Barrel Calorimeter Research and Development, Summer 2003

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Abstract

The *GlueX Experiment* has been designed to gain knowledge regarding the nature of confinement of Quantum Chromodynamics by mapping the spectrum of exotic hybrid mesons generated by the excitation of the gluonic field which binds quarks. The experiment will consist of a linearly polarized coherent bremsstrahlung photon beam and a hermetic detector. The hermetic detector contains a Barrel Calorimeter (BCAL). The BCAL is a large cylinder that consist of layers of scintillating fibers sandwiched between thin sheets of lead. The BCAL is currently in its research and development stages. This consists of testing and choosing the materials that the BCAL is made of, and developing methods of building it and accumulating data from it.

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I. INTRODUCTION

The *GlueX Experiment* is to be performed at Hall D at the Jefferson Lab in Newport News, Virginia. The experiment should produce the data required to validate predictions developed by Quantum Chromodynamics (QCD). The intriguing topic is the nature of confinement of quarks and gluons in QCD. Theories have indicated that the gluonic field between quarks forms flux-tubes that characterize the confinement. Furthermore, the excitation of these gluonic fields would lead to an entirely new spectrum of exotic hybrid mesons. To complete these goals and develop an understanding of these spectacular predictions the *GlueX Experiment* must be built. The apparatus required is extremely large and expensive, and several steps must be taken in its development. The experiment consists of a linearly polarized Coherent Bremsstrahlung (CW) photon beam, and a hermetic detector.

It is very important that the detector is hermetic for neutral and charged particles so that the entire event can be kinematically identified. To do this a solenoidal-based detector will be used. The members of the *GlueX* collaboration at the University of Regina have taken on the role of developing the Barrel Calorimeter (BCAL) portion of the detector. It is one of the larger and more expensive pieces of the experiment. The BCAL consists of layers of scintillating fibers sandwiched between thin sheets of lead. The BCAL is currently in the research and development stages at the University of Regina. Therefore the main tasks that must be completed are determining what materials to use to build the BCAL, what methods and equipment must be developed to build the BCAL, and how are high quality data going to be extracted from the BCAL. The work done this summer dealt with all of these issues. This included testing fibers for quality, building prototypes, testing and collecting data from the prototypes, developing software to simulate particle interaction with different types of scintillating fibers, and learning about detector simulation software and data analysis software.

II. FIBER TESTING

The BCAL's ability to measure deposited energy is dependant on layers of scintillating fibers sandwiched between thin sheets of lead. Therefore it is of great importance for one to be able to test the quality of these fibers and calculate their attenuation length and light collection. The quality and consistency of each batch of fibers was monitored by testing random samples from the batches of fibers against a *Gold* reference fiber. The *attenuation length* describes the attenuation of light as it travels the length of the fiber. The *light collection* describes the intensity of the spectrum throughout a specified length of fiber. The shape of the spectrum displays which wavelengths are affected by the specific doping of the fibers. Some wavelengths are absorbed while others are not. These tasks are achieved using the Ocean Optics, Inc. (OOI) SD2000 computer-controlled spectrometer system [2].

Data were collected from tests on two meter fibers. A pair of two-meter fibers were randomly selected from each of the batches prepared for the construction of the two-meter module. The procedure used for obtaining consistent data was developed by L. Snook [2]. The ends of the fibers had been previously polished to help provide a good connection with the OOI system. The fibers are connected to the OOI system by a method of coupling the fiber to be tested with the fiber from the OOI system. This was done using SMA connectors and bushing assemblies. Furthermore to increase the quality of the connection between the fibers an optical couplant was used [2]. A dab of optical couplant was put on the ends of the test fiber prior to inserting it into the connectors to help hold the test fiber in the connector. To reduce any strain on the connection the test fiber was laid on a circular path (with aproximately a 0.5m radius) marked on the testing table. Although a detailed method was developed much caution was taken while developing the connection. If too much couplant was used when the fiber was pushed into the connector the pressure created pushes the fiber back out causing a poor connection. Sometimes air bubbles can form in the optical couplant and cause reflections and refractions that distort the collection of data. To prevent such downfalls the fiber must be pushed into the connector both firmly and gently, and wiggled in the connector until the maximum signal appears. The signal was viewed on a lab top which was connected to the OOI System via USB. Air bubbles can be removed by slightly loosening the connector's bushing assembly while wiggling the test fiber.

From the collection of data several plots can be created. An intensity plot, transmission plot, and absorbance plot are shown in Figures 1-4, respectively. The intensity plot displays spectra of different intensities with respect to wavelength for the fiber being tested (Slave), the reference fiber (Master), and the background (Dark). From this plot one can observe

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[4] Ocean Optics, Inc. 380 Main Street, Dunedin, FL 34698

that some of the wavelengths are absorbed by the fiber. Also it is apparent that the intensity from background is low. The intensity spectra for both fiber A and fiber B from bundle 001 can be observed in their respective figures.

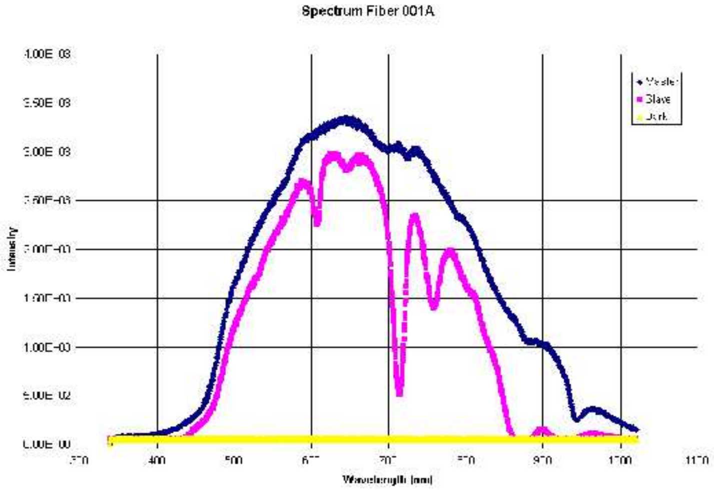

FIG. 1: Intensity Spectrum of Test Fiber A from Bundle 001 (pink) against the Reference Spectrum (blue) and Background Spectrum (yellow).

