Uniformly Rastering an Electron Beam on a Polarized Cryotarget

University of Richmond: David Brakman, Dr. G.P. Gilfoyle
Jefferson Lab: Chris Cuevas, Bill Gunning, Joe Grames

Background

Purpose

Create a pair of mathematical functions that, when applied as inputs to electromagnets, will deflect ("raster") an electron beam in a way that produces a uniformly intense circular pattern.

Jefferson Lab

The primary goal of Jefferson Lab is to understand how quarks and gluons interact to form nucleons and nuclei. One of the experiments in Hall B at Jefferson Lab will measure excited nucleon states more completely by controlling the spin states of a hydrogen target. For the HDice experiment, an electron beam will be incident on a polarized target of frozen hydrogen-deuteride ("H-D ice", Fig. 1), and the debris produced will be measured in CLAS12, the CEBAF Large Acceptance Spectrometer (Fig. 2). CLAS12 is designed to measure the reaction products between an electron beam and the target located near the center.

Figure 1: Target

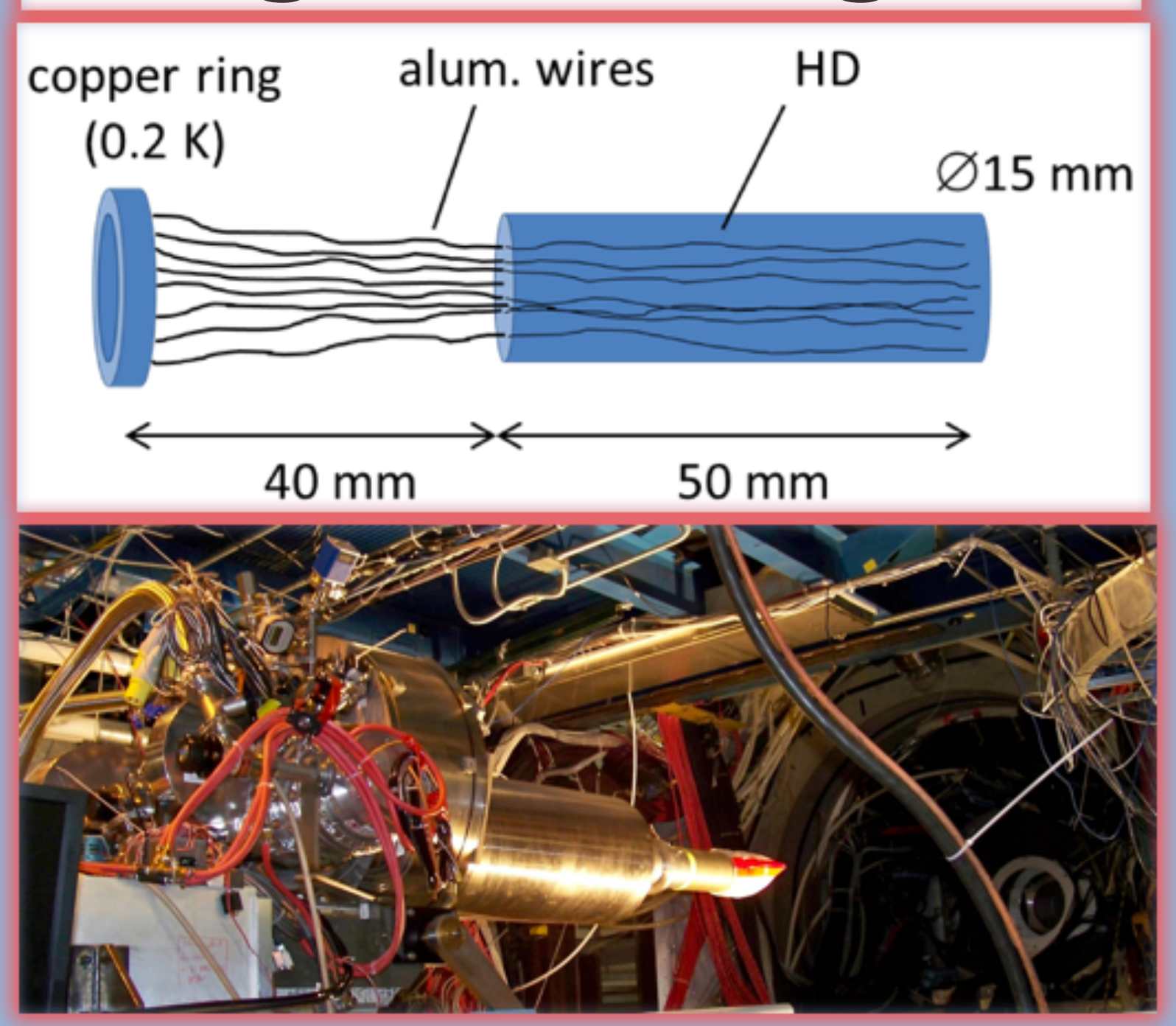
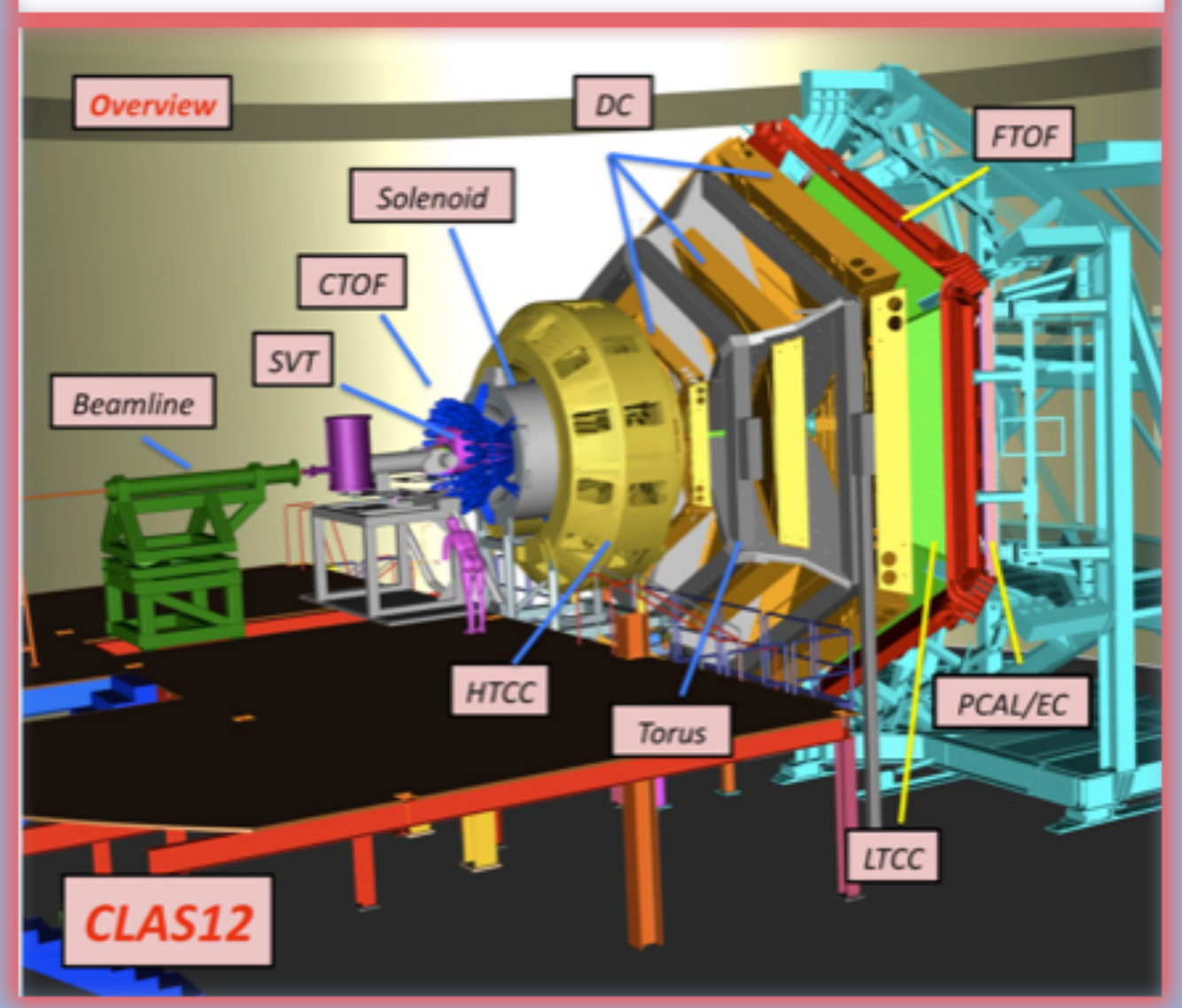


