Technical Note
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The Two-Photon Mass Resolution Measured by RadPhi

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Abstract

The translation from shower position and energy resolution in a calorimeter to the resolution in terms of two-cluster invariant mass depends upon the energy distribution of the photons and the target-detector geometry. Starting from the single-shower resolutions obtained with a similar calorimeter in the E852 experiment at Brookhaven, I estimate the width of the π^0 mass peak that is expected for the RadPhi experiment. In the analysis I distinguish between position-resolution and energy-resolution contributions to the mass width, and show under what circumstances each may be seen to dominate the error.

The two-photon mass resolution at the π^0 expected under the current *RadPhi* target geometry receives contributions from two sources: shower centroid resolution and shower energy resolution. From my study of electron showers in *E852* I obtained 1cm for the standard deviation on the shower centroid coordinates S_x and S_y relative to the electron impact measured by the tracking system in that experiment. The electron sample from *E852* contained showers of average energy 2-3GeV, somewhat higher than the average shower energy in *RadPhi*, but not by much. The range of incidence angles in the two samples is the same. I take 1cm to be achievable in the current experiment, at least for showers restricted to angles below 20^o which is the limit of the instrumented region of the wall at present. I approximate the error on the measured shower energy by the following formula,

$$\frac{\sigma_k}{k} = \frac{f_k}{\sqrt{k}} + f_0$$

where k is the gamma ray energy in GeV and $f_k = 8\%$. The constant term f_0 (nominally 2%) is neglected in what follows. The following linear approximation for the 2-photon invariant mass is good to 1% out to an opening angle of 4.0^o

$$m = \sqrt{k_1 k_2}\,\theta$$

The propagation of errors on the measured quantities k_1, k_2 and x, y leads to

$$\begin{aligned} V_m &= \left(\frac{\partial m}{\partial \theta}\right)^2 \left[\left(\frac{\partial \theta}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial \theta}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial \theta}{\partial y_1}\right)^2 S_{y_1}^2 + \left(\frac{\partial \theta}{\partial y_2}\right)^2 S_{y_2}^2\right] + \\ & \quad \left(\frac{\partial m}{\partial k_1}\right)^2 \sigma_{k_1}^2 + \left(\frac{\partial m}{\partial k_2}\right)^2 \sigma_{k_2}^2 \\ &\approx 2k_1 k_2 \left(\frac{S_x}{d}\right)^2 + \frac{m^2}{4} f_k^2 \left(\frac{k_1 + k_2}{k_1 k_2}\right) \end{aligned}$$

where d is the distance from the centre of the target to the effective mid-plane of the showers inside the lead-glass wall. This assumes that $S_x = S_y$. To go further I must assume a typical value for the lab energy $k_1 + k_2$ of the π^0. While some of the π^0's are directly produced in a quasi-two-body reaction and carry away essentially all of the incident photon energy, others appear in association with other mesons as decay products in a continuum below the two-body peak. Our trigger acceptance being what it is, most of the π^0's we record are of the second variety, as can be seen in Fig. 1, which shows the total energy of two-gamma clusters that form a π^0.

Fig. 1 was obtained after having made several calibration passes through the data from runs 3013-3014 to obtain approximate calibration constants for the individual blocks. This was necessary in order to clearly identify the π^0 peak. The placement of the π^0 mass window is shown, for this rough calibration, in Fig. 2. This data sample contains all of the two-cluster events accepted by the trigger in runs 3013-3014, subject to the following two additional cuts. These were applied offline in order to enrich the sample with π^0's.

1. fiducial cut: centroid of all clusters must lie outside of a circle 10cm in diameter centred on the beam hole in the LGD.

2. total energy cut: energy sum of all clusters must be greater than 1GeV.

Note that the width of the π^0 peak in Fig. 2 is NOT an accurate reflection of the experimental resolution of our apparatus under the above conditions because the plot is made using the same data as was used to generate the calibration. It is shown here only to indicate how the π^0 energy spectrum (Fig. 1) was obtained for this data sample. The total energy cut was suspended in making Fig. 1 so that the full spectrum would be visible.