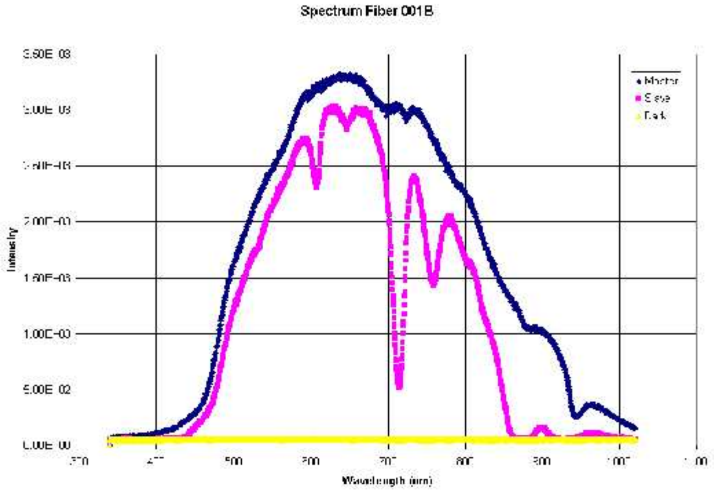

FIG. 2: Intensity Spectrum of Test Fiber B from Bundle 001 (pink) against the Reference Spectrum (blue) and Background Spectrum (yellow).

The percentage of light transmission down the tested fiber was also analysed. Transmission is the percentage of energy that passes through the tested fiber relative to the amount that passes through the reference fiber. A plot of the percentage transmission with respect to wavelength was created. These transmision spectra were developed by subtracting the respective Dark spectrum from its Master spectrum or Slave spectrum, and then calculating the percentage of Slave intensity with respect to the Master intensity.

$$\%Transmission_{\lambda} = \frac{S_{\lambda} - D_{\lambda}}{M_{\lambda} - D_{\lambda}} * 100\% \tag{1}$$

In this equation S is the Slave intensity at wavelength λ, D is the Dark intensity at wavelength λ, and M is the Master intensity at wavelength λ. The percent transmission spectrums for fiber A and fiber B have been placed together in the transmission figure.

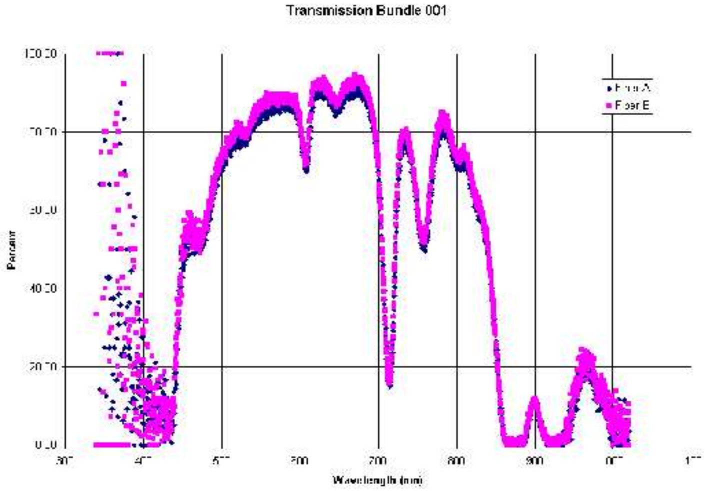

FIG. 3: Percentage of Transmission for different Wavelengths, for Fiber A and Fiber B.

Calculations were also made to determine absorbance with respect to wavelength. From these calculations absorbance spectra were created. The absorbance spectrum is a measure of how much light is absorbed by the test fiber.

$$Absorbance_{\lambda} = -log_{10}\left(\frac{S_{\lambda} - D_{\lambda}}{M_{\lambda} - D_{\lambda}}\right) * 100\% \tag{2}$$

In this equation S is the Slave intensity at wavelength λ, D is the Dark intensity at wavelength λ, and M is the Master intensity at wavelength λ. The absorbance spectrums for fiber A and fiber B have been placed together in the absorbance figure.

Further analysis of this data will be done to develop accurate GEANT simulations of the light output from the BCAL. When creating the GEANT simulations one will need to know

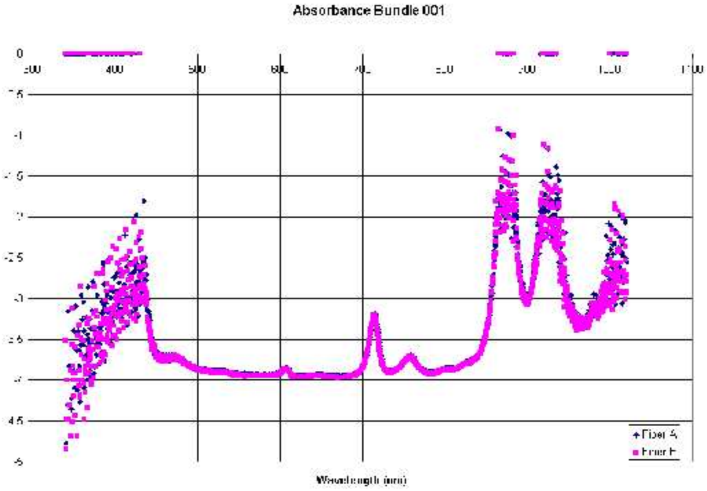

FIG. 4: Absorbance for different Wavelengths, for Fiber A and Fiber B.

what will be read out of the end of the fiber when energy is deposited in the fiber. These spectra can be used to develop several conversions that will be needed.

