ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-THPO061

BEAM CHARACTERIZATION OF THE MYRRHA-RFQ*

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Abstract

The Linear Accelerator for the MYRRHA project [1] is under construction. In a first step, the linac up to 100 MeV will be realized. The LEBT section has been set into operation in Belgium and the RFQ is installed in summer 2018. A system to analyze the ion beam consisting of a slit-grid emittance scanner, a beam dump and a momentum spectrometer, called diagnostic train descripted in [2], will be set on the rails to characterize the beam at the RFQ injection point. The results will be used to adjust the optimal matching for the RFQ. After the measurements downstream the LEBT, the diagnostic train begins its journey along the beam line and at the first station the RFQ is installed. The accelerated beam of the RFQ is then analyzed and optimized. In addition to optimization of transmission the artificial production of beam offsets in the LEBT is of special interest. These will be measured at the injection point to estimate the range of possible offsets. In the following measurements these offsets will be used to study the influence of the offsets on the RFQ performance. Furthermore, the RFQ parameters are varied to see their influence on the beam transport, transmission and beam quality.

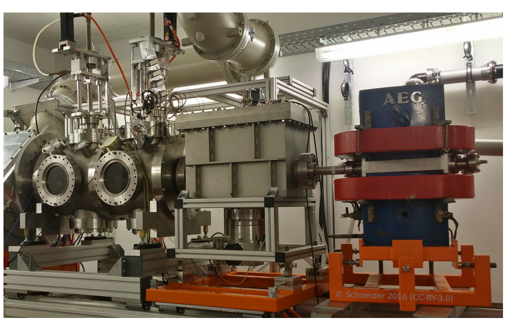

Figure 1: The diagnostic train in operation (left to right): emittance meter – beam dump – momentum spectrometer.

INTRODUCTION

In order to optimize the transport of an ion beam in an accelerator, it is important that each component is tested and optimized as independently as possible after its installation. For this purpose, the installation of the MYRRHA injector includes a measurement of the ion beam after the installation of each individual acceleration component. A flexible diagnostic train was developed to measure the ion beam at different stations along the accelerator chain using the same components for comparable results.

Based on the experiences in [2] numerical evaluations were performed to prepare and optimize the beam and its measurements.

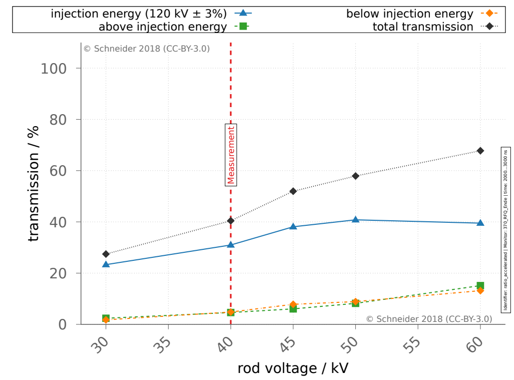

Figure 2: Influence of the rod voltage on the transmission of a Helium beam (120 keV, 1 mA) at rod voltages of $U_{\mathrm{Rod}} = 30\,\mathrm{kV} \ldots 60\,\mathrm{kV}$, operating the RFQ in transport mode. The beam remains unaccelerated. The measurements of [2] were performed at $U_{\mathrm{Rod}} \approx 40\,\mathrm{kV}$.

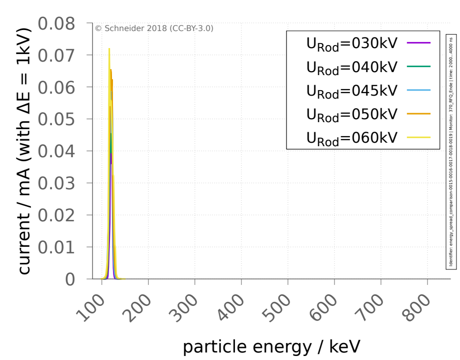

Figure 3: Energy histogram for a Helium beam (120 keV, 1 mA) at various rod voltages of the RFQ in transport mode. The beam remains unaccelerated and the energy spread is very narrow. This makes it perfect for the calibration of a momentum spectrometer.

