

# Assembly Manual for the Berkeley Lab Cosmic Ray Detector

By  
Michael Collier and Lyle Wolfley\*



**Version 2.0.3 – October 2006**

\*For correspondence contact – Howard Matis – [hsmatis@lbl.gov](mailto:hsmatis@lbl.gov)



# Cosmic Ray Detector

<b>Introduction</b>	<b>4</b>
<b>Scintillator</b>	<b>4</b>
<b>Cutting</b>	<b>4</b>
Equipment and Supplies	4
Procedure	4
<b>Lucite Cookies (optional)</b>	<b>6</b>
Equipment and Supplies	6
Procedure	6
<b>Polishing</b>	<b>10</b>
Equipment and Supplies	10
Procedure — Coarse (600 grit)	10
Procedure — Medium (~800 grit)	12
Procedure — Fine (~1200 grit)	12
<b>Scintillator with Photomultiplier</b>	<b>14</b>
<b>Wrapping</b>	<b>14</b>
Equipment and Supplies	14
Procedure	14
<b>Attaching and Gluing</b>	<b>16</b>
Equipment and Supplies (End Mount Photomultiplier)	16
Procedure (End Mount Photomultiplier)	17
Equipment and Supplies (Side Mount Photomultiplier)	20
Procedure (Side Mount Photomultiplier)	20
<b>Circuit Board</b>	<b>25</b>
<b>Soldering</b>	<b>25</b>
Equipment and Supplies	25
Procedure	27
<b>Casing</b>	<b>32</b>
<b>Wiring</b>	<b>34</b>
Equipment and Supplies	34
Procedure	34
<b>Appendix A: Suppliers and Parts</b>	<b>36</b>
<b>Scintillator Paddles</b>	<b>36</b>
<b>Circuit Board</b>	<b>36</b>
<b>Appendix B: Resistor Color Codes</b>	<b>38</b>
<b>Appendix C: Optional Casing</b>	<b>39</b>
<b>Casing (End Mounting Photomultiplier)</b>	<b>39</b>
<b>Casing (Side Mounting Photomultiplier)</b>	<b>41</b>
<b>Appendix D: Optional Protection Circuit</b>	<b>42</b>
<b>Appendix E: Acknowledgements</b>	<b>43</b>



# Cosmic Ray Detector

## Introduction

The Berkeley Lab Cosmic Ray Detector consists of 3 main components that must be prepared separately before they can be assembled. These components are the scintillator, circuit board, and casing. They are described in the following main sections, which may be completed in any order. There are two different types of photomultipliers which can be used; end mount and the side mount. The end mount phototubes have a better optical coupling, but are much more expensive than the side mount phototubes. The side mount phototubes make an excellent detector.

## Scintillator

Preparing the scintillator paddles (Figure 1) involves several steps — cutting the scintillator material to the appropriate size and shape, preparing and attaching Lucite cookies (optional), polishing the edges, gluing the end to the photomultiplier tube (optional), and wrapping the scintillator. Since the detector has 2 paddles, each of the following sections needs to be repeated for the other paddle.

### Cutting

The scintillator material must be cut to the appropriate shape to fit onto the photomultiplier tube correctly. Although professionals cut and mill scintillator carefully with special equipment, for our purpose, a regular saw is sufficient. The saw can be a table saw, band saw, jigsaw, or even a hacksaw, but it should be one with a blade that can get wet.

Generally, people handling scintillator should wear gloves to extend the life of the material; the oils from skin deteriorate the scintillator surface over time. However, our detector can tolerate such deterioration.

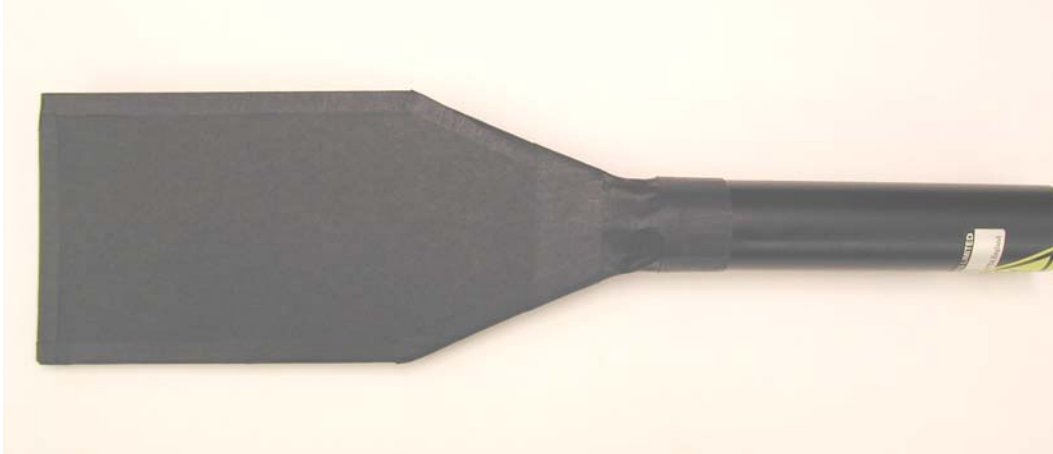
### Equipment and Supplies

- Scintillator sheet (1/4" thick)
- Film marker (or ink pen)
- Saw (medium spaced teeth)
- Cool water

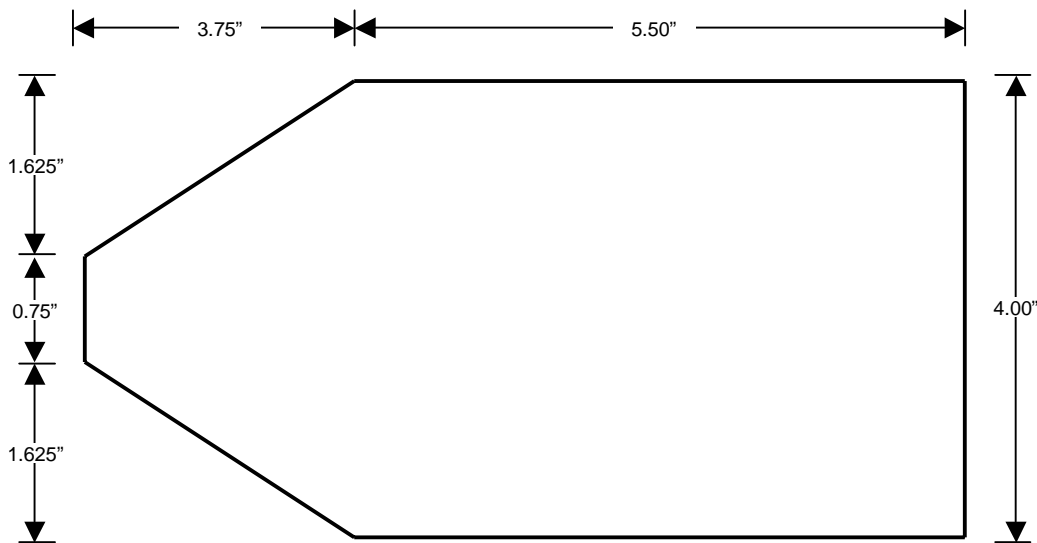
### Procedure

1. **Mark the scintillator sheet with a film marker (or ink pen) according to the dimensions in Figure 2.** The manufacturer's paper cover may be left on at this time.
2. **Cut the scintillator sheet with a saw along the lines drawn in step 1.** Be sure to cut along the outer edge of the line; the excess will be sanded away in the polishing process.

3. If your saw is not continuously wet (drawing water from a tray), then stop to wet it periodically. The water is to keep the scintillator from melting onto the blade...
4. Remove the paper cover, if you have not already.



**Figure 1:** Completed scintillator paddle with end mount photomultiplier.



**Figure 2:** Dimensions for cutting scintillator material.

## ***Lucite Cookies (optional)***

The Lucite cookies (Figure 4) attach to the end of the scintillator (the end that will be joined with the photomultiplier tube). They fill in the extra space not taken by the scintillator end on the photomultiplier. They are helpful only if you plan to glue the scintillator to the photomultiplier; they provide a broader gluing surface. Because of this purpose, the cookies do not even need to be Lucite; any plastic — even left over scintillator — is sufficient. However, try to find a material that will absorb a minimum of light (that is, a black material is not a good choice). Preparing the cookies involves several steps similar to preparing the scintillator itself: cutting, gluing, and polishing. The cookies may be attached to the scintillator before or after it has been polished.

Cutting Lucite or other plastic is much like cutting the scintillator except that Lucite or other plastic is not as fragile and may be handled more roughly. To minimize the amount of cutting, choose a cylinder or disk of plastic that is  $3/4$  of an inch in diameter. Otherwise, for example, if you use leftover scintillator, you will have to cut out 2 semicircles (the photomultiplier end is circular with a diameter of about 1 inch).

Gluing the cookies is much like gluing the scintillator to the photomultiplier end. You may want to use the same optical cement just to practice mixing and applying it, but any strong adhesive for plastics will work.

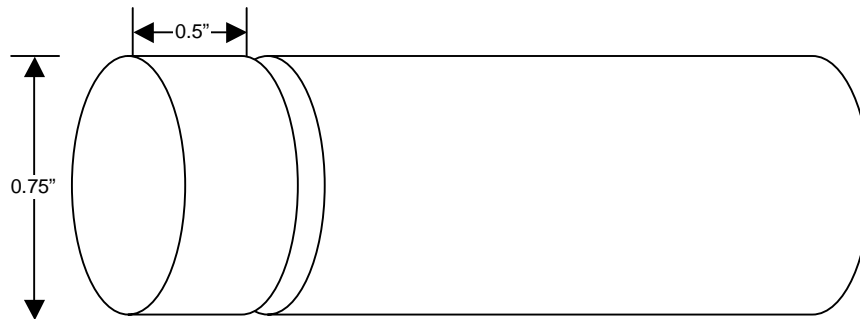
Polishing the cookies is a matter of preference. The surfaces that are glued to the scintillator should be at least smoothed with coarse sandpaper (600 grit). The surfaces that attach to the photomultiplier end will be polished with the rest of the scintillator edges (next section) unless you attach the cookies after polishing the scintillator.

## **Equipment and Supplies**

- Lucite or plastic ( $3/4$  inch diameter cylinder or disk preferred)
- Saw (as in Cutting section)
- Sandpaper (600 grit)
- Adhesive for plastic (optical cement preferred)
- Film marker (or ink pen)
- Clean cloth or tissue

## **Procedure**

- 1. Mark the plastic cylinder crosswise for a  $1/2$ " thick disk.** If you have some other shape of material, then mark 2 semicircles with a radius of  $3/8$  of an inch.
- 2. Cut the plastic along the marks.**



**Figure 3:** Cylinder of Lucite (or other plastic) showing dimensions for cut.



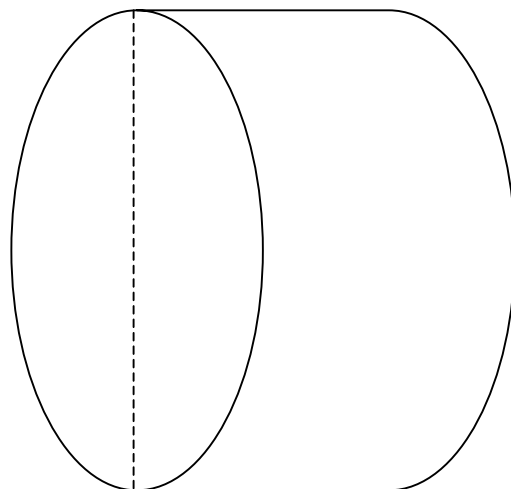
**Figure 4:** Lucite cookies (half cylinders) attached to 3/4-inch end of scintillator (center strip).



