BCAL Simulations for the Hall-B Tests

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Abstract

Simulations were carried out to study the response of the electro-magnetic Barrel Calorimeter of the GlueX Project during beam tests at Hall-B. Specific issues that were investigated included energy leakage from its sides, extraction of timing signature and the effect of the beam pipe elements. The results were in agreement with expectations.

Key words: beam tests, scintillating fiber, barrel calorimeter, simulations
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1 Introduction

The electro-magnetic barrel calorimeter, BCAL, for the GlueX Project [1–3] consists of alternating layers of thin lead sheets and 1-mm-diameter scintillating fibers (SciFi). The BCAL is segmented into 48 modules with each module comprised of approximately 18,300 4-m-long fibers, thus requiring a total of over 3,500 km of fibers. For a schematic of the BCAL and its configuration in the production runs see Figure 1.

A 4 m-long prototype module, termed 'Module 1', was constructed in 2004. Module 1, shown schematically in Figure 2, has a rectangular cross section of 13×23.0 cm^2. Over 70 km of double-clad fiber and 12 kg of epoxy were used in its construction. The scintillating fibers were made by PolHiTech and are blue-emitting with a peak emission wavelength of 420 nm and an attenuation length of 350 cm. The fibers have a diameter of 1 mm (with 3% and 1% being the thickness of the first and second cladding layers) and the thickness of the lead sheets is 0.5 mm. The module has 186 planes of Pb/SciFi. The total

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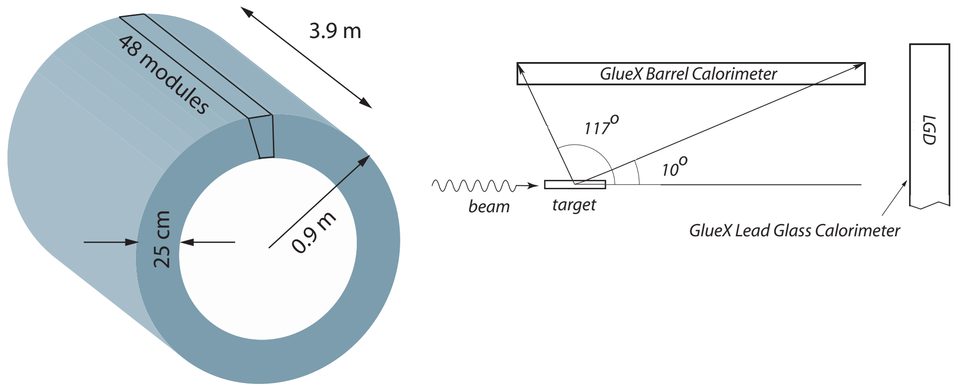

Fig. 1. Schematic of the GlueX Barrel Calorimeter (BCAL) and its placement in the GlueX detector (not to scale).

weight of the module is 0.76 metric tons (including associated aluminum and steel plates). The composite has a Pb:SciFi:Epoxy ratio of 37:49:14 and an overall density of ≈ 5 gm/cm^3 and a radiation length (X_0) of 1.5 cm. Each layer of the module to be tested has 96 SciFi's spaced 1.35 mm apart (center-to-center) with the layers being 1.18 mm apart so that a uniform SciFi density is presented across the shower path.

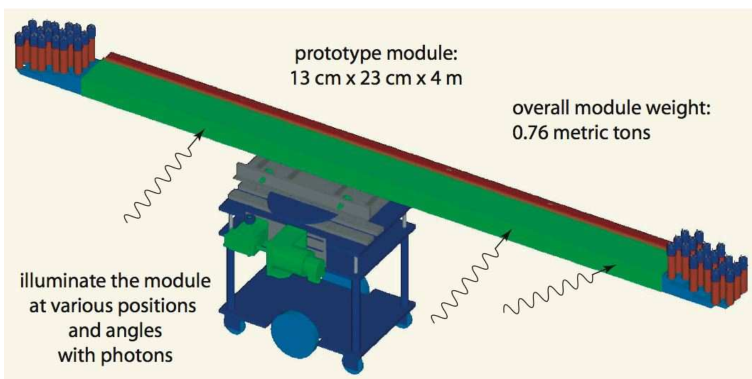

Fig. 2. Schematic of the prototype BCAL module with its proposed readout scheme and support cart.