III. CONSTRUCTION OF *MODULE 0*

The BCAL required for the *GlueX Experiment* is a large device, and it consists of expensive materials. Furthermore it will take numerous person-hours to build. For those reasons several stages of development have been planned in order to develop reliable and efficient methods for constructing these Pb/SciFi detectors. The BCAL will consist of several of these Pb/SciFi detectors. The first step taken was the construction of the *Baby Module*. The *Baby Module* with dimensions 96cm(l) x 13cm(w) x 10.1cm(t) was completed in November of 2002 (see 5). The next stage was the construction of *Module 0*. *Module 0* with dimensions 195cm(l) x 13cm(w) x 19cm(t) is twice the length of the *Baby Module*, but is still only half the size of the detectors needed for building the BCAL. Using the knowledge gained from constructing the *Baby Module*, a team of five students and three physicists set out to construct *Module 0*.

Before construction could begin preparations were needed. Aproximately 200 layers of lead and scintillating optical fibers were required for the desired dimensions. Since 96 fibers were needed per sheet of lead approximately 200 sheets of lead and 20,000 fibers had to

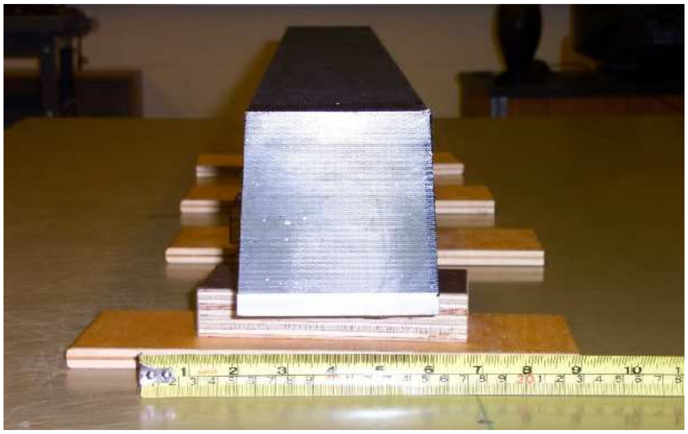

FIG. 5: End view of *Baby Module*.

be prepared. Once a lead sheet was cut to the desired size it was swaged. Futhermore the swaging process lengthened the sheet by about 3%. For this reason a mask was created such that the lead sheet would be aproximately 200cm after swaging. The fibers were also cut to the desired length and then were bundled into groups consisting of 96 fibers. Another key component in the preperation was the electro-pneumatic press. The 1m press that was built for the construction of the *Baby Module* needed to be expanded to 2m to accomodate *Module 0*. The press consists of a long aluminum base that the module is built on, and ten pneumatic pistons that apply uniform pressure on the module after each building session. From experience gained from building the *Baby Module*, extra caution was taken to keep the 2m module staight. This was done by adding teflon guides to the press, and by making a groove in the aluminum base and mounting a fiber in it. The mounted fiber would act as a guide for the first lead sheet, and the teflon guides would help keep the module square as its height increased.

Each layer of lead and fiber optics was glued with a two-component optical epoxy. The epoxy would begin to set after about an hour and a half. For this reason a building session could only last an hour and a half so that the press could nicely flatten out the module before the epoxy fully set. Therefore, enough lead and fibers had to be prepared to accommodate the current day's requirements. On average 8-10 layers could be completed in a building session, so that acted as a benchmark for the amount of supplies needed. Therefore during construction the daily activities would consist of three main tasks: preparing the lead, preparing the fibers, and building the module.

To prepare the lead, sheets were cut from a large roll of lead (see Fig. 6). A galvanized steel mask was used to cut the sheets. Once the sheets are cut they must be swaged. The swager puts 1mm grooves on both sides of the lead sheet. The swaging process sometimes caused the sheet to curve in one direction or the other. This was possibly due to the sheet not being under uniform pressure throughout the swaging process, as result either of the rollers on the swager needing adjustment or a sheet of lead that did not have uniform thickness. Whatever the reason, many swaged sheets were not straight and could not be used for building the module. The straight swaged sheets were then marked as to which way they went through the swager, and then rolled and stored until needed.

FIG. 6: Roll of Lead.

The fibers did not require as many tasks to prepare, but some needed to be tested before they could be used in construction of the module. The fibers have a length of 410cm. They were cut into equal lengths 205cm long so that they would protude from each side of the module when glued between the lead sheets. As mentioned above, the fibers were bundled into groups consisting of 96 fibers. Two fibers from each bundle were tested for quality, as described in the previous section.

The building process was slightly more complicated and required 4-5 people. The first task to be completed was cleaning off the top surface of the module. Before the press was put down at the end of a building session the outer edge of the top lead sheet was covered with vaseline. This prevented seapage of glue into the grooves on the top lead sheet, but the vaseline had to be removed before building could proceed. The next task to be completed was preparing the two-part optical epoxy. This was usually done by the “Gluer” who was responsible for applying the glue between each layer during the building session. The proper amount of glue that had to be prepared was discovered through trail and error. Once the glue was completely mixed it was applied to the lead sheet using a paint brush. While this was happening, one person prepared the fibers for each layer. This consisted of taking a bundle of fibers and laying them out on a long table. Once they were relatively untangled and their ends were aligned, an aluminum clamp was attached to the ends of the fibers and an aluminum guide (comb) was placed on the fibers next to the clamp (see Fig. 7).

