Commissioning the TAMUTRAP RFQ cooler/buncher

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In order to efficiently load ions into a Penning trap, the ion beam should be bunched and have a low energy with sufficiently small time and energy spread. A gas-filled linear RFQ Paul trap cooler and buncher is particularly adept at such beam preparation, and has been developed and characterized for use at TAMUTRAP. This work is described in detail in the PhD thesis of Michael Mehlman.

An approximately 5m section of horizontal beamline (see Fig. 1) has been installed at the TAMUTRAP facility to facilitate the commissioning and characterization of the RFQ cooler and buncher, the pulsing cavity, and the diagnostic stations, among other beamline elements. In addition, though, it will be carried over to the final TAMUTRAP facility with very little changes to its current configuration. The most important elements in this set up are, in order: the Heat Wave Labs ion source followed by a 2mm collimator, Einzel lens, 2-axis beam steerer, 10mm collimator, diagnostic station, 2-axis beam steerer, injection optics, 6mm entrance diaphragm, RFQ electrode structure, 6mm exit diaphragm, extraction optics, 2-axis beam steerer, and diagnostic station, respectively. To achieve the required vacuum, turbo pumps with pumping speeds of 1000L/s and backed by dry scroll roughing pumps are placed at the locations of the diagnostic stations.

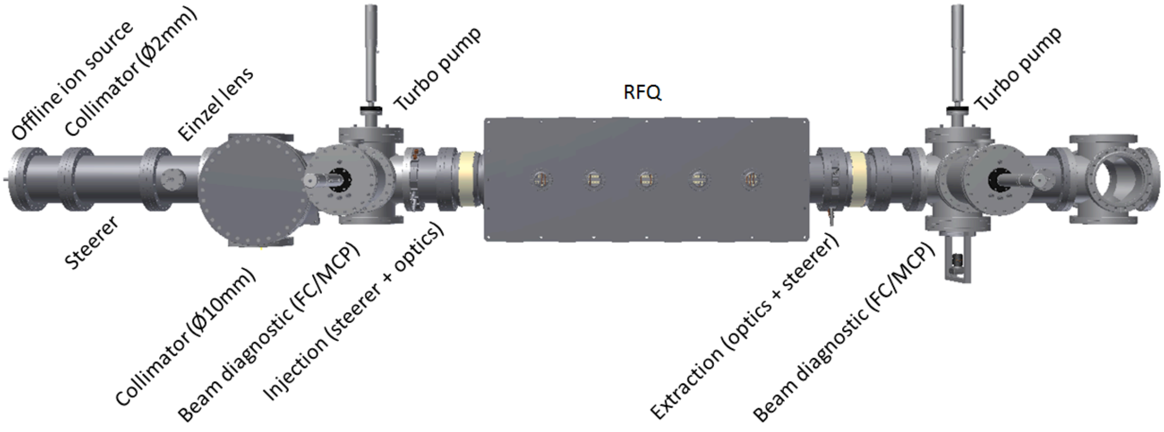
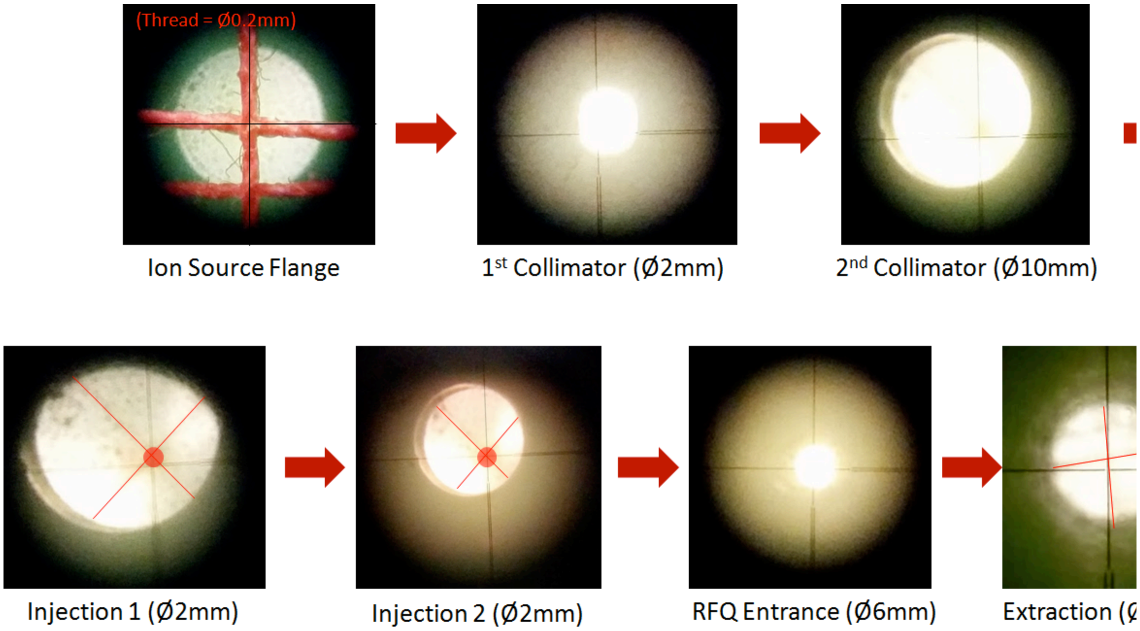