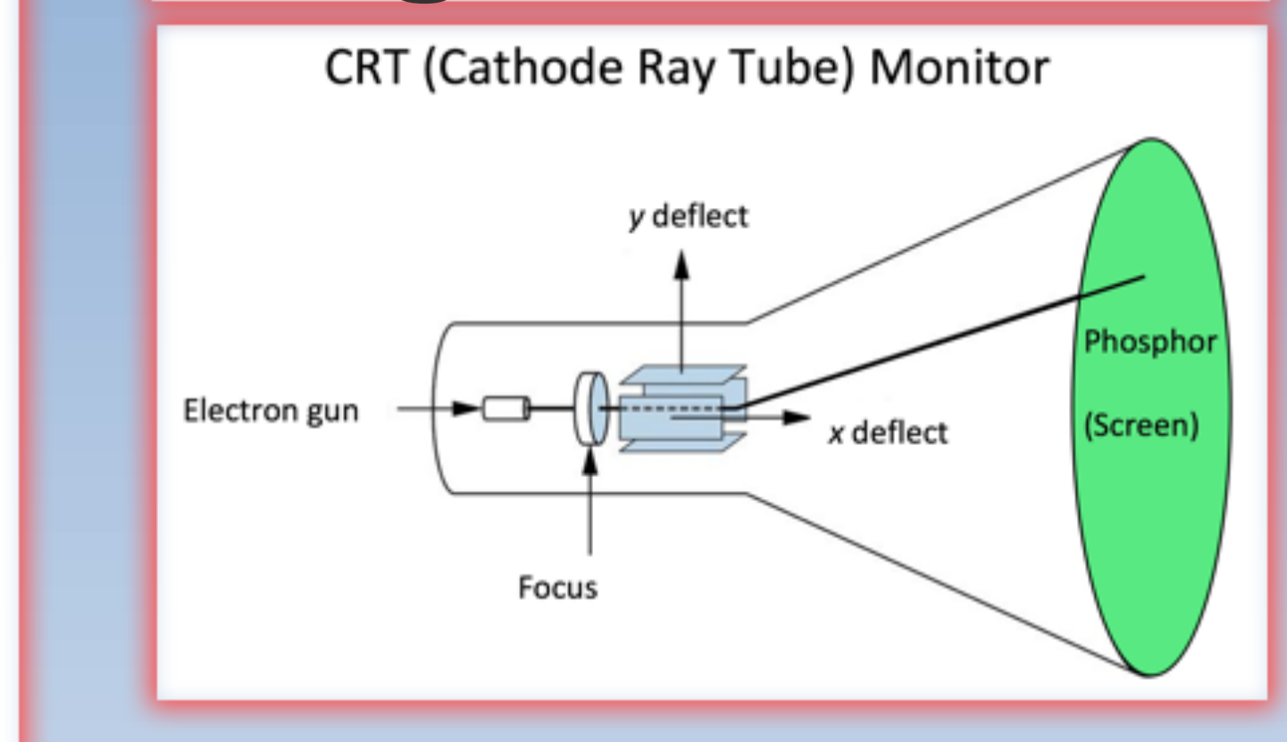
Figure 2: CLAS12



Rastering

Rastering is the production of a 2D pattern from the oscillating deflection of an electron beam. The deflection is achieved by varying the voltage applied to electromagnets arranged horizontally and vertically around the beam. This basic setup is common to our experiment as well as CRT monitors, diagrammed in (Fig. 3). In the HDice experiment, it is necessary to raster the beam uniformly so that no portion of the frozen hydrogen-deuteride (labeled HD in Fig. 1) of the cryotarget receives excess heat and depolarizes.

Figure 3: CRT



Methods

Model Development

