Construction of the Event Plane Detector Prototype

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Abstract

I am not sure if Alex finds an abstract necessary for this document, but I'll put something here as a placeholder just in case. Also, check with him to see if the margins are okay.

1 Motivation and Background

We present here a comprehensive account of the operations conducted at LBNL concerning the R&D of the proposed Event-Plane and Centrality Detector (EPD) at STAR. Briefly, the EPD serves to improve event-plane reconstruction for heavy-ion flow measurements and trigger detection for "good" events within a certain z-vertex range. For more information pertaining to the physics of the EPD, see our proposal in reference [1].

The design and goals of the EPD have evolved considerably over the course of the R&D process, and each component of the final design, documented in what follows, was carefully chosen for optimal performance given various budget constraints. The fundamental characteristics of the EPD include radiation detection by plastic scintillating tiles and a redirection of the signal photons through wavelength shifting fibers. The signal is then coupled to clear optical fibers which are subsequently fed into Silicon Photomultipliers (SiPM) for signal amplification. The major design topics that were researched include optimizing the tile geometry, the fiber groove geometry, fiber coupling techniqes, and fiber polishing techniques. Throughout the research process, 3D-printing technology was utilized to quickly experiment with custom connector designs to be printed on-site at LBNL.

At the time of this writing, a full prototype sector has been installed at Brookhaven National Laboratory (BNL) for use in the STAR detector. Minor modifications may be implemented in the final design, contingent on the results from measurements using the aforementioned prototype. These are likely to be small adjustments in the scintillating pad sizes to optimize for both the space constraints in the STAR cave and for resolution requirements at varying radii. Nonetheless, the vast majority of the design process and detector specifications will be covered in what follows.

2 Simulations

This section will be for talking about the simulations that we based the prototype design off of, including why we used a 26 sector design and such.

3 Testing

This section will be for describing our test scintillator tiles and setup:

3.1 Electronics

3.2 Connectors

See "Fiber Connection" section.

3.3 Tile and Groove Geometry

The final tile design was inspired by the Barrel Electromagnetic Calorimeter (BEMC) [Citation here]. Since the beginning of R&D, the sigma groove geometry for the WLS fiber seemed to be the most likely candidate for the final design, but other geometries were both designed and tested at LBNL. For example, the four-fiber straight line and spiral shapes shown below [insert figure] were designed with the assumption that more fiber coverage corresponded to a higher sensitivity to radiation. However, we found that the sigma geometry was capable of single photon detection and represented the simplest implementation. In addition, the small improvement in efficiency afforded by the other geometries wasn't found to be significant enough to justify complications that arose from, say, coupling multiple fibers to a single SiPM or increasing the risk of fiber damage associated with tightening the bending radius. In this respect, we stuck to the status quo, albeit with the groove closer to the center of the tile, as opposed to the BEMC choice of the grooves essentially at the tile edges [see figure to be inserted].

In contrast with the BEMC, and due to unique spacial constraints set for the EPD placement at STAR, we do not feed the WLS fibers through the rear face of the tiles into an undulating channel. Rather, the fibers exit directly out the front face of each tile and eventually organized through custom printed fiber collectors. This is because the SiPMs will be positioned near the large toroidal magnet in such a way as to shield them from radiation damage by fast neutrons.

All tile designs were made using the SolidWorks [trademark or something here] software, elaborated on in the subsequent section, and sent to the LBNL machine shop for construction. From the start, we knew we wanted multiple tiles printed together, with a 90% depth separation cut between each, as was done for the BEMC. This would constitute one "sector", in the shape of a trapezoid, that would extend radially outward from the beampipe. Of course, since each tile must be optically isolated from any signals in other tiles, we experimented with filling the groove with optical glue and coating the tile sides with reflective paint. However, there would still be the possibility of signal contamination through the remaining 10% of uncut tile holding the sector together. Ultimately, the final procedure involves breaking this 10% remainder (not done for the BEMC) after the sector is fastened in place by a custom built mechanical structure [credit to OSU?]. This preserves the mechanical robustness of the sector, the primary reason for initially keeping the 10% groove, while providing true optical separation between tiles.