FIG. 1. The test line for commisioning the RFQ, pulsing cavity, diagnostic stations, and other beam elements**.**

Alignment of the RFQ cooler/buncher test line was performed via optical transit. The optical axis has been recorded by two targets on the high bay floor (one on a shielding block and one on a fixed cement wall), and one midplane mark on a nearby steel I-beam. The optical transit that was used to generate the axis to which all elements were aligned can be replaced by re-aligning to these targets.

Once the optical axis had been established, centers of the flanges that are used to support the beam line were forced into alignment via 1/2-13 set screws located on the beam supports (as discussed in a previous annual report). The center of the flange was located by threading a thin (diameter approximately 0.2mm) red thread that was wound between pins located in bolt holes of the flange separated by 90 degrees. The location at which the threads crossed was considered the flange center to within about the diameter of the thread. Several elements were further aligned within the centered flanges via set screws on individual electrodes. In general, the process was performed on elements in sequence, beginning with the ion source flange. Results at the seven locations of beam alignment can be seen in Fig. 2.



Ion Source Flange

1st Collimator (Ø2mm)

2nd Collimator (Ø10mm)

Injection 1 (Ø2mm)

Injection 2 (Ø2mm)

RFQ Entrance (Ø6mm)

Extraction (

FIG. 2. Final Alignment of the test beamline.

After the alignment procedure was completed, the vacuum chamber was sealed on each end, and pumped down. Overall, critical elements were aligned to within 1mm in any direction by this process, with the majority of elements centered to the arbitrary optical axis to within 0.5mm, which should be sufficient for TAMUTRAP.

