BCAL Length Study using HDFast

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A series of HDFast simulations are presented, in order to help determine the minimum length required for the BCAL.

I. INTRODUCTION

A matter of continuing discussion within the GlueX Collaboration is the optimal length of the Barrel Calorimeter (BCAL). This has an impact on the location and operation of a number of components of the GlueX spectrometer, including the Cerenkov detector, the TOF wall, and the forward Lead Glass Detector (LGD). Together, the BCAL and LGD are solely responsible for the detection of photons through electromagnetic calorimetry, and so it is desirable to not have any gaps in acceptance between the two detectors, provided this requirement does not interfere with the optimal placement and operation of the TOF wall and Cerenkov.

This question can be partly addressed with the use of HDFast simulations. In order to speed-up program execution, MCFast by default ignores multiple scattering and energy loss in its initial track "tracing" but includes them in the second-iteration "pseudo-fit". This results in particle tracks which are a good representation of the true detector performance, but the detector hits all fall along a track with no scattering and may not be appropriate for pattern recognition studies [1]. This is particularly inappropriate for charged particle studies, where cumulative energy loss and multiple scattering can result in a particle trajectory in the solenoidal magnetic field which differs greatly from the ideal case. For photons, however, which travel in straight line tracks, the approximations normally implemented in MCFast may not be as bad, in which case HDFast can be an appropriate tool for photon acceptance studies.

Here, I present a series of HDFast simulations for various LGD and BCAL geometries, to constrain the minimum acceptable length necessary to avoid significant gaps in the acceptance between the LGD and the BCAL.

II. SIMULATIONS ASSUMING A 172 CM SQUARE LGD

The first set of simulations were performed using the default LGD geometry, as coded into HDFast (`usr_lgd.c`) as of April, 2004. In this case, the LGD is a square array of dimension 172×172 cm^2, with its front face located at $z = 575$ cm in the Hall D reference frame. The four middle crystals are removed, creating a beam hole of 8×8 cm^2. The BCAL has an inner radius of 65 cm, with its upstream edge located at $z = 17$ cm. The target is located at $z = 50$ cm.

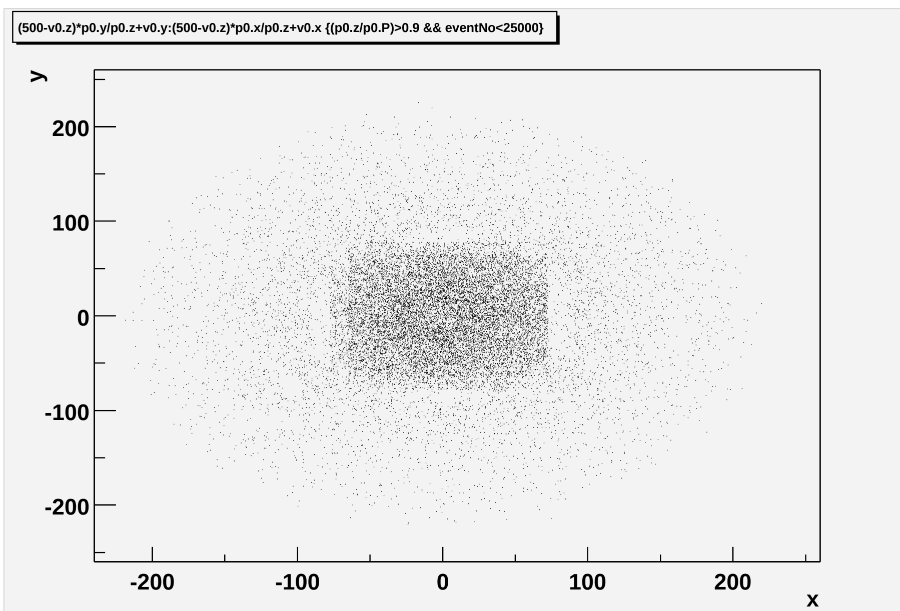

FIG. 1: Forward going photon tracks projected onto an imaginary plane at $z = 500$ cm, for a simulation with a BCAL length of 375 cm. Photon hits on the square LGD (center) and cylindrical BCAL (outer ring) are clearly visible. The gaps above and below, left and right, of the square LGD indicate holes in photon acceptance for this geometry.

