The Lead/Scintillating Fibre Barrel Calorimeter (BCAL)

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Outline

The BCAL in GlueX

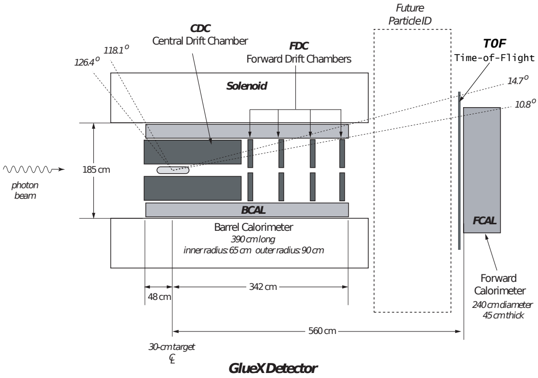


Figure: Schematic of the GlueX Detector. The detector has cylindrical symmetry about the beam direction.

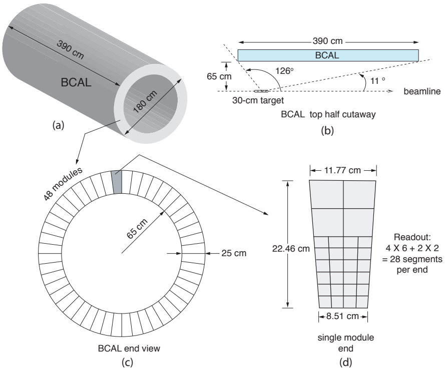


Figure: The GlueX BCAL. (a) BCAL schematic; (b) a BCAL module side view; (c) end view of the BCAL showing all 48 modules and (d) an end view of a module showing readout segmentation.

The calorimeters play multiple roles: Primarily, they are to detect the photons from η and π^0 decays; The positions and energies of the photons must be determined with sufficient accuracy and resolution resolution to allow for a complete kinematic reconstruction of the event. Secondarily, some dE/dx and PID information.

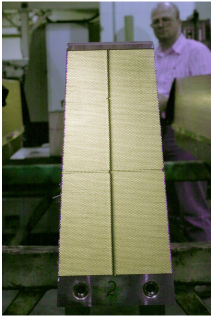


Figure: A photograph of a final production module for the BCAL.

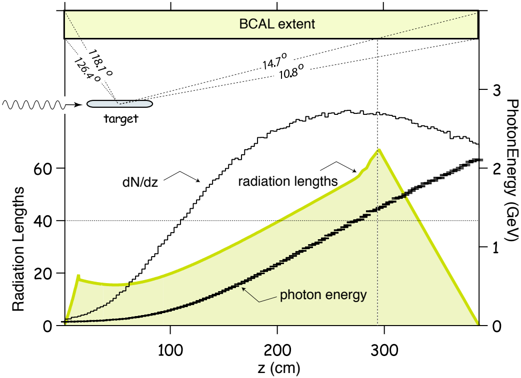


Figure: The distribution of photons, their energy and integrated path length through the Pb/SciFi matrix as a function of position along the length of the BCAL for one of the GlueX signature reactions, $\gamma p \rightarrow \eta\pi^0 p \rightarrow 4\gamma p$, is shown. The target position and angular range subtended by the BCAL are also presented.

Module Details

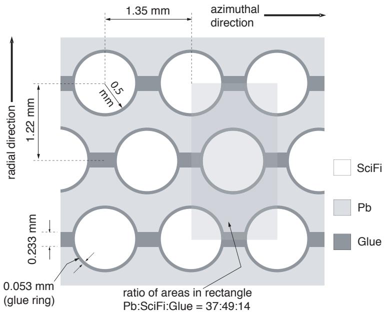


Figure: The BCAL fibre matrix showing the placement of 1 mm diameter fibres in the azimuthal and radial directions. Particle tracks would appear to enter the matrix from the bottom.

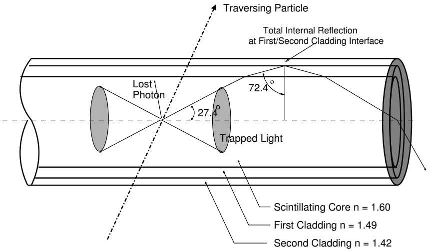


Figure: A simple schematic of a standard double-clad fibre showing the trapping of optical light for meridional rays.