4 Computer Graphic Design

Based on the simulations, described in section 2, it was determined that the optimal design of the detector would be two 26-sector disks on either side of the event plane. Each sector would extend radially from the beam pipe and touch side-to-side forming a complete icosikaihexagon. The prototype discussed in this paper represents one of these 26 sectors.

The prototype was designed using a 3D computer-aided design software called SolidWorks distributed by Dassault Systémes. The model and the actual dimensions of the prototype in centimeters are pictured in figure 1. In summary, the prototype is a narrow trapezoidal shape 103.8 cm long made from 1 cm thick plastic scintillator. It is 22.87 cm wide at the top and 1.4 cm wide at the bottom edge close to the beam pipe. The sector is divided into 24 pads that are optically separated (see section 5) and of varying widths ranging from four to six centimeters.

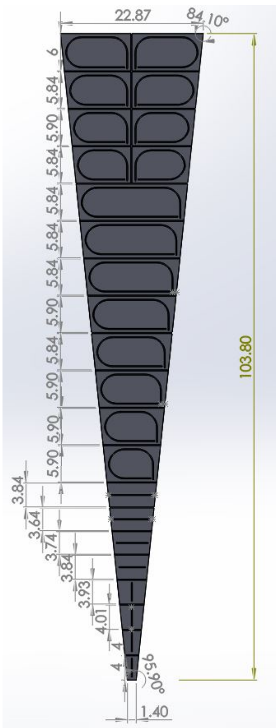

Figure 1: SolidWorks model of the EPD prototype showing dimensions in centimeters.

Each of the 24 pads in the prototype has a 0.16 cm groove to hold the optical fibers used to collect event signals. In the larger pads at the top of the prototype the grooves are sigma-shaped, with the fibers coming out of the scintillator at an angle at the bottom of each pad. This is illustrated in figure 2.

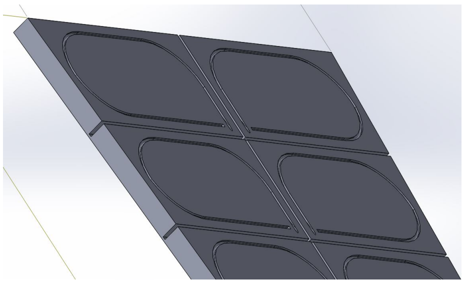

Figure 2: Closeup of the SolidWorks model of the EPD prototype showing the sigma shape and incline of the fiber grooves.

The optical fibers used in the prototype have a maximum bending radius of 2.5 cm so the sigma-shaped grooves could not fit in all of the pads. Therefore, straight line grooves, pictured in figure 3, were employed in the smaller pads at the bottom of the prototype.

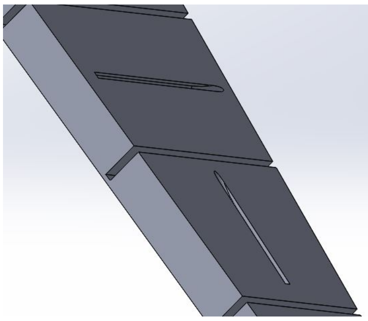

Figure 3: Closeup of the SolidWorks model of the EPD prototype showing the shape and incline of the fiber grooves at the bottom of the detector.

5 Scintillator Assembly

The prototype was cut in LBL's machine shop from three 30x30 cm plastic scintillator tiles. Need what kind of scintillator they are. Ask what steps were used for the polishing. Find out what reflective paint was used.

This section is for talking about the scintillator tiles and the cutting, polishing, painting, taping and gluing of them into one piece.

6 Fiber Preparation

The fibers used in the scintillator tiles for signal collection are Kuraray Y-11(200) Wavelength Shifting Fibers (WLS). These fibers have an attenuation length of

$\lambda = 399$ cm. In order to transmit as much light as possible the fibers need to have polished ends cut perpendicular to the fibers' longitudinal axes. A six-step process as outlined below was utilized to achieve the desired quality of the fiber ends.

1. The required lengths of fiber were cut from the spool. This step leaves the ends of the fibers jagged, as shown in figure 4.

