0.1 Calorimeter

Essential to this experiment is solid angle matching, which means that for each kinematics the solid angle of the electron detector must match the fixed solid angle of the proton detector, which is the HMS. For the Q^2 = 11 point, the electron scattering angle is larger than the proton recoil angle, and therefore the Jacobian for the electron is larger than 1, and hence the solid angle for the electron detector must be larger than that of the proton detector. For the lower Q^2 points the opposite is true and the electron detector solid angle is smaller than the proton.

Of course, the situation here is exactly the same as for the Gep-III experiment in Hall C, for which a new large lead glass calorimeter array (BigCal) was constructed (See Fig. 1). This is the ideal detector for the electron in this experiment as well, as no modifications will be necessary. BigCal consists of 32 columns times 32 rows of 3.8×3.8 cm^2 bars of Protvino lead glass blocks at the bottom, and 30 columns times 24 rows of 4.0×4.0 cm^2 from RCS (Yerevan blocks) placed on the top. The total frontal area is thus 2.63 m^2. At a distance of 10.0 m away from the target, the detector offers a solid angle of 26 msr to the electrons of the ep reaction, which is desired for the Q^2 = 11 data point. For the lower Q^2 points, BigCal can be located at 15 m from the target. In Fig. 0.1, the horizontal and vertical positions at the face of the calorimeter are plotted for each Q^2 point. The pulse height from every lead glass bar is digitized. In addition, after splitting in the multiplexer/amplifier circuit, a copy of the original signal is added in groups of eight channels for timing purposes, as well as for constructing the calorimeter trigger. The timing information helps distinguish noise from true charge sharing. The important for identifying elastic ep events is measuring the position at the calorimeter. This is used to determine the electron's angle and the ep angular correlation is part of the cut to identify elastic events. During Gep3, the position resolution was estimated to be 8 mm.

0.1.1 Radiation Hardness of BigCal

BigCal was used in experiments 04-019 (Gep2γ), 07-002 (WACS) and 04-108 (Gep-III) 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 perma-

