Limited Streamer Tube and Capacitor Testing
for BABAR Detector
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Abstract:
Testing of Limited Streamer Tubes (LSTs) has been conducted on the first set of LSTs meant for installation in the BABAR detector. The tubes are kept under high voltage (between 5 and 6 KV) as often as possible to ensure their durability. Three tests were conducted: signal charge, leak and radioactive source. Testing is conducted to ensure that no damage occurred during transport of the LSTs from Italy where they were constructed. Following testing, the tubes were made into modules for future installation in the BABAR detector.

Capacitor testing was conducted to ensure the longevity and validity of capacitors meant for voltage decoupler box components. The capacitors underwent high voltage (10
KV) as well as high temperatures. Following testing, capacitors were sent on to another facility.

**Introduction:**

The Ohio State High-Energy Physics group is part of a larger association of university groups and researchers called the B\textsubscript{A}B\textsubscript{A}R Collaboration. This collaboration focuses its study on the decay of neutral B mesons and its antiparticle the B-bar, hence the name. The goal of the B\textsubscript{A}B\textsubscript{A}R Collaboration is the systematic study of asymmetries of the CP operation concerning the decays of neutral B mesons. Two B meson particle-antiparticle pairs give data relevant to the study of CP violation. These two are the B\textsubscript{d} and B\textsubscript{s} mesons.

Both B\textsubscript{d} and B\textsubscript{s} are neutral in charge. The B\textsubscript{d} meson is composed of a d and anti b quark pair, and its associated antiparticle has the composition b anti d. The B\textsubscript{s} meson on the other hand is composed of an s anti b quark pairing, which is likewise reversed for its antiparticle with composition d anti s. The B\textsubscript{d} pair have a mass of 5279(+/-2)MeV/c\textsuperscript{2} (ref [1]) and a mean lifetime of 1.56(+/-6)x10\textsuperscript{-12}s (ref [1]). The B\textsubscript{s} pair has a mass of 5369(+/-2)MeV/c\textsuperscript{2} (ref [1]) and a mean lifetime of about 1.6(+/-1)x10\textsuperscript{-12}s (ref [1]). Unfortunately for researchers, decays that give information concerning CP violation are few and far between.

CP is the combined operation of charge conjugation (C) and parity (P). Charge conjugation is an operation, which changes a particle into its antiparticle by changing all relevant quantum numbers. The parity operation changes the spatial coordinates by moving given points through an origin to the diametrically opposite location. CP was considered invariant until 1963 when Jim Cronin, Val Fitch and their colleagues discovered that in certain weak decays of the neutral K meson CP was not conserved. Certain systems composed of equal matter and antimatter content known as CP eigenstates are not changed by the CP operation. CP violation is exhibited where there is a difference between decay rates of particles and their antiparticles to the same final state (CP eigenstate). Violation of this operation occurs mainly through the mixing of the CP eigenstates in the physical states rather than by directly CP violating decays. Since few
systems are possible of achieving such mixing, high-energy physicists assume this is the reason why CP violation is found in few systems.

When the universe was created in the Big Bang, a large amount of energy was released. The energy spurred the creation of particles and antiparticles. By thermal equilibrium, the total matter to antimatter ratio would have to be one to one, and the total baryon number would be zero by modern cosmological theories. As the universe cooled, particles and antiparticles began to come back together and pair annihilate. Since there was an equal creation of particles to antiparticles, it would be assumed that all pairs would annihilate leaving nothing behind. Obviously this is not the case. Since CP asymmetry allows for differing decay rates of particles and antiparticles, it is theorized to be the reason for the predominance of matter over antimatter in the universe.

By the Standard Model, the B meson has many decay modes that will have large particle-antiparticle asymmetries. In addition, the high degree of $B^0$ and $B^0$-bar mixing combined with the long lifetime suggested that violation of CP might be observed in neutral B meson decay. Of interest to the study of CP asymmetry, neutral self-conjugate pairs of mesons are the important systems. Two such existing systems exist concerning the b quark, namely $B_d$ and $B_s$ that have previously been described. Table 1 lists several CP asymmetries in the $B_d$ and $B_s$ decays. Of great interest is the decay known as the “Golden Event” $B^0 \rightarrow J/\Psi K_s$. This decay’s importance is because of its ease of discernment. The Golden Event occasionally breaks down into two easily identified muons making it ideal for researcher.