# Cosmic Ray Detector

- 3. If you are using a cylinder, make an additional straight cut through the center of the disk from step 2 (dashed line in Figure 5).**
- 4. Smooth the base edge of the semicircles with 600 grit sandpaper.** Follow the same method described in the Coarse Polishing section. Be sure to wipe or wash the sanded surfaces.
- 5. Check to make sure that the cookies, when attached to the scintillator, will fit on the photomultiplier end.** If they are too big, then trim and smooth as appropriate.
- 6. Prepare the adhesive according to the manufacturer's instructions.** See the Gluing section if you are using the optical cement.
- 7. Glue the bases of each semicircle wing to the top and bottom surfaces of the scintillator at its 3/4-inch edge.** Be sure to glue the cookies such that their semicircular flat surfaces are flush against the 3/4-inch edge of the scintillator. This is especially important if you are gluing the cookies after polishing the scintillator.
- 8. Let the winged scintillator sit undisturbed until the adhesive has hardened or dried.** You may need to brace the pieces together in some way while the adhesive sets.





**Figure 5:** Disk of Lucite (or other plastic) with dashed line to show cut.

## ***Polishing***

In order for the very faint flashes of light from cosmic rays to reach the photomultiplier tube, the interface between the tube and scintillator end as well as the other edges must be very transparent. For that reason, the scintillator edges must be polished. (The broad top and bottom surfaces do not need to be polished.) Polishing includes 3 levels — coarse, medium, and fine.

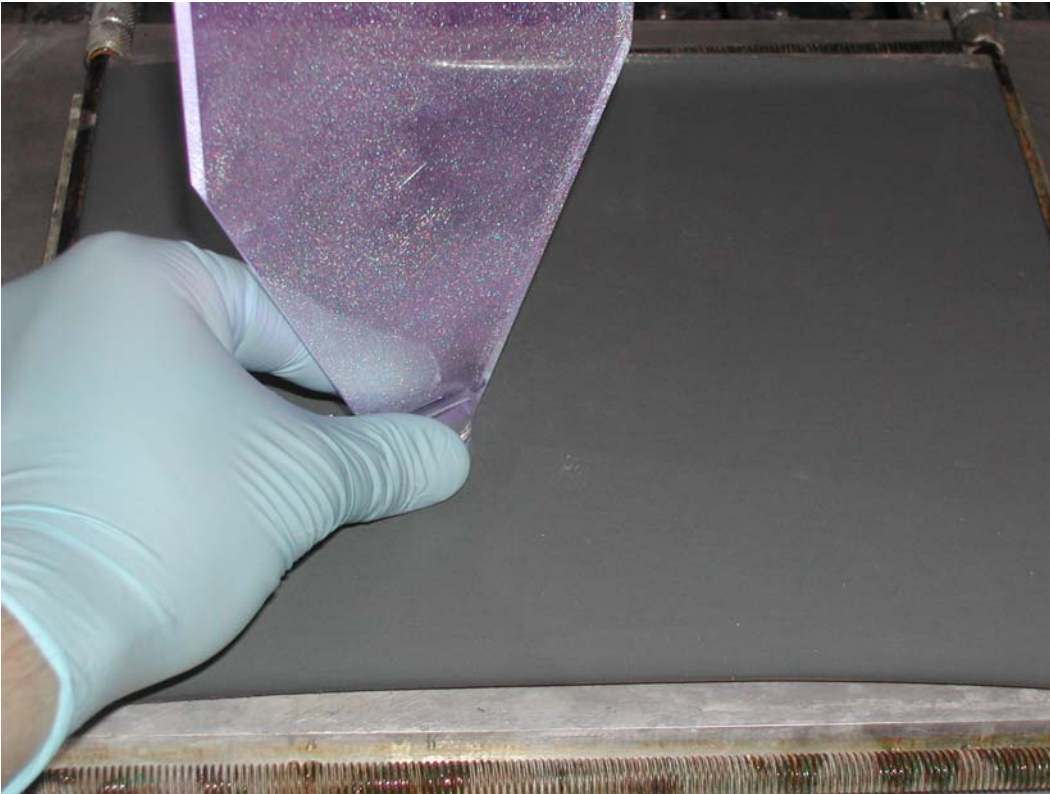
## **Equipment and Supplies**

- Scintillator cut to shape
- Flat, solid surface
- Rotating pad (if available)
- Felt
- Sandpaper (600 grit)
- Putz Pomade
- Alumina powder
- Clean cloth or tissue
- Cool and warm water

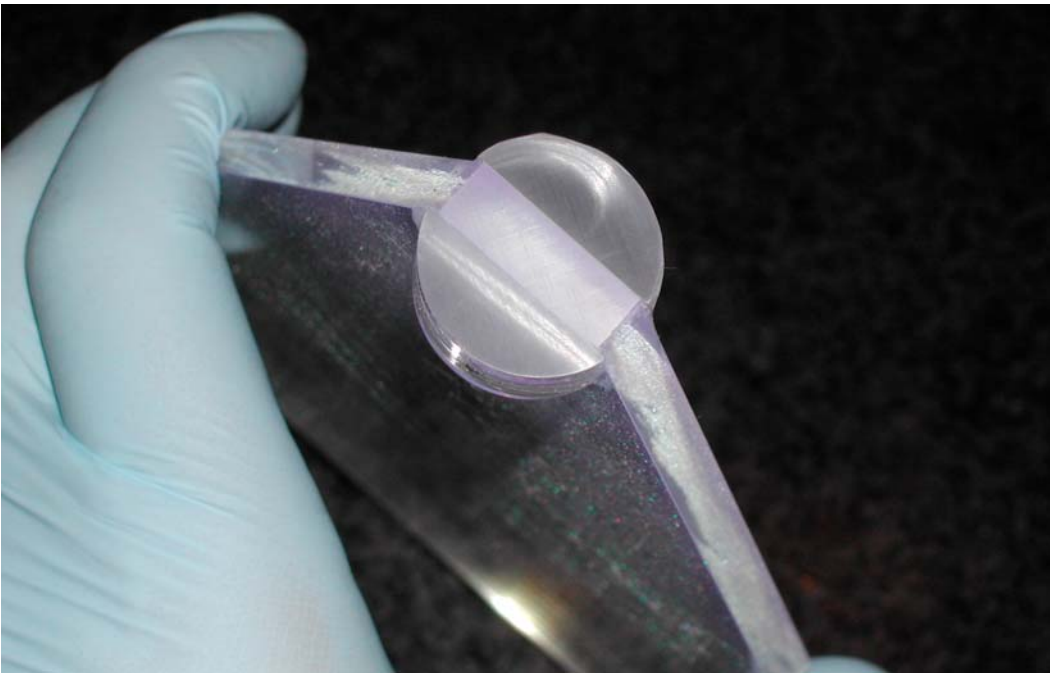
## **Procedure — Coarse (600 grit)**

- 1. Break a piece of 600 grit sandpaper.** That is, holding 2 opposite ends, pull the paper firmly across a straight metal or stone edge (such as a stainless steel sink or stone countertop) as if polishing a shoe with a rag. This takes out the uneven roughness of the paper.
- 2. Moisten the sandpaper with clean water.** The water will keep the plastic material from filling the pits and valleys in the paper. You may want to periodically re-wet the paper to clean it while sanding.
- 3. Place the piece of sandpaper on a solid, flat surface with the sand side facing up.**
- 4. Firmly hold the edge of the scintillator flat against the sand paper and push along it in a straight path until you reach the end of the paper.**
- 5. Stop, lift up the scintillator edge, and return it to the starting position.**
- 6. Repeat steps 4 and 5 until the scintillator edge is flat and evenly sanded.** The scintillator edge should have grooves or striations all going the same direction and continuous across the surface; it should have no glossy areas.
- 7. Rinse the scintillator with clean, cool water and dry with a clean cloth or tissue.**

**Note:** Be sure to follow the same direction on each stroke when sanding. This will ensure even sanding. You should also vary the path along the sand paper to maintain sanding effectiveness.



**Figure 6:** Coarse surface of scintillator.



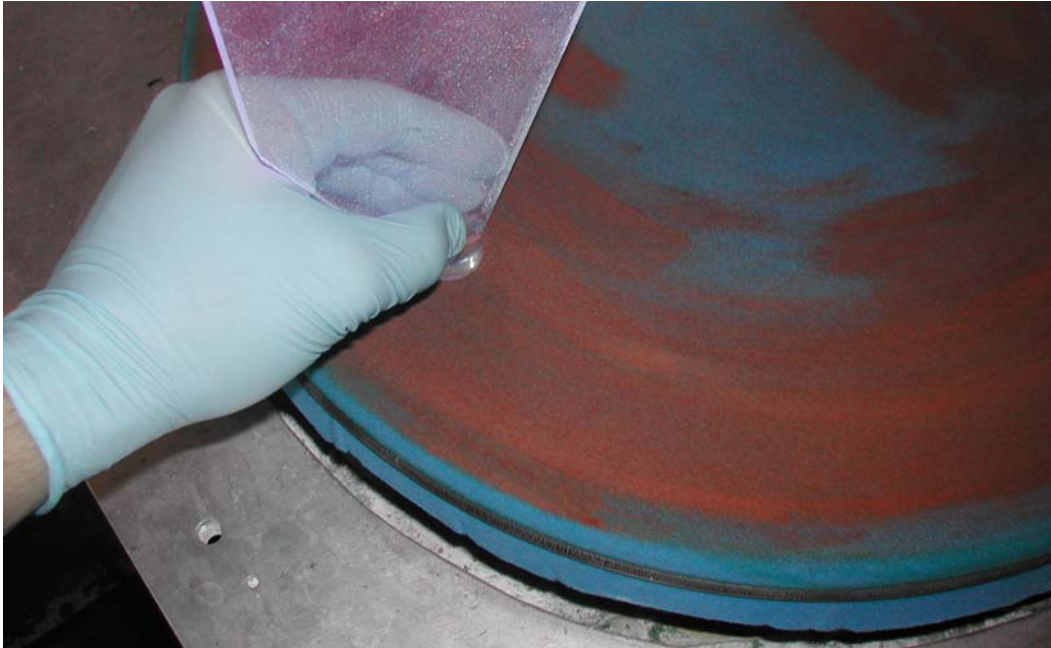
**Figure 7:** Scintillator edge flat and evenly sanded with Lucite cookies.