Our design goals for the energy and timing resolution dependence on photon energy, based on the KLOE calorimeter [4] experience, are:

$$\frac{\sigma(E)}{E} = \frac{5\%}{\sqrt{E(\mathrm{GeV})}} + 2\% \qquad (1)$$

$$\sigma_t = \frac{56 \text{ ps}}{\sqrt{E(\mathrm{GeV})}} + 133 \text{ ps} \qquad (2)$$

Our results are expected to improve upon these due to the use of double-clad fibers which will result in increased photon statistics.

2 Simulations

Selected simulations were carried out to examine the expected performance of Module 1 for the beam test conditions, including effects of energy leakage due to misaligned beam spot, timing distributions and energy resolution.

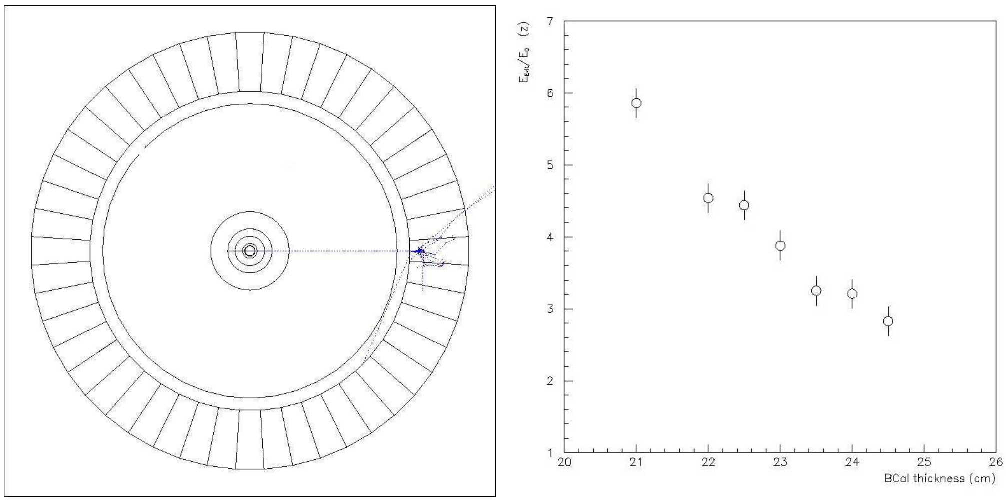

Fig. 3. *Left panel:* A sample 1 GeV incident photon entering the BCAL. *Right panel:* The simulated shower leakage (in percent) from the rear of the BCAL is shown.

