01-222N(A) -- DIAGNOSTICS FOR WEAK BEAMS AND HIGH TRANSMISSION

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Purpose: Since the early 1990's in the field of low energy nuclear science there has been worldwide interest in an advanced facility capable of producing energetic, high-quality beams of radionuclides. The purpose of this LDRD project is to develop design concepts for the major components of the Rare Isotope Accelerator (RIA). This project aims to develop proper diagnostics for the most exotic rare isotope beams that will be available only in very low intensity even at RIA. These diagnostics will be essential to tune the post-accelerator and obtain high-transmission.

Approach: The wide range of beam intensity that will be available at the RIA poses a significant difficulty when it comes to obtaining sufficient diagnostics to tune the post-accelerator. A detector system with sufficient dynamic range and fairly rugged against beam damage needed to be developed for this application. A system based on detection of secondary electrons with fast position sensitive detectors was developed and tested at the ATLAS facility.

Technical Progress and Results: We have developed, fabricated, and tested a beam image monitor (BIM) that can be used to provide snap shot images of low intensity beam profiles. The device is sensitive at a wide dynamic range which spans from ~10^2 to ~10^{12} pps. With the advent of double-plane slits or a pepper pot plate, this system can be used to scan transverse emittance profiles in both the x-x' and y-y' phase space planes, simultaneously. Conventional diagnostic devices used for heavy ion accelerators generally require at least 10^9 pps intensity to carry out similar diagnostics, which is not practical when considering beams with very low intensities, such as rare isotope beams. Furthermore, the detection system used here can be used for a wide range of incident ion velocities. Compared with solid-state detectors and scintillators that are inserted directly into the beam, this type of detection system is less susceptible to beam induced damage resulting in longer lifetimes and less maintenance.

The test was done using single charge state krypton beams at energies ranging from 3.6 keV/u to 18 keV/u. The device's sensitivity was monitored for intensities below 10^{12} pps and an emittance scan was recorded and analyzed. The spatial resolution was characterized by comparing the emittance profile with that obtained by a wire scanning device which had better resolution but sensitive only to intensities above 10^{11} pps.

Recently, the device has been used to aid in the transport of ~6 MeV/u radioactive beams, such as ^{17}F, produced by pick-up reactions with a gas cell target at the ATLAS accelerator facility.

A layout of the BIM is illustrated in Fig. 1. The beam comes in from the left and passes through any necessary slits or apertures, such as a pepper pot plate. Particles strike a flat aluminum surface that is oriented at 45° relative to the beam direction. The plate serves as a dynode since the ion signal is converted to a burst of secondary electrons (SE). These secondaries are promptly accelerated by a 5-15 kV potential imposed by a grid lying parallel to and 5 mm from the surface. Motion feedthroughs are used to insert the aluminum foil dynode and a dual slit plate upstream. A position sensitive microchannel plate (MCP) is excited by the secondary electrons and further amplifies the signal induced by the secondaries. The MCP is parallel to the conversion surface as well and lies 47 mm after the grid. The accelerating potential is distributed evenly enough such that the electrons are accelerated perpendicular to the conversion surface, thus the system may be used to map the ion beam intensity along the transverse plane.

The actual detection of the signal is done with the combination of a phosphor screen and a light sensitive detector. A monochromatic CCD (charge coupled device) would be sufficient for detecting the light signal; however, we chose a CID (charge integrating device) since it has less cross sensor-induced noise as well as less thermal induced noise. A dual MCP detection system was actually used here to obtain a high gain. The second MCP lies 0.5 mm behind the first, such that the channel holes align. Both MCPs are identical at 41 mm in diameter and can sustain a maximum bias of 1000 VDC each. A resistive circuit was constructed to allow both MCPs to have equal biases and run off of a single power supply. The dual MCP system has a combined maximum gain of $4 \cdot 10^7$. About 0.5 mm behind the second MCP is a type P-20 phosphor plate. It is biased at 3 kV relative to the MCP output to convert the accelerated electron's energy into photons of predominantly 560 nm wavelength. The quantum efficiency is estimated to be about 0.063 photons/eV/electron in this wavelength region. The spatial resolution for a single particle exciting the MCP surface is better than 0.15 mm according to the manufacturer's specification.

