Event-Plane and Centrality Detector Test Bench Proposal

Brandon McKinzie, Michael Lomnitz, Alexander Schmah

March 25, 2015

1. Motivation / Background

A test bench will be constructed to begin research and development for an Event Plane and Centrality Detector (EPD) for Beam Energy Scan (BES) II. The EPD serves the following purposes: event plane reconstruction for heavy-ion flow measurements, centrality determination by particle multiplicity measurement, trigger detection for "good" reactions within a certain z-vertex range. It will be the main upgrade for the Beam Energy Scan Phase II program. As written in section four of the EPD proposal, the result of the overall R&D program should be answers to the following questions:

1. What is the optimal pad geometry for different radii?
2. Are waveshifters needed and if yes, how do we install them?
3. What is the optimal connection between SiPM and scintillator?
4. Can multiple hits be distinguished, and what kind of ADC is needed?
5. What timing resolution can we achieve with the setup?
6. How will the radiation damage influence the measurement?

At present, we are most interested in questions 1, 4, and 5. We associate optimal pad geometry with high detection efficiencies and clear signal shape. The results of tests related to pad geometry should then include efficiencies and signal shapes for each different proposed tile, as discussed in the Equipment section. As far as hit discrimination, we are less concerned with individual pulse heights and more interested in a charge-integration technique. This is because simultaneous hits on a tile will travel different distances to the ADC, and an integration method would provide a better representation of the incident hits. Finally, the timing resolution is dependent on the dead times of each detector element and how they interact. We hope to find a setup that optimizes this timing resolution for fast data collection.

In order to answer these questions, we plan to construct a test bench with the proposed detector technology and conduct cosmic ray measurements. The final stage of the R&D will be building a prototype of two fully equipped sectors with about 16 channels each. We expect to have a construction proposal ready at the end of 2015. The final apparatus has to be ready in 2018 with a partial commissioning in 2017.

2. Measurements of Interest

As stated in the EPD proposal, we need to check which silicon photomultiplier's (SiPM) performance is sufficient for our purpose. Presently, we will be conducting measurements using Hamamatsu S12572 and S13360 series multi-pixel photon counters (MPPC). We are interested in the following SiPM measurements:

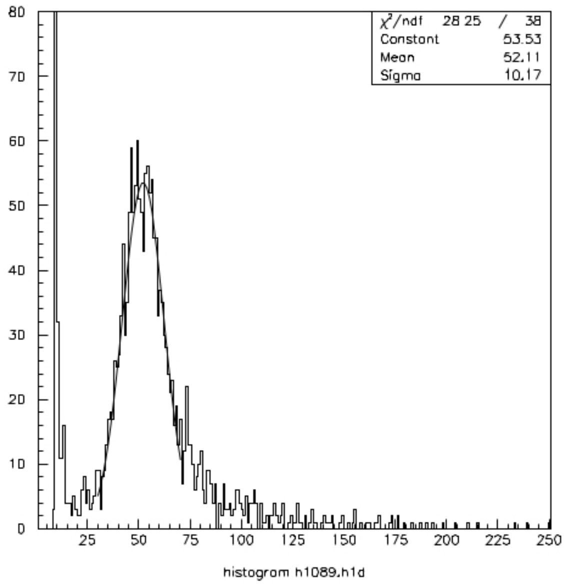
- Efficiency for single m.i.p. hits
- Uniformity of pulse area and efficiency as a function of poisition of hit on a scintillator
- Pulse shapes for m.i.p.'s
- Gain vs bias voltage
- Timing resolution
- Dark noise characteristics
- Temperature stability

Overall, we want to see how the Megatile - WLS Plastic - SiPM setup will perform via cosmic ray measurements. We hope to trigger on an incident cosmic ray with the setup, measure the signal, then measure the same ray again as it exits the apparatus for timing measurements. We hope to see fast triggering and fast decay time from the scintillator.