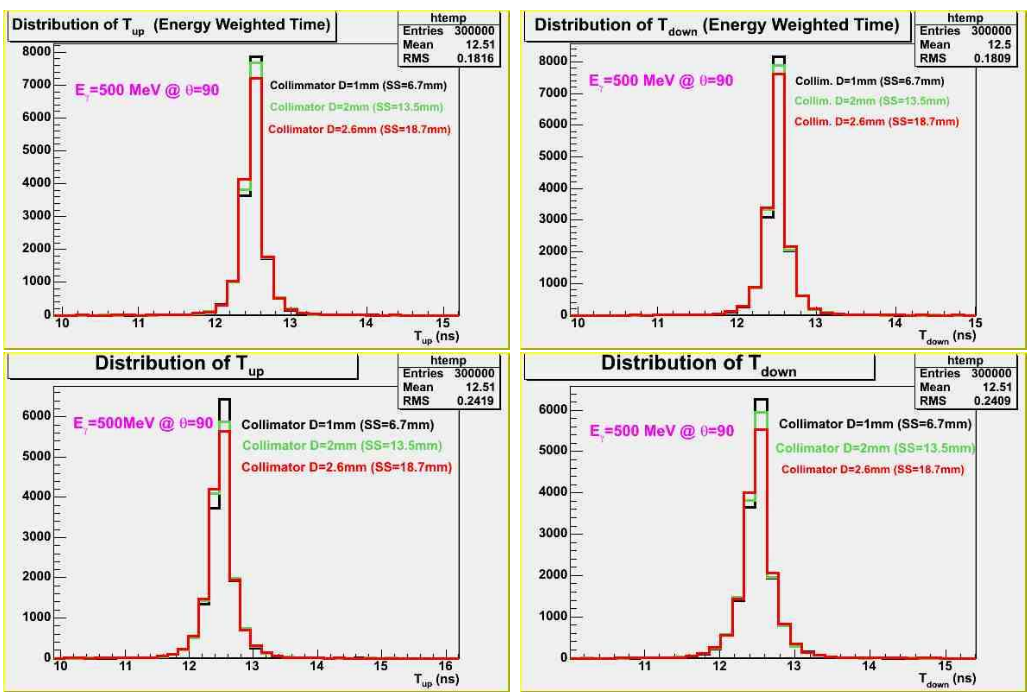

Fig. 4. Simulated timing distributions extracted based on the energy-weighted time and the start time of the energy deposit in the readout cell, respectively, for different collimator apertures and for 500 MeV incident photons.

A typical simulated 1 GeV photon event entering the BCAL at 90 degrees with respect to the beam direction and the percent energy leakage from the rear of the module are graphed in Figure 3, in the left and right panels, respectively. The leakage, with respect to the incident energy E_0, depends weekly on X_0 beyond 23 cm thickness.

Figure 4 shows BCAL readout time distributions (up and down or north and south for the beam test configuration) for three different spot sizes (collimators of 1 mm, 2 mm and 2.6 mm of aperture size), where the incident photon has 500 MeV energy and enters at the middle of the BCAL module. Time is extracted in two ways: in an energy-weighted manner and by using the start time of the energy deposit in the readout cell. The effect of the collimator size on these timing distributions is negligible. The Gaussian-fitted widths of the energy-weight distributions are about 20% narrower than those determined from the start of the energy deposit, i.e. the prompt light.

Figure 5 shows BCAL readout time difference distributions (up minus down or north minus south for the beam test configuration) for a a realistic beam spot size of 18.7 mm and a pencil beam of 0.5 mm, where the collimator is set at the expected 2.6 mm aperture and the incident photon has 500 MeV energy and enters at the middle of the BCAL module. The time difference is extracted in two ways: energy-weighted time and y using the start time of the energy deposit in the readout cell. The Gaussian-fitted widths of the expected distributions are about 5% wider than the ideal (pencil beam) ones.