The electrode structure of the TAMUTRAP RFQ cooler and buncher (see Fig. 3) is

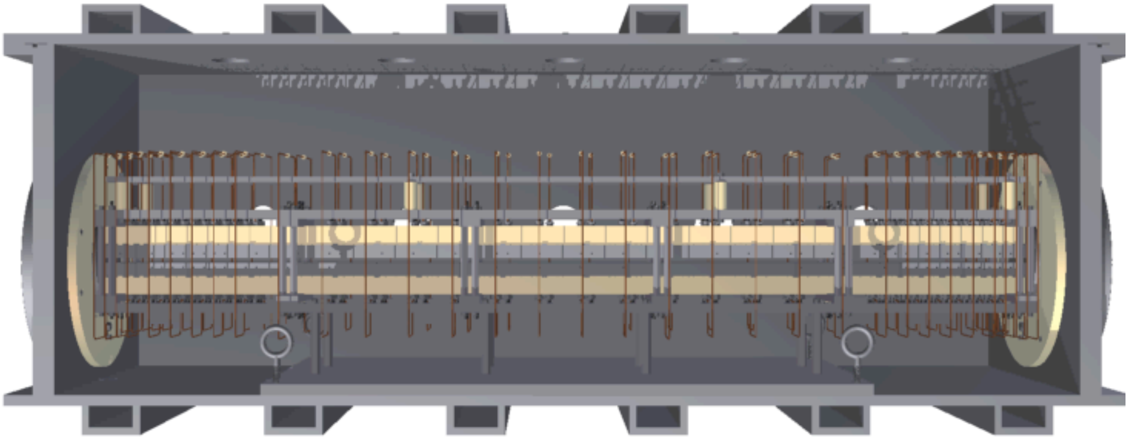


FIG. 3. The mechanical structure of the RFQ cooler/buncher

composed of four rods with radius of curvature r=7mm that are rigidly held at a surface-to-surface rod spacing of $2r_0$=12mm for opposite rods, yielding a characteristic ratio of r/r_0=1.16. The structure is approximately 87cm in length, and is separated axially into 33 segments to enable the application of a linear drag potential.

The device has been optimized to ensure mechanical rigidity, hide dielectrics, and achieve the minimum gap between adjacent segments. Care has also been taken to minimize electrical impedance by minimizing material in critical locations. The main structure is composed of 8 custom fabricated parts, with the remainder of the assembly coming from precision stock components. Apart from electronics, all components used are made of aluminum, stainless steel, or ceramic for vacuum considerations.

Analog electronics have been developed to drive the device, with each segment receiving a unique adjustable DC potential for fine-tuning of the axial electric field. RF is coupled to the segments in vacuum using vacuum safe ceramic capacitors and resistors (Fig. 4), ensuring a minimum of line-impedance. Switching of the final segments during ejection is accomplished by a single Behlke HTS 31-03-GSM high voltage, ultra fast solid-state switch. The switch itself demonstrates a switching time on the order of 500ns, which is slowed to approximately 50μs due to the RC circuit attached to each electrode that is used to protect the DC power supply. Despite the relatively slow switching time, satisfactory bunch characteristics have been observed, as will be discussed.

FIG. 4. A photo of the TAMUTRAP RFQ with in-vacuum electronics attached.

The cooler/buncher device has been assembled, and initial commissioning has been completed. Continuous mode efficiencies are calculated as the ratio of the beam current measured on Faraday cups located prior to the injection optics and after the extraction optics of the cooler/buncher, as in Fig. 1. Preliminary results are shown in Fig. 5, and all efficiencies are reported at 0V/mm drag potential. The efficiency for each energy and pressure combination was found to be optimized by a distinct drag potential setting, so the decision was made to facilitate comparison by choosing a constant 0V/mm rather than possibly introducing additional error into the measurements by choosing a sub-optimal drag potential. As a result, all efficiencies should be able to be improved to some degree by adjusting the drag potential. The peak efficiency of around 60% a great improvement over the approximate 13% efficiency of the prototype device and comparable to efficiencies achieved at existing world-class facilities.