Diagnostic Train

The diagnostic train as seen in Fig. 1 consists of an emittance meter followed by a beam dump with an 1 mm aperture and a trailing momentum spectrometer.

It was set up for measurements at the Frankfurt Neutron Source and is now calibrated for the upcoming measurements at the MYRRHA injector in Louvain-la-Neuve, Belgium.

* This work is supported by the German Federal Ministry of Education and Research (BMBF) #05P15RFRBA and HORIZON 2020 for the MYRRHA project #662186 and HIC for FAIR.
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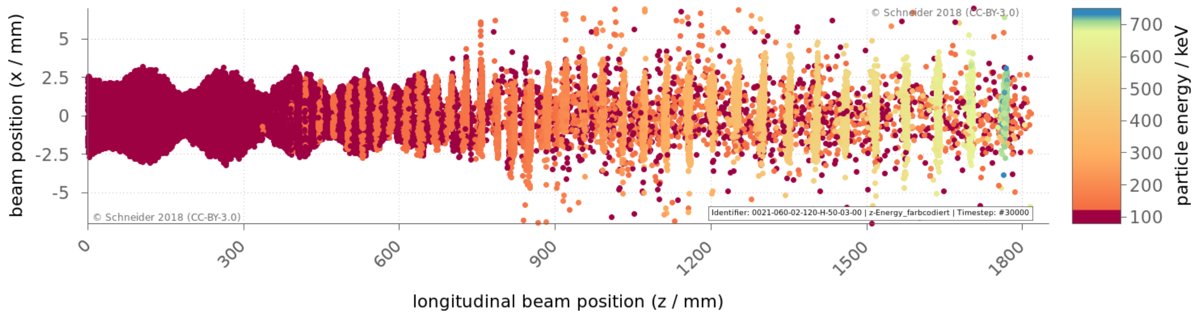

Figure 4: z-x-plane of the RFQ in acceleration mode, the energy of the individual particles is color-coded. The final energy is 700 keV (green), which is reached in the last cell. Parameters are: $U_{\mathrm{Rod}} = 60\,\mathrm{kV}$, $I_{\mathrm{Beam}} = 50\,\mathrm{mA}$, $W_{\mathrm{B,in}} = 120\,\mathrm{keV}$.

NUMERICAL EVALUATION

To evaluate the measurements made so far, the ion beam was simulated with the 3D particle-in-cell-code bender [3]. In these measurements, a He^+-beam was adjusted for a transport through the RFQ. Helium gives some advantages over protons for this experiments: as it has only one (practical reachable) charge state, one can establish a controlled environment and exclude multiple peaks due to different molecular forms of Hydrogen (H_2^+, H_3^+). Though a He^+-beam can be matched transversally into the RFQ acceptance, the longitudinal acceptance is unreachable in case the extraction potential (120 keV) is equal to the one of the design ion (H^+). Figure 2 shows the possible transmission for a He^+-beam matching the transversal acceptance of the RFQ for different rod voltages.

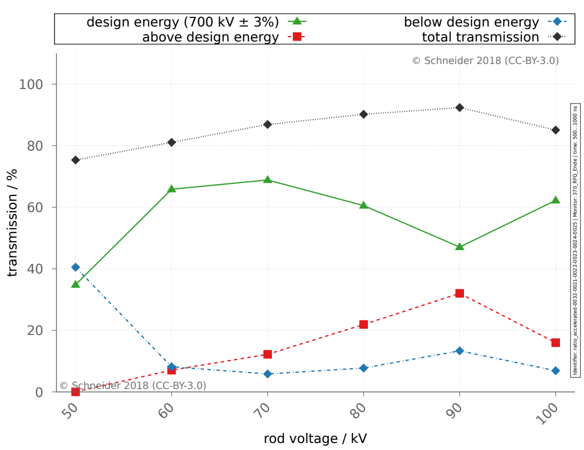

Figure 5: Influence of the rod voltage on the transmission of a proton beam (120 keV, 50 mA) at rod voltages of $U_{\mathrm{Rod}} = 50\,\mathrm{kV} \ldots 100\,\mathrm{kV}$ operating the RFQ in acceleration mode. It can be seen that the optimal transmission does not necessarily coincide with the largest proportion of accelerated particles.

