Development of the Tagger Microscope

(Prototype for the Gluonic Excitation Experiment)

Introduction

The Gluonic Excitation Experiment (GlueX) is intended to help in the exploration of the confinement of quarks and gluons inside the hadron. The ultimate objective of the experiment is to provide much needed data to assist the quantitative understanding of the confinement of quarks and gluons in quantum chromodynamics (QCD). QCD is a quantum field theory of the strong interactions (color force) which was introduced, soon after the existence of quarks was proposed, as a way to explain the coexistence of quarks at identical quantum states inside the hadron without violation of the Pauli Exclusion Principle. QCD is an important part of the Standard Model of Particle Physics. Confinement, formally known as Color Confinement, is the phenomenon that color charged particles cannot be isolated singularly and therefore cannot be directly observed. Analytic proof does not currently exist to shows that QCD should be confining. One theory is that confinement, a unique property of QCD, is due to gluons (force carriers) having color charge. Therefore, as two quarks are separated narrow tubes (strings) are formed by the gluon field which brings the quarks back together. Due to this occurrence the color force that hold them together, which is large between quarks, remain constant regardless of distance. Understanding the soft gluonic field responsible for binding quarks in hadrons is required in order to understand confinement.

The GlueX experiment will produce a linearly polarized photon beam using coherent Bremsstrahlung produced by sending a coherent high energy electron beam from the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility through a diamond crystal. The diamond crystal and electron beam are orientated so that the electrons travel nearly parallel to the planes of the atoms in the crystal, which ~~will~~ produce photons that are polarized in the direction perpendicular to the plane of the atoms. The photon (electromagnetic radiation) production occurs by Bremsstrahlung produced from a high energy electron deflected (acceleration of a charged particle) in the electric field of an atomic nucleus. The photons and deflected electrons will pass through magnetic fields produced by a

Quadrupole Magnet and a Dipole Magnet, called the Tagger Magnet. Since the photons have no charge they ~~will~~ continue on unaffected, but the charge of the electrons ~~will~~ cause the electrons to deflect in the magnetic fields. The amount of deflection which occurs is based on the magnitude of the electron's energy and therefore allows us to measure its energy by measuring its deflection using the Tagger Microscope. The Tagger Microscope will be placed on the Parallel-Point Focal Plane and centered at the Vertical Plane of the electron beam. The microscope will measure the electron's location based on its interaction with SciFi within the microscope. The interaction of a charged particle with the scintillators will result in the production of light which will be measured through the microscopes electronics. Since "tagging" is a statistically meaningful thing, the signal will be time stamped which will help us to later correlate the electron to its photon pair that produced an excited meson within our target, thus a "tag" will be placed on the photon of interest. This way accidental "tags" can be dealt with by statistic methods. The GlueX experiment will produce mesons (subatomic particle composed of one quark and one antiquark) by using gamma rays (photons) to excite our target, a deuterium nucleus. Photoproduction is expected to be particularly effective in producing exotic hybrid mesons (mesons having internal gluon excitation), which will provide the ideal laboratory for testing QCD in the confinement regime since these mesons explicitly manifest the gluonic degrees of freedom. A hermetic solenoid-based detector will be used for collection of data on meson production and decays. The statistics after the first year of operation is expected to exceed current Photoproduction data by several orders of magnitude.

The discussion of this paper is ~~to deal with~~ the conceptual and physical analysis that has occurred to date in the production of a prototype for the Tagger Microscope that will be used in the GlueX experiment. The Tagger Microscope consists of four (4) main components: Parallel Railing System, Fiber Bundles, Electronics, and Housing/Support Structure. These components have been scaled down for the Prototype which will allow us to assess the feasibility of the basic concepts and design. Completion of the Prototype is scheduled for February 2010, followed by a beam-line test at Thomas Jefferson National Laboratory which will occur the following month. What follows is a detailed description of the Tagger Microscope (Prototype) and the evolution which took place in its development for the GlueX Project.

Parallel Railing System

The Parallel Railing System (see Figure ?) was designed for the mounting of fiber bundles and consists of: two main railings, multiple Popsicle sticks, three step motors, and various support components. The system has been adapted for a wide variety of fine-tuning, both manual and automatic, throughout its intended life cycle. All of the components for this system, with the exception of the step motors and required electronics, will be mounted inside the main structure and will be completely sealed from light. The three step motors and required electronics including wiring will be mounted on the underside of the main housing frame. This configuration was developed for a variety of reasons. With either configuration, external or internal mounting, conduction will occur since the components are being mounted directly to the aluminum housing which is essentially a heat sink. Nevertheless by placing these components on the exterior of the main structure, versus inside, we are able to limit the penetrations through the Housing structure, which will be light sealed, and provide a less confined heat sink, e.g. better cooling, for the power supply and electronics of the step motors. The natural convection air flow, resulting from the heat emanating from the components, and any possible forced convection due to air conditioning flow inside the beam-line building of the laboratory, will accommodate greater cooling of components and help to reduce component failures inside the sealed Housing due to increased temperature levels. An additional benefit is gained by placing the motors on the underside of the Housing structure since this will allow for most motor maintenance and troubleshooting to take place without disturbing both the light sealed chamber of the Housing structure and other delicate components that are located within the confined space of the Housing structure.

