Barrel Imaging Calorimeter SFIL Design and Construction

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1 SFIL Preparation

In order to test full integration of the BIC calorimeter readouts and the Astropix [1] tracking, we want to produce a test setup that mimics the final BIC design, with a bulk lead/scintillating fiber (Pb/SciFi) section and multiple single-layer Pb/SciFi fiber sections separated by Astropix layers, for use in beam tests or with cosmics. The stand-in for the bulk section will be the already-existing 'baby BCAL' (a 60 cm long prototype BCAL module), and some preliminary tests have already been done with correlating AstroPix signals with baby BCAL hits [2]. For the single-layer sections, we are producing two scintillating fiber imaging layers (SFILs), which are Pb/SciFi fiber layers, about one inch in thickness, instrumented with light guides and SiPMs.

The two Pb/SciFi fiber blocks we are using are old BCAL prototype layers built on aluminum plates. The aluminum plates are 17.5'' × 6'' and 3/4'' thick, and the Pb/SciFi fiber blocks are 1'' thick, the same length, 17.5'', and have a width of 4'' (see Figure 1)[1]. The scintillating fibers run lengthwise along the blocks.

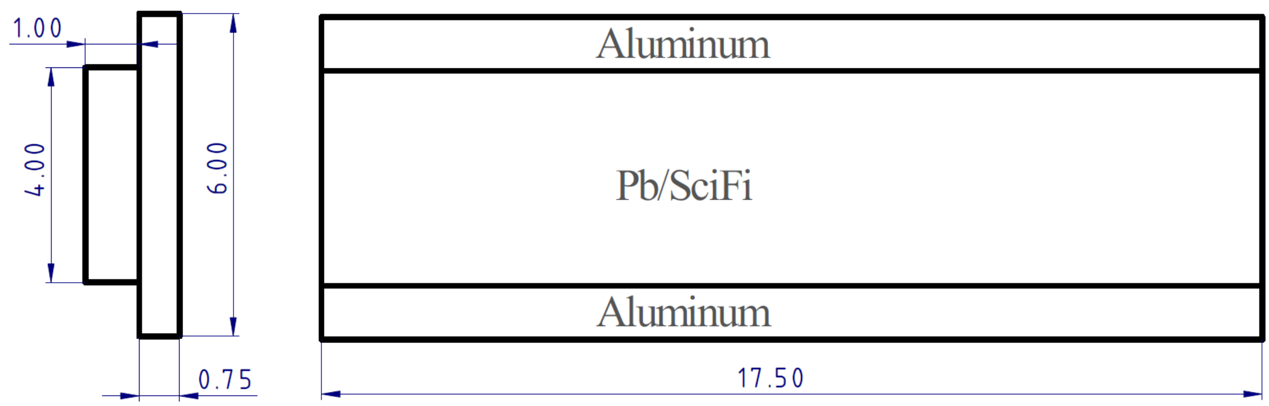

Figure 1: Dimensions (in inches) of the BCAL prototype Pb/scintillating fiber blocks used as the bases of the SFILs.

Four light guides (and a SiPM for each of them) will be held on either side of a block to read out scintillation light emitted by the fibers when particles pass through them and deposit energy. So, each end of each block will need four light guides, the means to hold the light guides in place, four SiPMs, the means to hold the SiPMs in place, and electronics to read out the SiPM signals.

1.1 Light Guides

For this project, we are using a simple light guide that is quick to produce and easy to handle. The light guides are 8 cm long with a 3/4'' square base (somewhat arbitrary) and a 13 mm square top (to match the SiPM array dimensions).

A local company, Ross Machine Shop, produced a number of test guides while learning how to machine with acrylic. These guides are visibly cloudy, so we tried a variety of different polishing methods on these test guides, but the unpolished guides straight from the shop outperformed our polishing attempts (mostly because we could not find the rubber polishing pads we would normally use with our lapping machine [rotating stage for polishing]). The unpolished guide from the first test batch is labeled 'R#3' and the unpolished guide from the second round of testing is labeled 'R#5.' R#5 is much more clear than R#3, though not as clear as a nicely polished acrylic. These were produced from a 3/4'' × 3/4'' bar of extruded acrylic with beveled edges. Thus, the base of these light guides are beveled squares rather than squares with sharp corners. A company from Thunder Bay, BrainShift Inc., produced a few high-quality guides from acrylic and from borosilicate glass. These guides are very nicely polished, appearing clear with only a few minor scratches visible. The acrylic guides seem to have been heat treated for polishing, evidenced by slight warping of the guides at the corners. One of each of these, labeled 'BS acrylic' and 'BS glass,' were tested alongside the guides from Ross. The 16 guides machined for use with the SFILs, labeled 'SFIL1' through 'SFIL16,' were done by Ross using a larger sheet of cast acrylic (similar optically to extruded acrylic and supposedly easier to machine with), so these guides have proper square bases. They have a similar