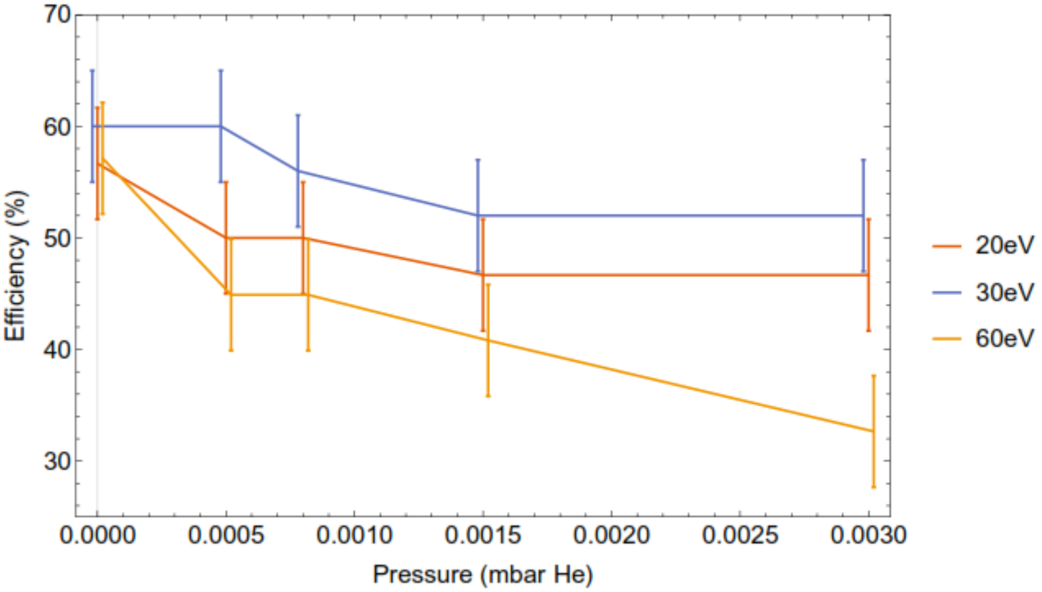


FIG. 5. Efficiency as a function of pressure at three different incident beam energies for the TAMUTRAP RFQ cooler/buncher.

In normal use, the TAMUTRAP RFQ cooler/buncher will be operated in bunched mode, collecting ions of interest for some set amount of time, bunching, and ejecting them in a tight packet. Individual ions are detected by a 40mm Beam Imaging Solutions MCP detector. The resulting time-spectrum relative to the ejection signal generated by the control system was fit by a skewed Gaussian, as in Fig. 6, yielding a Full Width at Half Max (FWHM) characterizing the time-spread of the bunch and the integrated number of counts per bunch (up to an arbitrary constant dependent on acquisition and analysis). It should be noted when comparing bunch characteristics to other facilities that fitting with a standard Gaussian resulted in a poorer fit, but also significantly reduced the observed FWHM due to exclusion of the low-count large-time tail of the distribution. Caution should be observed when comparing integrated number of counts between data points, as fluctuation of up to 10% in ion source current was observed on a several minute time scale.

The operation of the RFQ in bunched mode was investigated systematically by testing the effect of adjusting one operating parameter at a time. While it is true that various parameters are no-doubt correlated, the parameter space was too large to evaluate the variables co-dependently. A small subset of the operating parameters tested systematically is presented here.

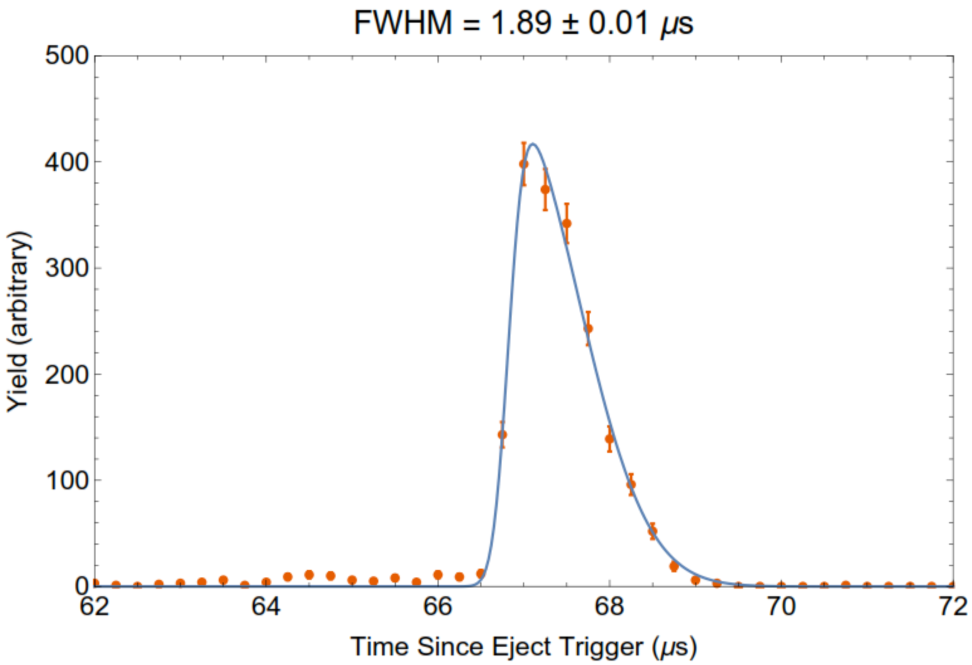


FIG. 6. Time spectrum of bunched ions. Plotted are the counts as a function of time since eject-trigger along with a skewed Gaussian fit.

