

1 Radiation hardness of BigCal

BigCal was used in experiments 04-019 (Gep2 γ), 07-002 (WACS) and 04-108 (GEP3) in Hall C between October 2007 and June 2008. Before the experiments, BigCal was roughly calibrated with cosmic muons. The first task with beam was commissioning BigCal using 1.06 GeV elastic electrons. To reduce the radiation damage, BigCal has an absorber consisting of four removable aluminum 1-inch thick plates in front of the lead glass. In addition, a lucite plate (for checking the lead glass PMTs with an LED system) and a 1/2 inch aluminum plate are permanently placed in front of the lead glass. Two absorber configurations were used during the calibration. The first used only one plate and the second used all four aluminum plates which results in thicknesses of 0.43 X_0 and 1.29 X_0 respectively. In Fig. 1, the measured energy resolutions are plotted as filled red squares at their given aluminum thickness. Also plotted in Fig. 1 are the predicted energy res-

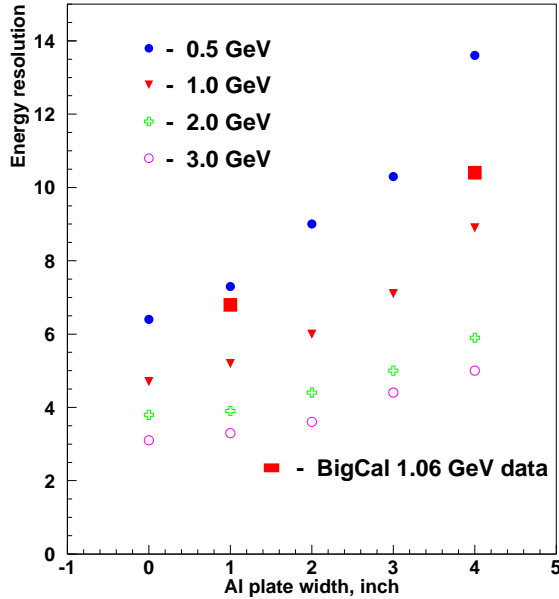


Figure 1: *BigCal* energy resolution (red solid boxes) obtained during commissioning using 1.06 GeV elastic electrons with two different absorber thicknesses, 0.43 X_0 and 1.29 X_0 , compared to Monte Carlo simulations for different energies as function of the additional Al absorber thickness.

olutions at different incident electron energies and aluminum thicknesses from a GEANT Monte Carlo simulation [1]. The experimentally achieved energy resolution differs by about 1-1.5% from the simulations and is among the best results obtained with this type of calorimeter especially given the additional absorber and the large number of channels.

During E04-019 and GEP3, which both measured the elastic ep reaction, the PMT gains in BigCal could be continually monitored using the predicted electron energy calculated from the measured angle and momentum of the proton detected in the HMS. Depending on the kinematics, the experiment could collect enough data in 1 to 8 hours to do a calibration. Due to the darkening of the lead-glass from radiation damage, there was an effective drop in the PMT gain and the energy resolution in BigCal gradually increased throughout the experiments. Most of the time, the PMT gain shifts were corrected in software, but when the shifts became large enough the HV of the PMTs was adjusted to increase the gain. By the end of the experiments the energy resolution was $24\%/\sqrt{(E)}$ resolution, despite doing a partial UV curing of BigCal in January 2008 in the middle of the experiments. Fig. 2 is a plot of the relative PMT gain versus the accumulated charge throughout all of the experiments. The relative gain, normalized to one at the beginning of the experiments, was obtained by averaging the gain of all the channels. For the relative gains shown in Fig. 2, when adjustments of the PMT HV were made the new gain was normalized to the previous value so that effective gain comparison can be done relative to the initial high voltages. A number of BigCal configuration changes were done during these experiments. For each new configuration, the effective gain of the PMTs would change (mainly due to dependence of the energy loss in the absorber on the electron energy) and a correction was applied at the beginning of each kinematics to ensure the continuity of the gain before and after the change of the kinematics. Generally, the different slopes in Fig. 2 correspond to different kinematics: different beam energy, angle and distance to the calorimeter.

After the E04-019 kinematics point with BigCal at 32° (blue points in Fig. 2), the Wide Angle Compton Scattering (WACS) experiment started. WACS used a 6% radiator in front of a 15cm target liquid hydrogen target with BigCal placed at 11m distance and an angle of 26° . Since normal WACS running did not have elastic ep events, the gain could not be monitored continuously. Only at the end of WACS was data taken for elastic ep events. The calibration point is the solid red triangle in Fig. 2 which shows a steep decline in the BigCal gain during the WACS experiment due to the forward BigCal angle and the radiator at the target.

