U62
U2	U2	U16	U16	U30	U30	U44	U44	U58	U55	U72	U62
U3	U3	U17	U17	U31	U31	U45	U45	U59	U56	U73	U63
U4	U4	U18	U18	U32	U32	U46	U46	U60	U56	U74	U63
U5	U5	U19	U19	U33	U33	U47	U47	U61	U57	U75	U64
U6	U6	U20	U20	U34	U34	U48	U48	U62	U57	U76	U64
U7	U7	U21	U21	U35	U35	U49	U49	U63	U58	U77	U65
U8	U8	U22	U22	U36	U36	U50	U50	U64	U58	U78	U65
U9	U9	U23	U23	U37	U37	U51	U51	U65	U59	U79	U66
U10	U10	U24	U24	U38	U38	U52	U52	U66	U59	U80	U66
U11	U11	U25	U25	U39	U39	U53	U53	U67	U60	U81	U67
U12	U12	U26	U26	U40	U40	U54	U53	U68	U60	U82	U67
U13	U13	U27	U27	U41	U41	U55	U54	U69	U61	U83	U68
U14	U14	U28	U28	U42	U42	U56	U54	U70	U61	U84	U68

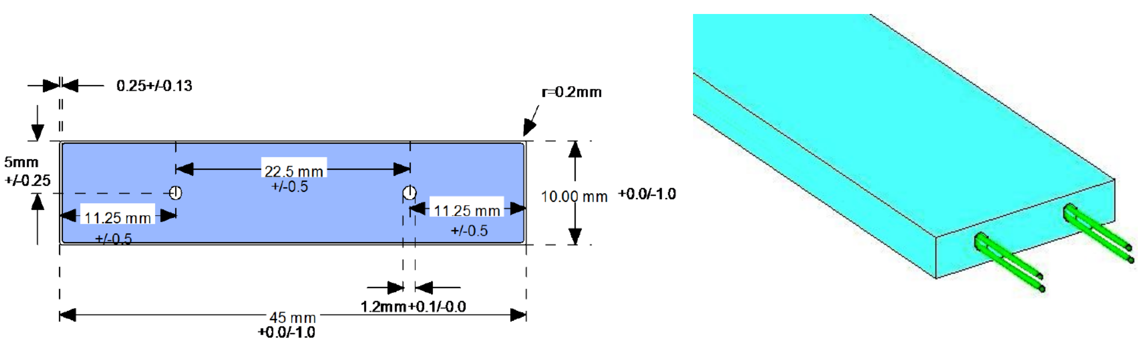

FIG. 4: (LEFT) designed dimensions of scintillator cross section. (RIGHT) rendering of the strip with two fibers in each hole.

TABLE III: Correspondence between strips and PMTs for V strips. V1 is the shortest strip. The W-view has the same strip-PMT correspondence.

Strip	PMT	Strip	PMT	Strip	PMT
V1	V1	V27	V14	V53	V38
V2	V1	V28	V14	V54	V39
V3	V2	V29	V15	V55	V40
V4	V2	V30	V15	V56	V41
V5	V3	V31	V16	V57	V42
V6	V3	V32	V17	V58	V43
V7	V4	V33	V18	V59	V44
V8	V4	V34	V19	V60	V45
V9	V5	V35	V20	V61	V46
V10	V5	V36	V21	V62	V47
V11	V6	V37	V22	V63	V48
V12	V6	V38	V23	V64	V49
V13	V7	V39	V24	V65	V50
V14	V7	V40	V25	V66	V51
V15	V8	V41	V26	V67	V52
V16	V8	V42	V27	V68	V53
V17	V9	V43	V28	V69	V54
V18	V9	V44	V29	V70	V55
V19	V10	V45	V30	V71	V56
V20	V10	V46	V31	V72	V57
V21	V11	V47	V32	V73	V58
V22	V11	V48	V33	V74	V59
V23	V12	V49	V34	V75	V60
V24	V12	V50	V35	V76	V61
V25	V13	V51	V36	V77	V62
V26	V13	V52	V37		

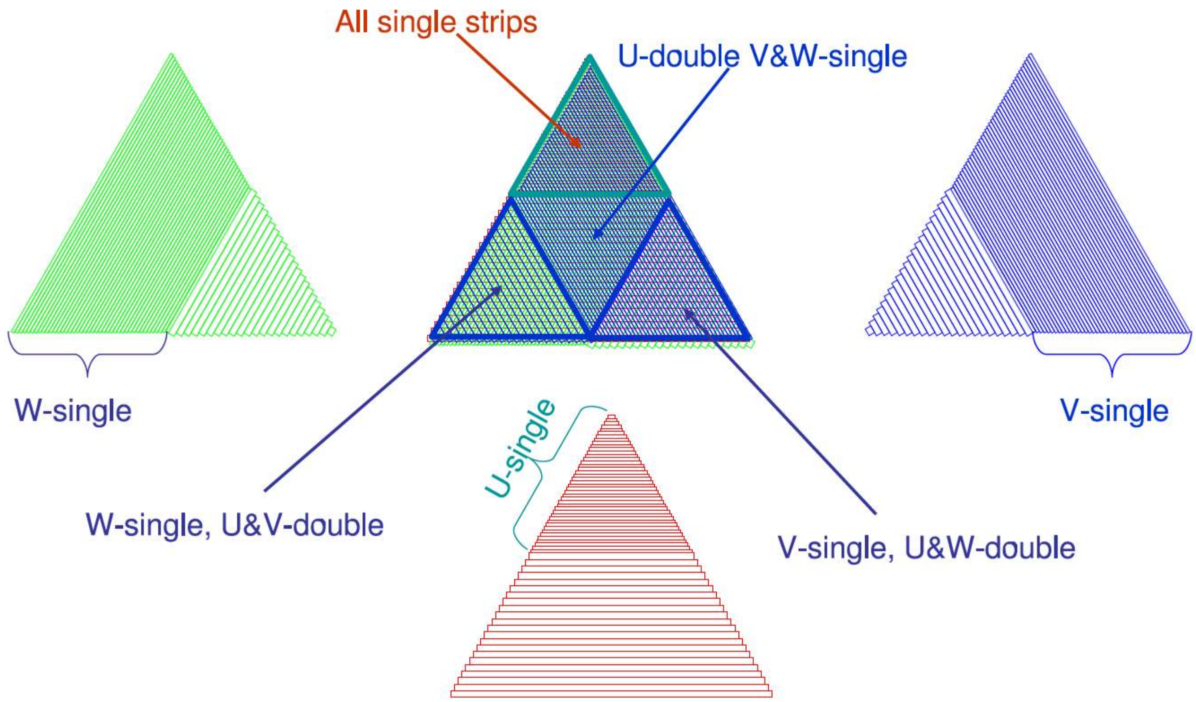

FIG. 5: Arrangement of readout channels for U (red), V (blue) and W (green) layers. The upper middle plot shows the superposition of all three views. The U PMTs are mounted on the left side of the triangle, as seen in this view from the target, while the V and W PMTs are mounted along the base.

III. SCINTILLATOR LAYERS

The scintillator strips used in PCAL were made by Fermi National Accelerator Laboratory (FNAL). These scintillator strips were produced using the extrusion method. The base material of the scintillator is polystyrene, and each strip has a diffuse reflecting surface made of TiO_2. This surface layer is co-extruded during the manufacturing process and has a thickness of < 0.25 mm. Each strip has two holes through the length of the strip (see Figure 4). These holes are also co-extruded during the manufacturing process [2]. The holes are big enough to allow easy insertion of two 1 mm diameter fibers.

The scintillator strips have been delivered to JLAB in two lengths: 420 cm (1450 strips) and 450 cm (2710 strips). The shorter strips are used for the U-view, and the long ones for the V- and W-views. Two PCAL strips were cut from each original strip. In Figures 14 to 16 in Appendix A, the scintilator layer, the shape and the design dimensions of the PCAL strips are shown. Note: in the tables presented on the figures there are 85 U-strips and 78 V- and W-strips. The shortest pieces in each layer are a dummy pieces and are now used in readout, have not even been furnished with fibers.

Due to the triangular shape of the layer, the length of each strip is defined by its position in the layer, and the exact position in the layer depends on the width of strips longer than that strip in the layer (stacking of layers starts from the longest strip). Therefore, the final cut length of the strips was determined based on the average width of the strips in the layer and thus varied slightly from the design value.

A. Strip widths

The average width for the scintillators in the given layer was measured before the scintillators were cut. To measure the average width, $\bar{\Delta}$, the original strips for that layer (42 original strips for the U layers and 39 original strips for the V and W layers) were laid down on a table, then the total width of the stack was measured and divided by the number of scintillators to get the average scintillator width. The scintillators were cut at JLab and at the College of William and Mary (WM). The U-strips for all modules and the V- and

W-strips for the first module were processed at JLab. The strips for the V- and W-views of the remaining five modules were measured and cut at WM. Table IV shows the average scintillator width of each layer for each PCAL module. The information for some of the layers has been lost. As one can see from the available data, the largest deviation from the design value for the width, 45 mm, is less than 0.3 mm, whereas the tolerance specified for this dimension was ±1 mm.

Together with measurements of the width, the thickness of the strips at several locations along their length was measured as well. In Figure 6 results from measurements of the thicknesses at several locations for fifteen 420 cm long strips are shown. Points #7 and #8 correspond to the end points, which have been cut out. In general thickness variations were < 0.3 mm (the tolerance on the thickness was 1 mm).

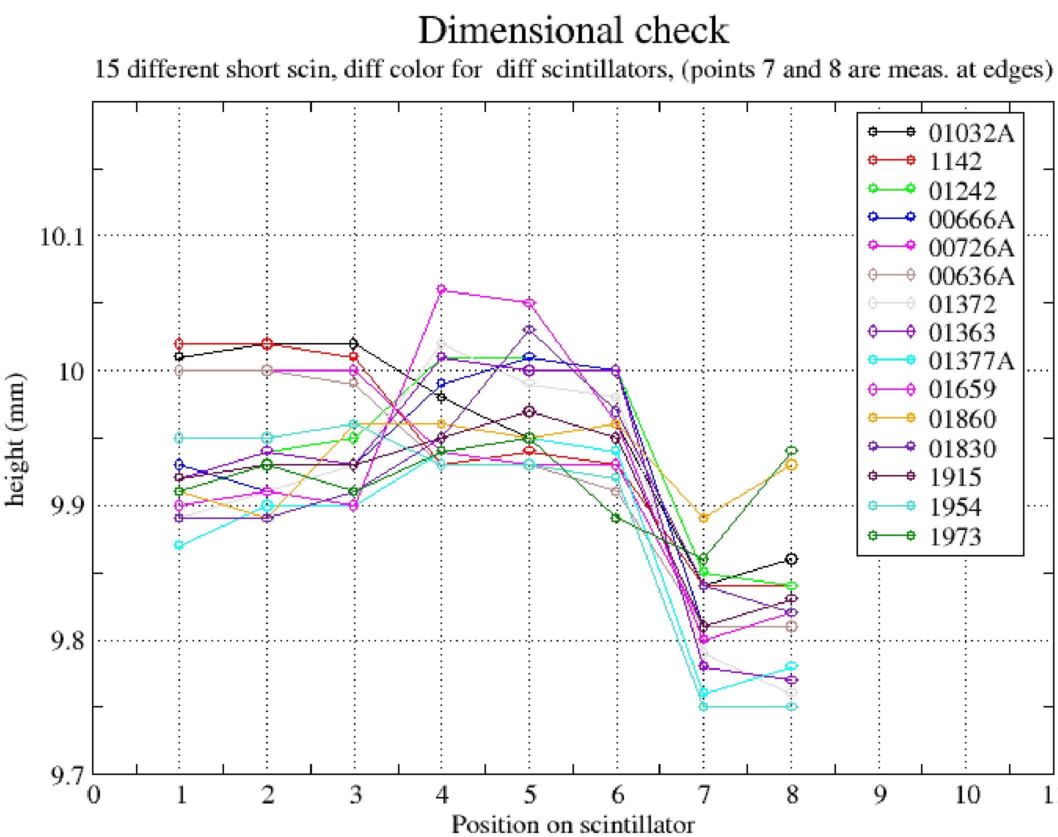

FIG. 6: Measured thickness for 15 strips at different locations along the 420 cm length.

layer	module 1	module 2	module 3	module 4	module 5	module 6
U1	45.26 mm	45.18 mm	45.17 mm	45.29 mm	45.28 mm	45.24 mm
U2	45.26 mm	45.18 mm	45.17 mm	45.29 mm	45.28 mm	45.24 mm
U3	45.26 mm	45.18 mm	45.17 mm	45.29 mm	45.28 mm	45.24 mm
U4	45.26 mm	45.18 mm	45.17 mm	45.29 mm	45.28 mm	45.24 mm
U5	45.26 mm	45.18 mm	45.17 mm	45.29 mm	45.28 mm	45.24 mm
V1	45.13 mm		45.10 mm	45.03 mm	45.03 mm	45.06 mm
V2	45.14 mm		45.05 mm	45.02 mm	45.02 mm	45.12 mm
V3	45.15 mm		45.06 mm	45.02 mm	45.02 mm	
V4	45.14 mm		45.06 mm	45.00 mm	45.00 mm	
V5	45.13 mm		45.09 mm	49.97 mm	45.01 mm	
W1	45.12 mm		45.04 mm	45.13 mm	45.03 mm	45.11 mm
W2	45.12 mm		45.03 mm	45.11 mm	45.07 mm	45.11 mm
W3	45.12 mm		45.06 mm	45.12 mm	45.07 mm	
W4	45.12 mm			45.16 mm	45.01 mm	
W5	45.12 mm		45.04 mm		45.04 mm	

TABLE IV: The average scintillator width of each layer.

IV. POSITION OF THE SCINTILLATOR LAYERS IN THE BOX

The 15 scintillator layers and 14 lead layers of each module are sealed in a box with aluminum sidewalls and composite windows. The area of each layer is the same and is defined by the retaining system installed on two of the sidewalls (identified by "retaining bar" in Figure 7). In each layer, the strips are lined up against two sides of the triangle, and are shimmed with springs on the third side. For all three layers, the readout does not include the tip of the triangle for that layer (indicated for the U layer by the small red triangle in Figure 7). The size of these regions (height of the small triangle) is typically < 5 cm.