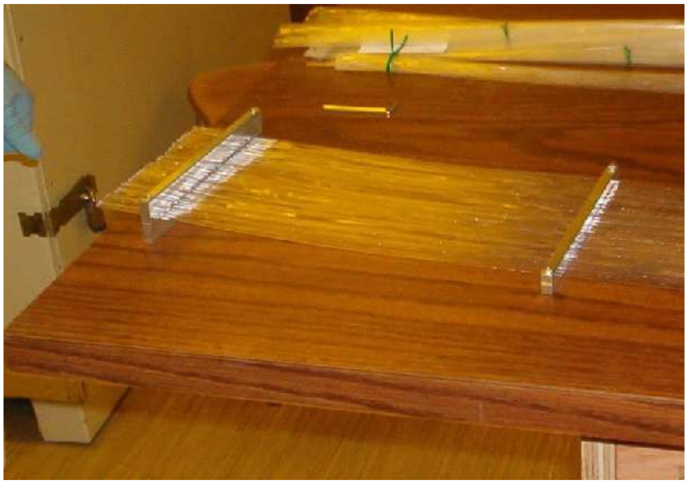

FIG. 7: Bundle of fibers after clamp and guide have been positioned.

Once the fibers were ready in the clamp and guide and the glue had been evenly applied to the surface of the lead sheet, the fibers were caried over to the press. It took two people to carry the fibers over to the module, and then they continued to hold the ends of the fibers. A third person was used to slide the guide down the fibers to help untangle them. Then a fourth person placed the fibers into the grooves of the lead sheet. This fourth person was responsible for all of the fibers laying in their groove properly without any of the fibers crossing or jumping into adjacent grooves. This person also confirmed that the right amount of fibers were present, and removed any debris that may have landed on the module. Once the fibers were all in place the Gluer went over the fibers with the glue brush. While this was happening two people unrolled, cleaned, and then carried the next sheet of lead over to the press.

The mark made on the sheet of lead after swaging was used to alternate the placement of the sheets of lead in every layer so that the module rises vertically. The two people that carried the lead sheet over to the press continued to hold it above the module while a third person carfully placed the sheet on top of the layer of fibers. Much caution was taken during this procedure so that none of the fibers were bumped out of their groove, and so that the sheet was put on straight. The sheet's grooves must be aligned with the proper fibers so that the module was built straight up. This process continued for several layers until the time for the building session had elapsed, and then the outer edges of the top layer of lead was covered with vaseline as mentioned above. A large sheet of teflon was placed over the top layer of lead for protection. In addition, a large sheet of aluminum was placed on top of the teflon sheet. The pneumatic pistons were then put in place and activated. The pistons were activated in steps from the middle of the module to the ends, to promote the oozing of excess glue from the ends. Although it is okay for some glue to leak out of the ends, one should be careful not to waste excessive amounts due to the extreme costs of the epoxy. Once all of the pistons were activated the module was left under pressure for approximately 24 hours while the epoxy cured.

Once enough layers had been completed to obtain the desired dimensions the module was shipped away to be machined and polished at a commercial vendor. After the module was machined all of its sides were relatively smooth. The ends of the module were also polished, and are very smooth as depicted in Fig. 8.

FIG. 8: View A of *Module 0*.

Several pieces of knowledge from the construction of the *Baby Module* were applied during the construction of *Module 0*, and several new pieces of knowledge were obtained. It has become very apparent that the larger the module becomes the more difficult the construction becomes. The materials are larger and harder to handle, and more people are required to do each task. Furthermore, just as new equipment and techniques were implemented in the construction of *Module 0* that were not required for the *Baby Module*, new equipment and techniques will be needed for the full size 4m module. For example it will become more diffucult to obtain straight sheets of lead after swaging because any irregularity seen with the 2m length will only be magnified with the 4m length. Also, a more efficient way for laying down the fibers will probably be required. Even at the 2m length it became very difficult when a bundle became very tangled, or contained a large amount of static between individual fibers. Another idea that could make the building process more time efficient is for construction to be done in a *Clean Room*. An unnecessary amount of time was spent removing debris from the module.

IV. TESTING OF *BABY MODULE* AND *MODULE 0*

Once construction of the module was completed tests were carried out, having two aims: a) The quality of the module must be analysed, and from this analysis modifications can be made to our methods of construction. b) It is important to test the modules ability to collect data since that is the ultimate purpose of the detector.

Initial tests are very simple. First the module can be observed without any equipment. For example, broken or damaged fibers will show up as dark spots on the end surfaces. If an abundance of the fibers are dead (dark) further analysis must be done to determine what caused the damage. Fortunately, both the *Baby Module* and *Module 0* have very few dead fibers. Next, measurements can be made to determine how straight the module is and if it has uniform thickness. Another test that was found to be usefull is the *ruler test* (see Fig. 9). This is done by placing a straight edge behind one of the modules ends, and then looking at it from the other end. The image produced should also be a straight edge. If it is not straight, it means that in one or more layers of fibers have *jumped tracks*. This fault can be seen clearly in the *Baby Module*. Due to the *ruler test* done on the *Baby Module*, adjustments were made in the construction of *Module 0* and the problem was fixed. More extensive tests can be done with the use of electronics and a data-acquisition system (DAQ)

The tests done with electronics consisted of the following pieces of equipment: photomul-

