**Determining Muon Detection Efficiency Rates of Limited Streamer Tube Modules using
Cosmic Ray Detector**

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ABSTRACT

Determining Muon Detection Efficiency Rates of Limited Streamer Tube Modules using Cosmic Ray Detector. MAGGIE PAN (Cornell University, Ithaca, NY, 14853) PETER KIM, CHARLIE YOUNG, & MARK CONVERY (Stanford Linear Accelerator Center, Menlo Park, California 94025).

In the Babar detector at the Stanford Linear Accelerator Center, the existing muon detector system in the Instrumented Flux Return gaps is currently being upgraded. Limited Streamer Tubes (LST) have been successful in other projects in the past, and are thus reliable and sensible detectors to use. The tubes have been assembled into modules to strengthen the mechanical structure [2]. Before installation, numerous tests must be performed on the LST modules to ensure that they are in good condition. One important check is to determine the muon detection efficiency rates of the modules. In this study, a cosmic ray detector was built to measure the efficiency rates of the LST modules. Five modules themselves were used as muon triggers. Two z strip planes were also constructed as part of the setup. Singles rate measurements were done on the five modules to ensure that high voltage could be safely applied to the LST. Particle count vs. voltage graphs were generated, and most of the graphs plateau normally. Wire signals from the LST modules as well as induced signals from the strip planes were used to determine the x-y-z coordinates of the muon hits in a stack of modules. Knowing the geometry of the stack, a plot of the potential muon path was generated. Preliminary results on muon detection efficiency rates of the modules in one stack are presented here. Efficiencies of the modules were determined to be between 80% and 90%, but there were large statistical errors (7%) due to the limited time

available for cosmic data runs. More data samples will be taken soon; they will hopefully provide more precise measurements, with 1-2% errors for most modules before installation. Future work includes systematic studies of muon detection efficiency as a function of the operating voltage and threshold voltage settings.

INTRODUCTION

The B-factory at the Stanford Linear Accelerator Center, which consists of two PEP-II rings and the Babar detector, is currently being used to study matter and antimatter asymmetry in nature. High-energy collisions between electrons and positrons take place to produce millions of B and B-bar meson pairs. The mesons decay into leptons, neutrinos, and other hadrons, and the Babar detector records these decay products. The ultimate goal is to understand the slight differences between the laws of physics for matter and the laws for anti-matter by analyzing the decay patterns of B and B-bar [1].

Muons, a type of lepton, are produced in the decay of B and B-bar mesons. They provide separation of B and B-bar mesons, because B mesons decay predominantly to negatively charged muons, while B-bar mesons decay to positively charged muons. One specific part of Babar, the Barrel Resistive Plate Chambers (RPC) in the Instrumented Flux Return gaps, detects these muons as well as neutral hadrons. The Instrumented Flux Return has six sextants. There are nineteen layers of RPCs in each sextant to ensure that only muons travel completely through the detector. After six years of operation, performance of the RPCs has deteriorated. Now, plastic Limited Streamer Tubes (LST) and z strip planes are to replace the present muon detector system. Only twelve layers of LST detectors will be used in each sextant of the IFR, and six layers will be filled with brass plates. The remaining layer cannot be accessed. One of the main targets of the new LST system is increased muon efficiency detection with low false (pion punch through) rate. The extra material stops pions from penetrating to outer layers.

An LST consists of eight cells each 15 mm by 17 mm positioned inside a graphite-coated polyvinyl chloride (PVC) structure. Situated at the center of each cell is a silver-plated wire 100 μm in diameter [2]. The entire setup is then enclosed in a plastic sleeve and a mixture of gases is

circulated inside. The current gas mixture is 8% isobutane, 3% argon, and 89% carbon dioxide [2]. Gas inlets, high voltage connectors, and ground connectors are inserted at one end of the LST module. A transition board is attached to the other end for signal cable connections. A phi plane containing two signal cables is attached to the top of the module to provide grounding. The wires in the modules and z strip planes are used to collect charge produced by ionizing radiation in the LST [2]. By combining the wire signals and induced strip signals one can determine the coordinates of the muon path through the modules.

A total of 72 z strip planes will be installed in the IFR. The layers of a z strip plane are shown in Figure 1. A z strip plane consists of several layers of mylar, a layer of copper foil, strips of copper tape, and six signal cables. Each cable consists of 16 conductor lines. Thus, there are a total of 96 channels, corresponding to the 96 copper tape strips. Each copper strip is 35 mm wide, and there are 2 mm gaps between strips. The total thickness of the plane is only 1 mm. The two main functions of z planes are that they provide true ground for LST modules, and that the 96 strips can determine the z coordinates of the muon hits in the modules.

