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A radiation-hard beam position monitor for high energy photon beams

R.T. Jones[a,*], A.M. Carroll[a], C. Pelletier[a], and I. Senderovich[a]

[a] *University of Connecticut,*
2152 Hillside Road, Storrs, CT, USA
E-mail: richard.t.jones@uconn.edu

ABSTRACT: A novel photon beam position monitor has been designed and constructed for use in the coherent bremsstrahlung beam collimator in Hall D at Jefferson Lab. The beam position monitor will be placed directly in front of the tungsten collimator, to count the relative flux of photons on the face of the collimator as a function of radius and azimuthal angle. Real-time information on the centroid of the photon beam spot at the collimator will be fed back to steering magnets on the electron beam to maintain the required alignment of ± 200 μm between the photon beam centroid and the collimator axis. A prototype of this detector was built and tested in the tagged photon beam in Hall B in Spring 2011. Results from this test show a beam centroid position resolution of 46 μm rms when the beam centroid is within 5 mm of the collimator axis, and no worse than 120 μm rms for misalignments between 5 mm and 15 mm. These results exceed the requirements for Hall D with a comfortable margin, and were obtained with photon beam intensities considerably lower than those planned for use in Hall D. Detector signals were found to be close to the middle of the designed dynamic range of 10^6. The bandwidth limit was determined to be 1 kHz, sufficient to monitor the dominant frequency components of beam motion that are expected for the 12 GeV beam.

KEYWORDS: beam position monitor; active collimator; coherent bremsstrahlung; photon beam profile.

[*]Corresponding author.

Contents

1. Collimation requirements

The GlueX experiment [**?**] is designed to search for exotic mesons in the mass range 1.5 – 2.5 GeV/c^2 produced by a 9 GeV polarized photon beam interacting in a liquid hydrogen target. The polarized photon beam will be generated from a primary electron beam from the CEBAF accelerator at Jefferson Lab in Newport News, Virginia following the upgrade of the accelerator to 12 GeV. The secondary photon beam is produced by passing the electron beam through a thin bremsstrahlung radiator, then passing the two beams through a dipole "tagger" magnet which bends the electrons into a beam dump, and at the same time analyzes the energy of those electrons which lost a significant fraction of their energy to a photon in the radiator. A timing coincidence between an event in the photoproduction target and a counter on the tagger focal plane tags the energy of the beam photon that produced the event.

Normally a bremsstrahlung beam is unpolarized because it is an incoherent superposition of photons generated by scattering from each of the atoms in the radiator independently. However, if the radiator is crystaline and it is oriented so that one of the crystal planes is slightly inclined with respect to the incident electron direction, a process known as coherent bremsstrahlung takes place in which the momentum transfer from the electron is absorbed by all of the atoms in the crystal instead of by a single atom. Coherent bremsstrahlung photons are polarized in the plane containing the incident electron momentum and the normal to the scattering plane in the radiator crystal.

The photon beam for the GlueX experiment will be generated from a diamond crystal radiator that is oriented such 12 GeV electrons passing through it produce coherent bremsstrahlung peak in the photon intensity spectrum at 9 GeV, as shown in figure 1. The upper curve shows the general characteristics of a bremsstrahlung spectrum, dropping with photon energy like $1/E$, except that discrete peaks with sharp edges appear at particular locations in the spectrum. This spectrum was computed for the particular radiator orientation that places the largest peak edge at 9 GeV.

The lower curve in the same figure shows the effect of collimation on the beam rate spectrum. Collimation can only remove flux from the beam, so the rates for all energies are lower after the

