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# A bootstrap method for gain calibration and resolution determination of a lead-glass calorimeter

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**Abstract**

We describe a method for calibration of a lead-glass calorimeter that does not require a beam of known energy. The technique was used to calibrate the RADPHI lead-glass calorimeter at Jefferson Lab. The technique described can be applied to any segmented electromagnetic calorimeter capable of detecting all-photon decays of mesons, for example, $\pi^0 \to 2\gamma$, $\eta \to 2\gamma$ or $\omega \to \pi^0\gamma$. We also demonstrate how the measured $2\gamma$ mass width of the $\pi^0$ and $\eta$ mesons can be unfolded to extract the single-shower energy and position resolution functions of the calorimeter.


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## 1. Introduction

The photon detector built for the RADPHI experiment [1] at the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility (Jefferson Lab) was designed to detect and measure all-photon decays of $\phi$ mesons photoproduced in a 50 MHz tagged bremsstrahlung photon beam. The primary component of this detector was a 620-element lead-glass electromagnetic calorimeter. This paper describes methods to determine the calibration and resolution characteristics of the detector without the use of a beam of known energy.

The lead-glass detector (LGD) is shown in Fig. 1. It consisted of 4 cm × 4 cm × 45 cm blocks arranged in a 28 × 28 cell array with an approximately circular shape. The long axes of the blocks were oriented parallel to the beam. The four central blocks were removed to permit the unscattered photon beam to pass to the photon beam dump. The array was instrumented with type FEU-84-3 phototubes. A one-piece support structure held the phototubes in place relative to the lead-glass array, one tube per block, with each phototube viewing its corresponding lead-glass block across a small air gap.

The front face of the LGD was positioned 103 cm downstream from the target and subtended an angle of approximately 27° from the beam line. The target was a Beryllium cylinder of length 2.53 cm, and diameter 2.87 cm. The compact target allowed the interaction vertex to be approximated as the target center. The interactions of interest produced photons with energies up to 5 GeV,

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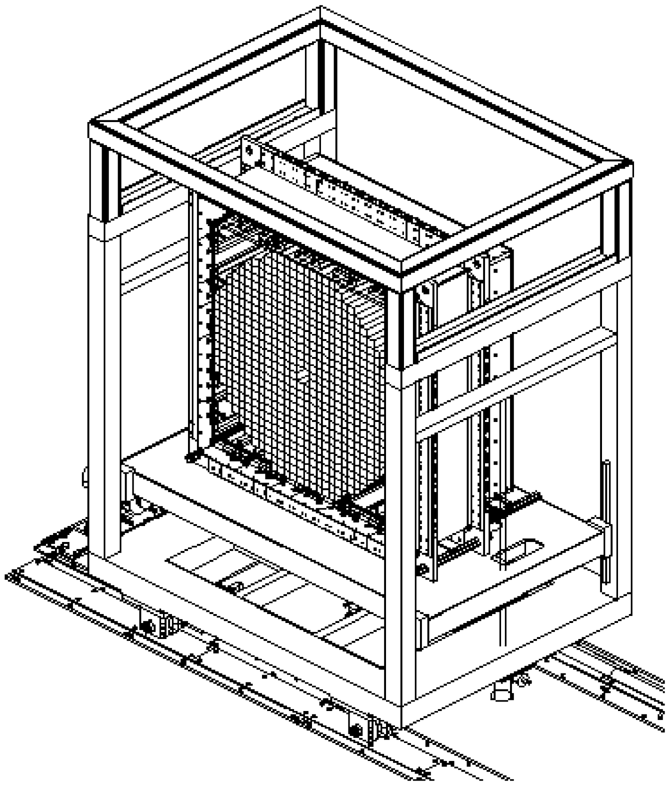

Fig. 1. The LGD mounted on its transporter; the glass stack is shown with the uninstrumented corner blocks removed for clarity.

generating electromagnetic showers that occupied several calorimeter cells. Photons with energies as low as 100 MeV could be reconstructed.

## 2. Shower reconstruction

### 2.1. Cluster finding

The photons to be reconstructed in the calorimeter are the decay products of mesons produced by interactions of the photon beam in the small cylindrical Beryllium target. Approximating the initial point of all produced photons as the center of the target, the direction of a photon is determined by the position of any space point along the axis of the shower generated by the photon in the calorimeter. The determination of the four-vector is completed by measuring the energy of the photon.

A photon incident on the calorimeter deposits energy in several neighboring LGD blocks. The first step in reconstructing the photon four-vector is to identify the blocks which shared the energy deposited by the electromagnetic shower.

The algorithm to associate groups of blocks into "clusters" has three steps.

In the first step, the algorithm searched the list of LGD block pulse heights for the block with the largest energy deposition, called the "seed" block. Neighboring blocks containing deposited energy are associated with the seed block to form a cluster. This procedure is then repeated to form clusters from the remaining blocks in the list. In each step, one considers only "active" blocks, i.e. those which are not already associated with clusters. Initially all blocks with ADC values over pedestal are active. Once one cluster is completed, the blocks in the cluster are removed from the list of active blocks and the process is repeated until the highest-energy block remaining is below some minimum seed energy, chosen to correspond to 150 MeV. At this stage the found clusters are no larger than $3 \times 3$ blocks and not all blocks in the active list are used, i.e. associated with a cluster.

In the second step, the clusters are expanded by incorporating unused blocks contiguous with clusters into the original groups. If a block is near two step-1 clusters, the block is associated with both clusters, its energy shared in proportion to the energy contained in the central portion of the clusters.

The third step repeats the first step but allows a seed block to have a lower minimum energy, chosen to correspond to 50 MeV. Once all possible seed blocks are exhausted, the cluster-finding procedure is finished.

### 2.2. Shower position and energy corrections

To a first approximation, the total energy of a reconstructed shower is equal to the sum of the observed energy in each of the blocks that belong to a cluster. For showers near normal incidence, improved resolution can be obtained by introducing a small nonlinear correction that takes into account a few-percent increase in the response of lead glass to showers above 1 GeV because of attenuation and light-collection efficiency effects in the blocks [2]. For showers at incidence angles above about 15°, however, the shower energy and centroid positions are coupled, requiring a more sophisticated approach.

To find the direction of the photon, a vector is constructed beginning at the center of the target and ending at the point $(X_c, Y_c, Z_m)$ where $X_c$ and $Y_c$ are the measured coordinates (discussed below) of the shower centroid in the transverse plane of the LGD and $Z_m$ is the estimated longitudinal coordinate of the maximum of the shower profile inside the LGD. The direction and energy of the photon that created the shower are written in spherical coordinates as $(E, \theta, \phi)$ where $\theta$ is the polar angle with respect to the beam direction and $\phi$ is the azimuthal angle in the transverse plane. At incidence angles of order 10° the reconstructed direction depends mainly on $(X_c, Y_c)$ and is insensitive to $Z_m$, while the dependence of reconstructed $E$ on $Z_m$ can be absorbed into the nonlinear correction described above. At incidence angles above 15°, however, the dependence of the reconstructed photon momentum on $Z_m$ must be taken into account explicitly. The acceptance of RADPHI depends upon reconstructing showers as far as 25° from the normal. Furthermore, at angles beyond 20° there are increasing effects from shower leakage out of the sides of the array, which introduces a bias in both the