Cosmic muons constantly pass through the modules. The muons ionize the gas inside, producing positive ions and electrons. These electrons in a high electric field create streamers that flow towards the high voltage wire. Due to the high resistivity of the graphite surface inside the PVC structure, production of streamers is localized. As the streamer flows towards the high voltage wire, pulses are produced.

The high voltage connector circuit diagram is shown in Figure 2. The 400pF capacitor allows charge to go through but not high voltage. Thus, the signal can be safely read out of the module. When the connector is attached to the module, high voltage is directed into the LST. The signal comes out of the module through the same exact path; however, the one mega-ohm

resistor blocks the signal from going back to the high voltage supply. Instead, it sent through the capacitor, and then through the two cables of the phi plane to the transition board on the other end. The transition board is connected to a Front End (FE) crate that holds many FE boards. The FE crate amplifies, shapes, and digitizes the signal. Then, the signal is sent to the data acquisition crate (DAQ), which reads out the signal and sends the data to a computer for analysis.

Before the LST modules are installed into the Babar detector, tests must be made on the LST to ensure that they function properly. One such test is to characterize the LST through the determination of absolute muon detection efficiency of each module. Usually, scintillator counters are used as external muon triggers. However, many large counters would be needed to cover the large area of the modules. As a result, this option is costly as well as inefficient. Instead, the LST modules themselves are used to provide muon triggers. The design includes an upper trigger counter and a lower trigger counter. The upper trigger counter consists of three modules and a z strip plane that are placed above a stack of LST modules. The lower trigger counter consists of two LST modules and another z strip plane. This group is placed below the stack. Signals from the five LST modules and z strips are sent into a FE board. They are then read out through normal data acquisition channels to a computer. Coincidence signals in both counters provide triggers used to read out the signals of the LST modules in the stack. In the absence of a magnetic field, muons should travel in a straight line through the modules. Thus, a potential muon path can be drawn from the upper and lower counter signals. In this paper, we discuss the production process of the z strip planes and our progress in determining the muon detection efficiency rates of the LST modules in one stack.

MATERIALS AND METHODS

Z Plane Production

As part of the production process of the cosmic muon detector, two special z planes smaller than the regular z strip planes were built. After the layers were put together, the copper strips and the conductor lines were connected with solder joints. Then, the planes were checked for shorts. The capacitances of each channel to the ground were measured. The capacitances of each copper strip to the ground should be between 2 nF and 4 nF, depending on the length of the strip. If two strips are shorted, the capacitance doubles. If a strip is shorted to the ground, there is no capacitance.

Once all the copper strips had been soldered and there were no more shorts, the z strip planes had to be baked and laminated. First, vacuum tubes were taped down around the planes, and the ends were placed into vacuum holes. Then, a plastic cover was put above the planes. A thin layer of cotton cloth was placed above the plastic cover so that air pockets could be avoided. A final layer of plastic was then put above the entire setup, and a vacuum pump lowered the pressure to around 1 or 2 Torr. The z planes had been laid on top of a special metal table that contained a heater plate. Underneath the metal, current is generated with high resistance heater tapes. There are 20 heater strips for uniform heating distribution and 20 thermocouples to monitor the temperature. The goal was to heat the plane to 200 °F. Blankets covered the planes to keep the plate at minimal dissipation. After about an hour, most of the plate was heated to around 200 °F. The heater strips were turned off, and the blankets were lifted. After the z planes had cooled, the vacuum was turned off and the plastic and cotton cloths were removed. The planes were then checked again for any shorts.

To completely finish the z planes, “pigtails” were attached to the cables. Pigtails are short strips of cable with pins on one end. First, the ends of the z plane cables were scratched. Then a thin layer of solder was soldered onto each of the scratched surfaces. For the pigtails, both sides of one end were scratched, but the pin side was left alone. The pigtails were positioned so that the scratched end was directly on top of the cables, but also so that some of the solder from the z plane cables were still visible. The scratched end of the pigtail was then soldered to the cables. Since this was a delicate process, multiple checks were performed to identify and repair shorts between the copper strips. For extra protection, the soldered joints were laminated using several sheets of mylar. They were ironed together above and below the joints. The lamination made the vulnerable part of the cables more sturdy and less able to be broken. Finally black caps were placed on the ends of the pigtails so that they could be inserted into the high voltage connector.

