An Estimate of the Expected π^0 Mass Resolution from BCAL Measurements

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Abstract

This note summarizes a simulation study carried out to estimate the response of the BCAL calorimeter in measuring the the π^0 mass for the reaction $\gamma p \to b_1^+(1235)\pi^0 n$ where the $b_1^+\pi^0$ mass is 2 GeV/c^2 and the $b_1^+(1235)$ decays into $\omega\pi^+$ The assumed energy resolution and time resolution of BCAL used here is based on preliminary results of the BCAL test run in September 2006. This is a preliminary estimate of the mass resolution – a full GEANT simulation with a proper photon reconstruction also taking into account energy degradation due to material (tracking chamber endplates and cables, for example) is in progress or will be soon.

Overview: One of the signature reactions for exotic hybrid searches in GlueX is the reaction $\gamma p \to b_1^+(1235)\pi^0 n$ where $b_1^+(1235)$ decays into $\omega\pi^+$ and $\omega \to \pi^+\pi^-\pi^0$. Favored decay modes of an exotic hybrid are into $q\bar{q}_P + q\bar{q}_S$ (*e.g.* $b_1 + \pi$). To identify an exotic $J^{PC} = 1^{-+}$, in particular $C = +$, we want $I = 1$ for $b_1\pi$, hence non-zero charge. The final state for this reaction is $\pi^+\pi^-\pi^0\pi^+\pi^0 n$. In this note we focus on the π^0 from the ω decay and the bachelor π^0 when both photons from each π^0 decay are detected by BCAL. We assume a $b_1^+\pi^0$ mass of 2 GeV/c^2 and an incident photon energy of 9 GeV.

BCAL Resolution Based on Preliminary Test Run Studies: A preliminary analysis of the test data from the BCAL September 2006 test run number 2334, where the photon beam was incident on the BCAL module at the center and at 90°, yields the following for the energy resolution and time resolution:

$$\frac{\sigma_E}{E} = \frac{0.05}{\sqrt{E}} + 0.02 \tag{1}$$

$$\sigma_t(\text{ps}) = \frac{106}{\sqrt{E}} + 150 \tag{2}$$

where E is in GeV. The energy resolution was obtained by doing a crude estimate of the calibration constant (conversion of ADC counts into energy) by comparing the geometric mean of the sums of phototubes at the North end of the BCAL module and the South end to the energy reported by the photon beam tagger. The phototube gains were sufficiently well balanced prior to the run so that a single calibration constant for all phototubes yielded results for energy resolution that were close to expectations. The Gaussian width of the distribution of energy difference between calorimeter and tagger energy, for various bins of tagger energy (see Figure 1(a)), was fitted to a function of the form $a/\sqrt{E} + b$ and the result was the values for constants shown in equation 1. Blake Leverington did a proper calibration by allowing the calibration constant for each phototube to vary and minimized the width of the energy difference distribution. His resulting resolution function has a statistical term (a) that agrees with what I obtained and a floor term (b) which is a factor of two smaller and in line with expectations from KLOE.

I estimated the time resolution (see Figure 1(b)) by doing a Gaussian fit to the distribution of TDC difference between North and South phototubes for phototube pairs 7 and 8 (first two layers of the middle) for bins of tagger energy to obtain σ_t(ps) as a function of E. This was fitted to a form $c/\sqrt{E}+d$. Note that the fit parameters $c = 106 \pm 13$ and $d = 150 \pm 22$ should be compared to the nominal KLOE numbers of 54 and 136 respectively. I did not correct for the finite width of the photon beam. Blake will be doing a much more refined estimate of the time resolution including the variation as a function of angle and position along the module. In what follows I make the simple assumption that the time resolution is constant along the module and equal to the value at the center.