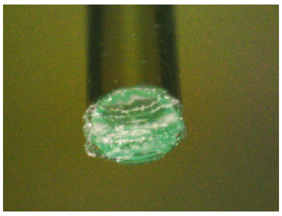

Figure 4: One end of a WLS fiber after being cut from the spool.

2. A razor fiber cutting tool was used to cut the ends of the fibers. The fiber cutting tool is shown in figure 5. When done correctly, the fiber ends were smoothly cut perpendicular to the longitudinal axis of the fiber with minimal fraying of the encasing cladding. However, the razor often left silver residue on the cut surface. These aspects are shown in figure 6.

Figure 5: Razor tool used for cutting fibers perpendicular to their longitudinal axis.

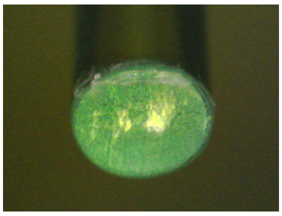

Figure 6: Fiber end after having been cut using the razor tool in figure 5.

3. Polishing began using a fiber polishing sheet with a grit of 5 µm. These sheets are sold by Thorlabs, with the black 5 µm grit size being the largest of four sizes. A plastic fiber holder was designed and fabricated with the 3D printer in order to maintain the fiber's perpendicular cut surface while polishing. The fibers were polished using a figure-eight pattern 30-40 times to achieve uniform quality in this step.

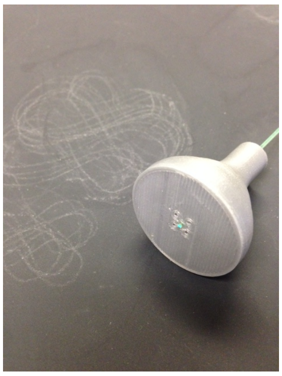

Figure 7: Plastic holder with a WLS fiber on top of a black polishing sheet exhibiting the figure-eight polishing pattern.

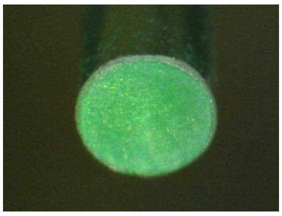

Figure 8: WLS fiber end after using the black polishing sheet.

4. The next highest grit size polishing sheet was then used on the fiber ends. This would be the red 3 µm sheet shown in figure 9. The result of polishing with this grit size is shown in figure 10. Again, a uniform polish was achieved using a figure-eight pattern 30-40 times.

Figure 9: Fiber holder and fiber on top of the red polishing sheet.

5. The fiber ends were then polished in a figure-eight pattern with the second lowest grit 30-40 times. In this case the second lowest grit size is the green 1 µm polishing sheet. The sheet is shown in figure 11 while the result of this step is shown in figure 12.

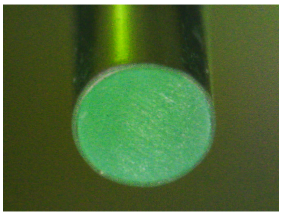

Figure 10: Result of polishing in step 4.

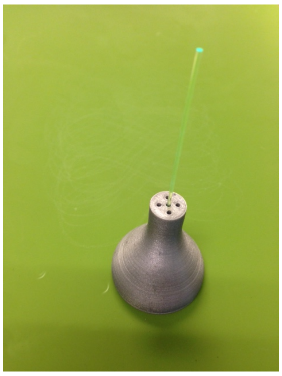

Figure 11: Fiber holder and fiber on top of the green polishing sheet of the second lowest grit size.

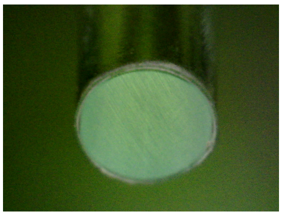

Figure 12: Result of step 5.

6. Finally, the ends of the fibers were polished in 30-40 figure-eights on the white sheet with the lowest grit size of 0.3 µm. After this step the ends of the fibers had a smooth, mirror-like quality. In some cases this step revealed one or two deep scratches as shown in figure 14. To remedy this, steps 3 through 5 were repeated until a satisfactory quality polish was achieved. Also, if too much pressure was applied to the fiber while polishing the cladding often became frayed. In these cases it was often necessary to start over from step 2.