Since the Scintillating Fiber (SciFi) cross-sectional width of two millimeters (2 mm) can help to provide discrimination between electrons created by coherent and incoherent Bremsstrahlung and increase Tagging Efficiency by reducing accidental tags; we needed a way to exploit this ability of the fibers by adjusting their vertical location. The step motors that have been chosen for use in the Parallel Railing System will allow for fine adjustments in the vertical direction (y-direction) on the order of less than 2x10^-5 of an inch (1.8 deg per step & 28 turns per inch). These vertical adjustments will provide the capability of zeroing in on which of the five (5) SciFi rows we wish to use. Since our tagging efficiency is only approximately 20% for the fibers adjacent to the centrally focused fiber and about 2% for the fibers in the outer most rows, we needed a way to zero in on the focus of the beam so that we can secure the signal from the surrounding rows, thereby lowering the amount of accidental tags that are recorded. Accidental tags result from the counting of a signal in the Tagger Microsoft which was not the result of an electron that was the Bremsstrahlung pair of a photon that interacted with the target. These accidental tags can result from an electron whose photon pair was stopped by the collimator or just never interacted with the target, they can also result from environmental events which cause a signal in the SciFi. These environmental events can result from things such as: back splashing from the beam dump, particle showers from an electron hitting structural components, or other such events. Additionally, by using three step motors in our parallel railing design we have afforded ourselves with the ability to align the axes of the SciFi parallel to the incoming electron beam, therefore permitting us the opportunity of maximizing the light yield inside the SciFi due to an incoming electron and thereby increasing the potential that a strong signal will be registered for the event by the electronics. Improving signal strength will give a larger pulse height and therefore help us with our analysis of the data by allowing us to more easily filter out noise and deal with the larger time walk for the leading edge discriminator which is being used for data processing.

The five hundred (500) Waveguide/Scintillating Fiber (W/SciFi) lengths (see figure ?) for the full scale Tagger Microscope will be segregated into twenty (20) bundles each containing twenty five (25) W/SciFi lengths arranged in a compact five by five (5x5) cross-sectional square. Each bundle will be glued to a single Popsicle Stick (see Figure 3). The design of the Popsicle Stick will allow for the Bundle/Popsicle Stick combination to slide freely while the Parallel Railings are being adjusted. Once adjustments of the Railings are completed the threaded rods of the Popsicle Stick, which protrude through the Railings, can be locked into place by tightening the nut on the end of the threaded rod that is under each Railing. The Prototype has been designed to contain only one (1) bundle of twenty five (25) W/SciFi lengths which will be mounted on a single Popsicle Stick in a 5x5 square as mentioned previously.

The method of using parallel railings for mounting the Popsicle Sticks and thus the Bundle of W/SciFi lengths was designed so as to allow for a continuous range of motion, from seven (7) to ninety (90) degrees, of the angle of the Bundle lengths (x-direction) with respect to the Housing length (z-axis) (see Figure 4). The need for the face of the Bundles (i.e., end of the SciFi exposed to the incoming electron flux) to have an angle that is not parallel to the Housing structure in the y-direction comes about because of the location of the horizontal Parallel-Point Focal Plane created as a result of the 1.5 Tesla (T) dipole Tagger Magnet. In order for the electron flux to enter the fiber bundles perpendicular to its surface and have all twenty (20) bundles lie on the focal plane, we must place the Tagger Microscope Housing Structure on the focal plane and consequentially angle the Parallel Railing System so as to produce an angle of the fiber bundles approximately seven (7) to twelve (12) degrees off the face of the Housing Structure (i.e., the side of the Housing Structure that will see the incoming electron flux). Unlike the remotely operated adjustments in the y-direction of the Parallel Railing System due to the step motors, the angular adjustment of the fibers, in the x-z direction, must be made manually while the beam line is shut down. Here we can clearly see one of the advantages of having a remotely controlled system, e.g. allowing fine-tuning adjustments while the beam line is on.

