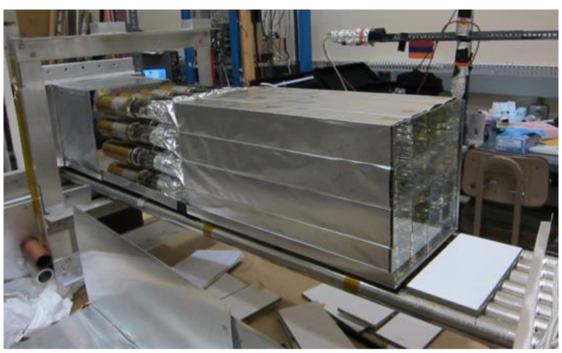
Report on the ECAL prototype

Introduction

The SBS Electron Calorimeter (ECal) that will be used in the proton electric form factor experiment uses lead glass blocks to detect the elastic electrons. At the high luminosity of the experiment, the lead glass will suffer radiation damage which degrades light collection of the block and the energy resolution of the calorimeter. Extensive tests were done at JLab that showed that heating the lead glass to 225^{o} C for one hour can anneal the expected radiation damage. With the radiation dose rate predicted for the experiment continuous thermal annealing at 225^{o} C is needed to obtain a balance between the rate of damage and annealing. The PMT needs to operate at temperatures below 40^{o} C, so a 15cm long light guide is used to create distance between the PMT and the oven. The desired heat profile in the oven is 225^{o} C at the front end of the lead glass which drops to 185^{o} C at the back end of the lead glass where the radiation damage is less. Then the area where the PMT is located is cooled by air to a temperature of 38^{o} C. To test the concept, a prototype calorimeter inside an oven was built. The continuous thermal annealing was tested with beam in Hall A in the spring of 2015 using elastically scattered electrons to monitor the energy resolution of the calorimeter.

Construction of Prototype of SBS ECal

To test the concept of constant thermal annealing, a prototype detector (named “C16”) with 4x4 array of lead glass blocks inside an oven was constructed. In Figure 1, photos of the initial stage of construction of the C16 are shown. Each lead glass block has frontal area of 4.2x4.2 cm^2 and length of 34.3 cm. The blocks are wrapped in aluminum foil. A cylindrical light guide with diameter of 2.5 cm and length of 15cm was optically glued to the lead glass. The PMT was also optically glued to the light guide.



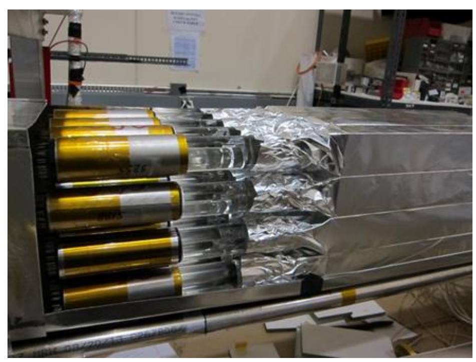


Figure 1 Photo of C16 lead glass blocks, light guide and PMTs.

This was enclosed in a thin aluminum box to make it light tight. In Figure 2, the left photo shows how the heating cable was wrapped around the lead glass with a buffer of glass tiles between the cable and the lead glass. The right photo in Figure 2 shows the glass foam insulation wrapped in aluminum foil that is packed around the lead glass. In Figure 3, the left photo shows the C16 enclosed in thin aluminum panels and the right photo shows the front of the C16. Thermocouple wires can be seen extending out of the front of the C16. Thermocouples were used to measure the temperature of the lead glass at front and back of the lead glass and in the area of the PMTs. The photos in Figure 4 show the C16 from the back. In the left photo, part of the cooling system can be seen. A blower blow air through a copper pipe which was cooled to room temperature by coiling the copper pipe around a fan (seen on the floor) since the air temperature for air directly from the blower was too warm. The air was blown in the back and directed by small diameter tubing to the gaps between the PMTs. After tuning the blower and heating elements the temperature profile of 225^{o} C at the C16 front, 185^{o} C at the rear of the lead glass and 38^{o} C at the PMTs was achieved.

