Physics and Detector Performance Metrics for the GlueX Experiment

GlueX-doc-1063-v3

1 Photon Beam

The photon beam is produced by having a low-emittance 12 GeV electron beam incident on a thin ($\approx 20\ \mu$m) single crystal diamond wafer. After passing through the wafer, the electron beam is bent by a dipole magnet (the *tagger* magnet) into the beam dump. A small fraction, about 0.01% of the electrons, emit a photon via incoherent bremsstrahlung or coherent bremsstrahlung, the latter leading to an enhancement over the incoherent spectrum at a photon energy determined by the angle between the incident electron direction and the wafer. By exploiting the tight energy–angle correlation for the coherent photons, collimation of the photon beam can be used to enhance the fraction of photons of the coherent radiation incident on the GlueX target. This has the effect of increasing the degree of linear polarization and eliminating a large fraction of the low-energy photons that dominate the incoherent component of the spectrum. An instrumented collimator, with a 3.4 mm hole, will be placed about 22 m upstream of the GlueX detector and about 75 m downstream of the diamond crystal radiator. Sweeping magnets and secondary collimation ensure that particles produced in the collimator which could have produced background in the GlueX detector are eliminated. The layout of the photon beam line is shown in Figure 1.

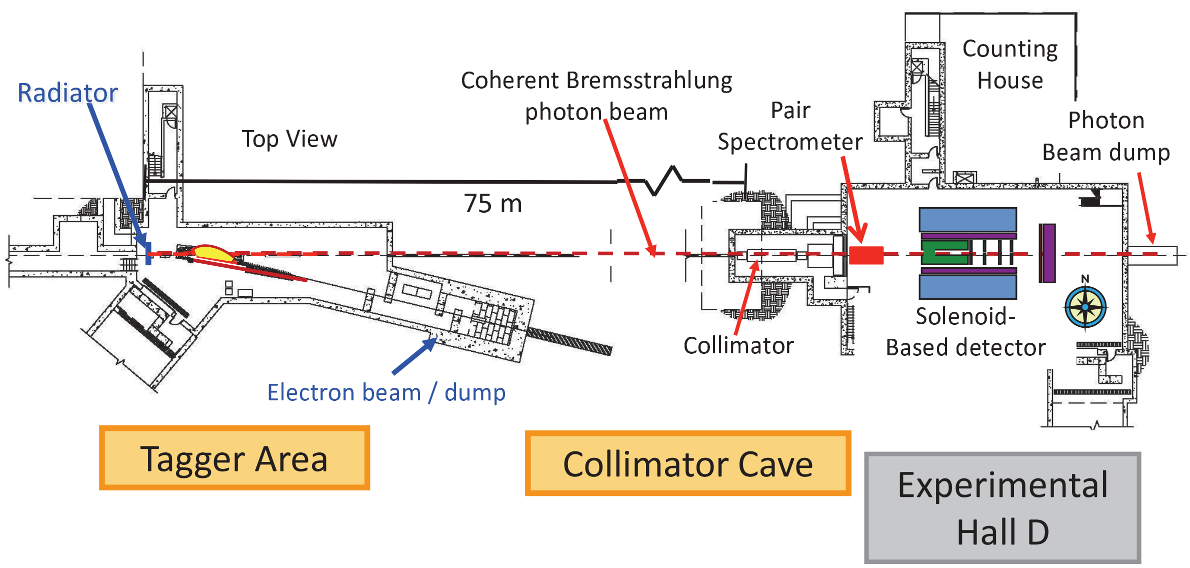

Figure 1: Schematic of the Hall D photon beam line. The electron beam enters the building housing the *tagger* magnet from the left, and the photon beam is produced in the diamond crystal indicated as "Radiator" in the figure. The tagger magnet is located just downstream of the radiator and bends the electron beam to the dump. The photon beam passes through the tagger hall and and a ∅10 inch buried beam line to enter the Hall D building in the collimator cave. The GlueX detector is shown in Hall D after the pair spectrometer.