## Procedure — Medium (~800 grit)

1. **Cover a rotating pad machine with felt.** If you do not have such a machine, then just attach the felt to a flat surface as was done for the sandpaper. The polishing will be just more tedious.
2. **Sprinkle some Putz Pomade (~800 grit) onto the felt.** The red material in Figure 8 is the putz. If you do not have a rotating pad, go on to step 5.
3. **Power the rotating pad machine.**
4. **Lightly hold the scintillator edge flat against the rotating pad until polished.** Be sure to polish against the grain or striations made by the sandpaper. The edge is finished for this step when the Putz has polished away the sandpaper's grain. This may take 1-10 minutes for each edge, depending on your skill.
5. **If not using a table, polish in the same manner as with the sandpaper.** That is, hold the edge flat against the felt and push in straight lines against the grain made by the sandpaper. The edge is finished for this step when the Putz has polished away the sandpaper's grain. This may take 5-15 minutes for each edge, depending on your skill.
6. **Wash the scintillator of the Putz Pomade and dry with a clean cloth or tissue.** Mild detergent and water should be used for washing.

## Procedure — Fine (~1200 grit)

1. **Use a fresh piece of felt on the rotating pad machine or flat surface.**
2. **Sprinkle the felt with alumina powder.**
3. **Moisten the powdered felt with warm water.**
4. **Polish according to the steps for the Putz.** Polishing with the alumina powder takes about the same amount of time as for the Putz.
5. **The scintillator edge is polished when it has no visible grain or striations and is very glossy.**



**Figure 8:** Scintillator being polished with putz on rotating round pad.



**Figure 9:** Polished surface of scintillator.

## Scintillator with Photomultiplier

### Wrapping

Wrapping the scintillator paddle with opaque materials ensures that the photomultiplier tube detects only the flashes of light produced by cosmic rays. Also, wrapping the scintillator with the photomultiplier provides mechanical support.

### Equipment and Supplies

- Scintillator paddle
- Aluminum foil (heavy duty)
- Black cardstock
- Black masking tape
- Thin tape (e.g., Scotch)
- Pencil
- Scissors (or utility knife)

### Procedure

1. **Mark 2 pieces of black cardstock according to the dimensions in Figure 2.** The dimensions are the same as those for the scintillator, but the cardboard should be a pencil line smaller.
2. **Cut the cardstock along the marks made in step 1.** Be sure to cut just slightly smaller than the dimensions of the scintillator.
3. **Set the cardstock pieces aside and lay a sheet of aluminum foil out on a clean, flat surface with the shiny side up.**
4. **Place the scintillator in the center of the foil and neatly fold the foil over the surfaces and edges of the scintillator.** Be sure that the wrapping is tight, like a birthday present (Figure 10).

**Note:** Keep the **aluminum foil away from the scintillator end that attaches** to the photomultiplier. The end of the photomultiplier is run at high voltage. Care must be made to prevent any possible electrical contact. **It must be insulated.** Wrap the foil to just the surface of the Lucite cookies (if you are using cookies).

5. **Tape the foil (with the thin tape) to keep it tightly wrapped.**
6. **Place a small piece of thin tape curled back on itself onto each of the top and bottom surfaces of the scintillator (Figure 11).** This curl of tape is to hold the pieces of cardstock in place when trying to seal the edges of the scintillator with the black masking tape.
7. **Now stick a piece of the cut black cardstock onto each of the top and bottom surfaces of the scintillator.** Be careful to fit the cardstock so that a



8. Sliver of space shows between it and the scintillator edges. This space will allow the black masking tape to make good contact with the edges.
9. **Measure out segments of the black masking tape and stick them onto the scintillator edges.** Be careful to wrap the tape tightly around the corners to ensure good adhesion onto the foil and cardstock.



## Attaching and Gluing

There are two different photomultipliers which can be used for the cosmic ray detector. The first is the end mount photomultiplier, which connects directly with the edge of the scintillator with its flat edge (Figure 14). Although it provides for excellent light transmission, the joint between the photomultiplier and the scintillator can easily be broken. Another problem with them is that they are expensive. The adjustment potentiometer is difficult to reach in the casing described by this manual.

The second type of photomultiplier is the side mount version, which requires a cylindrical cardboard tube for structural support. This version is much more stable because the cardboard holds the scintillator and photomultiplier in place. The photomultiplier is held inside the tube at a 90-degree angle to the scintillator (as in Figure 18). The disadvantage with the side mount version is the scintillator is flat and the photomultiplier is curved. Because the photomultiplier is curved, only a long thin line will actually be touching the scintillator. For that reason it is suggested that this connection be glued with all cracks filled in (see **Figure 20**). Nevertheless, the detector will work if there is not a glue joint.

For a better detector, the polished scintillator end should be glued to the glass of the photomultiplier tube with optical cement. The optical cement serves not only to bond the scintillator to the photomultiplier but also to reduce the differences in the indices of refraction between the 2 interfaces. The index of refraction for scintillator is typically 1.58, while it is typically 1.52 for glass. Air has a refractive index of nearly 1. Having light pass from a medium of high index to a medium of such low index causes the light to scatter at the interface and not enter the phototube. The optical cement, with a refractive index of 1.57, minimizes such loss.

When using scintillator that is  $\frac{1}{4}$ " or thicker, there is enough light produced by cosmic rays that some light loss can be tolerated at this junction. Therefore, the optical cement is preferred but not essential. Optical grease is another alternative that can be used instead of optical cement. It is very easy to apply and makes excellent light coupling.

### Equipment and Supplies (End Mount Photomultiplier)

- Scintillator
- Photomultiplier tube (P30CW5 phototube and base)
- Stand for tubes (optional)
- Optical cement
- Lens cloth
- Black tape

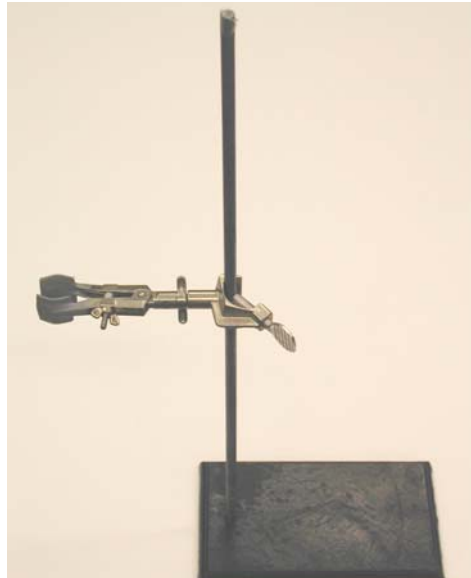


## Procedure (End Mount Photomultiplier)

- 1. Mix the optical cement components, if necessary.** Follow the manufacturer's instructions for mixing the cement.
- 2. Let the optical cement mixture sit, if necessary, for 15 minutes.** Sitting allows the air bubbles to escape the mixture. The time may vary among different brands of cement; follow the manufacturer's instructions. Alternatively, you may vacuum the air bubbles out in a small vacuum chamber designed for the purpose (a household vacuum cleaner will not work).
- 3. Meanwhile, place the photomultiplier tube onto the stand such that the glass end is facing up.** If you do not have a stand (as shown in Figure 12), then use some improvised method to hold the photomultiplier with its glass side up (and keep it held for 24-48 hours undisturbed).
- 4. Clean the surfaces to be glued — the glass of the photomultiplier tube and the polished end of the scintillator — with the lens cloth.** Follow any additional instructions provided by the manufacturer of the optical cement for surface preparation.
- 5. Place a couple drops of the settled optical cement onto the glass of the photomultiplier.** Be careful that the cement does not drip down the sides. If your photomultiplier does not have a lip on its edge, you may want to make a temporary one with some tape.
- 6. Set the scintillator end carefully onto the cement and glass of the photomultiplier.** Be sure to not trap any air between the surfaces. You may want to place one edge down first and gently lower the other edges — like closing a hinged lid — to squeeze out the air.
- 7. Let the scintillator and photomultiplier sit undisturbed (Figure 13) for 24-48 hours or the length of time specified by the manufacturer of your optical cement.** You may brace the scintillator resting on top of the photomultiplier if necessary. Do not lift the scintillator end off the glass unless you plan to clean the surfaces again and re-glue.
- 8. Now wrap black masking tape around the joined ends of the photomultiplier and scintillator (Figures 15 and 16).** Be sure that all areas of the scintillator are completely covered so that no light leaks through.

**Note:** If you did not glue the ends of the photomultiplier and scintillator, be extra thorough when taping them together so that they do not come apart during detector assembly. The casing for the cosmic ray detector will help keep the scintillator and photomultiplier in position and alleviate some of the stress on the tape.

9. Set the paddle aside once it is wrapped. Let the scintillator rest on a raised surface (or, conversely, let the photomultiplier sit in a recessed surface). This arrangement will keep strain off the joined ends of the scintillator and photomultiplier, which is especially important if they are not glued together.



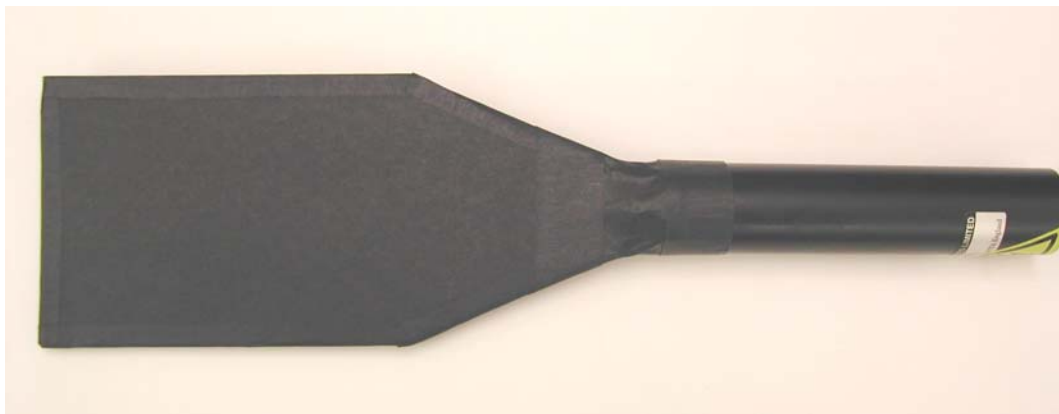
**Figure 12:** Stand to hold photomultiplier and scintillator.