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Fiber Bundles

As stated previously, there will be five hundred (500) individual Waveguide/Scintillating Fiber (W/SciFi) lengths (see figure ?) used in the full scale Tagger Microscope. These individual fiber combinations will consist of two parts: a two centimeter (2 cm) SciFi and a twenty seven Inch (27 in) Waveguide. These W/SciFi lengths will be segregated into twenty (20) bundles, aligned side by side in the horizontal direction, each containing twenty five (25) W/SciFi lengths arranged in a compact five by five (5x5) cross-sectional square. The size and type of fibers were chosen specifically based on characteristics they could provide, which would be beneficial to our project. There are many types of SciFi and Waveguides on the market; some are round while others are square, there are ones with single layer cladding and others with multilayer cladding. We chose to use square fibers to allow for better area coverage efficiency, e.g. closer packing of fibers in a confined space. Square fibers offered us the ability to minimize the gaps between fibers when grouped in bundles, e.g. square fibers allow for parallel and perpendicular sides of the fibers to mate more cleanly than the rounded sides of circular fibers would. Thus we can minimize the loss of signal that would have occurred more readily if round fibers, of similar size, were used. The square fibers also provide us with easier vertical and horizontal alignment since they can easily be mounted in straight vertical and horizontal lines which help to maximize the accuracy at which we can locate the influx of electrons and thus determine the energy of the incoming electrons. The determination of the size of fibers that would be used was initially based on the capability of our electronics. We wanted to have a fiber cross section that would correspond to a signal of up to 2 MHz based on the influx of electrons. Even though the criteria for selecting the size of the fibers were primarily based on the signal capacity of our equipment, our choice has also yielded several other benefits for the project. The selected fiber size has given us the ability to use a single row of horizontal fibers at a time to produce the most efficient output. In order to fully understand why a two milimeter (2 mm) square fiber provides this advantage we must first be aware of the reason for measuring the energy of these electrons and how they were produced which was alluded to in the introduction. The GlueX

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Experiment starts with a twelve GigaElectronVolt (12 GeV) electron beam which is targeted at a thin twenty micron (20µm) diamond wafer. As the electron beam passes through the diamond, Bremsstrahlung can occur and a resulting lower energy electron and photon beams result. The photon is used later on in the experiment, as discussed in the introduction. The electrons and photons then pass through a quadrupole magnet which mainly adjusts the vertical focal plane of the electron beam by focusing it vertically, while the photons pass straight through unaffected. It should be noted that at the same time the electron beam is being focused in the vertical direction it is also causing slight divergence of the beam in the horizontal direction which is mitigated by the design of the poles in our magnet. Next the photon and electron beams encounter the dipole Tagger Magnet; again the photon beam pass through unaffected as before, but the magnetic field causes the charged electrons to deflect based on the energy they have (e.g., a lower energy electron will bend more than one with higher energy). This is where the Tagger Microscope comes into play. By measuring the amount of deflection we can determine the energy of that electron. With this information and the fact that we know the initial energy of the electron which caused the Bremsstrahlung, we can calculate the energy of the paired photon and "tag" that photon with that particular energy. Note that not all of the photons interact with or even make it to our target; therefore we need some way to account for these photons and disregard the measurement of the corresponding electron which was their Bremsstrahlung pair. These signals from the Tagger Microscope are known as "Accidental Tags", which can also include signals from other charged particle sources, i.e. electron dump back-spray, scatter from electrons that strike structural material, etc. We can minimize this problem in several ways. Initially the photons that are a result of incoherent Bremsstrahlung tend to be produced with a greater angle of deflection and do not end up continuing on to the target because they are filtered out by the first of several collimators. The collimators are made of different materials and placed at set locations along the route to the target, with the first collimator having the narrowest opening and (assisting with) providing the polarization of the photon beam. The subsequent collimators have larger openings and have more to do with filtering out particles created further along in the beam line. In order to help filter out the data corresponding to accidental tags, thus helping us improve the Tagger Efficiency, we use only one horizontal row of fibers at a time for our data stream. The SciFi cross-sectional size of 2 mm that was selected permits us to have only one row actively collecting data since its size allows approximately 70% of the influx of electrons to be counted. The method of securing fiber rows affords us the opportunity to filter our data stream of some of the electrons produced by incoherent Bremsstrahlung, much the same way the collimators do. Another consideration that was taken into account during the fiber selection process was the decay time of the fiber. We needed a fiber that would readout fast enough to be ready for the next electron, so as not to miss counting the next electron, but long enough to allow for reading of the signal. The rate at which we wish to process data is currently between 3 to 4 MHz, so by choosing a fiber with a decay time of 2.7 ns as we did by selecting the BCF-20 SciFi from Saint-Gobain Crystals, we ensured that we would be able to achieve our desired counting efficiency of 95% which lies between 3 to 4 MHz.