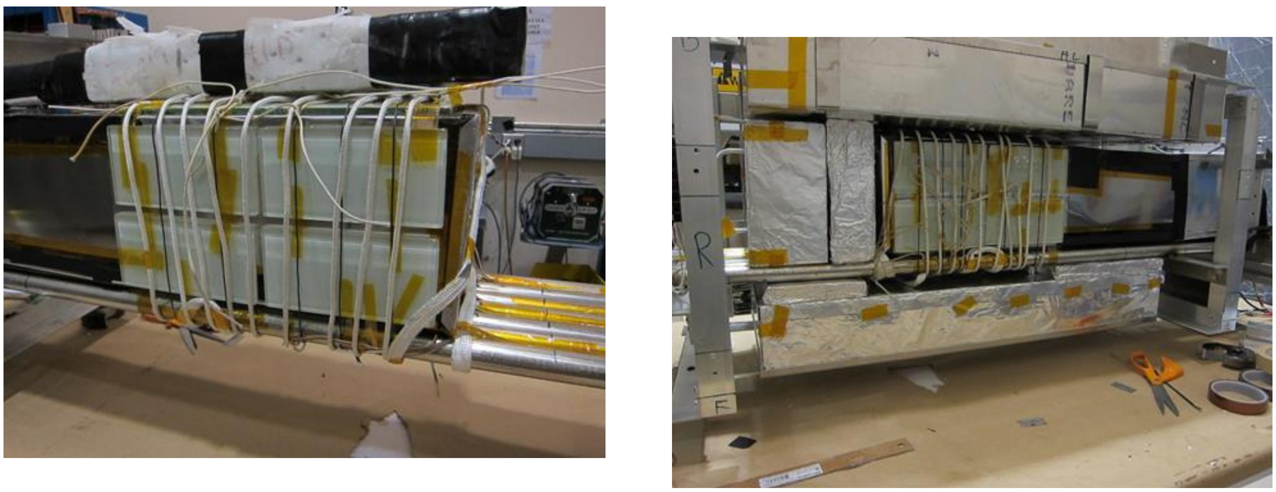


Figure 2 The heating cable is wrapped around the lead glass with glass tiles between cable and blocks. The glass foam insulation was wrapped in aluminum foil and packed around the lead glass and light guides.

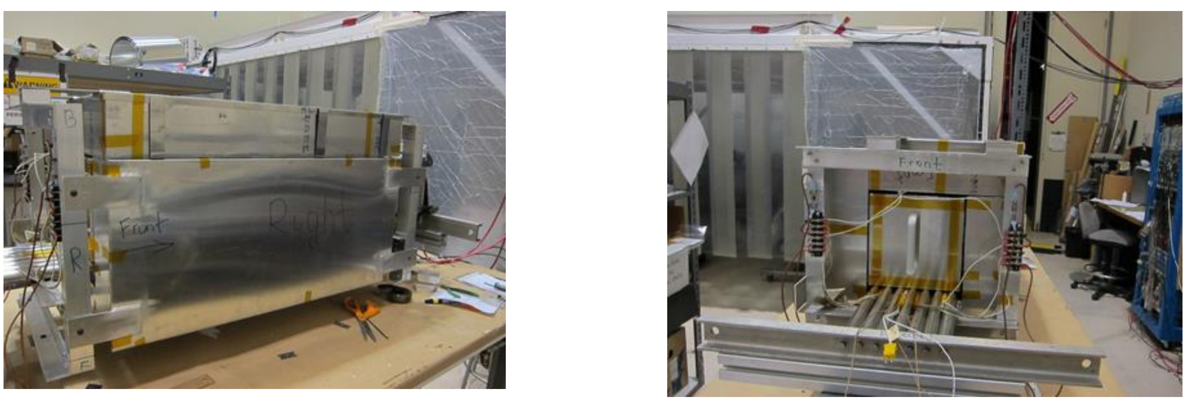


Figure 3 The left photo shows the detector after enclosing it in thin aluminum panels. The right photo shows the front of the prototype with thermocouple wires coming out of the front.

