Scintillating Fiber Inspection and Test Plan

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Abstract

This document contains description of the handling and assessment protocols for production scintillating fibers for the ePIC Barrel Imaging Calorimeter (BIC) at Argonne National Laboratory, including the equipment used, setup, and step-by-step instructions for measuring attenuation lengths, number of photoelectrons, scintillation spectra, and diameters of fibers.

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1. SCINTILLATING FIBER PROPERTIES

The ePIC Barrel Imaging Calorimeter (BIC) will have 4,900 km of 455-cm-long scintillating fibers, with emission in blue wavelengths and with a single layer of optical cladding. The following base materials for the core and cladding are satisfactory: i) Core: The base material for the core of the fibers shall be polystyrene. The nominal index of refraction of the core material is 1.59. ii) Cladding: The fibers will be single-clad fibers, with the cladding being 4% of the fiber diameter. The base material for the claddings shall be polymethylmethacrylate, with index of refraction of 1.49.

The key properties of the fibers are listed below.

- **Fiber handling**: Scintillating fibers are sensitivity to incandescent or fluorescent indoor lighting, which can damage them and affect their properties. Special procedures are required for handling, testing, and storage.
- **Diameter**: The diameter mean value and variation shall be 1.00+/-0.01 mm, RMS < 0.02 mm. This will be measured using a digital caliper.
- **Emission Spectrum**: The fibers should emit in the blue-green wavelength range. This will be tested using a spectrophotometer.
- **Attenuation Length**: The attenuation length for blue light should be > 4m. The batch-to-batch or lot-to-lot variation of light yield and attenuation length should be less than 10%.
- **Light Yield:** The average response to a 90Sr source shall be greater than 3.5 photoelectrons measured using a bialkali PMT or a SiPM at 200 cm from the source, with the opposite end of the fiber being blackened. The batch-to-batch or lot-to-lot variation of light yield and attenuation length should be less than 15%. As a practical matter, the light output will be determined in comparison to average light yield of a set of "standard reference fibers", identified during the First-Article testing, with an agreed upon light yield and attenuation length to which all subsequent production batches will be compared.
- **Scintillation Decay Time**: The decay time should be less than 3 ns. This property will not be tested, as it is a standard performance parameter of scintillating fibers.
- **Delivery Method**: The fibers will be delivered in canes, having a length of 4.55 m +/-0.01m. The length will be verified using a tape measure.

2. PROCESSES AND PROCEDURES

This section will describe the processes and procedures that are required to evaluate each of the properties described the preceding section.

2.1. General Product Quality

2.1.1. In-Process Testing

The manufacturer must test and document its quality control of fiber production. Measurements of attenuation length and light output shall be performed periodically. The manufacturer must specify the frequency and procedures used to test the scintillating fibers. Random selection of a pre-agreed percentage of the fibers from the production lot should be a minimum statistical sample tested by the manufacturer.

2.1.2. Incoming Inspections or Acceptance Testing

Acceptance of the fibers will take place within 20 working days after receipt of the shipment. The acceptance tests consist of procedures which check particular parameters relevant to the specifications to accept shipment. They are not intended to substitute for the manufacturer warranty on the scintillating fibers meeting their specifications. The statistical sample will consist of randomly selected fibers from each lot. Shipments of scintillating fibers passing the following checks will be accepted: i) Each shipment will be inspected visually for physical damage, and select fibers for color and transparency. If the visual inspection is satisfactory, the fibers will be tested further to determine whether they meet the specifications, as outlined above. ii) The attenuation length and light output relative to the standard reference fibers will be measured for a sample of fibers. Lots failing contract specifications will be rejected.

2.1.3. Verification Testing

Verification testing upon shipment receipt is required to assure that it meets the minimal stated performance requirements. Randomly selected fibers from each lot and batch will be tested, using the procedures specified in Section 3 and verified against manufacturer's test results on the key properties: light output, attenuation length, diameter, spectrum.

2.1.4. Failures and Non-Conformances

If more than 1% of the fibers from a given lot fail visual inspection or for one or more of the criteria in Section 1, the lot will be rejected. The outcome will be communicated to the manufacturer, and a joint decision will be taken whether the product shall be returned to the manufacturer.

