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FIRST RESULTS FOR A 50 MeV BEAM INDUNCED FLUORESCENCE MONITOR FOR BEAM PROFILE MEASUREMENTS

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Abstract

Nusano is developing a 50 MeV alpha ($^4He^{++}$) particle accelerator (The Nusano accelerator can also accelerate $^2H^+$, $^3He^{++}$, $^6Li^{3+}$, $^7Li^{3+}$, and a few other heavier ions), primarily to produce medical radionuclides. The accelerator produces an average current of 3 mA_e with 20 mA_e average macro pulse current. This results in an average beam power of 75 kW, and an average beam power within the macro pulse of 500 kW. The beam profile at the exit of the DTL is approximately Gaussian with a radius (FWHM) of about 3 mm. Designing diagnostics for this beam is challenging, as diagnostics that intercept beam will receive a very high heat load. A BIFM (Beam Induced Fluorescence Monitor) is being developed to measure beam profiles. Nitrogen gas is leaked into the beamline. Excitation of the nitrogen by beam particles is captured using an image intensifier. The signal generated is directly proportional to the beam current. A prototype system has been constructed and tested on a lower intensity alpha beam. First results indicate we can measure beam profile to a 100 µm accuracy. Production system is currently being designed.

EXPERIMENTAL SYSTEM

The 50 MeV alpha particle accelerator Nusano is developing will be commissioned in 2025. The 47.3 MeV at the University of Washington Medical Cyclotron Facility was used as a test facility to evaluate the BIFM (Beam Induced Fluorescence Monitor) intended to be installed on the beamline. The cyclotron provides 20-40 μA_e alpha beam, which is a good model for the Nusano beam.

The experimental apparatus is shown in Figure 1, consists of a vacuum chamber that the beam passes through. In the chamber the beam particles interact with nitrogen leaked into the chamber and photons are generated by decay in excited nitrogen. The light exits the chamber through a window and is directed by lenses and mirrors into an image intensified camera (Photonis iNocturn HI-QE Blue). Since the light emitted is directly proportional to the density of nitrogen and the beam current, by analyzing the images generated the beam distribution can be measured. A calibrated PMT is also provided to measure light intensity received by the camera.

Control of the nitrogen pressure is critical to correct operation of the BIFM. The experimental system allowed for both pulse and CW nitrogen flow, but the data presented here is entirely based on CW flow. One of the key goals of the project was to determine the ideal nitrogen pressure for the system. The system also includes vacuum chokes that allow the pressure in the measurement chamber to be about an order of magnitude higher than the pressure in the surrounding vacuum system.

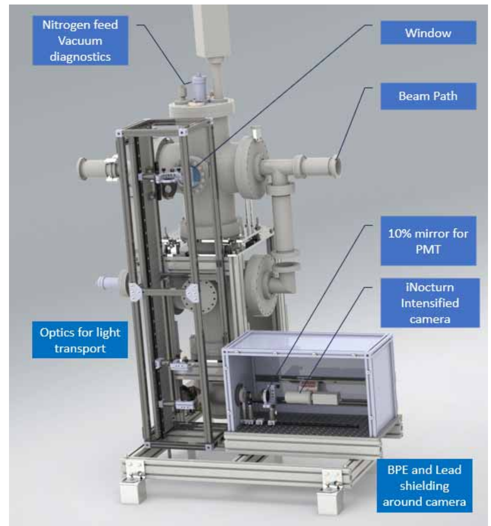

Figure 1: CAD drawing of experimental system.

RESULTS

A basic raw data image is show in Figure 2. The beam is the horizontal strip shown in the blue outline. The crescent shape, and the three dots (red outline), are compound reflections of light generated by ionization of background gas in the cold cathode pressure gauge.

In order to understand the resolution of the BIFM a picture was taken with a test pattern located at the beam position. Combining this with the data averaged across the beam part of the image indicates a spatial resolution on the order of 100 µm (see Figure 3).

