BaBar IFR Replacement R&D

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Abstract:

IFR Replacement R&D. MELISSA BERRY (Baker University, Baldwin City, Kansas, 66006)

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The Instrumented Flux Return (IFR) of the BaBar detector will soon need to be replaced by a more robust muon detection system. Scintillator bars with embedded Wavelength Shifting (WLS) fibers and Limited Streamer Tubes are two replacement technology options. The scintillator bars are tested for attenuation length; and causes for the large width of the Photo Multiplier Tube (PMT) signal are analyzed by Monte Carlo simulation. Cooling techniques for Avalanche Photo Diodes (APD) are investigated. The fairly high attenuation length coupled with the narrow PMT signal make the scintillator a viable option for a muon detecting system. Continuing work will focus on increasing timing resolution using an APD to read the signal from the WLS fibers, and investigating the lifetime of the APD. The ability to read a signal from the LST on external copper strips is tested and signals are found to be clearly distinguishable from noise. The voltage is compared to count rate to find that the optimal operating voltage for the LST used is 4600V. Further studies will be conducted in strip readout and fabrication as well as in the optimal isobutane content in the gas mixture that flows through the tube.

Introduction:

In order to understand the complex processes of particle annihilation and decay, it is necessary to be able to account for all energy and momentum. For this reason, it is imperative that all particles are detected, measured and identified. One of the most difficult particles to detect is the muon. Muons can be isolated by stopping (or destroying) other particles and low

energy muons with steel sheets. The muons can then be tracked using a variety of different technologies. The current muon detection system in place on the BaBar detector is comprised of 19 layers of Resistive Plate Chambers (RPC). Unfortunately these are failing rapidly and will need to be replaced. Two different options for replacement of the muon detection system are currently being investigated. Although the second option will be the one used for the upgrade, the first option has potential for future use and should be further investigated. The upgrade will take place in the summers of 2004 and 2005.

Option 1: Scintillator Bars with WLS Fibers

Muons pass through an extruded polystyrene scintillating bar, causing the plastic to emit showers of photons (which can quickly be re-absorbed,) as the muons lose energy inside the bar. To prevent the re-absorption of the photons, 4 WLS fibers are embedded in each Scintillator bar. Many of the photons are absorbed by the fiber and emitted at a different wavelength, at which some will totally internally reflect to the end of the fiber and be detected. The flux of photons is best measured with a PMT, however the PMT will not function in the 3 Tesla magnetic field of the BaBar detector. As such, an APD must be used to detect photons as they leave the WLS fibers. (Lometti 2002)

Option 2: LST

LSTs rely on high voltage wires (100 microns in diameter) to pick up ionized electrons left by muons traveling through a gas mixture. The wires are contained in a casing of PVC. As the electrons are ionized and travel to the central wire, they produce an image charge on copper strips located above and below the casing. The signals on the copper strips are read in order to

track the muon's movement. The copper strips are arranged with one set per tube running the phi direction of the detector and another set running the z direction in order to locate the muon accurately.

Studies have already been performed using both of these technologies in order to detect muons. The primary focus of the work done with the scintillator is to better understand its utility and refine the techniques used for collecting data. Although the LST has been used successfully in other experiments, the technology is fairly new to SLAC. For this reason, the LST is primarily being tested to gain experience with using the LST to produce clean signals in the SLAC facility. [1]

Scintillator Bars with Wavelength Shifting (WLS) Fibers

Materials and Methods:

The scintillator with WLS fiber is extruded polystyrene scintillator with 4 imbedded fibers, setup in an aluminum box that is approximately 13x30x400cm (see Figure 1). The scintillator bar used in this setup is constructed from two separate scintillator bars (cross section 2x5cm,) that are optically connected using epoxy. A strong connection is made by coating one end of each bar liberally with epoxy and sandwiching them together, and clamping the scintillators in place until the epoxy is hardened. The connected scintillators are then taped to a piece of wood for stability of the connection and run the length of the box. The WLS fibers are left sticking out the ends about 15-20cm and are mounted into a molded plastic fitting with epoxy. After the epoxy has hardened, the fibers are sanded down and polished. The fitting is

optically connected to the end of the PMT using optical grease, applying grease liberally, being sure that there are as few air bubbles as possible. [2]

The whole scintillator and PMT setup must be completely light-tight to lessen noise. This is accomplished using a combination of aluminum plates coving the box as well as black cloth shrouds. Signal interference can occur if any part of the box is not properly grounded or the cables being used are improperly shielded. During this particular setup many signal interference problems occurred due to either improper grounding or photon pollution from WLS fiber that was exposed to the lighting of the room.