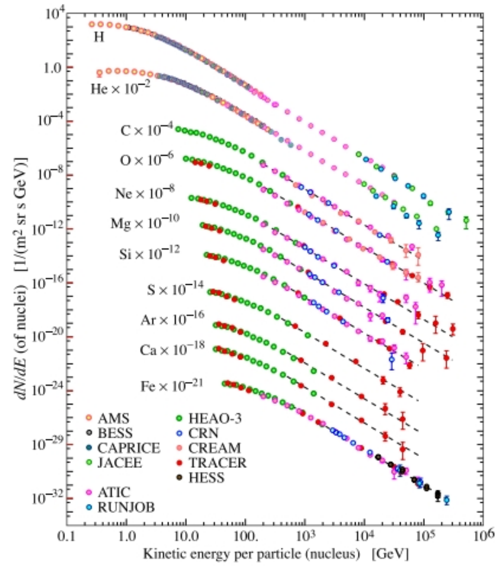
2.1 Cosmic Ray Measurements

See Figure 5 and the Procedure section for a rough idea of the proposed setup. Essentially, we place our detector in between two trigger paddles built from the same scintillator/WLS fiber/SiPM technology. Cosmics incident on the paddles will trigger data acquisition from the detector placed in the middle. The size of the triggers will be made small (about 2x2 cm) in comparison to the detector. The distance between the detector and both paddles will be made large to improve timing resolution. The most important initial measurement is confirmation of electric signals from the SiPM to the ADC at a rate typical of cosmic ray measurements. In the case of the BEMC cosmic measurements, the trigger rate associated with the coincidence signal of two muon-counters was 0.15 Hz and the ADC gate was 100 ns. Figure 1a shows a BEMC plot of the ADC pulse height spectrum from cosmic muons for tile/fiber assemblies. To obtain light yield information, the spectra were fitted with a Gaussian function. Since we are using a similar setup as the BEMC, we expect to measure similar pulse spectra, with expected differences arising from different trigger sizes/rates.

Eventually, we want to know the efficiency/light yield as a function of the hit position. However, in order to reduce the time needed to conduct the initial measurements, we will first measure the detection efficiency on a limited region. In other words, we want to know what fraction of triggered particles are measured by the detector. After this measurement is complete, it can be used as a baseline reference for more precise measurements using either an electron beam (see next subsection) or further cosmic measurements of finer position resolution. This depends on the accessibility of an electron source during the measurement stage.



(a) The ADC pulse height spectrum from cosmic muons for tile tile/fiber assemblies from documentation on the BEMC prototyping stages. Data corresponds to about 3000 events at an unspecified point of measurement.



(b) Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus are plotted vs energy-per-nucleus. Figure Credit: P. Boyle and D. Muller [3].

The trigger scintillators above and below the tile will be made small compared to the tile. By doing this, we know roughly where the cosmic ray struck the detector and can record the light yield information for a given tile region. Figure 1b shows that, for particles with energy on the order of 1 GeV, the rate of arrival is about 1,000 $m^{-2}s^{-1}$. However, this is rate of arrival *at the top of the atmosphere*. For the vertical flux of cosmic rays at ground-level, experimentalists use I = 1 $cm^{-2}min^{-1}$ for horizontal detectors[3].

Using this information and relevant tile quantities, we can estimate how long it should take to measure 500 cosmics for a given trigger scintillator size. The proposed tiles are 12 cm x 12 cm, so a reasonable resolution in hit position would be 2 cm x 2 cm trigger scintillators. Therefore, the time required to detect 500 cosmics is

$$t = \frac{\frac{500counts}{4cm^2}}{\frac{1count}{cm^2min}} = 2 \text{ hr } 5 \text{ min}$$

So, depending on the solid-angle acceptance of incident cosmics on the trigger, we expect a collection of 500 cosmics to take about 2 hours.

2.2 Electron Gun Measurements

With a radiation source, we can determine which groove geometry exhibits optimal light collection. This would likely be done by scanning over the tiles with a Sr-90 source to give a relative light yield from different positions on the tiles. With plots of hit detection as a function of source position, one for each groove geometry, one could compare light yields/efficiencies scanned over the entire tile.

An advantage of the chosen SiPMs is low crosstalk. This means that a given detecting pixel is less likely to affect other nearby pixels or cause them to produce pulses separate from output pulses. We can take advantage of this characteristic in radiation source measurements because we know (roughly) where the detected particles are originating and, on average, their energy. Using this information, we can measure whether or not the SiPM output accurately reflects the strength of the input beam. In other words, should we measure more signal than expected, this is indicative of noise complications/interactions between the detector elements. Such measurements would have to take into account other factors, such as the level of SiPM dark count, which is the rate of registered counts without any incident light [1]. The chosen SiPMs are rated for a typical dark counts of 1000 kcps (S12572), 90 kcps (S13360-1350CS), and 500 kcps (S13360-3050CS). Thus, by conducting these measurements, we can obtain a better understanding of the overall signal-to-noise ratio in our setup and how it varies depending on the chosen SiPM.