In the following I consider a π^0 with 1.5GeV in the lab. These pairs have a maximum lab opening angle of 10^o and appear as clusters separated by about 23cm in the LGD, where I take $d = 124$cm, the sum of the

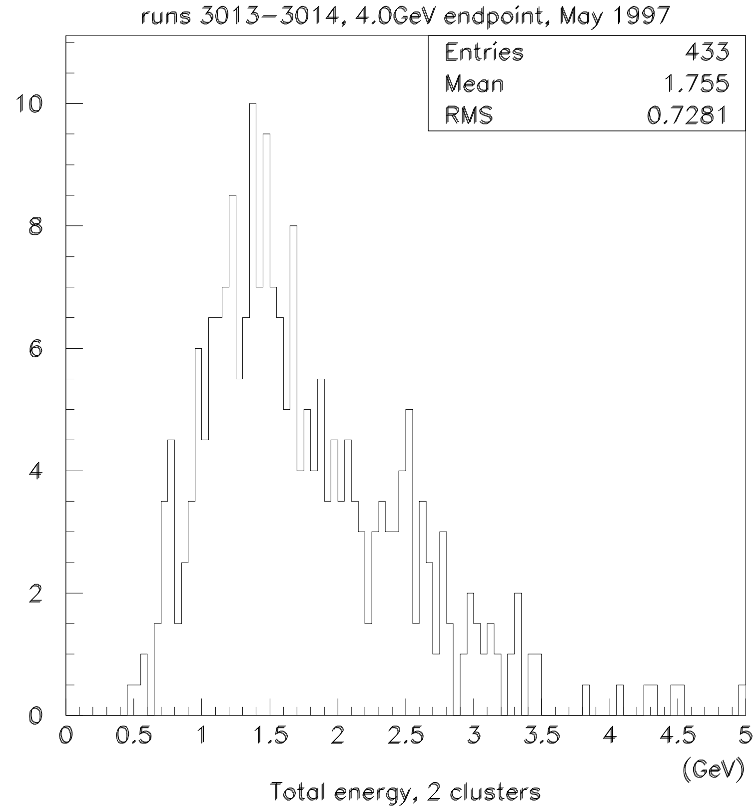

Figure 1: Distribution of total energy in the calorimeter for two-cluster events that fall near the π^0 in invariant mass. The trigger required some minimum total energy in the calorimeter, zero charged particles within the forward acceptance, coincidence with a tagged bremsstrahlung photon of energy at least 3.2GeV, and a charged particle in the recoil proton detector.

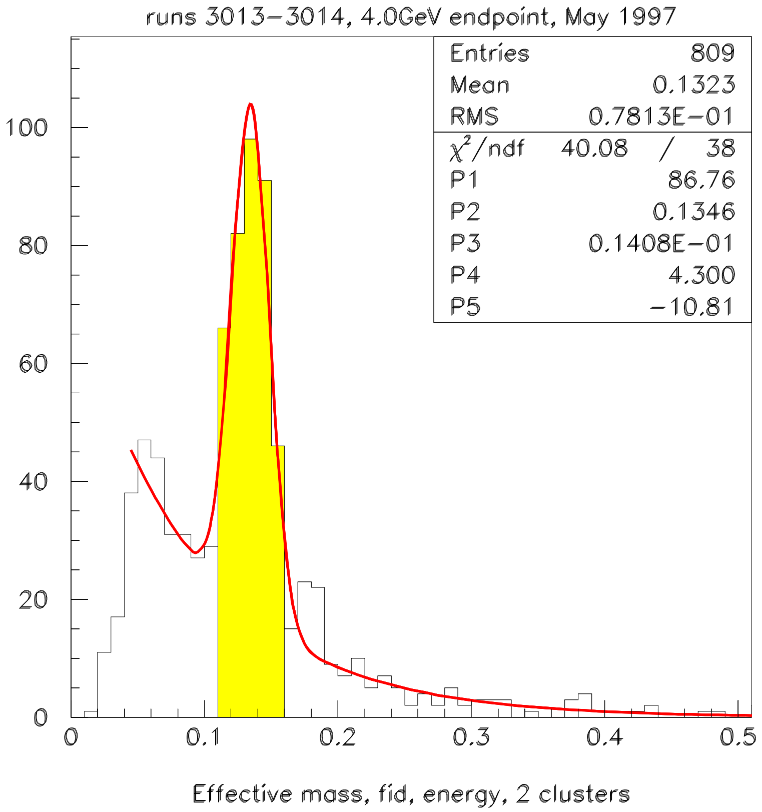

Figure 2: The histogram is the entire 2-cluster data sample once the cuts described in the text have been applied, and a calibration has been performed. The mass peak is somewhat artificially narrowed due to the fact that the same data set is plotted here as was used to perform the calibration.