After WACS the beam was down for a one month period, so it was decided to

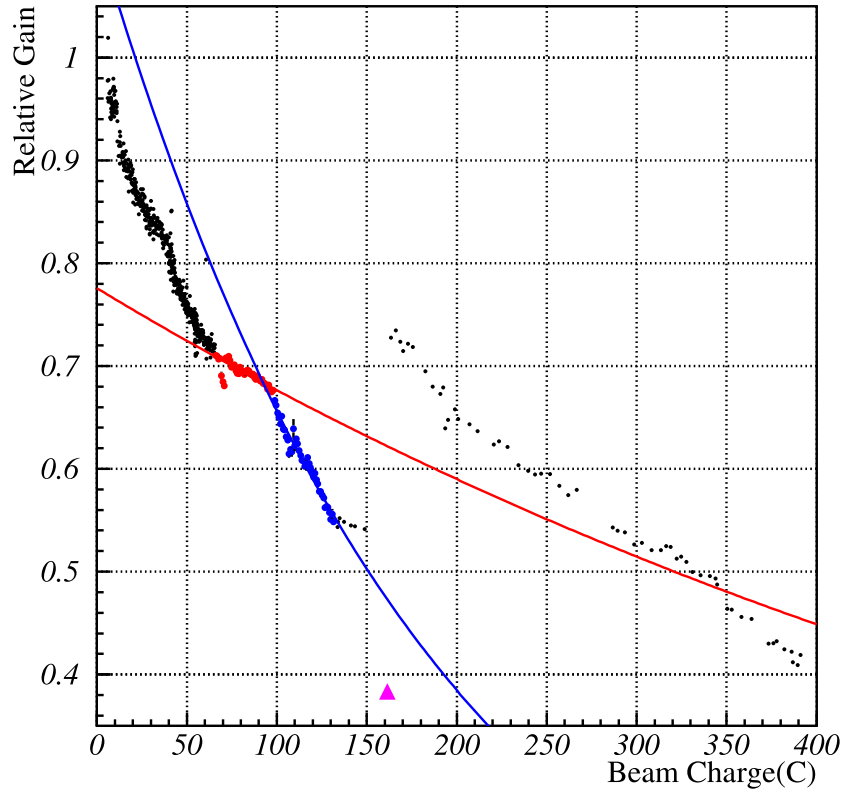


Figure 2: Mean gain of BigCal during the GEP-III experiments in Hall C (October 2007 - June 2008) as a function the accumulated beam charge in coulombs. The red (blue) points are during E04-019 with BigCal at angle of 44.9° (32°). The data points are fitted with $a \exp -bC$ (results given in Table 1). No data for the week-long WACS experiment (E07-002) is given except the last run (solid magenta triangle) just before the UV curing.

restore the lead glass by using UV curing. Curing of the glass was performed with a specially constructed UV lamp that covered a quarter of the frontal calorimeter area. The lamp was moved at four different positions with an average time of 3 days per position. The effect of the UV curing corresponds to the jump in Fig. 2 between the red triangle (at 39%) indicating the gain before the curing and the next upper point (at 74%) after the curing. Fit with exponential function gives 1.24% per hour gain increase. Because of concerns about glass heating, there was a gap of 2" between the UV bulbs and the glass. During the curing it turned out that the glass temperature rose by a few degrees, so the UV lamps could have been placed closer to the glass. Low power bulbs (14W) were used so that damage to the PMTs that were left in place during the curing did not occur. After the GEP experiment two UV lamps were built to cure the calorimeter for the SANE experiment with expected total curing time of 60 days per position. Constant check of the PMT performance showed no deviation from the normal gain, except some relaxation time was needed after long (several weeks) period of UV illumination.

The BigCal positions for this proposed experiment will be between 30.0° to 35.5° and at 10 m from the target. To estimate the gain loss due to radiation damage to BigCal in this proposed experiment, two kinematic settings from E04-019 that had BigCal at 32° and 44.9° were studied. Both settings placed BigCal at about 11-12 m from the target. As shown in Fig. 2, the data points were fitted with exponents: $a \exp -bC$ and the rate constant b is given in Table 1. Using GEANT simulations, the energy fluxes per coulomb through the front of the calorimeter have been estimated for the both settings. As seen in Table 1, these numbers are roughly proportional to the gain loss rates estimated from Fig. 2. Thus, for the GEP4 kinematics, one can predict that the gain loss by assuming that the gain loss changes linearly with angle and target length. The BigCal distance for the target is similar for the proposed experiment and the E04-019 points, so no extrapolation for distance is needed. The predicted gain loss per Coulomb is given in Table 1. With 75uA current and 50% running efficiency, one expects 3.25 C /day which means a 3.4% drop in gain per day for the $Q^2 = 13$ point. Given the length of the experiment, a UV curing of the lead-glass will be needed on average of once a week (about 24% drop in gain) during the experiment.

We intend to build a permanent UV light box in front of the glass. By placing the bulbs right next to the glass and increasing the power and density of the bulbs we expect to increase the UV flux by at least 5 times resulting in a gain increase rate of above 6%/hour. This means in 4 hours about one weeks worth of damage to the lead glass could be cured. The curing of the lead glass could be done during normal beam maintenance down times which happen every week, so that

Experiment	angle deg.	Dist. m	Target Length cm	Beam Energy GeV	Gain loss rate b	soft photon flux J/cm ² /C
E04-019	44.9	12	20	2.839	0.14 %/C	0.0039
E04-019	32.0	11.2	20	3.539	0.53 %/C	0.013
GEP4 ($Q^2 = 6$)	30.0	10	30	6.6	1.11 %/C	
GEP4 ($Q^2 = 10.5$)	35.5	10	30	8.8	0.80 %/C	
GEP4 ($Q^2 = 13$)	31.3	10	30	11.0	1.04 %/C	

Table 1: Gain loss per coulomb of beam estimated from the Fig. 2 for E04-019 at two angles. The GEANT prediction for the soft photon flux per coulomb for the two E04-019 points. For each GEP4, the gain loss per coulomb is estimated by interpolating between E04-019 points and scaling for the increased target thickness.

the experiment has no loss inefficiency.

References

- [1] Monte Carlo calorimeter simulations, including Cherenkov photon propagation through lead-glass, developed by K. Shesternanov, IHEP, Protvino, Russia (2002).
- [2] A. Gasparyan, private communication.