Coherent bremsstrahlung, which is similar to the Mössbauer effect, is a scattering process whereby the momentum transfer is to the entire crystal and not a single atom in the crystal. As the recoil momentum $\mathbf{q}$ for the bremsstrahlung interaction is very small, it is possible to align the crystal so that the Laue condition $\mathbf{g} = \mathbf{q}$ is satisfied. Here $\mathbf{q}$ is the crystal's recoil momentum in units of $m_e c$ and $\mathbf{g}$ is an inverse lattice vector. Under these conditions the scattering amplitudes of many periodically located atoms sum and the bremsstrahlung cross section is greatly enhanced. One requirement for a coherent bremsstrahlung source is the availability of high quality crystals with a suitable lattice structure. The best crystals presently available are synthetic diamond single crystals. One characteristic of the diamond crystal which is very important for its performance as a coherent bremsstrahlung radiator is the mosaic spread of the crystal. The mosaic spread of a crystal is the angular spread in the normal vector to the crystal planes. If a diamond has a lot of internal stresses or imperfections then there will be a lot of dislocation in the crystal structure which leads to a large mosaic spread. Selected synthetic diamonds can have mosaic spreads as small as 30 μm. This should be compared to the characteristic angular divergence of incoherent bremsstrahlung of $m_e/E = 43$ μm. As the spread in angular orientations in the crystal is smaller than the characteristic angle for the incoherent bremsstrahlung interaction it is possible to collimate the photon beam after sufficient drift distance and enhance the fraction of the coherent bremsstrahlung photons relative to the incoherent photons. A second factor which plays an equally important role in the production of coherent bermsstrahlung photons is the quality of the electron beam. The emittance of the beam must be small enough so that the beam can be focused to a reasonable spot size on the crystal while still having an angular divergence which is small relative to the crystals mosaic spread. The CEBAF accelerator is a few pass machine which will be able to deliver an extremely low emittance DC beam. The requirements for the Hall D beam are given in Table: 1. The angular divergence at the crystal for a spot size of 1.6 mm is 6 μrad well below the angular spread intrinsic to the diamond crystals.

Electron beam energy	12 GeV
Electron beam emittance	$\epsilon_x < 10$ mm-μrad
	$\epsilon_y < 2.5$ mm-μrad
Electron beam energy spread	$< 0.1\%$
Uncertainty in electron beam energy	$< 0.1\%$
Spot size at Hall-D radiator	$800 < \sigma_x < 1600$ μm
	$300 < \sigma_y < 600$ μm
Beam image size at 76 m from the radiator	$\sigma_x < 0.6$ mm
	$\sigma_y < 0.6$ mm
Beam halo	$< 5 \times 10^{-5}$
Beam position stability at collimator	± 200 μm
Electron beam current	$0.3\text{nA} < I_e < 3\mu\text{A}$

Table 1: Summary of the expected characteristics of the CEBAF 12 GeV beam relevant to the GlueX experiment[**?**].

The combination of the availability of high quality single crystal man–made diamonds with the excellent beam quality of the CEBAF 12 GeV beam enable one to design a polarized photon beam facility with excellent characteristics well suited to the search for exotic mesons. In Figure 2 the projected energy spectrum and polarization for the photon beam are shown assuming the above beam parameters and a diamond crystal with 30 μm mosaic spread. The figure in the left panel shows how the energy spectrum of the photon beam changes as the dimension of the collimator 75 m downstream of the diamond is varied. The top curve corresponds to the uncollimated beam. Here the $1/E_\gamma$ characteristic shape of the incoherent bremsstrahlung spectrum is clearly seen with the peak structure of the coherent bremsstrahlung spectrum superimposed, E_γ is the