In this scenario, because the LGD is a square only ~30% larger than the BCAL inner diameter, gaps in photon acceptance naturally arise. The effect of this is shown clearly in the simulation presented in Fig. 1. To eliminate these gaps, the BCAL must be extended downstream in length. As the BCAL length is increased, the BCAL intercepts a greater proportion of photons, and the holes in the photon acceptance are eventually filled. The necessary BCAL length to achieve maximum acceptance is shown in Fig. 2.

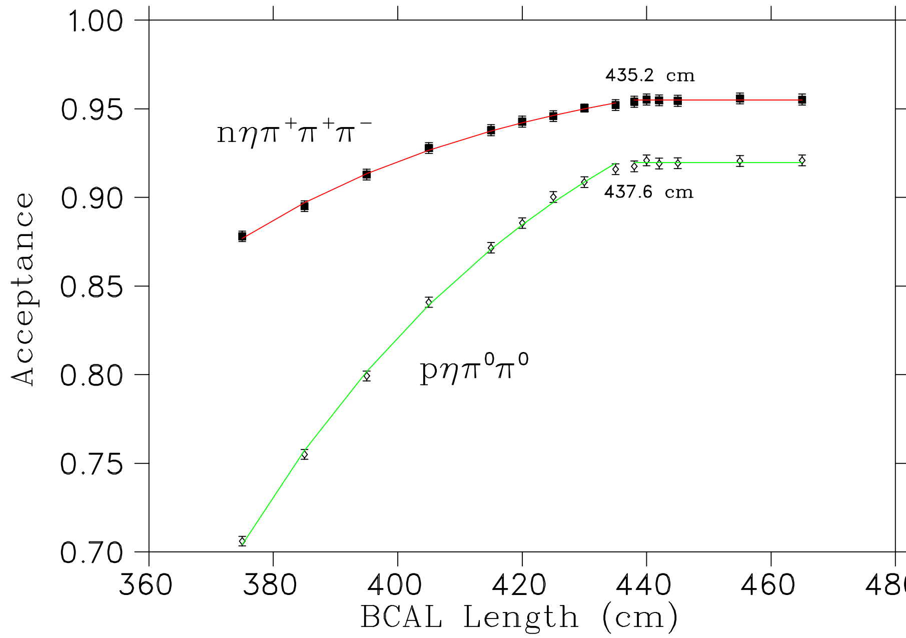

FIG. 2: HDFast simulation results for a square LGD and various BCAL lengths, as indicated. In both simulated reactions, the only η decay channel considered is $\eta^0 \rightarrow \gamma\gamma$. Thus, the $p\eta\pi^0\pi^0$ final state is neutrals only (other than the recoil proton), while the $n\eta\pi^+\pi^+\pi^-$ final state mixes both charged and neutral tracks. For a given BCAL length, the $n\eta\pi^+\pi^+\pi^-$ acceptance is naturaly larger than for $p\eta\pi^0\pi^0$, because many low momentum charged tracks are trapped in helical tracks by the solenoidal field, and so are not sensitive to the calorimeter geometry. [Simulations courtesy of B. Jasper.]

In this scenario, the BCAL is unacceptably long. The front of the Cerenkov detector is presently planned to be at $z = 410$ cm (measured from the upstream end of the solenoid), and so the two detectors are in conflict. The conclusion of this study, therefore, is that a square LGD of this size is not optimal, and alternate geometries must be investigated.

III. SIMULATIONS ASSUMING A 122 CM RADIUS LGD

If one takes a similar number of LGD crystals, and rearranges them into a circular pattern, the result is a detector of 122 cm nominal radius [2]. The resulting geometry is shown in Fig. 3.