3. Equipment

The EJ-200 Plastic Scintillator [4], Wavelength Shifting Plastics, and S12572 MPPC have been chosen for the proposed detector technology. The EJ-200 Plastic Scintillator has long optical attenuation length and fast timing. The scintillator tiles will either (a) contain WLS fibers which absorb the scintillator light and emit it isotropically at longer wavelengths, or (b) be directly coupled to an attached SiPM (no WLS fiber).

The WLS fibers will be installed into grooves on the surface of the tiles and fed out into the SiPMs. We recognize the time-spread induced by the WLS fiber in the larger tiles, but this level of time precision is not needed for the larger tiles. This is because there will be a far narrower time spread in the smaller and more central tiles. The degree of time spread is dependent on the chosen geometry of grooves into the tiles. The geometry is to be determined during this phase of R&D. The three primary geometries of interest are shown in Figure 3. We will be ordering the EJ-200 scintillating plastic with dimensions 28cm x 28cm and widths of 0.5 cm, 1.0 cm, and 2.0 cm. These large tiles will be cut down to three smaller tiles of dimensions 12 cm x 12 cm and the remaining tile material will be further cut down to experiment with smaller tile geometries. The milling for the proposed groove geometries will be done in the LBL machine shop.

The lines on the tiles indicate where the WLS fibers are to be inserted into a groove. A side-view of the proposed U-shaped grooves is shown below in Figure 7, specifically for the straight-groove design. The shape and depth of the groove is the same for all three shown designs. Another possible groove shape of interest involved the upper edges curling into each other more, resembling an upside-down Ω. Once the WLS fibers are installed into these grooves, they will be sealed in with optical glue.

When installed, the individual tiles in a given sector will be physically connected, separated only by a

90% depth groove-cut, as shown in Figures 2 and 6. Reflective paint will be applied to the side of these tile-edge grooves, and the grooves themselves will be filled with epoxy. These “separation” grooves, as used in the BEMC, optically isolate the tiles from each other while maintaining mechanical robustness of the tiles. Since scintillated photons may reflect off the bottom 10% of the un-milled tile underneath the groove, we need to measure and account for any possible crosstalk between the tiles (i.e. one scintillation from one tiling affecting an adjacent tile). A more complete list of proposed tile geometries is shown at the end of this report in Figure 6.

Each WLS fiber will be fed to a SiPM, which in our case will be a general-purpose Multi-Pixel Photon Counter (MPPC)(Hamamatsu S12572 or S13360). MPPCs require low voltages and exhibit high gain, high photon detection efficiency, and high-speed response. They have excellent time-resolution (250 ps FWHM) and a wide spectral response range (320-900 nm). In addition, they have the advantage of being immune to magnetic fields and resistant to mechanical shocks. Such properties make these MPPCs promising technology for the EPD. As shown in Figure 4, the S12572 series has a photon detection efficiency of 35% for incident photons with λ = 450 nm, the peak sensitivity wavelength of the SiPMs.[1]

The peak emission wavelength of the Y11 WLS fibers, which will be incident on the SiPMs, is rated at 476 nm. This is roughly a 5.6% difference. The SiPMs have a photon detection efficiency of 35% at the peak sensitivity wavelength of 450 nm, so we expect to see near-peak photon detection efficiencies from the WLS fibers to the SiPMs. The chosen scintillator is also well-matched with the Y11 WLS fiber. The scintillator