Transport Mode

As seen in Fig. 2, the transmission depends on the rod voltage, increasing rod voltage results in an increased transmission rate. Of interest is the energy spread of the Helium beam downstream the RFQ because it is crucial for the calibration of the momentum spectrometer.

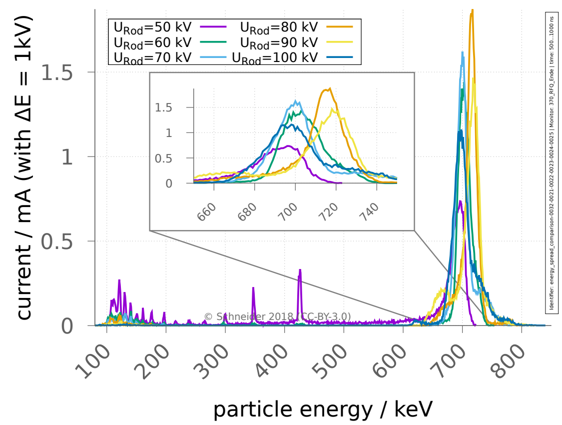

Figure 6: Energy histogram of a 120 keV, 50 mA proton beam downstrem the RFQ in acceleration mode at rod voltages of $U_{\mathrm{Rod}} = 50\,\mathrm{kV} \ldots 100\,\mathrm{kV}$.

Figure 3 shows the energy histogram of an Helium beam (120 keV, 1 mA) downstream the RFQ. The energy spread is very narrow and exactly at the injection energy of 120 keV. Therefore it is perfect to calibrate the momentum spectrometer of the diagnostic train. The simulations confirmed that the ions are transported by the RFQ but not accelerated. This mode is called the *transport mode* in which the RFQ operates only as a focussing transport element and does not accelerate the beam. The *transport mode* is well suited for calibrating a momentum spectrometer and the support of RFQ conditioning with the ion beam scrubbing technique, similar to [4].

RFQ Beam Optimization

Simulations for the later acceleration of protons have been carried out to optimize the RFQ transport. First results of the impact of various rod voltages on the transmission and energy spread are shown in Figures 4–6, 8 and 9. The rod voltage was choosen for variation in the range of $U_{\mathrm{Rod}} = 50\,\mathrm{kV} \ldots 100\,\mathrm{kV}$. An example for $U_{\mathrm{Rod}} = 60\,\mathrm{kV}$ is shown in Fig. 4

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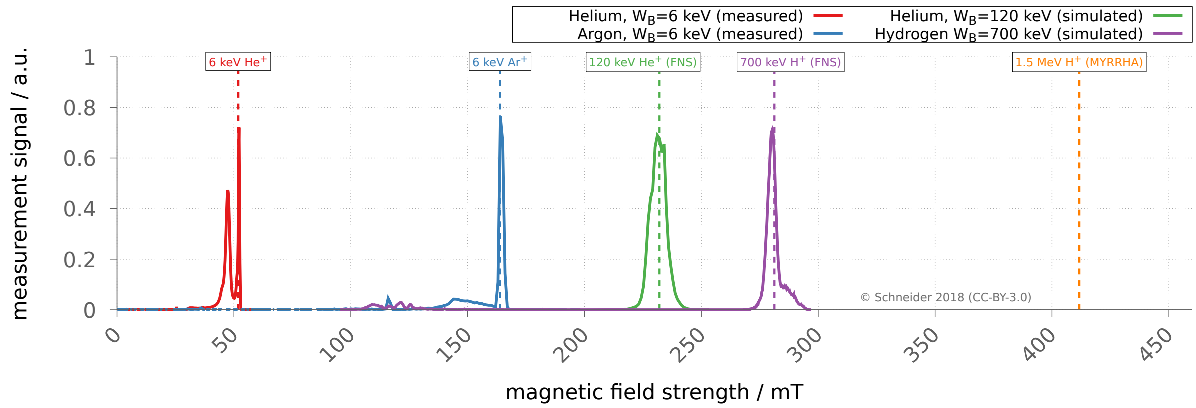

Figure 7: Momentum spectra of the several cases discussed in this paper. While Helium and Argon at $W_B = 6$ keV are measured, Helium at $W_B = 120$ keV and protons at $W_B = 700$ keV (both downstream the RFQ) are simulated with the PIC-code bender.