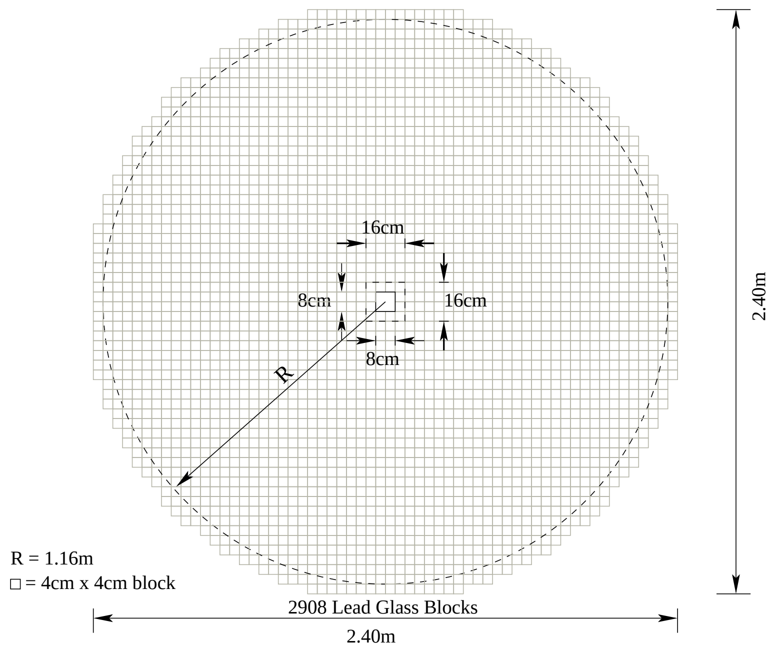

FIG. 3: Layout of the round LGD. The dashed lines indicate the guard crystal cuts used in the study. [Figure courtesy of B. Leverington, based on information provided by S. Teige.]

After come discussion with J. Kuhn of Carnegie Mellon University, we agreed on a number of modifications to this geometry for the purposes of our analyes:

- Photons hitting the layer of crystals next to the beam hole should be excluded, since they will not deposit their full energy in the LGD and will be difficult to reconstruct. Thus, these are considered "guard crystals", and the effective size of the beam hole in the code should be 16×16 cm^2.

- The LGD physical semi-major axes in the x and y directions are 120 cm long, but photons hitting the outermost layer of crystals should be similarly discarded. Simulations were performed with two alternate effective radii, which are smaller than the physical LGD radius because of the guard crystals. The first set of simulations assumed an effective radius of 116 cm (shown in Fig. 3), and the second set assumed a radius of

108 cm.

- The assumed target center position of 50 cm in `usr_lgd.c` is incorrect, and this was changed to its correct position at $z = 65$ cm.

As before the upstream edge of the BCAL was held constant at $z = 17$ cm.