The U strips are lined up and pressed against a retaining bar at the back sidewall (the longest side of the longest strip is in direct contact with the retaining bar). The readout ends of the U-strips with the 27.1 degree cut are pressed against the retaining bars on the

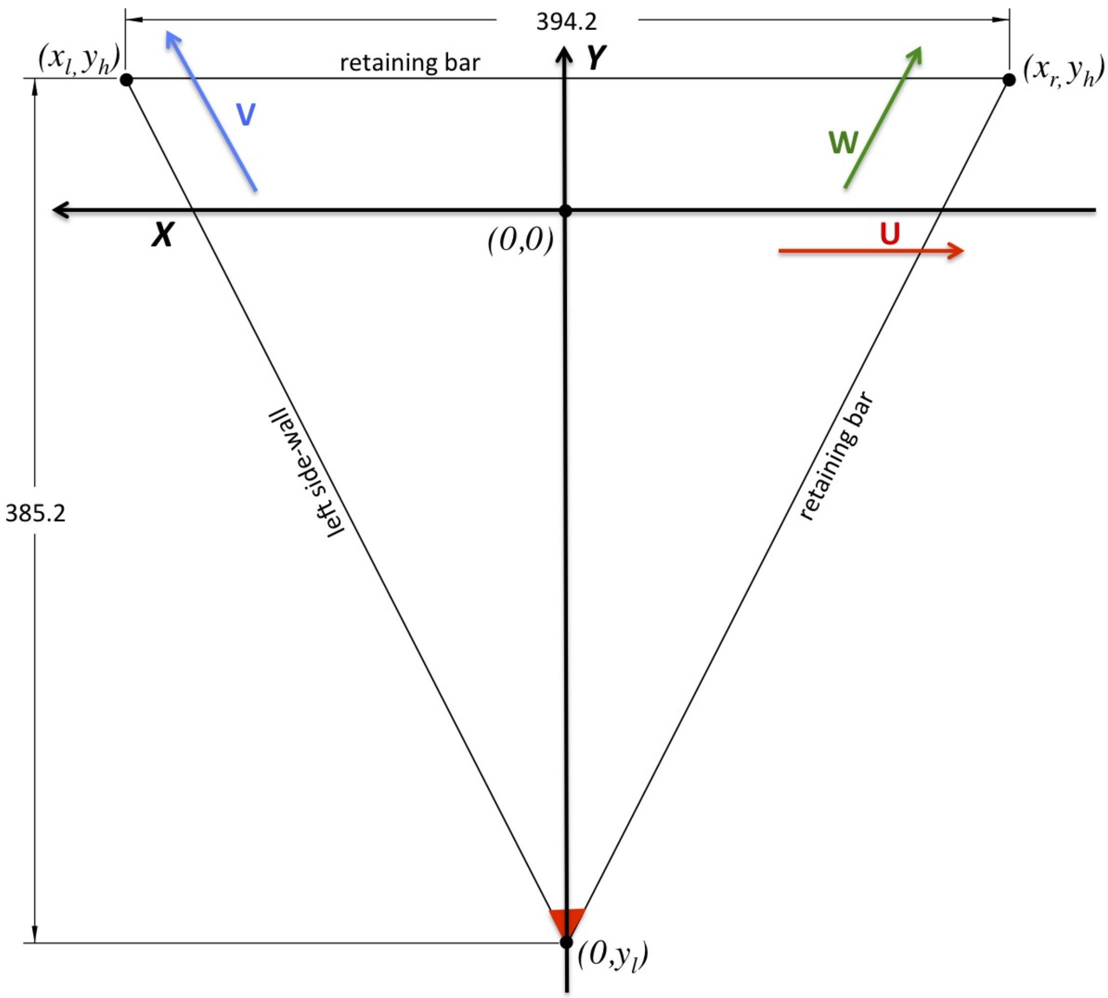

FIG. 7: The area defined for a scintillator layer. Dimensions are in cm. The local PCAL coordinate system (X, Y) is shown, where the origin defines the point where a line from the target is perpendicular to the (X,Y) plane. The strip direction and readout ends are indicated by arrows. The view is from the target looking downstream.

right-side wall (as seen from the target looking towards the sector mid plane.) The longest U strip was cut to the length L_1 specified by the design (see Figure 14), while the other strips were cut according to the following formula:

$$L_{ij} = L_1 - 2 \times (i-1) \times \bar{\Delta}_j \times \tan(27.1^o), \tag{1}$$

where j is the layer number, i is the strip number, and the $\bar{\Delta}_j$ is the average width of the strips in the layer i as given in Table IV.

The V strips were lined up and pressed against the left sidewall in Figure 7. The readout ends with the 27.1 degree cut are pressed against the retaining bars on the back sidewall and the cut formula is:

$$L_{ij} = L_1 - (i-1) \times \bar{\Delta}_j \times (\tan(27.1^o) + \tan(35.8^o)). \tag{2}$$

The notations of i, j, and $\bar{\Delta}_j$ are the same as for Eq.(1) and the available average widths for the V layers are presented in Table IV. The L_1 value for V-layer is shown in Figure 15.

The W strips were lined up against the retaining system of the right sidewall (the longest strip is in contact with the retaining system aluminum bar). The readout ends with the 27.1 degree cut are pressed against the retaining bar on the back sidewall. The lengths for the W strips were calculated according to Eq.2 and the average widths for the W layers are presented in Table IV as well. The L_1 value for W-layer is shown in Figure 16.

The scintillator strips were shimmed at the opposite to the readout ends. The gap between the end of the strip and the sidewalls (for the U and W layers) or the retaining support (V layer) was measured for Module #6 using an electronic caliper. In Table IX the sizes of the gaps between the support and the scintillator ends for one layer of U, V and W views are shown. In Figure 8, the alignment of the readout end of the V strips (top) and the alignment of the U strips (bottom) are shown. Once all scintillators in the layer were in place, a small piece of scintillator about $3 - 4$ cm wide was installed to fill the gap at the tip of the triangle (bottom photo of Figure 8).

The lead layers were shimmed as well to eliminate gaps between the sidewall (or retaining supports) and the edge of the lead sheet.

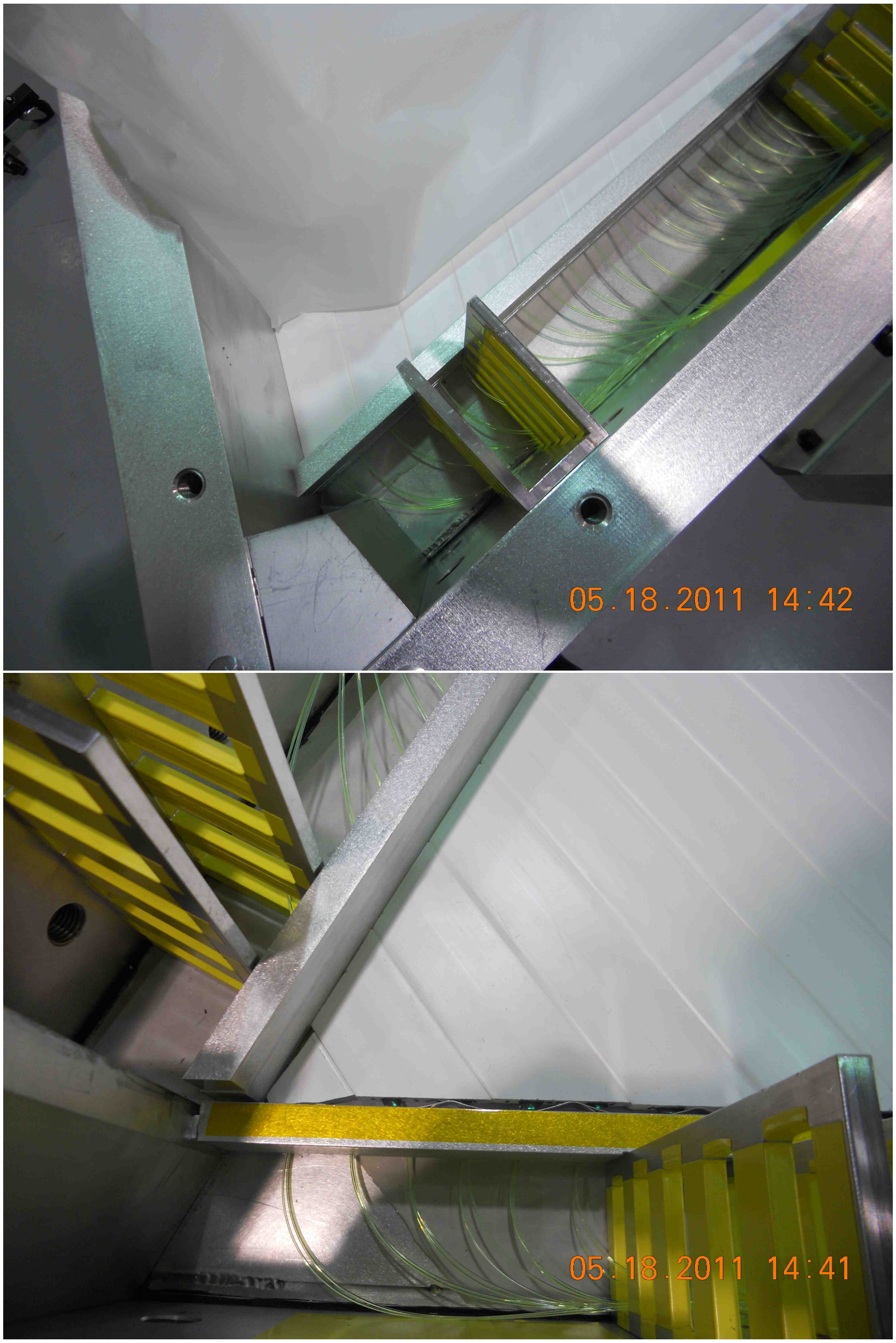

FIG. 8: (TOP) Alignment of the V strips at the readout end against the retaining system of the U readout layer. (BOTTOM) Opposite end to readout shows springs and shims (U layer).

V. PCAL COORDINATE SYSTEM AND THE READOUT CHANNELS

As shown in Figure 7, the base b and height h of the PCAL triangle are $b = 394.2$ cm and $h = 385.2$ cm. The base angle is $\alpha = 62.9$ degrees. Note that this triangle defines the region of the overlap of three views, while the individual layers are slightly smaller. We define the PCAL coordinate system as an (xyz) cartesian system with the x-axis parallel to the base of the triangle and going from right to left when looking downstream along the beam. The direction of the Y-axis points from the apex of the triangle towards the base (away from the beam) and coincides with the height of the isosceles triangle. The left corner of the base (as seen from the target) is at $x_l = b/2 = 197.1$ cm and $y_h = 94.4$ cm and the right corner is at $x_r = -b/2 = -197.1$ cm and $y_h = 94.4$ cm. The apex is at $x = 0$ cm and $y_l = -290.8$ cm. The line connecting the CLAS12 center and the PCAL coordinate center is perpendicular to the (xy) plane, coincides with z direction and forms 25 degree angle with beam direction, see Figure 9. Each readout channel is a line on this plane, parallel to one of the sides. A hit is defined as an intersection of three readout lines (or strips) and is a point on the (xy) plane. The z-coordinate is defined in such a way that the upstream face of the scintillators for U Layer-1 is at $z = 0$ and the z-axis direction points downstream.

A. U stereo coordinates

The U layer strips are parallel to the base or back sidewall of the triangle, with the longest strip flush against the retaining bar of the back wall, so the longest edge of the longest strip is at $y = 94.39$ cm. As was discussed above there are 84 scintillator strips in the U layers but only the shortest 52 strips are readout individually, while the longest 32 strips are paired to form 16 readout channels. The U PMT readout edge is defined by $y = y_h - (x_r - x) \times \tan(\alpha)$ and it is useful to define a length u parallel to this readout edge. For the readout channel (PMT) U$_j$, the so called u-coordinate will be defined as:

$$u_j = \begin{cases} (j - \frac{1}{2}) \cdot \frac{\bar{\Delta}}{\sin(\alpha)} & : j \leq 52 \\ (2 \cdot j - 53) \cdot \frac{\bar{\Delta}}{\sin(\alpha)} & : j > 52, \end{cases} \qquad (3)$$

where $\bar{\Delta}$ is the average width of the layer. This notation assumes that the shortest strip (#84 on the engineering drawing) is the first readout channel (j=1).

In the PCAL (XY) coordinate system, only the y coordinate is defined for the U readout channels. For the U readout channel j, y_j is defined as:

$$y_j = y_0^U + u_j \cdot \sin(\alpha), \tag{4}$$

where

$$y_0^U = y_h - 84 \cdot \bar{\Delta} \tag{5}$$

The X coordinate of a U channel is undefined and will be in the range:

$$-\frac{x_r}{h} \cdot (y_j - y_l) < x_j < \frac{x_r}{h} \cdot (y_j - y_l). \tag{6}$$

The above definition of y_j includes the fact that the U strips are flush against the back sidewall retaining bar and the location of each strip is defined relative to this bar.

B. V stereo coordinates

The V layer strips are parallel to the left side of the triangle as defined in Figure 7, with the longest V strip flush against the sidewall. There are 77 scintillator strips in the V layers. For the V readout, the shortest 30 strips are paired into 15 readout channels, while longest 47 strips are readout individually to a single PMT channel. The coordinate v_j on the readout side for channel j is defined as:

$$v_j = \begin{cases} (2 \cdot j - 1) \cdot \frac{\bar{\Delta}}{\sin(\alpha)} & : j \leq 15 \\ (j + 14.5) \cdot \frac{\bar{\Delta}}{\sin(\alpha)} & : j > 15. \end{cases} \tag{7}$$

The x coordinate of the V channel j at $y_j = y_h$ is:

$$x_j = x_0^V + v_j, \tag{8}$$

where

$$x_0^V = x_l - 77 \cdot \frac{\bar{\Delta}}{\sin(\alpha)}, \tag{9}$$

The correlation between the x and y coordinate of the V hits is:

$$y = y_h - (x - x_j) \cdot \tan(\alpha). \tag{10}$$

C. W stereo coordinates

The W layer strips are parallel to the right side of the triangle as defined in Figure 7, with the longest W strip flush against the retaining bar of the U readout side. The readout arrangement is very similar to the V view. There are 77 scintillator strips in the W layers. For the W readout, the shortest 30 strips are paired into 15 readout channels, while the longest 47 strips are readout individually to a single channel. The coordinate on the readout edge, w_j, is defined exactly the same way as in Eq.7:

$$w_j = \begin{cases} (2 \cdot j - 1) \cdot \frac{\bar{\Delta}}{\sin(\alpha)} & : j \leq 15 \\ (j + 14.5) \cdot \frac{\bar{\Delta}}{\sin(\alpha)} & : j > 15. \end{cases} \tag{11}$$

The x coordinate of the W channel j at $y_j = y_h$ is defined as:

$$x_j = x_0^W - w_j, \tag{12}$$

where

$$x_0^W = x_r + 77 \cdot \frac{\bar{\Delta}}{\sin(\alpha)}. \tag{13}$$

The correlation between the x and y coordinate of the W hits is:

$$y = y_h - (x_j - x) \cdot \tan(\alpha). \tag{14}$$

VI. PCAL HIT POINT IN THE CLAS12 COORDINATE SYSTEM

We define the CLAS12 coordinate system as a cartesian (X_C, Y_C, Z_C) system, where Z_C points along the beam, X_C is the horizontal axis pointing to the left looking downstream of the target (along the Z_C axis) and Y_C is the vertical axis pointing upwards.

With simple transformations any point in the PCAL (xyz) coordinate system can be transformed into the CLAS12 (X_C,Y_C,Z_C) coordinate system. First we perform a transformation from the PCAL coordinate system to the so-called sector coordinate system. In the sector coordinate system Z_S coincides with Z_C, but the $X_S Z_S$ plane defines the mid-plane of each sector. The relation between (X_S,Y_S,Z_S) and (X,Y,Z) is:

$$\begin{pmatrix} X_S \\ Y_S \\ Z_S \end{pmatrix} = \begin{bmatrix} 0 & \cos(\beta) & \sin(\beta) \\ 1 & 0 & 0 \\ 0 & -\sin(\beta) & \cos(\beta) \end{bmatrix} \times \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix}, \tag{15}$$

where $\beta = 25°$ is the angle between the PCAL z and Sector Z_s (or CLAS12 Z_C) axes. The constants $x_0 = 294.9$ cm, $y_0 = 0$, and $z_0 = 632.4$ cm are the coordinates of the PCAL coordinate system center in the sector coordinate system, see Figure 9.

The next step is to perform a rotation according to each sector location to transform (X_S,Y_S,Z_S) to (X_C,Y_C,Z_C):

$$\begin{pmatrix} X_C \\ Y_C \\ Z_C \end{pmatrix} = \begin{bmatrix} \cos(\phi) & -\sin(\phi) & 0 \\ \sin(\phi) & \cos(\phi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{pmatrix} X_S \\ Y_S \\ Z_S \end{pmatrix}. \tag{16}$$

Here $\phi = (n-1) \times 60°$, where n is the sector number. The above translation of (x,y,z) to (X_C,Y_C,Z_C) is for the case of ideal alignment. There is a known translational shift in the origin of the PCAL coordinate system of $\Delta x = +0.953$ cm to allow additional clearance of the U PMTs from the EC sidewalls [3].