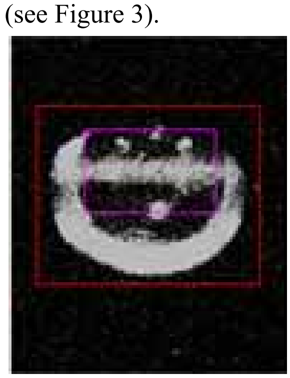

Figure 2: Basic image show the beam induced fluorescence (show in the blue box). The crescent shape, and the three dots (red box), are a compound reflection from the cold cathode pressure gauge.

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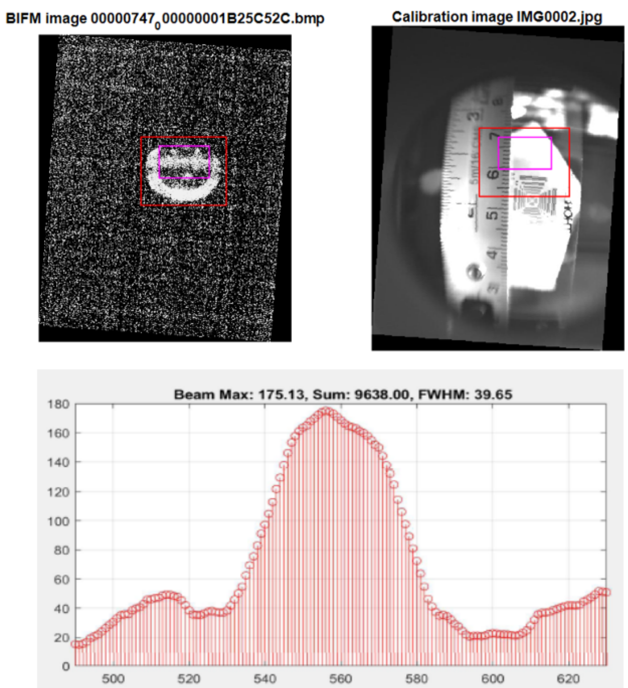
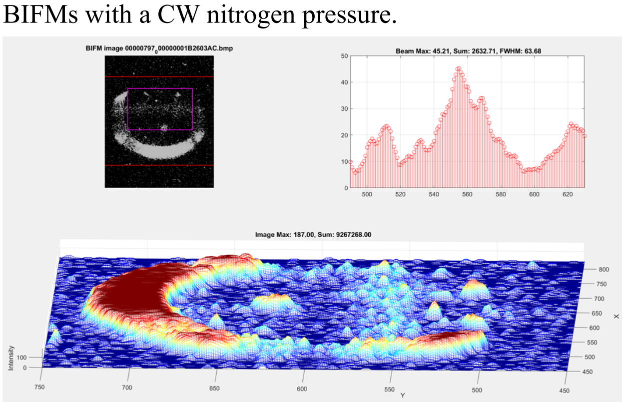


Figure 3: Spatial resolution of the BIFM. The upper left shows a beam induced image. The upper right is the calibration image. Note the blue and red boxes represent matching areas. The lower image indicates the averaged data from pixels in the beam box.

Variation with Nitrogen Pressure

Varying the nitrogen pressure varies the intensity of received light (Figure 4). The received beam signal is proportional to the nitrogen pressure. The light from the cold cathode gauge is not because it saturates the detector at the highest pressures.

Pulsing the nitrogen gas feed, to reduce the load on the rest of the vacuum system, was considered but the data tends to indicate that Nusano can probably operate the BIFMs with a CW nitrogen pressure.



