UPGRADE OF THE ISAC TIME-OF-FLIGHT SYSTEM

V.A.Verzilov, J. Lassen, R.E. Laxdal and M. Marchetto, TRIUMF, 4004 Wesbrook Mall, Vancouver, BC V6T2A3, Canada.

Abstract

The ISAC accelerators at TRIUMF accelerate stable and radioactive ion beams in a wide range of intensities and energies. The beam diagnostics was designed with the aim to support the beam delivery in every possible operating regime. The ISAC-II time-of-flight (TOF) system is capable of measuring the beam velocities at intensities ranging from 10^{10} down to ~ 10^{4} ions per second. It consists of three high resolution timing secondary electron emission monitors with associated acquisition electronics and software and has been in operation since 2006. Recently all monitors were rebuilt in order to facilitate their alignment with respect to the ion beam. At the same time the system was also equipped with an UV alignment and calibration laser system that allows performing an accurate absolute calibration and functionality check of the monitors without a need for an ion beam.

INTRODUCTION

The ISAC facility was constructed with the primary goal to accelerate and transport intense exotic radioactive beams produced by the isotope separation on-line (ISOL) method [1]. Although ISAC has been in operation since 1998, the science program was significantly enriched in the last few years by increasing available beam energies after putting into operation medium and high beta sections of the ISAC-II superconducting linac. The beam energies at ISAC-II experiments now vary from 1.5 MeV/u up to about 11 MeV/u and beam intensities from hundreds of ions/s up to tens of nA. To measure the beam energy at various intensities a time-of-flight system is available [2]. The system consists of three identical secondary emission monitors with a design absolute accuracy of better than 0.1 %. In each monitor the signal is produced in a microchannel plate (MCP) by secondary electrons generated by the accelerated beam interacting with a thin wire stretched along the axis of a grounded metal cylinder (Fig.1). The beam velocity and, thus, beam energy is derived from the measured ion transit time between the monitors. The MCP sensitivity can be substantially varied by adjusting the applied high voltage bias allowing for reliable beam detection in a wide intensity range. The system has been in operation since 2006 and several modifications were proposed to improve the operational efficiency and accuracy.

MECHANICS UPGRADE

Precision energy measurements require an accurate centring of the beam at all three monitors. Firstly, this results in about the same count rate from the three monitors and, therefore, the same statistics. Secondly, an offset beam compromises the ratio between a useful signal and the background due to the residual gas ionization. The latter may result in drifting and spreading of the signals in time. During operation of the TOF system it turned out that tuning the beam to strike all three wires optimally took considerable time. In addition, there was no space in the beam line to install extra steering elements to aid this tuning. The remedy was to upgrade the monitor actuator mechanics to facilitate the alignment procedure.

The original TOF monitor design was pneumatic allowing only two fixed monitor positions [2]. While the cylinder with a wire was mounted on an actuator and could be inserted and retracted, the MCP was attached to the diagnostics box plate and, thus, fixed in position. In the new design both concepts were changed. To make the measurements beam position independent the new design keeps the mutual configuration of the cylinder and the MCP unchanged. They were connected by a bracket attached to the tip of a sliding rode and are jointly actuated (Fig.1). The whole assembly is now driven by a stepper motorized linear actuator with a step size of 0.1 mm within a range of 84 mm. The step size and speed can be adjusted according to the need.

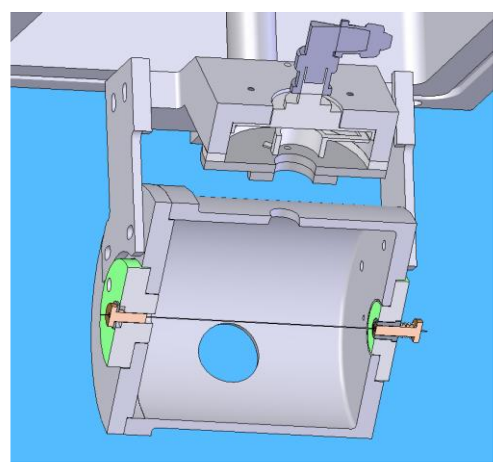

Figure 1: Beam intercepting wire, grounded cylinder and MCP detector assembly on a linear actuator.

In addition to counting stepper motor steps, the absolute position of the monitor device is read back by means of a linear potentiometer. Two limit switches are available to indicate extremes of the travelling range. Each monitor is mounted on the diagnostic vacuum box at 45 degree with respect to vertical and horizontal directions and as such allows scanning across the beam to find the beam centre (Fig.2).

All three TOF monitors were manufactured, assembled, installed and tested in the winter of 2011. The intermonitor distances were measured with a laser tracker to sub-mm accuracy. These distances are 2.193m between the first and the second monitors and 9.071m between the second and the third ones. The distances are used in the beam energy determination.