The measurements made use a trigger to count the amount of photons received by the PMT when a cosmic muon passes through the scintillator at a certain distance from the PMT. The trigger is a two-plate cosmic ray telescope, each plate being made of a small scintillator bar (1x4x12cm) that is optically connected to 2cm diameter PMT. This device is completely encased in black electrical tape to protect it from photon pollution. The trigger plates are placed on the top and bottom of the scintillator. The top trigger plate rests on a 0.5cm thick lead plate in order to eliminate low energy, soft muons; and runs parallel to the main scintillator (the location of which is marked on the outside of the box for easy positioning of the trigger plates). The bottom trigger plate is placed underneath the aluminum box containing the scintillator, running perpendicular to the scintillator, so that the trigger fires when muons pass through the scintillator.

Signals from the top and bottom plates of the trigger are run through an octal discriminator (LeCroy 623B) and must be tuned in such a way that one signal will fall completely within the gate of the other; this typically requires adjusting the gate width. The signals from the discriminator are then run to a logic unit (LRS 365AL) that will create a pulse only when the two signals coincide. At this time it is necessary to tune the PMT signal to fall

within the signal from the logic unit. It is also helpful to note that the PMT may not have a signal every time the trigger has a signal. After the signals are properly tuned the signal from the logic unit is run to the gate of a charge integrating ADC unit (LeCroy 2249W) and the PMT signal is run through a channel in the ADC.

Data is collected from the ADC module using a CAMAC crate. The Jorway 73A crate controller reads signals from the modules and sends them to a Linux computer using a SCSI interface which runs a data acquisition program called CAMAC developed at Fermilab, that functions in the following way: The crate number, slot number of the module and channel number of the signal must be specified. The program clears any memory in the crate to begin with fresh data. The program begins a run by looking for a LAM from the specified channel. When the computer receives a LAM signal it reads out data and displays it listing the channel number, the number of the data point and the ADC measurement of the pulse. The program clears the LAM and continues recording data in a loop until it is stopped manually or there are 1,000,000 data points.

The APD that must be used to read data from the WLS fibers in a strong magnetic field functions best at low temperatures (see Figure 2.) If the temperature is not steady or the APD is too warm, the noise will be too great compared to the signal. For this reason a Peltier Cooler is attached to the APD (see Figure 3). The heat from the hot side is constantly dissipated by a dissipation block, while Cal 9900 Autotune PID Temperature Controller designed at SLAC is used to keep the temperature of the cold side constant.

Results:

Figure 4 shows a sample of the data obtained from the PMT. It is skewed right, but roughly Gaussian neglecting the large peak which forms at the "zero value," or pedestal. A

Gaussian curve is fit to the most normal section of the data using the Root program (shown in the upper right plot of Figure 4), excluding the majority of the tail and the pedestal. The data is fit multiple times adjusting the fit range to 2 standard deviations (or 1 in the case where the signal is too close to the pedestal, and the pedestal would lie within 2 standard deviations.) The graph made in Root is used to find the average pedestal value, which is then subtracted from the mean of the Gaussian fit.

Figure 5 shows the mean value of the PMT readout is plotted against the distance of the trigger plates from the PMT to determine the attenuation length of the scintillator. An exponential curve is fit to the data using a chi-squared fit. The maximum attenuation length shown is 310cm.

Figure 6 shows a graph of a Monte Carlo that demonstrates the variation of the attenuation length based on the error of the measurement of the placement of the trigger counters. The error in attenuation length due to the error of this specific measurement is approximately $\pm 3.5\text{cm}$.

The path length of a muon through the scintillator was simulated by a Monte Carlo that used the cosmic ray telescope boundaries as parameters. The distribution obtained from this simulation is shown in Figure 7.

Each path length from the aforementioned path length Monte Carlo was randomly assigned a value based on a landau distribution in order to describe the energy loss of a muon traveling through the scintillator. The landau value is multiplied by 2 (the ideal path length) and plotted and is also plotted multiplied by the path length used to generate the landau value (see Figure 8.)

The temperature controller was found to be able to keep the APD at about 5 degrees celcius to within ± 1 degree. The main cause for the temperature fluctuation while using the controller is heat leakage from one side to the other.

Discussion and Conclusions:

The pedestal in the data of Figure 4 can be ignored because it is simply the PMT reading no photons at the time that the trigger counted photons. This is the result of a muon passing through the trigger plates, but missing the main scintillator; or photons being reabsorbed due to the attenuation length of the scintillator. However, the pedestal must be subtracted from the rest of the data, since it is a non-zero value that essentially shifts the data to the right. The width of the gaussian distribution can be explained in part by the distribution of the muon path length through the scintillator. The comparison of the two distributions in Figure 8 shows that the gaussian distribution of the ADC count is broadened by approximately 31% by the variation in path length of the muon through the scintillator alone. This calculation is done by dividing the sigma from the top distribution (1.919) by the sigma from the bottom distribution (2.778.) This factor greatly reduces the effective width of the gaussian distribution of Figure 4.

Based on the fairly narrow peak being read from the scintillator and the improved cooling mechanism for the APD it should be possible to achieve sufficient timing resolution with a scintillator for use in BaBar. Further studies must be done in using the APD to collect data in order to determine its exact timing resolution as well as its robustness.