For simplicity, we chose to make a dense spiral pattern (Fig. 4a, 4b). Let (r,θ) be the polar coordinates of the beam on the target at any time t. Approximate $\frac{dr}{d\theta}$ << 1 for a dense spiral, and let A be the area of the annulus swept by the beam.

Define $\frac{dA}{dt}$ const

$$\frac{dA}{dt} = k = \frac{d}{dt}(\pi r_t^2) = 2\pi r_t\frac{dr}{dt}$$

$$r_t \propto \sqrt{t}$$

The $\sqrt{t}$ envelope defines the pattern's refresh rate, and the number of sin/cos waves within in the envelope corresponds to the spiral's density.

Figure 4a: Basic y(t)

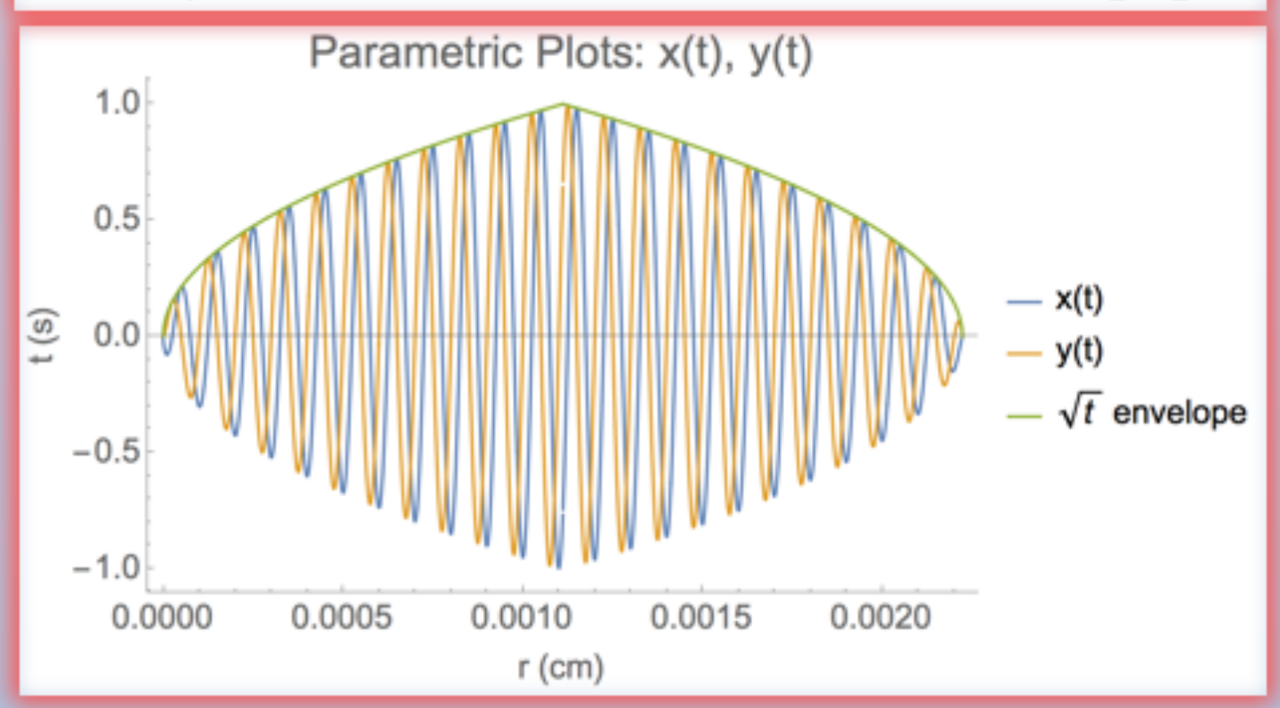
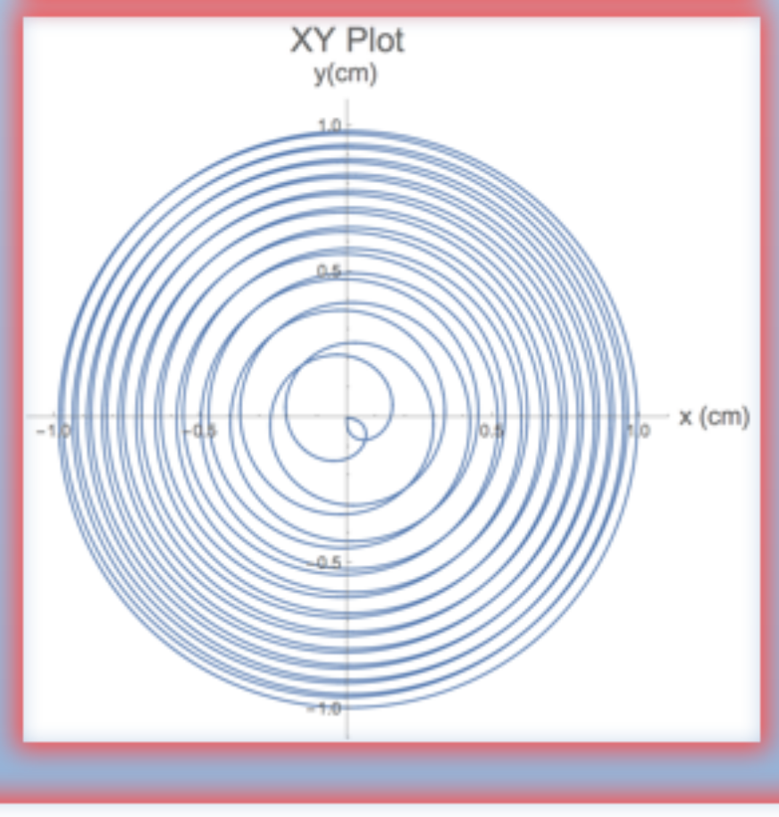