7 Coupling of the Fibers

The signals collected by the WLS fibers in the scintillator tiles are read by Silicon Photomultipliers (SiPMs) located about 5 meters from the actual detector. In order to allow the signals to reach the SiPMs with as little loss as possible

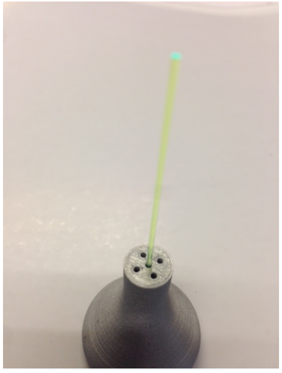

Figure 13: Fiber holder and fiber on top of the lowest grit size polishing sheet.

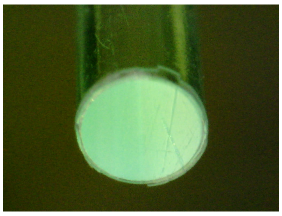

Figure 14: Result of step 6 exhibiting a mirror-like surface with the exception of two deep scratches on the right side of the fiber end.

the WLS fibers are connected to clear optical fibers with an attenuation length of 10 meters. This necessitates two points of connection: fiber to fiber and fiber to SiPM.

The connection between the WLS fibers and the clear optical fibers can result in appreciable signal loss if the fiber ends are misaligned. Although other published reports for similar couplings claimed to achieve a 10% signal loss with rudimentary connection techniques[citation needed], we consistently measured on the order of 50% loss with a basic custom printed connector, an initially puzzling result. The R&D effort that followed included the creations of many novel designs for fiber coupling, and after extensive trial and error experiments and consulting the modern literature,
that For this reason it was necessary to design a connector that is light-tight and correctly positions the axes of the fibers. The design was created in SolidWorks and built with the 3D printer. To increase the light-tight aspect of the connector the design was printed using black polylactic acid (PLA) plastic. The designs are shown below in figure

7.1 Fiber to SiPM Connection

Similar to the fiber-fiber connector, the fiber-SiPM connector is also required to be light-tight to reduce signal noise. However, if the fiber extends too far into the connector it could easily break the avalanche photodiode (APD) array of the SiPM. These parameters were kept in mind during the design process of the connectors.

To avoid breaking the APD, the insertion piece that holds the fiber in place was designed to extend into the SiPM holder by ?? mm, far enough to be light-tight while allowing room for the SiPM to fit without applying any pressure to the interface. The fiber is installed with its end flush with the end of the insertion piece, enabling the fiber to come into direct contact with the SiPM without breaking it. Once again black PLA plastic was used for the printing of the connectors to enhance their light-tight quality.

8 Prototype Assembly

This section is to discuss the gluing of the fibers into the scintillator, the wrapping of the prototype in aluminized mylar and black paper as well as the shrinking tube for the WLS fibers and attachment to the connectors.

8.1 Epoxy

8.2 Wrapping

In order to further ensure that signal photons are contained within the plastic scintillator, all tiles are tightly wrapped with aluminized mylar and then again with thick black tape [is it really called paper?]. We found that it wasn't sufficient to simply take a piece of mylar and hand-wrap it around the tiles, because the result isn't nearly tight enough. Instead, we drew a template cut for the mylar that would minimize the total surface area of the mylar while completely covering all faces of the tile, as shown in [need pic of template]. The mylar was then laid over the template and cut out with a box cutter for each tile. Any piece of the mylar that would be a fold on the tile was also perforated somewhat so as to ensure sharp edges all around. The result, shown in [picture of wrapped tile], is a tile in direct contact with the mylar at nearly all surface points.

To shield the tile from ambient contaminating photons, all tiles are then wrapped with black [paper?]. We found that this was more than enough precaution to obtain a clean cosmic ray signal in the lab. The corresponding measurements can be found in the Testing section.

8.3 Making the Fibers Light Tight

Shrinking Tube

8.4 Connectors

9 Installation

This section can be used for discussing any additional preparations made at BNL before installing the prototype. The frame and tube and other such things can be talked about here.

References

[1] *STAR R&D Proposal for an Event Plane and Centrality Detector for BES II* (More citation info here.)