At the pressures available for operation at TAMUTRAP, bunch characteristics have proven to be largely independent of gas-pressure. At the low-pressure extreme, the integrated number of counts begins to fall off, since there is a minimum amount of buffer-gas required for successfully cooling and bunching the incoming ions. This makes no comment on the effect gas pressure has on transverse emittance, which could worsen to some degree with increasing pressure due to gas collisions after ejection. FWHM and number of ions per bunch as a function

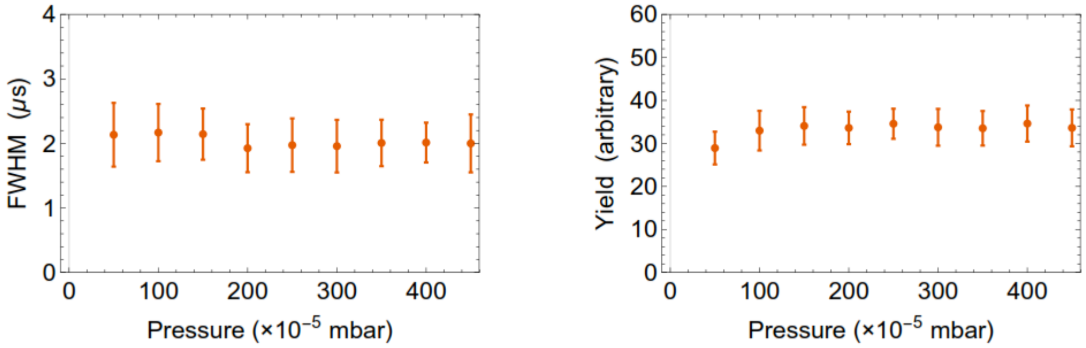


FIG. 7. FWHM and yield as a function of He gas pressure.

of gas pressure can be seen in Fig. 7.

A 30eV incident beam energy demonstrated the greatest continuous mode transmission efficiency of all incident energies tested for an uncooled beam. Since the TAMUTRAP RFQ will be employed exclusively as a cooler/buncher, it is more critical to determine what beam energy to use in bunched mode in order to obtain bunches with the smallest FWHM time spread and greatest yield (Fig. 8). This was accomplished by raising and lowering the voltage at which the RFQ platform is floated in order to achieve the desired potential difference from the ion source, which was held at approximately 10kV. The FWHM of the bunch's time spread is rather insensitive to the incident beam energy (phase space is reset in the device), while the overall yield degrades slightly at higher incident energies. In this regime, the number of counts per bunch decreases slightly, likely due to a reduced initial capture efficiency of the Paul trap for more energetic ions.

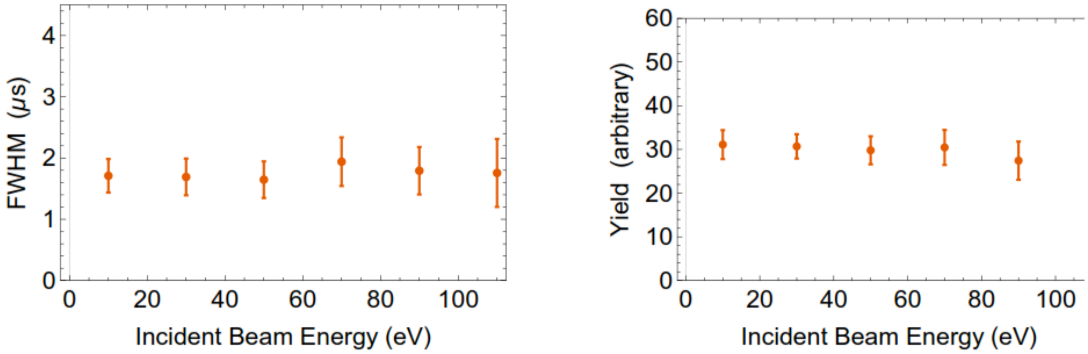


FIG. 8. FWHM and yield as a function of incident beam energy.

Additional systematic tests of the device have been performed, measuring bunch FWHM and yield as a function of eject duration, RF properties (frequency and voltage), incident beam current, and DC drag potential, and will be presented in detail in future work.