Figure 1: *The BigCal Calorimeter.*

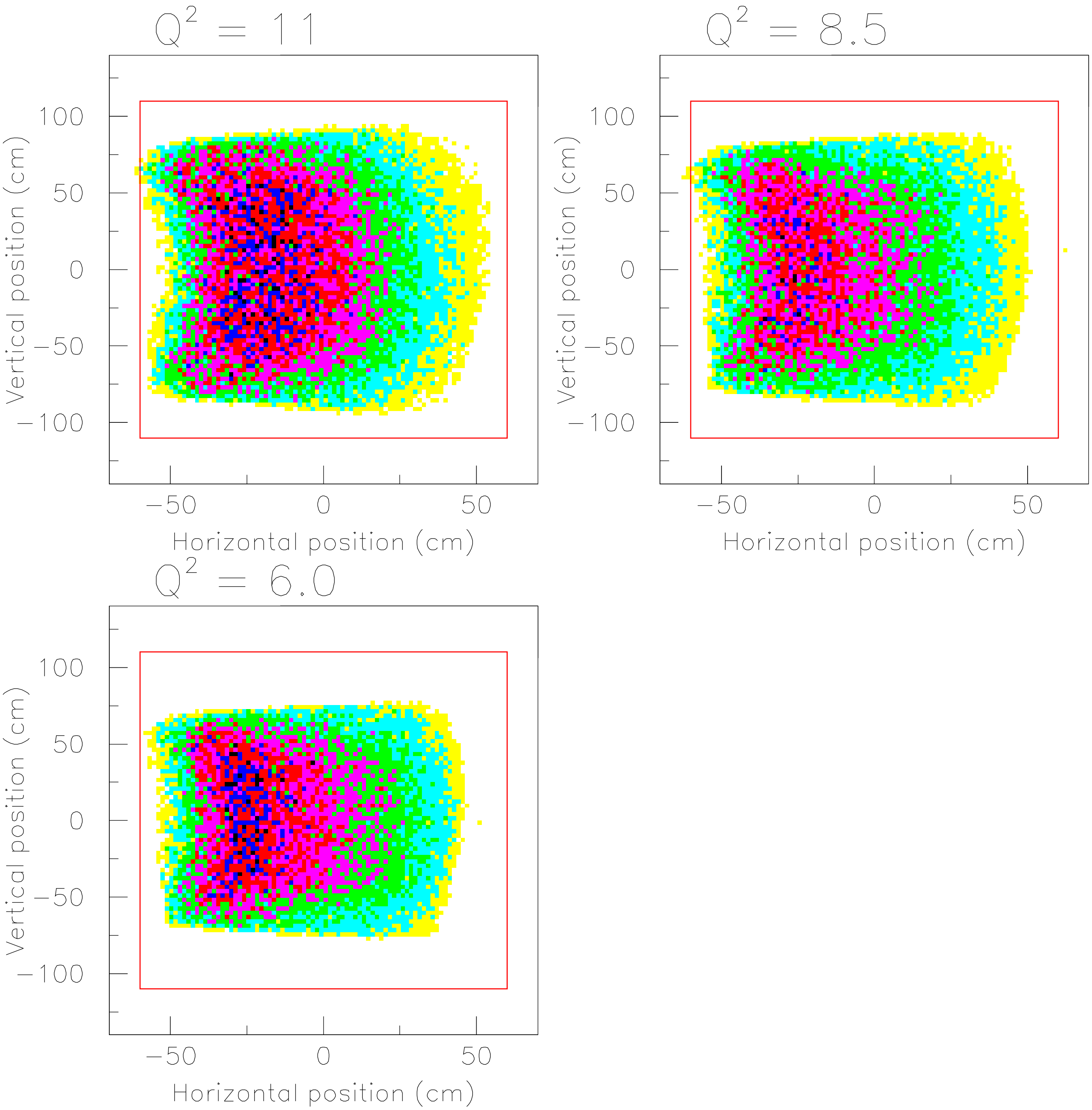

Figure 2: *From a SIMC calculation, the expected distribution of elastic electrons at the calorimeter at distance of 10 m for* Q^2 *= 11 GeV*^{2} *and 15 m for 8.5 and 6 GeV*^{2}*. The red box is the outer dimensions of the calorimeter.*

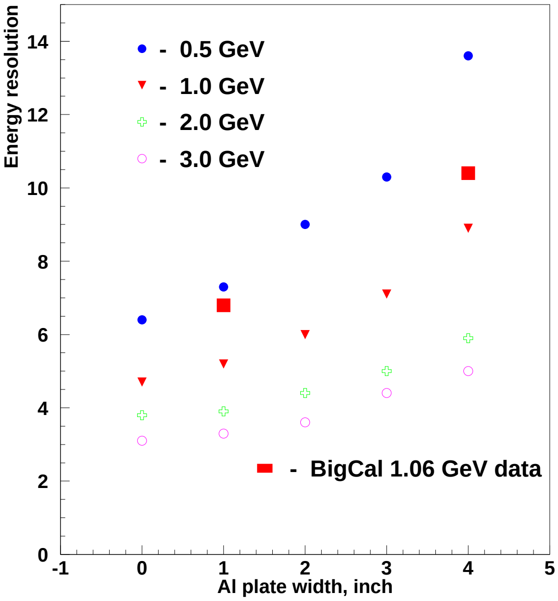

Figure 3: *BigCal energy resolution (red solid boxes) obtained during commissioning using 1.06 GeV elastic electrons with two different absorber thicknesses (total thicknesses of 0.43 X_0 and 1.29 X_0, respectively) compared to Monte Carlo simulations for different energies as function of the additional Al absorber thickness.*

nently placed in front of the lead glass. Two absorber configurations were used during the calibration. The first used only one of the removable aluminum plates, and the second used all four plates, which together with the permanent aluminum plate results in thicknesses of 0.43 X_0 and 1.29 X_0 respectively. In Fig. 0.1.1, the measured energy resolutions are plotted as filled red squares at their given aluminum thickness. Also plotted in Fig. 0.1.1 are the predicted energy resolutions at different incident electron energies and aluminum thicknesses from a GEANT Monte Carlo simulation [**?**]. 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 Gep-III,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 decreased (i.e. increased width) thoughout 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%/$\sqrt(E)$, despite doing a partial UV curing of BigCal in January 2008 in the middle of the experiments. Fig. 0.1.1 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. 0.1.1, 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. 0.1.1 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. 0.1.1), 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 were data taken for elastic ep events. The calibration point is the solid magenta triangle in Fig. 0.1.1 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 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. 0.1.1 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,