VII. FIBERS

In order to correctly reconstruct the shower energy, attenuation of the light reaching the PMTs must be taken into account. The attenuation length of the wave-shifting fibers is $L_0 \sim 400$ cm using a single exponential fit, one may consider to use two exponential correction for better accuracy. The distance light travels, $L = L_h + L_f$, depends on the distance from the hit position to the readout end of the scintillator, L_h, and on the length of the fibers from the readout end of the strip to the PMT, L_f. The light intensity at the PMT (I) relative to the light produced at the interaction point (I_m) is given by:

$$I = I_m \cdot e^{-L/L_0} \tag{17}$$

The fiber lengths from the readout ends of each strip to the PMT are given in Tables V, VI, and VII.

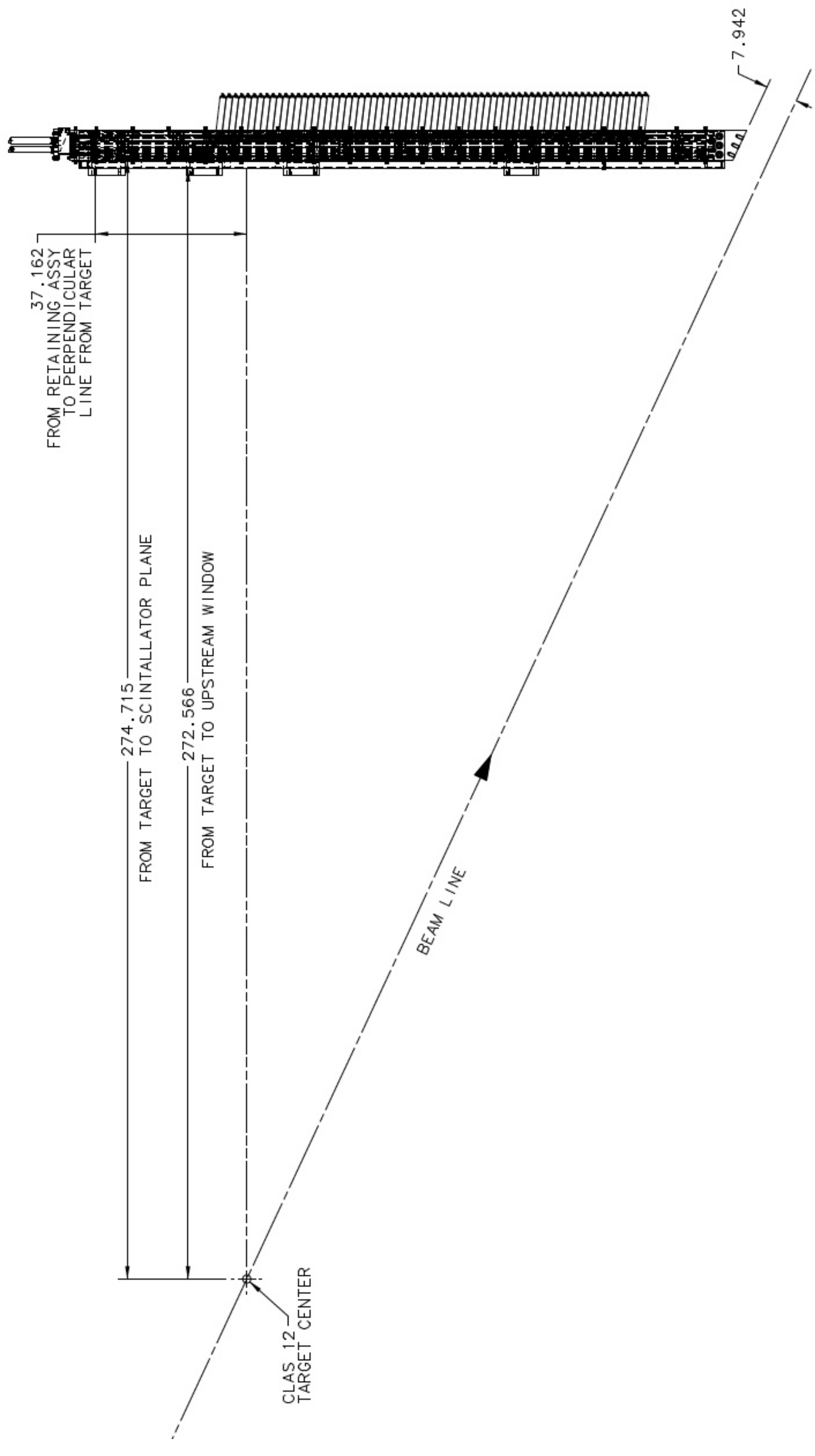

FIG. 9: PCAL position relative to the CLAS12 center and beamline (units are in inches).

TABLE V: Length of the fibers from the readout end of the U-strips to the PMT cathode.

Strip	L_f (cm)	Strip	L_f (cm)	Strip	L_f (cm)	Strip	L_f (cm)
U1	82	U23	66	U45	59	U67	44
U2	81	U24	66	U46	50	U68	46
U3	81	U25	65	U47	49	U69	47
U4	80	U26	64	U48	49	U70	49
U5	79	U27	64	U49	48	U71	50
U6	78	U28	63	U50	47	U72	52
U7	78	U29	62	U51	46	U73	53
U8	77	U30	61	U52	47	U74	56
U9	76	U31	61	U53	45	U75	57
U10	76	U32	60	U54	44	U76	59
U11	75	U33	59	U55	44	U77	60
U12	74	U34	59	U56	43	U78	62
U13	74	U35	58	U57	42	U79	63
U14	73	U36	57	U58	41	U80	65
U15	72	U37	57	U59	41	U81	67
U16	71	U38	56	U60	40	U82	69
U17	71	U39	55	U61	40	U83	73
U18	70	U40	54	U62	39	U84	75
U19	69	U41	54	U63	39		
U20	69	U42	53	U64	39		
U21	68	U43	52	U65	40		
U22	67	U44	51	U66	42		

TABLE VI: Length of the fibers from the readout end of the V-strips to the PMT cathode.

Strip	L_f (cm)	Strip	L_f (cm)	Strip	L_f (cm)	Strip	L_f (cm)
V1	50	V21	42	V41	51	V61	54
V2	49	V22	43	V42	52	V62	55
V3	49	V23	43	V43	52	V63	55
V4	48	V24	44	V44	52	V64	55
V5	47	V25	45	V45	52	V65	55
V6	46	V26	46	V46	52	V66	55
V7	46	V27	56	V47	52	V67	55
V8	45	V28	47	V48	52	V68	56
V9	44	V29	48	V49	53	V69	56
V10	43	V30	49	V50	53	V70	56
V11	43	V31	49	V51	53	V71	56
V12	42	V32	50	V52	53	V72	56
V13	41	V33	50	V53	53	V73	56
V14	40	V34	50	V54	53	V74	56
V15	40	V35	51	V55	54	V75	57
V16	39	V36	51	V56	54	V76	57
V17	39	V37	51	V57	54	V77	57
V18	40	V38	51	V58	54		
V19	40	V39	51	V59	54		
V20	41	V40	51	V60	54		

TABLE VII: Length of the fibers from the readout end of the W-strips to the PMT cathode.

Strip	L_f (cm)	Strip	L_f (cm)	Strip	L_f (cm)	Strip	L_f (cm)
W1	50	W21	42	W41	51	W61	54
W2	49	W22	43	W42	52	W62	55
W3	49	W23	43	W43	52	W63	55
W4	48	W24	44	W44	52	W64	55
W5	47	W25	45	W45	52	W65	55
W6	46	W26	46	W46	52	W66	55
W7	46	W27	56	W47	52	W67	55
W8	45	W28	47	W48	52	W68	56
W9	44	W29	48	W49	53	W69	56
W10	43	W30	49	W50	53	W70	56
W11	43	W31	49	W51	53	W71	56
W12	42	W32	50	W52	53	W72	56
W13	41	W33	50	W53	53	W73	56
W14	40	W34	50	W54	53	W74	56
W15	40	W35	51	W55	54	W75	57
W16	39	W36	51	W56	54	W76	57
W17	39	W37	51	W57	54	W77	57
W18	40	W38	51	W58	54		
W19	40	W39	51	W59	54		
W20	41	W40	51	W60	54		

Layer	Module 1	Module 2	Module 3	Module 4	Module 5	Module 6
1	2.16 mm	2.12 mm	2.18 mm	2.15 mm	2.09 mm	2.10 mm
2	2.19 mm	2.12 mm	2.12 mm	2.17 mm	2.13 mm	2.11 mm
3	2.16 mm	2.13 mm	2.12 mm	2.18 mm	2.16 mm	2.19 mm
4	2.20 mm	2.15 mm	2.24 mm	2.18 mm	2.05 mm	2.18 mm
5	2.20 mm	2.15 mm	2.13 mm	2.19 mm	2.09 mm	2.15 mm
6	2.15 mm	2.16 mm	2.18 mm	2.16 mm	2.08 mm	2.14 mm
7	2.16 mm	2.17 mm	2.05 mm	2.14 mm	2.09 mm	2.09 mm
8	2.20 mm	2.09 mm	2.11 mm	2.08 mm	2.08 mm	2.08 mm
9	2.16 mm	2.17 mm	2.12 mm	2.13 mm	2.15 mm	2.13 mm
10	2.17 mm	2.14 mm	2.22 mm	2.15 mm	2.10 mm	2.17 mm
11	2.15 mm	2.14 mm	2.20 mm	2.10 mm	2.12 mm	2.10 mm
12	2.16 mm	2.19 mm	2.17 mm	2.09 mm	2.16 mm	2.15 mm
13	2.16 mm	2.17 mm	2.20 mm	2.12 mm	2.13 mm	2.11 mm
14	2.20 mm	2.12 mm	2.20 mm	2.06 mm	2.08 mm	2.17 mm
Average	2.17 mm	2.14 mm	2.16 mm	2.14 mm	2.10 mm	2.13 mm

TABLE VIII: The mean thickness of each lead layer in Modules 1-6.

VIII. LEAD THICKNESS

Between two scintillator layers, there is one lead layer. For each PCAL module, there are a total of 14 lead layers. Each lead layer consists of two right-angle triangle shaped lead sheets. The hypotenuse of each triangle is parallel to the V or W sidewall (see Figure 10). To measure the thickness of each lead layer, 36 sample points were measured for each piece of lead (see Figure 11), which resulted in a total of 72 sample points for each lead layer. The thickness of each sample point was measured using the CHECK·LINE TI-25DL ultrasonic thickness gauge. Appendix C gives the detail of each sample point measurement (units are in mm). To get the average thickness for each layer, we averaged 72 sample points per layer. Table VIII gives the average thickness for each lead layer of each module. Figure 12 shows a distribution of the measured points for the lead sheets from all six modules.

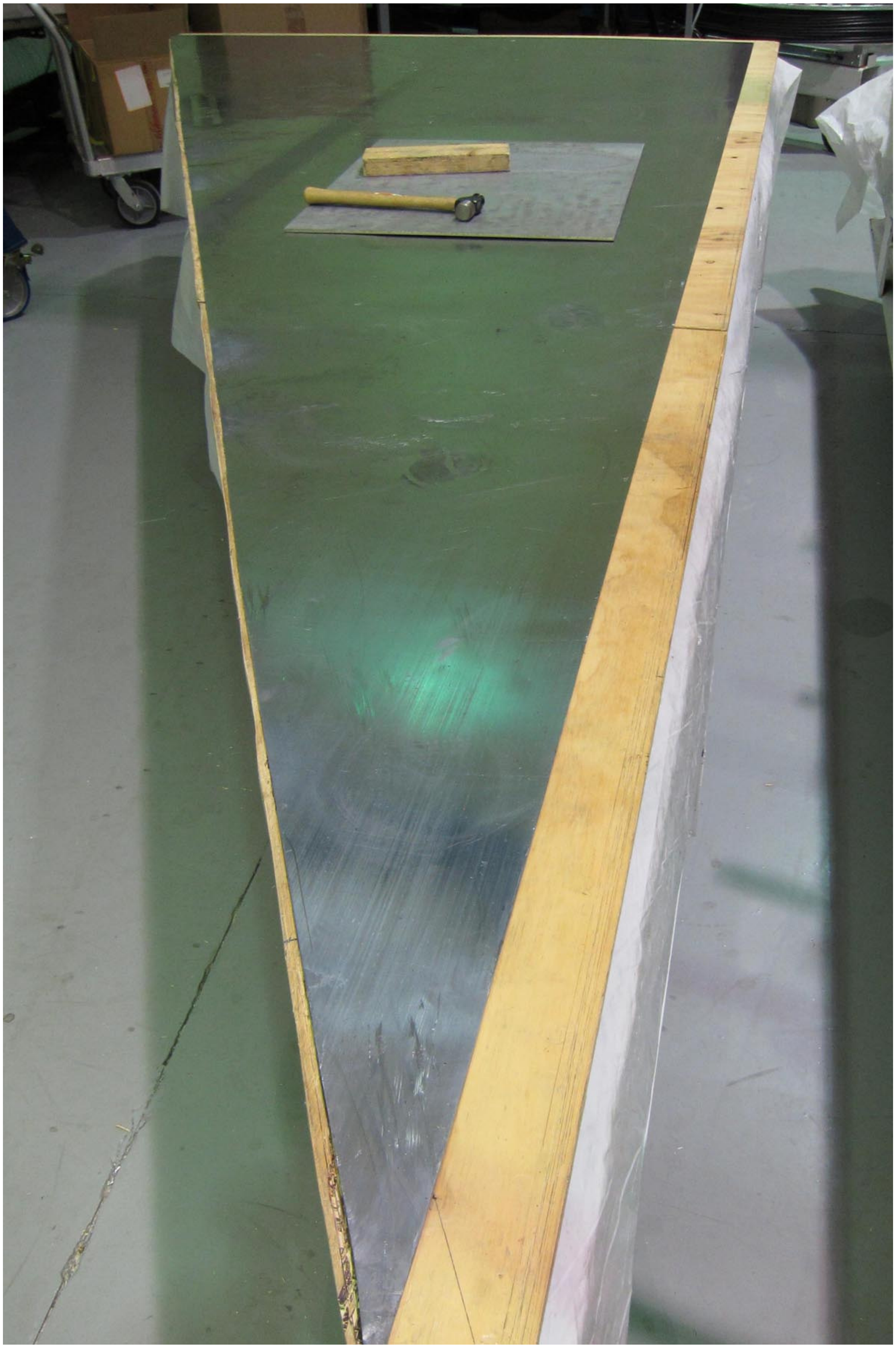

FIG. 10: One of two lead pieces used to construct a single lead layer. The hammer and the metal board are used to flatten the lead if needed.