<table>
<thead>
<tr>
<th>Class (iq)</th>
<th>Quark Sub-Process</th>
<th>Final State</th>
<th>Scientific Method Prediction</th>
</tr>
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<tbody>
<tr>
<td>1d/ 1s</td>
<td>anti b -&gt; anti c c anti s</td>
<td>$\Psi K_s/ D+D-$</td>
<td>-sin 2$\beta$/ 0</td>
</tr>
<tr>
<td>2d/ 2s</td>
<td>anti b -&gt; anti c c anti d</td>
<td>D+D-/ $\Psi K_s$</td>
<td>-sin 2$\beta$/ 0</td>
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<td>$\pi^+\pi^-/ \rho K_s$</td>
<td>sin 2$\alpha$/ -sin 2$\gamma$</td>
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<tr>
<td>4d/ 4s</td>
<td>anti b -&gt; anti s s anti s</td>
<td>$\Phi K_s/ \eta\eta$</td>
<td>-sin 2$\beta$/ 0</td>
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<tr>
<td>5d/ 5s</td>
<td>anti b -&gt; anti s s anti d</td>
<td>$K_s K_s/ \Phi K_s$</td>
<td>0/ sin2$\beta$</td>
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The BABAR Collaboration conducts its experiments at the B factory constructed at the Stanford Linear Accelerator Center and dedicated in October of 1998. The B factory consists primarily of the PEP II storage ring and the adequately named BABAR detector. The B factory at Stanford uses electrons and positrons extracted at collision energies from the Stanford Linear Accelerator (SLA) in designated bypass lines.

Stanford’s B factory is asymmetric, meaning the positrons and electrons are stored at different energies. The difference in energies is due to the PEP II storage rings. The PEP II is simply two PEP rings placed one on top of the other in the original PEP tunnel. As one ring stores electrons in an approximately 9 GeV beam (ref [3]) the second stores the positrons at about 3.1 GeV (ref [3]). Asymmetric electron positron colliders work best for the study of B meson decays. Operating at the γ(4S) resonance, asymmetric collisions result in the creation of two neutral B mesons (particle and antiparticle) moving at about 0.6 times the speed of light. This permits the B mesons’ decay times to be inferred from their now measurable decay lengths.

Diagram 1

The collisions of the B factory take place within the BABAR detector. As can be seen from diagram 1, there are six main subsystems to the detector. The first of these is
the Silicon Vertex Tracker (SVT). This apparatus tracks low-energy charged particles while also giving position information on other charged tracks. The second subsystem is the Drift Chamber (DCH). The chamber provides the main measurement of momentum for charged particles and assists in particle identification through energy loss measurements. The third is the Detector of Internally Reflected Cherenkov light (DIRC). This detector is used for identification of charged hadron particles. The fourth system is the Caesium Iodide Electromagnetic Calorimeter (EMC). This apparatus provides adequate electron and neutral electromagnetic particle identification and also information for identification of neutral hadrons. The fifth subsystem is the superconducting coil. The coil produces a solenoidal magnetic field of 1.5 T. The sixth and last major subsystem is the Instrumented Flux Return (IFR). This final apparatus is used for muon and neutral hadron identification as well as an iron breaker between the magnetic field and the rest of the laboratory.

In December of 2002, groups from Italy comprising Ferrara and Padova in conjunction with the US Universities of Princeton and Ohio State University proposed to replace the failing Resistive Plate Chambers (RPCs) in the Instrumented Flux Return with LST modules. LST tubes, which have been tested this summer, have been eight and seven cell detectors. Each 9 mm square cell is comprised of silver plated sense wire 100µm in diameter and runs along the length of the profile. Two cells comprise a channel for high voltage connection. Each profile is made of 1 mm thick extruded PVC and coated with graphite having a surface resistivity between 0.2 and 1 MΩ/square (ref [4]). The profiles are enclosed in a PVC sleeve for gas encasement. Plastic end pieces are attached on both ends of the sleeve and equipped with gas inlets, and connectors for high voltage and ground.

The purpose of the LSTs in the IFR is to detect muons and hadrons that have resulted from the positron-electron collision. Muons are leptons that were first identified in 1936 by Anderson and Neddermeyer in cosmic ray experiments. These particles have a mass of 105.7 MeV/c^2 (ref [5]) and a lifetime around 2.2x10^(-6)s (ref [5]). The electromagnetic properties of the muon are much like the electron. The relatively large mass gives this lepton an increased penetrating power than the electron. Where most charged particles would stop or decay before reaching the IFR, muons actually travel
through it. Due to the penetrating power of this particle, LSTs are necessary for their detection. As previously noted, the Golden Event is discerned because of the muons it results in. After replacing the RPCs researchers hope to be able to pinpoint more valid occurrences of this and other important decays involving muons.

**Laboratory Setup:**

Testing conducted took place at Smith Laboratory while high voltage storage occurred at the Van de Graff Laboratory both owned and operated by OSU.