**Figure 13:** Scintillator bonding with the end mount photomultiplier undisturbed for 24-48 hours.



**Figure 14:** Finished scintillator attached to end mount photomultiplier.



**Figure 15:** Scintillator and end mount photomultiplier wrapped in tape.



**Figure 16:** Close-up side view of interface wrapped in tape.

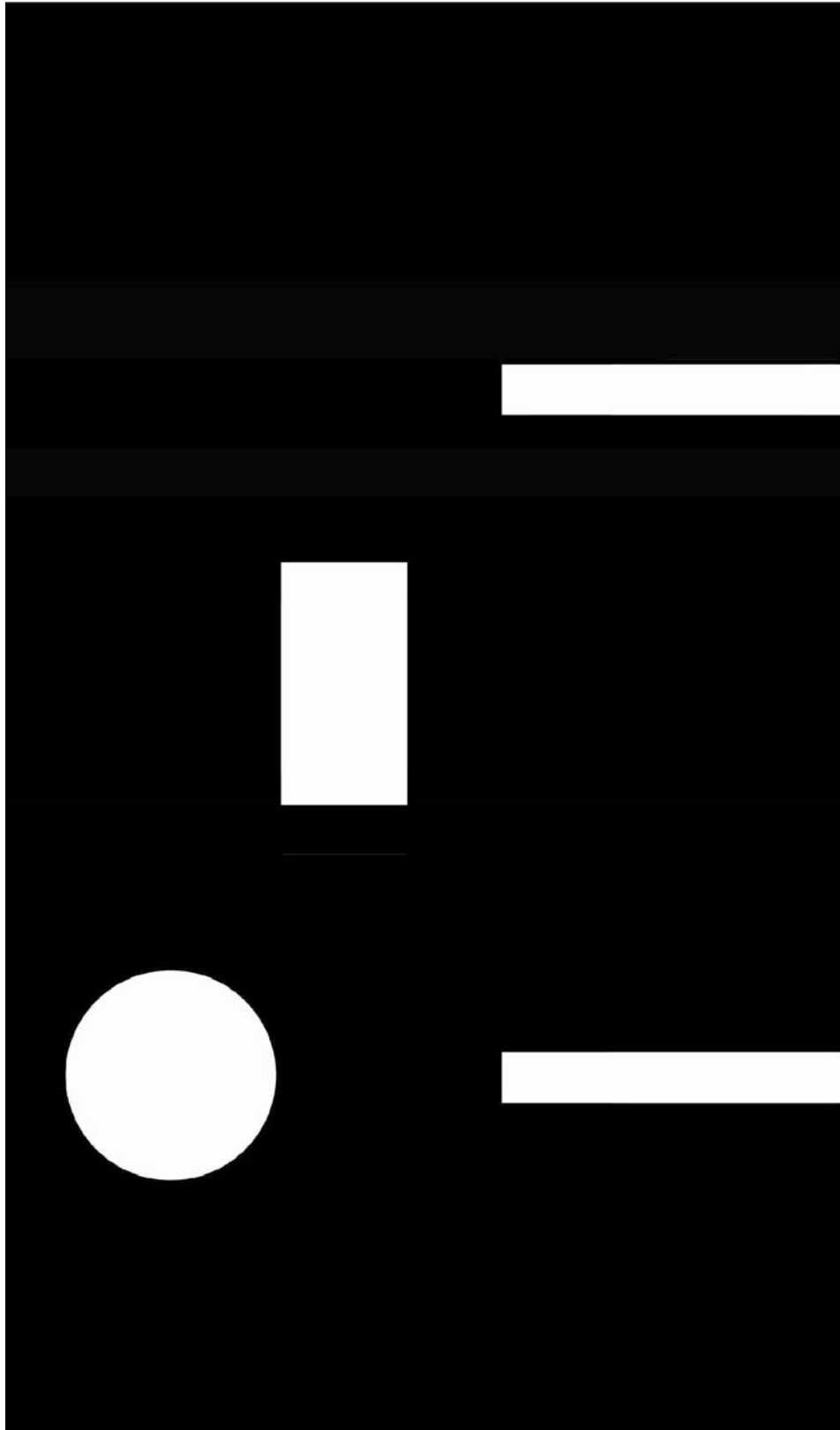
## Equipment and Supplies (Side Mount Photomultiplier)

- Scintillator
- Photomultiplier tube (931B + PS1252/5F phototube and base)
- Cardboard cylinder
- Stand for tubes (optional)
- Optical cement
- Lens cloth

## Procedure (Side Mount Photomultiplier)

1. **Before you can glue the scintillator and the photomultiplier together you have to cut out the cardboard tube.** It must be cut out to the specifications in Figure 17. Get a piece of paper and cut it out to Figure 17's specifications.
2. **Glue or tape the paper to the cardboard tubing positioned so that the two slits at one end are lined up lengthwise with the tubing.**
3. **Cut the pattern out.** Make sure that the cut out hole is very precise. This is because the photomultiplier must fit in the hole very snug and not be able to move around. It is suggested that you cut this hole out a little small and slowly widen it until the photomultiplier will barely fit.
4. **Carefully put the photomultiplier inside the tubing at a 90 degree angle.** This should be done so that only the plastic is showing outside the tube and the fit should be very snug.
5. **Push the scintillator through the cardboard slits until it is close to the photomultiplier.** The rectangular cutout should be right above this and allow you to look inside the tube.
6. **Make sure that the side of the photomultiplier which looks like a small metal grate is facing towards where the scintillator will join it.** This can be done by either looking through the end of the tube or through the top rectangular cutout.
7. **Mix the optical cement components, if necessary.** Follow the manufacturer's instructions for mixing the cement.
8. **Let the optical cement mixture sit, if necessary, for 15 minutes.** Sitting allows the air bubbles to escape the mixture. The time may vary among different brands of cement; follow the manufacturer's instructions. Alternatively, you may vacuum the air bubbles out in a small vacuum chamber designed for the purpose (a household vacuum cleaner will not work).

9. **Clean the surfaces to be glued — the glass of the photomultiplier tube and the polished end of the scintillator — with the lens cloth.** Follow any additional instructions provided by the manufacturer of the optical cement for surface preparation.
10. **Place a couple of drops of the glue between the scintillator and the photomultiplier.** Move them together so that they have a firm connection.
11. **Fill the cracks along the sides of the photomultiplier and the scintillator with glue.**
12. **Let the scintillator and photomultiplier sit undisturbed for 24-48 hours or the length of time specified by the manufacturer of your optical cement.**
13. **Wrap tape around where the entire tubing and especially where it touches the scintillator and making sure the end is covered.** Make sure that no light whatsoever can get inside the tape to the scintillator.



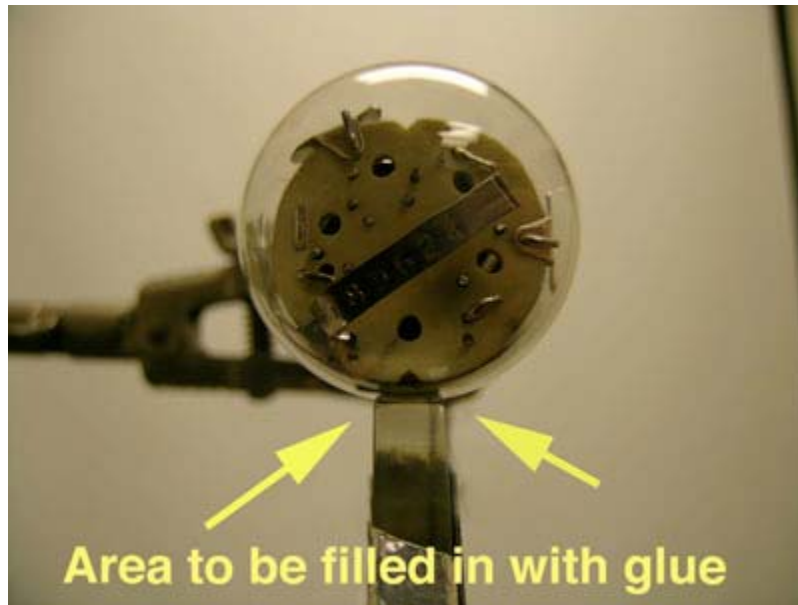
**Figure 17:** Cutout. Template for side mount photomultiplier cardboard tube.



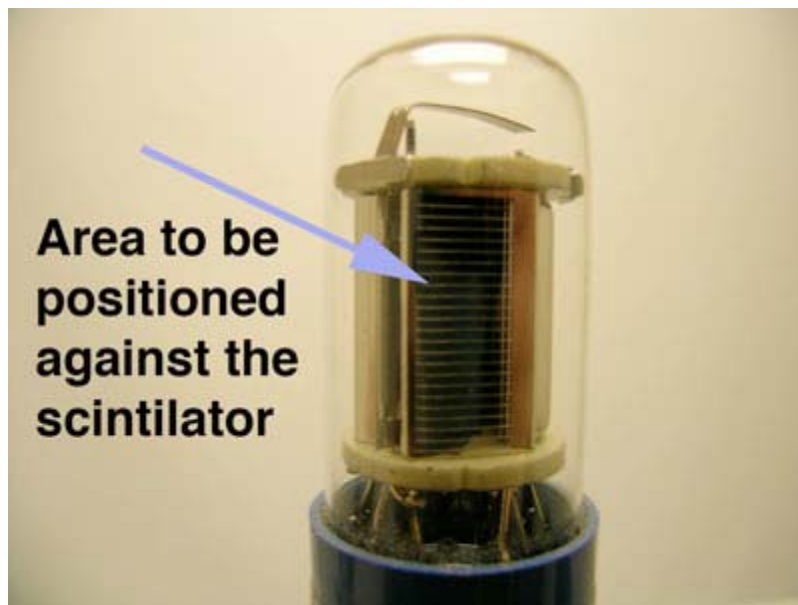
**Figure 18:** Side mount photomultiplier in cardboard tubing.



**Figure 19:** Side mount photomultipliers attached to scintillators.



**Figure 20:** The end of the scintillator touching the photomultiplier.



**Figure 21:** The section of the photomultiplier to be positioned against the scintillator.



## Circuit Board

The circuit board (Figure 22) processes the signals from the photomultiplier tubes, converting them to counts given as numbers on the display and beeps on the buzzer. It consists of a collection of resistors, capacitors, and semiconductor chips (integrated circuits) among other components soldered onto a board (Figure 22). The following sections outline how to assemble these components into a working board.

### Soldering

The components must be attached to the circuit board by soldering. The circuit board is labeled for each component with a letter and number, which appear next to names of the components in the list below.

If this is your first time soldering (or if your technique needs to be refreshed), you may want to practice on some pieces of scrap first. What is important to remember is that both the component wire and the metal pad on the board need to be hot for the solder to bond. Hold the soldering iron tip against both surfaces for about 1-2 seconds, and then feed the solder until the wire and pad are covered. The surfaces are hot enough when the melted solder flows across them on its own — like water saturating a paper towel. Be careful not to let the component get too hot; it is no good if it is melted.

Item	Description	#	Position on Board
1	51 $\Omega$ resistor	3	R1, R7, R19
2	470 $\Omega$ resistor	1	R12
3	1.1 k $\Omega$ resistor	2	R8, R20
4	4.7 k $\Omega$ resistor	3	R10, R11, R14
5	10 k $\Omega$ resistor	4	R2, R16, R22, R23
6	11 k $\Omega$ resistor	4	R3, R6, R15, R18
7	12 k $\Omega$ resistor	4	R4, R9, R17, R21
8	47 k $\Omega$ resistor	1	R25
9	100 k $\Omega$ resistor	1	R5
10	120 k $\Omega$ resistor	1	R13
11	100 k $\Omega$ variable resistor	1	R24
12	1.2 k $\Omega$ resistor array	3	RN1, RN2, RN3
13	100 pF capacitor	2	C5, C11
14	2.2 nF capacitor	1	C13
15	0.1 $\mu$ F capacitor	14	C3, C6, C7, C8, C9, C10, C12, C14, C15, C17, C18, C19, C20, C21

Item 12 will need to be replaced by single 1.2 k $\Omega$  resistors, as the old resistor array is not available for purchase.

