INSTRUMENTATION AT THE LOW INTENSITY FRONTIER: DIAGNOSTICS FOR THE STOPPED AND REACCELERATED BEAMS OF NSCL AND FRIB

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Abstract

A facility to stop and reaccelerate rare isotope beams is under commissioning at Michigan State University. It is based on gas stopping devices and a superconducting heavy-ion linac. Initially the facility will accelerate rare isotopes produced by the Coupled Cyclotron Facility. Later it will be operated as part of the Facility for Rare Isotope Beams (FRIB). The diagnostics system for the reaccelerator is particularly challenging because of the low energy and low intensity of the ion beam. It is largely based on detection techniques and instrumentation typically developed for nuclear and particle physics. Some of the devices already have been used to commission ReA and achieve project milestones, while others are in assembly and fabrication stages. A description of the devices and the current status of the diagnostics system will be presented along with examples of the experience so far with the diagnostics operation at the reaccelerator.

INTRODUCTION

Production of radioactive beams through fragmentation of stable nuclei, has been proven to be a very successful isotope production process for rare isotope accelerators. At the National Superconducting Cyclotron Laboratory (NSCL), radioactive beams produced with this technique, have energies of the order of 100 MeV/u, and intensities 1-10^6 pps.

Rare isotope beams at these energies are very suitable for probing nuclear structure properties in exotic nuclei. Beams of rare isotopes with energies close to the Coulomb barrier of nuclei, however, (around 3 - 5 MeV/u) offer exciting opportunities for studies of nuclear structure and reactions relevant to astrophysics because the temperatures at which stellar processes happen in the universe, correspond in the lab to ion beam energies of just a few MeV/u.

At Michigan State University (MSU), with the development of a facility of stopped and reacelerated beams, a broad range of rare isotopes from fragmentation reactions will be available for nuclear physics experiments at the astrophysically relevant energies. The facilty is based on the stopping of the beam in a gas, the subsequent charge breeding of the extracted ions in an Electron Beam Ion Trap (EBIT), and their re-acceleration by a Radiofrequency Quadrupole (RFQ) and a superconducting linac based on Quarter-wave resonators. Stable pilot beams of low intensity ($\sim$ 1 nA) produced by an off-line ion source are used for tuning of the linac. A scaling procedure to adapt the beam settings to the rare isotope of interest will be used. The above process requires the existence of a diagnostics system that can diagnose both pilot and rare isotope beam. Due to this low intensity and low energy regime of operation, diagnostics based on particle detectors has been developed. Systems similar in philosophy are in operation at low energy facilities such as TRIUMF [1], or, Argonne National Laboratory [2].

BUNCH LENGTH MEASUREMENT

To diagnose the longitudinal properties of the beam, secondary electron emission from a thin wire was used. A schematic of this diagnostic device adapted from [1] is presented in Fig. 1. The outer cylinder of the device is at ground potential while the wire is at negative voltage. Secondary electrons are emitted and directed by the field towards the cylinder. A microchannel plate detector registers the signal of the secondary electrons. The leading edge of the resulting pulse is detected by a VME-based V812 Constant Fraction Discriminator (CFD) by CAEN [3] and is used to provide a trigger for the electronics. The trigger logic employed is realized in a JTEC FPGA module [4] where the arrival time of the electron signal is compared to the RF timing signal. The timing difference between these two events is digitized by a CAEN V775 Time-to-Digital Converter (TDC) with a resolution of 25 ps. The resulting

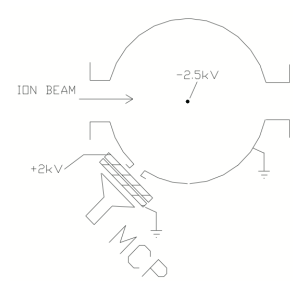

Figure 1: Schematic of the operating principle of a timing wire detector. Adapted from [1].

histogram of time events corresponds to a sampling of the timing for all the bunches detected. In a few seconds of operation, a measurement of the bunch length and separation can be obtained. A typical spectrum from one of the commissioning runs with ReA is shown in Fig. 2. A tim-