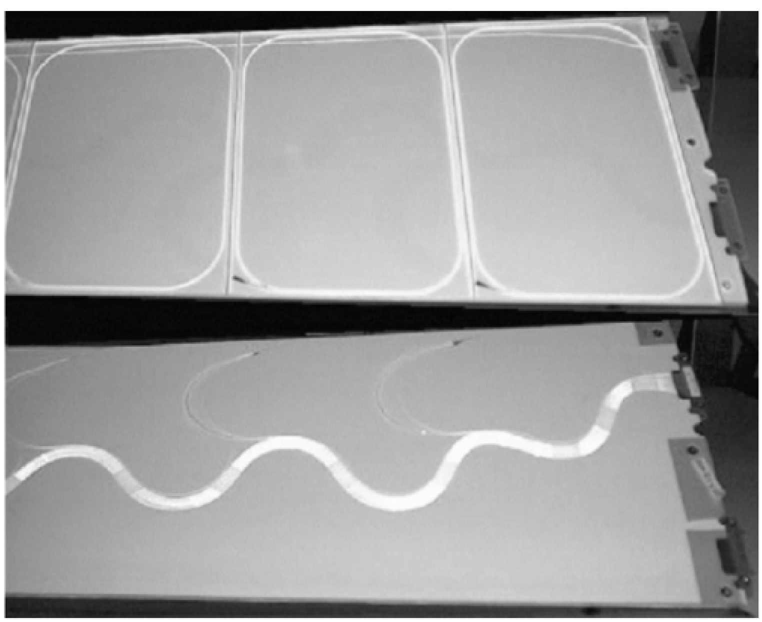


Figure 2: (From BEMC Technical Design Report) Upper photo shows separation grooves between tiles with σ shaped grooves for WLS fibers in the scintillators. Lower photo shows shows the opposite side of the fiber-routing layer, with wavelength-shifting fibers routed through undulating channels, from which they enter the σ grooves in each tile.

[1] For more SiPM specs, see Ref. [5]

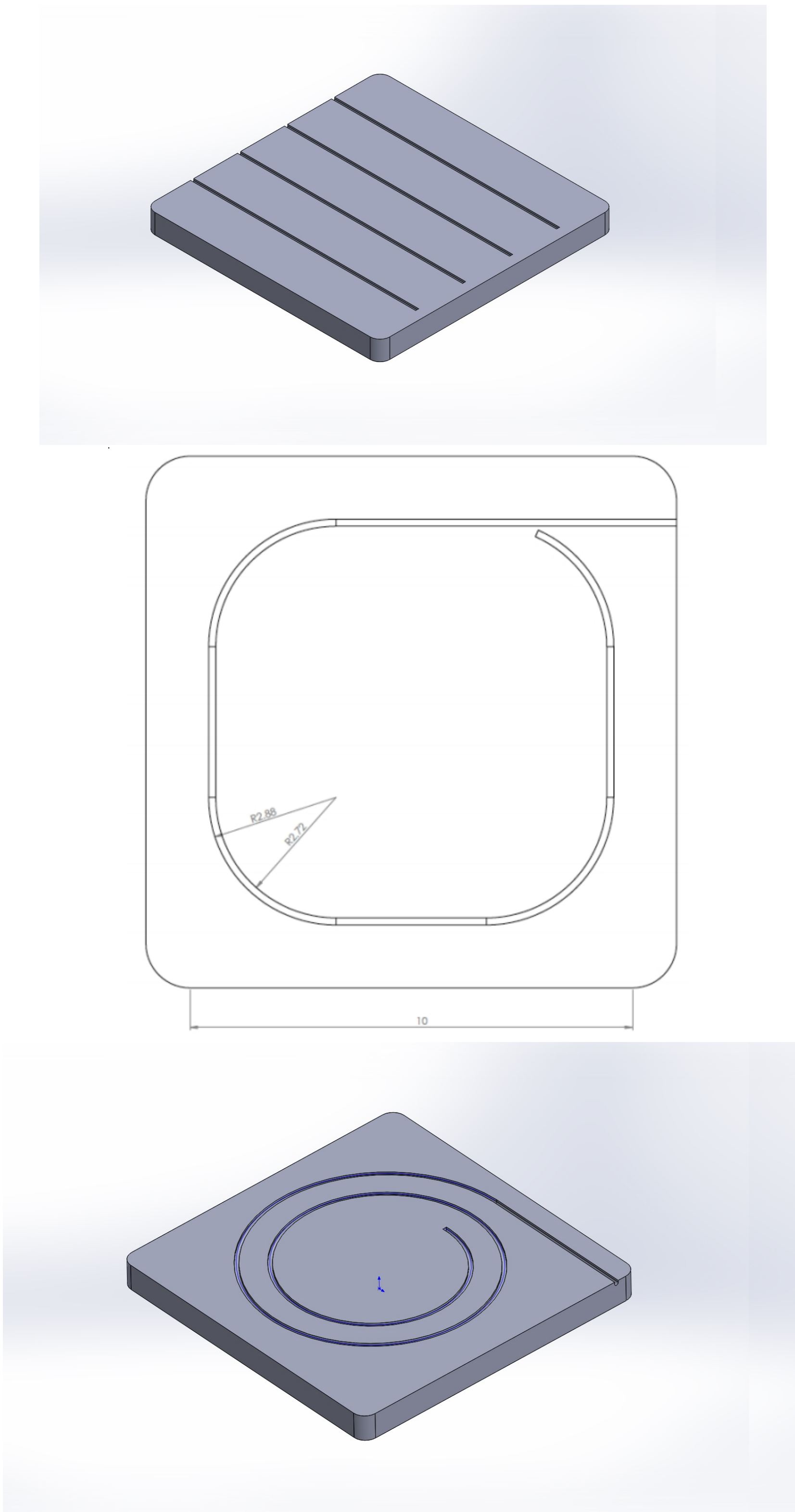
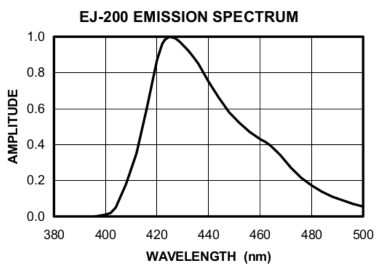
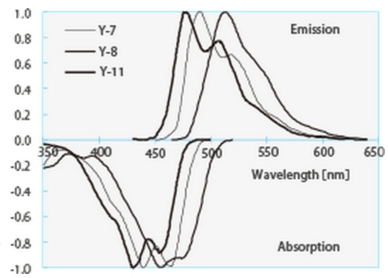