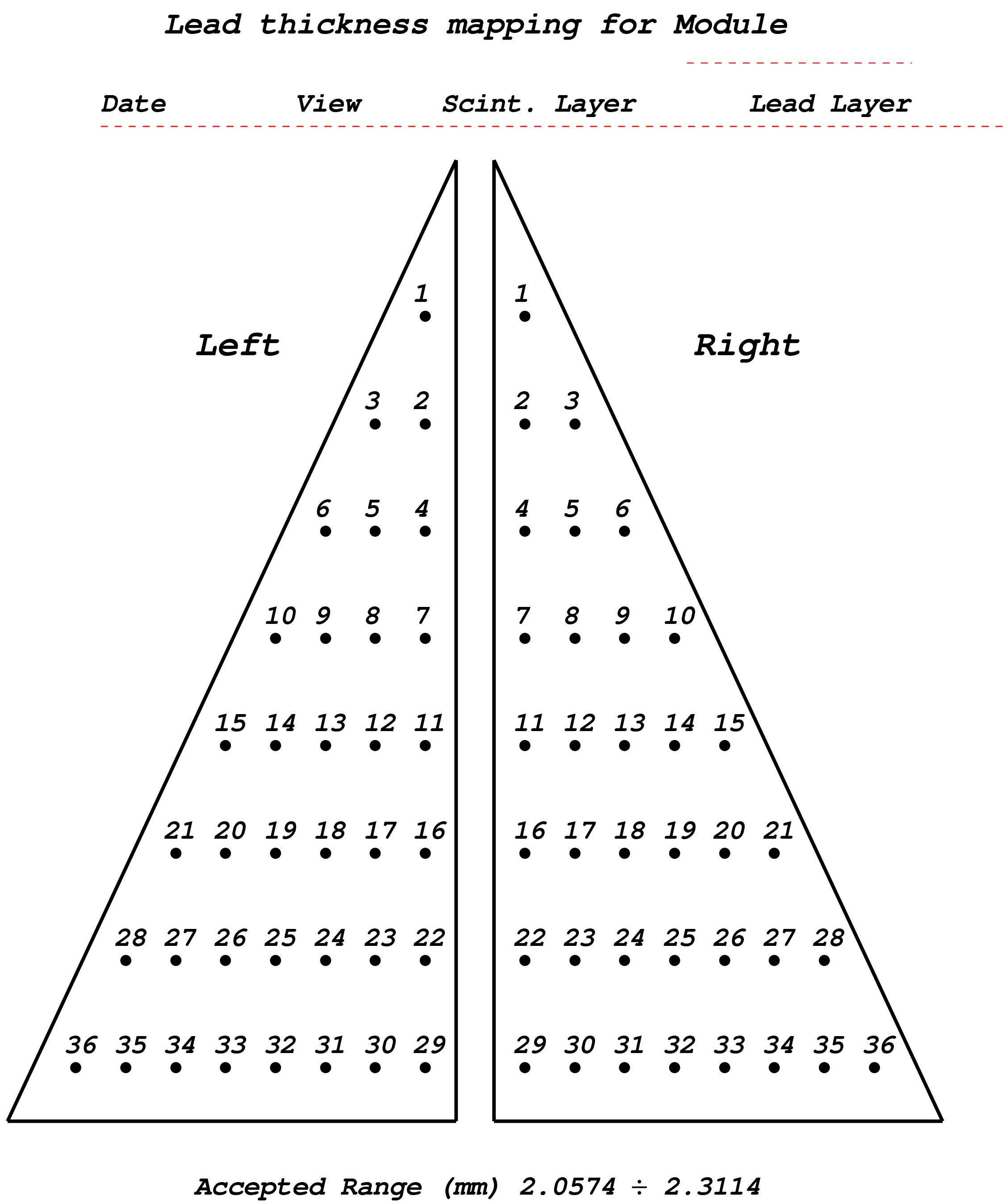

FIG. 11: A schematic plot that shows the sample points for the thickness measurements for each piece of lead.

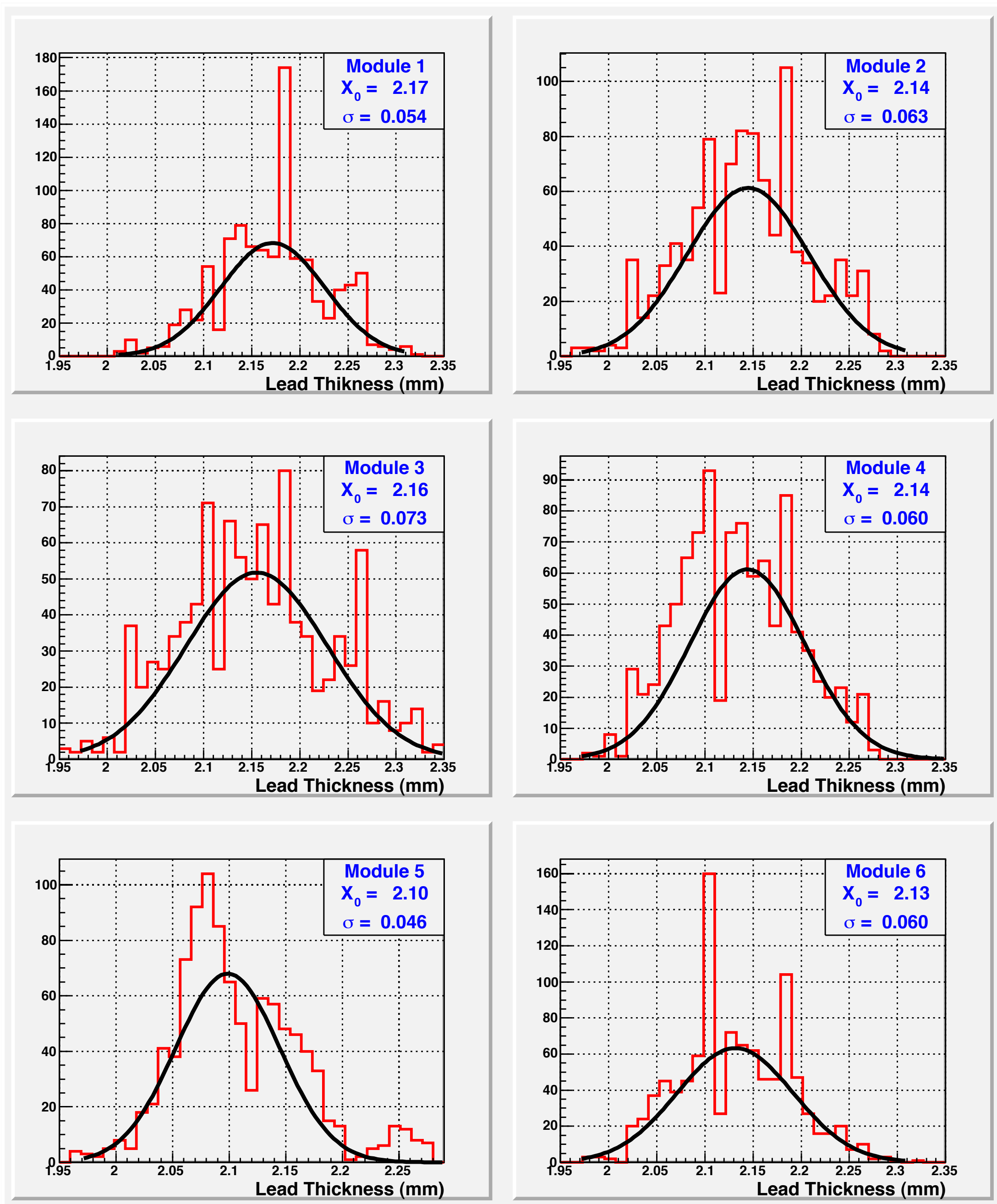

FIG. 12: The distribution of measured thicknesses of the lead sheets for each module.

IX. FORWARD CARRIAGE SECTOR ASSIGNMENT

Modules 1-6 were assembled between July 2011 and September 2013 and were installed on the Forward Carriage of Hall B in November-December 2013. The relationship between Module number and Sector number is shown in Fig. 13.

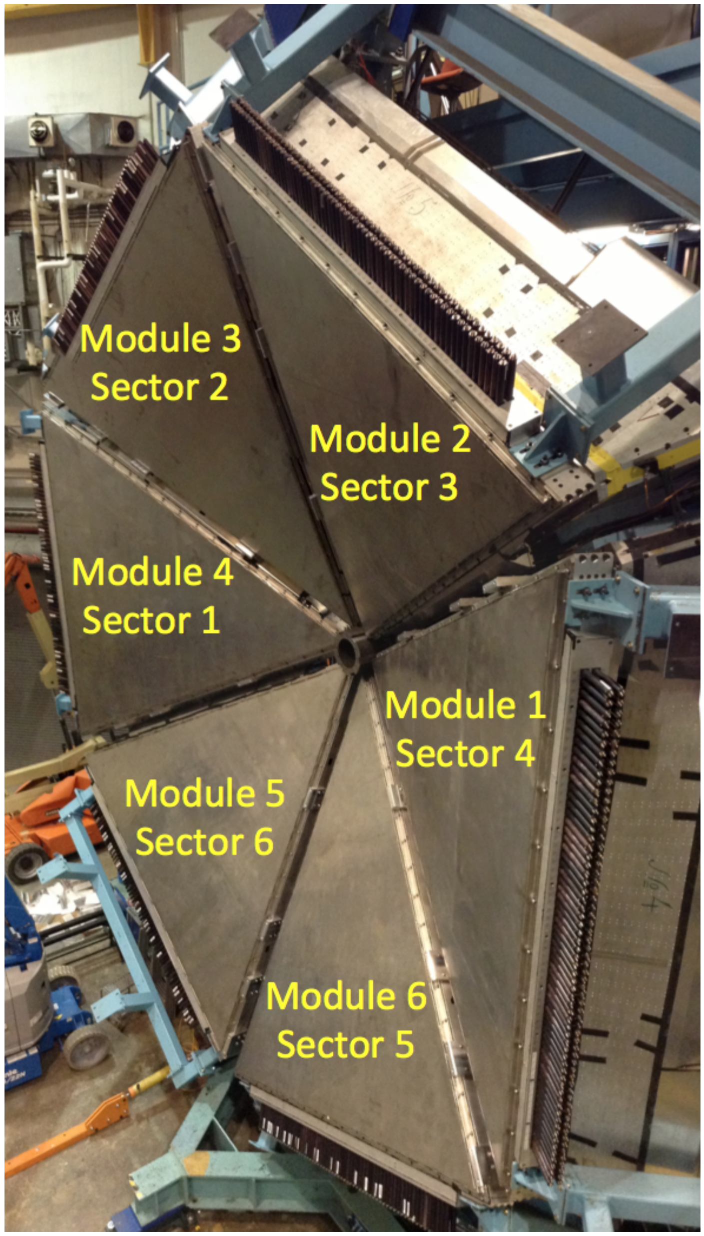

FIG. 13: Installed positions of the PCAL Modules on the Forward Carriage. The modules were installed in a clockwise sequence starting with Module 6 in Sector 5 and ending with Module 1 in Sector 4.

[1] G. Asryan, et al. "Pre-shower calorimeter for the CLAS12 detector", CLAS12 Technical Design Report, version 1.1, https://userweb.jlab.org/∼stepanya/clas12/preshower/master_pcal.pdf

[2] A. Daniel, et al. "Light transmission characteristics of scintillators for the pre-shower calorimeter", CLAS-NOTE 2010-012, 2010.

[3] D.S. Carman, "Forward Time-of-Flight Geometry for CLAS12", CLAS12-NOTE 2014-005, 2014.

Appendix A: The design drawings of U, V and W scintillators

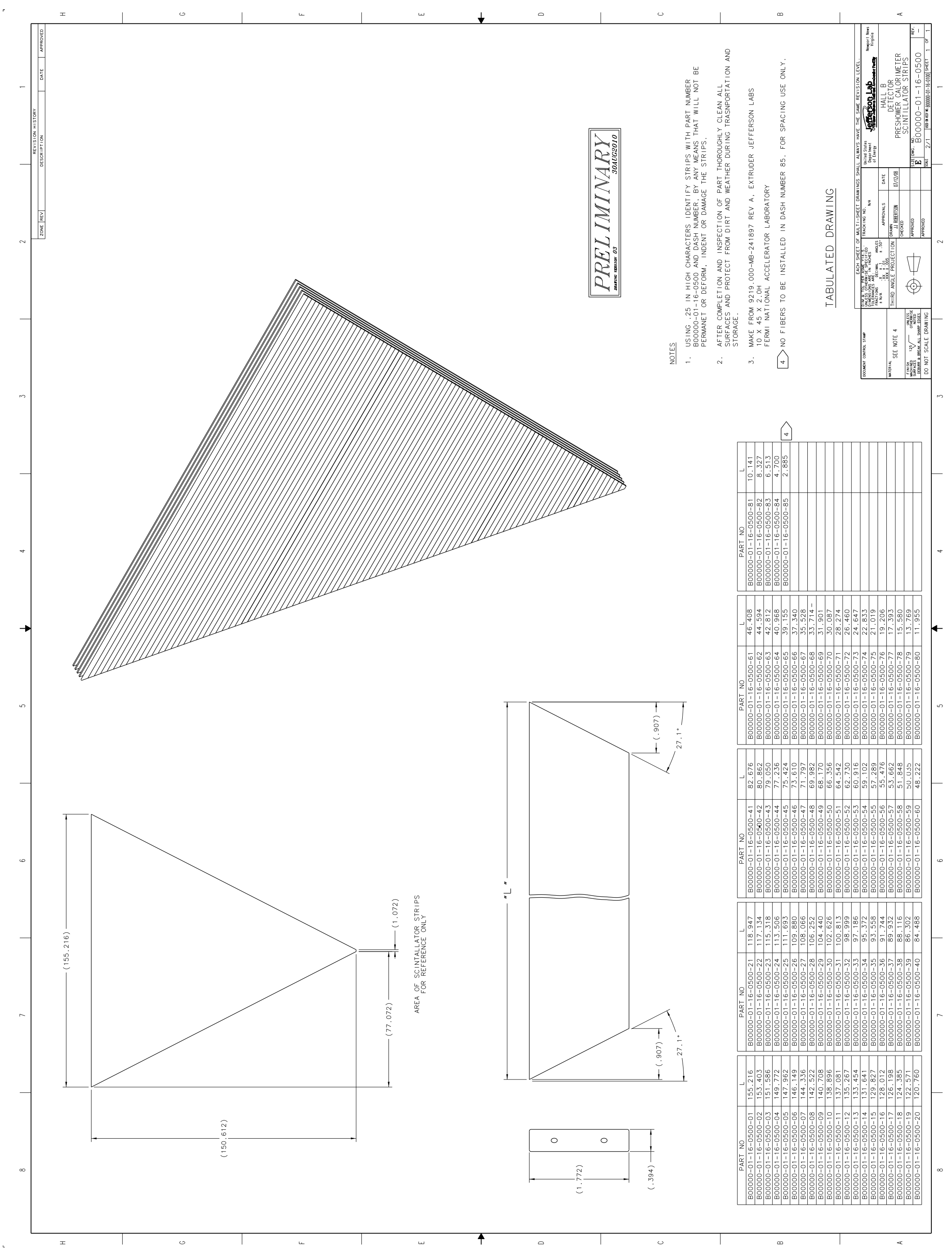

FIG. 14: A schematic drawing of thePCAL U layer.

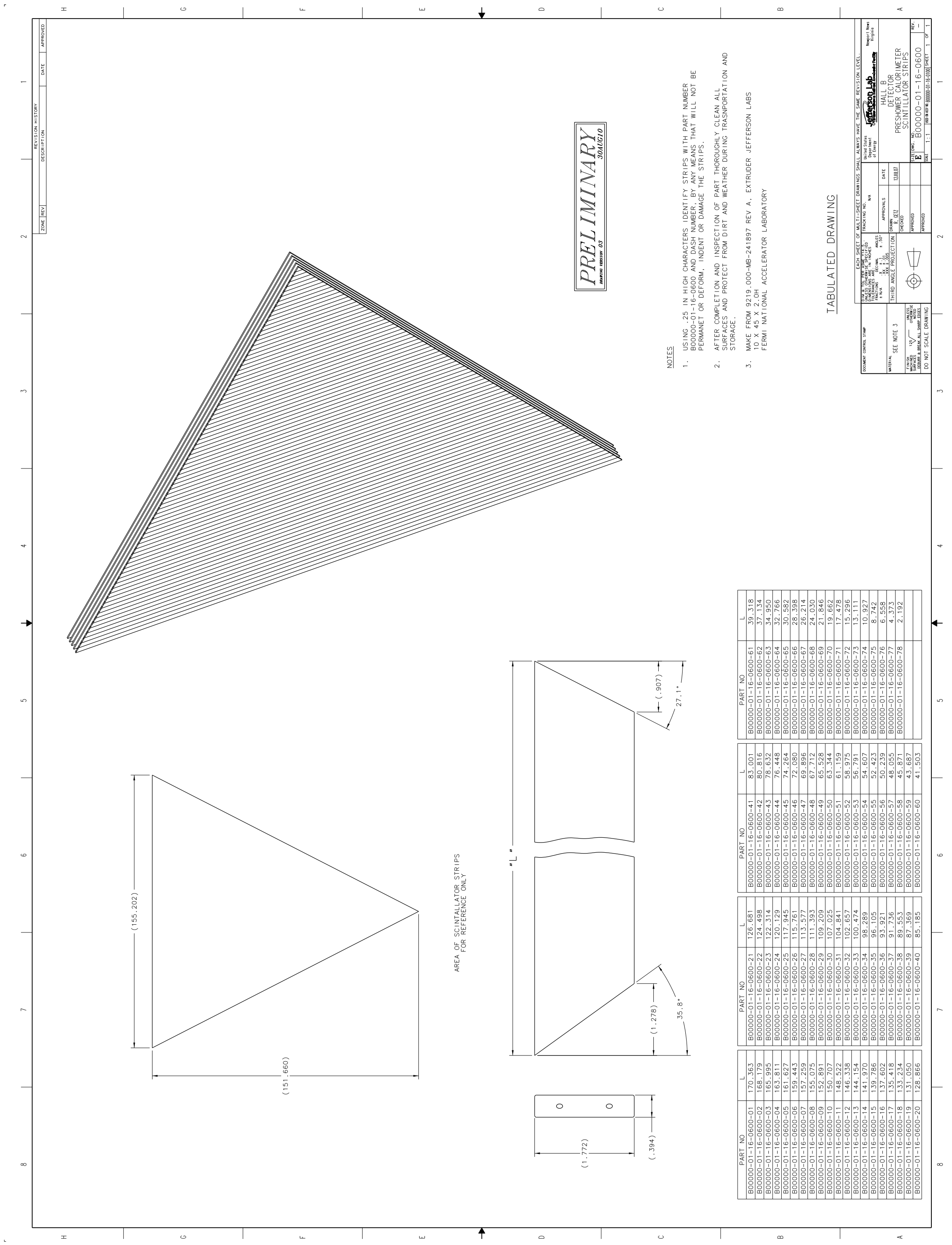

FIG. 15: A schematic drawing of the PCAL V layer.