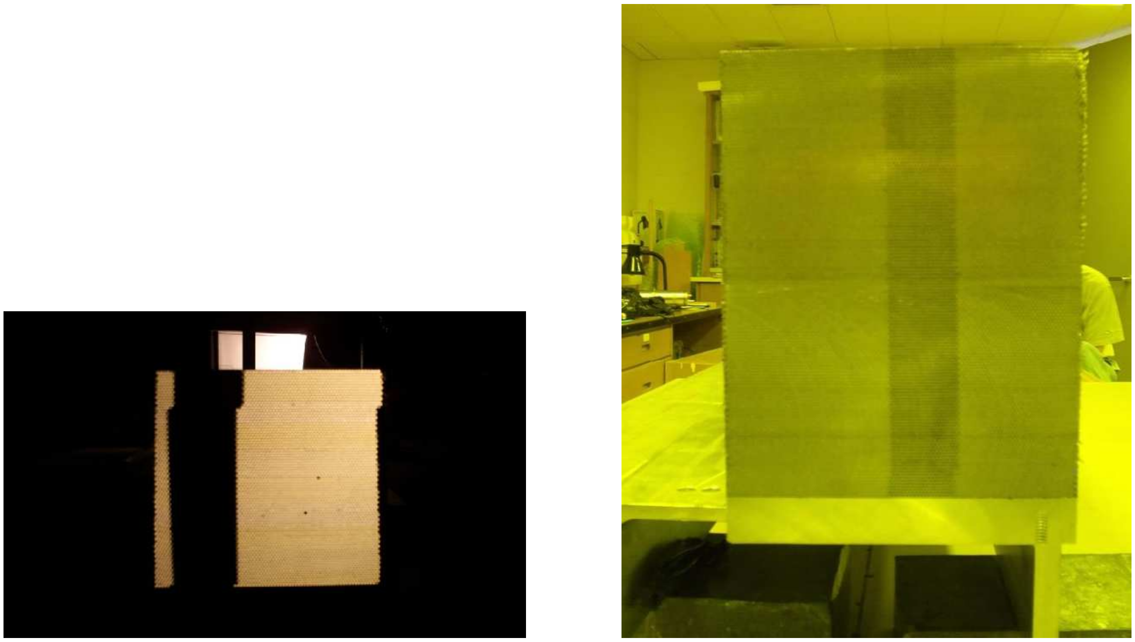

FIG. 9: *Ruler Test* performed on *Baby Module*(left) and *Module 0*(right).

tipliers (PMT), scintillators, high voltage power system, digital oscilloscope, data acquisition system, and a tower of electronics. The tower of electronics consisted of constant fraction discriminators (CFD), analog to digital converters (ADC), time to digital converters (TDC), a coincident board, and numerous delay blocks. Several different radioactive sources and a photo-diode were often used as well. Before running tests on the modules test were done on the PMTs. The tests were done to determine their time response and resolution, and to observe how *noisy* the PMT is. This was done by placing a NaI+Am241 source on the surface of the PMT. The PMT was then connected to the tower of electronics which was read out by the data acquisition system. Once the PMTs were tested individually a similar test was carried out on the modules. The source was now mounted on one of the ends of the module, and a PMT was mounted on the opposite end directly across from the source. The source and PMT were moved on a 1cm grid across the entire surface of the modules ends. For each position, an ADC and TDC spectrum was created. By taking the mean of the ADC spectrum for each position in the grid a surface scan can be developed. This surface scan demonstrates the quality of the scintilating fibers for each section of the module. In the construction of the *Baby Module* higher quality fibers were used for a few layers. These few layers are very apparent when observing the surface scan of the *Baby Module* (see Fig. 10).

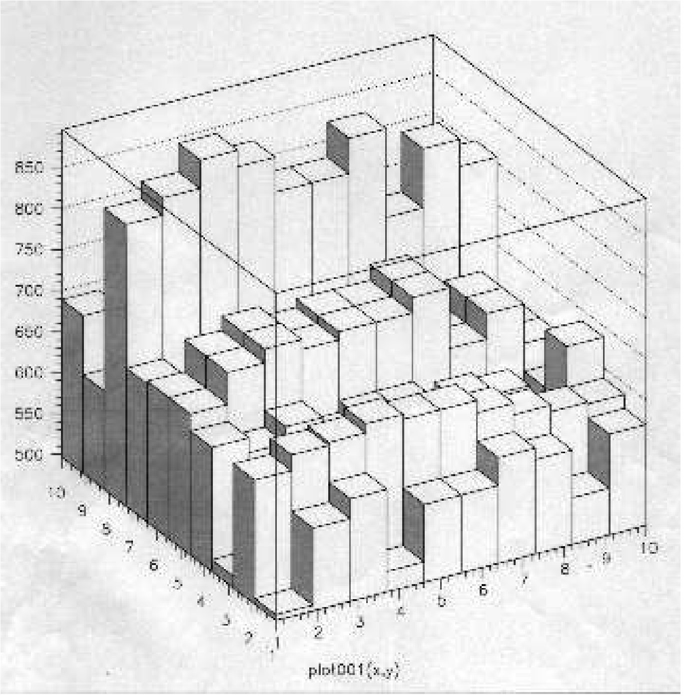

FIG. 10: Surface Scan of *Baby Module*.

The next step was to set up tests that are more relavent to the detector's actual use. The modules were set up to detect particles penetrating the surface of the detector. The idea was to collect data from the ends of the module from events occuring within the module and travelling down the fibers. This was done by attaching light guides to the ends of the module. These light guides were also attached to PMTs which were attached to the electronics. The power of nature and its cosmic rays were used to create events within the module. Therefore PMTs and scintillators were set up to act as triggers. This setup would then be left for several hours or days to collect data. Unfortunately, the collection of data has not been completed or analysed at this time. Throughout the preperation of all of these tests using electronics many precautions were taken. Due to the high voltages being used it is very easy to damage the equipment. All of the data acquisition was done with the lights off because of the sensitivity of the PMTs. Furthermore, when setting up the electronics each step was checked using the oscilloscope. This ensured that no damage would be done to the equipment and helped verify that the results obtained were correct.

V. EVENT SIMULATION IN FIBERS

There has been much time and effort spent, in the research and development stages of the BCAL, to determine what type and quality of fibers to use. Several quality tests have been done to compare products from different companies. The goal was to create a simulation were the materials and structures could be easily modified such that comparisons could be made regarding time resolution and light transmission, of an event, depending on the desired specifications.

To achieve the desired goal simulation code was written using C++. In order for the simulation to be coded much effort was required to develop the algorithms of ray tracing software. First of all, one must consider how the ray travels along and/or through a piece of fiber optics. This is strongly dependent on the indices of refraction of the material of the fiber's core and cladding and what material the fiber is placed in. Also one must consider the geometry of the fiber and the vector analysis of a ray travelling along and/or through the fiber. This must then be converted into useful data. Therefore, during the ray tracing simulation certain time and geometric values must be recorded and stored for later use. Once those goals were complete, randomness was implemented for several of the ray's initial variables. This was done so that numerous radomly generated rays could be traced to simulate an event which will consist of numerous photons.