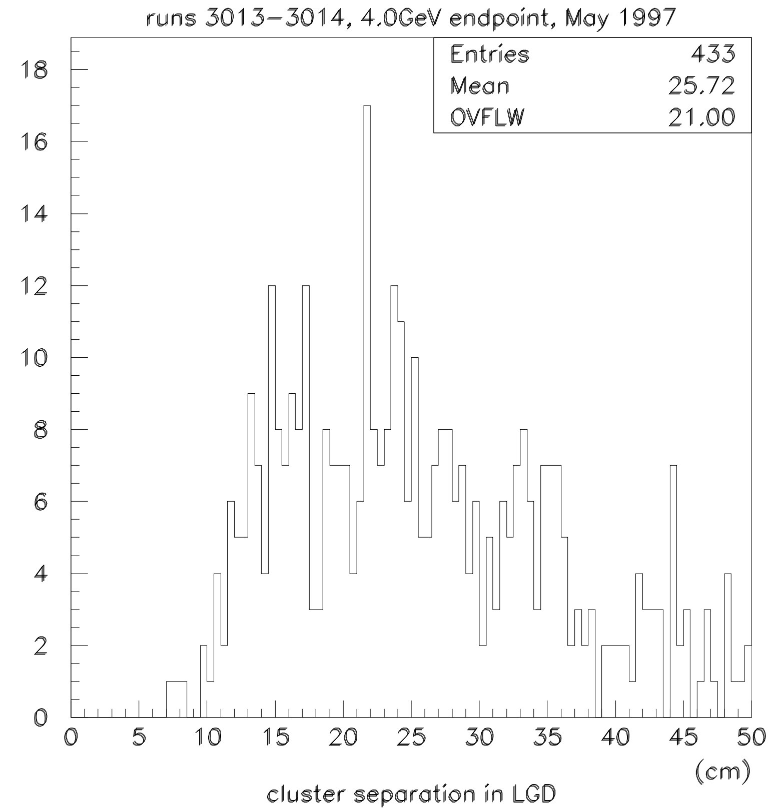

Figure 3: Distribution of the distance between two clusters on the entrance face to the lead glass wall for all two-cluster events passing the π^0 cuts described in the text.

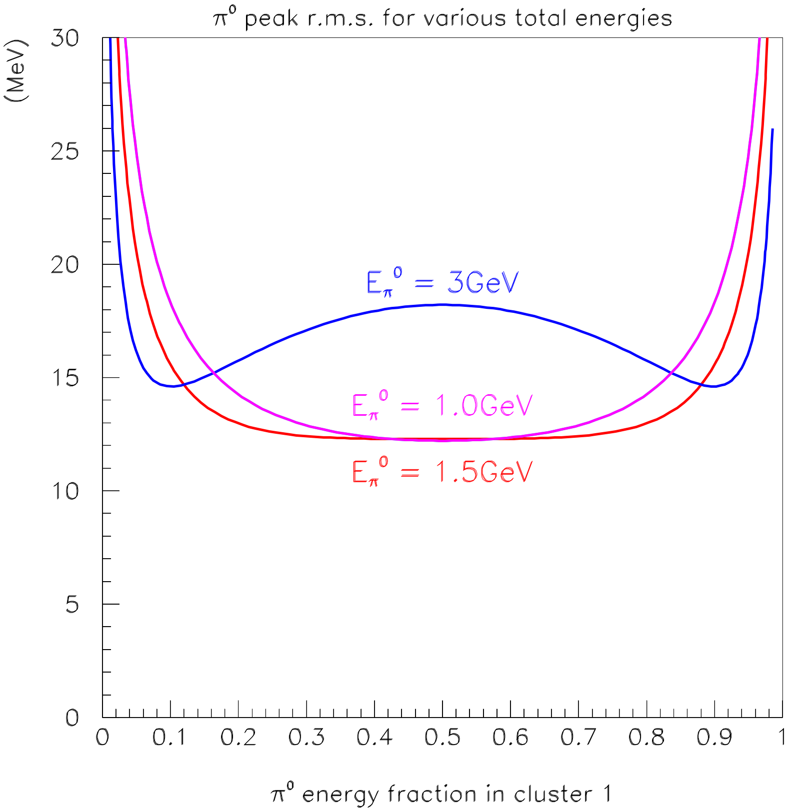

Figure 4: Expected 2γ invariant mass at the π^0 *vs* x the fraction of the energy carried by one of the photons, for various values for the energy of the initial π^0.