Experiment

The ECAL prototype was placed on a movable platform that placed it at beam height. The test was performed between April 30th and May 2nd. The beam energy was 2.056 GeV and the target was a 15cm long LH_2 cell. On April 30th, the calorimeter was rolled to approximately 30^{o} and 6.9m from the target

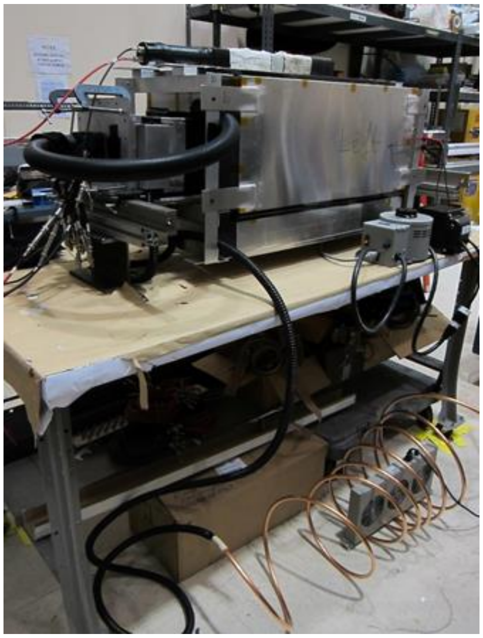
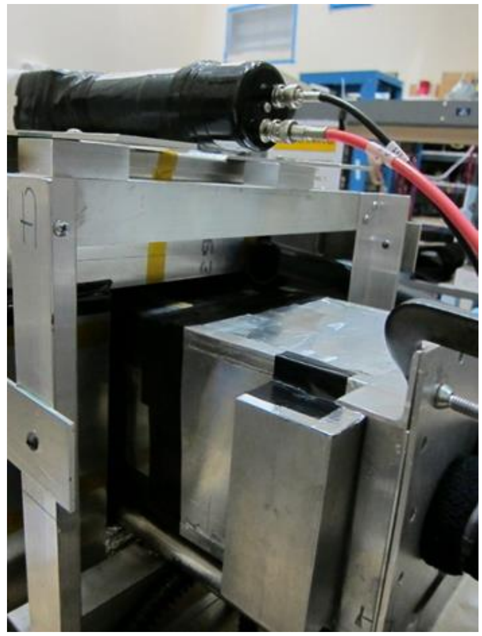
 

Figure 4 The left photo shows the back of the C16. Air was pumped from a blower into the back of the C16 to cool the PMTs down to about 38^o C. The right photo is a close up of the light tight enclosure for the PMTs and bases.

and the RHRS polarity was change to positive and set to accept elastic protons at 1.07 and angle of 48.74^o. The coincidence electrons are at 30.1^o and 1.578 GeV. At 6.9m away, the calorimeter covers about 25x25 mr and the momentum range of electrons hitting the calorimeter is 1.6%. The jacobian of the electron to proton solid angle is 1 for elastic scattering at this kinematic setting. The RHRS angular acceptance is about 60x120 mr so the ratio of RHRS single triggers to coincidence triggers is about 12:1. Initially, the heating for the oven was turned off.

The DAQ system was modified to accept the RHRS trigger. The DAQ was independent from the usual Hall A DAQ systems and run on the computer named hallavme14. The ADC signals for the calorimeter went into a FADC250 used in sampling mode with a sample every 4ns and a window of 60 samples.

A timeline of the beam current is shown in Figure 1. In the swing shift of April 30th, beam was restored and first an attempt to reach high current was done by accelerator. The accelerator was able to show that it could reach 60 uA that was needed to beam current calibration and target boiling studies. The program of a delta scan of elastic protons with 20uA beam on 15cm LH2 target was started. First the latency of the FADC was scanned in steps of 30 samples. Runs 718-731 were part on the latency scan and a coincidence was found at a latency of 155 samples. Only the ADC channels for the large angle row (blocks 4,8,12 and 16) showed a good ADC signal. For identifying blocks, the bottom row was labeled 1,2,3 and 4 with block 4 at the large angle side, then the second, third and fourth rows were labeled (5,6,7,8), (9,10,11,12) and (13,14,15,16). An entry to the hall was made to move the calorimeter about 10cm to larger angles. With the new position good ADC peaks where seen for all blocks. Runs 732-742 was used to optimize the HV and roughly gain match the ADC signals. The HV settings were fixed after run 743. Runs 743 and 744 were taken with 6uA beam. In software, the gains matching was refined further by using events in which at least four blocks had 1/6 of the total energy. The gains were match