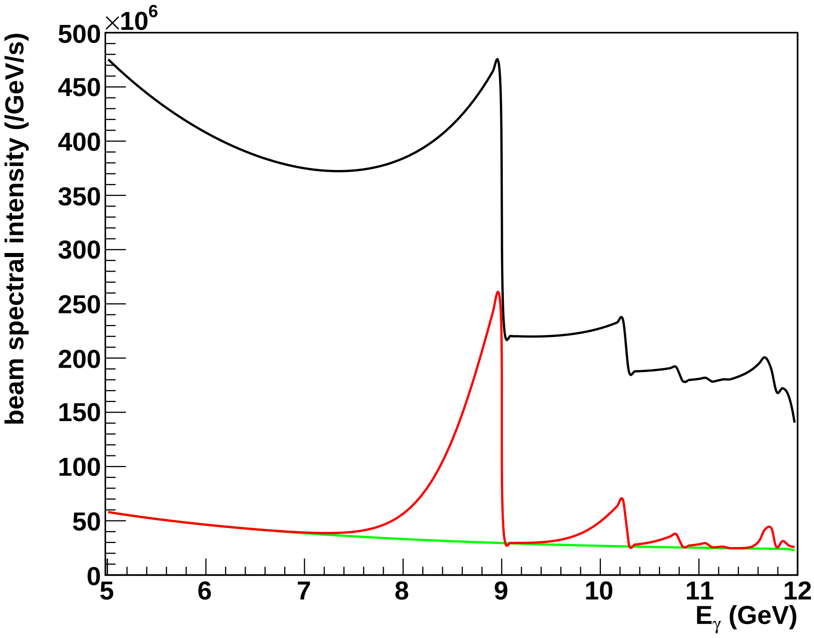

Figure 1. Photon beam rate spectrum under nominal running conditions of polarized beam for the GlueX experiment. The upper (black) curve shows the rate spectrum at the entrance to the collimator, and the lower curve (red) curve shows the spectrum after the collimator. The flat baseline (green) under the lower curve indicates the remaining incoherent (unpolarized) component of the beam after collimation, showing that it is a small fraction of the coherent bremsstrahlung component in region of the primary coherent peak.

collimator than before, but the collimation cuts much more deeply into the incoherent component (the baseline under the coherent peaks) than it does into the coherent peaks. In fact, the height of the peak at 9 GeV above the underlying continuum is essentially the same for the upper and lower curves, even though the continuum has been reduced by roughly a factor 4. Further reducing the collimator aperture would begin to reduce the coherent and incoherent yields together; in fact the post-collimator rate spectrum shown in figure 1 is very close to optimal for Hall D.

From figure 1 one deduces that 84% of all photons that are produced in the radiator are absorbed on the collimator, and only 16% of them reach the target. The Hall D collimator has a circular aperture of diameter 3.4 mm and is located a distance 76 m from the radiator. This corresponds to a collimation half-angle of 0.53 in units of the characteristic bremsstrahlung angle m_e/E, where $E = 12GeV$ is the energy of the primary electron beam and m_e is the mass of the electron. Under these conditions, the collimated beam contains 10^8 γ/s of tagged photons in the energy range 8.4 – 9.0 GeV, with an average linear polarization within that window of 36%.

Alignment of the photon beam on the collimator is accomplished by steering the electron beam using steering magnets located upstream of the radiator. These magnets are more than 80 m from the collimator, and must be capable of steering the electron beam such that its spot projected downstream onto the face of the collimator is centered on the aperture to within a fraction of its radius. A quantitative measure of the sensitivity to misalignment at the collimator is shown in

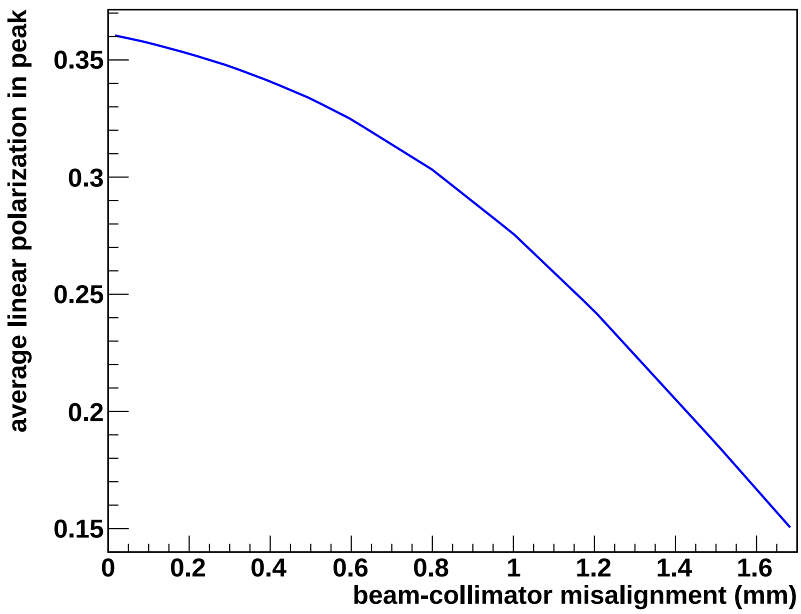

Figure 2. Photon beam polarization after collimation as a function of the offset of the beam centroid from the collimator axis. The polarization is the average value within the tagged window 8.4 – 9.0 GeV containing the primary coherent peak.

figure 2, which shows the average beam polarization in the primary coherent peak as a function of the displacement of the photon beam centroid from the collimator axis. The design goal for the systematic error on the average beam polarization is 1%, which corresponds to a maximum photon beam misalignment at the collimator of $\pm 200\ \mu$m.

2. Detector and readout

Tasdfah asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd. Asoiuh siuhihosi soiu hskjd asoiuh siuhihosi soiu hskjd.

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3. Simulation

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4. Beam test results

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5. Conclusions

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