3. EXPERIMENTAL/TEST SETUPS

3.1. Fiber Handling

3.1.1. General

1. Before placing a fiber on any surface (a tray, a testing station surface, etc.), ensure the surface is clear of dust, debris, and smudges. Surfaces can be cleaned with alcohol and Kim wipes. The fibers easily pick up dust and other motes of matter but are more difficult to clean. Take care to keep the fibers from touching the floor or other unclean surfaces during transportation or handling.
2. Wear clean gloves[1] when handling fibers.
3. At least two people should work together when transporting fiber pouches or loose fibers that aren't in a tray. Support the fibers all along their length; the fibers should be held as flat as possible without applying any pulling tension to the fiber. The permissible radius of curvature of the fibers is fairly small, as low as a few centimeters, but to avoid any unnecessary stress, do not bend the fibers to anything tighter than a 20-centimeter radius of curvature.
4. When transferring fibers from one tray to an adjacent one (or from a tray onto a testing station), using two people is still recommended. Before moving a fiber, ensure that it isn't tangled with other fibers along its entire length. While transferring, try to avoid resting or scraping the fiber on the top of the tray walls and pay close mind to the bending of the fiber (the walls on some of the trays are quite tall).

[1] Ansell 92-600 nitrile gloves

5. The fibers can be damaged from exposure to UV radiation. The overhead lights in the lab emit UV, so the overhead lights should remain off while uncovered fibers are in the room. For periods of time when no testing is being done and the overhead lights may be on, fiber trays and pouches should be either covered with black cloth (or UV protective film) or placed in the coffin with the lid closed. During general handling, polishing, and testing, only LED lighting (or desk lamps with UV film covering the bulbs) should be used.

3.1.2. Polishing

NOTE: Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

1. Move one pouch of fibers on top of the coffin along with an empty tray.
2. Slit pouch lengthwise along its edge.
3. Remove one fiber and place it in the tray.
4. Extend the tray off the south end of the coffin and the fiber out of the end of the tray such that it gently bends 90 degrees, allowing the end can be polished on the surface of the desk.

   NOTE: The permissible radius of curvature of the fibers is a few centimeters, but to avoid the risk of damaging fibers, refrain from bending any fiber past a 20-centimeter radius of curvature.

5. Place the fiber in the holder (aluminum puck) such that the end to be polished lies flat against the desk. Since the fibers are slightly smaller than the hole in the holder, the fiber should be manually held in place at the top of the holder (a small amount of downward pressure can also be applied to help give an even polish).
6. Move the fiber and holder in small, circular motions over 1500 grit paper for 10 – 20 seconds, clean the fiber end (for instance, with a Kim wipe), and repeat over 3000 grit paper and 4000 grit paper.
7. Inspect the fiber end by inserting the polished fiber tip into the front port of the microscope machine[2] (compare to unpolished and polished reference fiber).

Figure 1. Aluminum puck fiber holder and grit paper.

[2] RBTX-400G

NOTE: Small scratches and imperfections are expected, but no major scratches or obvious deformations should be present. See below for an example of an unpolished fiber (left) and a sufficiently polished fiber (right).

8. Tag the fiber: write a designation on a small piece of paper (4 cm x 1 cm or thereabouts), poke two small holes in the paper (one on either end of the long axis), and feed the fiber through the holes.