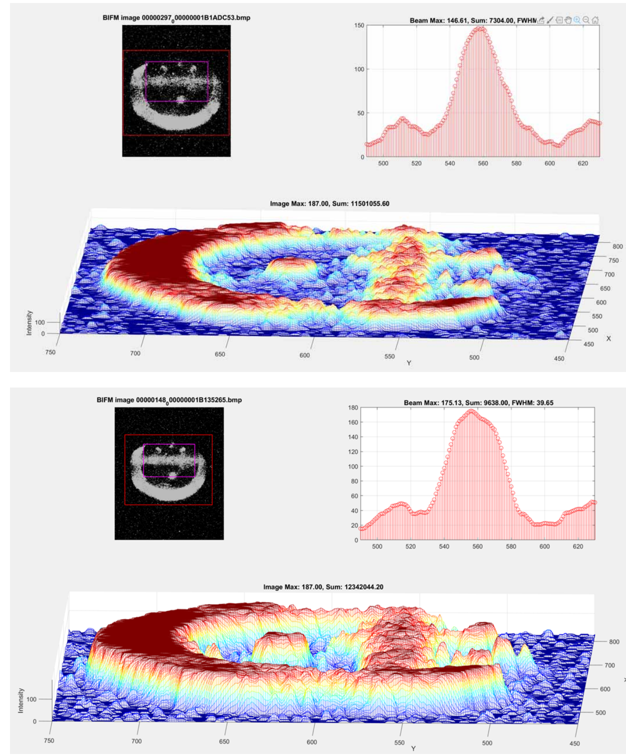


Figure 4: Variation of signal with nitrogen pressure. The upper data is at 2×10^{-5} torr, middle data is at 5×10^{-5} torr, and the lower data is at 7×10^{-5} torr.

Variation with Beam Position

As a test of system performance, the beam was steered up and down and BIFM was used to track the beam position (Figure 5). The beam centroid moves about 4.5 mm, which is consistent with the beam optics and limits placed by the collimators.

The beam profile is consistent with a wire scanner diagnostic. Direct comparison is difficult because the wire scanner is limited to a much smaller beam current than was used for the BIFM experiments.

UW / Nusano Comparison

The UW experiments were conducted primarily with 22 μA_e beam current. Clearly sufficient light was generated for the single layer MCP intensifier to form images (averaging several hundred images was necessary to generate good statistical data). Nusano will operate with 20 mA_e beam current, so 1000 times as many photons would be generated for the same nitrogen pressure. Nusano will reduce the nitrogen pressure to 5×10^{-7} torr resulting in a reduction in the number of photons by a factor of 100. This still results in Nusano generating 10 times the light seen in these experiments. This low nitrogen pressure should allow Nusano to operate the BIFMs with a CW gas flow, simplifying the diagnostics.

We are also evaluating the possibility of operating with the lower gain camera and using a puffed gas system.

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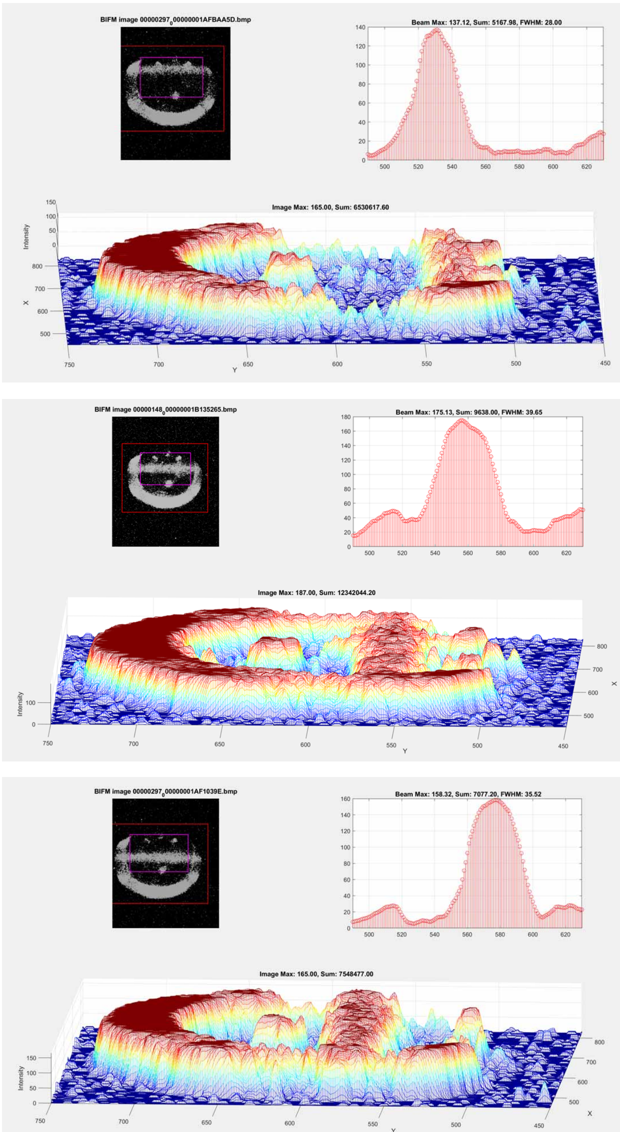