As we can see in Figure 2, the W/SciFi lengths consist of two components which must be cut, heat treated, and fused. The cutting that is required for both the waveguides and SciFi is accomplished in two steps. The two different types of fibers are received from the manufacturer in large spools measuring approximately two and a half feet in diameter. Lengths that have been determined from TurboCad three dimensional renderings of the Tagger Microscope are cut from the spools. An additional 1 cm is added to the calculated length before cutting, this ensures that any damage to the cladding due to the rough cut of the diagonal tool used is removed during the milling process. Once 25 fibers have been cut off the manufacturer's spool, they are grouped together and metal collars are placed around them to secure their positions in the bundle. Special care is taken to ensure that the fibers form a straight line once the collars are secured in place. The tendency of the fibers is to have a slight curvature to them due to the manufacture's packaging in large circular spools. It should be noted that the single metal collar used for the SciFi bundle is slightly larger in width than the ones used for the Waveguides. The reason for the larger collar is based on the fact that the small length of the 2 cm SciFi only allows for the use of one collar. Since we have found that milling the fibers to within a millimeter of the metal collar provides the maximum protection for the cladding of the fibers around the perimeter of the bundle it was both economical and prudent to keep the current metal collars for use with the Waveguide manufacturing and produce only one slightly larger version for the SciFi processing. Thus by make a special metal collar for the SciFi bundle, which is approximately 18 mm wide, we have allowed the milling of the fibers down to 1 mm above the collar surface on each side. This permits us to mill both sides of the fiber by simply flipping the metal collar in the End-Mill vice and therefore produce 25, 2cm, SciFi with minimal cladding damage. As briefly described for the SciFi, the same method of machining the fibers down to within 1mm of the collar surface is also done for the Waveguides. The Waveguides (BCF-98) that were selected for use are also manufactured by Saint-Gobain Crystals. The Waveguide is a multi-clad fiber made of both Acrylic and Fluor-acrylic with a core of Polystyrene. The main difference between the SciFi bundle and Waveguide bundle milling is that the Waveguide bundles require multiple metal collars to secure them in place since the length of Waveguide required is many times longer than the SciFi. Additionally, since the Waveguide bundle is longer and the collars are smaller, we are required to have a base plate (see Figure ?) attached to the collar on the end which is being milled to allow for securing the bundle in the vice of the End Mill prior to machining. The End Mill (see Figure ?) is used for fiber milling by setting the bit speed to approximately 1800 RPM with a cradle speed dialed down to its minimum. These settings permit the maximum amount of passes over the material, which allows for the cleanest and smoothest cut possible. The End Mill has the ability to achieve much higher bit speeds, but numerous trials have shown us that at higher speeds the vibration of the machine counters any benefits obtained by the closer passes and therefore a compromise has been found, between bit speed and machine vibration, at around 1800 RPM. In the pursuit of achieving the most efficient cut of the fibers, we attempted to use a four fluted cutting bit in hopes of a cleaner cut. Our trials produced promising results for the cleanness of the surface cut, but unfortunately resulted in severe damage to the cladding on 64 % of the fibers. The reasoning behind this was never definitively determined, but nonetheless the use of the four fluted bit was scrapped. Our testing to determine the optimal cutting procedure included consideration of not only visual inspections but also the ease of polishing the surface of the fiber ends after milling while still in the bundle. The polishing of the fibers as a bundle, which was done using copier paper as our "grit" material, help to determine height differences that the naked eye was unable to see. The basis behind this was that as the bundle of fibers were polished, we were able to see that the fibers closer to the perimeter of the bundle tended to polish more quickly for certain milling procedures while the center most fibers took much longer to show signs of polishing. Obviously some of this was caused by the inability of the polisher's hand to hold the bundle perpendicular to the paper, but we also were able to determine that some of the uneven polishing resulted from the fibers being pushed away at the bundle perimeter during milling. This was easily remedied by altering two of our procedures for cutting. First, as discussed earlier, we allowed the bundles to be machined down to within 1 mm of the metal support collar. This change ends up shortening the lever arm for the fibers and therefore in order to achieve the same deflection a much greater force must be applied. The second and more important change was made by having the cradle of the End-Mill move in such a direction as to have the cutting bit rotate into the bundle as it initially passes over the work. The trailing end of the bit will be turning in such a direction as to force the fibers away from the center of the bundle, but the amount of material that is removed by the trailing edge of the bit is miniscule and has been shown to produce virtually no damage to the cladding. Thoughts of increasing the size of our 5x5 bundles were partially countered by the fact that at present bundle size the bit of the End-Mill is only required to perform two passes in order to completely mill the surface of the bundle. In other words the bit has a diameter of approximately 6 mm and for a larger bundle sizes we would be required to make more than two passes to remove all bundle material to a lower height. The additional pass would inhibit our ability to always have the leading edge of the End-Mill bit turn into our work as shown in figure?. At speeds of 1800 RPM a great deal of friction is occurring which can produce substantial amounts of heat, especially at slow cradle speeds. The way we are able to counter any side effects due to the friction, i.e.

fibers melting which can result in rough cleaving/cutting of material, is to use a compressed air cooling system. The Air Chiller (see Figure ?) was designed and constructed by our group in order to not only remove the heat generated in the bit and fibers, but also to assist in the removal of cut material to promote a cleaner cut. The Air Chiller is filled with an ice and water mixture which allows the air from the machine shops low pressure air system to be cooled via the submerged copper tubing and then directed through a nozzle at the material and bit. A temperature drop of approxiametly ??? ^{o}F has been achieved, which has been proven to provide sufficient cooling to mitigate melting and promote the brittleness of the material, thus leading to cleaner cleaving of the material. Our trials to date have been so successful that no additional preparatory steps are required, once cut, if the Waveguides and SciFis are being laser welded together. If optical glue is being used, then only about 5 minutes of polishing is required to get the fibers ready for gluing.