- 0.96 mm core of doped polystyrene and two layers of polymethylmethacrylate cladding: acrylic (3%) and fluor-acrylic material (1%).
- the passage of ionizing electrons through the core produce 8000 optical photons/MeV (disputed)

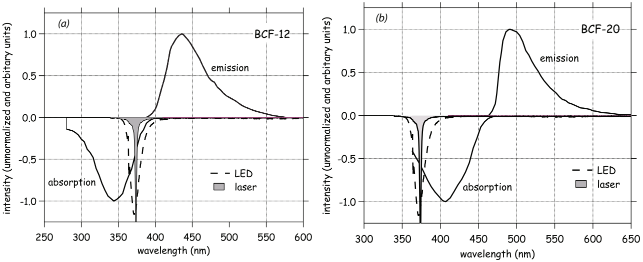
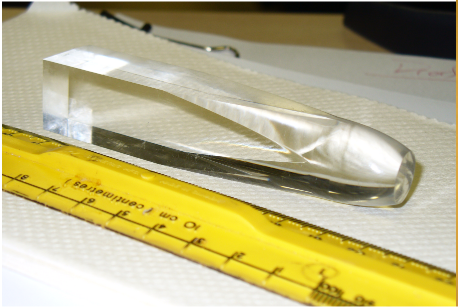


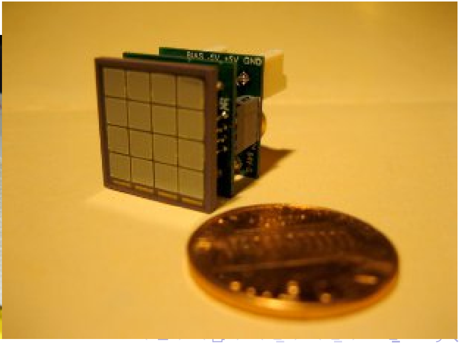
Figure: Emission and absorption spectra from the secondary dye of (a) blue BCF-12 and (b) green BCF-20 fibres.

- Kuraray SCSF-78MJ fibres are used for the production modules
- each 1mm fibre will trap ∼5.3%(min.) (total internal reflection) of the produced light in the fibre
- the fibres have an average bulk attenuation length of ∼350 cm.
- the readout detectors must be sensitive to the optical spectrum of the fibres

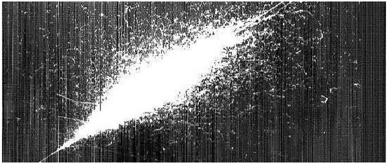
Readout

- Attached to the end of each module is an array of acrylic light-guides to concentrate the light to a smaller area which is read-out a Silicon Photomultiplier array.
- The large amount of noise from the SiPM sets the threshold for the energy in each BCAL cell.





Electromagnetic Showers



Reminder: radiation length is both (a) the mean distance over which a high-energy electron loses all but 1/e of its energy by bremsstrahlung, and (b) 7/9 of the mean free path for pair production by a high-energy photon

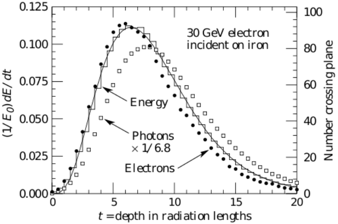


Figure: The fractional energy deposition per radiation length.

Total thickness of the BCAL perpendicular to the beam : $15.5X_0$ where $X_0 = 7.06$ g/cm^2 or 1.45 cm.