[1]Most measurements in this section are given in imperial units. Imperial units were used for most of the SFIL building process to maintain unit consistency with purchased hardware and machine shop standards.

cloudiness as the R#3 guide. Lastly, Ross machined two more guides, one with the original extruded acrylic bar, labeled 'R#6,' and one with the cast acrylic sheet, labeled 'R#7,' simultaneously to test if the type of acrylic may have been the reason for the decrease in quality. Visually, both of these are less cloudy than R#3 and are similar in appearance.

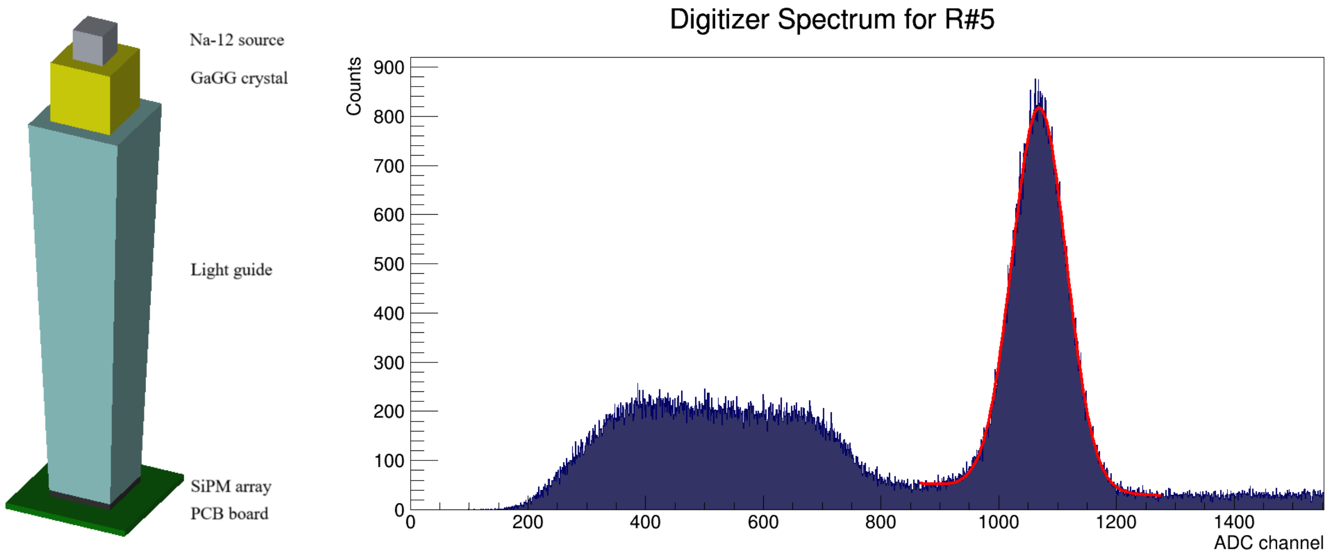

Figure 2: Physical setup for light guide testing (left) and the resulting digitizer spectrum for R#5 (right).