Figure 4b: Basic XY



Simulation

The patterns shown in Fig. 4a, 4b correspond to a desired trace of the beam on the surface of the HDice target. We simulated the spatial distribution of beam intensity over the target by at recording the (x,y) locations of the beam trace at numerous evenly-spaced times t as counts in the bins of a 2D histogram (Fig. 5a). The amounts by which each bin's height deviated from the average formed an informative sampling distribution (Fig. 5b). The gaps and peaks in the center correspond to maxima and minima of beam intensity that needed to be smoothed out.

Figure 5a: Simulation 1

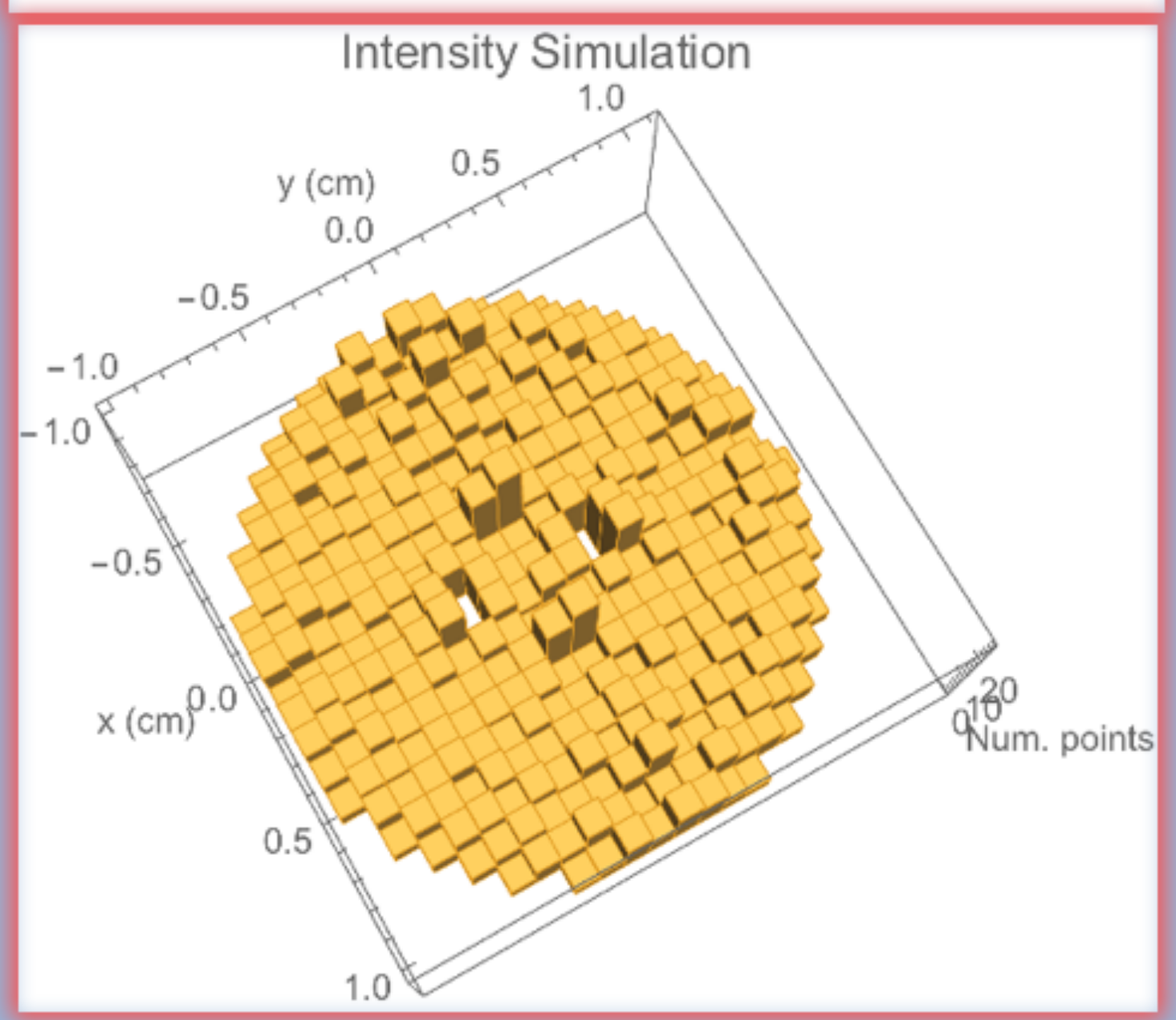


Figure 6a: "Resets"

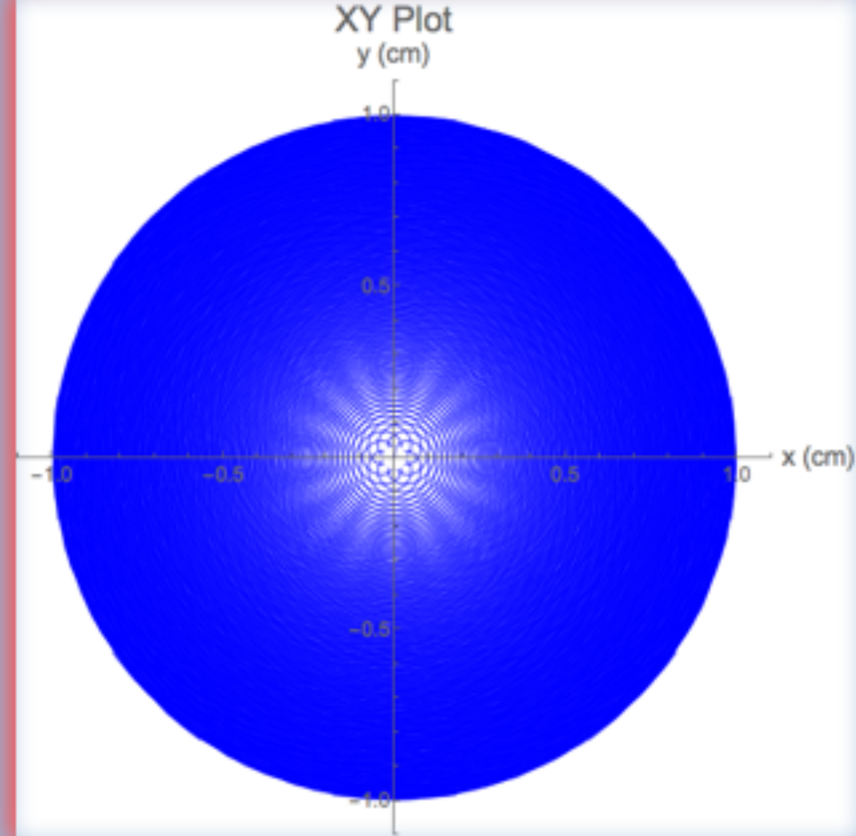
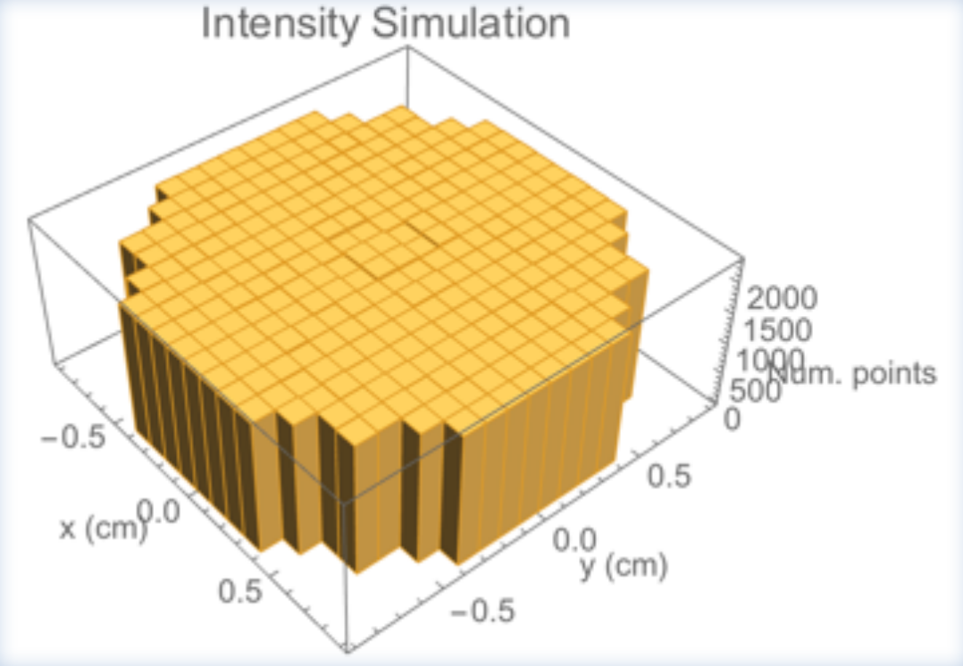


Figure 6b: Uniformity



Model Enhancement

We made small changes to the density of our pattern so that an integer number of sin/cos waves would not fit in a single envelope. The effect was to make the spiral "reset" to different points, smearing out nonuniformities in the center of the XY pattern.