Diagram 2

Gas Mixing System used at both Smith and Van de Graff Laboratories

Original Design by Ian Schambach
The gas mixing setup shown in Diagram 2 is present in both the Smith and Van de Graff Laboratory. As can be seen, each gas enters the system via a mass flow controller. This device limits the amount of gas released into the mixing chamber. The mixing chamber itself is basically a holding tank that all the gases are injected into. Before entering the gas distributor, the mixed gas has to go through a compression coupler. The coupler keeps the gas flow at a constant rate keeping the gas entering the tubes from fluctuating. The gas distributor simply distributes the gas among the tubes hooked up to the gas flow system. The pressure bubbler keeps the tubes from becoming over pressured and possibly exploding in the off chance that the gas flow in the sleeve is somehow blocked off. To make sure the gas exits the tube, a second bubbler is placed on the gas outlet. Several valves and toggles are dispersed throughout the system to ensure room air does not enter the system during tank or LST transfers.

Diagram 3

Table Setup for LST testing

Diagram 3 shows the layout of the testing table located at Smith Lab. All damage tests are performed on the scan table. The conveyor system moves a cart from which the
radioactive source is suspended. The tabletop is covered with a conducting sheet, whose purpose will be explained further on. The voltage decoupler sorts the high voltage between 5 and 6 KV from the low voltage signal transmitted by the signal wires. The signal rate box takes the low voltage information from the voltage decoupler and gives data of the signal rates within each wire. A central computer that is connected via the link box controls the entire system.

The final setup concerning the LSTs is the module-gluing table. There are four gluing tables setup in Smith Laboratory. The table is comprised of a long metal sheet covered in a thin plastic sheet. A metal stationary sidebar is attached along the length of one side of the table and acts to hold the module during the gluing process. The other sidebar is composed of two removable metal bars. Unlike the other bar, these beams are not stationary and have about an inch of free movement. Eight crossbeams are also part of the table setup. They ensure the tubes are solidly pressed against the copper plane as the epoxy cures.
The other task my group performed was the testing of capacitors meant for use in the voltage decouplers for use with the LST modules. Capacitor testing was a two-step process, which for simplicity has been divided into a pre and post oven phase. Pre oven testing made use of a bulk capacitor-testing device depicted above that held around 150 capacitors. The device was made specifically for this testing task. In addition to the device, testing required the use of an ammeter as well as a grounding device to ensure safe voltage ramping. The post oven phase required the use of a smaller testing device. Unlike the pre oven tester, the post oven tester held only between 6 and 12 capacitors at a time. Recording of testing results for both phases was done on a computer using a Microsoft Excel spreadsheet.

Testing:

The majority of the work conducted this summer has focused on the testing of LST tubes and the creation of modules from the tubes that passed. The LSTs were constructed in clean rooms in Italy and shipped to the United States. When the LSTs first arrive, they are stored in the Van de Graaff. These tubes are hooked up to a high voltage power supply between 5 and 6KV. In addition, a gas mixture is also constantly being flushed through the LSTs. LSTs undergo nearly a week under high voltage before any are taken for testing at Smith.

Testing is conducted at OSU and Princeton to ensure that the tubes were not damaged in the shipping process or contain flaws in construction, which could cause failure. Problems in tubes are most expected to be from leaks in the sleeve or where the sleeve meets the end plate, dust that was somehow encased in the sleeve, or chips of the graphite coating on the profile, which have come loose. There are three tests which each tube must pass before it can be used to make a module: leak, signal charge and radioactive source.

The leak test is simply a test to ensure that the tube in question does not have a leak. The tube being tested is flooded with gas until bubbles are formed in the outlet bubbler. The gas is shut off and the valve closed. Within the bubbler, a meniscus should have formed due to the pressure of the gas within the tube. After five minutes the location of the meniscus is checked. If the meniscus has moved or is no longer evident,
the tube has a leak. Following module creation, this test is repeated to ensure there are no leaks following gas inlet replacement. Leaks are dangerous due to the volatility and poisonous nature of the gas mixture.

Graph 1

Sample graph of signal rates from signal charge test

The signal charge test ensures the stability of the tube’s reactions under high voltage. The tube is again flushed with gas. In this case however, the process takes approximately forty minutes to ensure that the room air that might be present within the sleeve has been forced out. The capacitance of each voltage connector to ground connection is measured. The ground and high voltage connectors are hooked up to the voltage decoupler and the scanning process is begun. The process is automated and results are recorded by the computer to be sent to the BABAR database. The scan tests the tube’s stability of measurements between 5 and 6KV. It is between these two voltages that the most accurate and testable reactions occur. A graph of sample results is shown in
Graph 1. The x-axis gives the voltage in volts while the y-axis gives the amount of signals that have occurred. The “plateau” region is what is looked for in these scans. All channels must show this plateau in the same general region to pass and move to the last test.