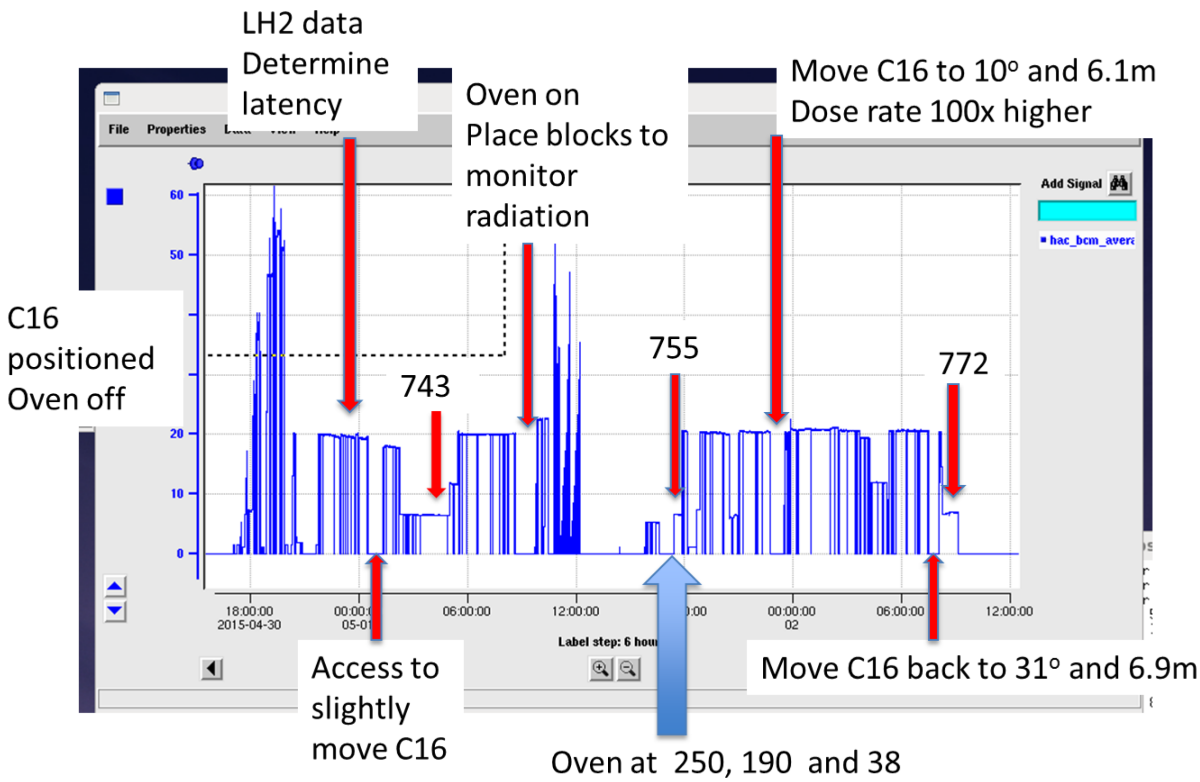


Figure 5 Timeline of the beam current during the C16 test.

to give a summed ADC count of 14,000 (arbitrary number). Summed ADC spectra were produced for each combination of four blocks in the C16. After the software optimization, the energy resolution for run 743 was 8.8 +/- 0.3 %. Run 745 was taken at 12uA. Runs 746 through 753 were taken at 20uA.

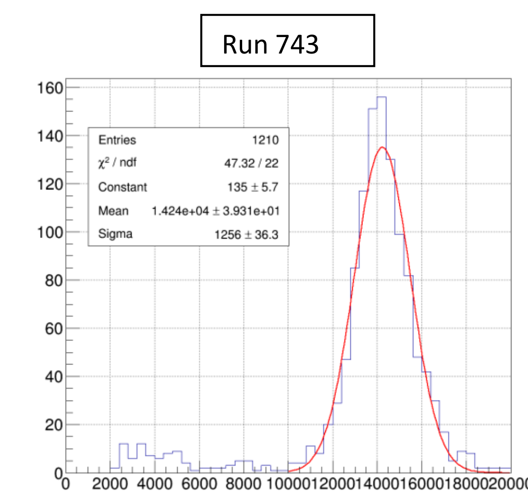


Figure 6 ADC spectrum for the sum of 4 blocks when each of the blocks had at least 1/6 the total energy is plotted. The energy resolution is 8.8 +/- 0.3%

Entry to the hall was made at around 10am on May 1st to turn the oven on. At the same time, to monitor the radiation dose, lead glass blocks were placed on the C16 platform with one block along the side of the C16 on the small angle side and another bar in front of the C16 perpendicular to the face. Other lead glass bars were placed at locations on the spectrometer platform near the C16 platform.