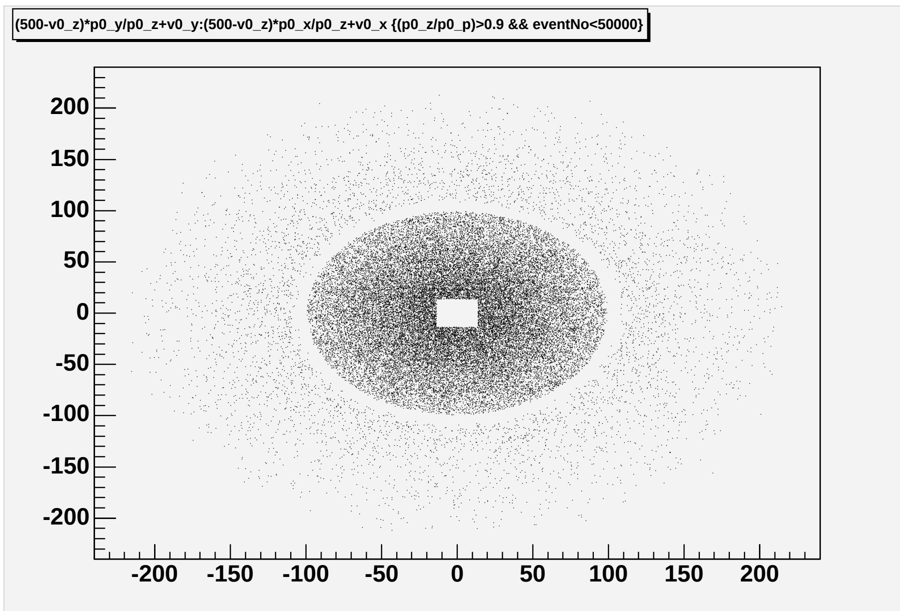

FIG. 4: Forward going photon tracks projected onto an imaginary plane at $z = 500$ cm, for a simulation with a BCAL length of 305 cm and a round LGD of 116 cm effective radius at $z = 575$ cm.

The locations of hit photon tracks on an imaginary plane at $z = 500$ cm are shown in Fig. 4 for one representative simulation. The LGD (inner ring) and BCAL (outer ring) are clearly distinguishable. What is most interesting to note, however, is that although the BCAL length in this simulation is 70 cm shorter than that shown in Fig. 1, the total areal "gaps" between the LGD and BCAL are comparable. With the 172 cm square LGD, its four corners are shadowed by the BCAL, and the crystal usage is inefficient. A 122 cm radius LGD allows for efficient crystal usage, so the BCAL does not need to be as long.

Acceptances versus BCAL length are shown for two representative simulated reactions, assuming two different guard crystal cut radii on the LGD, in Fig. 5. The minimum BCAL length, in order to avoid gaps in the photon acceptance, is 20 cm longer in the case of the more restrictive LGD guard crystal cut. In Fig. 2, photons were counted on a "hit or miss" basis in the calorimeters, without regard to whether their full energy is deposited. The equivalent data in Fig. 5 are the solid squares. Since the full containment of showers has not been taken into account, this study sets a lower bound of 361 cm on the BCAL length.

A single event display with a 365 cm long BCAL is shown in Fig. 6. In the top projection (lower left), we observe a shower which exits from the downstream end of the BCAL. It is clearly desirable to contain the energy of these showers. Since there is a gap of over 150 cm between the BCAL and the LGD, electrons/positrons and photons from these showers are probably not energetic enough to make it to the LGD, because of the fringe field that might bend them away, and energy loss in the Cerenkov material.

While it is highly desirable to contain showers hitting the downstream end of the BCAL near $z = 17 + 361 = 378$ cm, we should not do this in a way which degrades the performance of the spectrometer overall. Simply extending the length of the BCAL will not solve the shower containment problem, but merely shift it to larger values of z. A better solution,