The first step taken to develop the ray tracing software was to create the environment of the simulation. The simulation was created for a round fiber with single cladding. Therefore all of the properties of the fiber were implemented such that they could be easily manipulated. The properties of the fiber were closely related to those of Kuraray Co., Ltd. [3], which consist of a Polystyrene (PS) core and a Polymethylmethacrylate (PMMA) cladding (see Fig 11). The properties implemented are the core radius, cladding thickness, length of fiber, index of refraction of the core and cladding, and the speed of light in the core and cladding. Also, the index of refraction of the material surrounding the fiber is implemented.

Once the properties of the fiber are set, some minor characteristics of the simulation are declared. These include the number of particles run through the simulation to generate an event, the time range of interest and the number of bins for storing data.

Subsequently, the tracing of an individual ray (photon) was implemented and then looped over the number of particles set for the event. This implementation was written in a function

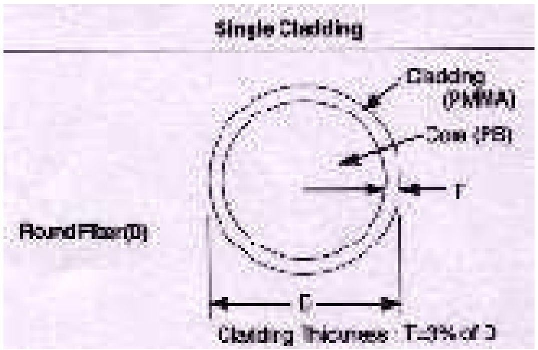

FIG. 11: Cross section of single cladding fiber as shown by Kuraray Co., Ltd.[3]

called *start()*. At the beginning of each individual ray several initial properties of the ray are randomly assigned. These initial values describe the ray's initial position and direction in the fiber. This consists of: a radial position from the center of the fiber, r, a position along the length of the fiber, Z, an angle from the axis along the length of the fiber, Ω, and an angle from an axis perpendicular to the axis along the length of the fiber, Ψ, all of which are set randomly within a desired range, and shown pictorially in Fig. 12.

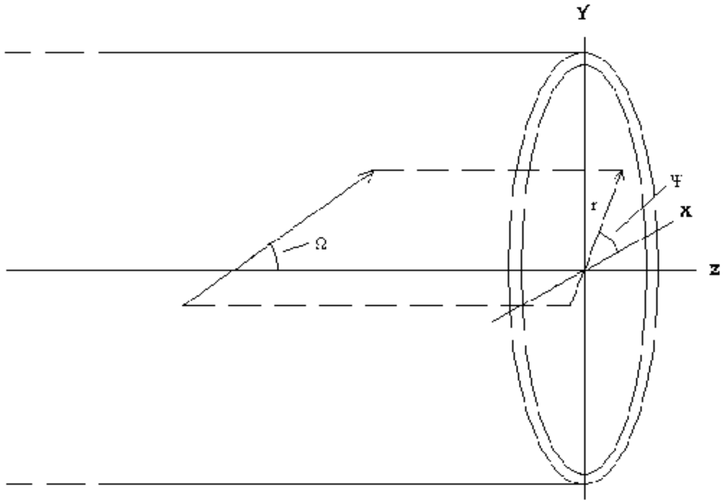

FIG. 12: This figure displays a ray in the fiber and its projection on the surface of the fiber.

From these initial values it is determined in what medium the ray starts in and what medium boundary it will first encounter. From this an initial vector, λ, is developed which describes the direction of the travelling ray.

$$\lambda = a\hat{x} + b\hat{y} + c\hat{z} \tag{3}$$

Once a boundary is hit, the distance the ray travelled in a particular medium is calculated and then converted into time. Also once the ray hits a boundary, it is known that it will continue to reflect off of or transmit through another boundary until it either escapes the fiber's outer cladding boundary or reaches the end of the fiber. Each time the ray encounters a new boundary the distance travelled and time ellapsed to reach the new boundary from the previous boundary are calculated. The distance is calculated from the magnitude of the vector.

$$|\lambda| = \sqrt{a^2 + b^2 + c^2} \tag{4}$$

Furthermore the time is calculated from knowing the distance travelled in a specific medium as well as the speed of light in that medium.

$$time = \frac{|\lambda|}{Velocity\ of\ Light\ in\ Medium} \tag{5}$$

These values are summed individualy as the ray travels along the fiber in order to determine the total distance travelled in each medium and hence the total time elapsed for the ray to reach the end of the fiber.

Every time a new boundary is encountered, as the ray travels along the fiber, a new vector must be developed. The new vector must be given the proper direction and scaled to interesect with the next boundary. It is each individual vector that is used to determine the distance and time travelled as discussed previously. In order to determine the proper direction and normalization of the new vector several calculations and checks must be made. First of all it must check what boundary the current vector (ray) is incident on. Then the boundary the new vector (ray) will be incident upon must be determined. In order to determine the latter boundary calculations must be done to determine if the ray will reflect or transmit upon interaction with the current boundary. This can be broken down into three types of interactions which are shown in Fig. 13.