During the initial trials our focus was on the use of optical glue for attaching the SciFi to the Waveguides, but recently development have shown the Optical Glue from Epoxies, Etc. is too brittle and does not provide sufficient strength to hold these components together reliably. The option of gluing the fibers together is still being researched, this time using BC-600 or other glues with the required optical properties. As a result of our numerous gluing trials we have achieved an optimal procedure for gluing the fibers which has virtually eliminated almost all of the drawbacks to gluing. The three main problems that were encountered during our attempts to glue the SciFi and Waveguides together were: excess glue seepage, fiber misalignment, and entrapped air bubbles in the glued fibers. Let us discuss the later problem first, entrapped air bubbles in the glued fibers. The obvious problem to this occurrence is due to the degradation of the optical properties of the fiber core. As the light passes from the SciFi to the Waveguide any change in the index of refraction of the material which the light passes through will increase the probability of the light being deflected out of the core and never making it to its intended final end point, the Silicon Photo Multipliers (SiPM). This problem stemmed from two basic procedures in our old gluing process. The first procedural process which augmented the introduction of air bubbles into our system of gluing was the mixing of the glue itself. The optical glue which we used came as a two part mixture, Epoxy Resin and Hardener. These two components were measured out and mixed together just prior to application on the fibers. The viscous nature of both the resin and hardener not only made it difficult to mix the two but also caused most of entrainment of air in the mixture during the blending process. Luckily the working time for this glue was sufficiently long enough for us to make an attempt at reducing the entrained air. Older procedures included the heating and popping of surface bubbles with the syringe used to apply the glue. Unfortunately these attempts only helped to slightly reduce the presence of air bubbles. Finally a procedure was developed that not only eliminated all entrained air bubbles from the mixed glue but also increased the working time available by reducing the time required to remove entrained air. Upon completion of thoroughly mixing the two part glue, the container holding the glue is placed on a vacuum plate and a bell jar is placed over it. Immediately we turn on the vacuum pump and begin to draw a vacuum inside the bell jar. At around 15 inches of Hg vacuum the container of glue begins to bubble rapidly while it releases the air that is entrained within it. After a minute the release of air from the glue stops and the surface of the glue is littered with un-popped bubbles. Upon release of the vacuum within the bell jar, the surface bubbles pop and clear glue with no entrained air emerges. This procedure virtually removes the problem of air in the gluing process. Unfortunately the old procedure that was used for gluing reintroduced this problem and also tempted the gluer into using too much glue. The old way of gluing had the fibers aligned with a small gap between the two and relied on capillary action to draw in the glue, which was applied via a syringe, to fill all voids (see Figure ?). Unfortunately excess glue was required in order to completely fill this gap and the excess tended to wick down the length of the fibers and glue the fibers to the mounting block, which often ended in a glued assembly being broken during the removal process from the alignment block. Our latest procedure uses the equipment from previous trials but in a new way. The fibers are still mounted in the alignment block and aligned so that a uniform small gap is formed between the SciFi and Waveguides when the two parts of the alignment block are pushed together, but the new technique has us place the two parts of the alignment block on their end. This allows for the ends of both the SciFi and Waveguides to be exposed and parallel to the ground. Next a syringe is filled with glue as before but this time the glue is carefully applied to the surface of each fiber. Special care is used in the form of using a magnifying glass to apply precisely one third to one half a drop of glue to each fiber. The magnifying glass assists us in this process by helping us to ensure that the complete surface area of the fiber end is coated with a thin layer of glue. Most applications of the glue end up spreading across the entire surface but occasionally the surface tension of the glue is too great and a bubble is formed in the center of the fiber. Fortunately this easily remedied by using end of the needle of the syringe to gently drag the bubble across the surface of the fiber, thereby coating it completely. Once both the SciFi and Waveguide ends have been completely coated with a thin film of glue, the fibers are placed back onto the alignment block and pushed together. The capillary action which occurs along with the fact that both surfaces have been completely coated helps to virtually prevent any entrapment of air bubbles. Additionally, the reduction of approximately 2 to 3 drops of glue from each fiber pair during the gluing process helps to reduce the flow of glue from the mating surfaces of the fibers and has increased our productivity to 100% viable fibers for use after gluing.