The CID sensors accumulate a charge that is directly proportional to the total photon flux absorbed at each respective location. The charge is integrated over a 33 ms period and each sensor is discharged after each read. The electronics within the camera allow the CID sensors to be read out in the RS-170 standard of rastering images. The signal is amplified and then fed into a PCI-1408 frame grabber circuit board. The board features its own amplification with programmable gain to processes the signal before it is delivered to an 8-bit flash ADC. The images are digitally processed in real time with the use of National Instruments IMAQ software and may be stored for later reference or processing. The image signal may also be split to be monitored simultaneously with a TV monitor. The beam imaging system including MCP, phosphor screen, FO rod and CID camera was purchased commercially from the Colutron Research Corporation.

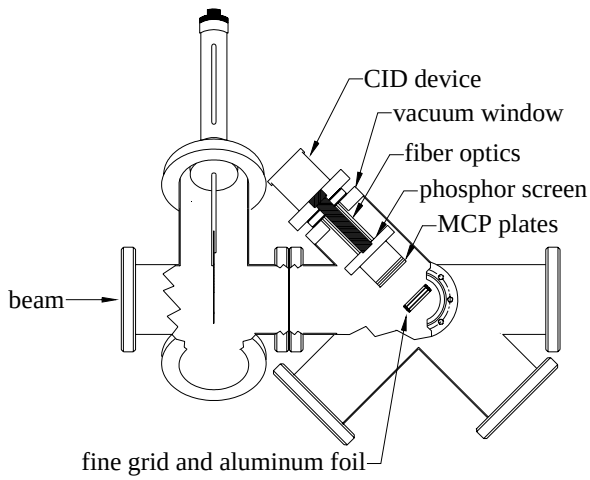


Figure 1. Diagram of the BIM.

A test bench at the "8°+27° West" beam line at the Argonne Dynamitron accelerator was configured to test the performance of the detection system with stable $^{84}Kr^{+1}$ DC beams. The beam energy used ranged from 300keV to 1.5MeV for our experiments. Two dipoles bending in the same direction are used to select the isotope of interest over a 15 m long transport line and a quadrupole doublet refocuses the beam as it is delivered to the target region.

The properties of secondary electrons ejected from the aluminum conversion surface were studied carefully both by numerical simulation and measurements. The broadening of electron beam was particularly investigated. These studies resulted in the copper grid with mesh size 0.33 mm and -13 kV potential on the conversion surface in order to obtain the best possible spatial resolution on the phosphor screen which is approximately 0.5 mm.

The tests with $^{84}Kr^{1+}$ ions from the Dynamitron accelerator have shown that a beam of 3.6 keV/u or 18 keV/u can be well resolved with an intensity as low as $4{\cdot}10^{2}$ pps. The latter value is the lowest beam intensity achievable using the attenuators. The maximum intensity could be higher than 200 nA; however, the extent of the grid and MCP detector lifetime may suffer. We did not observe deleterious beam effects even when running at up to 10^{12} pps and 1.5 MeV for several hours. A plot of the beam distribution is shown in Fig. 2. Bitmap images of single snap shots of two different beams are illustrated in

Fig. 3. Figure 3(a) is that of 18 keV/u krypton ions at rate of $4{\cdot}10^2$ pps. Each resolvable spot represents at least one ion collision event.