Whether the ray is reflected or transmitted is determined by comparing the reflection coefficient, R, with a randomly generated number. The reflection coefficient is calculated by the method described in Griffiths [4]. If the random number generated is less than or

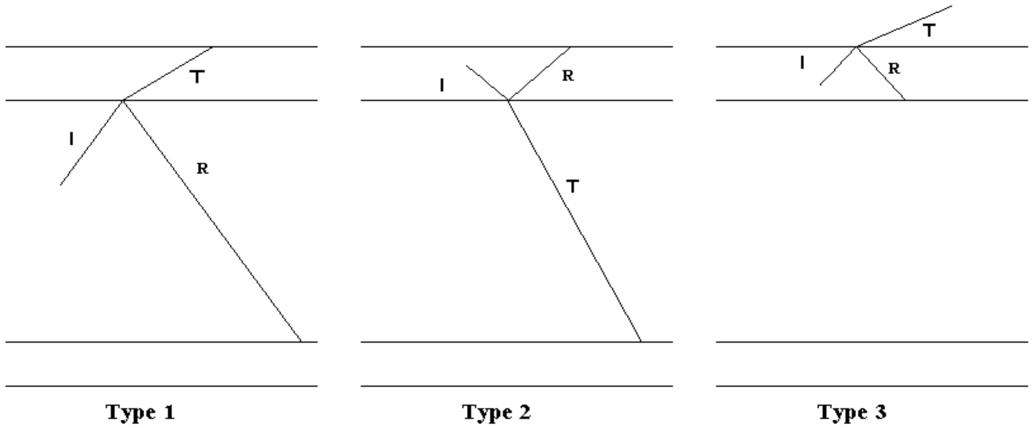

FIG. 13: *Three Types of Interactions*; The incident ray, **I**, falls upon the core cladding boundary from either the core side or cladding side, or it falls upon the outer cladding boundary from the cladding side. The possible resultant transmitted, **T**, and reflected, **R**, rays are also shown.

equal to R the incident ray will be reflected, and if the random number is greater than R the incident ray will be transmitted. Once this step is complete, the direction of the new ray is determined using *Snell's Law.* The new vector is then scaled such that it ends at the next medium boundary. This process continues within a loop until the ray reaches the end of the fiber or escapes through the outer boundary of the fiber. There are two special cases that deserve mention. There are certain rays that can be incident upon the outer cladding boundary such that when they reflect they miss the core and again hit the outer cladding boundary. The new vector is treated in the same way but extensive checks were developed to determine which medium boundary would be hit when reflection from the outer cladding boundary occured. The second special case occurs when the ray transmits through the outer cladding boundary. When this occurs the ray is lost. Therefore the loop is exited immediately and the particle is binned as escaped. Much care was taken in developing these algorithems to account for each possible occurance.

Each time a particle reaches the end of the fiber or escapes it is binned using a function called *bin_time(double time).* All of the escaped particles are binned in the first bin. All of the particles that reach the end of the fiber are binned by the time taken for the particle to reach the end of the fiber. Once all of the particles have been traced along the fiber and binned the data is output such that it can be viewed using spreadsheet software, or *Maple*. From there the data can be further analysed.

Throughout this discussion the use of random numbers was mentioned several times. The random numbers came from a function called *rand_gen(int max, int type)*. This function was written such that it is called with a maximum value, which acts as the ceilling for the random number, and a type. The type determinees if a real number or an interger are returned. The function also uses the *random()* and *srand(int seed)* functions, which are supplied by C++.

The ray tracing software was then used to simulate several configurations of the fibers parameters. The following plots (Figs. 14-17) were created from data generated from the simulator. The dimensions of the fiber's core and cladding have been set to the specifications provided by Kuraray Co. Ltd. [3]. In all cases the refractive index of the core is 1.59. The simulator was then run for the cladding having a refractive index of 1.49 (single cladding spec), and 1.42 (outer refractive index of double cladding spec). In addition the simulator was run with the fiber in air (refractive index 1.00), and with the fiber immersed in glue (refractive index 1.56). The simulator was run for a two-meter length of fiber with each rays origination and direction being random. (Note: For these measurements the position along the fiber's length where the ray originates was held constant. All other variables remained random.)

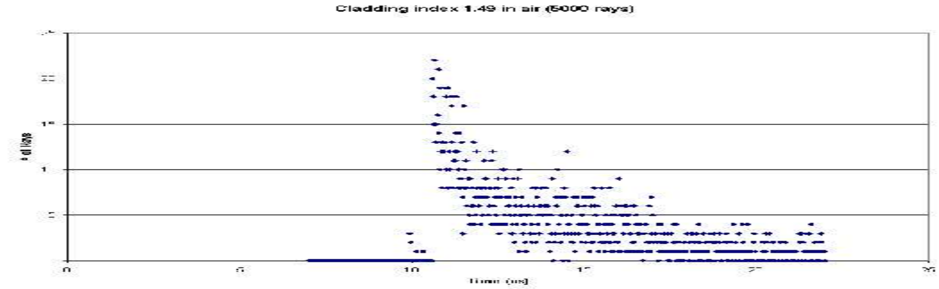

FIG. 14: Time resolution for rays travelling along the 2m fiber with Core index of 1.59 and cladding index of 1.49. The fiber is in air and 5000 rays were used in the simulation. % Transmission: 58.1% # Of Rays Escaped: 2095.

It is apparent that changing the cladding's refractive index while the fiber is in air does not greatly affect the fraction of rays transmitted to the end of the fiber. On the other hand

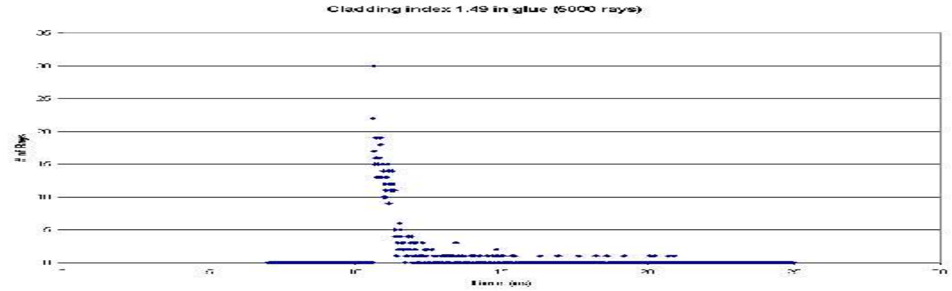

FIG. 15: Time resolution for rays travelling along the 2m fiber with Core index of 1.59 and cladding index of 1.49. The fiber is in glue and 5000 rays were used in the simulation. % Transmission: 12.1% # Of Rays Escaped: 4347.