Test Bench Setup

We constructed the setup shown in Fig. 7a to test our ability to produce the XY pattern in Fig. 6a with the electromagnets to be used in the UITF test. The x(t), y(t) waveforms specified above are loaded into a waveform generator whose output amplified to drive coils of wire on steel beam pipe. A probe recorded the current in both coils; the result is plotted in Fig. 7b.

Figure 7a: Test Bench

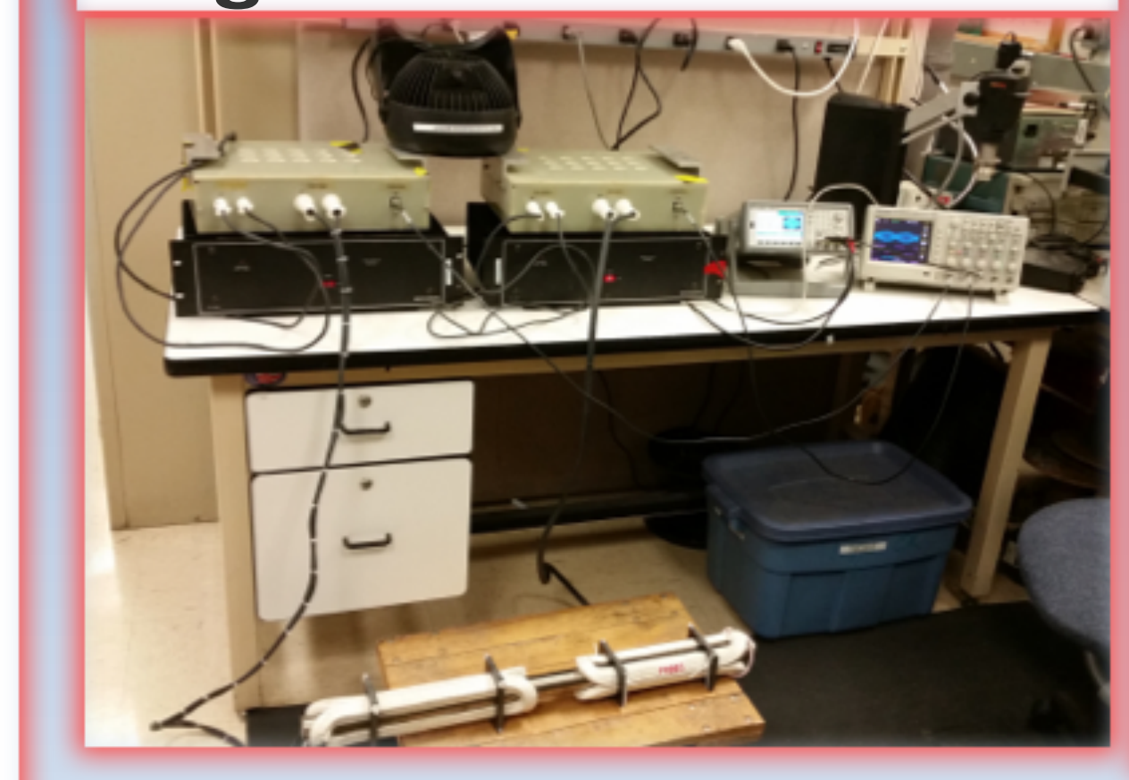
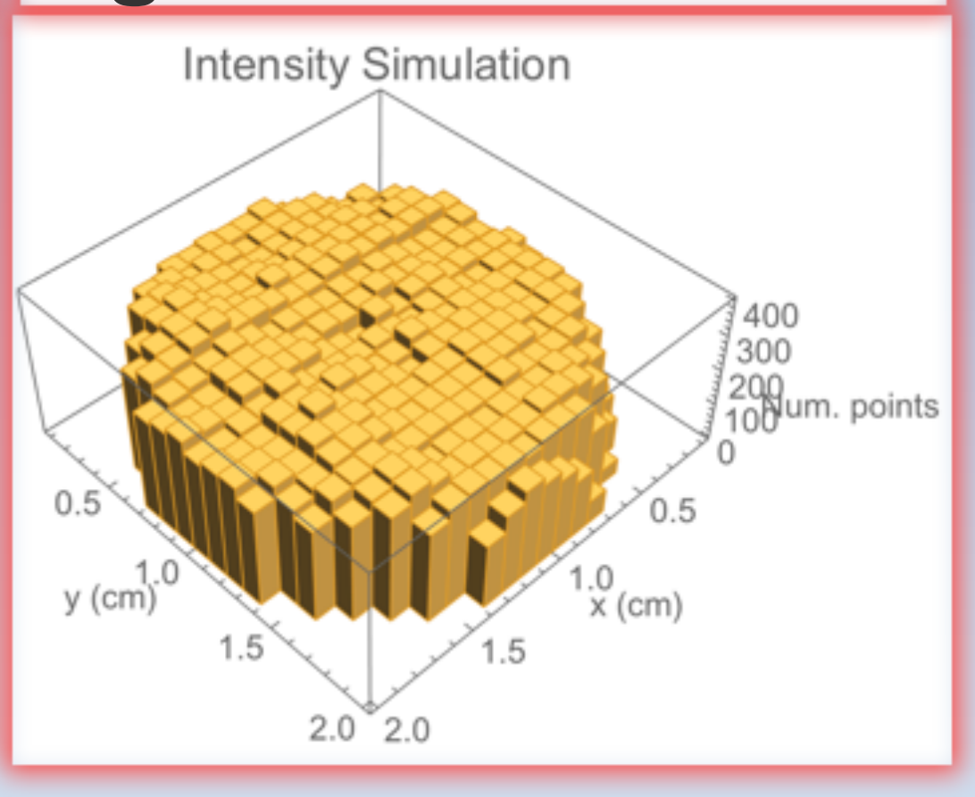