Figure 5: Beam steering. The beam centroid was moved up and down and the position followed on the BIFM. The centroid travel is about 4.5 mm, which is consistent with beam optics and collimators.

RADIATION DAMGE

The long optical path and shielding are to reduce the radiation dose on sensitive electronic such as the camera. Nusan's beam line will be exposed to high radiation dose. Up to 25,000 mrem/hour on the switchyard floor, and more than order of magnitude higher at beam height. This dose is primarily from neutrons (~90%) and gammas (~10%). The UW facility also has a high dose of neutrons from their neutron treatment beam.

Images taken before and after operation of the neutron beam (Figure 6) clearly show an increase in the number of dead pixels as well as a reduced sensitivity.

The experimental setup had limited shield due to space constraints on the beamline.

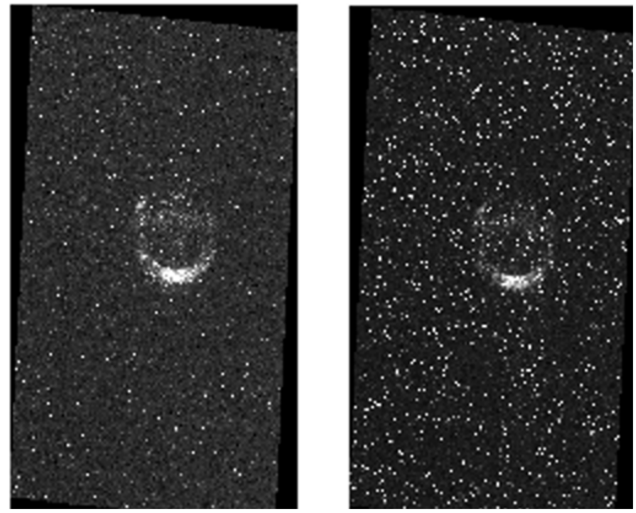

Figure 6: Neutron damage, primarily to the camera system. The image on the left was taken at the end of the first day of operation. The image on the right was taken after the neutron treatment beam had been running for an entire day.

NEXT STEPS

The camera settings were not optimal at the UW experiments. Several pixels were saturated. The gain can be turned down on the camera or we could change the image size. For example, increasing the image size on the camara by a factor of two, in both directions, would decrease the brightness and increase the spatial resolution to 50 µm.

The camera showed some radiation damage so shielding around the camera will have to be increased. The limited shielding at UW was mostly a function of space constraints.

We had several problems with small light leaks into the darkened optics boxes. These will be redesigned to reduce light leaks and make them easier to work with.

The cold cathode vacuum gauge generated significant light problems. This will be relocated, and reflective surfaces darkened.

CONCLUSIONS

The first test of the Nusano BIFM was very successful. All project goals were achieved and then some. An improved version of the system is being designed and constructed. Emphasis is on a system that can be deployed and maintained along the beamline. Nusano will eventually deploy 35 BIFM systems along the beamline. Some are for specific diagnostics or tuning applications, but many are expected to be part of routine operations.