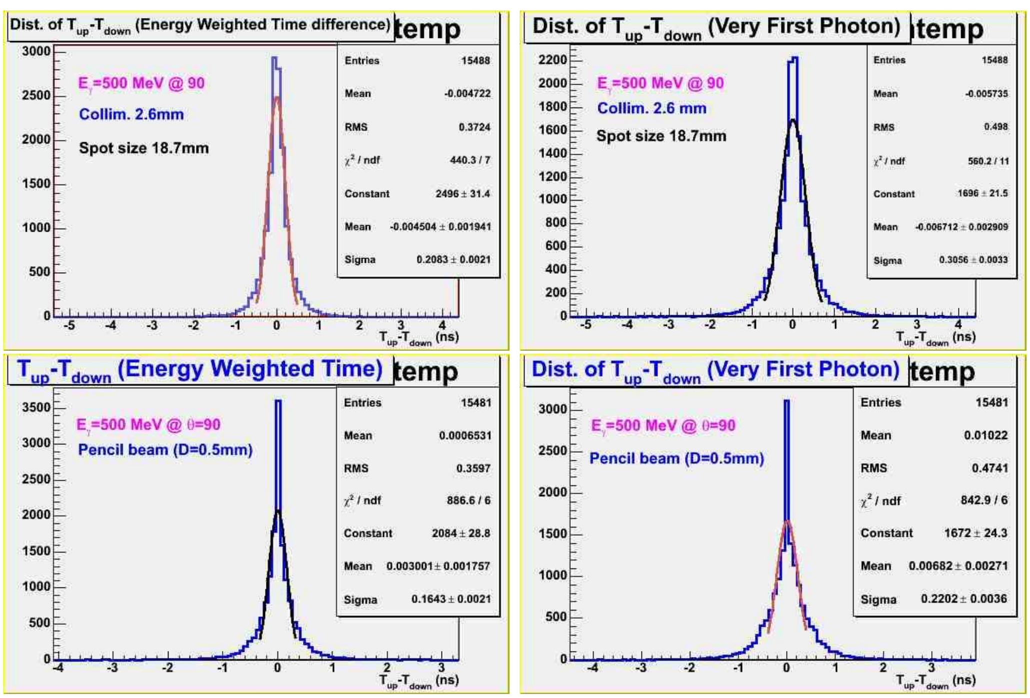

Fig. 5. Simulated timing difference distributions, for a pencil beam and a realistic beam at the planned collimator aperture, for 500 MeV incident photons. Further details are presented in the text.

Figure 6 displays the percentage of the shower energy that leaks out from the four sides of the BCAl module when the incident photon beam is shifted from the BCAL center towards the vertical direction. The rapid increase/decrease of the leakage through the upper/lower sides of the Module is evident as the beam approaches/recedes to/from the upper/lower edge. The front and rear distributions are relatively flat except at extreme misalignment.

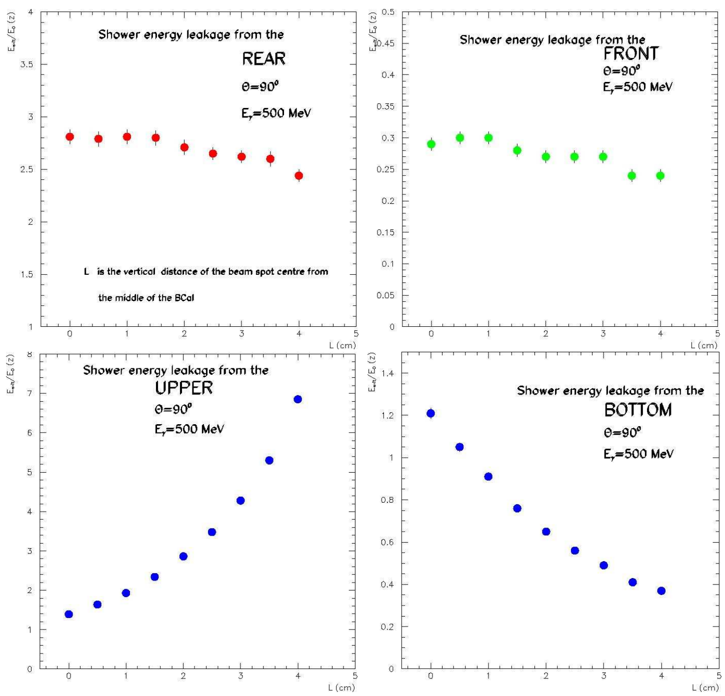

Fig. 6. Simulated percentage of the shower energy that leaks out from the four sides of the BCAl module when the incident photon beam is shifted from the BCAL center by 0.5 cm, 1 cm, 1.5 cm, 2 cm, 2.5 cm 3 cm, 3.5 cm and 4 cm towards the vertical direction.