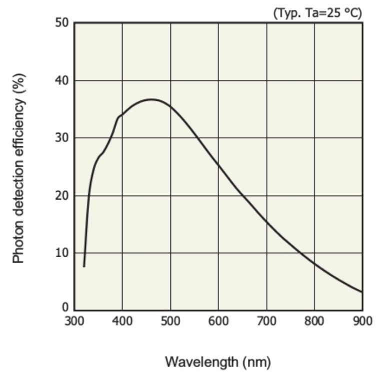
Figure 3: Different proposed tile / WLS designs. All tiles are 12x12 cm. The four-line grooves are each 2.4 cm apart.



(a) EJ-200 Scintillator



(b) Y11 WLS Fiber (darkest line)



(c) Hamamatsu SiPM MPPC (detection efficiency)

Figure 4: Emission/Absorption spectra for detector components.

has a peak emission of 425 nm and the Y11 has peak absorption at 430 nm. Figure 4 illustrates, from left-to-right, how likely a photon is to be emitted by the scintillator, absorbed by the Y11 WLS fiber, emitted from the fiber, and finally detected by the SiPM.

Summary of Materials

The full list of materials to be ordered is as follows:

Material	Size	Quantity
EJ-200 Plastic Scintillator	28x28 cm tile ; 0.5 cm thick	3
EJ-200 Plastic Scintillator	28x28 cm tile ; 1 cm thick	3
Y-11 WLS Fibers	1 mm	6 meters
Y-11 WLS Fibers	0.5 mm	6 meters
Hamamatsu MPPC S12572	3x3 mm	3
Hamamatsu MPPC S13360-1350CS(3050CS)	1.3x1.3 mm (3x3 mm)	3
Driver Circuit for MPPC C12332	n/a	3
Oscilloscope	n/a	1
5V Power Source	n/a	3

As for more general lab equipment/accessories, we have ordered optical glue, but we may need optically opaque epoxy if possible. We have ordered reflective paint and optical grease. Finally, We will need a mechanical structure to support the three scintillators (2 triggers, 1 detector) and mylar wrapping to cover the plastics.

4. Procedure

We plan on conducting cosmic ray tests using a similar setup as shown in Figure 5. However, our setup will have notable differences. Namely, we won't be using any lead plates, we plan on triggering with two SiPM arrangements above and below our detector, and we will be sequentially testing the three WLS groove geometries discussed earlier instead of the straight fiber setup in Figure 5. All measurements will first be carried out on the sigma tile geometry. Then, after these first test results are analyzed, the proposed building procedure and design will be finer-tuned for all subsequent tests. This approach is more time-efficient than building and assembling all the design setups at once before understanding the details of how a single test run may operate.