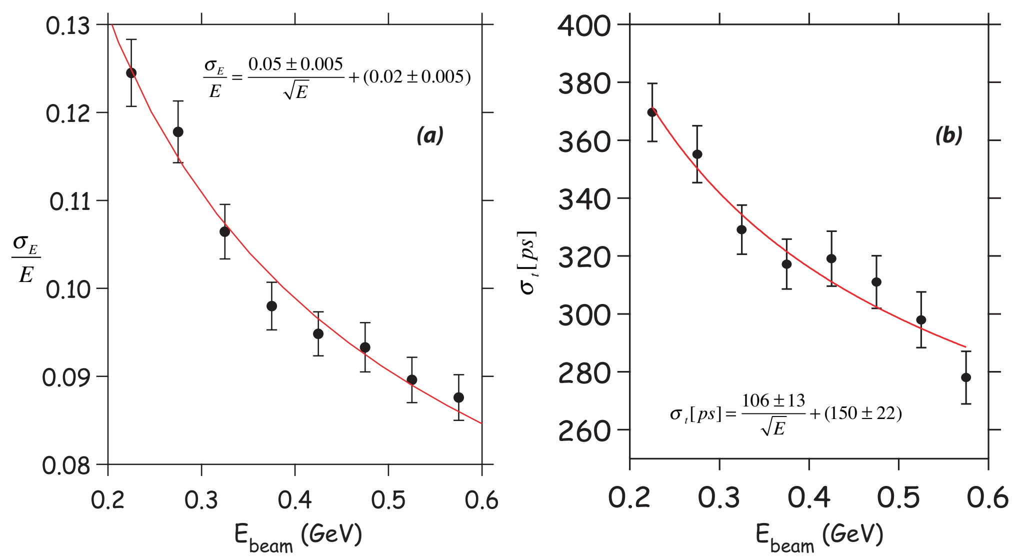

Figure 1: (a) Dependence of σ_E/E for BCAL as a function of incident photon energy. The curve is a result to a fit of a function of the form $a/\sqrt{E}+b$ where $a = 0.050 \pm 0.005$ and $b = 0.020 \pm 0.005$; (b) Dependence of σ_t for BCAL as a function of incident photon energy. The curve is a result to a fit of a function of the form $c/\sqrt{E}+d$ where $c = 106 \pm 13$ and $d = 150 \pm 22$.

Other BCAL Assumptions: In this simulation I assume that the velocity of light propagation down the BCAL fibers is 1.6×10^8 m/s that takes into account the index of refraction of the fiber and light bounces[1]. This translates into the resolution in z, δz, as a function of photon energy, E_γ, as shown in Figure 2(a). The asymptotic value of $\delta z \approx 4$ cm is consistent with what it quoted in the Design Report[2].

Assuming a BCAL inner radius of 0.65 m and a target center to downstream end of BCAL distance of 3.42 m, we can estimate the relative error in polar angle as a function of angle from the forward-most angle that intercepts BCAL – an angle of $\approx 11°$ – to 90°. The polar angle resolution is shown in Figure 2(b) for photon energies of 0.1, 0.5, 1.0 an 2.0 GeV and is not consistent with what is quoted in the Design Report[3].

Guided by the Design Report and based on Jetset results, the azimuthal position resolution is expected to be given by 5 mm/$\sqrt{E}$ or ≈ 7.7 mr for a 1 GeV photon.

[1] GlueX Design Report of October 2004 - page 84.
[2] ibid. pg 73.
[3] Matt Shepherd pointed out earlier that the errors in the Design Report were underestimated.

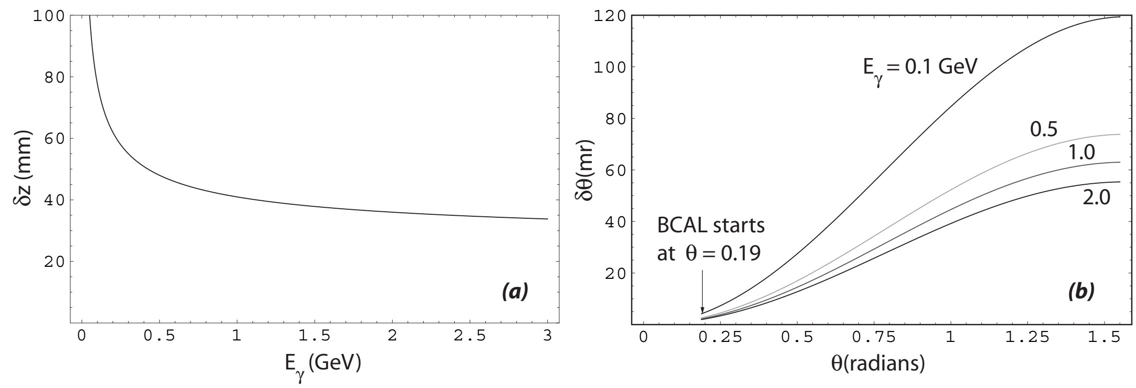

Figure 2: (a) Expected error in z position as a function photon energy, E_γ, using equation 2; (b) Expected error in polar angle, θ_γ as a function of θ_γ for various photon energies for photons entering BCAL.

Simulation Details: In this note I only considered events in which the four photons from the bachelor π^0 and the π^0 from the decay of the ω were detected by BCAL. The distribution of photon energies and angles is shown in Figure 3 and the correlation of angle and energy is shown in Figure 4.

Figure 5 shows results of a Gaussian fit to the diphoton mass distribution for photons from the the bachelor π^0 and from the π^0 from the decay of the ω. The corresponding π^0 mass resolutions are 12.3 and 13.0 MeV respectively using the resolution functions of equations 1 and 2. If I use the nominal KLOE numbers for energy and time resolution, the corresponding mass resolutions are 10.7 and 11.7 MeV.