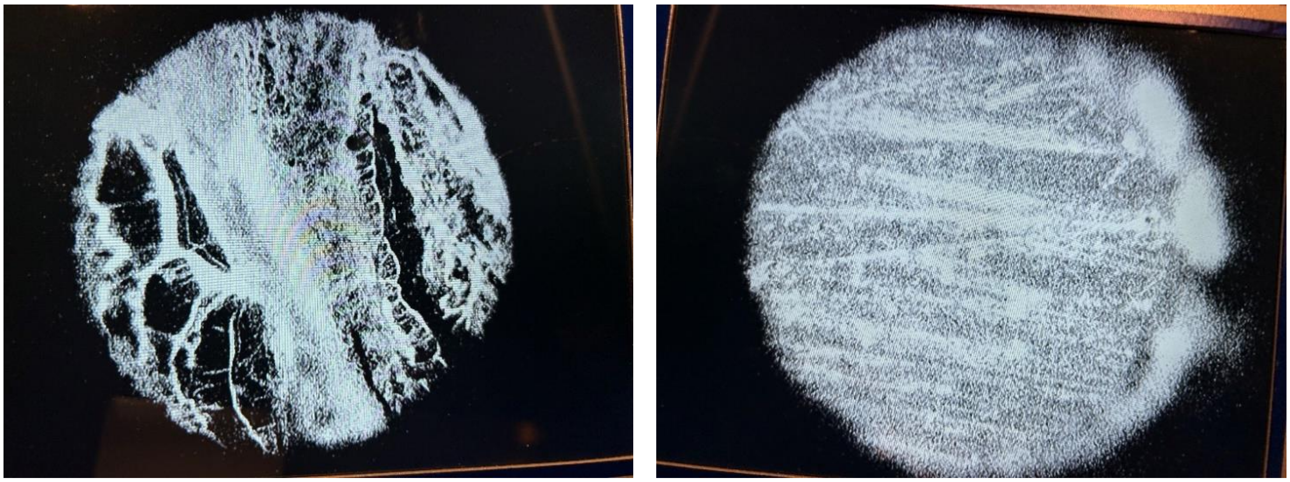

Figure 2. Left: Unpolished (factory rough cut) fiber. Right: Polished fiber.

NOTE: The designation should be something like TYPE-FA-##, where 'TYPE' should be 'L' for Luxium fibers, 'KS' for Kururay single-clad fibers, and 'KD' for Kururay double-clad fibers ('FA' here means 'First Article'). For example, the first single-clad Kururay fiber could be tagged 'KS-FA-01,' and the twenty-third Luxium fiber could be tagged 'L-FA-23.' Designations for future fibers could replace 'FA' with something like the batch, lot, and pouch numbers.

9. Retract the fiber back into the tray and the tray fully back onto the coffin.
10. Repeat steps 3 through 9 until the desired number of fibers are polished on one side (50).
11. Close the fiber pouch with tape for storage.
12. Rotate the tray so the unpolished ends of the fibers can be polished.
13. Place a new empty tray on the coffin next to the current tray.
14. Repeat steps 3, 4, 5, 6, 7, and 9, now moving the fibers from the full tray to the empty tray, until the desired number of fibers are polished on both sides (45). The remaining fibers will remain polished on only one side for now (5). These single-polished fibers will be used to test the progressive effects of polishing and blackening by doing measurements with the end rough cut, polished, then polished and blackened.

3.1.3. Blackening

NOTE: Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

1. Situate a tray of fibers such that the end of the tray with the fiber ends to be blackened extends slightly over the edge of a surface.

2. Extend some double-polished fibers out of this end of the tray a few centimeters so the fiber ends are suspended in open air. The extended fibers should not touch one another, and the fibers that are not polished on both ends should remain unblackened for now.
3. Dip the fiber ends of the extended fibers in black paint[3] such that the end of each fiber is completely covered. Touching the fiber ends to the surface of the paint should be enough (no paint is needed on the outer surface of the fibers).
4. Allow the paint to dry completely while suspended in open air (10 – 15 minutes, but will vary based on the specific paint used), then retract the extended fibers into the tray. Examine the painted tip and determine if a second coat is needed.
5. Repeat steps 2 through 4 until all double-polished fibers in the tray (45) are blackened.

3.1.4. Resource Requirements

Listed in Section 3.1 (General).

3.1.5. Test Conditions

Listed in Section 3.1 (General).

3.1.6. Equipment

Listed in Section 3.1 (General).

3.2. Diameter

NOTE: Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

1. At any time, select 20-30 fibers from each tray for diameter measurements.
2. Using a micrometer caliper, gently measure and record the diameter of each fiber at five evenly spaced points along the length of the fiber. The fibers are ~ 455 cm long, so measure approximately every 75 cm (75 cm, 150 cm, 225 cm, 300 cm, and 375 cm). An estimation by eye will be fine.

   NOTE: Use the flat part of the caliper to avoid scratching or slicing the outer layer of the fiber and take care not to apply much force to avoid crushing the fiber.