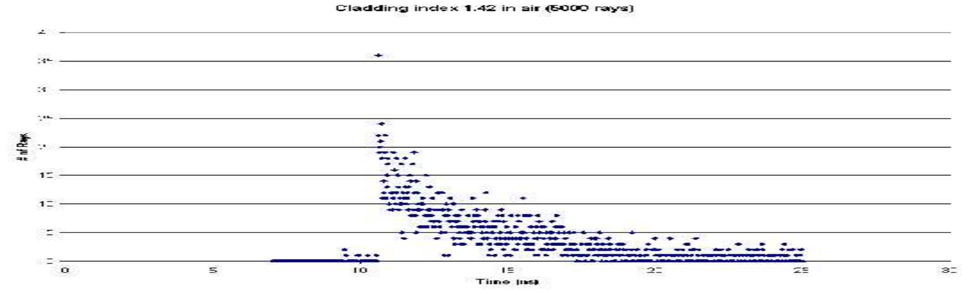

FIG. 16: Time resolution for rays travelling along the 2m fiber with Core index of 1.59 and cladding index of 1.42. The fiber is in air and 5000 rays were used in the simulation. % Transmission: 57.0% # Of Rays Escaped: 2149.

mounting the fibers in air, rather than glue, significantly improves the total transmission of rays to the end of the fiber.

VI. SIMULATIONS USING GEANT AND ANALYSIS USING ROOT

Currently simulations regarding the *GlueX* project have been generated using GEANT 3. GEANT 3 is Fortran-based software. The data generated by GEANT 3 has been analysed using PAW, PAW++, and JAS. There is a new object-oriented data-analysis framework developed at CERN called ROOT. This new software is written in C++. Many members of the *GlueX* colaboration believe that ROOT will be implemented for analysing their data in the future. This intuition is fueled by the growing popularity of GEANT 4. GEANT

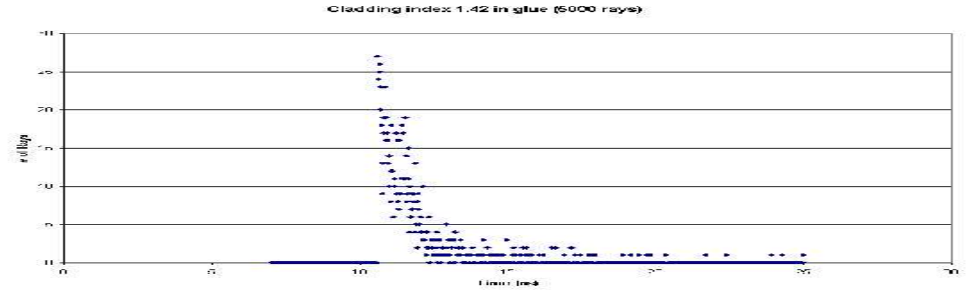

FIG. 17: Time resolution for rays travelling along the 2m fiber with Core index of 1.59 and cladding index of 1.42. The fiber is in glue and 5000 rays were used in the simulation. % Transmission: 21.3% # Of Rays Escaped: 3934.

4 is also written in C++. Therefore it will be very convenient to use ROOT jointly with GEANT 4. GEANT 4 is used to simulate particles passing through matter. It has all of the tools required for detector simulations. The object-orientated style of both pieces of software allows the user to both customize and extend their capabilities.

The colaboration has not started writing any simulations with GEANT 4. On the other hand members of the colaboration would like to start using ROOT to analyse data. The goal was to be able to analyse data with ROOT that was generated by GEANT 3. Currently GEANT 3 creates a binary file the contains the output from a simulation. Interpreters have been written so that this binary file can be used as input for analysis systems like PAW. Since an interpreter will not be needed to go from GEANT 4 to ROOT, it didn't seem useful to develop an interpreter from GEANT 3 to ROOT. Furthermore it is possible to convert .HBOOK files generated by PAW into .ROOT files which are compatible with ROOT. Therefore any data generated by GEANT 3 can be made into a .HBOOK file through PAW, and then converted into a .ROOT file and analysed using ROOT. This is done by the following method.

Root contains a program called *h2root* that converts HBOOK/PAW histogram or ntuple files into ROOT files. Simply use the shell script command:

```
h2root file_name.hbook file_name.root > output.log
```

If the ROOT file name is not specified it will assign the same file name as the HBOOK file. Once this is complete you can draw your histograms or process ntuples using ROOT.

Here is a sample of each.

Tfile f("converted_file_name.root"); //Connects you to the file

h12.Draw(); //Displays histogram named h10

h40.Draw("variable"); //Displays column "variable" from ntuple h40

The names of the histograms, ntuples, and variables can be viewed when the conversion takes place. From the example above **h12** would have been **HBOOK id 12**. Further information on this subject can be found at: **http://root.cern.ch/root/HowtoConvert.html**

VII. CONCLUSION

Throughout the summer several steps have been taken towards developing the BCAL. The research and development stages are very large tasks when dealing with an operation such as the *GlueX Experiment.* From the fiber testing and ray tracing software knowledge has been gained regarding scintillating fibers. The hours spent building *Module 0* has expanded the methods, techniques, and capabilities of Pb/SciFi detector construction. Furthermore by testing these prototypes knowledge was gained regarding the techniques used for collecting data from Pb/SciFi detectors. The testing of the modules also displayed progress and improvements in the construction methods as module quality improved from the *Baby Module* to *Module 0.* Finally, progress was also made in the area of data acquisition and analysis. The *GlueX Experiment* will be generating enormous amounts of data. Therefore, it has been advantageous becoming familiar with the data acquisition and analysis systems that will be used in future simulations and experiments. There are still many more mountains to climb and oceans to cross in the journey towards the *GlueX Experiment.* Hopefully, by combining efforts amoung the collaboration and continuing extensive research and development, fewer obstacles will be met in the *GlueX*'s future.

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