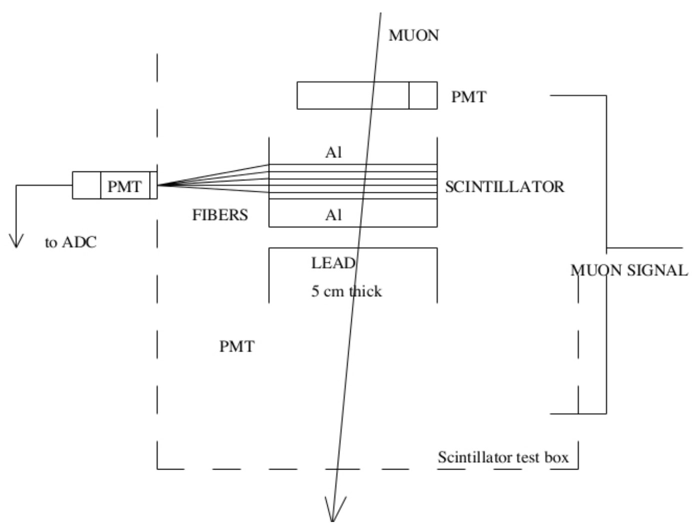


Figure 5: Cosmic muon telescope used in the prototyping stage of the BEMC.

Whether or not we will trigger with the proposed detector prototype itself or, rather, a previously verified PMT arrangement has yet to be determined. Regardless, the decision to place the triggers above and below the detector is for accurate hit determination and analysis. For example, if the top and bottom triggers detect a signal but the prototype detector in the middle does not, this is indicative of a problem in the middle detector, and we can correct for this error more quickly. In addition, by changing the size and/or position of the two triggers, we can determine light collection efficiencies as a function of position, as discussed in the Measurements section. Geant4 simulations have also been made for the proposed detector and will serve as a means of comparison for the measurements. The results of these light collection tests will play a major role in determining which WLS fiber/groove geometries will be employed in the EPD.

After all cosmic data is collected, analyses will be performed to provide estimates for levels of crosstalk, SiPM detection efficiencies, signal peak-to-noise ratios, luminosities, etc. After the cosmic measurements, additional tests may be conducted with an radiation source. This would provide another method of determining which groove geometry (straight, sigma, or spiral) is associated with optimum light collection.

In terms of results, we want to obtain detector efficiencies, for small trigger cross sections, as a function of discriminator setting. Plots indicating the detector's time resolution are also desirable, but the statistics afforded by cosmic/radiation source measurements with an oscilloscope will limit the tightness of bounds for confidence levels on time resolution. We also hope to obtain plots of dark count/crosstalk for the SiPMs as well as the full detector apparatus.

We estimate it will take about 4 - 5 weeks to obtain all the necessary materials. After that, it should take another week for the machine shop to mill the grooves into the scintillating tiles. Then another week or two will be needed to setup the test bench/equipment in a suitable area. We can then conduct basic functionality and preliminary cosmic tests on the equipment to ensure all components are operating as expected, which should take about another week or two. From there we can take the proposed position-dependent hit measurements. The data collection and analysis process for these measurements should take approximately 4 weeks. In summation, this phase of R&D should be near completion in (using conservative end of estimates) 14 weeks.