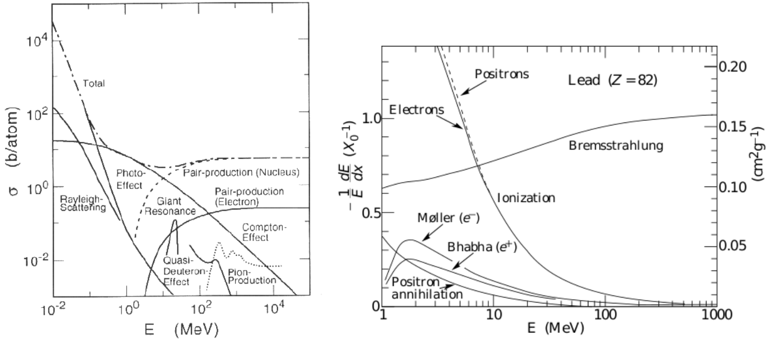


Figure: (left) Photon total cross sections as a function of energy in lead. (right) Fractional energy loss per radiation length in lead as a function of electron or positron energy. Electron (positron) scattering is considered as ionization when the energy loss per collision is below 0.255 MeV.

- Note: A small fraction (0.2%) of the bremsstrahlung energy will produce hadrons.

Energy Resolution

- The BCAL is a sampling calorimeter: an active medium (Sci.Fi.) which generates signal and a passive medium as an absorber (lead).
- the stochastic term a for a sampling calorimeter is expected to be proportional to $\sqrt{t/f}$, where t ($\sim 0.5mm$) is the absorber thickness and f is the sampling fraction (f $=$ 12.5%).
- Intrinsic shower fluctuations result in a stochastic term in the energy resolution: due to sampling fluctuations($\sim$4%), photoelectron statistics ($\sim$2%), and dead material in front of the calorimeter.
- Detector non-uniformity and calibration uncertainty result in a systematic, or constant, term.

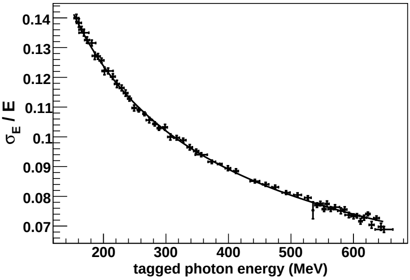


Figure: Energy resolution vs. E_{BEAM} for photons for $\theta = 90^\circ$ and $z = 0$ cm.

From JLAB2006 photon beam test in Hall-B:

$$\frac{\sigma_E}{E} = \frac{5.4\%}{\sqrt{E(\mathrm{GeV})}} \oplus 2.3\%, \qquad (1)$$

Timing Resolution

- the double ended readout allows for the position of the shower to be determined
- a time difference resolution from the beam test of $\sigma_{\Delta T/2} = 70$ ps/$\sqrt{E(\text{GeV})}$ ps.
- this results in a position resolution of $\sigma_z = 1.1$ cm for a 1 GeV photon.
- energy and position resolution agree with KLOE's beam test results.

Monte Carlo: What do we expect?

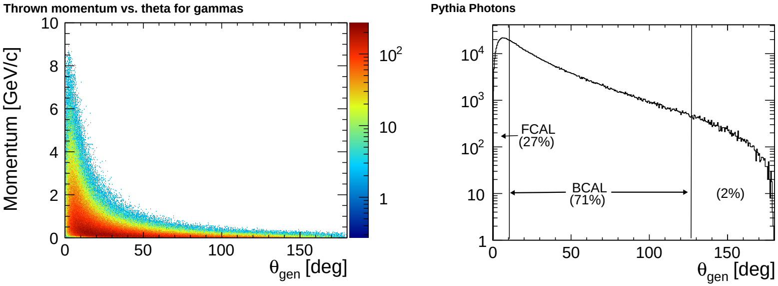


Figure: (left) Generated momentum vs. θ distribution for photons from PYTHIA decays. (right) The projection of (a) onto the θ axis.

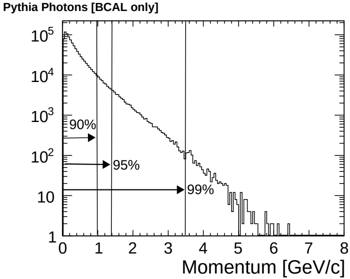
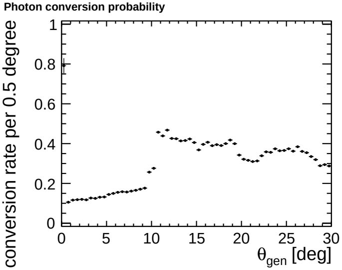


Figure: The momentum distribution for photons which would strike the BCAL only.