3.3. Emission Spectrum

3.3.1. General

NOTE: Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

1. Turn LED power supply on: V = 3.5 V, A = 0.045 A.
2. Place a tray with fibers to be tested between the static tray and the puck board (grooved testing board) such that the polished ends of the fibers are closest to the photospectrometer[4].
3. Verify that the photospectrometer is laying on its side and is stacked on materials such that the input port aligns with the Ocean Optics fiber holder at the end of the puck board.

[3] REVEL Acqua Color acrylic paint (black matte).
[4] Ocean Optics SD2000

4. The photospectrometer should be routed through an ADC into a USB port on the DAQ laptop. Login to this computer and open the 'SpectraSuite' application. Verify that the application has identified the ADC as a device. If it has not, close the application, remove and replug the USB cord, and restart the application until the ADC is identified.
5. In the SpectraSuite application, close the initial graph that is displayed. This will prevent a memory leak.
6. Start a new transmission measurement (File > New > Transmission Measurement). This should open a new window for configuring the measurement. Select channel 0 as the input channel and select 'next.' Set the 'integration time' to 500 ms, the 'scans to average' to 3, and the 'boxcar average' to 10, then select 'next.' The light reference spectrum is not pertinent to our measurements, so click the light bulb and select 'next.' The dark reference spectrum requires complete darkness in the photospectrometer port. Turn off any bright lights and block the light from entering the channel 0 port with a black cloth or a fingertip and click the light bulb. Finally, select 'finish' and a new graph should be present in the application's main window.
7. The 'S' button above the graph can be used to enter `scope mode.' The button next to the 'S' button, which shows a dark light bulb and a dash, is scope mode with the dark reference spectrum subtracted. Press this button.
8. Carefully slide the photospectrometer into the puck board such that the fiber holder is inserted into the channel 0 input port.
9. Slide the LED box to the south end of the puck board, near the photospectrometer.
10. Select a blackened fiber, remove its tag, and insert the polished fiber end under the LED box into the fiber holder until the fiber is abutting the photospectrometer.

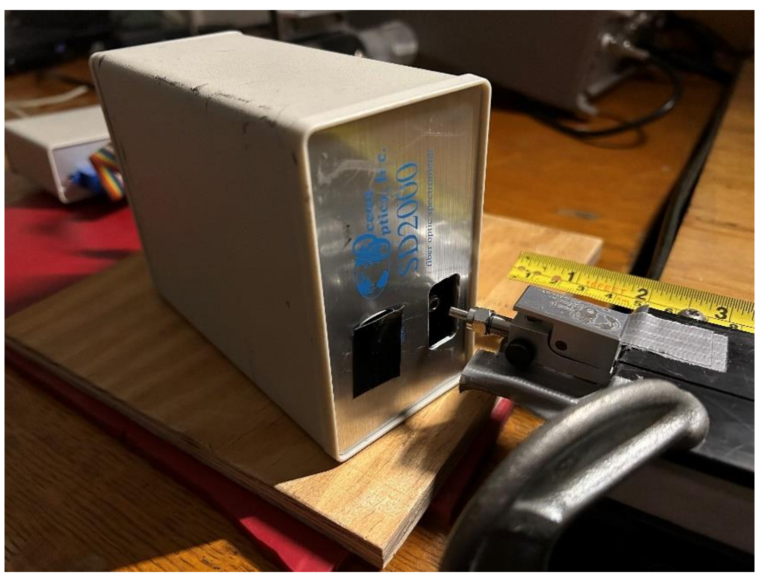

Figure 3. Spectrophotometer and fiber chuck (holder).

NOTE: Take care to not bend the fiber much. Most of the fiber can stay in the tray while inserting the polished end into the fiber holder, but take enough of the fiber out so the fiber can be inserted without bending it past the conservative 20 cm radius of curvature limit.

NOTE: The photospectrometer measurement is very sensitive to the connection between the fiber and the sensor. Dust or debris in the input port or small angular variations between the fiber and sensor can cause drastic reductions in light collection. If the spectrum looks different than expected (low amplitude or unexpected shape), reseating the fiber may resolve the issue.