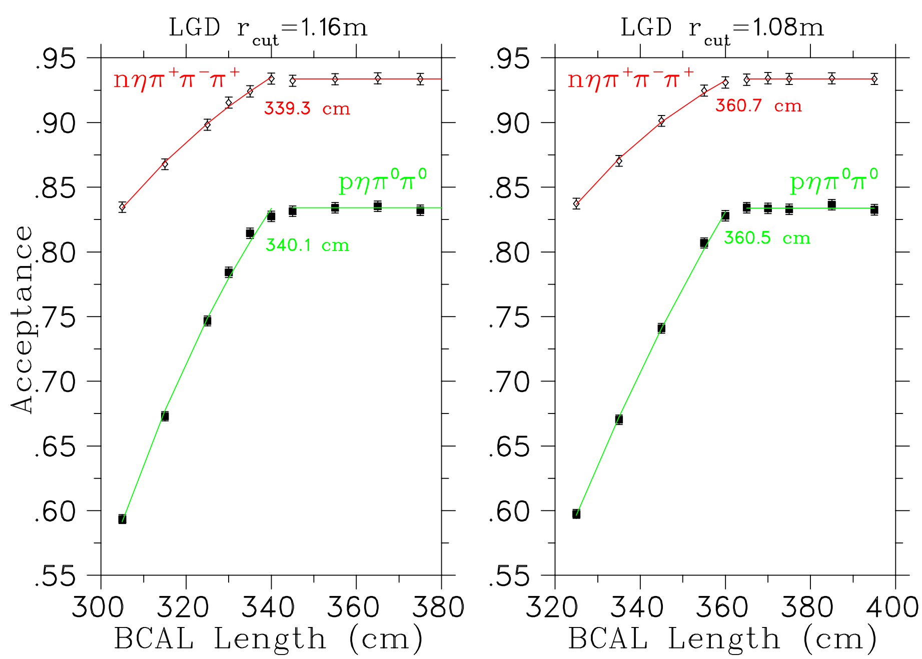

FIG. 5: HDFast simulation results for a round LGD and various BCAL lengths, as indicated. The data on the left are for a $r = 116$ cm software cut on the LGD, while the data on the right are for a $r = 108$ cm cut radius. The maximum acceptances shown here are about 5% lower than those in Fig. 2 because of the larger effective beam hole assumed in the simulations, but this should have no other effect upon the functional dependence.

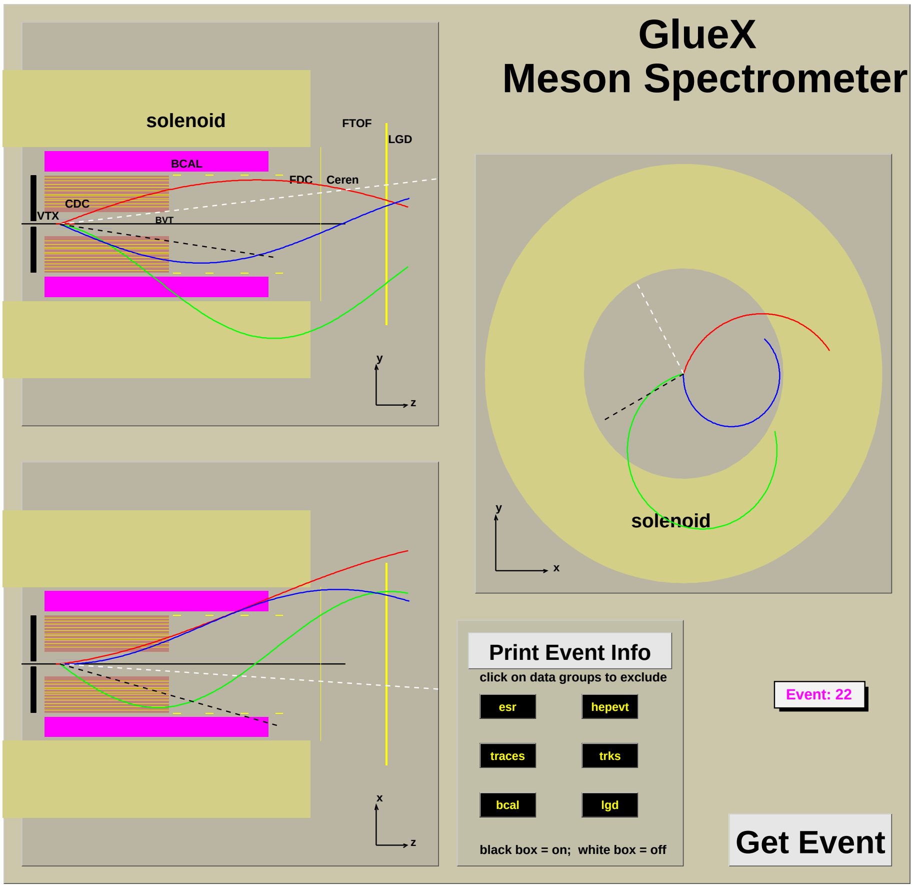

FIG. 6: Single event display of a simulated $n\eta\pi^+\pi^-\pi^+$ event, for a BCAL of 365 cm length.

although more difficult to implement, would be to chamfer the downstream end of the BCAL, in order to contain showers from photons hitting an angle greater than 11^o but allow those hitting at a more shallow angle to pass unobstructed to the LGD. Since the LGD is expected to have better energy and angle resolution than the BCAL for these photons, this would also lead to overall better spectrometer performance.