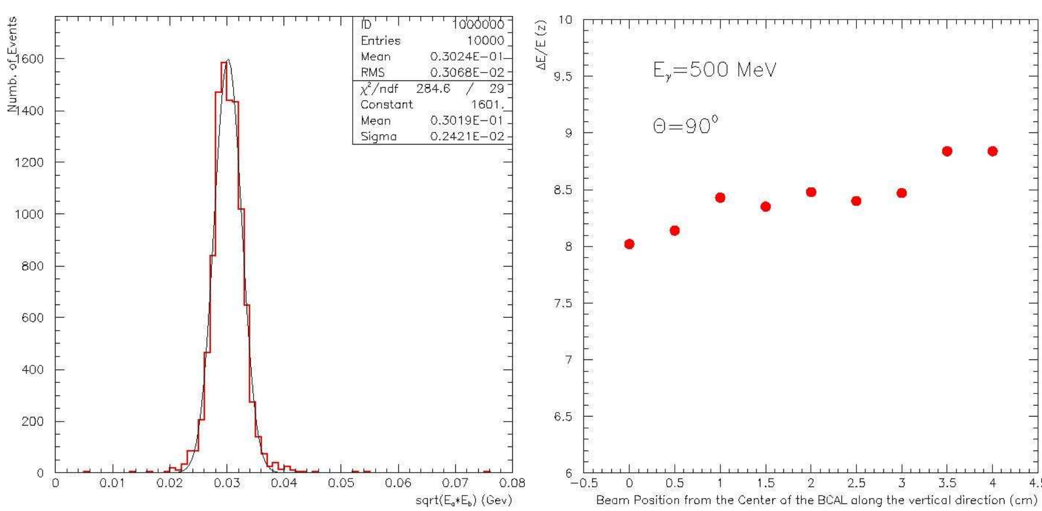

Fig. 7. Simulated energy resolution from a deliberate misalignment of the beam in the vertical direction. Details are listed in the text.

Figure 7 shows the effect on energy resolution of a deliberate misalignment of the beam in the vertical direction. The plot on the left shows a sample distribution of the geometric mean of the energy calculated from both ends (north and south) of the BCAL when the beam spot with the uniformly distributed area of 18.7 mm of diameter (after collimation by a 2.6 mm-collimator) enters the BCAL at 0 cm, 0.5 cm, 1 cm, 1.5 cm, 2 cm, 2.5 cm, 3 cm, 3.5 cm and 4 cm, respectively, from the BCAL centre towards the vertical direction. E_a and E_b are the attenuated energies at the left and right sides of the BCAL and are determined as:

$$E_a = E_{dep} \cdot \frac{exp(-|-200. - z|)}{\lambda} \quad (3)$$

$$E_b = E_{dep} \cdot \frac{exp(-|200. - z|)}{\lambda} \quad (4)$$

where E_{dep} is the energy deposited in the SciFis, λ is the attenuation length (set to 300 cm for this simulation), and z is z-position of the entry point. The Gaussian-fitted sigma to each geometrical-mean energy distribution, obtained for the different beam positions, is plotted on the right panel. As the misalignment increases, its negative effect on the resolution due to the energy leakage is evident.

Figure 8 shows the GEANT simulation with the incorporation of all elements of the Hall-B beam pipe, including the respective number of radiation lengths (top two panels). These include the Hall-B target residual hydrogen gas and aluminum vessel, as well as the PrimeX Beam Profile Monitor (BPM) and the scintillator 'Veto' counter that is planned to be placed immediately behind the BPM and used to veto charged particles and assist in the establishment of the timing reference for the tagger counters.

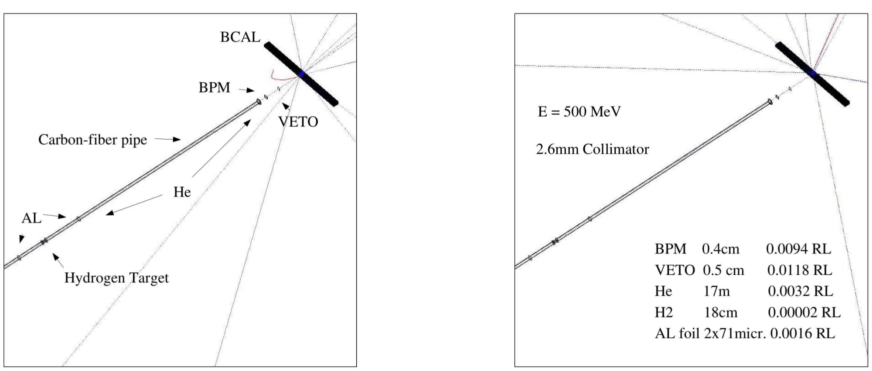

Fig. 8. Simulations of the beam pipe elements for the Hall-B tests. Details are listed in the text.