To compare the transmission quality of these guides, we inspect the energy spectrum of light produced by a known source passing through the guides. We use a Na-12 positron source placed atop a Gadolinium Aluminium Gallium Garnet (GAGG) scintillating crystal, both placed atop a light guide balanced vertically on it's small square side on a Hamamatsu S14 SiPM array[3] (dry contact everywhere), as depicted on the left side of Figure 2. The SiPM array signals are passed to an electronics board which amplifies each signal, sums the signals, and shapes the final signal for input into a data acquisition system. The circuit diagrams for the pre- and post-summing amplifier circuits are shown in Figure 3. For these tests, the SiPM signal is read out by a Caen DT5790N digitizer [4], which acts as an analog-to-digital converter (ADC), converting the signal from the SiPM into an energy. The energy spectrum of the Na-12 source includes a characteristic 511 keV peak from the annihilation of the produced positron. An example of this spectrum taken with this setup with the peak region fit to a Gaussian plus first-degree polynomial is shown on the right side of Figure 2. The position of that peak in the ADC spectrum tells us the average amount of light that passes through the light guide to the SiPM from an annihilation event, and the width of the peak relates to the spread of energies one might expect to see from an annihilation event, which includes contributions from the scintillator, the SiPM, and the light guide. Table 1 gives the results of this test for each guide.

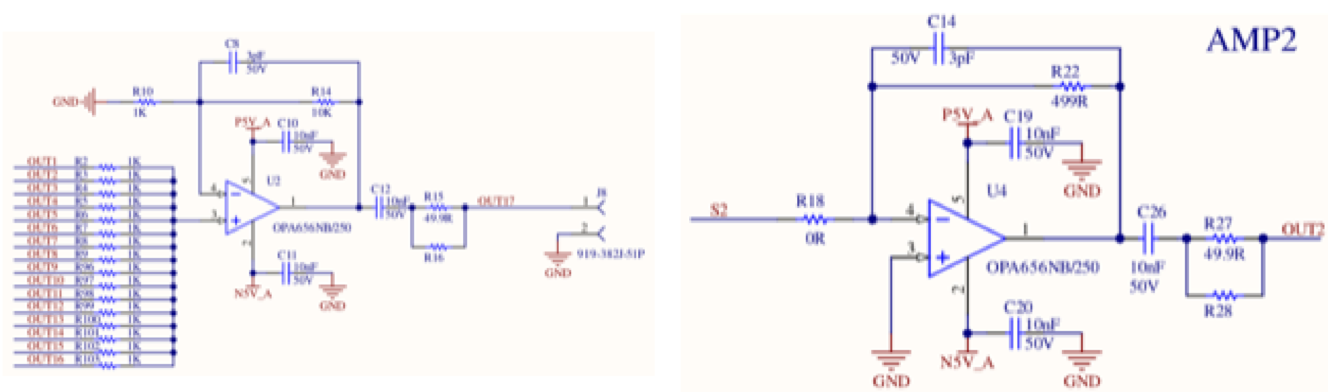

Figure 3: Circuit diagrams for pre-summing (left) and post-summing (right) amplifying circuits used on the SiPM amplifier boards.

These results confirm much of the the conclusions reached from visual inspection of the guides. In terms of peak means, the borosilicate glass BrainShift guide performed the best, the acrylic BrainShift guide and R#5 gave

Table 1: Gaussian fit mean (μ), width (σ), full-width-at-half-maximum (FWHM), and resolution (FWHM/μ) of the 511 keV peak of the Na-12 energy spectrum for various light guides.