Graphs 2-5

Sample Radioactive Source Scan Graphs
The final test conducted is the radioactive source scan. The setup of the test is the same as for the signal charge test. The computer automatically carries out running of the test and data acquisition. Resulting data for each test is sent to the BABAR database for record keeping purposes. As noted earlier in the paper, the tabletop of the scanning table is covered with a metal sheet. Cesium 137 is used as a radioactive source, which is passed above each tube channel by use of the conveyer system. Radiation from the Cesium is pulled through the tubes by the conducting table surface. Just like when muons pass through the detector, a current is formed in the signal wire that is recorded. If the current recorded in any channel goes above 1µA, the tube has failed the test. Sample graphs of the resulting data for each channel can be seen in Graphs 2-5. The x-axis depicts the width of the tube in mm, while the y-axis gives the achieved current in nA.

It must also be noted that once a tube has failed the test once it is not discarded. Tubes that have failed one or more tests are later retested. Any LSTs that pass on this second testing process is tagged as second class and move on to be made into modules. Second class tubes are only paired with other second-class tubes in the module creation process.

The gas mixture used for damage testing is the same as will be used at SLAC once the muon detectors have been completed. The three-gas mixture used is argon, isobutane and carbon dioxide. Argon is responsible for the signal created by a muon’s passing. The signal is caused by the ionization of argon from the energy of the passing particle. Ionization causes current in the sensing wire, which the computer records. Isobutane acts to limit argon’s reaction keeping it from causing too many signals. Carbon dioxide’s presence is necessary to ensure the stability of the mixture. The gas eliminates sparks from occurring in the tube, which could be hazardous. Carbon dioxide comprises 89 percent of the final mixed gas while isobutene and argon make up 8 and 3 percent respectively.

Once the testing process has been completed, LST tubes move on to be made into LST modules. Modules are composed of four parts: two tubes, a steel strip and a copper ground plane. The copper ground plane is set between the two sidebars on the gluing table. A usual two-part epoxy is mixed and spread along the surface of the plane. The
tubes are placed perpendicular to the ground plane on both edges of the plane. Care must be taken that the side that contacts the plane be the side closest to the gas inlets. More epoxy is spread along the tube side opposite the copper plane. The LSTs are gently lowered down so they lie parallel to the plane. A steel strip running all but two inches of the length of the tubes is inserted between them. The strip is shortened to ensure it doesn’t act as a conduit between the two ends of the ground plane. Excess epoxy is wiped clean and the two LSTs are compressed together by the adjustable sidebar. The top plates are secured to the sidebars to ensure the tubes dry flush to the copper plane. The gas inlets of the two end pieces are removed and replaced with new gas inlets, plugs and a short plastic tube that connects the two end pieces allowing gas flow between them. The final step is the attachment of the ryan board. This is a small computer board that connects the ground plane to the signal rate boxes. The board is glued to the bottom of the copper plane and the leads from the copper plane are soddered to the board at connection points.

Capacitor testing began around the fifth week of the summer program. As stated earlier, testing can be divided into the two categories of pre and post oven. The capacitance of each capacitor was measured to make sure it fell into the expected forty percent error. Capacitors were inserted into the large grouping tester. Once one-forth of the tester is filled, Mylar strips are inserted between the leads of the capacitors to prevent sparking. The pre oven tester is hooked up to the high voltage supply and ramped up to 10 KV. Care must be taken during ramping to ensure that no sparking occurs. The current of the tester is measured to ensure the system’s current falls into expected parameters. The system is slowly ramped down and grounded. The ramping and measuring procedure is repeated once the tester is half full and again when filled. When the current for the full device is taken however, it is recorded in the computer for record keeping. The pre oven testing is concluded with the detaching of the tester from high voltage and its placement into the oven for high temperature exposure.

Post oven testing begins following several days of high temperatures in the oven. The capacitance of each capacitor is measured and recorded in the computer. When six to twelve have been measured, they are placed into the post oven tester. This smaller tester is hooked up to the high voltage supply. The same precautions are taken in the
ramping as conducted in the pre oven testing. The current of the system is checked and recorded following twenty seconds under high voltage. The system is ramped down and grounded. The tested capacitors are loaded into cardboard sleeves and sent to another facility.

**Conclusion:**

Over the course of the summer, more than one hundred fifty first and second-class modules were created and sent on to SLAC. The completed modules account for about one-third of the total modules needed for installation in the IFR. Installation of the LSTs began last week and is expected to take the next month. Groups from Princeton, OSU and Stanford are on location assisting in this operation. The B Factory will begin operations once upgrades have concluded.

There are several tasks remaining before the completion of this project. The BABAR detector will be run with only one-third of the modules installed. The reasoning behind this is to test how LSTs will hold up under testing conditions prior to total installation. Creation of the remaining LST modules is scheduled to begin next summer. The first shipment of tubes for testing is already in storage and under high voltage at the Van de Graff. Voltage decoupler manufacturing is also planned to begin shortly. These decouplers will be equipped with the capacitors that were tested this summer.

**Acknowledgements:**

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References:


