Monte Carlo study of a mm-scale collimator for use in the GlueX photon beam

R.T. Jones
*University of Connecticut**
(Dated: January 21, 2016)

Normalization of the absolute flux of the bremsstrahlung photon beam for the GlueX experiment relies on a direct counting measurement of the entire beam performed placing a highly efficient calorimeter, the total absorption counter (TAC), directly in the beam near the position of the experimental target. This measurement must be done at very low beam intensity, so as not to overwhelm the TAC with pile-up. The absolute rate measured with the TAC is used to calibrate a pair spectrometer that serves as a continuous relative beam rate monitor, so that the flux can be measured when the TAC is removed. Maintaining stable beam operation when the flux is low enough for efficient operation of the TAC is a challenge because a certain minimum electron beam current is required for the beam stabilization system to function properly. It has been proposed that reducing the primary photon beam collimator diameter to around 1 mm would allow the electron beam current to remain at 10 nA and still achieve sufficiently low photon flux for the happy operation of the TAC. The photon beam has never been simulated with so small a collimator, and so it raises the question of whether it would produce a usable beam, or whether the halo from scraping on the inner walls of the collimator might overwhelm the flux of the beam that passes through without interactions. This article reports on results of a detailed Monte Carlo simulation of the GlueX beamline with a steel collimator insert inside the standard 5 mm tungsten aperture, with a focus on the spatial and spectral properties of the beam at the GlueX target.

I. INTRODUCTION

Commissioning of the GlueX total absorption counter (TAC) is planned to take place during the winter 2016 run. The purpose of the TAC is to measure the absolute flux of the collimated beam at or near the location of the GlueX target. Because it counts every photon in the beam, the TAC can only be operated at very low photon beam intensity. By running simultaneously with the pair spectrometer (PS), the TAC runs will set the absolute normalization of the will be used to which will be used to set the absolute normalization of the PS, which is capable of running simultaneously with data taking at the highest intensities foreseen for GlueX. The remainder of this report is focused on determining suitable running conditions for the normalization runs during which both the TAC and the PS converter are in the beam.

The count rates in the PS and the TAC are different by approximately 4 orders of magnitude, 3 of which come from the thickness of the converter (approx10^{-3} rad.len). The fourth comes from the fact that the TAC sees every photon in the beam, while the PS sees only those above 50% of the end-point energy and of those, only the fraction whose pair energy asymmetry falls within the PS acceptance. Of course there is some freedom in setting the threshold energy in the TAC, but even when operating at a relatively high threshold, the flux of low-energy photons in the beam still contribute to the TAC rate through pile-up. While there is no way to avoid pile-up at some level in a bremsstrahlung beam, keeping the total rate of photons above some low energy cutoff like 100 MeV below a certain level allows the TAC threshold be be set low enough that it has a high uniform efficiency over the full spectral range of the PS. This is the goal for the PS/TAC calibration runs.

For the purposes of this study, I consider that optimum operating conditions for a TAC normalization run would be around 1 MHz of total rate in the collimated beam above a 100 MeV cutoff. This may be ultra-conservative, but if we can achieve stable operation at this level then we are guaranteed to be able to achieve our goals for this run, and we can always raise the rate if it is safe to do so. Under these conditions, the actual count rate in the PS will be a factor ≈ 2 lower than this (I assume a TAC threshold in the range 1.0-2.0 GeV), and a corresponding PS trigger rate below 100 Hz. At these total rates, it would take a 4-5 hr run to achieve 1% statistical precision in the independent normalization of 150 PS energy bins.

---

*http://zeus.phys.uconn.edu

Over the course of this run, it is important for the beam conditions to remain stable, especially the beam intensity and position on the collimator. This is achieved by making sure the electron beam intensity and position remain stable, which in turn relies on beam line locks and monitors that require a certain minimum current for reliable operation. Over time we expect that low-current operations will improve, but for the winter 2016 run I assume that stable operations over a period of several hours requires a minimum electron beam current of 10 nA. The thinnest photon radiator we have available is $2 \cdot 10^{-5}$ rad.len.thick, which produces a total photon flux of $53 \cdot 10^{6}$ /s above 100 MeV at the radiator. Reducing this by a factor 50 requires a collimator with a diameter of order 1 mm.

II. PHOTON BEAM SIMULATION

The smallest collimator we currently have available in Hall D has an aperture diameter of 3.4 mm. The geometry of the clean-up collimator and shielding downstream of the primary collimator has been optimized using Monte Carlo simulation and shown to produce a clean photon beam with negligible halo. As one reduces the collimator diameter, at some point this should cease to be the case as the ratio of surface to area of the acceptance region shrinks. The purpose of this study is to answer the following questions.

- What halo would be expected for a collimator with a mm-size diameter hole?
- If it were constructed as a steel insert that fits inside the existing tungsten collimator, would it work?
- What would be the effect if it were shorter than the full 18 cm length of the tungsten bore?
- Is the halo described above sufficiently small that its effect on the systematics of the absolute beam normalization using the TAC will be negligible.

In this study I used a steel insert with an outer diameter of 5 mm and an inner diameter of 1.1 mm. It was just 15 cm long (8.5 rad.len.) inserted until the front end is flush with the front of the tungsten collimator. A cut-away view of the collimator is shown in Fig. 1.

One million beam photons were generate in the simulation, starting from a 12 GeV electron beam with nominal CEBAF emittance and beam properties for GlueX incident on a 20 micron diamond radiator. The crystal radiator is oriented to place the coherent edge at 9 GeV. This is not the same radiator as the thinner $2 \cdot 10^{-}5$ rad.len. radiator to be used for TAC runs, but for the purposes of answering the above questions it is completely adequate, and it gives additional information through the structure of the spectrum about how much scattering in the collimator walls is contaminating the beam. The photon spectrum in the tagger and at the GlueX liquid hydrogen target are shown in Fig. 2. From the right-hand plot in the figure, it is clear that the collimator is doing its job of selecting the central core of the photon beam, and is not significantly contaminated by secondary photons from showers in the collimator. To check if those photons might be present in the beam at lower energies in the spectrum, I measured the total fraction of all photons reaching the liquid hydrogen target that had seen *any* interactions since leaving the diamond radiator. The result is 3%, and their spectrum is shown in Fig. 3.

The impact distribution of all particles in the photon beam are shown in Fig. 4. The left plot shows all particles, and the right shows only those over 500 MeV at the point where they passed through the target entrance plane. The innermost circle within which the maximum intensity occurs is the shadow of the 1.1 mm steel insert in the primary collimator. The next circle outside that is the shadow of the 5 mm tungsten collimator inside which the steel insert is embedded. Even though the steel stops most of the photon flux, the tungsten around it is still needed to absorb the debris that the insert creates. The larger circle outside that is the shadow of the secondary clean-up collimator. The right plot shows that most of the beam halo is very low energy electromagnetic radiation at the few hundred MeV scale or below. Considering only particles in the beam area with energies above 500 MeV, the halo fraction is 3%, dropping to 2% if the low-energy cutoff is raised to 2 GeV.

III. CONCLUSIONS

Given that the beam spot does show tails around the central disk, the last question to be answered is how this halo translates into a systematic error in the absolute beam flux normalization measured using the

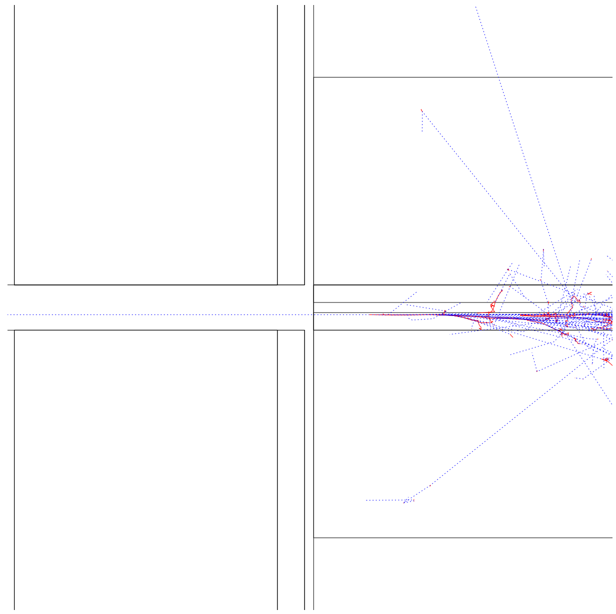

FIG. 1: Cut-away view of the collimator with the steel insert, as defined in the Monte Carlo geometry used for this study. The beam enters from the left in this figure, and passes through the 5-mm hole in the active collimator (the left half of the figure) before reaching the front face of the primary tungsten collimator located at the vertical midplane in the figure. The inner steel insert is inside a 5-mm hole through a tungsten block, which in turn is placed inside the larger lead collimator that surrounds it. The figure shows a beam photon that interacts in the steel collimator and generates a shower that gets absorbed in the collimator material.

TAC. For this, one must define an effective acceptance radius for the beam. This clearly must be smaller than the radius of the liquid hydrogen target and also the entrance aperture of the TAC. The target tapers from a radius of 12.37 mm at the upstream end down to 0.78 mm at the downstream end. The entrance aperture to the TAC is larger than this, so I take 0.75 mm as the effective acceptance diameter of the photon beam at the GlueX target. According to the simulation described above, the fraction of the total photon flux within this radius at the GlueX target is 99.3% for photons of all energy above 1 MeV, rising to 99.98% for all photons reaching the GlueX target with more than 500 MeV energy. By almost any standards, the systematic normalization error coming from the photon beam halo in this simulation is negligible.

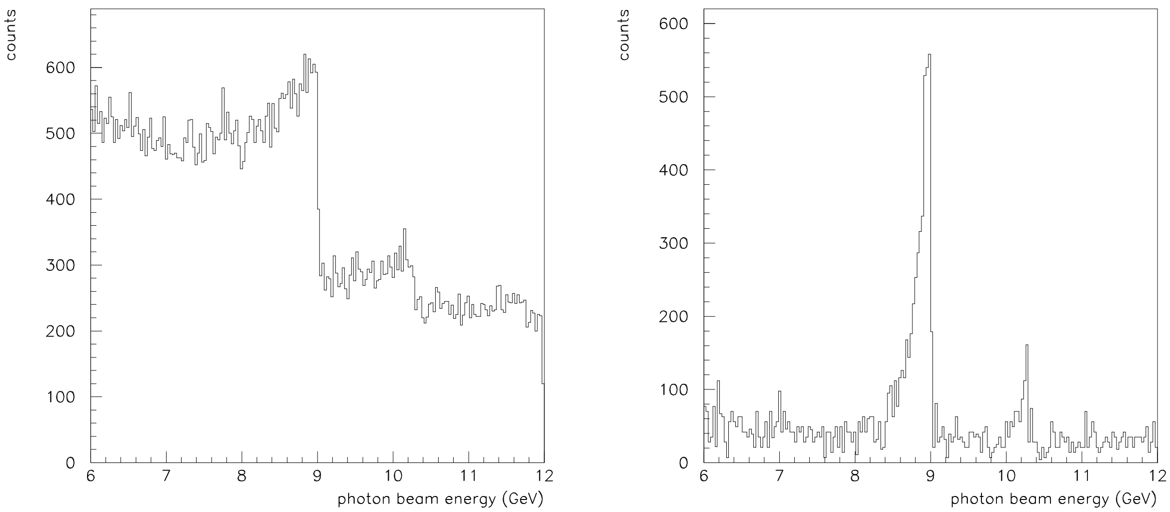

FIG. 2: Simulated photon beam spectrum for all photons exiting the diamond radiator (left) and for all photons that reach the GlueX liquid hydrogen target (right) with the steel insert installed in the 5-mm tungsten primary collimator.

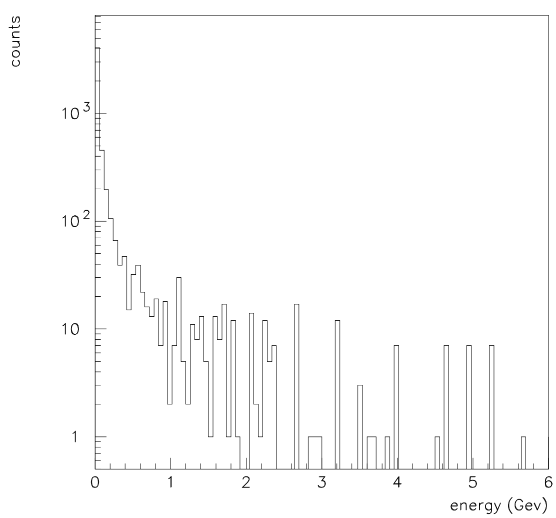

FIG. 3: Spectrum of the 3% of all particles in the photon beam that reach the GlueX liquid hydrogen target, having been generated through interactions somewhere between the radiator and the GlueX target. Of these, 95% are photons, with the remainder being mostly electrons and positrons. The energy spectrum of the charged 5% component is similar in shape to the one shown above for the aggregate.

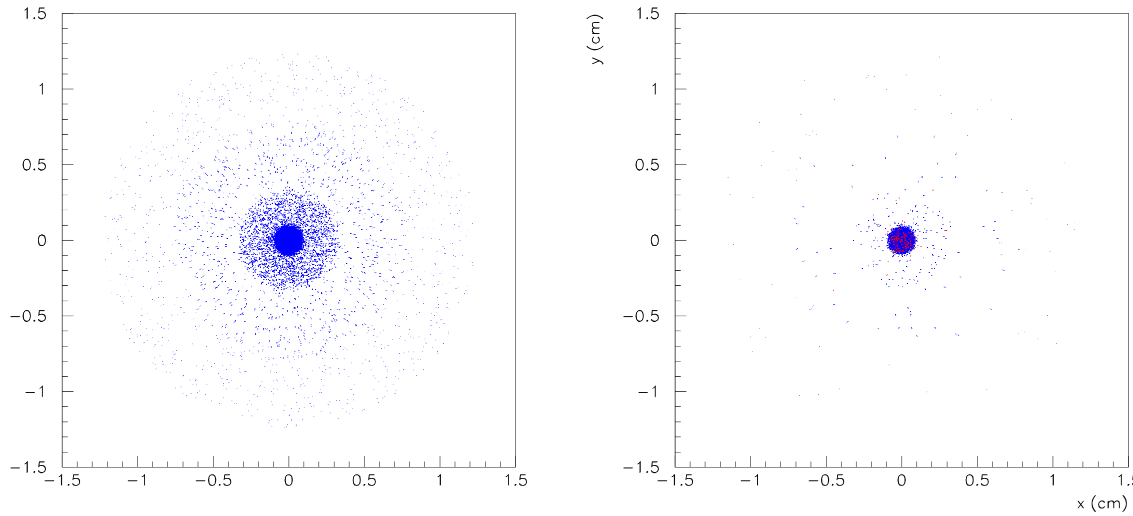

FIG. 4: Transverse impact distribution of all particles in the photon beam reaching the GlueX liquid hydrogen target (left) and only those over 500 MeV (right). Photons are shown by blue points, and charged particles with red points. In the left plot, 84% of all impacts are within the innermost intense dot. In the right plot, the corresponding fraction is 97%, increasing to 98% if the low-energy cutoff is raised to 2 GeV.