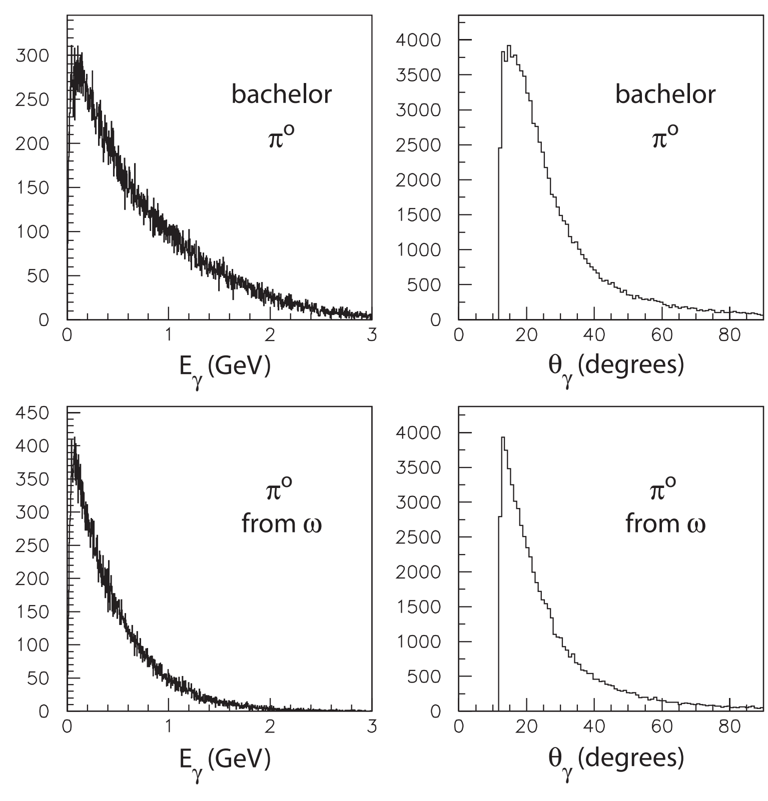

Figure 3: Distribution in energy and polar angle for photons entering BCAL.

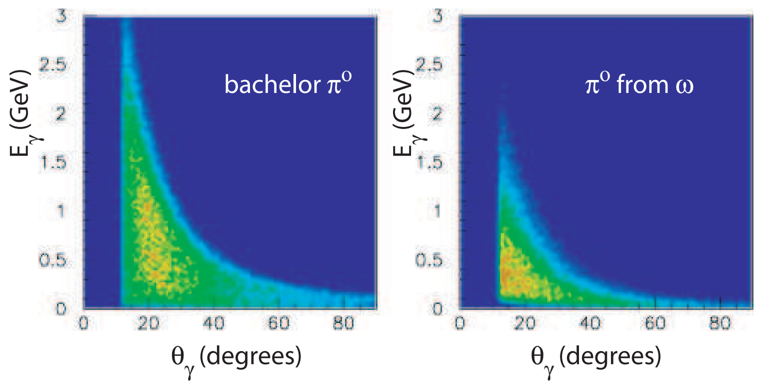

Figure 4: Correlation of energy with polar angle for photons entering BCAL.

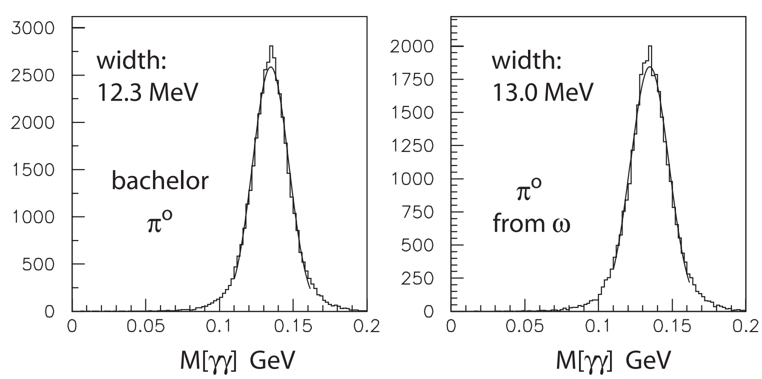

Figure 5: The plots show results of a Gaussian fit to the diphoton mass distribution for photons from the the bachelor π^0 and from the π^0 from the decay of the ω. The corresponding π^0 mass resolutions are 12.3 and 13.0 MeV respectively using the resolution functions of equations 1 and 2. If I use the nominal KLOE numbers for energy and time resolution, the corresponding mass resolutions are 10.7 and 11.7 MeV.