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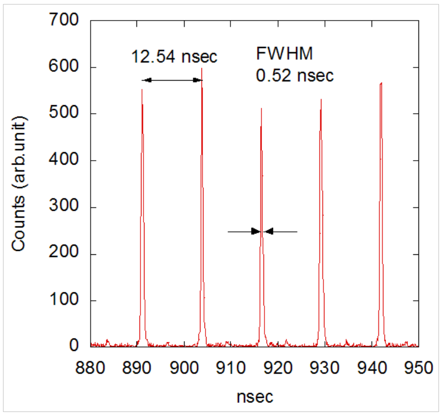

Figure 2: Timing spectrum taken with the timing wire detector for a He^{+} beam after the ReA RFQ. Each of the peaks corresponds to a collections of sample timing for the ReA bunches. A bunch width of 520 ps FWHM and a repetition rate of 80.5MHz (12.54 ns bunch separation) is verified.

ing resolution better than 200ps FWHM has been achieved with this diagnostic. A photo of the actual device is shown in Fig. 3.

Figure 3: Photo of the timing wire diagnostic of ReA taken at an angle parallel to the direction of the beam. The beam enters the device through the aperture and interacts with the 100 μm Tungsten wire at the center of the cylinder. In this photo the MCP detector is visible (disk with BNC connector) on the right.

RELATIVE BEAM ENERGY MEASUREMENT AND CAVITY PHASING

The elastic scattering of ions by a heavy nucleus can form the basis for the development of a phasing detector [1]. The ion beam interacts with a 40 nm thick self-supported Au foil and the scattered beam particles hit a PIPS-type Si detector manufactured by CANBERRA [5] which is placed at an angle of 30 degrees with respect to the beam. Due to the kinematics of the reaction, the number of particles entering the solid angle subtended by the detector is correlated to the mass number of the ions in the beam and the beam energy. A schematic of the diagnostic device

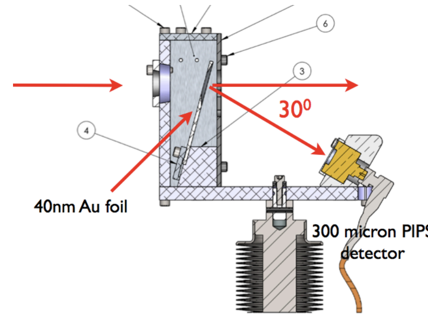

Figure 4: Schematic of the operating principle of the elastic scattering diagnostic.

is shown in Fig. 4. A photo of the actual device is presented in Fig. 5. Inside the vacuum chamber, a ^{241}Am alpha particle source is mounted for calibration and detector test purposes. The source is placed in such a way that when the drive is retracted from the beam, alphas can interact with the detector, but this is not geometrically possible while the device is intersecting the beam path. The particles deposit

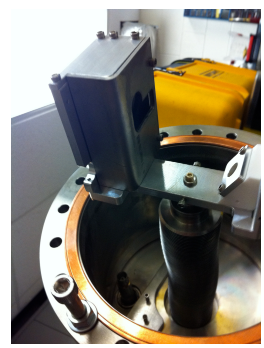

Figure 5: Photo of the ReA elastic scattering detector diagnostic. The Au foil is inside the protective box on the left side of the picture while the PIPS detector is mounted inside the white macor insulator holder on the right side of the picture.

all their energy inside the 300 μm thick Si and this energy is subsequently converted to an electrical pulse for each particle. This pulse is amplified by a MESYTEC [6] MRP-1 charge-sensitive preamplifier. The signal is directed to a MESYTEC MSCF-16 shaper-discriminator. The analog part of the signal is directed to a MESYTEC ADC for histogramming. The logical NIM-pulse of the discriminator output containing timing information for this signal is directed into the same FPGA-based trigger logic described earlier. The elastic scattering diagnostic has been routinely used in the last 2 years for ReA commissioning. In Fig. 6, an example of the capabilities of the diagnostic device is presented. The peaks in the graph correspond to energy boosts from different acceleration elements in the linac, starting with the RFQ and employing up to 6 accelerating cavities. The location of each of the peaks on the x axis corresponds to the energy the beam has after each element.