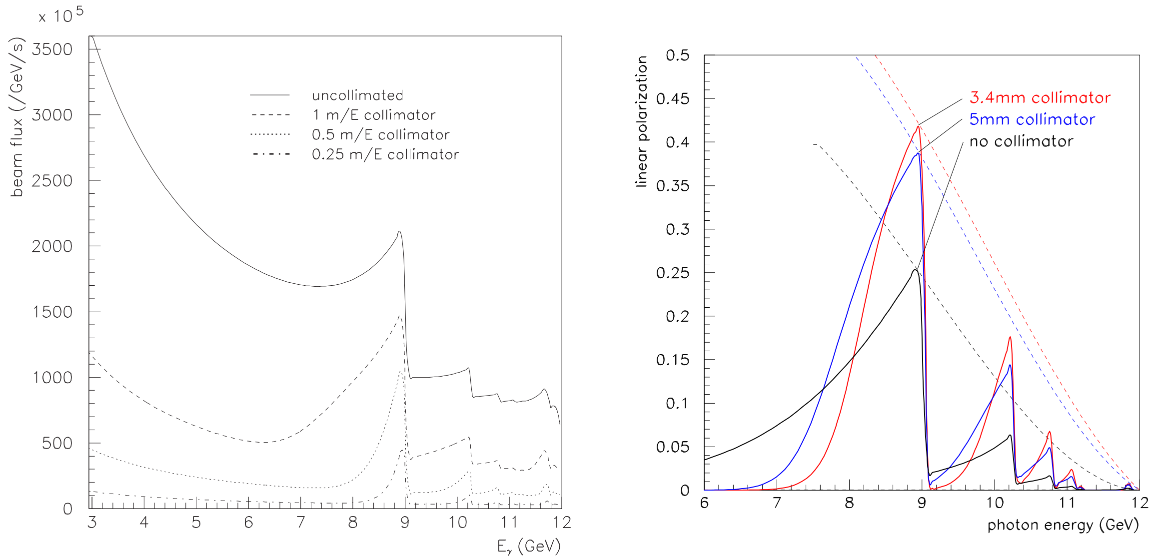

Figure 2: Left Panel: The photon flux is plotted as a function of the photon energy. The different curves correspond to different apertures in the collimator. The collimator apertures are selected to be fractions of the mass of the electron over the electron beam energy (m_e/E_e) which is the characteristic angle for incoherent bremsstrahlung. Right Panel: The polarization of the photons is plotted as a function of photon energy for three different collimator apertures under the condition that the crystal is oriented so that the coherent bremsstrahlung peak sits at 9.0 GeV. The dashed curves indicate how the peak polarization would change if the crystal is rotated to a different peak photon energy.

photon energy. With the planned collimator dimension of 3.4 mm (corresponding to 0.5 m_e/E) most of the photons generated by incoherent bremsstrahlung are collimated while 90% of the coherent bremsstrahlung photons pass through the collimator. In the right panel the polarization of the photon beam is plotted as a function of the photon energy. The curves on this plot correspond to the condition where the crystal is orientated so that the coherent bremsstrahlung condition is satisfied for 9 GeV photons. The dashed curves correspond to how the polarization at the peak of the coherent bremsstrahlung spectrum changes as the orientation of the crystal is changed and the coherent bremsstrahlung peak is moved to higher energies. The optimum configuration depends on the physics one wishes to study. The polarization is higher if the photon energy peak is moved to lower energies but this also reduces the mass range for the experiment. The displayed curve with a 3.4 mm collimator aperture corresponds to the optimum configuration. This configuration yields photons in the range of 8.5 to 9.0 GeV with a peak linear polarization over 40%. The normal running conditions at GlueX correspond to operating with a 2.2 μA 12 GeV beam and a 20 μ thick diamond. Under these conditions a flux of 10^8 photons are anticipated in the energy range of 8.5 to 9.0 GeV. During the initial year of running it is expected to run at lower photon fluxes.

The electrons emitting 8.4 to 9.1 GeV bremsstrahlung photons will be momentum analyzed using a focal plane spectrometer leading to a photon energy resolution of about 2.5 MeV. A 3-D model of the *tagger* spectrometer is shown in Figure 3. The spectrometer magnet is a 1.5 T 6.3 m long dipole. The beam of photons, 12 GeV electrons and the electrons resulting from the