The four panels of Figure 9 show the simulated percentage of energy leakage out of four sides (rear, front, top and bottom) of the BCAL module. The losses total 3.2% from front and rear and 2.8% from the upper and lower sides. Of course, the latter two types of losses to not represent a problem since such events would be captured by adjacent BCAL modules in the production runs.

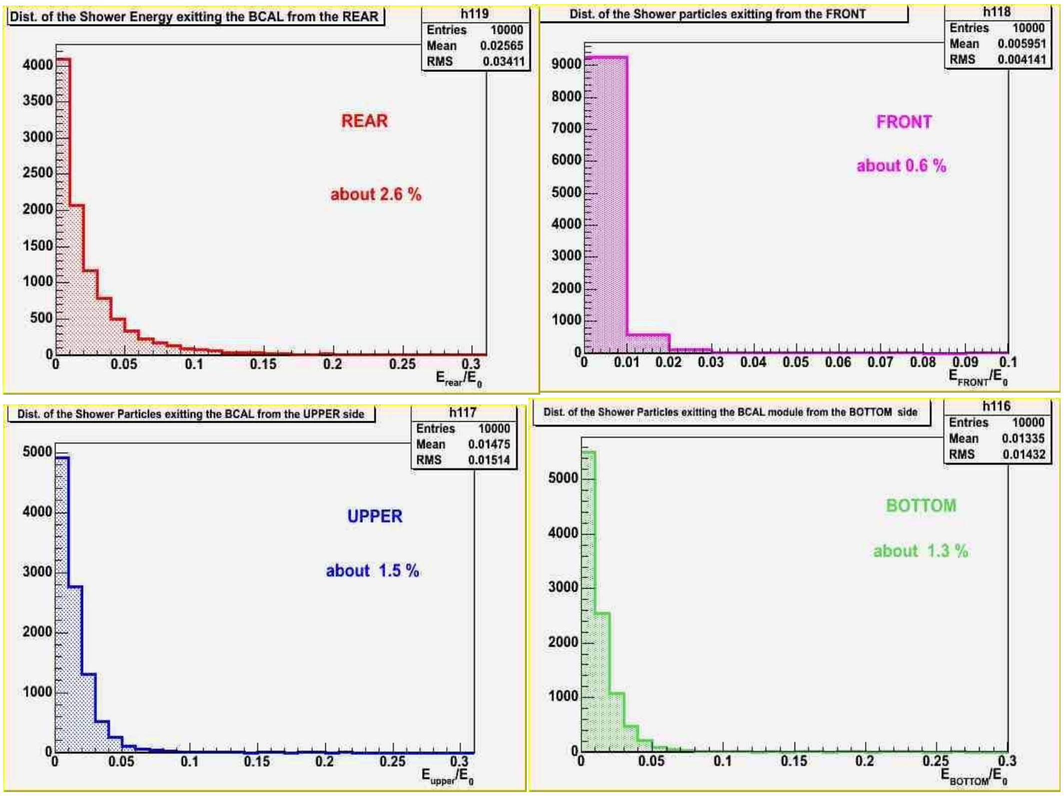

Fig. 9. Simulations of the beam pipe elements for the Hall-B tests. Details are listed in the text.

3 Conclusions

The expected performance of the prototype blue-scintillator-based module (Module 1) of the BCAL following GEANT simulations is presented herein. The results follow expectations.

- The percentage of energy leaking out the rear of the module flatens out after 23 cm of thickness, allowing some flexibility in the choice of thickness for the aluminum base plate.
- Preliminary comparisons of the timing difference calculated from an energy-weighted algorithm and one based on the first photon (prompt signal) are in rough agreement with each other. More work needs to be done on this topic especially in conjunction with the development for the shower and charged particle reconstruction for the BCAL.
- A deliberate vertical misalignment of the beam results in a deterioration of the energy resolution from 8% to 9%. During the beam tests a careful

vertical scan was done to ensure that the beam spot was striking the middle of the module vertically.

- The contribution of pair production to valid BCAL hits from beam pipe elements is small baed on the radiation lengths of the material in the path of the photons.

The analysis of the Hall-B beam tests is well underway and results will be reported soon.

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