At around 5:00 pm on May 1st, access was made to check on the oven heater and the temperatures at the front, back and the PMTs was measured to be 250, 190 and 38° C. Data was continuously taken. In Figure 8, the summed ADC spectra for run 764 is plotted and an energy resolution of 9.1 +/- 0.3% was measured.

Figure 7 The lead glass blocks used to monitor the radiation dose after the C16 was placed at 10^{o} and there was 20uA beam on the 15cm LH2 target. Block 1 was placed parallel to the C16 along the beamline side of the C16. Block 1 has damage at the front (left side of photo) and along the side. Block 2 was placed in front of the C16 and perpendicular to the front face. Blocks 3,4 and 5 were located at different locations on the spectrometer platform that was near 30^{o}. These blocks show only moderate damage.

At around 11:00 pm on May 1st, access was made to check the oven temperatures and the lead glass blocks which monitored the radiation damage. The oven temperatures were 250, 190 and 38^{o} C. The lead glass block next to the C16 on the beamline side showed slightly discoloration while the block in front of the C16 showed little damage. Given limited beam time, it was decided to increase the dose rate by moving the C16 to smaller angles and closer to the target. The C16 was moved to about 10^{o} and 6.1m from the target. The oven was left on and data was taken with the RHRS with 20uA beam on the LH2 target.

At around 7:30am on May 2nd, a hall access was made. The oven temperatures were 271, 170 and 38^{o} C. As shown in Figure 7, the lead glass bars near the C16 were dark brown which indicated a high dose rate. The estimated dose is 30 kRad for the seven hour period. This is about 8 times the expect dose rate during the Q^2 = 12 GeV^2 kinematics of the SBS GEp experiment. The C16 platform was moved back to its original position of 30.1^{o} and 6.9m. The beam was a restored and data was taken for run 772. In Figure 8, the summed ADC spectrum is plotted and the energy resolution of 9.7 +/- 0.3 % was measured. This is only a slight increase resolution energy resolution after period of high radiation dose. This demonstrates that the continuous thermal annealing will work.

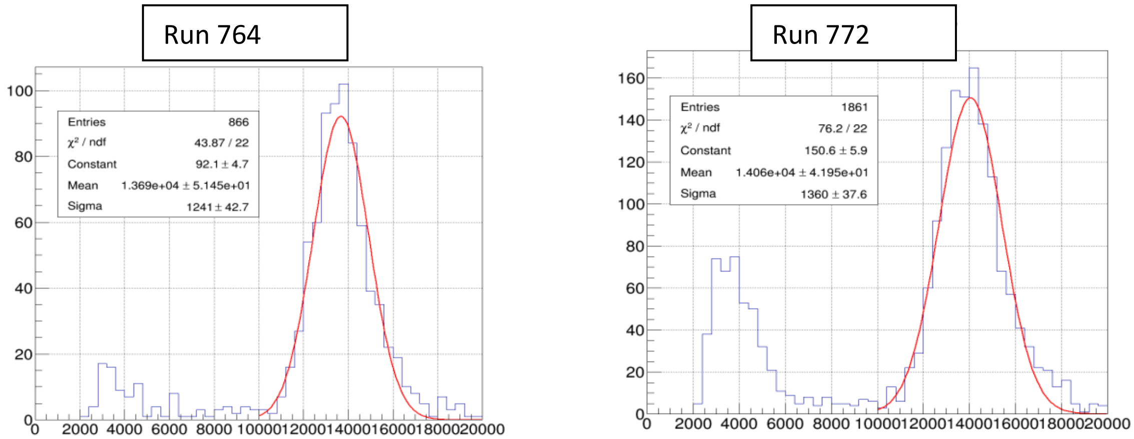


Figure 8 The ADC spectra for the sum of 4 blocks when each of the blocks had at least 1/6 the total energy. Run 764 is before the high radiation dose period and the energy resolution is 9.1 +/- 0.3%. Run 772 is after the high radiation dose period and the energy resolution is 9.7 +/- 0.3%.