11. Carefully transfer the rest of the fiber into the puck board groove, starting from the polished end.

    NOTE: The fiber can be guided and lightly pushed into the groove, but avoid using excess pressure which could pull the fiber out of the fiber holder.

12. Once the fiber is comfortably in the groove, hold the fiber in place with a small piece of tape at the end of the puck board (the fiber will hang off the board slightly). This tape helps keep the fiber flat in the groove and ensures the fiber won't fall off the puck board.
13. Move the LED box to the desired position (as with the attenuation measurements, start at 12 cm, then move to 20 cm and increase in increments of 10 cm from there).
14. With all lights turned off (and black cloths/garbage bags blocking any other light sources in the room like screens, status lights, the power supply display, and the ambient hallway light coming into the room from under the door), save the spectrum (File > Save > Save Spectrum).
    - The first time this is selected, a window will open for configuration of the save file.
    - Check the box indicating that saves should be stopped after a set number of measurements and set the number of measurements to 1 (default 100).
    - Enter a standardized file stub (something like DESIGNATION_, where 'DESIGNATION' is the fiber's tag designation) and select the save folder ('BIC_FirstArticle').
    - Change the file type to `Tab Delimited' and set the desired number of digits to 1 (this dictates how the program handles numbering in file names). This will save the spectrum in the specified location as 'DESIGNATION_0.txt.'
    - For subsequent measurements, selecting File > Save > Save Spectrum will save the spectrum immediately as 'DESIGNATION_#.txt'.
    - Move the LED box and save the spectrum at as many positions as required.
    - Once all spectra for a fiber have been saved, select File > Save > Stop Export. The next save command will reopen the save file configuration window.
15. Slide the LED box back near the photospectrometer.
16. Remove the retaining tape and feed the fiber into the static tray starting at the blackened end. Remove the polished end of the fiber from the fiber holder and under the LED box when nearing the photodiode end, again taking care not to bend the fiber excessively.
17. Reapply the fiber tag.
18. Repeat steps 10 through 17 for each fiber to be tested (2 blackened fibers).
19. Carefully transfer the tested fibers from the static tray back into their original tray.

3.3.2. Resource Requirements

Listed in Section 3.3 (General).

3.3.3. Test Conditions

Listed in Section 3.3 (General).

3.3.4. Equipment

Listed in Section 3.3 (General).

3.4. Attenuation Length

3.4.1. General

NOTE: Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

1. Turn LED[5] power supply[6] on: V = 3.3 V, A = 0.015 A. The current should hang around 0.01 A while running. The system takes 20-30 minutes to stabilize.
2. Place a tray with fibers to be tested between the static tray and the puck board (grooved testing board) such that the polished ends of the fibers are closest to the photodiode[7].
3. Verify that the photodiode is held horizontally and is stacked on metal shims such that the photodiode center aligns with the Ocean Optics fiber holder[8] at the end of the puck board.
4. Slide the LED box to the south end of the puck board, near the photodiode.
5. Select a fiber, remove its tag, and insert the polished fiber end under the LED box into the fiber holder with the fiber sticking out of the holder slightly (5 millimeters is plenty).

   NOTE: Take care to not bend the fiber much. Most of the fiber can stay in the tray while inserting the polished end into the fiber holder, but take enough of the fiber out so the fiber can be inserted without bending it past the conservative 20 cm radius of curvature limit.
6. Carefully transfer the rest of the fiber into the puck board groove, starting from the polished end.

Figure 4. Fiber testing tray (puckboard) showing the 1mm-diameter groove along its length.

[5] Marktech Optoelectronics MT3700N3-UV
[6] Keithley 2231A-30-3
[7] Hamamatsu S2281
[8] Ocean Optics Bare Fiber Adapter Kit

NOTE: The fiber can be guided and lightly pushed into the groove but avoid using excess pressure which could pull the fiber out of the fiber holder.

7. Once the fiber is comfortably in the groove, hold the fiber in place with a small piece of tape at the end of the puck board (the fiber will hang off the board slightly). This tape helps keep the fiber flat in the groove and ensures the fiber won't fall off the puck board.
8. Place a small dab of optical grease[9] on the polished fiber end, just enough to cover the face of the fiber end.
9. Carefully slide and press the photodiode face onto fiber, aligning the photodiode glass perpendicular to the fiber by eye. Continue pressing until the fiber is pushed into the holder and the holder face is flush with the photodiode glass.

Figure 5. Close up of the fiber chuck against the photodiode window.

NOTE: This can take a few attempts. If the alignment doesn't look right or if the grease is smeared on the photodiode glass and the coupling needs to be re-done, slide the photodiode away, reset the fiber, remove the grease from the fiber and photodiode glass as per steps 15 and 16, and repeat this step until the coupling is satisfactory.

10. The previous step will have produced some slack in the fiber between the holder and the retaining tape. Gently (without pulling the fiber) re-press the fiber into the groove, starting from the polished end. While doing this, hold the fiber down in the groove with one hand while guiding the next length of fiber into the groove with the other. When approaching the end of the puck board, remove the retaining tape to prevent extreme bends in the fiber and replace the tape when the fiber is once again comfortably in the groove.
11. Ensure the tape measure, which runs alongside the puck board in a wooden trough, is pushed away from the puck board, as it can get stuck underneath the LED box and interfere with the measurements.
12. With all lights turned off (and black cloths/garbage bags blocking any other light sources in the room like screens, status lights, the power supply display, and the ambient hallway light coming into the room from under the door), record the photodiode current with the picoammeter[10] (shielding the

[9] Eljen EJ-550
[10] Keithley 6485

picoammeter glow with the viewing box, if necessary) every 10 cm. The first measurement should be taken at 12 cm, since the LED box is blocked from getting to the 10 cm mark, then continue measurements at 20 cm, 30 cm, and so on. Past 300 cm, measurements can be taken every 20 cm to save some time.

Figure 6. UV LED housing and acrylic runner.

NOTE: It is helpful to plot the measurements as they are being taken. For example, if the data is being recorded in a spreadsheet, a plot of current vs. distance can be pre-made so the plot is updated automatically as data is entered. This will help to confirm that the measurements are reasonable and to detect anomalies in the form of sudden, unexpected jumps in photodiode current from one measurement to the next. Such an anomaly may be due to short-term instability of the LED (remeasurement at the offending position may resolve the issue), it may be a baseline shift in the LED (the preceding few measurements may need to be redone, or the whole fiber may need to be restarted), or it may be light leakage in the fiber (check for cracks or liquid on the fiber which would glow brightly under the LED). The LED baseline shifts are generally on the order of 0.5-1 nA while measurements are typically 10-40 nA, so small shifts are unlikely to effect fit results (especially when averaged over many fibers).

13. Slide the LED box back near the photodiode.
14. Remove the retaining tape and feed the fiber into the static tray starting at the blackened end. Remove the polished end of the fiber from the fiber holder and under the LED box when nearing the photodiode end, again taking care not to bend the fiber excessively.
15. Remove the optical grease from the fiber and photodiode glass with a Kim wipe.
16. Clean the photodiode glass with a small amount of ethanol and the Kim wipe.
17. Reapply the fiber tag.
18. Repeat steps 5 through 17 for each fiber to be tested (45 blackened fibers, 5 single-polished fibers).

NOTE: The tests will also be repeated on the 5 single-polished fibers after polishing their other ends with no blackening. The purpose of this is to investigate the effect that leaving the far end unpolished has compared to blackening in terms of light reflected back down the fiber from the far end.

19. Carefully transfer the tested fibers from the static tray back into their original tray.

3.4.2. Resource Requirements

Listed in Section 3.4 (General).

3.4.3. Test Conditions

Listed in Section 3.4 (General).

3.4.4. Equipment

Listed in Section 3.4 (General).

3.5. Light Output

3.5.1. General

NOTE: Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

1. Verify that the Sr-90 source is in the lead collimator, the power supplies[11] are set to provide +5 V and -5 V to both two-stage amplifier boards and +27.5 V to bias both the trigger and signal SiPMs[12], the signal SiPM is plugged into channel 0 of the Caen digitizer[13], and the trigger SiPM is plugged into channel 1. Power on the digitizer.
2. The digitizer should be plugged into a USB port on the DAQ computer. Login to this computer and open the 'CoMPASS' application through a terminal. Select 'Open a previously saved project' and open the 'BIC_FirstArticle' folder.
3. Verify 'Settings' tab settings:
   - Discriminator > Threshold = 10 lsb for channel 0, 15 lsb for channel 1
   - QDC > Energy coarse gain = 40 fC/lsb
   - QDC > Gate = 320 ns
   - QDC > Pre-gate = 16 ns
   - Trigger/Veto/Coincidences > Coincidence Mode = Paired AND
4. Verify 'Acquisition' tab settings:
   - Acquisition mode = Waves
   - 'Timed run (s)' should be checked
   - Time = 600
   - 'Save raw data' should be checked
   - 'Save filtered data' should be checked
   - File format = ROOT
   - File saving option = Single file
   - Energy format = ADC channel

[11] Tektronix PWS4721 and Keithley 2220-30-1
[12] 3x3 mm^2 SensL C-Series 30050
[13] CAEN DT5790N

5. In the 'Plot' window (if the Plot window isn't open, select 'Open plot window' from the main window), select 'New Energy Histogram' to add a plot of the input energy spectra. Select 'New Waveform' to add a plot which periodically displays individual input waveforms. The channel source for each plot can be changed in the top-left corners of the plots. These plots will update as a run progresses and can help with identifying odd behaviour like excess noise or ringing in the SiPMs or setup errors like poor scintillator placement, incorrect software settings, or poor contact between the fiber and signal SiPM.
6. Remove the center board from the coffin.
7. Place a tray with fibers to be tested between the static tray and the testing board such that the polished ends of the fibers are closest to the signal SiPM and replace the center coffin board.
8. Select a blackened fiber and insert the polished fiber end into the fiber holder until the fiber is abutting the signal SiPM. For this test, the fiber tag does not need to be removed.

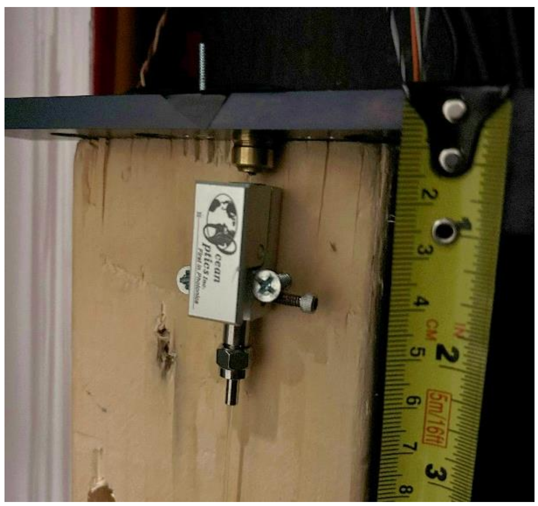

Figure 7. Fiber chuck and brass connector in front of measuring SiPM.

NOTE: Take care to not bend the fiber much. Most of the fiber can stay in the tray while inserting the polished end into the fiber holder but take enough of the fiber out so the fiber can be inserted without bending it past the conservative 20 cm radius of curvature limit.

9. Carefully transfer the rest of the fiber onto the testing board, starting from the polished end.
10. Once the fiber is fully on the board, hold the fiber in place with a small piece of tape at the end of the board. This tape helps keep the fiber flat and ensures the fiber won't fall off the board. The fiber should be held straight, but not taut.
11. Referencing the adjacent measuring tape, place the collimator at the desired position on one side of the fiber so the groove sits parallel to the fiber. Gently hold the fiber in the groove and place the trigger scintillator on the other side of the fiber such that it holds the fiber in the groove. Ensure the fiber is straight and that the fiber is still abutting the signal SiPM.
12. Close the coffin lid.