Figure 7b: Test Obsv.

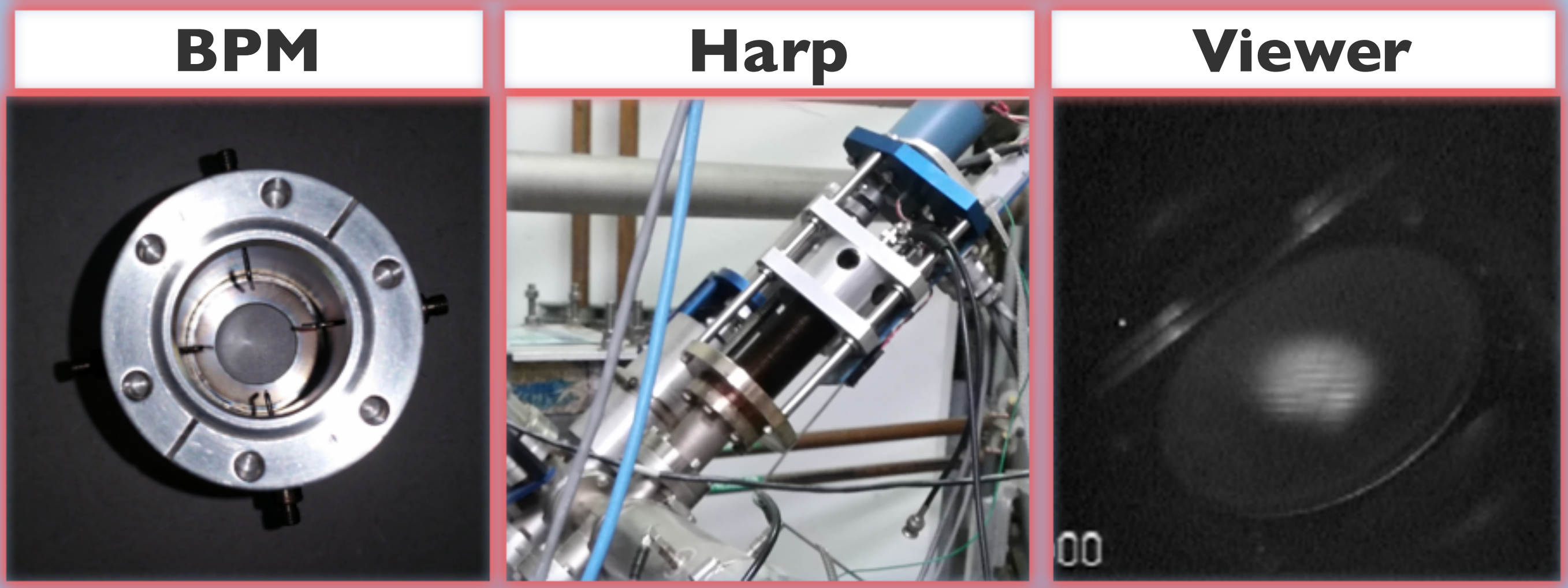


Outcome

Beam Test

We received permission to test our raster scheme in the CEBAF Injector. At this location, the beam has not traveled through the linear accelerators and remains at a relatively low energy of 6.5 MeV. Due to time constraints, we used equipment in place at the injector: a beam position monitor (BPM), a three-wire "harp", and a Chromox view screen.