The BCAL in the Monte Carlo

- Energy and timing resolutions from the beam test have been encoded in HDGEANT along with sampling fluctuations (from other Monte Carlo) and expected SiPM detector noise.
- Cells with hits close by that exceed a threshold are clustered together to create a "DPhoton" object.
- How does the other detector material affect the BCAL?
- Generate photons with a range of energy (0 to 4 GeV) and illuminate the entire BCAL!



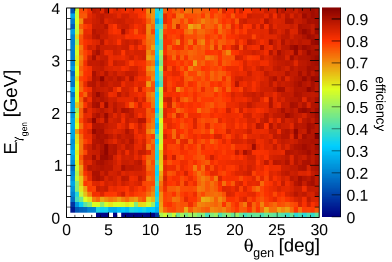
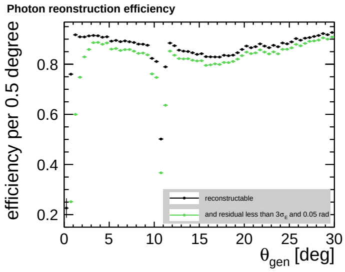


Figure: (left) Single photon conversion probability as a function of incident polar angle from 0° to 30°. (right) Single photon reconstruction efficiency as a function of energy and polar angle.



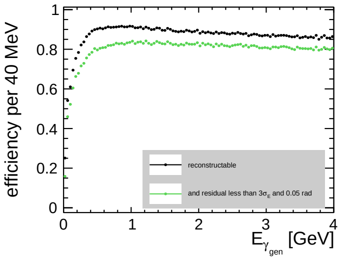


Figure: (left)The polar angle projection from previous slide. The efficiency clearly degrades in the gap region. (right) The energy axis projection from previous slide.

let's try an $\eta\pi^0 \rightarrow 4\gamma$!

What if we use everything we've learned and try to reconstruct $\eta\pi^0 \rightarrow 4\gamma$.

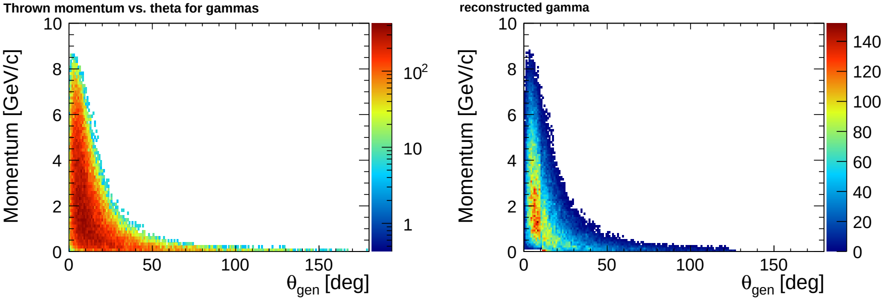


Figure: The momentum versus polar angle distribution for photons from $\eta\pi^0 \rightarrow 4\gamma$ decays. (left) Thrown events and (right) reconstructed events shown with a linear scale to show the gap in efficiency at $\theta_{gen} = 10^0$ more clearly.

Not everything is perfect...

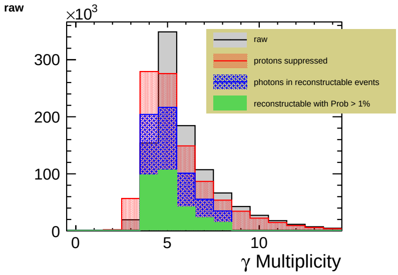


Figure: Photon multiplicity for reconstructed $\eta\pi^0 \rightarrow 4\gamma$ signal events.

- Extra clusters are formed in many cases (split-offs, conversions in other detectors) Messy!
- Events with charged particles are even messier, as they will also form clusters.

Summary

- the final BCAL modules are currently being constructed in Regina
- the properties of the BCAL are well understood and are included in MC
- the BCAL seems to function well in MC to reconstruc $\eta\pi^0$ decays
- however, some improvements in reconstruction are still needed to identify photon showers properly with the BCAL