Light Guide	μ (ADC channels)	σ (ADC channels)	FWHM (ADC channels)	Resolution (%)
R#3	892.46 ± 0.18	38.69 ± 0.20	90.88 ± 0.47	10.183 ± 0.053
R#5	1078.60 ± 0.20	44.69 ± 0.22	105.23 ± 0.51	9.757 ± 0.047
BS acrylic	1046.19 ± 0.19	43.14 0.20	101.58 ± 0.47	9.709 ± 0.045
BS glass	1142.17 ± 0.21	45.35 0.23	106.79 ± 0.54	9.350 ± 0.048
SFIL1	902.15 ± 0.15	38.54 ± 0.14	90.76 ± 0.32	10.060 ± 0.035
SFIL2	870.37 ± 0.14	37.05 ± 0.13	87.24 ± 0.31	10.023 ± 0.036
SFIL3	913.40 ± 0.15	38.79 ± 0.14	91.33 ± 0.32	9.999 ± 0.035
SFIL4	876.74 ± 0.15	37.54 ± 0.13	88.40 ± 0.31	10.083 ± 0.035
SFIL5	903.52 ± 0.15	38.18 ± 0.14	89.91 ± 0.32	9.951 ± 0.036
SFIL6	885.27 ± 0.15	37.69 ± 0.13	88.75 ± 0.31	10.025 ± 0.035
SFIL7	885.79 ± 0.15	38.03 ± 0.13	89.56 ± 0.32	10.111 ± 0.036
SFIL8	886.84 ± 0.15	37.75 ± 0.13	88.89 ± 0.31	10.023 ± 0.035
SFIL9	906.89 ± 0.15	38.56 ± 0.14	90.79 ± 0.32	10.012 ± 0.035
SFIL10	888.33 ± 0.15	37.89 ± 0.13	89.23 ± 0.31	10.045 ± 0.035
SFIL11	884.73 ± 0.15	37.93 ± 0.13	89.31 ± 0.31	10.094 ± 0.035
SFIL12	910.02 ± 0.15	39.12 ± 0.14	92.12 ± 0.33	10.123 ± 0.036
SFIL13	898.14 ± 0.15	38.40 ± 0.14	90.43 ± 0.32	10.069 ± 0.036
SFIL14	882.20 ± 0.15	37.77 ± 0.13	88.93 ± 0.31	10.081 ± 0.036
SFIL15	873.02 ± 0.15	37.61 ± 0.13	88.56 ± 0.31	10.145 ± 0.036
SFIL16	890.62 ± 0.15	38.11 ± 0.13	89.75 ± 0.31	10.077 ± 0.035
SFIL average	891.13 ± 13.17	38.06 ± 0.52	89.62 ± 1.24	10.058 ± 0.051
R#6	956.03 ± 0.16	40.55 ± 0.14	95.48 ± 0.330	9.987 ± 0.035
R#7	1007.44 ± 0.16	42.09 ± 0.15	99.12 ± 0.360	9.839 ± 0.035

a similar performance with $\sim 8\%$ lower means (despite the much less cloudy appearance of the BrainShift guide), R#3 performed $\sim 22\%$ worse than the glass guide, and the 16 SFIL guides, on average, performed similarly to R#3. Both R#6 and R#7 performed better than R#3, as expected from the visual inspection, but neither were as good as R#5. Additionally, the cast acrylic guide, R#7, performed better than the extruded acrylic guide, R#6, so the drop in quality observed in the 16 SFIL guides was likely not due to the material change. It's unclear at this time what caused the quality difference.

1.2 SiPMs and Electronics Boards

The four SiPM arrays on each end of an SFIL are attached to custom PCB boards and read out through separate amplifier boards which amplify and sum the individual signals from each array. The board which holds the SiPM arrays is 120 mm $\times$ 40 mm with four pads for soldering the arrays to the board[2]. The pads are placed in a row, centered on the board, spaced 0.77'' apart (center-to-center). The light guide bases are 3/4'' wide, so this allows for a 0.02'' gap between light guide bases to account for manufacturing tolerances and light guide wrapping. Signals from the SiPM arrays exit the back of the board through four ribbon cable connectors, one for each SiPM array, as seen in Figure 4.

Each ribbon cable attaches to a stand-alone amplifier board. These amplifier boards use the same circuitry as the board used for the light guide testing (see Figure 3). The boards, ribbon cables, and output signal cables are tested with a similar setup as the light guide tests to ensure everything is in working order.

1.3 Mechanical Components and Construction

In order to hold the light guides and SiPM boards in place, a series of 3D-printed plates, themselves held in place by screw rods attached to the aluminum plate of the SFIL, are used. For each SFIL, two 3/8'' screw rods are used, one on either side of the Pb/SciFi block, running lengthwise along the SFIL and protruding on both ends.

[2]Initially, we intended to have some boards populated with S13 SiPM arrays and others with S14 SiPM arrays, but the two models have different output pinning structures. These boards were designed with the pinning structure of the S14s in mind, so for now, we've populated all the boards with S14 SiPM arrays.