Figure 7: Beamline Measuring Devices

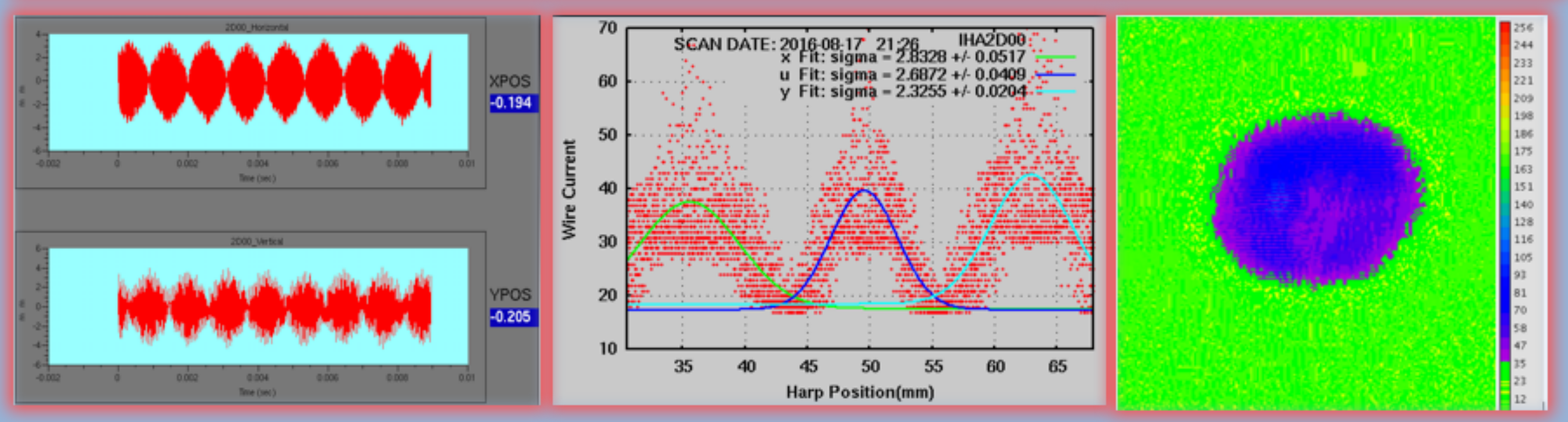


BPM

Harp

Viewer

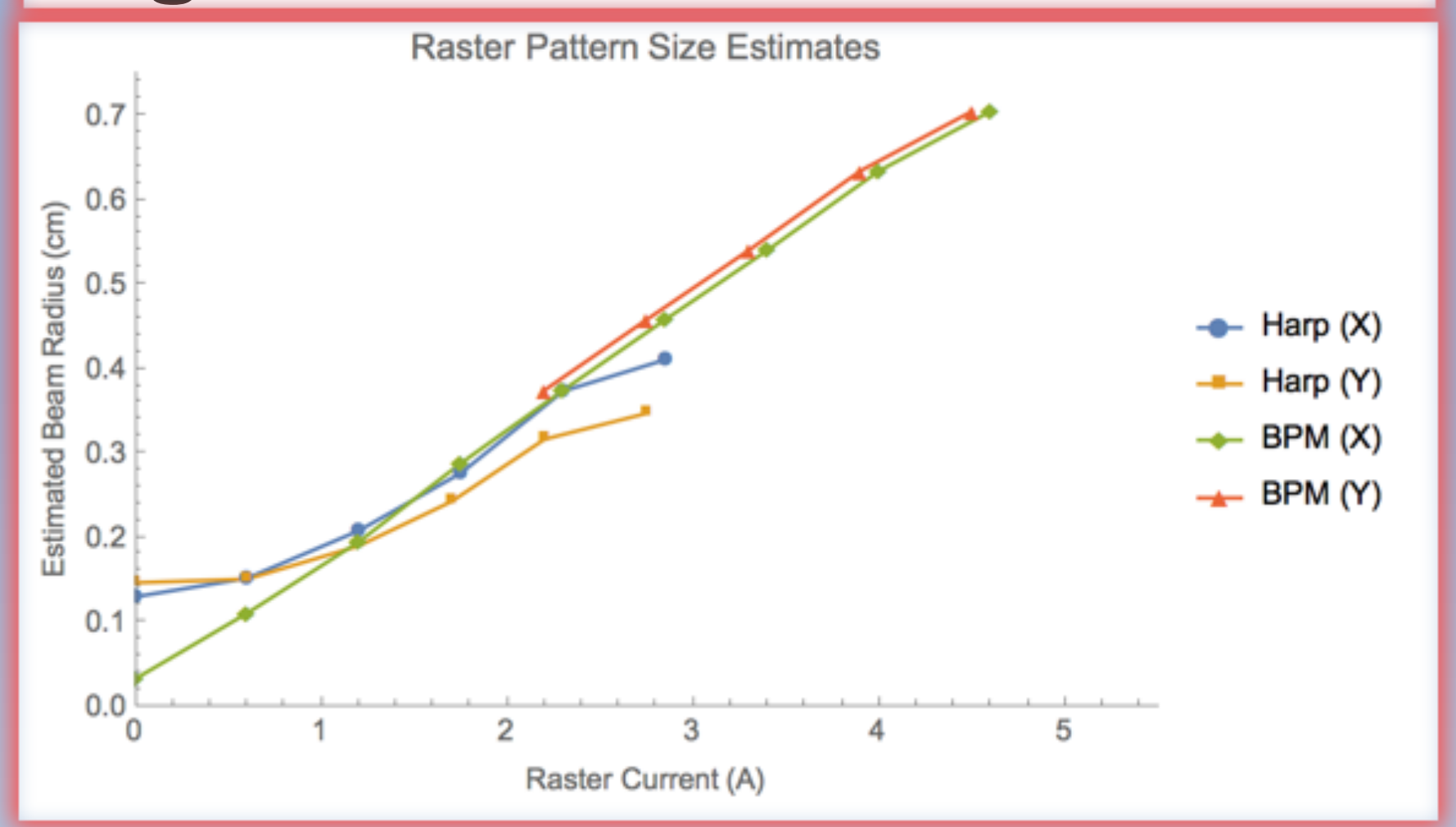
Figure 9: Sample Device Outputs



Results

We were unable to extract a complete measure of uniformity from the equipment. Measurements of raster size from different equipment disagree, as shown in Fig. 10.

Figure 10: Size Measurements



Conclusion

We adequately specified a pattern that should be produced but did not succeed in exactly reproducing the pattern with the electron beam. Qualitatively, measurements suggest that the overall procedure is mostly correct, and this work should be an adequate start for further work by the HDice group at JLab.