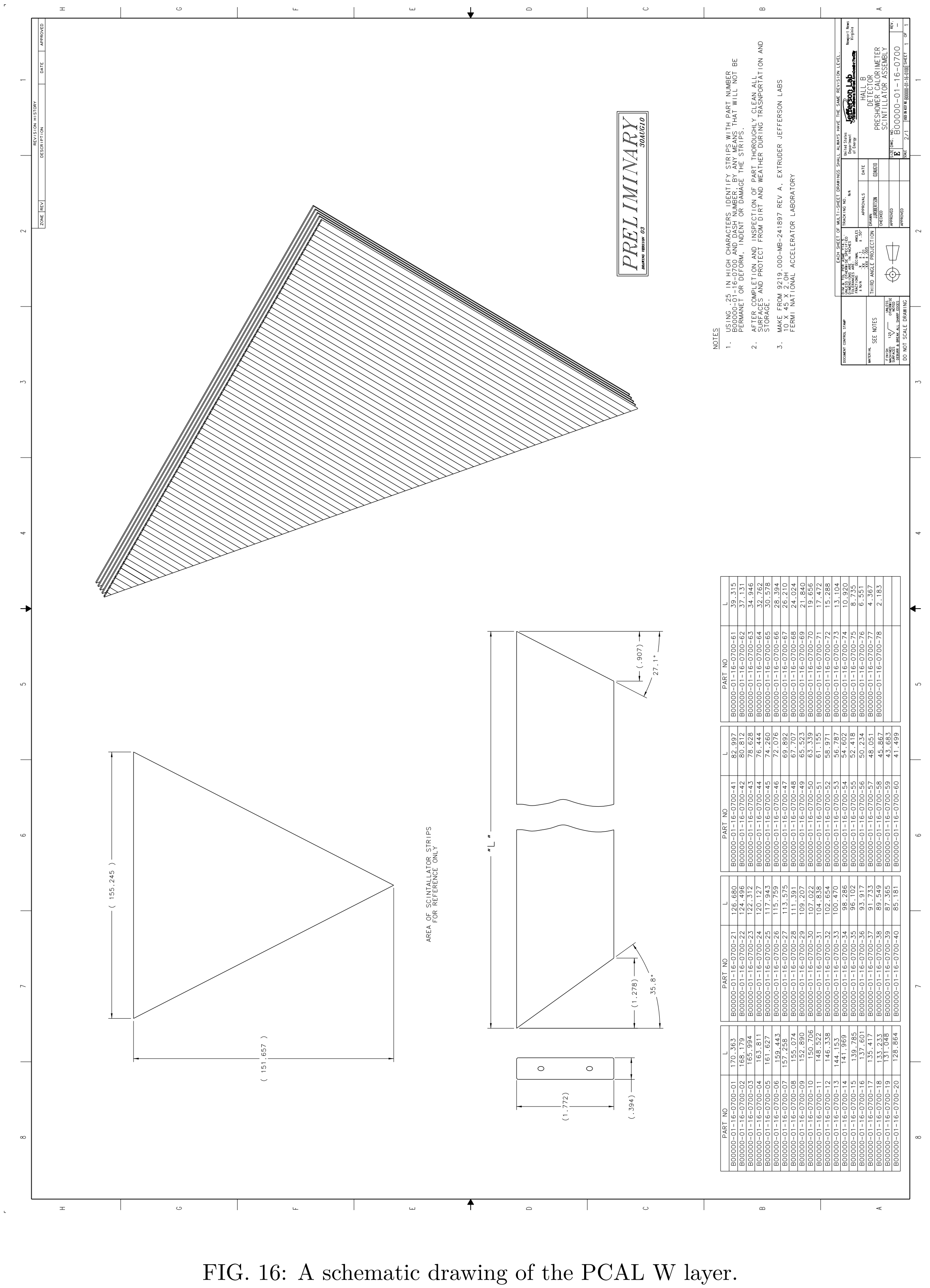

FIG. 16: A schematic drawing of the PCAL W layer.

Appendix B: Gap Between Scintillator Ends and the Sidewall or Retaining Bars

	U	V	W		U	V	W
1	6.51 mm	6.31 mm	5.22 mm	43	5.44 mm	4.08 mm	3.91 mm
2	5.65 mm	5.92 mm	4.63 mm	44	5.43 mm	3.89 mm	4.06 mm
3	6.08 mm	6.20 mm	5.32 mm	45	5.22 mm	3.88 mm	3.96 mm
4	5.46 mm	5.07 mm	4.87 mm	46	4.64 mm	4.08 mm	4.27 mm
5	4.57 mm	6.64 mm	4.79 mm	47	4.96 mm	4.01 mm	4.09 mm
6	5.98 mm	3.79 mm	4.47 mm	48	4.73 mm	3.88 mm	4.09 mm
7	5.46 mm	3.59 mm	4.21 mm	49	5.08 mm	4.55 mm	4.19 mm
8	4.60 mm	3.79 mm	4.43 mm	50	4.63 mm	4.49 mm	4.23 mm
9	4.72 mm	3.71 mm	4.46 mm	51	4.33 mm	4.75 mm	4.58 mm
10	5.30 mm	3.65 mm	4.51 mm	52	5.55 mm	4.55 mm	4.89 mm
11	5.25 mm	3.98 mm	4.35 mm	53	5.20 mm	4.71 mm	5.05 mm
12	4.98 mm	3.83 mm	4.23 mm	54	4.73 mm	4.56 mm	5.25 mm
13	4.42 mm	3.56 mm	4.30 mm	55	4.62 mm	4.75 mm	4.96 mm
14	6.62 mm	3.40 mm	4.28 mm	56	4.85 mm	4.81 mm	5.06 mm
15	6.27 mm	3.68 mm	4.10 mm	57	4.82 mm	4.87 mm	5.27 mm
16	4.86 mm	3.50 mm	4.15 mm	58	4.97 mm	5.08 mm	6.02 mm
17	4.35 mm	3.46 mm	3.97 mm	59	4.87 mm	4.97 mm	6.27 mm
18	5.80 mm	3.39 mm	4.05 mm	60	4.21 mm	4.70 mm	6.56 mm
19	5.07 mm	3.26 mm	3.82 mm	61	4.63 mm	5.07 mm	5.11 mm
20	5.23 mm	3.26 mm	3.81 mm	62	4.41 mm	5.15 mm	5.81 mm
21	4.95 mm	3.22 mm	3.85 mm	63	4.56 mm	5.55 mm	6.13 mm
22	4.44 mm	3.27 mm	3.61 mm	64	4.65 mm	5.71 mm	6.31 mm
23	4.71 mm	3.17 mm	3.56 mm	65	4.90 mm	6.30 mm	6.46 mm
24	4.31 mm	3.32 mm	3.40 mm	66	4.42 mm	6.35 mm	7.24 mm
25	3.87 mm	3.21 mm	3.24 mm	67	4.70 mm	6.88 mm	6.03 mm
26	4.22 mm	2.88 mm	3.60 mm	68	7.00 mm	6.43 mm	6.17 mm
27	4.56 mm	2.95 mm	3.42 mm	69	5.79 mm	6.65 mm	6.07 mm
28	3.99 mm	3.10 mm	3.12 mm	70	5.64 mm	6.81 mm	6.39 mm
29	3.82 mm	3.03 mm	3.24 mm	71	5.79 mm	7.20 mm	4.79 mm
30	5.20 mm	3.04 mm	3.25 mm	72	6.38 mm	7.17 mm	5.20 mm
31	4.87 mm	3.31 mm	3.24 mm	73	5.90 mm	7.56 mm	5.08 mm
32	4.33 mm	3.35 mm	3.29 mm	74	5.44 mm	7.24 mm	6.04 mm
33	4.18 mm	3.61 mm	3.28 mm	75	5.78 mm	7.41 mm	4.65 mm
34	4.82 mm	3.84 mm	3.49 mm	76	6.75 mm	8.07 mm	4.65 mm
35	5.13 mm	3.63 mm	3.25 mm	77	6.14 mm	7.35 mm	4.18 mm
36	4.55 mm	3.59 mm	3.27 mm	78	5.36 mm		
37	4.03 mm	3.93 mm	3.38 mm	79	5.90 mm		
38	5.28 mm	3.84 mm	3.14 mm	80	6.66 mm		
39	5.03 mm	3.62 mm	3.27 mm	81	6.55 mm		
40	4.50 mm	3.77 mm	3.54 mm	82	6.41 mm		
41	4.39 mm	3.96 mm	3.55 mm	83	6.96 mm		
42	4.12 mm	4.05 mm	3.73 mm	84	7.45 mm		
average					5.15 mm	4.59 mm	4.49 mm

TABLE IX: Distance between the scintillator ends and the retaining bars (for U and W strips) and the sidewall (for V strips) for module 6.

Appendix C: Lead Thickness of Each Sample Point

Table X to Table XIX give the lead thickness measured for each sample point from PCAL module 1 to module 5. Thise numbers are in units of mm. The column headings show the layer measured, while (L,R) refers to the (left,right) triangular shaped lead sheet.

	1R	1L	2R	2L	3R	3L	4R	4L	5R	5L	6R	6L	7R	7L
1	2.06	2.14	2.10	2.15	2.01	2.16	2.07	2.14	2.21	2.16	2.10	2.08	2.12	2.08
2	2.07	2.14	2.13	2.14	2.01	2.18	2.06	2.16	2.09	2.19	2.11	2.11	2.07	2.13
3	2.12	2.17	2.18	2.16	2.07	2.24	2.11	2.18	2.16	2.19	2.17	2.14	2.13	2.15
4	2.05	2.17	2.11	2.20	2.03	2.19	2.08	2.18	2.10	2.19	2.10	2.15	2.08	2.16
5	2.10	2.18	2.15	2.20	2.08	2.21	2.14	2.20	2.15	2.21	2.14	2.13	2.13	2.15
6	2.15	2.20	2.19	2.24	2.13	2.25	2.20	2.24	2.19	2.23	2.19	2.15	2.18	2.17
7	2.09	2.14	2.16	2.16	2.05	2.21	2.10	2.21	2.15	2.16	2.26	2.04	2.11	2.13
8	2.13	2.13	2.19	2.19	2.10	2.25	2.15	2.22	2.17	2.20	2.14	2.07	2.14	2.15
9	2.19	2.15	2.21	2.21	2.15	2.27	2.20	2.25	2.21	2.21	2.19	2.08	2.19	2.17
10	2.19	2.17	2.23	2.23	2.18	2.27	2.22	2.22	2.24	2.26	2.21	2.10	2.23	2.17
11	2.10	2.10	2.17	2.14	2.03	2.20	2.14	2.22	2.15	2.11	2.12	2.02	2.17	2.10
12	2.14	2.17	2.17	2.17	2.08	2.21	2.19	2.23	2.19	2.14	2.15	2.03	2.18	2.12
13	2.17	2.14	2.24	2.17	2.14	2.25	2.23	2.26	2.23	2.16	2.19	2.05	2.21	2.13
14	2.21	2.16	2.25	2.19	2.17	2.26	2.25	2.27	2.25	2.18	2.22	2.07	2.25	2.14
15	2.23	2.16	2.25	2.18	2.19	2.25	2.25	2.26	2.26	2.23	2.24	2.09	2.26	2.14
16	2.13	2.12	2.15	2.13	2.03	2.13	2.15	2.16	2.17	2.08	2.15	2.03	2.18	2.08
17	2.15	2.14	2.19	2.16	2.09	2.16	2.19	2.19	2.19	2.14	2.17	2.05	2.20	2.09
18	2.19	2.16	2.24	2.19	2.16	2.18	2.24	2.22	2.24	2.16	2.21	2.08	2.26	2.10
19	2.22	2.17	2.26	2.19	2.18	2.19	2.25	2.24	2.26	2.16	2.25	2.10	2.27	2.13
20	2.25	2.17	2.26	2.19	2.20	2.19	2.25	2.24	2.27	2.18	2.26	2.09	2.29	2.12
21	2.24	2.21	2.25	2.18	2.20	2.18	2.19	2.23	2.27	2.16	2.26	2.08	2.29	2.11
22	2.13	2.11	2.14	2.13	2.02	2.13	2.13	2.15	2.17	2.13	2.18	2.03	2.17	2.04
23	2.16	2.13	2.19	2.18	2.08	2.15	2.18	2.19	2.20	2.15	2.20	2.07	2.20	2.07
24	2.21	2.16	2.25	2.18	2.14	2.19	2.21	2.21	2.24	2.19	2.23	2.09	2.26	2.08
25	2.23	2.16	2.27	2.21	2.17	2.19	2.24	2.23	2.28	2.20	2.25	2.11	2.28	2.09
26	2.25	2.16	2.26	2.21	2.20	2.20	2.25	2.23	2.28	2.21	2.26	2.11	2.29	2.09
27	2.25	2.17	2.25	2.18	2.20	2.19	2.24	2.22	2.27	2.18	2.27	2.10	2.28	2.11
28	2.24	2.17	2.22	2.20	2.19	2.18	2.22	2.19	2.26	2.17	2.27	2.09	2.26	2.09
29	2.18	2.14	2.07	2.13	2.01	2.10	2.08	2.16	2.14	2.16	2.14	2.09	2.14	2.03
30	2.13	2.13	2.14	2.18	2.07	2.14	2.15	2.19	2.18	2.18	2.18	2.08	2.19	2.07
31	2.18	2.14	2.19	2.18	2.11	2.15	2.19	2.20	2.21	2.20	2.23	2.10	2.25	2.08
32	2.20	2.15	2.23	2.19	2.16	2.18	2.24	2.21	2.26	2.21	2.28	2.13	2.27	2.08
33	2.24	2.15	2.24	2.19	2.19	2.18	2.25	2.20	2.27	2.20	2.26	2.13	2.28	2.09
34	2.24	2.15	2.24	2.18	2.20	2.17	2.25	2.19	2.27	2.19	2.27	2.13	2.29	2.09
35	2.22	2.14	2.21	2.18	2.18	2.13	2.24	2.17	2.25	2.17	2.26	2.10	2.26	2.08
36	2.25	2.10	2.19	2.13	2.18	2.12	2.21	2.14	2.26	2.13	2.24	2.09	2.24	2.05

TABLE X: The sample points of the lead thickness for PCAL Module 1.

