GlueX Note - 1093
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Non-linear photon energy corrections in the FCAL

Mihajlo Kornicer
Department of Physics
Indiana University, Bloomington, IN 47405

1 Introduction

This document describes a calibration procedure used to obtain photon momenta from reconstructed shower energy and position. For this study photons were generated from the center of the GlueX target uniformly in full azimuth and up to 12 degrees in polar angle, with discrete energies in the range from 50 MeV to 8 GeV. Deposited energy of shower particles in a single FCAL block was attenuated along the block with attenuation length of $L = 100$ cm. The energy is smeared by a Gaussian distribution with the width that corresponds to a statistical term of 3.5%. Only hits with energy above a threshold of 20 MeV were recorded and used in shower reconstruction. This corresponds to $\approx$30 MeV deposited energy at the front face of the FCAL. The procedure to group hits into clusters was described in [1].

2 Energy reconstruction

The non-linear effects in the FCAL shower reconstruction were initially accounted for by using a simple power-law to describe the dependence of reconstructed cluster energy E_c on generated photon energy E_γ,

$$E_c = N \cdot E_\gamma^{1+\epsilon}. \tag{1}$$

where A and ϵ are normalization and non-linear factors, respectively. In this approach, the energy dependence of non-linear factor, ϵ, was neglected. The photon energy was calculated from reconstructed shower energy by simple inversion of Eq. 1.

A better agreement between reconstructed and generated photon energy up to 8 GeV can be achieved using the following equation

$$E_c = AE_\gamma \cdot \left(1 + \frac{E_\gamma^{1+\epsilon}}{B + C \cdot E_\gamma}\right), \tag{2}$$

where a linear form $C + B \cdot E_\gamma$ was introduced to reduce the non-linear corrections for higher energy photons. Previously, when the attenuation length of the glass was set to 200 cm, the effects of light attenuation for low energy showers were smaller and a constant non-linear correction was able to accommodate both low and high parts of the energy spectrum. Shorter attenuation length increases the signal loses of low-energy showers because they tend to develop earlier along a FCAL block. High-energy showers develop later along the block and part of the shower can even leak-out at the back of the block. For this reason the non-linear correction needs to be adjusted for high energy showers. This is done by a linearly increasing denominator in the second term of Eq. 2. Fig. 1 shows the distribution of mean fractional cluster energy as a function of generated photon energy (dots). The black curve was obtained by fitting this distribution using Eq. 2. The red curve represents the fit by Eq. 1. Eq. 2 is similar to the one used in the Radphi [2] experiment to account for angular-dependent nonlinear energy and depth correlations in the forward calorimeter. In the case of the GlueX forward calorimeter, there is no evidence that fitting parameters A, B, C and ϵ in Eq. 2 depend on polar angle.

3 Photon momenta reconstruction

Photon energy can be obtained from reconstructed cluster energy by solving equation

$$E_\gamma = \frac{E_c}{A} - \frac{E_\gamma^{1+\epsilon}}{B + C \cdot E_\gamma}, \tag{3}$$

iteratively. The number of iterations for the given precision increases with photon energy but does not exceed 10 for 0.1% accuracy. After applying above equation to correct cluster energy, normalized photon energy becomes a flat function of generated energy (top plot in Fig. 2).

The average photon position in the FCAL along the beam (z) axis depends on photon energy through the expression for the average depth of showers in an electromagnetic calorimeter at normal incidence

$$z_A = X_0 \left[ln\left(\frac{E}{E_C}\right) + C_0 \right], \tag{4}$$

where X_0 is lead-glass radiation length, E_C is critical shower energy and C_0 is shower offset. Because the range of incident photon angles in the FCAL is small, the photon z-position,

$$z = Z_0 + z_A cos\theta, \tag{5}$$

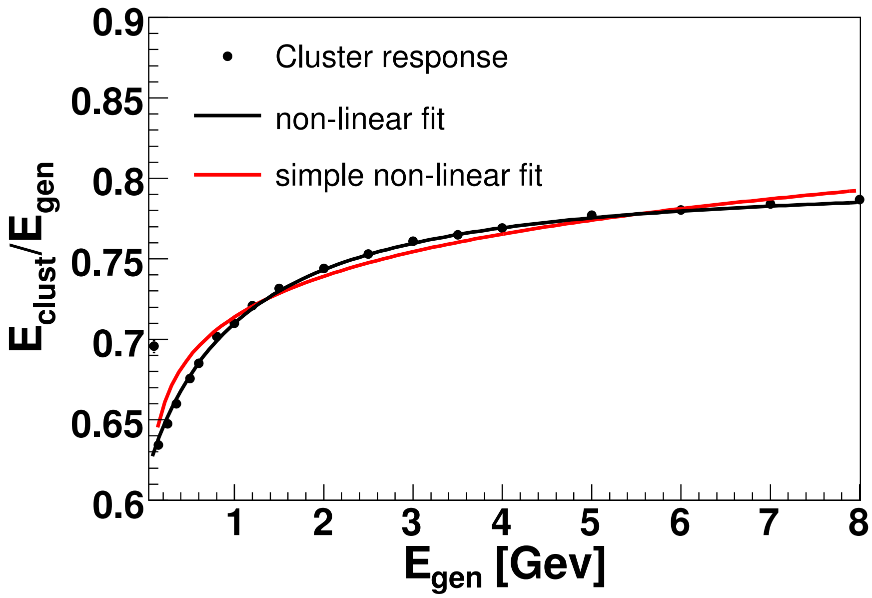


Figure 1: Reconstructed cluster energy normalized to generated photon energy (dots). Black line represents the fit by the function given in Eq. 2, while red line indicates simple power-law fit (Eq. 1).

where Z_0 is the distance between the target and FCAL, can be obtained iteratively without taking into account energy-angle correlation. However, in order to reconstruct photon incident polar angle correctly for the current GlueX setup, values for critical shower energy, E_C, and shower offset, C_0, needed to be modified from values used in the Radphi experiment: $E_C\,(0.014 \rightarrow 0.035)\,GeV$ and $C_0\,(2 \rightarrow 1)$. The bottom plot in Fig. 2 shows the difference between generated and reconstructed photon polar angle after shower-depth correction was taken into account.