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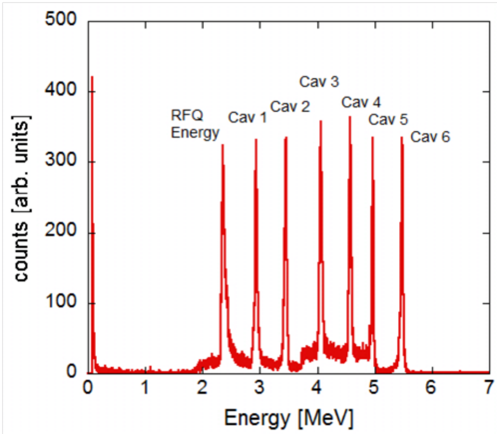

Figure 6: Superposition of 7 elastic scattering spectra taken with He^+ beam accelerated at different energies by different components of the ReA linac. The spacing between each peak in the spectrum corresponds to the energy increase caused to the beam by each accelerating element.

DIAMOND DETECTORS

A diamond detector based diagnostic device is under development at NSCL. Diamond detectors are very interesting as diagnostics devices mainly because of their radiation hardness and high counting rate capabilities. The first tests of Diamond detectors to be used potentially for the ReA low energy beams were performed using radioactive sources of alpha particles. Two Single-Crystal Chemical Vapor Deposition (SCCVD) diamond detectors were obtained from Diamond Detectors ltd [8]. The detectors had a thickness of 200 μm and a square surface of 4.5 $\times$ 4.5 mm. A simple data acquisition setup consisting of a preamplifier, Spectroscopy Amplifier, Ortec Maestro MCA and Oscilloscope was used for the first tests. Two types of preamplifiers were used. One was a Moritz DBA-III type broadband preamplifier manufactured by Greenstream [7] which is optimized for fast timing applications. The second was a regular Ortec charge-sensitive preamplifier for Si detectors which we used to shape the signal with a longer time-constant. This second setup allowed as to obtain energy information from the Diamond detector even though our data acquisition system was optimized for counting with slower-response Si detectors.

A spectrum using a ^{249}Cf α source in this setup is shown in Fig. 7. The energy resolution is enough to distinguish the alpha particle peaks at 6.2 MeV and 5.8 MeV. However, further tuning of the electronics and DAQ hardware should allow for a better energy resolution. Using the Moritz-type preamplifier the signal corresponding to 5.5 MeV α particles from a ^{241}Am source is shown in Fig. 8. The fast rise time and width of the signal verifies the high-rate and fast timing capabiities of diamond detectors. In-beam tests of a diamond-detector based diagnostic at ReA will follow to

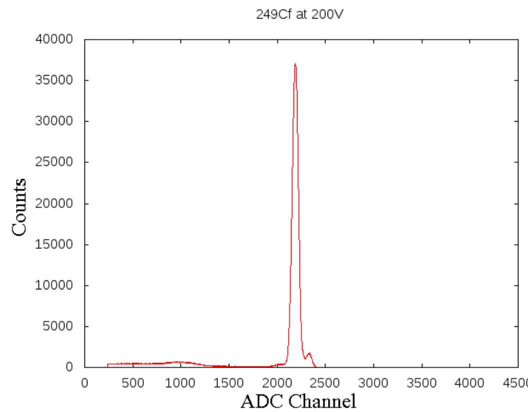

Figure 7: Spectrum taken with the single-crystal diamond detector using a ^{249}Cf alpha particle source. The 200 μm thick detector was biased at 200V

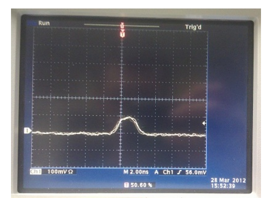

Figure 8: Screenshot of the pulses generated by 5.5 MeV α particles detected with the diamond detector and amplified with the Moritz-type DBA-III preamplifier. The FWHM width of the signal pulses is about 2 ns with a rise time of the order of 200 ps.

further characterize their response and assess their operational value.

CONCLUSIONS

A beam diagnostics system for low energy and intensity stopped and reaccelerated beams of NSCL is currently under development. Devices to determine energy boost and phase of the Superconducting linac's cavities have been developed and commissioned. Development of a diamond detector based diagnostic is underway and tests of its performance will follow.

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