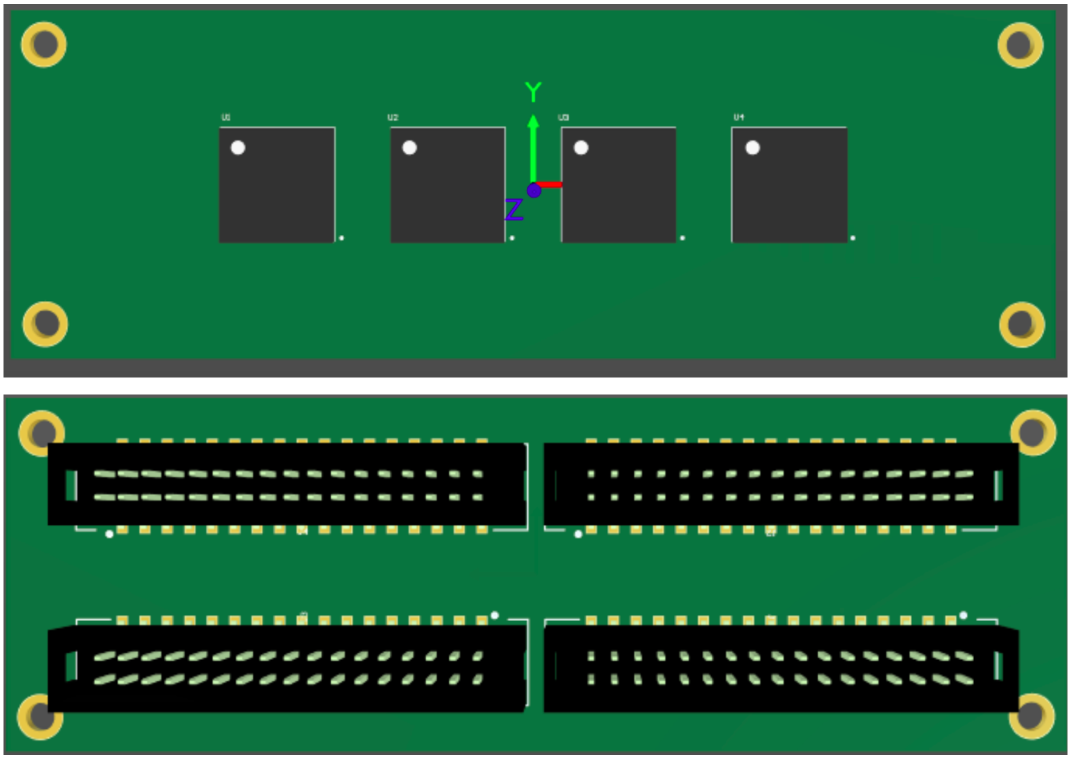

Figure 4: Rendering of the front and back of a 4-pad SiPM PCB board. SiPMs are soldered to the four pads and signals from the SiPMs exit the back of the board through the four ribbon cable connectors.

Each rod is held in place with two 3D-printed brackets, with the centers of the screw rods held 4.94'' apart. Each bracket is 2'' long and consists of a base and a clamp, the cross sections of which are shown in Figure 5. The bracket base is bolted to the aluminum plate and the clamp is screwed into the base to hold the screw rod in place. Lifting the assembled SFILs by the screw rods (or any plates attached to them) will likely result in damage; an SFIL should only be handled by its aluminum plate. The height of the bracket base is such that the centers of the screw rods are aligned with the center of the Pb/SciFi block.

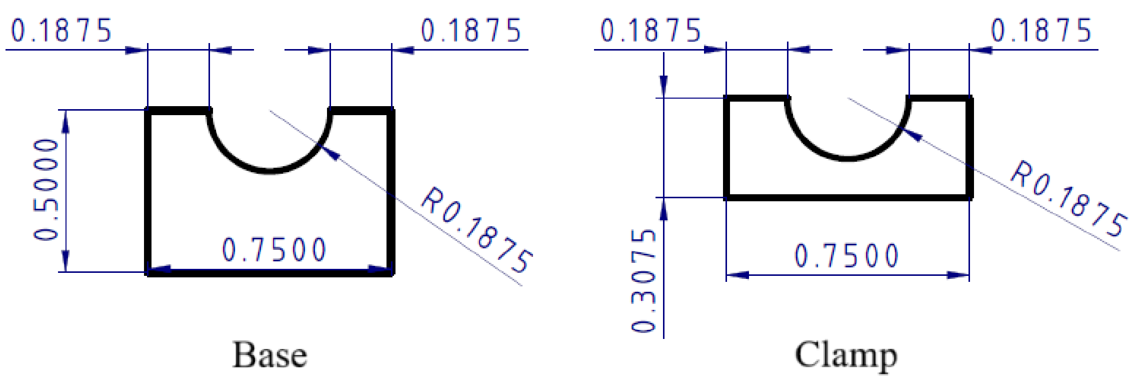

Figure 5: Cross-section of the bracket base and clamp used to secure the screw rods to the SFIL (dimensions in inches).