An additional method of fusing the fibers using laser welding is also being considered. Research into laser welding the fibers has taken two paths: contract manufacturing and in-house welding. A number of companies that specialize in laser welding of plastics have been contacted and samples have been shipped for testing with results still pending. As for the in-house method of laser welding the fibers, an Excimer Laser has been procured and is currently been set up for testing. Numerous calculations and simulations have been run to determine the best approach for the optics and power level to be used. The approaches of other experiments to the problem of fusing fibers have been researched and contacts with these labs have been made. In particular, ties between personnel at Michigan State University have been formed and the splicing unit which they developed has been shipped to us and is currently being setup for testing at the University of Connecticut. This unit uses a high intensity lamp directed at the fibers through a small hole in a metal plate, which acts as a collimator, thereby allowing most of the heat to be directed only at the splicing area of the fibers. Additionally, a forced air cooling system is directed at both the fibers and heat lamp. At each end of the unit there is a set of blocks which are in physical contact with the glass tubing that encases the fibers. A set of small holes are drilled into a groove on each lower block and fittings are attach to the blocks which connect to a vacuum pump. The rapid cooling of the glass tube and fibers will help to minimize the melting of the fibers outside our desired area of fusing. As mentioned previously, the fibers will be encased inside a glass tube during the fusing process. This specially made glass tube will serve several purposes. First it will provide perfect alignment of the SciFi and Waveguide throughout the fusing process. Secondly the clear glass tube will help to maintain the shape of the fibers during fusing. In order to fuse the fibers we must attain a temperature close to the melting point of the material. Since the cladding has a lower melting point than the core, which must be completely fused in order to obtain the maximum optical properties that we require, we can conclude that there is a high probability of melting the cladding prior to completely fusing the core. By having the glass tube we provide a way to contain the melting cladding, maintain alignment, and preserve the precise square shape of the fiber which we require. Third the glass tube will help provide a way to draw heat from the fibers during the cooling process. The forced cold air system will provide convection to cool the glass while at the same time conduction from the heat sink blocks at the top and bottom of both ends of the tube will also aid in the removal of heat from the glass and therefore a large temperature gradient between the glass and fiber to maximize cooling of the fused fiber.

The major difference that we have found between the fibers used at other laboratories and the fibers which we have selected, other than most other labs have seemed to use round versus square fibers, is the materials used for the core and cladding. Our fibers are a multi-clad fiber with both Acrylic and Fluor-acrylic used in the cladding and polystyrene used for the core, while most other laboratories used the same material for both the core and cladding which is equivalent to the materials our cladding is made of. This difference becomes an issue due to the drastic difference between the melting points of the material in the core versus the cladding. When the core and cladding materials have the same or even similar properties, i.e. melting point and boiling point, the temperature distribution across the fiber as they are laser welded is not as much of a concern. In our case, the boiling point of the cladding material is only 40 ^{o}F above the melting point of the core material, therefore a great deal of consideration must be given to focus the laser and provide a pulsed beam so as to heat to core enough to allow complete fusing of the core but at the same time prevent heating the cladding to the point of boiling away. Simulations have shown that a majority of the heat is drawn away via forced convection instead of conduction through the fiber. Knowing this it is our intention to use a focused pulsed laser, which will provide sufficient attenuation in the material, while simultaneously cooling the cladding by using a forced cold air system.

The final stage of W/SciFi length preparation prior to installation into the Tagger Microscope will include annealing of the fibers to a predetermined shape. Essentially the fibers will be heat treated and then cooled all while under stress, e.g. bent to a particular shape, in order to give the material a contour similar to the shape it will be required to take while mounted inside the Tagger Microscope. This reshaping will serve several purposes including the reduction of stresses on the fibers once mounted and facilitate the mounting of fibers in the confined space of the Tagger Microscope. The shaping, heating, and cooling of the fibers bundles will be accomplished through the use of a preformed PVC pipe (see Figure ?) in which the bundles will be mounted. The mounting of the bundle will be accomplished by having screws placed through the pipe and into the metal support collars around the bundles. By having proper spacing of the support collars, e.g. in the length direction, and specific location of holes drilled into the PVC pipe we are able to give not only a bend to the bundle but also a twist to it along the length direction. Since a schedule 40 pipe is being used the pipe wall thickness is enough to support the stresses while minimizing water seepage during the heat treatment. Once the fiber bundles are secured in place then end-caps are screwed onto both ends of the PVC pipe. These end-caps will have fittings on them to allow for connection of rubber tubing. One end of the rubber tubing will connect to the lab faucet while the opposite end will be placed into the drain. Once the tube is filled and any trapped air is removed, the flow maybe turned down to a minimum to allow the hot water to flow through the pipe for several minutes during which time the fiber bundles will reach an equilibrium temperature. Once the fibers are heated to equilibrium the water can be secured and drained. The end-caps should be left on to allow the fibers to cool more slowly. If hot water is left to sit in the pipe, it will slow the rate of cooling but provide no additional benefits and only extend the required time for this procedure. Upon completion of this procedure the individual fibers will be pre-formed and are ready for mounting once dry.

Additional procedures were tested for polishing of the fibers and should be noted even though they were deemed either unviable or unnecessary. An attempt was made at using a chemical to expedite the polishing of fibers. It was found that this chemical provided no significant benefits to the polishing procedure, but did in fact have a negative effect on the cladding material. The polishing chemical seemed to make the cladding material softer and more prone to flaking away from the core. In addition the chemical paste was inclined to be forced up into the spacing between the bundled fibers and create additional problems. Another attempt was made to speed up the polishing process by using liquid nitrogen to cool the fiber bundle prior to polishing it on paper, our preferred grit media for polishing. The colder temperatures appeared to lower the required time needed for polishing, but caused problems once condensation formed and caused our grit media, copier paper, to change properties and become unusable. The idea of using liquid nitrogen for cooling the fiber bundles prior to and during cutting was considered but was rejected for numerous reasons and instead the air chiller system, that was previously mentioned, was used in its place.