The simulations show that the rod voltage has an influence on the total transmission and especially on the energy distribution of the particles. This allows to determine the optimal working point of the RFQ. The largest transmission of particles with a small $\frac{\Delta E}{E}$ ratio does not coincide with the optimum of the total transmission, as seen in Fig. 5.

In addition, the H^+-case can be used to crosscheck the simulation with the later measurements by the momentum spectrometer. The predicted spectra can be found in Fig. 6.

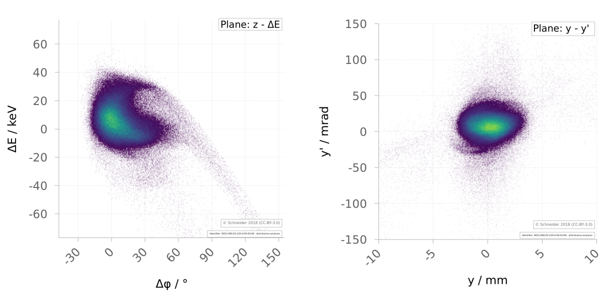

Figure 8: Particle distributions for the simulation of 50 mA protons with $W_B = 700$ keV at a rod voltage of 60 kV.

EXPERIMENTAL TESTS

In order to perform the calibration of the diagnostic train, a test stand with low beam energies was set up where a helium and an argon beam are measured with a beam energy of 6 keV. Figure 7 shows the momentum spectra for the experimental results (red: He^+, blue: Ar^+) as well as the expected spectra from the PIC-simulations for 120 keV Helium downstream the RFQ in transport mode and 700 keV protons downstream the RFQ in acceleration mode.

EMITTANCE MEASUREMENTS

The expected phase-space distributions were evaluated to be able to compare them with the later emittance measurements. The longitudinal and transversal distribution

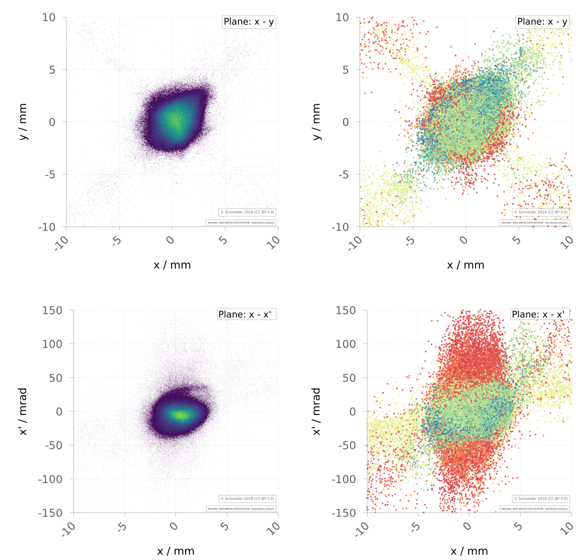

Figure 9: Particle distributions of the simulation of 50 mA protons with $W_B = 700$ keV at a rod voltage of 60 kV.

is shown in Fig. 8. Due to the possibilities offered by the Bender code, it was possible to transport all particles independent of their longitudinal energy to the end of the RFQ. Their distribution within the phase space is seen in Fig. 9.

OUTLOOK

Simulations show promising results and form the basis for further investigations of the effects of offsets at the RFQ injection plane. After the tests with the emittance measuring system, the diagnostic train is ready for operation. Once the diagnostic train has been calibrated at low energies, it is quickly ready for use to enable future measurements with high accuracy and low lead time. After the measurements at Frankfurt University are completed, the following up measurements will take place at the MYRRHA injector in Leuwen la Neuwe, Belgium.

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