Each of the three 3D-printed plate designs have the same cross-sectional area, 7'' × 2'', chosen (somewhat arbitrarily) so as to be slightly larger than the dimensions of the end of the SFIL base. Holes are drilled in each plate to allow the screw rods to pass through the plates. The first plate ('plate 1') is designed to hold the light guides in place on the end of the Pb/SciFi block. It is 3/4'' thick and features four tapered square holes (the taper matching the pitch of the light guides), in which the light guides sit. Specifically, the larger end of the taper is 0.621'' squared and the smaller end of the taper is 0.570'' squared. The design was produced by first modeling the four light guides in place, including the 0.02'' space between guides, then performing a boolean operation between the guides and the plate with the bottom of the plate placed halfway along the length of the guides (see Figure 6.

This plate pushes the light guides onto the end of the Pb/SciFi block, with dry contact or optical grease, using washers and nuts. A spring could be added between the washer and the plate, which would allow more even pressure distribution over the light guides, but limited space between this plate and other components makes this difficult.

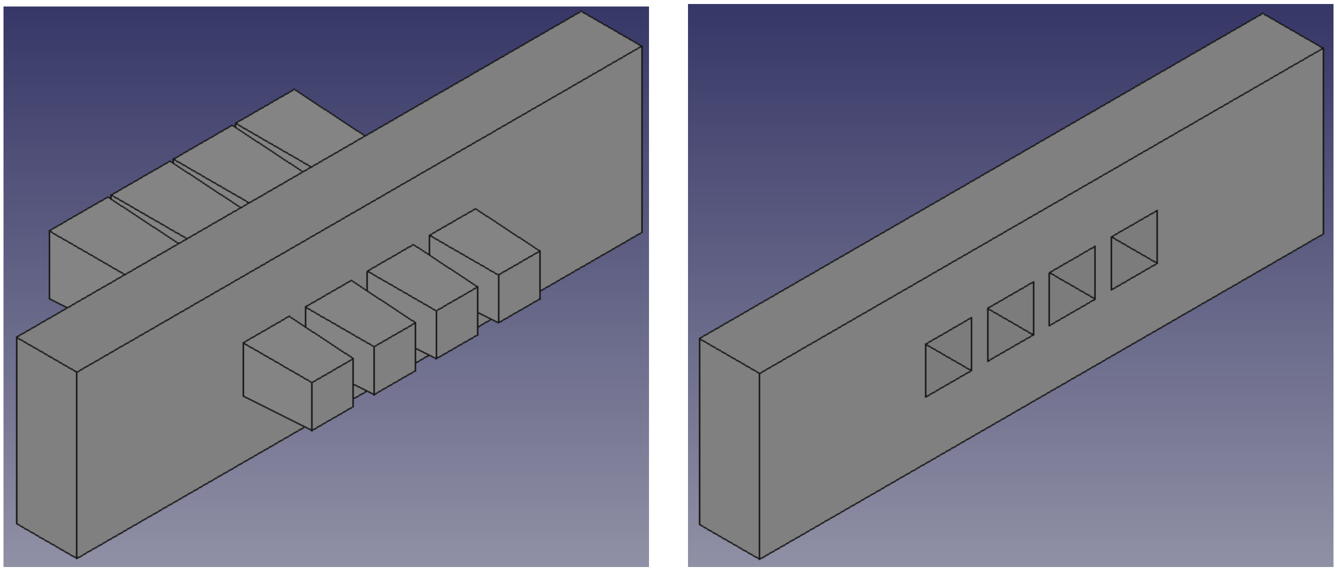

Figure 6: Rendering of plate 1, with and without light guides in place.

The next plate ('plate 2') is designed to provide stability for the bases of the light guides. It also features four square holes, this time with no taper and matching the size of the light guide base, 3/4'' squared (see Figure 7). The thin walls between the holes are 0.02'' thick, and the plate is 0.2'' thick. This plate can be affixed to the end of the SFIL with washers and nuts or with springs placed between it and plate 1, as it should be held flush with the Pb/SciFi block. Because it is relatively thin, too much tension on the springs or nuts could cause bowing or damage to the plate. In practice, it's unclear how useful this plate will be, especially since many of the thin walls have broken off during printing/cleaning.

