# Final Report:

# Fast Synchrotron Radiation Imaging System for Beam Size Monitoring

**Classification (accelerator/detector: subsystem)** Accelerator: Beam Monitoring.

**Personnel and Institution(s) requesting funding**

Jim Alexander, Mark Palmer, Eugene Tanke, Cornell University

**Project Leader** Jim Alexander
email: jima@lns.cornell.edu
phone: 607-255-5259

### Overview of Project

With the high intensity, low emittance beams needed to reach the luminosity goals of the linear collider, beam size monitoring will likely play an important role in machine operation. In the damping rings synchrotron radiation (SR) emitted by the bunch can provide a means of measuring transverse bunch size and shape. With suitable imaging and high speed detection of the SR, bunch size, shape, and position may be determined with single bunch discrimination and minimal disturbance to the passing beam. A system fast enough to capture such a "snapshot" of a single beam bunch would be a useful addition to the Linear Collider diagnostics package and also be a valuable contribution to general accelerator physics and technology.

We have proposed to develop imaging and detection techniques that could be used to directly image the synchrotron radiation. In this report we summarize the activities and accomplishments of the past year.

### Context for this Project

The ILC Baseline Configuration indicates a 6km ring with 2800 bunches at 5GeV. Although the lattice design is probably not yet settled, previous damping ring designs would lead us to anticipate a vertical bunch size at the midpoint of the dipole magnets around $\sim 5\mu m$ and a horizontal size around $\sim 40\mu m$, with a critical energy in the range $5 \sim 10$ keV. Synchrotron radiation is cast forward in a narrow cone of opening angle $1/\gamma$. An imaging system working in the optical region would be diffraction limited and incapable of resolving the small vertical size of the beam, but wavelengths below 1nm (ie X-rays above $\sim$1keV) will provide sufficient resolution. An optimal choice for the working energy is thus constrained from below by diffraction, from above by critical energy, and must be chosen to permit maximal transmission by the optical components yet maximal absorption by the detector.

Imaging and detecting these photons poses interesting technical challenges. A system suitable for damping ring use requires three principal components:

1. A point-to-point imaging optical system suitable for $1 \sim 10$ keV X-rays. Several technologies exist, including grazing angle mirror systems, diffracting aluminum or beryllium lenses, and Fresnel zone plates. We have chosen to focus on the Fresnel zone plates for their relatively high transmission coefficient and off-the-shelf availability.
2. A low-noise, high speed, high resolution one- or two-dimensional detector with sufficiently fast response to cleanly separate the closely spaced bunches that one will encounter in a Linear Collider damping ring (7ns in the present baseline configuration). Solid state pixel detectors are a plausible detector choice, offering 2-dimensional imaging and high granularity, as well as a low capacitance, low noise source adaptable to the needs of high speed readout. Nanosecond scale time resolution likely demands high mobility materials such as GaAs. Commercially available GaAs photodiode

receivers for 10GBit/sec ethernet systems exhibit 30ps rise and fall times. Another possibility is InSb pixel arrays which are in common use in infrared astronomy and infrared imaging. Although developed primarily for infrared applications, because of their high-Z composition both GaAs and InSb photodiode detectors are excellent x-ray detectors. The intrinsic spatial resolution of the detector and the magnification of the optical system must be optimized together to achieve best resolution. $25\mu m$-scale pixels are commonly available and suggest that the optics should be designed for $\times 5$ magnification.

3. A high speed data acquisition system to extract signals from the detector, perform signal processing and pass results to accelerator control systems in real time. Appropriate software would be required to render the results in a form easily interpreted by an operator.

**Activities and Accomplishments**

In previous funding under this program, we had developed and demonstrated a simple beam monitoring system consisting of a pinhole aperture, a single-pixel GaAs detector, and a high-speed data acquisition system capable of recording, digitizing, and storing pulse-by-pulse snapshots of the beam. By physically scanning the single pixel camera vertically through the x-ray flux we could map out the beam image in one dimension. Signal to noise at the peak was 26:1. Extended irradiation testing indicated a factor 2 drop in signal yield after an exposure of approximately 1000 GRad. Risetime of the signal was determined to be less than 300ps, but we lacked sensitivity to probe more finely. (We expect the actual risetime is probably well under 100ps.) The photodiode for these studies was obtained from what was then the Emcore Corporation.

In the past year we have extended the system to a 32-pixel linear array of GaAs photodiodes based on the 512-pixel linear array (G9494-512) obtained from Hamamatsu Photonics. In beam tests we established the signal to noise and radiation hardness characteristics similar to those seen in the Emcore single photodiode device, and could image the beam. Poor beam characteristics at the time of the run prevented an actual measurement of the vertical size of the beam, however.

We have also prepared a design for the optics and detector of a fully operational beam monitoring system to be deployed in CESR. For this purpose we developed Mathematica code to compute, from first principles, signal yield and spatial resolution, and optimized the design under the constraint that we must be able to image single bunches. What has emerged from this exercise is a very simple concept of a optical system consisting of a doublet of multilayer tungsten-carbon mirrors for monochromatization and a single 1mm diameter, 100-ring Fesnel zone plate close to the beam source. With a long optical arm this functions as a $\times 5$ magnifier with sufficiently good transmission to permit single bunch imaging with adequate signal-to-noise. The optimization process trades off spatial resolution and signal yield, with the result that the expected spatial resolution (referred to the source point) is $2 \sim 3\mu m$ and the signal yield is $\sim 600$ photons per bunch at typical beam currents and beam energies.

From here we plan to build a first prototype of this system in the summer of 2007, and a final version with the year. Design of the associated xray beamline is underway now with the participation of our CHESS colleagues.