### Equipment and Supplies

- Soldering iron
- Solder (medium diameter)
- Wet sponge
- Circuit Board

# Cosmic Ray Detector

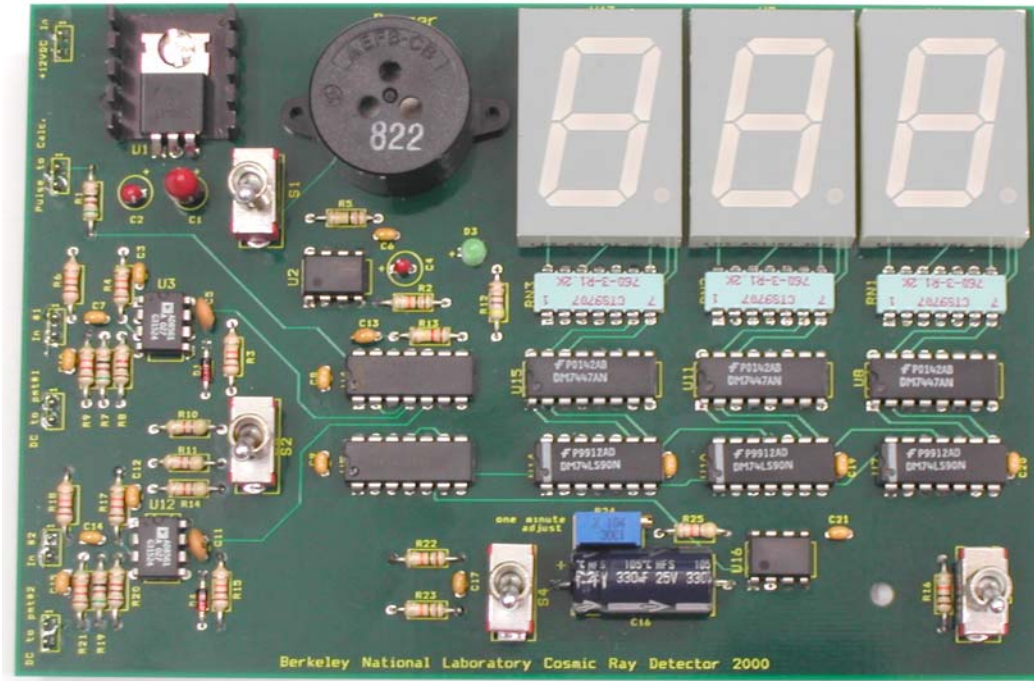


Figure 22: Completed circuit board.

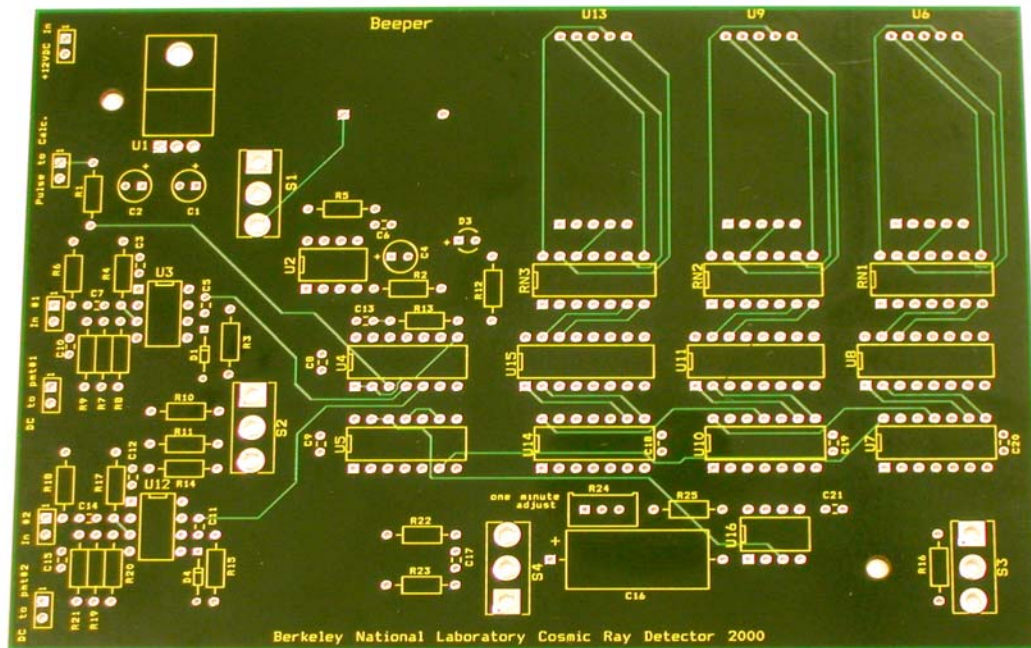


Figure 23: Empty circuit board.

Item	Description	Quantity	Position on Board
16	1 $\mu$ F capacitor	1	C4
17	6.8 $\mu$ F capacitor	1	C2
18	33 $\mu$ F capacitor	1	C1
19	330 $\mu$ F capacitor	1	C16
20	Diode	2	D1, D4
21	LED (green)	1	D3
22	Buzzer	1	D2
23	IC precision timer	2	U2, U16
24	IC 7 ns comparator	2	U3, U12
25	IC 2-in and gate	1	U4
26	IC QUAD 2-in n and gate	1	U5
27	IC Decade counter	3	U7, U10, U14
28	IC BCD-to-SEG decoder	3	U8, U11, U15
29	Large LED	3	U6, U9, U13
30	5 V regulator	1	U1
31	Switch on-on	2	S1, S3
32	Switch on-off-on	2	S2, S4
33	2 Pin header male	6	JP1, JP2, JP3, JP4, JP5, JP6

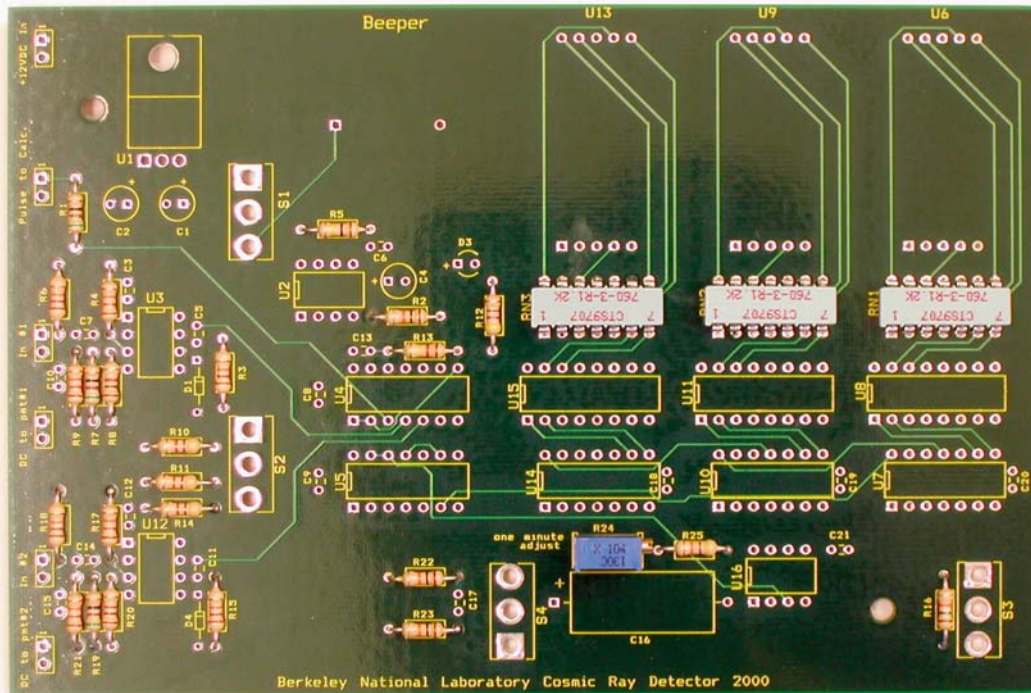
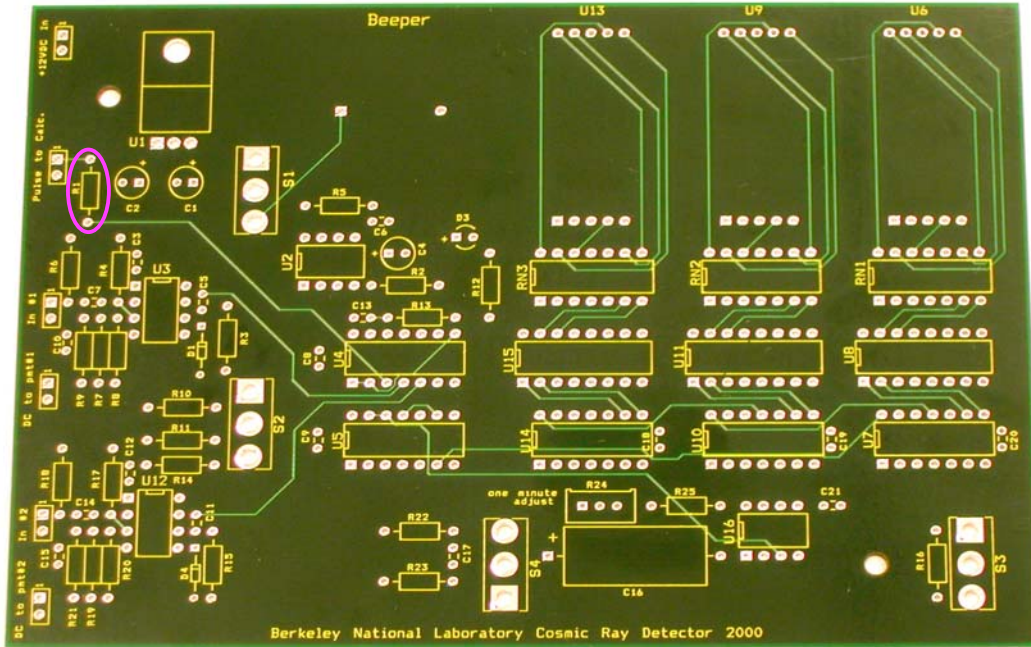
## Procedure

Although the order of assembly is not essential, you may want to start with the small pieces first and work your way up to the larger pieces. This order makes holding onto the pieces easier — they just lie flat against the table. Additionally, you may want to start with the resistors if you are unsure of your skill; resistors are less sensitive to damage by heat and provide good practice before moving on to more delicate components such as integrated circuits (IC).