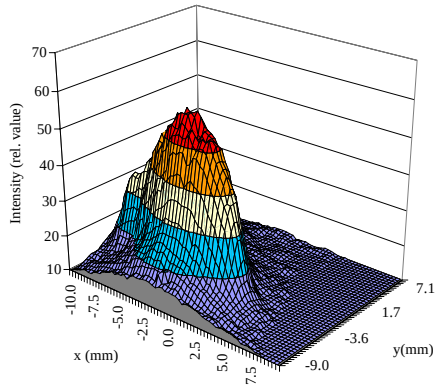
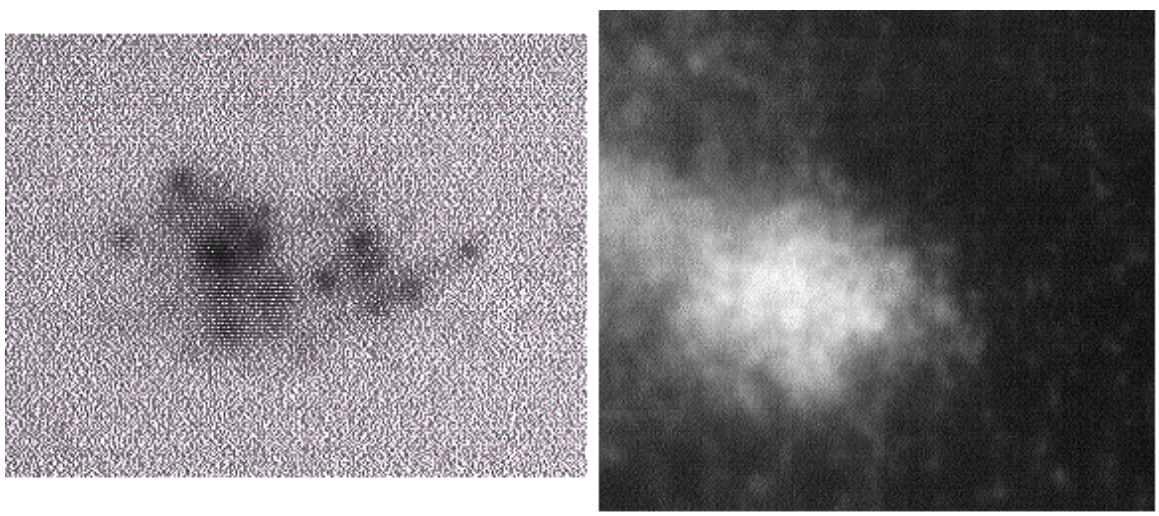


Figure 2. Transverse beam density distribution obtained for Krypton ($2{\cdot}10^7$ pps) beam.



(a) (b)

Figure 3. Beam images of a) low intensity ~$4{\cdot}10^2$ pps 18 keV/u krypton beam, area size is 5.1×6.5 mm·mm; b) Total intensity of 2.5 $\times 10^3$ pps of a radioactive beam line. Area covered in coordinate system of the beam is ~17.0mm×18.2·mm.

Since the MCP plates are highly insensitive to gamma radiation, this detection system is sufficiently immune to radioactive decay of a wide range of implanted particles. From a recent experiment we obtained the results illustrated in Fig. 3(b), where a momentum selected, mixed beam of $^{17}F^{9+}$ (67 MeV), $^{16}O^{8+}$ (56 MeV), and $^{16}O^{7+}$ (43 MeV) is striking the conversion surface. The $^{17}F^{9+}$ component constituted 68% of the $2.5{\times}10^5$ pps resulting from an inverse kinematics in-flight production technique used at the ATLAS to produce a variety of radioactive species at energies at or below the coulomb barrier.

Diagnostics of the transverse phase space characteristics of the beams are useful in characterizing the performance of devices used in any accelerator. Beams of rare isotopes must be transported with optimum efficiency while passing through a complex system of optical devices; therefore, it is important to measure the phase space area and orientation of the phase space ellipse in terms of its Twiss parameters. Located L=30.5 cm upstream from the dynode surface is a linear feed-through that can scan both a horizontal and vertical slit across the transverse plane of the beam. Each slit is 0.2 mm wide. The beam is aligned and focused within a region bounded by a circle of ~30 mm diameter such that each of the two slits, which are 45 mm in length, may scan both the *x*- and *y*- profiles. From these profiles the beam emittance in both horizontal and vertical phase spaces is reconstructed. The effect of the electron beam broadening over the drift space between the mesh and MCP plate can be accounted by a deconvolution of Gaussian functions.

Specific Accomplishments: There has been one refereed publication based on the work done under this LDRD project.

P.N. Ostroumov, P. Billquist, M. Portillo and W.Q. Shen, “Design and Test of a Beam Profile and Emittance Monitoring Device for Low Intensity Radioactive Beams,” *RSI*, 72(12) December 2001.