Limited Streamer Tubes

Materials and Methods:

The LST prototype being tested is comprised of 8 chambers, each one containing a 100 micron high voltage wire. The chambers are 3 sided and are in a sort of comb configuration.

The inside of these chambers is coated with highly resistive graphite that acts as a ground plane. The chambers are not completely closed and grounded so that image charges will form on strips outside of the tubes (see Figure 9.) Copper sheets with non-conducting backing are used to ground the outside of the setup and copper strips are made on the other side of the sheet with copper tape, which is carefully aligned so that strips are not touching one another. The LST prototype is sandwiched between the two copper grounding plates with the copper strip side toward the LST. The setup is secured by taping it to a wooden plank. The ground sides of the copper plates are grounded to the same ground as the circuit, which helps reduce noise and ringing of signal (see Figures 10 and 11).

The test LST is setup using a gas mixture of 3.03% argon, 7.87% isobutane and balanced with carbon dioxide. The gas is low in isobutene content for safety reasons, although the desired isobutane content is around 25%. The gas flow is controlled by a flow meter and kept to about 20-30 cc/min. The gas is run through Polyflow tubing to a bubbler to keep gas flowing and to keep the pressure in the LST approximately constant. The wires in the LST carry high voltage (provided by Bertan 5kV High Voltage Supply) run through a circuit (See Figure 11) that makes it possible to read the signal off of the high voltage wires.

One of the biggest challenges in reading the signal from the LST is the large post signal peak seen from the signal on the high voltage wire (see Figure 12.) It is difficult if not impossible to set the threshold to count every signal without counting any post signal peaks. In order to reduce this property of the setup an inhibit feature is setup to prevent recording any signal for 300ns after counting the main pulse. This is done using an output signal from an octal discriminator (LeCroy 623B) as an external trigger for a pulse generator, which creates a 300ns pulse, which is then run to a common inhibit on the discriminator. Another of the discriminator's

outputs is run to a scaler (TSI 1535) which will count the number of pulses generated by LST high voltage wires each having a 300ns wide inhibit following it. Although the signal from the actual LSTs will be read only from the copper strips, the signal from the wires and the strips are compared to check the efficiency of the strip readout (see Figure 12.)

Results:

Figure 13 shows the counts/minute recorded at 50kV intervals for discriminator thresholds between 30 and 60mV. The plateau is around 4600V. Breakaway voltage was around 4900V for this setup.

Discussion and Conclusions:

A higher concentration of isobutane would be optimal for the LST performance as it would increase the width and definition of the plateau seen in Figure 13. [3] [4]

The signal from the copper strips is consistent with the signal from the high voltage wire. However, since the strips read an image charge from the high voltage wires, the signal is positive. In order to use most electronics the signal must be negative so it must simply be inverted.

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Figure 1. The ends of 2 scintillator bars. The one of the left shows the WLS fibers while the one on the right is the dimensions of the bar used for this experiment.

Figure 2. The efficiency of the APD at varying temperatures (data provided by manufacturer)

Figure 3. The mounted WLS fibers are shown on the left, the APD is in the center. Just to the right of the APD is a Peltier Cooler and up and to the right of that a dissipation block

Figure 4. An example of data collected from the PMT using a peak-sensing ADC. All graphs excluding the one in the upper right show the entirety of the data.

Figure 5. The attenuation length for 2 different prototypes as determined by a chi-squared fit to the distance of the muon hit from the PMT vs. the number of events. The attenuation length for the upper curve is 260cm and 310cm for the lower curve.

Figure 6. The variation in attenuation length shown in cm measurement based on the error in measuring the location of the trigger counters. Approximately $\pm 5\text{cm}$.

Figure 7. Results from the Monte Carlo demonstrating the varying path lengths of muons through the scintillator. This simulation was parameterized with the size of the trigger counter plates and scintillator, as well as the distance of the plate from the scintillator. The greater the distance of the plates from the scintillator the shorter the tail would be.

Figure 8. The top graph shows the Landau distribution for a perfect setup (all pathlengths are 2cm.) The bottom graph takes into account the varying path lengths as seen in Figure 7. The bottom graph is also a landau with a sigma approximately 30% greater than that of the top graph. This demonstrates the effect of the path length on the broadening of the ADC count.

Figure 9. An open LST end. The PVC sleeve is seen at the left and the end cap of the tube at the right.

Figure 10. Circuit used to read signal off of a high voltage wire

Figure 11. Diagram of the LST setup, demonstrating both the gas and wiring systems.

Figure 12. Examples of LST signals. The LST is operating at 4.5kV in the top two plots and 4.3kV in the bottom two plots. The signal from the high voltage wire is in channel one and the signal from the copper strip is in channel two. Note that the strip is reading the image charge and thus has a positive pulse.

Figure 13. The knee voltage curves for the LST with differing discriminator threshold settings. The counts/min 4600V are consistent for all thresholds except 60mV. Smoother curves and clearer plateaus could be achieved using a higher concentration of isobutane.