target-LGD distance of 109cm and average shower penetration depth 15cm. The full distribution is shown in Fig. 3, including all clusters represented in Fig. 1. From the above equation for V_m the r.m.s. width of the π^0 mass peak is plotted in Fig. 4 *vs* the fraction x of the total energy carried by one of the clusters (symmetric under exchange of clusters). The mass resolution degrades as the energy of the π^0 increases above 1.5GeV, where the separation between the clusters has decreased to the point where cluster centroid error becomes dominant in determining the mass resolution. This crossover will take place at higher energies for the η meson. This shows that if we exclude the very asymmetric cluster pairs then we should be able to achieve a width of less than 15MeV for π^0's below 2GeV total energy.

To show the sensitivity of these results to the inputs S_x and f_k I evaluated the π^0 peak r.m.s. at $x = 0.5$ *vs* both of these parameters over a large range. The results are shown as a contour plot in Fig. 5. Note that a value for f_k greater than 8% can be used to estimate the effects of imperfections in the block-to-block calibration of the LGD. The red star shows what should be achievable under the current configuration of the experiment. Unfortunately the limited statistics we were able to collect during the May run at 4.0GeV may not be sufficient to demonstrate this on a sample independent from the one used for calibration. But this simple calculation indicates what we can expect to achieve.

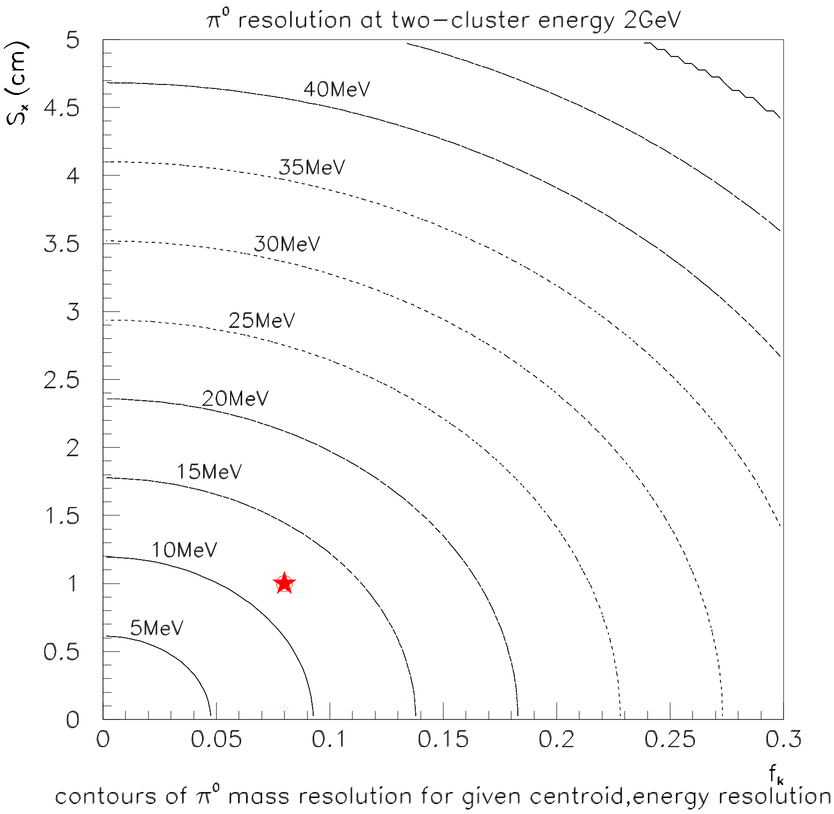

Figure 5: The histogram is the entire 2-cluster data sample once the cuts described in the text have been applied, and a calibration has been performed. The mass peak is somewhat artificially narrowed due to the fact that the same data set is plotted here as was used to perform the calibration.