A detailed estimate of the optimal BCAL geometry to contain showers hitting its downstream end will likely require the use of HDGeant, but we can make some quick estimate. A safe assumption is that we want these showers to at least experience the equivalent of the 23 cm thickness of the BCAL, so this sets an approximate upper limit to the BCAL length of $361 + 23 \cos 11^o$=384 cm. This yields an approximate downstream geometry shown in Fig. 7, in the $r_{cut} = 108$ cm scenario. More likely, one would construct the BCAL sections to their default design length of 390 cm, and chamfer the inner surface to the required dimension. This extra material will also ensure that there is no interference from the solenoid

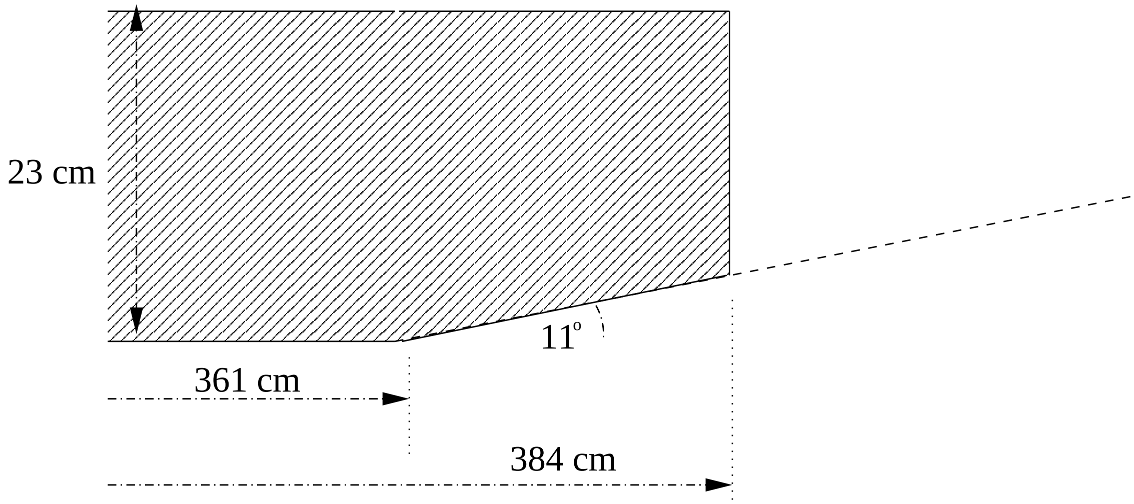

FIG. 7: Possible design of downstream BCAL configuration, to minimize conflict between the BCAL and LGD, assuming a 108 cm effective radius for the LGD. If one assumes a 116 cm LGD effective radius, all lengths can be reduced by approximately 20 cm.

yoke, which is not taken into account in the simulations.

IV. CONCLUSIONS

In conclusion, the BCAL length simulations have clearly indicated that a circular LGD with diameter greater than 2m is required. In this case, I think it is safe to say that at its inner surface, the BCAL probably does not have to be the full 390 cm length originally assumed. This is good news, as it will allow for a configuration which gives minimal conflict with the LGD. Detailed HDGeant simulations are probably required to finalize the optimal BCAL length and downstream end geometry. A firm decision also needs to be taken on the number of outer LGD guard crystals required, as this affects the final BCAL geometry.

[1] MCFast note "Track Tracing and Track Fitting in MCFast (For MCFast v5_1 and above)", September 19, 2001.

[2] S. Teige, private communication.