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Electronics

The objective of the Tagger Microscope is to measure the location of an electron which caused the production of a photon that interacted with our target causing an excited meson. By measuring the electrons location within the SciFi Bundles of our Tagger Microscope we can determine its energy and thereby calculate the energy of its photon pair which was a product of Bremsstrahlung resulting from the influx of coherent electrons through a thin diamond crystal. We have discussed many of the components which will aid us throughout this process, but in order to transfer the data stream produced via the SciFi we must use numerous electronic elements. The light signal produced within the SciFi by its interaction with a charged particle, e.g. an electron, is transmitted through the Waveguide. We must convert this electromagnetic signal to an electronic signal so that the data may be interpreted and put to use. In order to convert this data stream to a useful format, we use three basic electronic boards: Amplifier Board, Backplane, and Digital Control Board. Each board plays a crucial part in the transfer of a light signal to a digital signal. There will be one Amplifier Board (see Figure ?) per bundle of 25 W/SciFi containing 25 Silicon Photo Multipliers (SiPM), one for each W/SciFi. Each Amplifier Board provides space for mounting the SiPMs, initial signal amplification, and summation circuitry. The SiPM's are our direct link between the light signal and electronics. They can provide for a conversion of a single photon via an avalanche photodiode array. The SiPM produces a small current pulse which must be converted to a large pulse of voltage. The Transimpedance Amplifier Circuitry is used for this conversion from a small current pulse to a large voltage pulse. The amplifiers are equipped with on-line selectable gain control and online controllable bias voltages. Therefore, a uniform quality of readout of all the optical channels can be maintained during runtime. The signals from all five SciFis in a column are combined via the Summing Circuitry, since the energy in any of the SciFi's of a column should have the same energy. One of the most important considerations in the Amplifier Board design was the target acquisition system. The Tagger Microscope is to be readout with a 12-bit flash Analog Digital Converter (ADC) with a sampling rate of 250 MHz. The dead time of a channel, which can be considered the duration of the amplified signal, has a lower bound set by the decay time of the SciFi that was selected and an upper bound set by the sampling rate, 2.7 ns and 250 MHz respectively. All told there will be approximately 500 amplifiers in the full scale Tagger Microscope and this can pose a risk to other components within the Housing Structure that are more sensitive to higher temperature ranges, e.g. SiPMs, if power consumption for the amplifiers is set too high. The power consumption per amplifier has been set to 30mW, based on the confined space in the Housing Structure and the large number of amplifiers required, since each board will contain spares. The SiPM Digital Control Board (see Figure ?) is used for communicating with a computer via an Ethernet interface. This interface can be used to set the bias voltages and also send queries about voltages and temperatures at different points within the electronics. The Digital Control Board contains four main components: Field Programmable Gate Array (FPGA), Digital to Analog Converter (DAC), Analog to Digital Converter (ADC), and Ethernet Controller. The FPGA controls and monitors all other components on the board, while also accepting commands from the Master Computer. The DAC takes commands from the FPGA and outputs bias voltages to the SiPMs on the Amplifier Board. While the ADC measures critical voltage levels in the Tagger circuitry and reports these back to the FPGA. The Ethernet Controller is used to convert signals from the FPGA into standard computer networking signals, which allows for simple connection to the Master Computer. The Backplane is the interface between the SiPM Digital Control Board and the Amplifier board. It not only provides for the interface between the two other electronic boards through Euro Card Connectors but also provides a light seal for the penetrations in the Housing Structure which is required to access the Amplifier Board. During the design of the Backplane Board an extra layer of pure black FR-4 was added to the board in order to obtain the required opaqueness which would provide the light sealing qualities needed. A relatively thick layer of rubber gasket (1.3 mm) will be used between the board and the housing of the Tagger Microscope to provide completeness in the light sealing. Due to the thickness of the gasket material a concern was raised about possible bowing of the Backplane since the securing screws are on the four corners of the board. This concern and an apprehension about misalignment of the SiPMs with the Waveguide were both alleviated by a new design change. In the past the idea was to have the Amplifier Board suspended in place by its Euro Card Connector connection to the Backplane with only a piece of plastic, inside the housing, acting as runners on each side. This design elicited concerns with regards to alignment and reliability. It was thought that human error could cause the connector to not be fully inserted therefore misaligning the SiPMs and Waveguide Chimney. In the new design the Amplifier Board would no longer just be guided into position by plastic runners but instead have a bottom support at the end of these runners which provided a hard stop for the card. Calculations have shown that if the gasket material is removed from directly under the support screw holes and a small metal washer is inserted in place of the gasket material, then the Backplane can be securely tightened down without any worry of bowing the board and possibly allowing light in. Since the gasket material is slightly thicker than the metal washer, we can secure the Backplane down fully, containing a secure light seal, and having the bottom of the Amplifier Board come to rest on the hard stop. This will provide perfect alignment with the SiPMs and Waveguides without any unnecessary stresses. As stated throughout this paper, the GlueX Experiment uses several different methods to fine tune the data stream collected and statistically process the data so that accidental tags and noise can be eliminated. The electronics play a crucial role in this data filtering, such as allowing us to adjust the gain or bias voltage and interface with components directly.