	8R	8L	9R	9L	10R	20L	11R	11L	12R	12L	13R	13L	14R	14L
1	2.24	2.13	2.21	2.13	2.16	2.10	2.14	2.19	2.22	2.07	2.20	2.07	2.21	2.09
2	2.16	2.15	2.19	2.16	2.15	2.19	2.19	2.25	2.17	2.15	2.20	2.06	2.17	2.17
3	2.21	2.17	2.21	2.18	2.19	2.21	2.17	2.24	2.20	2.18	2.24	2.16	2.20	2.15
4	2.12	2.14	2.17	2.15	2.15	2.19	2.14	2.19	2.08	2.17	2.20	2.07	2.18	2.11
5	2.20	2.16	2.19	2.17	2.17	2.21	2.16	2.19	2.20	2.19	2.23	2.08	2.21	2.13
6	2.25	2.18	2.20	2.20	2.20	2.24	2.18	2.21	2.22	2.21	2.25	2.12	2.21	2.16
7	2.17	2.20	2.17	2.15	2.14	2.20	2.13	2.14	2.18	2.16	2.20	2.06	2.19	2.13
8	2.21	2.18	2.19	2.17	2.17	2.19	2.15	2.16	2.20	2.18	2.20	2.08	2.20	2.16
9	2.25	2.19	2.21	2.18	2.19	2.21	2.17	2.18	2.21	2.20	2.24	2.10	2.22	2.20
10	2.27	2.20	2.21	2.19	2.22	2.22	2.17	2.18	2.25	2.20	2.25	2.14	2.24	2.31
11	2.17	2.13	2.16	2.12	2.14	2.13	2.13	2.13	2.07	2.12	2.18	2.07	2.18	2.13
12	2.21	2.14	2.18	2.14	2.18	2.14	2.14	2.13	2.18	2.14	2.19	2.08	2.19	2.18
13	2.26	2.16	2.19	2.15	2.19	2.15	2.14	2.14	2.21	2.15	2.22	2.10	2.10	2.26
14	2.27	2.18	2.19	2.16	2.22	2.16	2.16	2.15	2.22	2.17	2.24	2.13	2.23	2.25
15	2.29	2.19	2.18	2.16	2.23	2.17	2.17	2.14	2.22	2.17	2.24	2.16	2.24	2.26
16	2.19	2.08	2.16	2.09	2.15	2.10	2.18	2.09	2.18	2.14	2.15	2.09	2.20	2.14
17	2.25	2.09	2.18	2.10	2.18	2.11	2.16	2.10	2.18	2.08	2.19	2.11	2.23	2.16
18	2.27	2.13	2.19	2.13	2.21	2.13	2.18	2.13	2.22	2.10	2.21	2.14	2.24	2.21
19	2.31	2.14	2.18	2.14	2.22	2.14	2.16	2.13	2.22	2.13	2.22	2.18	2.24	2.25
20	2.31	2.15	2.16	2.14	2.22	2.15	2.18	2.15	2.21	2.14	2.21	2.19	2.24	2.26
21	2.30	2.08	2.15	2.13	2.21	2.13	2.18	2.14	2.20	2.14	2.19	2.18	2.22	2.26
22	2.19	2.10	2.18	2.11	2.15	2.11	2.16	2.10	2.17	2.08	2.18	2.08	2.21	2.12
23	2.24	2.13	2.19	2.13	2.17	2.13	2.13	2.13	2.20	2.09	2.20	2.14	2.24	2.15
24	2.28	2.15	2.19	2.15	2.20	2.15	2.16	2.14	2.21	2.12	2.24	2.14	2.25	2.19
25	2.31	2.15	2.19	2.17	2.21	2.15	2.17	2.15	2.20	2.13	2.22	2.14	2.27	2.21
26	2.31	2.15	2.17	2.16	2.21	2.14	2.13	2.16	2.19	2.13	2.20	2.18	2.25	2.23
27	2.32	2.15	2.15	2.14	2.19	2.14	2.10	2.15	2.17	2.13	2.19	2.19	2.24	2.21
28	2.30	2.13	2.11	2.13	2.16	2.11	2.07	2.14	2.13	2.13	2.14	2.19	2.20	2.20
29	2.16	2.09	2.18	2.15	2.14	2.10	2.23	2.14	2.18	2.10	2.22	2.06	2.23	2.13
30	2.22	2.12	2.19	2.17	2.16	2.14	2.18	2.15	2.20	2.14	2.25	2.08	2.25	2.15
31	2.27	2.14	2.19	2.19	2.18	2.13	2.18	2.17	2.22	2.14	2.25	2.13	2.26	2.19
32	2.30	2.15	2.18	2.21	2.17	2.16	2.12	2.19	2.22	2.16	2.25	2.14	2.26	2.20
33	2.31	2.16	2.16	2.20	2.19	2.17	2.13	2.18	2.20	2.17	2.21	2.16	2.25	2.22
34	2.30	2.15	2.14	2.18	2.16	2.15	2.13	2.18	2.18	2.16	2.18	2.15	2.22	2.21
35	2.29	2.14	2.10	2.15	2.13	2.14	2.07	2.19	2.14	2.15	2.14	2.16	2.20	2.19
36	2.26	2.10	2.06	2.13	2.10	2.13	2.02	2.14	2.07	2.11	2.12	2.14	2.13	2.18

TABLE XI: The sample points of the lead thickness for PCAL Module 1 continued.

	1R	1L	2R	2L	3R	3L	4R	4L	5R	5L	6R	6L	7R	7L
1	2.09	2.09	2.06	2.15	2.09	2.03	2.08	2.06	2.08	2.06	2.14	2.09	2.06	2.10
2	2.09	2.06	2.06	2.10	2.15	2.00	2.13	2.07	2.09	2.05	2.16	2.07	2.02	2.09
3	2.14	2.11	2.09	2.14	2.18	2.04	2.14	2.09	2.14	2.08	2.20	2.10	2.06	2.14
4	2.07	2.07	2.05	2.09	2.13	1.99	2.16	2.06	2.08	2.04	2.15	2.07	2.07	2.10
5	2.13	2.10	2.07	2.14	2.18	2.04	2.19	2.09	2.13	2.08	2.19	2.15	2.11	2.13
6	2.15	2.17	2.15	2.15	2.18	2.07	2.21	2.13	2.17	2.10	2.21	2.15	2.16	2.14
7	2.08	2.05	2.03	2.07	2.15	1.98	2.10	2.06	2.13	2.02	2.13	2.06	2.07	2.06
8	2.14	2.09	2.05	2.10	2.17	2.03	2.15	2.09	2.15	2.05	2.16	2.08	2.12	2.10
9	2.13	2.13	2.10	2.13	2.19	2.06	2.19	2.13	2.20	2.09	2.18	2.09	2.18	2.13
10	2.15	2.15	2.12	2.15	2.22	2.09	2.21	2.15	2.22	2.13	2.23	2.13	2.19	2.15
11	2.05	2.02	2.00	2.05	2.13	1.97	2.16	2.05	2.15	2.03	2.13	2.06	2.13	2.08
12	2.08	2.06	2.03	2.09	2.14	2.02	2.17	2.07	2.19	2.04	2.16	2.08	2.17	2.11
13	2.12	2.09	2.08	2.11	2.19	2.06	2.22	2.11	2.24	2.07	2.19	2.13	2.22	2.14
14	2.13	2.14	2.10	2.20	2.22	2.08	2.24	2.16	2.25	2.10	2.22	2.16	2.24	2.16
15	2.14	2.13	2.13	2.14	2.24	2.10	2.22	2.16	2.24	2.13	2.23	2.14	2.24	2.18
16	2.06	2.04	2.02	2.05	2.16	1.98	2.20	2.03	2.21	2.04	2.15	2.07	2.20	2.09
17	2.09	2.06	2.06	2.11	2.19	2.03	2.23	2.05	2.25	2.09	2.18	2.10	2.25	2.11
18	2.15	2.09	2.09	2.10	2.23	2.06	2.26	2.09	2.27	2.08	2.22	2.13	2.26	2.14
19	2.14	2.13	2.10	2.12	2.26	2.07	2.27	2.14	2.29	2.13	2.24	2.14	2.28	2.17
20	2.19	2.14	2.15	2.14	2.27	2.08	2.26	2.15	2.28	2.14	2.25	2.16	2.27	2.19
21	2.17	2.15	2.15	2.14	2.25	2.11	2.24	2.16	2.25	2.15	2.24	2.14	2.26	2.16
22	2.03	2.03	2.05	2.09	2.16	1.97	2.20	2.01	2.19	2.02	2.17	2.07	2.16	2.11
23	2.06	2.07	2.08	2.12	2.22	2.03	2.24	2.07	2.24	2.06	2.20	2.08	2.24	2.13
24	2.16	2.09	2.10	2.13	2.24	2.05	2.23	2.09	2.26	2.10	2.24	2.14	2.24	2.20
25	2.18	2.12	2.15	2.15	2.27	2.07	2.25	2.13	2.28	2.14	2.25	2.17	2.25	2.19
26	2.17	2.14	2.18	2.15	2.27	2.08	2.23	2.15	2.26	2.21	2.27	2.15	2.24	2.19
27	2.15	2.19	2.19	2.15	2.26	2.08	2.22	2.16	2.24	2.18	2.25	2.16	2.23	2.17
28	2.12	2.16	2.20	2.14	2.21	2.07	2.17	2.16	2.20	2.16	2.23	2.13	2.20	2.17
29	2.09	2.03	2.10	2.07	2.18	1.98	2.14	2.02	2.17	2.02	2.20	2.06	2.16	2.10
30	2.10	2.07	2.10	2.10	2.23	2.01	2.18	2.06	2.21	2.07	2.24	2.10	2.19	2.16
31	2.15	2.11	2.14	2.16	2.25	2.04	2.22	2.09	2.23	2.09	2.27	2.14	2.25	2.18
32	2.16	2.14	2.19	2.16	2.25	2.07	2.24	2.14	2.27	2.15	2.27	2.15	2.24	2.24
33	2.18	2.16	2.18	2.18	2.25	2.10	2.23	2.16	2.24	2.16	2.28	2.14	2.23	2.24
34	2.15	2.16	2.16	2.18	2.24	2.10	2.20	2.16	2.23	2.17	2.26	2.14	2.20	2.20
35	2.14	2.16	2.14	2.18	2.19	2.11	2.17	2.21	2.18	2.17	2.22	2.08	2.20	2.19
36	2.16	2.14	2.13	2.15	2.18	2.09	2.13	2.15	2.15	2.15	2.18	2.07	2.15	2.16

TABLE XII: The sample points of the lead thickness for PCAL Module 2.

	8R	8L	9R	9L	10R	20L	11R	11L	12R	12L	13R	13L	14R	14L
1	1.97	2.11	2.14	2.06	2.08	2.06	2.14	2.10	2.15	2.11	2.11	2.12	2.00	2.09
2	2.01	2.07	2.16	2.11	2.13	2.04	2.17	2.07	2.14	2.08	2.13	2.10	1.99	2.10
3	2.17	2.09	2.18	2.15	2.15	2.08	2.18	2.10	2.18	2.13	2.16	2.13	2.02	2.14
4	2.03	2.04	2.16	2.10	2.15	2.03	2.14	2.05	2.13	2.08	2.13	2.14	2.02	2.09
5	2.06	2.07	2.19	2.19	2.15	2.07	2.19	2.09	2.17	2.13	2.18	2.10	2.05	2.14
6	2.09	2.11	2.23	2.17	2.24	2.07	2.24	2.11	2.20	2.15	2.20	2.08	2.06	2.15
7	2.02	2.03	2.18	2.09	2.13	2.05	2.14	2.05	2.12	2.13	2.14	2.16	2.03	2.10
8	2.06	2.07	2.20	2.14	2.14	2.08	2.22	2.07	2.15	2.15	2.18	2.14	2.06	2.13
9	2.11	2.11	2.26	2.16	2.19	2.09	2.21	2.10	2.21	2.16	2.21	2.12	2.09	2.14
10	2.15	2.15	2.25	2.19	2.21	2.10	2.24	2.13	2.23	2.17	2.21	2.09	2.10	2.16
11	2.03	2.02	2.17	2.08	2.13	2.07	2.12	2.16	2.15	2.13	2.13	2.11	2.05	2.09
12	2.06	2.04	2.18	2.11	2.15	2.09	2.17	2.07	2.18	2.16	2.16	2.14	2.06	2.13
13	2.10	2.07	2.21	2.15	2.20	2.11	2.18	2.09	2.20	2.18	2.18	2.17	2.05	2.14
14	2.13	2.12	2.24	2.19	2.22	2.13	2.20	2.12	2.23	2.29	2.19	2.18	2.12	2.15
15	2.14	2.15	2.24	2.18	2.24	2.15	2.23	2.13	2.26	2.20	2.19	2.19	2.12	2.16
16	2.06	2.03	2.18	2.05	2.14	2.08	2.11	2.02	2.15	2.14	2.13	2.14	2.03	2.11
17	2.09	2.07	2.20	2.07	2.16	2.12	2.21	2.06	2.18	2.17	2.16	2.16	2.08	2.14
18	2.13	2.11	2.22	2.10	2.20	2.14	2.19	2.09	2.24	2.19	2.16	2.19	2.12	2.16
19	2.15	2.11	2.25	2.16	2.25	2.17	2.19	2.11	2.25	2.21	2.17	2.24	2.24	2.17
20	2.15	2.15	2.25	2.16	2.23	2.15	2.20	2.13	2.27	2.20	2.17	2.21	2.13	2.17
21	2.14	2.16	2.23	2.16	2.22	2.13	2.18	2.15	2.26	2.19	2.14	2.21	2.12	2.17
22	2.03	2.00	2.18	2.11	2.11	2.08	2.14	2.03	2.16	2.13	2.14	2.19	2.05	2.12
23	2.09	2.04	2.22	2.07	2.14	2.13	2.18	2.07	2.21	2.19	2.16	2.17	2.07	2.15
24	2.13	2.08	2.15	2.09	2.18	2.13	2.19	2.10	2.27	2.18	2.17	2.20	2.08	2.17
25	2.14	2.10	2.26	2.12	2.20	2.15	2.21	2.13	2.28	2.20	2.18	2.21	2.09	2.19
26	2.14	2.13	2.26	2.15	2.21	2.15	2.21	2.14	2.28	2.20	2.17	2.20	2.10	2.19
27	2.11	2.15	2.23	2.15	2.19	2.14	2.18	2.15	2.27	2.17	2.14	2.20	2.11	2.21
28	2.09	2.15	2.20	2.14	2.16	2.11	2.16	2.14	2.24	2.25	2.11	2.19	2.09	2.17
29	2.04	2.02	2.21	2.03	2.15	2.12	2.15	2.04	2.19	2.13	2.19	2.14	2.05	2.14
30	2.08	2.09	2.25	2.07	2.19	2.14	2.18	2.09	2.23	2.15	2.19	2.18	2.08	2.16
31	2.12	2.07	2.26	2.09	2.21	2.18	2.19	2.14	2.25	2.17	2.21	2.21	2.14	2.20
32	2.14	2.10	2.27	2.14	2.21	2.18	2.19	2.16	2.28	2.18	2.22	2.22	2.12	2.20
33	2.13	2.13	2.26	2.17	2.20	2.17	2.19	2.16	2.28	2.18	2.21	2.21	2.11	2.21
34	2.10	2.15	2.24	2.18	2.19	2.15	2.17	2.16	2.26	2.17	2.19	2.22	2.10	2.20
35	2.10	2.15	2.21	2.18	2.17	2.13	2.14	2.15	2.23	2.13	2.18	2.18	2.08	2.18
36	2.04	2.14	2.21	2.15	2.13	2.08	2.09	2.13	2.18	2.13	2.13	2.15	2.05	2.14

TABLE XIII: The sample points of the lead thickness for PCAL Module 2 continued.