Additional Figures

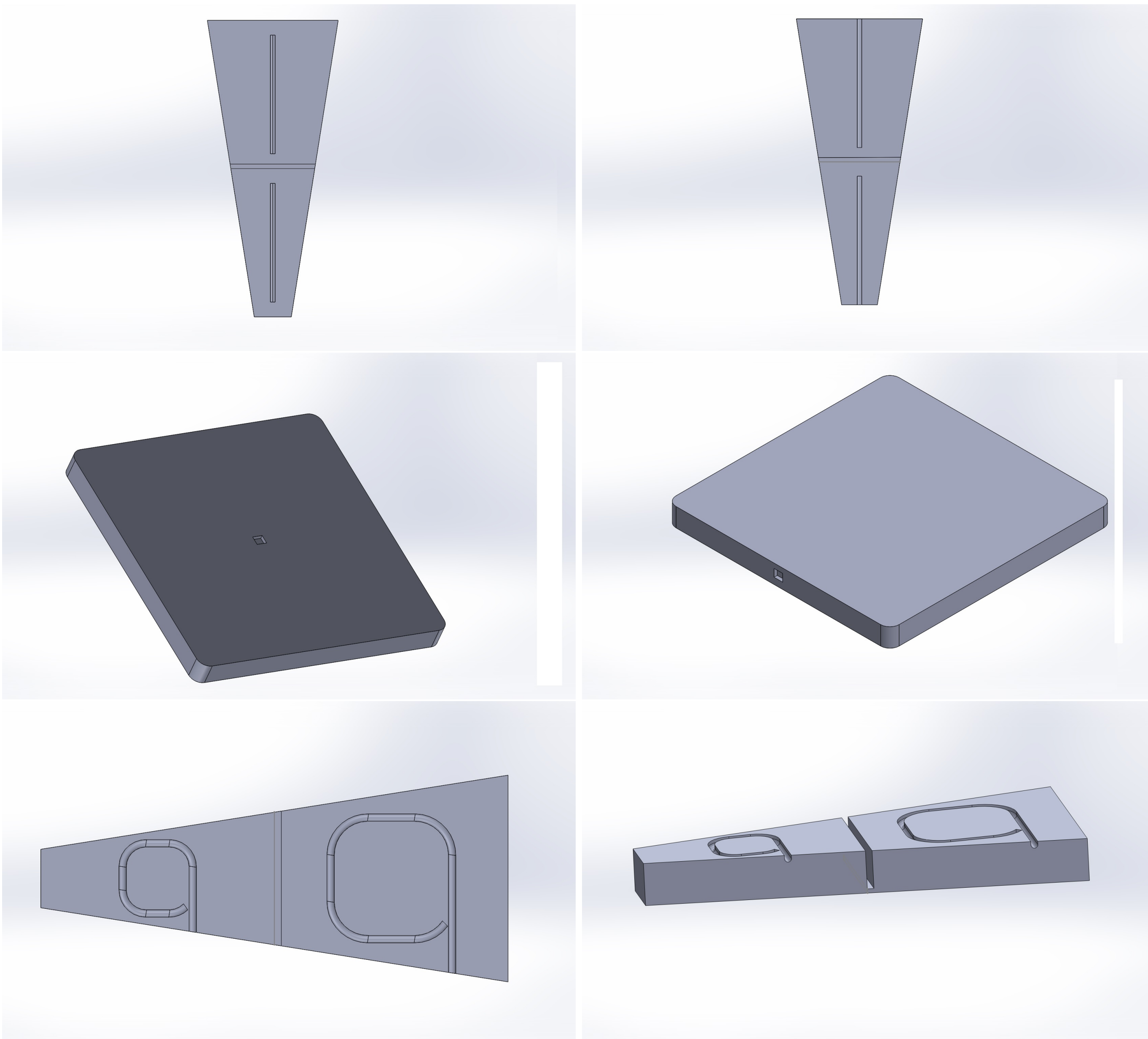


Figure 6: Various proposed tile-WLS-SiPM geometries. All tiles shown are 1 cm thick. The same designs will also be tested with 0.5 cm tiles. The trapezoidal figures are 1.25 cm at the base, and 2.8 cm at the top. In the middle of each trapezoidal figure is a 90% depth cut, leaving 0.1 cm of scintillating material between. The designs in the center indicate where a SiPM may be attached should we couple the SiPM directly to a scintillating tile. The lower two designs will likely not be tested due to the very small fiber bending radius needed, but are shown for reference/completeness.

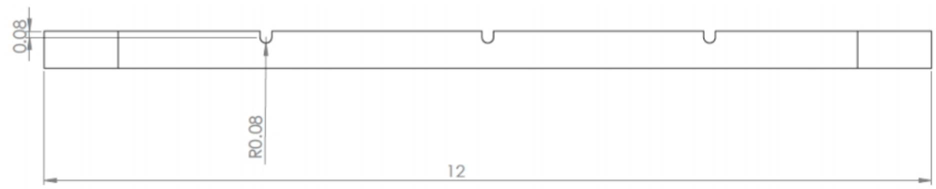


Figure 7: A side-view on a straight-groove tile design.

References

[1] *Photon Counting*. http://www.rp-photonics.com/photon_counting.html

[2] *BEMC Technical Design Report*. https://drupal.star.bnl.gov/STAR/subsys/bemc/documents

[3] *Physical Review D Particles, Fields, Gravitation, and Cosmology*. Ridge, NY: American Physical Society, July 2012. 305 - 306. Print.

[4] *EJ-200 Homepage*. http://www.eljentechnology.com/index.php/component/content/article/31-general/48-ej-200

[5] *Hamamatsu MPPC Data Sheet*. http://www.hamamatsu.com/jp/en/S12572-050P.html