System Check Using Oscilloscope and Singles Rate Measurements

To ensure that both the five modules and two z strip planes were functioning correctly, they were checked to make sure that signals could be read out. After applying high voltage to the modules, the signal lines on the transition boards of the LST modules as well as the pigtails of the strip planes were probed. An oscilloscope was then used to read the wire and strip signals.

After the five modules (modules 1062, 27, 2002, 1041, 1083) were known to be functioning properly from reading the signals on the scope, singles rate measurements were done using the Front End Card (FEC) output via a serial port connection to a computer. Singles rates measure the triggers of cosmic rays traveling through the LST modules [1]. Cables connected the modules to a high voltage distribution box and to an FE board. The high voltage to the modules was controlled using an Ethernet connection to a computer. Using 100-volt intervals, the voltage

was ramped up from 4600 volts to 5900 volts. At each voltage level, particle counts were collected for 100 seconds. At the same time, a Labview GUI interface on a second computer was used to plot the count vs. voltage graphs.

Cosmic Muon Detector

To assemble the cosmic muon detector, the larger z plane was placed on top of a stretcher, which was then mounted on top of a stack of modules. Three modules lay side by side on top of the z plane. Below the stack, the smaller plane was placed above a moving cart, and two modules were laid on top of the z plane.

All the modules in the stack (stack #4) were connected to a motherboard containing FECs. Each FEC contains sixteen channels. In the setup, one FEC was connected to the upper trigger counter, three FECs were connected to the modules, and one FEC was connected to the lower trigger counter. Both signals from the upper and lower trigger counters were Transistor-Transistor Logic (TTL) signals. They were sent to the DAQ, where it was converted into Nuclear Instrumentation Methods (NIM) signals to create trigger signals. Then they were converted back to TTL signals again. The reason for this switch back and forth was because the trigger board in the FEC had not arrived yet, so trigger signals had to be made using NIM discriminators and logic units.

Using an Ethernet connection from the DAQ, online data acquisition software was used to write the data to a disk. Then offline software was used to read back the data file. Since the geometry of the stack is known (i.e. which wire in each module corresponds to which FEC), the coordinates of the muon hits were determined.

RESULTS

System Check Using Oscilloscope and Singles Rate Measurements

Figure 3 and Figure 4 show the raw wire and strip signals, respectively, of one of the five modules used as muon triggers. The wire signal is negative because electrons from the ionized gas are attracted to the positive wire, and thus a negative signal is produced. Since the electrons are attracted to the wire, streamers of negative charge are created. An induced positive charge in the strips occurs to balance out. This is why the strip signal is positive.

Figures 5, 6, 7, 8, and 9 show the count vs. voltage graphs of both tubes for each of the five modules. The graph of Channel 1 in module 27 tube A rises instead of stabilizing into a plateau. Similar results occur for channel 1 of module 2002 tube A, channel 1 of module 1041 tube B, and channel 2 of module 1083 tube B.

Cosmic Muon Detector

Figure 10 shows the muon hits in the upper counter, in the stack of LST modules, and also in the lower counter. The vertical distance between the upper counter and lower counter hits is around 2 meters. Note that there are nine layers of modules in stack #4, and that there are nine muon hits recorded on the plot.

Figure 11 shows another plot of muon hits in the stack. In this case, there are only 8 muon hits recorded. Thus, one wire did not pick up the muon traveling through.

Table 1 shows the preliminary muon detection efficiency rates of each wire in the modules of stack #4. Most of the efficiency rates are between 80% and 90%. The statistical uncertainties are large (7%) due to the small number (~200) of tracks that go through each wire. In future runs, statistical errors of 1-2% are expected to be achieved.

The muon detection efficiency for each module averaged over the 8 wire channels were also determined. The efficiencies are shown in Table 2.

DISCUSSION AND CONCLUSION

If the channels in the LST modules are functioning properly, there should be large plateaus between 5300 volts and 5600 volts in the singles rate graphs. This implies another advantage of the LST detector; one can apply the same operating voltage to all modules and expect similar responses. Although several channels in the five LST modules show a big jump in singles rate, they occur only at very high voltages. The optimal range that will be used in the actual detector is 5400 volts, but the LST are checked at a higher voltage to ensure a safety cushion. Thus, these tubes will still function properly as trigger counters.

Based on the preliminary data taken so far, the relatively high muon detection efficiency rates are encouraging information for a successful muon detector system. The statistical uncertainties are still high due to the limited data sample, but new data currently being taken will provide much more precise measurements. Besides trying to obtain better results, future work also includes moving the cosmic muon detector to different stacks and measuring the muon detection efficiency rates of the other LST modules. The efficiencies of all modules can hopefully be measured before they are installed into Babar.