	1R	1L	2R	2L	3R	3L	4R	4L	5R	5L	6R	6L	7R	7L
1	2.14	2.17	2.01	2.08	2.13	2.02	2.19	2.27	2.09	2.09	2.13	2.14	2.04	2.02
2	2.16	2.12	2.02	2.07	2.13	1.98	2.15	2.27	2.08	2.08	2.16	2.13	2.04	2.03
3	2.19	2.15	2.07	2.10	2.16	2.02	2.17	2.29	2.11	2.10	2.16	2.13	2.07	2.03
4	2.15	2.13	2.03	2.10	2.14	2.03	2.14	2.21	2.13	2.10	2.11	2.07	1.98	2.00
5	2.19	2.12	2.07	2.11	2.17	2.04	2.16	2.24	2.19	2.09	2.16	2.11	2.04	2.03
6	2.23	2.15	2.13	2.14	2.22	2.04	2.20	2.29	2.19	2.12	2.18	2.14	2.09	2.03
7	2.15	2.14	2.06	2.18	2.13	2.06	2.14	2.18	2.14	2.05	2.16	2.10	1.98	2.00
8	2.18	2.14	2.09	2.13	2.16	2.05	2.17	2.21	2.23	2.09	2.19	2.10	2.03	2.02
9	2.22	2.15	2.13	2.14	2.19	2.05	2.20	2.26	2.22	2.09	2.22	2.14	2.07	2.03
10	2.24	2.15	2.16	2.15	2.23	2.07	2.21	2.30	2.24	2.13	2.22	2.16	2.08	2.07
11	2.14	2.10	2.04	2.04	2.13	2.04	2.13	2.23	2.16	2.02	2.19	2.10	2.02	1.97
12	2.18	2.14	2.08	2.14	2.16	2.05	2.16	2.22	2.20	2.10	2.24	2.13	2.06	1.98
13	2.21	2.16	2.12	2.12	2.19	2.07	2.19	2.27	2.22	2.13	2.25	2.14	2.09	1.99
14	2.24	2.18	2.14	2.15	2.21	2.07	2.21	2.30	2.26	2.12	2.30	2.16	2.09	2.14
15	2.25	2.17	2.16	2.22	2.20	2.10	2.21	2.31	2.23	2.12	2.25	2.17	2.13	2.05
16	2.14	2.11	2.05	2.03	2.13	2.05	2.16	2.21	2.13	2.01	2.19	2.14	2.03	1.96
17	2.18	2.14	2.10	2.07	2.18	2.06	2.20	2.25	2.19	2.05	2.22	2.10	2.07	1.98
18	2.21	2.17	2.13	2.09	2.19	2.08	2.23	2.29	2.22	2.09	2.26	2.13	2.09	2.00
19	2.25	2.19	2.16	2.14	2.19	2.10	2.24	2.30	2.24	2.11	2.27	2.18	2.10	2.02
20	2.24	2.19	2.17	2.15	2.21	2.09	2.23	2.31	2.21	2.10	2.26	2.20	2.11	2.05
21	2.28	2.19	2.16	2.16	2.19	2.08	2.21	2.32	2.20	2.12	2.24	2.17	2.09	2.04
22	2.15	2.13	2.08	2.03	2.13	2.05	2.18	2.19	2.09	2.02	2.25	2.09	2.06	1.96
23	2.19	2.16	2.13	2.08	2.17	2.08	2.21	2.23	2.14	2.05	2.25	2.08	2.10	1.97
24	2.21	2.20	2.17	2.13	2.19	2.09	2.24	2.27	2.18	2.07	2.28	2.13	2.15	1.99
25	2.24	2.19	2.17	2.16	2.20	2.09	2.25	2.32	2.16	2.11	2.27	2.15	2.13	2.03
26	2.24	2.19	2.17	2.16	2.20	2.08	2.26	2.31	2.20	2.13	2.26	2.16	2.11	2.02
27	2.22	2.18	2.17	2.16	2.19	2.08	2.24	2.32	2.15	2.13	2.25	2.16	2.16	2.02
28	2.19	2.16	2.15	2.16	2.17	2.08	2.21	2.32	2.13	2.10	2.17	2.15	2.05	2.04
29	2.16	2.15	2.06	2.04	2.14	2.04	2.16	2.18	2.08	1.96	2.22	2.04	2.09	2.00
30	2.20	2.15	2.10	2.09	2.18	2.06	2.20	2.22	2.15	2.05	2.25	2.08	2.10	2.00
31	2.23	2.18	2.14	2.14	2.20	2.06	2.24	2.26	2.16	2.07	2.26	2.11	2.13	2.00
32	2.24	2.19	2.16	2.17	2.20	2.07	2.25	2.30	2.17	2.07	2.28	2.15	2.13	2.03
33	2.24	2.20	2.16	2.19	2.20	2.07	2.26	2.32	2.17	2.07	2.28	2.16	2.12	2.04
34	2.23	2.19	2.14	2.19	2.18	2.06	2.25	2.32	2.13	2.10	2.24	2.16	2.11	2.05
35	2.20	2.16	2.13	2.18	2.16	2.05	2.22	2.31	2.11	2.07	2.18	2.16	2.07	2.05
36	2.17	2.12	2.09	2.16	2.13	2.02	2.20	2.29	2.04	2.07	2.13	2.15	2.02	2.04

TABLE XIV: The sample points of the lead thickness for PCAL Module 3.

	8R	8L	9R	9L	10R	20L	11R	11L	12R	12L	13R	13L	14R	14L
1	2.08	2.06	2.05	2.15	2.28	2.06	2.24	2.08	2.21	2.03	2.22	2.09	2.18	2.12
2	2.11	2.06	2.06	2.15	2.29	2.06	2.26	2.07	2.21	2.06	2.21	2.11	2.12	2.14
3	2.14	2.09	2.06	2.15	2.32	2.08	2.29	2.08	2.24	2.10	2.24	2.15	2.17	2.17
4	2.12	2.06	2.08	2.11	2.29	2.07	2.24	2.07	2.20	2.03	2.21	2.09	2.14	2.16
5	2.16	2.08	2.09	2.13	2.32	2.08	2.27	2.05	2.23	2.05	2.23	2.11	2.19	2.18
6	2.19	2.10	2.10	2.14	2.35	2.13	2.31	2.07	2.26	2.09	2.26	2.15	2.22	2.20
7	2.11	2.04	2.06	2.10	2.29	2.08	2.21	2.04	2.20	2.03	2.21	2.09	2.16	2.15
8	2.14	2.05	2.09	2.12	2.31	2.09	2.25	2.05	2.21	2.05	2.23	2.12	2.21	2.19
9	2.16	2.07	2.14	2.15	2.34	2.11	2.28	2.06	2.25	2.07	2.26	2.14	2.26	2.21
10	2.17	2.08	2.14	2.16	2.35	2.16	2.30	2.12	2.27	2.10	2.27	2.17	2.26	2.24
11	2.10	2.05	2.05	2.13	2.28	2.10	2.20	2.07	2.20	2.04	2.20	2.13	2.17	2.15
12	2.11	2.09	2.08	2.13	2.30	2.12	2.24	2.08	2.21	2.05	2.24	2.15	2.23	2.16
13	2.15	2.08	2.12	2.14	2.32	2.14	2.29	2.14	2.25	2.06	2.26	2.18	2.25	2.20
14	2.15	2.09	2.13	2.16	2.34	2.17	2.29	2.13	2.26	2.09	2.27	2.22	2.26	2.24
15	2.15	2.11	2.13	2.17	2.32	2.19	2.29	2.14	2.24	2.09	2.26	2.22	2.27	2.28
16	2.12	2.02	2.02	2.14	2.27	2.09	2.19	2.10	2.20	2.03	2.26	2.13	2.19	2.13
17	2.13	2.07	2.06	2.14	2.29	2.13	2.23	2.13	2.22	2.05	2.27	2.15	2.24	2.15
18	2.16	2.10	2.10	2.16	2.32	2.16	2.27	2.15	2.25	2.07	2.26	2.18	2.28	2.18
19	2.16	2.10	2.12	2.17	2.32	2.18	2.27	2.17	2.25	2.09	2.27	2.21	2.27	2.21
20	2.15	2.14	2.11	2.18	2.31	2.19	2.27	2.17	2.23	2.10	2.26	2.23	2.27	2.23
21	2.14	2.13	2.09	2.17	2.31	2.20	2.26	2.17	2.23	2.10	2.25	2.24	2.26	2.23
22	2.06	2.03	2.03	2.10	2.26	2.08	2.20	2.10	2.20	2.06	2.21	2.13	2.17	2.11
23	2.09	2.06	2.07	2.13	2.29	2.13	2.25	2.14	2.23	2.09	2.24	2.15	2.21	2.11
24	2.15	2.10	2.09	2.15	2.31	2.14	2.27	2.17	2.24	2.13	2.25	2.19	2.24	2.15
25	2.15	2.12	2.12	2.18	2.34	2.17	2.29	2.18	2.25	2.16	2.25	2.20	2.27	2.19
26	2.16	2.13	2.10	2.18	2.30	2.18	2.27	2.19	2.21	2.18	2.24	2.21	2.25	2.20
27	2.12	2.12	2.07	2.18	2.27	2.17	2.26	2.19	2.19	2.18	2.20	2.21	2.26	2.20
28	2.08	2.10	2.04	2.16	2.24	2.14	2.27	2.16	2.16	2.17	2.16	2.18	2.21	2.19
29	2.08	2.02	2.09	2.08	2.34	2.08	2.32	2.07	2.29	2.05	2.25	2.13	2.17	2.15
30	2.14	2.03	2.10	2.11	2.37	2.10	2.37	2.09	2.31	2.08	2.26	2.14	2.21	2.13
31	2.15	2.13	2.13	2.14	2.38	2.13	2.41	2.13	2.33	2.13	2.27	2.16	2.24	2.15
32	2.16	2.10	2.14	2.16	2.40	2.14	2.40	2.14	2.35	2.14	2.27	2.19	2.26	2.17
33	2.17	2.19	2.13	2.17	2.39	2.15	2.40	2.14	2.32	2.15	2.26	2.20	2.26	2.17
34	2.15	2.13	2.09	2.18	2.38	2.13	2.38	2.14	2.29	2.14	2.20	2.20	2.23	2.16
35	2.11	2.08	2.08	2.18	2.36	2.11	2.33	2.10	2.25	2.13	2.15	2.19	2.20	2.15
36	2.06	2.07	2.03	2.12	2.27	2.09	2.28	2.08	2.17	2.08	2.10	2.16	2.16	2.11

TABLE XV: The sample points of the lead thickness for PCAL Module 3 continued.

	1R	1L	2R	2L	3R	3L	4R	4L	5R	5L	6R	6L	7R	7L
1	2.08	2.20	2.09	2.13	2.14	2.07	2.09	2.10	2.05	2.14	2.05	2.09	1.99	2.16
2	2.10	2.10	2.09	2.11	2.16	2.08	2.11	2.10	2.07	2.10	2.10	2.14	2.01	2.19
3	2.14	2.13	2.15	2.10	2.19	2.09	2.15	2.12	2.10	2.19	2.13	2.14	2.04	2.27
4	2.10	2.10	2.06	2.09	2.18	2.08	2.11	2.09	2.08	2.17	2.12	2.13	2.02	2.18
5	2.14	2.11	2.11	2.09	2.16	2.10	2.14	2.10	2.13	2.19	2.14	2.15	2.05	2.25
6	2.16	2.16	2.16	2.12	2.22	2.14	2.16	2.13	2.15	2.23	2.16	2.18	2.09	2.26
7	2.12	2.12	2.09	2.11	2.10	2.11	2.13	2.11	2.10	2.17	2.11	2.14	2.03	2.18
8	2.15	2.14	2.14	2.12	2.14	2.13	2.16	2.13	2.13	2.20	2.14	2.17	2.06	2.18
9	2.17	2.16	2.17	2.15	2.18	2.15	2.19	2.15	2.16	2.24	2.15	2.19	2.08	2.23
10	2.18	2.24	2.20	2.17	2.21	2.17	2.20	2.16	2.18	2.27	2.19	2.22	2.09	2.25
11	2.09	2.14	2.09	2.13	2.16	2.16	2.15	2.13	2.13	2.18	2.10	2.14	2.03	2.16
12	2.14	2.15	2.16	2.13	2.19	2.20	2.17	2.15	2.15	2.20	2.13	2.17	2.06	2.18
13	2.17	2.18	2.19	2.16	2.23	2.21	2.20	2.19	2.17	2.24	2.14	2.20	2.08	2.21
14	2.17	2.20	2.21	2.19	2.25	2.26	2.23	2.21	2.19	2.26	2.17	2.22	2.09	2.23
15	2.17	2.21	2.21	2.22	2.25	2.26	2.24	2.21	2.20	2.28	2.16	2.23	2.10	2.24
16	2.08	2.13	2.10	2.14	2.14	2.14	2.14	2.14	2.10	2.19	2.07	2.17	2.04	2.14
17	2.13	2.14	2.16	2.16	2.19	2.19	2.19	2.16	2.15	2.21	2.13	2.18	2.05	2.18
18	2.21	2.17	2.20	2.20	2.21	2.23	2.21	2.20	2.19	2.25	2.13	2.20	2.08	2.21
19	2.18	2.20	2.22	2.21	2.24	2.24	2.22	2.23	2.21	2.27	2.15	2.23	2.09	2.24
20	2.16	2.21	2.22	2.24	2.24	2.26	2.24	2.24	2.21	2.27	2.16	2.23	2.10	2.25
21	2.14	2.21	2.20	2.23	2.23	2.26	2.24	2.25	2.21	2.26	2.16	2.21	2.10	2.25
22	2.11	2.11	2.11	2.13	2.09	2.14	2.14	2.13	2.10	2.18	2.05	2.14	2.02	2.13
23	2.14	2.14	2.16	2.16	2.16	2.16	2.17	2.15	2.14	2.20	2.09	2.17	2.06	2.16
24	2.20	2.16	2.20	2.18	2.20	2.18	2.20	2.22	2.18	2.24	2.13	2.20	2.07	2.20
25	2.17	2.19	2.23	2.20	2.22	2.21	2.21	2.22	2.20	2.26	2.15	2.22	2.08	2.24
26	2.16	2.20	2.25	2.22	2.24	2.22	2.23	2.23	2.22	2.28	2.16	2.23	2.09	2.25
27	2.13	2.21	2.23	2.22	2.22	2.21	2.24	2.23	2.22	2.26	2.16	2.21	2.08	2.24
28	2.08	2.20	2.20	2.20	2.20	2.24	2.23	2.22	2.21	2.24	2.15	2.20	2.07	2.21
29	2.13	2.14	2.14	2.11	2.17	2.13	2.12	2.16	2.11	2.16	2.06	2.12	2.02	2.14
30	2.18	2.11	2.19	2.15	2.21	2.13	2.16	2.14	2.15	2.20	2.09	2.17	2.04	2.16
31	2.17	2.13	2.23	2.16	2.26	2.16	2.20	2.17	2.18	2.26	2.12	2.21	2.07	2.20
32	2.18	2.15	2.25	2.18	2.27	2.17	2.20	2.18	2.20	2.26	2.15	2.21	2.09	2.21
33	2.16	2.14	2.24	2.19	2.28	2.18	2.22	2.19	2.21	2.26	2.15	2.21	2.09	2.26
34	2.14	2.16	2.22	2.18	2.27	2.15	2.22	2.18	2.22	2.25	2.16	2.20	2.08	2.20
35	2.10	2.13	2.19	2.16	2.24	2.14	2.21	2.17	2.22	2.24	2.15	2.17	2.07	2.17
36	2.04	2.07	2.18	2.15	2.22	2.13	2.22	2.15	2.20	2.19	2.14	2.11	2.04	2.27

TABLE XVI: The sample points of the lead thickness for PCAL Module 4.