- 1. Locate R1 on the circuit board and insert the 51  $\Omega$  resistor (Item 1) into it (Figure 24).** The resistor should sit on the label side of the board. Be sure to bend the wires slightly on the other side such that the resistor will hold in place. See Appendix B for color codes on resistors.
- 2. Turn the board to its backside and place the hot soldering iron tip to both the resistor wire and the metal pad on the board.**
- 3. Once the surfaces are hot (after ~ 1-2 seconds), feed the solder to them until they are covered.**
- 4. Repeat step 3 for the other wire.**
- 5. Trim the excess wire on the resistor.** Try to keep the wire about 1-2 mm long.
- 6. Repeat the above steps for other components.** See Figure 25 for resistors.



# Cosmic Ray Detector



**Note on Resistors:** For the variable resistor (Item 11), be sure that the adjustment screw faces rightward when looking at the board with its main label right side up.

For the resistor arrays (Item 12), be sure that they are in the right orientation. If you look at the writing right side up, then the upper right corner has an approximately square protrusion. This protrusion should be aligned with the square metal pad on the board.

**Note on Capacitors:** Items 16-18 (1  $\mu\text{F}$ , 6.8  $\mu\text{F}$ , and 33  $\mu\text{F}$  capacitors) have a particular orientation: align the + sign on the capacitor with the + sign on the board (corresponding to the square pad).

On Item 19 (330  $\mu\text{F}$  capacitor) is marked an arrow that points in the negative lead direction. Place this capacitor such that the base of the arrow aligns with the + sign (square pad). See Figure 26.

**Note on Diodes:** Item 20 (diode) has a specific orientation: the band on the diode corresponds to the band labeled on the board.

Item 21 (LED) should be placed such that the longer wire inserts into the square pad (labeled with + sign). See Figure 27.

**Note on Integrated Circuits:** Items 23-28 (integrated circuits) have specific orientations also. The dot in one of the corners should align with the square pad on the board. Some of them also have bands or notches or both. These bands and notches correspond to the square notches drawn on the board. They all have dots though, so you do not have to worry about the bands and notches. See Figure 27.

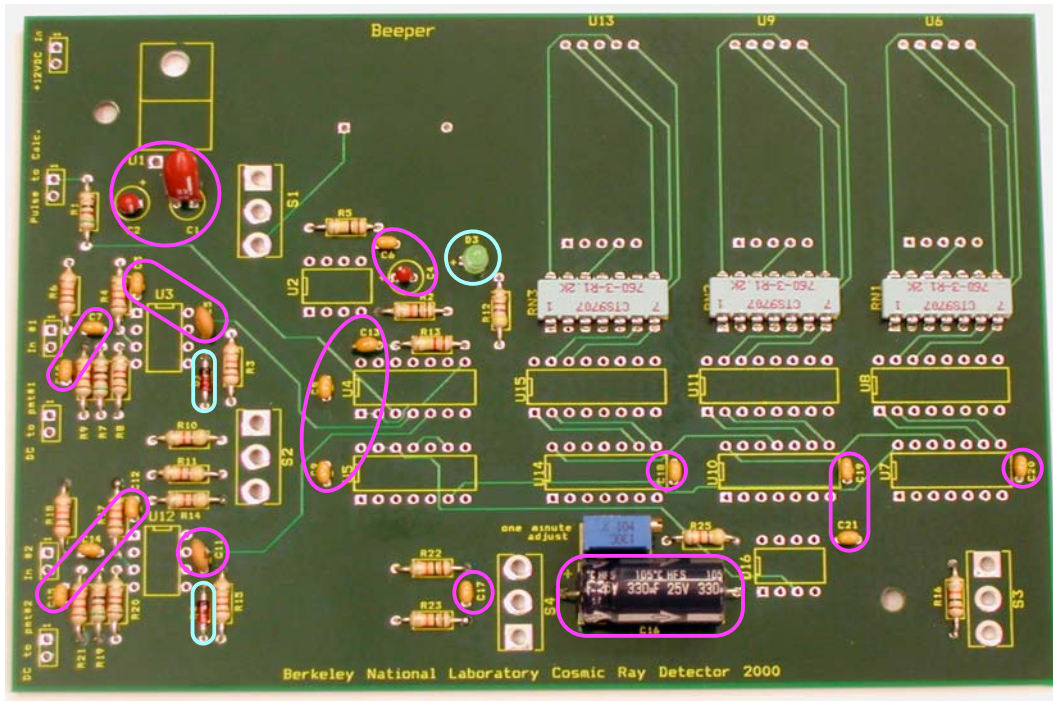
**Note on 5 V Regulator:** Item 30 (5 V regulator) has a definite orientation. With the lettering facing you, the left-most lead is “in” the middle is “ground” and the right most is “out.” Power from the power supply needs to go into the “in” lead, which should align with the square pad on the board. Simply place the heat sink (as shown in Figure 27) on the board, bend the 5 V regulator overtop it, and fasten them together with a nut and bolt.

**Note on Large LED:** Item 29 (large LED) should be placed such that the decimal point is in the lower right corner when looking at the board with the main label right side up.

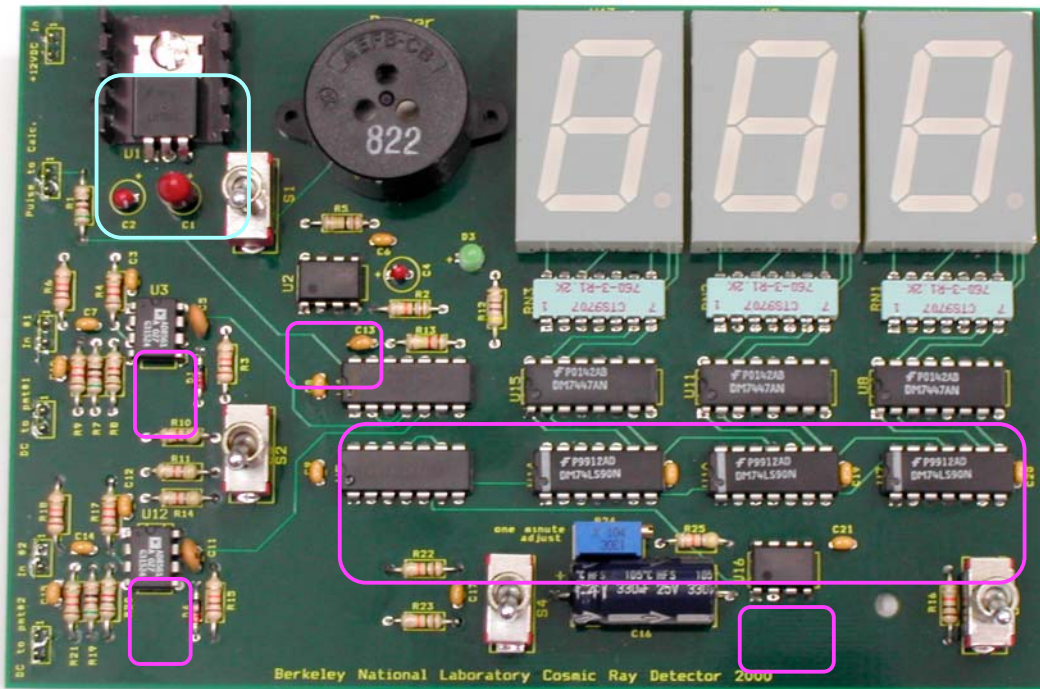
**Note on Switches:** Items 31 and 32 (switches) should be carefully distinguished. Be sure not to mix them; their orientations, however, do not matter.



# Cosmic Ray Detector

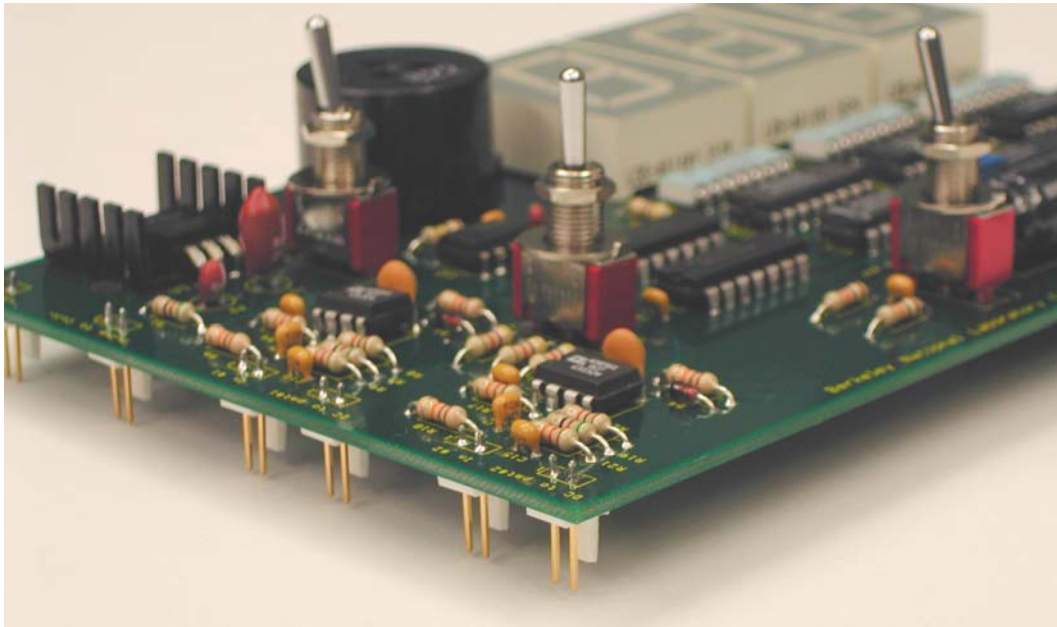


**Figure 26:** Circuit board showing highlighted capacitors (pink) and diodes (aqua).



**Figure 27:** Completed circuit board showing highlighted integrated circuits (pink) and 5 V regulator with heat sink (aqua).

**Note on 2 Pin Header:** Item 33 (2 pin header) should be placed on the underside of the board. The 2 pins should face the outer edge of the board while the polarizing plastic protrusion should face toward the inside of the board — as shown in Figure 28. Solder the pins from the topside of the board.



## Casing

The casing is important for holding together the components of the detector (Figure 29); the casing serves as an exoskeleton. You may design your own or you can follow the Berkeley Lab model (see Appendix C). Because we have two different photomultiplier options the casing will vary accordingly so you should use the appropriate design. If you choose to build your own design, keep in mind the requirements described below.

The spacing and orientation of the scintillator paddles are specific. The paddles must be parallel to each other and separated by 4 inches as measured from between the 2 surfaces (Figure 30). Also, the casing itself should have a sturdy opening between the gap of the scintillator paddles. This opening allows heavy objects (such as bricks and lead blocks) to be placed between the paddles, which is part of a couple of experiments.

When designing your casing, be sure to provide adequate support for the scintillator paddles at both the scintillator part and the photomultiplier part. This 2-part support keeps strain off the interface between them.

There is a safety bar which can be added. This is recommended so that it is difficult to put your hands on the energized circuit board.