The external cosmic muon trigger that has been built can also be used to study how the LST efficiencies depend on the operating voltage and the threshold cut on signal pulses. In the real environment inside the Babar detector, there will be a higher background rate due to the accelerator beam background and other noises. Optimal setting of the threshold cut will have to be established as data is being taken, and an efficiency table as a function of the threshold at a given HV would be useful.

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REFERENCES

- [1] Nicholas Johann Harmon, “Quality Control of Muon Detectors for Babar at The Ohio State University,” *REU 2003 Reports*. http://www.physics.ohio-state.edu/~reu/03reu/REU2003reports/Harmon_final.pdf (July 11, 2004).
- [2] “A Barrel IFR Instrumented with Limited Streamer Tubes,” Babar LST Project. <http://www.slac.stanford.edu/BFROOT/www/Detector/LST/documentation/LSTprop-A4-May30-ajss.pdf> (July 6, 2004).

Figures

Z PLANE ASSEMBLY IN STRIP REGION EDGE VIEW FROM BACKWARD END HAVING LONG PIGTAIL & CONNECTORS

Figure 1. Diagram of the layers of a z strip plane.

Figure 2. Circuit diagram of the high voltage connector.

Figure 3. Oscilloscope reading of a raw LST wire signal with no amplification.

Figure 4. Oscilloscope reading of a raw z strip signal with no amplification.

Figure 5. Count vs. Voltage graphs for singles rate measurement on module 1062.

Figure 6. Count vs. Voltage graphs for singles rate measurement on module 27.

Figure 7. Count vs. Voltage graphs for singles rate measurement on module 2002.

Figure 8. Count vs. Voltage graphs for singles rate measurement on module 1041.

Figure 9. Count vs. Voltage graphs for singles rate measurement on module 1083.

Figure 10. Plot of muon hits in the modules of stack #4. The zero x-coordinate position corresponds to the edge of the stack of modules. Since, the upper trigger counter is wider than the stack, the top trigger hit has a negative x-coordinate.

Figure 11. Another plot of muon hits in the modules of stack #4.

Tables

Module #	Tube A Efficiencies				Tube B Efficiencies			
	Wire 1	Wire 2	Wire 3	Wire 4	Wire 1	Wire 2	Wire 3	Wire 4
46	0.8516	0.864	0.8613	0.8823	0.864	0.8772	0.8468	0.8076
47	0.9086	0.895	0.8888	0.9086	0.8826	0.8861	0.9134	0.932
57	0.85279	0.83	0.8935	0.8655	0.8163	0.8168	0.8605	0.8641
56	0.85279	0.83	0.8888	0.8709	0.8367	0.792	0.8894	0.8703
61	0.86802	0.87	0.8842	0.8709	0.8775	0.8564	0.8846	0.9074
60	0.8477	0.875	0.912	0.8924	0.8724	0.8712	0.8605	0.8518
63	0.87817	0.815	0.8611	0.8709	0.852	0.891	0.8942	0.8765
64	0.8883	0.86	0.8657	0.8924	0.852	0.8811	0.8942	0.8888
50	0.8934	0.93	0.9027	0.8924	0.8826	0.9455	0.9086	0.8827
51	0.8708	0.8771	0.8571	0.8609	0.8106	0.85	0.834	0.7884
49	0.7951	0.7962	0.8101	0.8156	0.8198	0.8333	0.8284	0.7911
54	0.8374	0.8148	0.883	0.8783	0.8492	0.8625	0.8333	0.8601
55	0.8472	0.8518	0.8421	0.8571	0.8793	0.8483	0.8437	0.8704
58	0.9014	0.8518	0.8654	0.8835	0.8542	0.8625	0.8906	0.8341
59	0.8472	0.8518	0.8947	0.8994	0.8844	0.8957	0.8593	0.917
62	0.798	0.8624	0.9064	0.8888	0.8743	0.8909	0.8906	0.9015
53	0.8768	0.8941	0.9181	0.8941	0.9296	0.9383	0.8906	0.9378
52	0.8152	0.8148	0.8333	0.8387	0.8468	0.8708	0.8627	0.8444

Table 1. Preliminary muon detection efficiency rates of each wire in the modules in stack #4. Values are $\pm .06$ standard deviation.

Module #	Efficiency
47	0.89
57	0.84
54	0.85
56	0.85
55	0.86
61	0.87
58	0.87
60	0.87
59	0.88
63	0.86
62	0.88
64	0.87
50	0.90
53	0.91

Table 2. Muon detection efficiency for each module averaged over the 8 wire channels. Values are $\pm .02$ standard deviation.