	8R	8L	9R	9L	10R	20L	11R	11L	12R	12L	13R	13L	14R	14L
1	2.03	2.09	2.09	2.11	2.09	2.14	2.07	1.98	2.16	2.00	2.06	2.07	2.03	2.05
2	2.04	2.08	2.08	2.14	2.05	2.13	2.08	2.02	2.00	2.12	2.06	2.06	2.07	2.06
3	2.06	2.10	2.11	2.15	2.15	2.16	2.10	2.03	1.98	2.11	2.08	2.08	2.08	2.06
4	2.06	2.07	2.09	2.13	2.08	2.13	2.09	2.00	2.00	2.13	2.09	2.07	2.06	2.04
5	2.06	2.09	2.12	2.15	2.15	2.16	2.11	2.02	2.02	2.13	2.13	2.08	2.07	2.05
6	2.08	2.10	2.14	2.18	2.15	2.18	2.14	2.03	2.04	2.13	2.14	2.08	2.08	2.08
7	2.15	2.09	2.10	2.13	2.07	2.14	2.09	2.03	2.06	2.14	2.08	2.08	2.04	2.07
8	2.09	2.09	2.13	2.14	2.11	2.15	2.12	2.04	2.07	2.14	2.13	2.09	2.06	2.06
9	2.09	2.09	2.15	2.16	2.14	2.18	2.15	2.05	2.09	2.14	2.13	2.13	2.08	2.07
10	2.13	2.09	2.14	2.18	2.14	2.19	2.17	2.07	2.10	2.15	2.14	2.13	2.08	2.06
11	2.05	2.08	2.08	2.13	2.07	2.13	2.09	2.04	2.09	2.11	2.06	2.13	2.02	2.06
12	2.07	2.09	2.10	2.15	2.10	2.14	2.13	2.05	2.09	2.13	2.09	2.13	2.04	2.07
13	2.09	2.10	2.17	2.18	2.14	2.17	2.14	2.07	2.11	2.13	2.13	2.15	2.06	2.07
14	2.04	2.09	2.12	2.20	2.15	2.20	2.17	2.08	2.13	2.14	2.13	2.15	2.06	2.07
15	2.16	2.08	2.13	2.08	2.15	2.19	2.17	2.09	2.11	2.14	2.12	2.17	2.06	2.10
16	2.06	2.08	2.07	2.13	2.13	2.14	2.11	2.00	2.08	2.11	2.06	2.10	2.02	2.05
17	2.07	2.09	2.09	2.15	2.13	2.18	2.14	2.03	2.09	2.12	2.09	2.13	2.04	2.07
18	2.09	2.09	2.13	2.16	2.15	2.17	2.16	2.07	2.10	2.14	2.10	2.14	2.06	2.10
19	2.09	2.09	2.09	2.18	2.16	2.19	2.17	2.07	2.11	2.13	2.11	2.15	2.06	2.06
20	2.09	2.08	2.13	2.19	2.16	2.19	2.18	2.08	2.10	2.12	2.11	2.15	2.06	2.08
21	2.13	2.06	2.09	2.17	2.15	2.18	2.19	2.07	2.11	2.13	2.13	2.14	2.06	2.04
22	2.09	2.08	2.09	2.13	2.07	2.13	2.11	2.02	2.02	2.10	2.06	2.10	2.00	2.06
23	2.06	2.08	2.08	2.14	2.14	2.15	2.14	2.04	2.05	2.10	2.08	2.15	2.03	2.09
24	2.08	2.09	2.09	2.15	2.15	2.17	2.16	2.07	2.07	2.12	2.09	2.16	2.05	2.08
25	2.08	2.08	2.08	2.18	2.18	2.19	2.18	2.08	2.10	2.11	2.10	2.16	2.06	2.07
26	2.08	2.07	2.08	2.16	2.14	2.18	2.18	2.05	2.08	2.11	2.11	2.17	2.06	2.05
27	2.09	2.05	2.06	2.15	2.17	2.18	2.19	2.05	2.08	2.09	2.10	2.16	2.06	2.03
28	2.08	2.03	2.09	2.14	2.21	2.16	2.19	2.04	2.08	2.08	2.10	2.14	2.05	2.02
29	2.03	2.10	2.08	2.18	2.07	2.13	2.10	2.02	2.03	2.09	2.05	2.15	2.00	2.08
30	2.05	2.13	2.09	2.14	2.11	2.14	2.14	2.04	2.05	2.11	2.08	2.15	2.03	2.08
31	2.07	2.13	2.11	2.15	2.15	2.15	2.17	2.07	2.07	2.11	2.09	2.18	2.06	2.09
32	2.09	2.13	2.11	2.17	2.18	2.16	2.19	2.09	2.08	2.11	2.12	2.18	2.06	2.08
33	2.07	2.10	2.11	2.16	2.14	2.16	2.18	2.07	2.08	2.11	2.12	2.19	2.07	2.09
34	2.06	2.08	2.09	2.15	2.18	2.17	2.19	2.06	2.08	2.06	2.11	2.18	2.07	2.07
35	2.04	2.04	2.13	2.14	2.15	2.14	2.19	2.07	2.07	2.11	2.13	2.16	2.07	2.08
36	2.00	2.02	2.04	2.11	2.16	2.10	2.17	2.05	2.07	2.07	2.11	2.16	2.05	2.02

TABLE XVII: The sample points of the lead thickness for PCAL Module 4 continued.

	1R	1L	2R	2L	3R	3L	4R	4L	5R	5L	6R	6L	7R	7L
1	2.06	2.05	2.08	2.08	2.10	2.24	2.02	2.04	2.07	2.02	2.05	2.14	2.14	1.96
2	2.09	2.06	2.09	2.14	2.07	2.26	2.00	2.03	2.08	2.07	2.04	2.08	2.18	1.94
3	2.11	2.07	2.11	2.11	2.06	2.28	2.02	2.06	2.09	2.09	2.06	2.11	2.16	1.97
4	2.14	2.05	2.11	2.12	2.05	2.25	2.02	2.08	2.08	2.07	2.05	2.06	2.15	1.94
5	2.14	2.06	2.14	2.10	2.06	2.28	2.03	2.01	2.09	2.08	2.07	2.08	2.18	1.97
6	2.14	2.09	2.15	2.14	2.06	2.28	2.04	2.05	2.09	2.10	2.07	2.11	2.18	1.99
7	2.09	2.09	2.10	2.11	2.02	2.24	2.01	2.00	2.10	2.08	2.05	2.12	2.15	1.99
8	2.13	2.08	2.13	2.12	2.07	2.28	2.04	2.06	2.10	2.11	2.06	2.13	2.16	1.98
9	2.13	2.09	2.15	2.11	2.06	2.26	2.05	2.04	2.10	2.11	2.07	2.14	2.17	2.02
10	2.13	2.10	2.16	2.11	2.06	2.26	2.06	2.08	2.09	2.13	2.07	2.14	2.17	2.02
11	2.08	2.08	2.13	2.09	2.02	2.26	2.02	2.08	2.09	2.08	2.04	2.09	2.16	1.96
12	2.09	2.08	2.14	2.10	2.04	2.24	2.05	2.09	2.11	2.10	2.06	2.09	2.16	2.00
13	2.11	2.09	2.15	2.12	2.05	2.25	2.06	2.08	2.11	2.14	2.07	2.13	2.18	2.03
14	2.12	2.13	2.17	2.13	2.09	2.25	2.06	2.17	2.10	2.15	2.07	2.16	2.17	2.04
15	2.13	2.12	2.18	2.15	2.07	2.26	2.07	2.12	2.09	2.16	2.07	2.14	2.17	2.05
16	2.06	2.06	2.13	2.08	2.03	2.25	2.02	2.20	2.08	2.04	2.02	2.08	2.15	1.96
17	2.08	2.08	2.15	2.09	2.05	2.25	2.04	2.06	2.10	2.08	2.04	2.13	2.16	1.99
18	2.10	2.09	2.16	2.12	2.16	2.25	2.06	2.06	2.09	2.10	2.05	2.10	2.17	2.03
19	2.10	2.11	2.18	2.13	2.09	2.25	2.06	2.10	2.09	2.13	2.06	2.13	2.17	2.04
20	2.11	2.12	2.18	2.11	2.07	2.26	2.06	2.06	2.08	2.14	2.06	2.14	2.16	2.06
21	2.11	2.10	2.18	2.11	2.07	2.25	2.10	2.09	2.09	2.14	2.06	2.14	2.15	2.07
22	2.06	2.05	2.13	2.08	2.04	2.23	2.02	2.09	2.07	2.00	2.01	1.99	2.16	1.94
23	2.08	2.07	2.15	2.11	2.06	2.25	2.04	2.00	2.08	2.03	2.03	2.04	2.17	1.99
24	2.09	2.09	2.16	2.12	2.07	2.26	2.05	2.00	2.09	2.08	2.04	2.08	2.18	2.08
25	2.10	2.09	2.17	2.09	2.07	2.26	2.06	2.03	2.08	2.10	2.05	2.09	2.17	2.06
26	2.09	2.13	2.18	2.12	2.07	2.26	2.06	2.04	2.09	2.11	2.05	2.10	2.17	2.07
27	2.09	2.09	2.18	2.13	2.07	2.25	2.07	2.08	2.08	2.13	2.06	2.10	2.15	2.08
28	2.09	2.07	2.18	2.08	2.08	2.19	2.12	2.03	2.07	2.13	2.05	2.09	2.13	2.06
29	2.04	2.07	2.11	2.08	2.07	2.24	2.00	2.06	2.06	1.98	2.01	2.00	2.19	1.96
30	2.06	2.07	2.13	2.11	2.07	2.26	2.03	2.03	2.08	2.02	2.03	2.05	2.17	1.97
31	2.07	2.08	2.15	2.13	2.07	2.27	2.04	2.07	2.08	2.05	2.05	2.08	2.18	2.02
32	2.08	2.08	2.15	2.12	2.07	2.27	2.05	2.06	2.09	2.08	2.05	2.11	2.18	2.04
33	2.09	2.09	2.16	2.14	2.07	2.26	2.06	2.04	2.09	2.09	2.06	2.14	2.16	2.09
34	2.09	2.08	2.16	2.13	2.06	2.24	2.05	2.04	2.09	2.15	2.06	2.13	2.16	2.08
35	2.09	2.07	2.16	2.10	2.07	2.23	2.07	2.08	2.08	2.14	2.05	2.13	2.12	2.07
36	2.08	2.06	2.16	2.08	2.05	2.18	2.07	2.03	2.07	2.11	2.04	2.10	2.16	2.07

TABLE XVIII: The sample points of the lead thickness for PCAL Module 5.

	8R	8L	9R	9L	10R	20L	11R	11L	12R	12L	13R	13L	14R	14L
1	2.08	2.02	2.07	2.13	2.04	2.05	2.07	2.08	2.15	2.14	2.07	2.14	2.03	2.09
2	2.06	2.04	2.07	2.11	2.03	2.06	2.08	2.08	2.15	2.19	2.10	2.12	2.03	2.08
3	2.06	2.06	2.08	2.16	2.04	2.06	2.08	2.13	2.16	2.19	2.07	2.16	2.04	2.10
4	2.07	2.04	2.08	2.10	2.05	2.04	2.08	2.07	2.15	2.23	2.07	2.13	2.03	2.08
5	2.09	2.05	2.10	2.14	2.03	2.07	2.09	2.09	2.16	2.14	2.09	2.14	2.03	2.10
6	2.10	2.08	2.10	2.17	2.04	2.08	2.09	2.11	2.17	2.19	2.08	2.16	2.09	2.10
7	2.07	2.03	2.10	2.13	2.07	2.13	2.08	2.10	2.14	2.12	2.09	2.13	2.04	2.01
8	2.08	2.07	2.11	2.15	2.04	2.15	2.10	2.10	2.15	2.15	2.08	2.14	2.04	2.04
9	2.11	2.09	2.13	2.17	2.07	2.15	2.11	2.14	2.18	2.15	2.10	2.17	2.07	2.07
10	2.11	2.11	2.12	2.20	2.07	2.16	2.11	2.14	2.18	2.19	2.10	2.19	2.06	2.09
11	2.07	2.04	2.10	2.14	2.05	2.14	2.09	2.09	2.16	2.17	2.08	2.13	2.04	2.09
12	2.08	2.06	2.13	2.16	2.06	2.17	2.10	2.13	2.15	2.18	2.09	2.15	2.06	2.10
13	2.10	2.08	2.14	2.19	2.07	2.17	2.13	2.14	2.16	2.20	2.10	2.17	2.07	2.14
14	2.13	2.10	2.14	2.23	2.08	2.18	2.13	2.15	2.17	2.18	2.09	2.18	2.06	2.13
15	2.10	2.10	2.13	2.24	2.10	2.29	2.14	2.15	2.17	2.18	2.10	2.18	2.05	2.13
16	2.06	2.08	2.09	2.15	2.14	2.07	2.09	2.11	2.14	2.15	2.08	2.17	2.04	2.13
17	2.07	2.10	2.10	2.17	2.06	2.09	2.12	2.14	2.15	2.08	2.11	2.15	2.06	2.15
18	2.08	2.12	2.12	2.20	2.08	2.11	2.13	2.14	2.16	2.19	2.13	2.16	2.13	2.15
19	2.08	2.13	2.12	2.23	2.10	2.14	2.13	2.15	2.15	2.19	2.09	2.20	2.08	2.16
20	2.09	2.14	2.14	2.25	2.10	2.17	2.14	2.16	2.16	2.20	2.09	2.18	2.08	2.16
21	2.07	2.13	2.12	2.27	2.10	2.16	2.14	2.16	2.15	2.20	2.08	2.16	2.07	2.18
22	2.05	2.05	2.08	2.15	2.06	2.16	2.08	2.05	2.14	2.07	2.06	2.14	2.04	2.04
23	2.06	2.07	2.10	2.19	2.07	2.17	2.10	2.09	2.14	2.11	2.08	2.17	2.06	2.07
24	2.07	2.10	2.11	2.22	2.08	2.17	2.11	2.11	2.15	2.14	2.08	2.19	2.08	2.09
25	2.08	2.12	2.10	2.25	2.09	2.15	2.11	2.14	2.15	2.16	2.08	2.20	2.07	2.13
26	2.07	2.14	2.10	2.26	2.09	2.13	2.11	2.16	2.14	2.17	2.07	2.21	2.07	2.15
27	2.07	2.13	2.10	2.27	2.10	2.09	2.10	2.15	2.14	2.17	2.07	2.20	2.08	2.14
28	2.02	2.11	2.09	2.27	2.08	2.07	2.08	2.15	2.11	2.17	2.06	2.20	2.08	2.14
29	2.07	2.02	2.09	2.18	2.03	2.06	2.08	2.12	2.16	2.08	2.07	2.14	2.07	2.02
30	2.13	2.06	2.10	2.22	2.04	2.07	2.08	2.15	2.16	2.13	2.07	2.18	2.05	2.06
31	2.09	2.08	2.10	2.27	2.06	2.11	2.09	2.17	2.18	2.17	2.08	2.19	2.06	2.08
32	2.08	2.09	2.12	2.27	2.06	2.13	2.09	2.18	2.17	2.17	2.08	2.20	2.08	2.10
33	2.08	2.11	2.12	2.28	2.06	2.15	2.09	2.19	2.17	2.17	2.07	2.20	2.07	2.13
34	2.07	2.11	2.09	2.28	2.07	2.17	2.08	2.19	2.16	2.20	2.08	2.25	2.07	2.13
35	2.05	2.11	2.09	2.28	2.06	2.18	2.07	2.18	2.15	2.18	2.06	2.18	2.09	2.13
36	2.04	2.08	2.07	2.27	2.05	2.16	2.07	2.16	2.14	2.15	2.05	2.17	2.06	2.11

TABLE XIX: The sample points of the lead thickness for PCAL Module 5 continued.