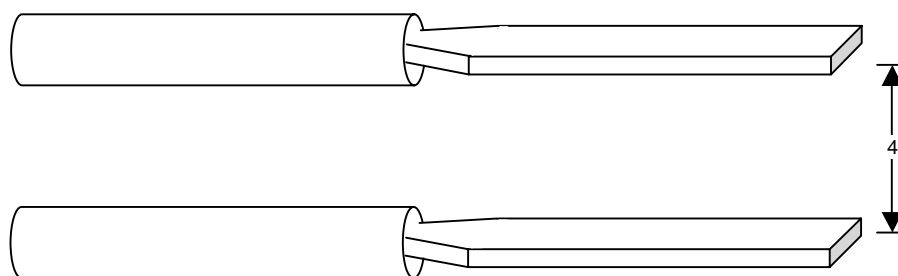
The circuit board is the other component that needs to be attached to the casing. It should be placed such that the switches are accessible and that the LED display is clearly visible. Also, it has a variable resistor (that controls the length of a timed count) that may need to be adjusted. In the Berkeley Lab design (Figure 29), the circuit board is mounted onto the end panel of Lucite. This is done by bolting the actual switches on the circuit board to the Lucite panel. If you are using the side mount phototube it is also possible to drill a small hole in the Lucite panel so that you can adjust the sensitivity of the photomultiplier.

Additionally, you should consider the data cables that need to pass through the casing. The connectors allow you to plug in power and data cables without tugging on the circuit board (especially during transportation). Also, they allow interchanges of standard cables for wall transformers and CBL data cords. (This is useful for instances in which the initial wall transformer or CBL cord stops working or is misplaced.)





**Figure 29:** Completed cosmic ray detector.



**Figure 30:** Illustration of separation between scintillator paddles.

## Wiring

Once the electronic parts of the detector are mounted to the casing, they must be connected to each other with wires. The 2 pin headers on the circuit board allow the wires to be plugged in rather than soldered. Because these are polar headers, you must be careful to distinguish your hot and ground wires appropriately when making the corresponding plugs.

### Equipment and Supplies

- Wire stripper
- Wire cutter
- Electrical tape
- Solder
- Soldering iron
- Moist sponge
- 2 pin header connectors
- Crimp female pins
- Crimp tool
- CBL cable

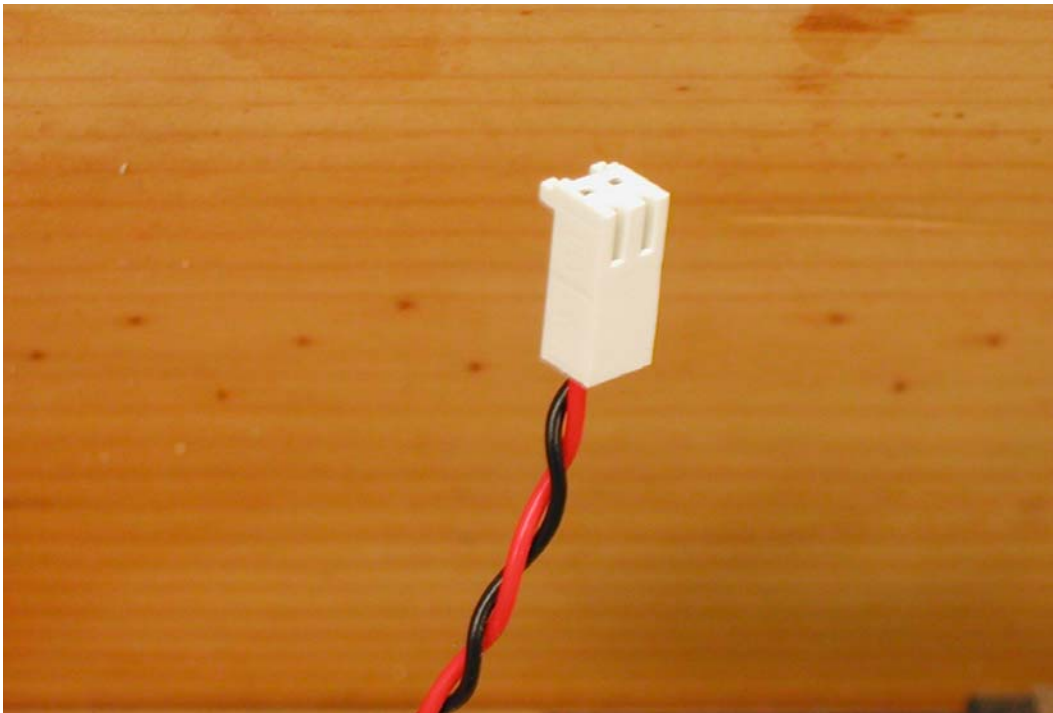
### Procedure

1. **Strip the end of the wire that will attach to the board using the wire stripper.** Be sure to strip enough away such that the exposed wire makes good contact with the crimp pin.
2. **Tin the stripped end of the wire.** That is, first twist the frayed end with your fingers to make it tight, and then lightly solder the twisted end. Be sure to keep the wire thin to fit into the crimp pin.
3. **Insert the tinned wire into the crimp pin as far as it goes and place the pin in the crimp tool.** This may be awkward and frustrating depending on your skill and the crimp tool you use. You may want to place the pin in the crimp tool first and then insert the wire. Do what works best for you.
4. **Crimp.** Again, this may become frustrating; you may have to try this several times before you master it.
5. **Repeat for all the other wires.** However, if your photomultiplier has additional wires for setting the gain, do not crimp them. Instead, short the gain wires by twisting them together, soldering them to each other, and then wrapping tape around the exposed ends (Figure 31).
6. **Insert crimp pins into 2-pin header connector as far as they go.** You may feel a click; they should not pull out (Figure 32).

**Note:** Be sure to insert the pins in the correct orientation. That is, when plugged into the board, ground should match with ground on the board (circular metal pad) and hot / signal should match with hot / signal on the board (square metal pad). Ground is typically black while hot is typically white or red.



**Figure 31:** Gain wire shorted.



**Figure 32:** Power wires attached to 2 pin header connector.



# Cosmic Ray Detector

## Appendix A: Suppliers and Parts

The following subsections list certain parts available from some suppliers. Berkeley Lab does not endorse these suppliers but offers their names for the sake of convenience. The end mount photodetector referred to in this manual is package, P30CW5. The side mount photodetector is package 931B + PS1252/5F.

### ***Scintillator Paddles***

Part	Quantity	Supplier	Phone Number	Web Address
Scintillator	1 - 10" X 12" X 1/4" sheet	Bicron	(440) 564-2251	<a href="http://www.bicron.com">www.bicron.com</a>
		Eljen Technology	(888) 800-8771	<a href="http://www.eljentechnology.com">www.eljentechnology.com</a>
Optical Cement	250 ml	(same as above)		
Photomultiplier	2	Electron Tubes Ltd.	(800) 521-8382	<a href="http://www.electrontubes.com">www.electrontubes.com</a>

### ***Circuit Board***

Please contact Dr. Howard Matis at (510) 486-5031 or [HSMatis@lbl.gov](mailto:HSMatis@lbl.gov) for information on obtaining the circuit board. It may be possible to purchase circuit board components from Digi-Key at 1 800 DIGI-KEY or [www.digi-key.com](http://www.digi-key.com). Please note that one part may have to be purchased from Newark Electronics – 1 800 2 NEWARK.

A parts list is on the next page. In addition to those parts, you also need a wall transformer that supplies 800 mA at 12 V DC. These transformers are common and can be found at any electronics store. Be sure to get the corresponding connector for the casing if you choose to use one.

# Assembly Manual



\*Parts are constantly changing. Check <http://www.lbl.gov/abc/cosmic/> for latest version

Item	Parts* List #	Description	#	Digi-Key Part§	Position on Board
1	13	51 Ω resistor	3	51QBK-ND	R1, R7, R19
2	14	470 Ω resistor	1	470QBK-ND	R12
3	15	1.1 kΩ resistor	2	1.1KQBK-ND	R8, R20
4	16	4.7 kΩ resistor	3	4.7KQBK-ND	R10, R11, R14
5	17	10 kΩ resistor	4	10KQBK-ND	R2, R16, R22, R23
6	18	11 kΩ resistor	4	11KQBK-ND	R3, R6, R15, R18
7	19	12 kΩ resistor	4	12KQBK-ND	R4, R9, R17, R21
8	20	47 kΩ resistor	1	47KQBK-ND	R25
9	21	100 kΩ resistor	1	100KQBK-ND	R5
10	22	120 kΩ resistor	1	120KQBK-ND	R13
11	23	100 kΩ variable resistor	1	3296X-104-ND	R24
12	12	1.2 kΩ resistor array	21	1.2KEBK-ND¶	RN1, RN2, RN3
13	1	100 pF capacitor	2	P4037A-ND	C5, C11
14	2	2.2 nF capacitor	1	1119PHCT-ND	C13
15	3	0.1 μF capacitor	14	399-2155	C3, C6, C7, C8, C9, C10, C12, C14, C15, C17, C18, C19, C20, C21
16	4	1 μF capacitor	1	478-1833-ND	C4
17	5	6.8 μF capacitor	1	P2037-ND	C2
18	6	33 μF capacitor	1	P2052-ND	C1
19	7	330 μF capacitor	1	4036PHCT	C16
20	8	Diode	2	1N4148-TPMSCT-ND	D1, D4
21	10	LED (green)	1	160-1080-ND	D3
22	9	Buzzer	1	102-1116†	D2
23	27	IC precision timer	2	296-1411-5-ND	U2, U16
24	28	IC 7 ns comparator	2	AD8561AN	U3, U12
25	29	IC 2-IN and gate	1	DM7408N-ND	U4
26	30	IC QUAD 2-in n and gate	1	DM74LS00N-ND	U5
27	32	(N) Decade counter	3	526-NTE74LS90£	U7, U10, U14
28	33	IC BCD-to-SEG decoder	3	DM7447AN-ND	U8, U11, U15
29	31	Large LED	3	67-1485-ND	U6, U9, U13
30	26	5 V regulator	1	LM340T-5.0-ND	U1
31	24	Switch on-on	2	CKN1021-ND	S1, S3
32	25	Switch on-off-on	2	CKN1025-ND	S2, S4
33	11	2 Pin header	6	A23897-ND	JP1, JP2, JP3, JP4, JP5, JP6
34	35	2 Pin header connector	6	A19490-ND	Connects with Item 33
35	36	Pins for header connector	12	A23962-ND	Can use pliers
36	34	Power Supply	1	412-112103£	12 VDC – 0.8 A
37	37	Heat Sink	1	294-1114-ND	For voltage regulator

§Digi-Key – <http://www.DigiKey.com>

¶Replace each resistor array with 7 discrete resistors (1.2K 1/8 watt) placed across each location (e.g. from pin 1 to pin 14, 2 to 13 etc.) so you will need 21 resistors.

†You will need to bend the leads slightly to fit inside the holes.