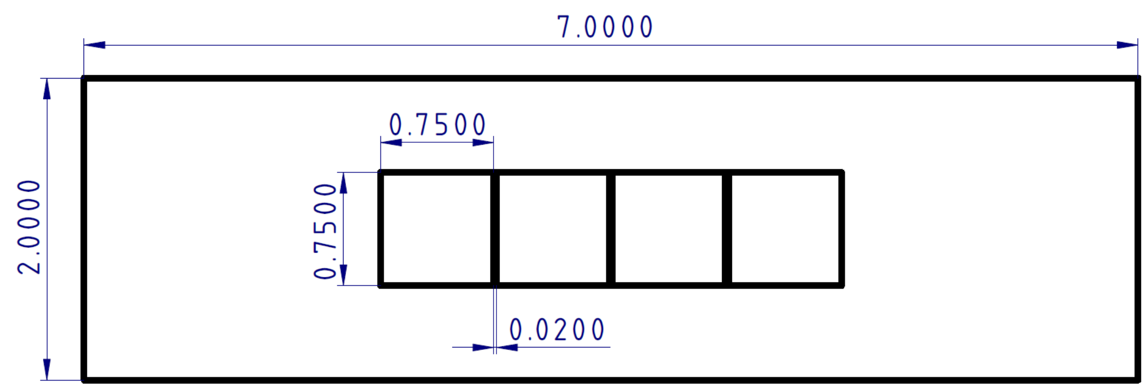

Figure 7: Diagram of the cross-section of plate 2 (dimensions in inches).

The last plate ('plate 3') is designed to hold the SiPM PCB board in place. It will sit directly behind the board, with the board screwed to the plate at each corner. The plate is 1/4'' thick and has two large holes which fit around the connectors on the back of the board (see Figure 4). The holes are sized such that the walls of the plate are 0.08'' away from any connector. The specific dimensions are given in Figure 8. This plate is again held with either washers and nuts or with spring tension. Spring tension would help to evenly distribute pressure over the four SiPM arrays, but careful tightening of the nuts should suffice. Optical cookies (currently using $\sim$ 14 mm squared cookies cut from an Eljen EJ-560 [5] 3 mm thick sheet) can also be inserted between the SiPM arrays and the light guides.

A rendering of a fully-instrumented SFIL, with brackets, screw rods, light guides, plates, SiPMs, and fasteners in place is shown in Figure 9. Figure 10 shows a labeled close-up of one end of an SFIL.

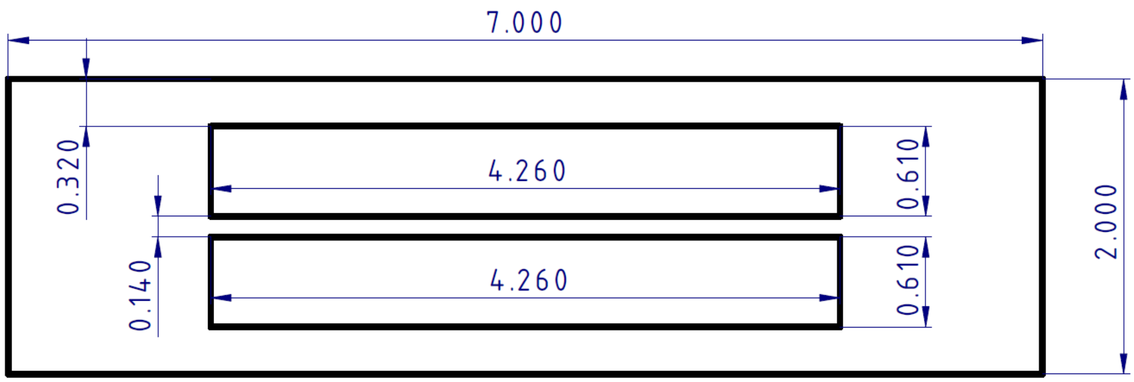

Figure 8: Diagram of the cross-section of plate 3 (dimensions in inches).