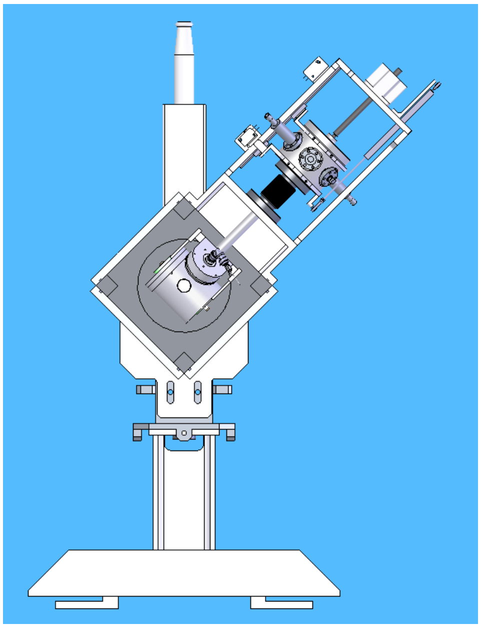

Figure 2: The retractable and adjustable TOF monitor in the beam line.

CALIBRATION LASER

The TOF system design accuracy of 0.1% in beam energy measurements assumes that all three monitors are absolutely identical and the delays in cables and electronics are known. In practice this is not always the case. Small variances in construction, applied voltages and signal propagation through cables and electronics are difficult to detect and correct to the required level. A more practical approach is to calibrate the system with a precisely known beam energy (velocity). For calibration of our TOF system a pulsed UV laser with a photon energy sufficient to generate efficient photo electron emission from the TOF monitor wires was chosen. In this way the laser light plays a role as a "reference beam" travelling at a well known speed. The idea was considered since the conceptual design but implementation took a few years.

An inexpensive passively Q-switched MicroChip Nd:YAG UV laser was acquired (Teem Photonic, model SNU-02P-100) for use in the calibration setup. The laser generates <500 psec pulses at a repetition rate of about 9 kHz. The average output power is 2 mW at a wavelength of 266 nm. The laser and the light shaping optics were mounted on an optical table 30 m upstream of the TOF monitors (Fig.3). The laser beam transport was complicated by the fact that an 11 mrad horizontal divergence of the laser is about ten times larger than the vertical one. A short focal length concave lens was used to strongly expand the beam in both planes and collimate it with an aperture. In this way a fraction of the light with a similar angular divergence in both planes was selected and then focused by a convex lens towards the centre of the TOF system. The beam was brought into the accelerator vacuum space through an UV grade fused silica window.

Alignment of the laser light through a 30 m long beam pipe of 50 mm in diameter was not trivial and was accomplished via two mirrors on fine adjustment mirror mounts. The final tuning was done with the help of a plastic acrylic scintillator installed in the vacuum space and viewed remotely with a GigE CCD camera. The laser spot size varied along the extent of the TOF system by about 1 mm (FWHM). A size of 0.5 mm was measured at the focus by moving the TOF monitor transversely and recording the count rate.

The propagation time of the laser light between the TOF monitors was measured by comparison of the arrival times of the monitor signals and the signal from a fast photodiode located on the optical table. Approximately half of the laser light was deflected towards the photodiode by a 50% beam splitter located in front of the laser head.

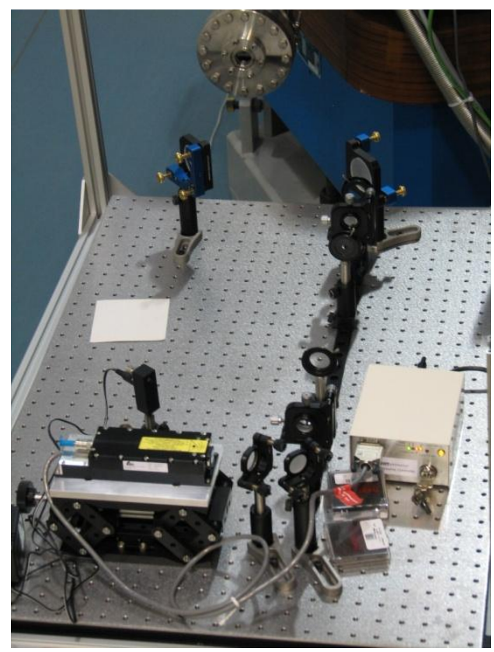

Figure 3: Calibration laser set up with light shaping and steering optics and fast photodiode.

A typical timing spectrum measured with the laser light is presented in Fig.4. Each peak had a nearly Gaussian shape with a FWHM of about 250 ps and was fitted with a Gaussian to determine its centre position. From the known distances between the monitors the true propagation times of the light were determined and compared with the measured ones, so that all necessary corrections could be determined. The calibration procedure determined that, taking the first monitor as reference, a value of 600 ps needs to be added to the second monitor data and a value of 230 ps to be subtracted from the third monitor data.