13. In the 'Acquisition' tab, enter a standardized run name (something like DESIGNATION_#, where 'DESIGNATION' is the fiber's tag designation and '#' is the distance of the source from the signal SiPM).
14. With all lights turned off (and black cloths/garbage bags blocking any other light sources in the room like screens, status lights, the power supply display, and the ambient hallway light coming into the room from under the door), power the signal and trigger SiPMs and start a run with the CoMPASS software by clicking the green 'Start' button in the Plot window.
15. Once the run has completed, power down the SiPMs. Ensure the SiPM power is off before opening the coffins or turning on any lighting.
16. Repeat steps 12 through 16 for various source positions (test at 20 cm, 30 cm, 40 cm, 50 cm, 75 cm, 100 cm, 125 cm, 150 cm, 175 cm, 200 cm, 250 cm, and 300 cm for 2 blackened fibers [for comparison against other attenuation length measurement methods], and at 20 cm and 200 cm for each other fiber to be tested).
17. Remove the retaining tape and feed the fiber into the static tray starting at the blackened end. Remove the polished end of the fiber from the fiber holder when nearing the signal SiPM end, again taking care not to bend the fiber excessively.
18. If the fiber tag was removed, reapply the fiber tag.
19. Repeat steps 8 through 20 for each fiber to be tested (45 blackened fibers).
20. Carefully transfer the tested fibers from the static tray back into their original tray.

Figure 8. Left: 90Sr lead container/collimator. Right: Plastic scintillator and SiPM trigger.

NOTE: A background measurement should also be done with the fiber between the collimator and trigger scintillator as normal, but with the fiber removed from the holder (so no light is delivered to the signal SiPM). Only one such run should be required for each fiber type.

3.5.2. Resource Requirements

Listed in Section 3.5 (General).

3.5.3. Test Conditions

Listed in Section 3.5 (General).

3.5.4. Equipment

Listed in Section 3.5 (General).

4. ENVIRONMENT, SAFETY & HEALTH CONSIDERATIONS

The procedures will be implemented in a way consistent with the environment, safety, and health policies of the relevant work areas at Argonne National Lab and Brookhaven National Lab.

Gloves should be worn when handling any fibers and the overhead lights must remain off to avoid UV light damage to the fiber. LED lighting (desk lamp and phone lights) should be used instead.

5. RECORDS AND DOCUMENTATION

The delivery schedule shall be determined at a later date, once the contract has been signed and details are negotiated between the EIC Project and the vendor (Kuraray).

It is desirable that the fibers be shipped flat in individually wrapped packages (sleeves) of about 100 canes per package with fibers coming from the same original lot (ingot). Packages within one labeled container shall have canes from one single lot. Each sleeve should clearly indicate the number of canes contained, while the container should indicate the total number of canes and sleeves, as well as the lot number. The documentation shall also indicate a certificate of testing and the results obtained.

5.1. Manufacturer/Producer Records

The manufacturer will be responsible for maintaining records (travelers) of all raw material that are used in the fabrication process and document the processes and procedures that were used for production. The resultant documentation will be compiled into a report and will be provided to the project as part of the deliverable, which will be reviewed, validated, and then placed in the central data repository. The manufacturer must test and document its quality control of fiber production. Measurements of attenuation length and light output shall be performed periodically. The manufacturer must specify the frequency and procedures used to test the scintillating fibers. Random selection of a couple percent of the fibers from the production lot should be a minimum statistical sample tested by the manufacturer.

Experience with Kuraray exists from the GlueX-BCAL construction and manufacturer/producer records were shared with the University of Regina and Hall D/Jefferson Lab at that time (2009-2011).

5.2. Deliverable Documentation and Records

This includes test results, tables of measurements, parameter lists or other records that must be provided to the project. All testing and inspection data that is collected as part of the validation, verification and testing plan will be provided to the project as part of the final report.

List all deliverable documentation here.

- Storage and handling procedures.
- Manufacturer's measurement procedures, fiber end treatment, including "reference fibers" performance, fiber drawing and lot/batch labelling method.
- Shipment schedule and packing lists.
- Attenuation Length and Light Output of an agreed-upon percentage of fibers and transmission of these data in Quality Data Sheets (e.g. Excel files) to the BIC team.

6. REFERENCES

D. Kolybaba and Z. Papandreou (2012). *Barrel Calorimeter Construction Documentation, GlueX-Doc-1573.* Department of Physics, University of Regina, SK Canada, https://halldweb.jlab.org/doc-private/DocDB/ShowDocument?docid=1573.

Kuraray. (2022). *Plastic Scintillating Fibers.* Kuraray, America, Inc, Houston, TX, USA. https://www.kuraray.co.jp/uploads/5a717515df6f5/PR0150_psf01.pdf.