£Mouser Electronics – <http://www.mouser.com/>

## Appendix B: Resistor Color Codes

3 colored bands and possibly a gold or silver band code each resistor, which identify the resistance in ohms. The first 2 bands (starting from the farthest on the left — opposite the gold or silver band if present) indicate the first 2 digits of the resistance. The third band indicates the multiplier of 10. The color codes are

Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

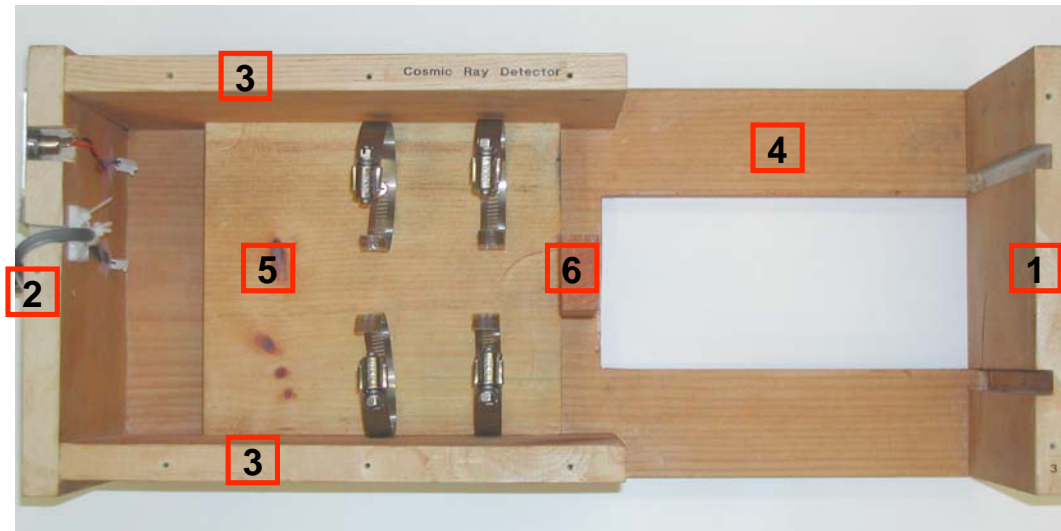
For example, a resistor coded blue-red-orange is 6-2-3, which stands for  $62 \times 10^3$  ohms (or 62 k $\Omega$ ).

Usually, the resistor also has a fourth band — the gold or silver one. This band indicates the tolerance of the stated resistance: gold stands for 5% and silver for 10%

## Appendix C: Optional Casing

### Casing (End Mounting Photomultiplier)

The table that follows lists pieces and their dimensions for the casing developed at Berkeley Lab. Figure 33 shows the casing with numbered pieces that correspond to the numbered pieces of the table. (The metal brackets shown in the picture hold the photomultipliers.)



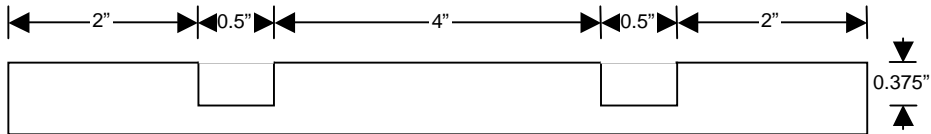
**Figure 33:** Berkeley Lab casing with pieces numbered.

Piece	Quantity	Width [inches]	Length [inches]	Thickness [inches]
1	1	6.5	9	0.75
2	1	6.5	9	0.75
3	2	6.5	11.25	0.75
4	1	9	21	0.75
5	1	7	8	1.5
6	1	1.5	6.5	0.75

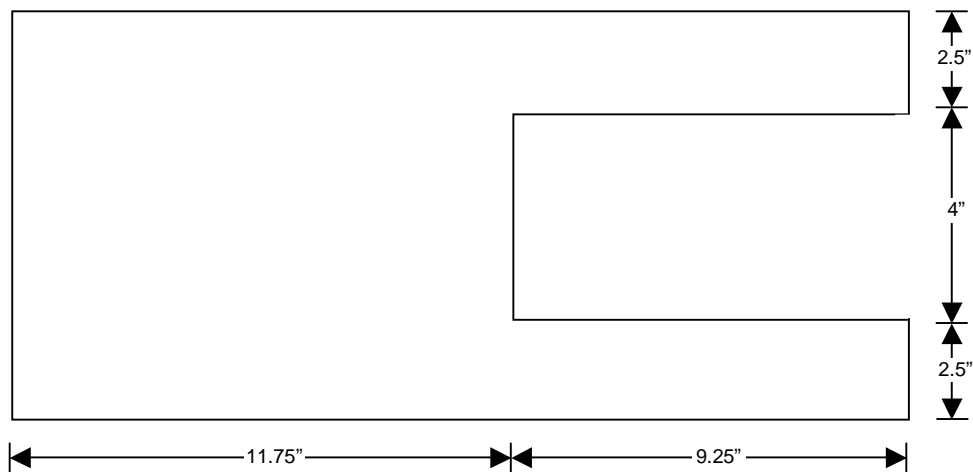
The grooves in Piece 1 are 0.375 inches deep and 0.5 inches wide. They are 2.5 inches from the top and bottom edges of the board and 4 inches apart from each other. Piece 4 and the Lucite end panel have the same shape and special dimensions shown in Figure 34.

# Cosmic Ray Detector

You may want to decrease the cutout for Piece 4 to 3" (instead of 4"), so that items can be supported on the plastic and wood backing. This ledge is useful to place absorbers between the scintillators. This ledge is useful for supporting heavy absorbing objects such as clay or lead bricks between the scintillator paddles.



**Figure 34:** Piece 1



**Figure 35:** Dimensions for Piece 4 and Lucite end panel.

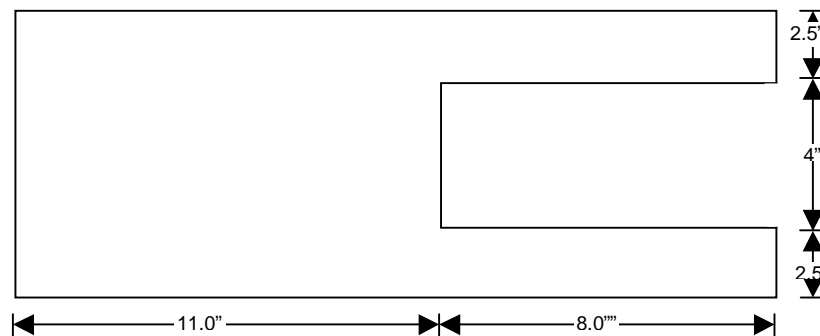


## Casing (Side Mounting Photomultiplier)

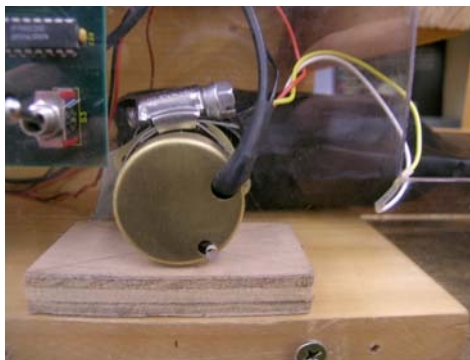
The following dimensions correspond to the Side Mount Photomultiplier assembly. The length of the entire structure has been changed, while most of the other dimensions have remained the same. The Lucite end panel has different dimensions as well. The clamps holding down the side mount photomultipliers are shown below in Figure 37. They are mounted on small wooden block, which is attached to the case.

Piece	Quantity	Width [inches]	Length [inches]	Thickness [inches]
501	1	6.5	9	0.75
2	1	6.5	9	0.75
3	2	6.5	11.25	0.75
4	1	9	19	0.75
5	1	7	8	1.5
6	1	1.5	6.5	0.75

Piece 1 will have the same grooves in it as in the end mounting photomultiplier.



**Figure 36:** Dimensions for Piece 4 and Lucite end panel.

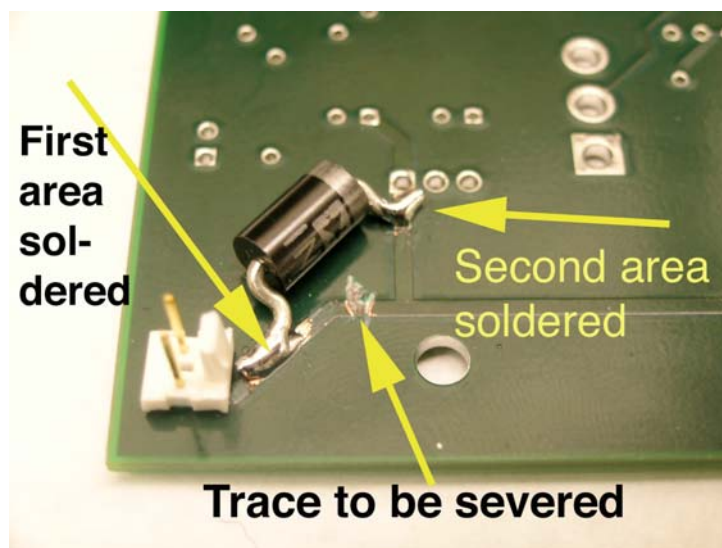


**Figure 37:** Clamped side mount photomultiplier.

## Appendix D: Optional Protection Circuit

**WARNING!** If you make a mistake and reverse the polarity of the input voltage, you will destroy several of the components. If you are not comfortable cutting into the circuit board, then do not attempt this procedure. To install this protection circuit, you should follow the following steps.

1. Take out the circuit board and locate the power bus (the big trace on the backside). See Figure 38.
2. Follow the trace until it branches off into two directions.
3. Take a scalpel and cut the trace. You must leave the area where it branches off alone. Check the location in the Figure 38.
4. Scrape off the insulating layer so you will see exposed metal.
5. Find your way along the trace from the beginning and when you meet where it branches off take the direction which is perpendicular to the trace you were following. The end of this is only an inch or so away. At the end scrape away the top layer exposing the metal.
6. Solder the diode to these two scraped away areas making sure that the cathode end is soldered to the place you scraped away second.
7. Test that you have installed the diode correctly, by using the “diode” setting on a multi-meter.



**Figure 38:** Diode soldered onto the back of the circuit board.

## Appendix E: Acknowledgements

We welcome corrections and improvements to this manual. Please send them to Howard Matis – [hsmatis@lbl.gov](mailto:hsmatis@lbl.gov).

The William F. and Edith R. Meggers Project Award from the American Institute of Physics helped in large part to fund the Berkeley Lab Cosmic Ray Detector. Additional support came from the Department of Energy, Center for Science and Engineering at Lawrence Berkeley National Laboratory, and the Energy Research Undergraduate Laboratory Fellowship.

This manual is a revised and expanded version of LBNL-46911, which was written by Colleen Twitty and Howard Matis.

Version 1 was written by Michael Collier who attended New Mexico State University. Lyle Wolfley provided additional details for version 2. These included how to incorporate the side mount phototube. He currently attends East Bay Waldorf High School.

This manuscript was prepared for the US Department of Energy under contract number DE-AC0-76SF00098.