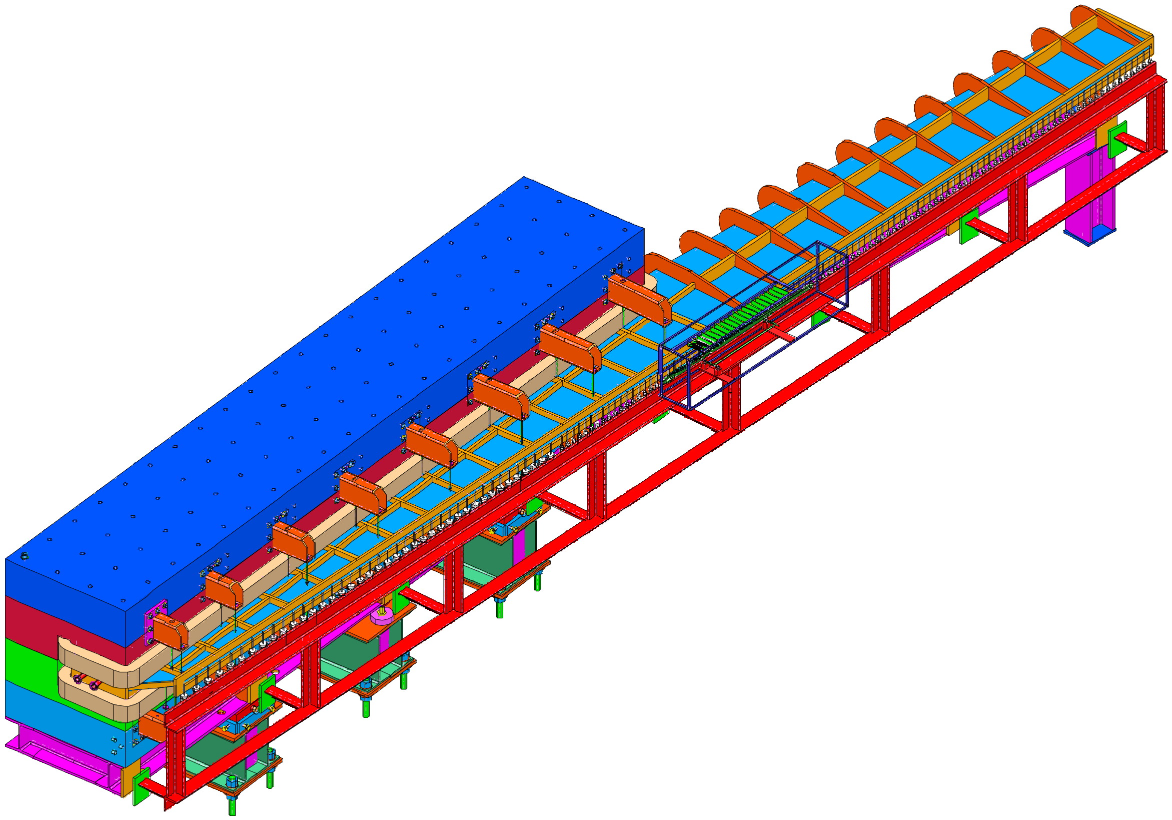

Figure 3: 3-D model of the Hall D tagging spectrometer.

bremsstrahlung interactions in the diamond enter the magnet on the left of the figure. A channel cut in the yoke of the magnet allow the photons to pass through unaffected. The 12 GeV electrons which did not interact in the $10^{-4}X_0$ thick diamond are bent by 13.4 degrees by the magnet and propagate to the electron dump. The electrons which did radiate a photon have reduced energy and are fanned out by the magnetic field. An 11 m long vacuum chamber is needed to contain the electrons until they reach the focal plane. Two detector packages are placed on or just behind the focal plane to detect the electrons. A fixed array hodoscope is located in the spectrometer focal plane and detects electrons which radiated photons in the range 25% to 97% of the beam energy. This corresponds to electrons in the range 0.36 GeV to 9 GeV. The fixed array is primarily used to measure the photon energy spectrum over a wide range of energies which is needed to optimize the crystal orientation. The second detector system which is seen in the figure near the middle of the vacuum chamber exit window is the tagger microscope detector. This device is an array of 2×2 mm scintillation fibers read out with silicon photomultiplier sensors. The fiber array is 5 fibers high and 100 fibers long and will normally be positioned so that it measure electrons in the momentum range of 2.9 to 3.7 GeV, this corresponds to photons between 8.3 and 9.1 GeV. A review of the GlueX photon beam line and tagger magnet was successfully completed in November 2008.