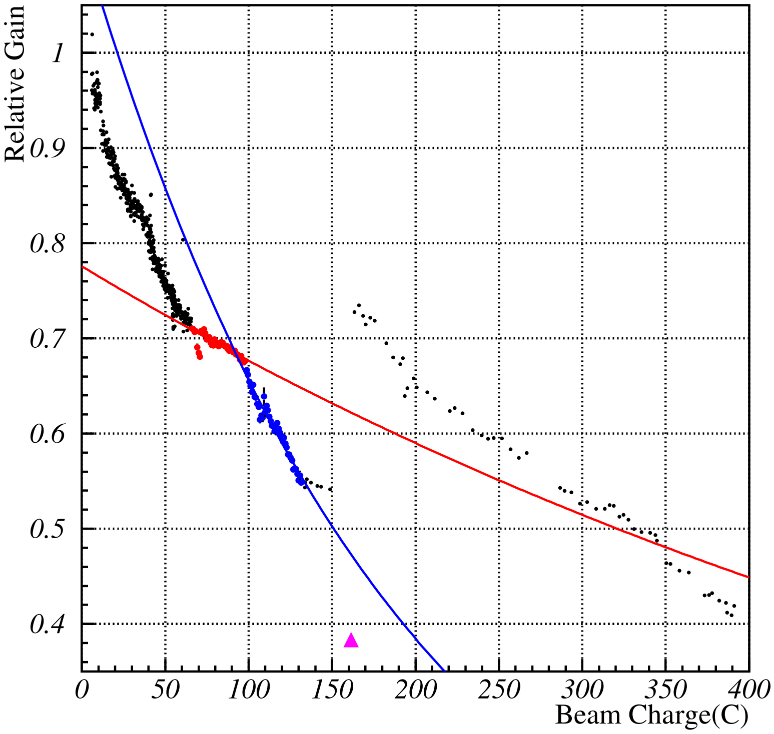

Figure 4: *Mean gain of BigCal during the Gep-III experiments in Hall C (October 2007 - June 2008) as a function the accumulated beam charge in coulombs. The red (blue) points are during E04-019 with BigCal at angle of 44.9° (32°). The data points are fitted with* ae^{-bC} *(results given in Table 0.1.1). No data for the week-long WACS experiment (E07-002) is given except the last run (solid magenta triangle) just before the UV curing.*

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
Gep-IV (Q^2 = 6)	20.1	15	30	8.8	0.75%/C	
Gep-IV (Q^2 = 8.5)	19.9	15	30	11.0	0.75%/C	
Gep-IV (Q^2 = 11)	25.5	10	30	11.0	1.4%/C	

Table 1: *Gain loss per coulomb of beam estimated from the Fig. 0.1.1 for E04-019 at two angles. The GEANT prediction for the soft photon flux per coulumb for the two E04-019 points.*

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 be placed closer to the glass. Low power bulbs (14W) were used so that damage the PMTs that were left in place during the curing did not occur. After the Gep-III experiment, an additional UV lamp was built so that two UV lamps were available 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.

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. 0.1.1, the data points were fitted with the form: ae^{-bC} and the rate constant b is given in Table 0.1.1. Using GEANT simulations, the energy fluxes per coulumb through the front of the calorimeter have been estimated for the both settings. As seen in Table 0.1.1, these numbers are roughly proportional to the gain loss rates estimated from Fig. 0.1.1. Thus, for the Gep-IV kinematics, one can predict the gain loss by assuming that it changes linearly with angle and target length and also accounting for changes in distance from the target. The predicted gain loss per Coulomb is given in Table 0.1.1.

With 75uA current and 50% running efficiency, one expects 3.25 C /day which means a 4.6% drop in gain per day for the Q^2 = 11 point. For the two lower Q^2 points, a 2.4% drop in gain per day is predicted.

We intend to built a permanent UV light box in front of the glass. The lucite plate and 1/2”thick aluminum plate will be removed. 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. For the Q^2 = 11 point, this means in 5.5 hours about one week’s worth of damage to the lead glass could be cured. This could be worked into the normal beam studies down periods. For the two lower Q^2 points, the lead glass could be cured between changes of kinematics.