Fig. 3 shows fractional energy resolution dependence on photon energy. The fit to standard expression for energy resolution

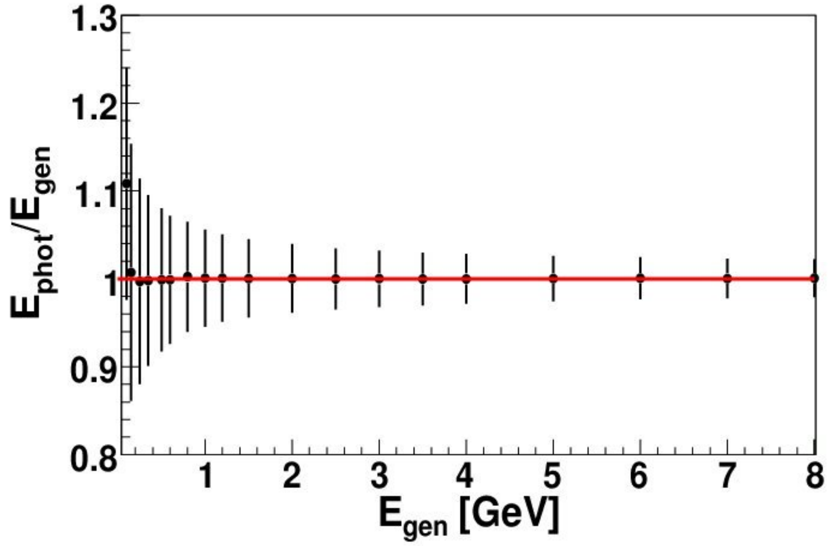
$$\frac{\sigma_E}{E} = \frac{A}{\sqrt{E}} + B, \tag{6}$$

gives $A = 5.6\%$ for the statistical term and $B = 0.6\%$ for the floor term.

References

[1] M. Kornicer, Photon reconstruction in the FCAL, GlueX-Doc-823, (2007)

[2] R. T. Jones, at al. A bootstrap method for gain calibration and resolution determination of a lead-glass calorimeter, Nucl. Inst. and Meth. A 566 (2006) 366.



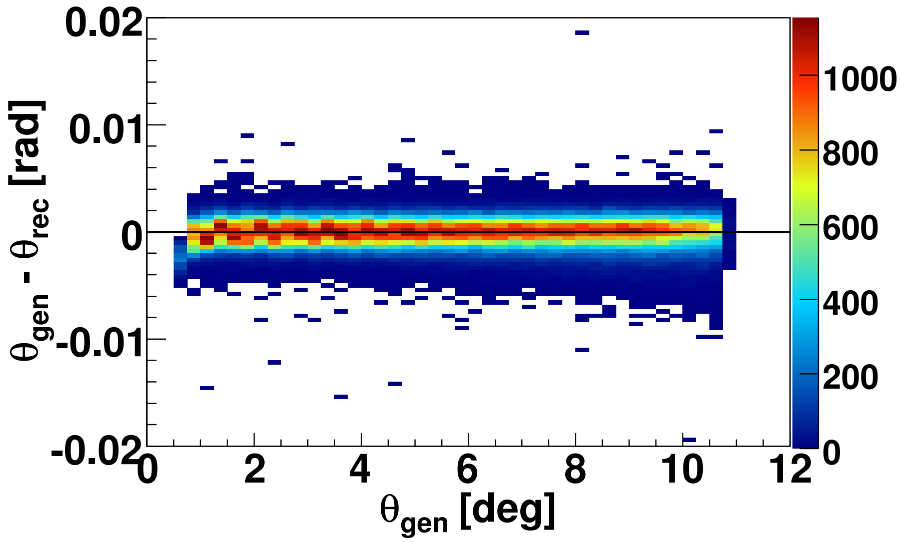


Figure 2: Normalized photon energy as a function of generated energy (top). The bottom plot shows the polar angle error as a function of generated photon angle.

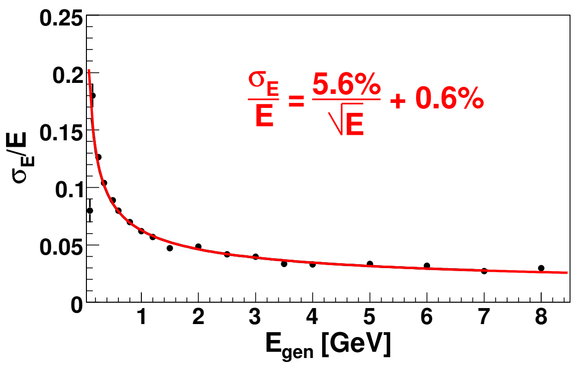


Figure 3: Fractional photon energy resolution fitted to the standard expression for calorimeter energy resolution.