Housing Structure

Housing Structure will be centered at the cross-section of the Vertical Focal Plane and the Parallel-Point Focal Plane that the Quadrupole Magnet and Dipole Magnet make (respectively). The Housing Structure is mainly composed of aluminum, with the exception of the guides (runners) for the Amplifier Board. The main housing framing consists of 3 inch L-shaped angled aluminum (ASTM B308). This framing is larger than what is structurally needed but with help with constructing components and stability of the unit. Aluminum was chosen as our main construction material based on its relatively low density and sufficient structural strength. The housing height and width are primarily based on the requirements of the W/SciFi's. In order to conserve space but yet provide accessibility for assembly and repair, we chose to have the fibers curve back over themselves when going from the bundle to the Waveguide Chimney. The height of the light sealed compartment was selected based on a reasonable radius of curvature that the fibers could obtain without damage or excessive stress. The housing width was calculated based in part on the SiPM Digital Control Board width and the size of the Parallel Railing System. Since the fibers are to be offset by only 7 to 10 degrees off the z-axis of the Housing Structure, the fibers end up curling back over themselves to connect to the Waveguide Chimney. The Waveguide Chimney (see Figure ?) is used to secure the end of the Waveguides so that they align precisely with the SiPMs on the Amplifier Board. Since this alignment is so essential to the transfer of the light signal to a digital signal, we designed a special guide and stop for each Amplifier Board. The two guides (runners) that make up part of one assembly are suspended from the top plate of the housing and have a bottom hard stop connected. The guides are made of plastic stock with a slot milled into to side to allow for the Amplifier Board to travel freely, yet securely, down it. The bottom hard stop is also made of the same plastic stock but is simply secured firmly to the two guides. The bottom hard stop has no need for grooves since the guide slots run the full length and it has been determined that the forces on the Amplifier Board will not cause it to bow or deflect away from the Waveguide Chimney. The Parallel Railing System is mounted to the Base Plate of the Housing Structure, which is made from an Aluminum plate. Predrilled holes allow for perfect alignment of the Railing System, Step Motors, and power supplies. The Base Plate is suspended off the surface of the laboratory floor by mounting brackets that support the Base Plate and allow the L-shaped angled Aluminum used for the outer frame to protrude down and also act as support feet. The suspension of the Base Plate will allow for mounting the step motors on the underside, along with their controls and power supply. The two side plates and top plate used for the light sealed chamber will be securely fastened to the frame using self tapping screws. In addition, the mating surfaces of the frame and these plates will be covered with light sealing black caulk before their installation. The Back Plate will be installed using wing nuts and rubber gasket. The reason for this is that continual access to the light sealed chamber will be needed, especially during the initial testing phase. Testing using cameras inside the chamber will be required to ensure a proper light seal. Additionally the initial setup and testing of the Parallel Railing System will require a number of penetrations into the light sealed chamber. The rectangular shape of the Housing Structure is slightly interrupted by the design of the section facing the influx of electrons (front section). This interruption comes in the form a slight inset of the frame from halfway down the height of the structure to the bottom. This offset has been introduced to minimize the possibility of scattering from an electron incident upon the structural frame. The minor offset and the location of the Parallel Railing System is intended to minimize the introduction of accidental tags into our data stream. The top half of the front section will be covered with a solid Aluminum plate in the same manner as the side and top panels. The lower half will be covered with a thin opaque Mylar film to allow for the transition of electrons but not light. The only special precaution that we need to abide by is the fact that the edges and corners of the supporting frame must be rounded in order to prevent tearing of the Mylar film.

Conclusion

With the use of components such as the three step motors in our parallel railing design we have afforded ourselves with the ability to do things such as align the axes of the SciFi parallel to the incoming electron beam, therefore permitting us the opportunity of maximizing the light yield inside the SciFi due to an incoming electron and thereby increasing the potential that a strong signal will be registered for the event by the electronics. Improving signal strength will give a larger pulse height and therefore help us with our analysis of the data by allowing us to more easily filter out noise and deal with the larger time walk for the leading edge discriminator which is being used for data processing. Past consensus among physicists has been to limit the subtraction of signals to less than 10%, fortunately the use of statistical analysis will allow us to gather large quantities of data and subtract greater than 10% to achieve superior accuracy and virtually eliminate any time walk based on noise and shifting the level of the base line. Other components considerations have be invested into the design in the GlueX Experiment to increase both Tagger and Counter Efficiencies. In doing so we have been able to theoretically reach our intended goal of 95% Counter Efficiency.

References

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