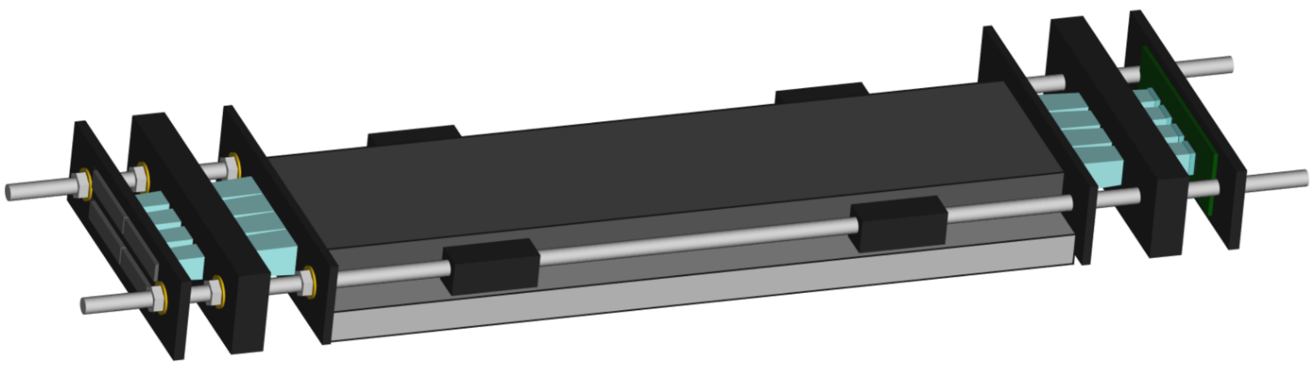

Figure 9: Rendering of a fully-instrumented SFIL.

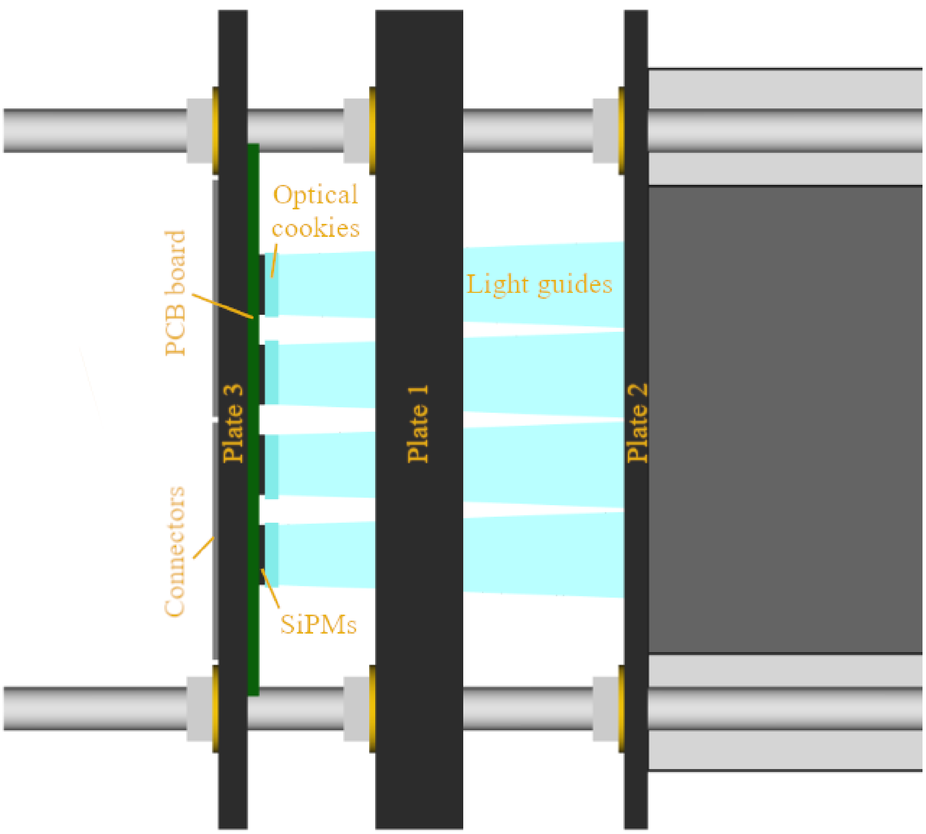

Figure 10: Labeled close-up of one SFIL end.

References

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