Brief GlueX Note
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Reconciling Photoelectron Yield Estimates for the BCAL Test Module

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This note summarizes some of the information we have on photoelectron yields (N_{pe}) from measurements with cosmic rays and photon beam. We also examine to what extent these numbers are consistent.

N_{pe} from photon data

Alex Estimate - method 1: I estimated N_{pe} per end of the prototype BCAL module from the beam test Run 2334 - beam normally incident at the center. For each of eight bins in beam energy, from 200 to 600 MeV, I plotted the distribution in the ratio of the north sum to the south sum and fitted the resulting distribution, for each energy bin, to a Gaussian, yielding μ_R and σ_R. Under the assumption that the number of photoelectrons per end, N_{pe} is given by:

$$N_{pe} = 2\frac{\mu_r^2}{\sigma_R^2}$$

the photoelectron yield per end is plotted in Figure 1 as a function of beam energy. A fit to a straight line:

$$N_{pe} = a + b \cdot \mathrm{E(MeV)}$$

yields $a = 14 \pm 4$ and $b = 0.634 \pm 0.01$. Extrapolating to 1 GeV gives us 647 ± 10 photoelectrons.

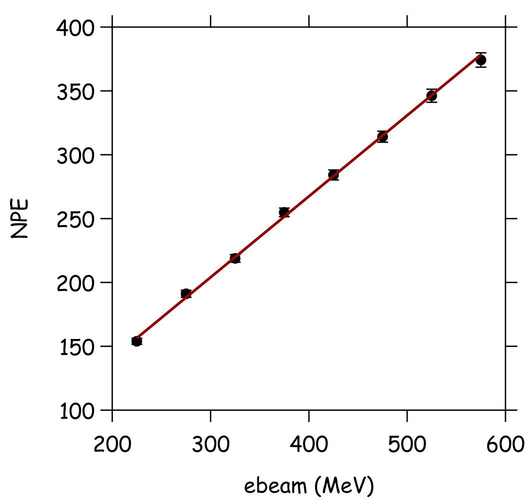

Figure 1: The number of photoelectrons per end of the BCAL module as a function of energy.

Alex Estimate - method 2: For the highest energy point (575 MeV) in Figure 1, the number of photoelectrons is 374 ± 6. Another approach is to apply the technique to each of the 18 channels to get a number of photoelectrons per channel and then add. The total number of photoelectrons in the 6 channels in the center of the module (channels 7 through 12) is 373 ± 7. Summed over all channels the total number of photoelectrons is 440 ± 8. Applying the scaling factor of $440/374 = 1.18$ to the 647 ± 10 photoelectrons at 1 GeV found above, the new number is 761 ± 12 photoelectrons at 1 GeV.

Blake Estimate: Blake did a similar calculation (e-mail communication on 1/7/2007) using a Poisson fit rather than a Gaussian fit. He finds that at 500 MeV $N_{pe} = 292$. At that energy Alex's estimate is $N_{pe} = 330 \pm 8$.

Comparison with KLOE: Alex and Blake get consistent N_{pe} estimates. Alex's extrapolations to 1 GeV lie between 650 and 760 photoelectrons. KLOE quotes $N_{pe} \sim 700$.

N_{pe} from cosmic ray data:

Andrei estimates $N_{pe} \sim 25$ per end per channel for events where the cosmic ray traverses three channels, one on top of the other. I note here that one of the KLOE studies of blue fibers coupled directly to a bi-alkali photocathode 2 m from a crossing minimum ionizing particle yields about 2 photoelectrons per mm of traversed fiber (actually they quote 1.7 to 2.25. Using this, one would expect $N_{pe} \sim 38$ per channel in our case compared to our observed $N_{pe} \sim 25$. The difference may be due to coupling of the fiber to phototube.

Reconciling photon data and cosmic ray data:

In an earlier analysis Alex finds that for contained cosmic rays in a single layer (a layer consists of three channels - one on top of the other) the summed ADC distribution peaks at 1007 channels. From beam data, Alex and Blake find a consistent overall conversion of ADC counts to energy - Alex's number is 0.107, that is, energy = $0.107\times$ ADC counts. So a vertical penetrating cosmic ray is equivalent to a photon horizontally incident with energy 107 MeV. Based on Andrei's estimate of $N_{pe} \sim 75$ for three channels, a 107 MeV photon should yield $N_{pe} \sim 75$ per end. Extrapolating this to 1 GeV corresponds to ~ 700 photoelectrons.

A vertically incident cosmic ray passes through 3 channels. Each channel is 3.8 cm thick and on average corresponds to 1.9 cm of scintillating fiber. Assuming an energy loss of 2 MeV/cm in scintillator, that corresponds to 3.8 MeV per channel or 11.4 MeV for three channels. The equivalence of a vertically passing cosmic ray to a 107 MeV photon corresponds to a sampling fraction of about 11%, assuming more or less full shower containment for the photon.

Photoelectron yield estimates for cosmic data:

Based on KLOE numbers we should expect $N_{pe} \sim 38$ per channel for cosmic rays. Can we understand this from first principles? For scintillator, the photon yield per MeV of deposited energy is $N_0 = 8000$ photons/MeV. We showed above that the energy deposited in scintillator per channel is $E_{dep} = 3.8$ MeV. From the Bicron brochure, the minimum capture ratio for single-clad fibers is $f_{cap} = 0.034$. In our study of the emission spectra for blue and green fibers (GlueX-doc-924) we saw that for a XP2020 coupled to blue fiber

2 m from the source, the fraction of light surviving is $f_{surv} = 0.24$. In that same note we estimate the average XP2020 quantum efficiency to be $QE = 0.14$ assuming a blue fiber. So the N_{pe} should be:

$$N_{pe} = N_0 \cdot E_{dep} \cdot f_{cap} \cdot f_{surv} \cdot QE = 35$$

For BCAL we are using double-clad as opposed to single clad fibers and the improvement in the capture ratio should be 5/3 which would yield $N_{pe} \sim 58$. The light guide used for the BCAL test may have a transmission of ~ 0.6 which would get us back to $N_{pe} \sim 38$.