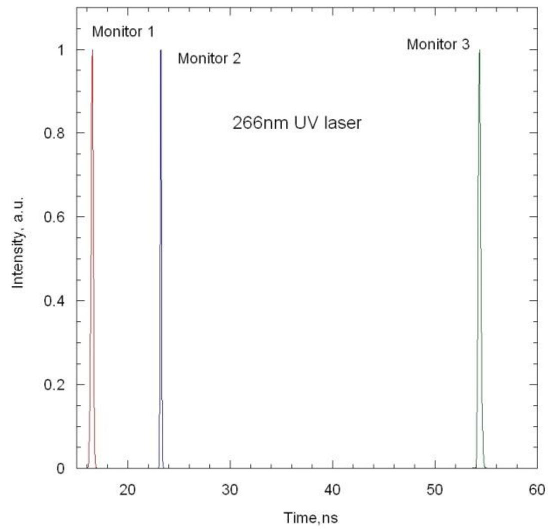

Figure 4: Calibration laser time spectra. Each peak is normalized to its maximum.

Another important application of the laser for the TOF system is that all functionality checks do not require an ion beam anymore and can be performed during shutdown or maintenance periods. Calibration and checks can now be done on-line or off-line and at any moment as required.

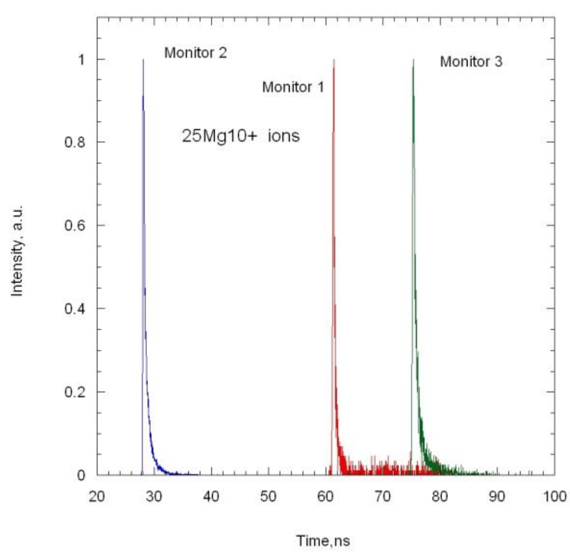

Figure 5: $^{25}Mg^{10+}$ pilot ion beam time spectra. Each peak is normalized to its maximum.

BEAM ENERGY MEASUREMENTS

For verification purpose the corrections obtained from the laser calibration were applied to two different energy measurements. Before measurements each TOF monitor was positioned in the centre of the beam by scanning across the beam until the maximum count rate is reached. Then the time spectra were recorded. An example spectrum for the $^{25}Mg^{10+}$ beam is given in Fig.5. The peak position was accurately determined by applying a fit to the data. Depending on the tuning of the accelerator, the peak shape can vary substantially. An asymmetric Lorentz fit was applied to the data in these measurements resulting in a peak width of about 400 ps (FWHM). During the data analysis three values of beam energy E_{21}, E_{32} and E_{31} are obtained in each measurement. Here indexes refer to the monitors used to calculate the beam energy. The present operational approach for calculating the final beam energy is to weigh the three different energies with their relative error [3]. To verify the laser calibration procedure no weights were applied to the data and an average energy, standard deviation and relative error were calculated from the three TOF values. Both raw data and data taking into account the calibration factors are summarized in Table 1.

The table shows that applying the calibration corrections dramatically (by a factor of 25-30) improves the consistency between the TOF data recorded by the three monitors. We also believe that due to the laser calibration the absolute accuracy improved to better than 0.1% in both measurements performed.

Table 1: Results of Applying Calibration Data to Ion Beam Energy Measurements

Ion beam	E_{ave} MeV/u	σ_E MeV/u	σ_E/E_{ave} %
$^{25}Mg^{10+}$, uncorrected	9.3197	0.1608	1.72
$^{25}Mg^{10+}$, corrected	9.2759	0.0062	0.07
$^{22}Ne^{4+}$, uncorrected	2.2797	0.0192	0.84
$^{22}Ne^{4+}$, corrected	2.2745	0.0007	0.03

ACKNOWLEDGEMENTS

The authors thank D. Cameron, B. Minato, J. Holek and D. Lang for assembly and installation of the TOF monitors and the calibration laser.

REFERENCES

[1] P.Bricault, M.Dombsky, P.W.Schmor, and G. Stanford, Nucl. Instr. and Meth. B. 126, 231 (1997).
[2] V.A.Verzilov, R.E.Laxdal, M.Marchetto and W.R.Rawnsley, "Time Domain Diagnostics For The ISAC-II Superconducting Heavy Ion Linac" DIPAC2007, Venice 2007, WEPB07,p.247 (2007); http://www.JACoW.org.
[3] M. Marchetto, R.E. Laxdal, V. Zvyagintsev, "Beam Quality and Operational Experience with the Superconducting Linac at the ISAC-II RIB Facility" PAC07, Albuquerque, New Mexico, USA, TUPAN003,p.1392 (2007); http://www.JACoW.org.