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Developments at the CERN-ISOLDE Offline 2 mass separator

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ABSTRACT

The Offline 2 mass separator laboratory is part of the CERN-ISOLDE Offline facilities - a suite of installations required to perform essential quality control on target and ion source units before irradiation at CERN-ISOLDE (Catherall et al., 2017) [1]. The facility is also used for extended preparatory offline studies as a prerequisite before conducting any beam development on-line, especially establishing systematic effects. The Offline 2 separator resembles the on-line CERN-ISOLDE Frontend and employs identical services such as beam instrumentation, gas delivery system, laser ionization and the equipment control system. The facility is able to generate dc as well as bunched non-radioactive beams up to an energy of 60 keV. The mass resolving power of the existing 90° dipole mass separator magnet is $R \approx 500$ (Warren et al., 2020) [2]. The ion beams can be cooled and bunched in an unmodulated RFQ. In order to study effects of the RFQ buffer gas on the formation of molecular species, a dedicated identification setup is required. We intend to employ a Wien filter downstream the RFQ. This work presents initial beam dynamics simulations through the entire Offline 2 facility to prepare injection into the RFQ. The fields of the RFQ are also shown serving as a basis for field map PIC simulations. Furthermore, we present the status of the emittance meter preparations in front of the separator magnet allowing a comparison to the beam dynamics simulations.

1. Introduction

At the on-line RIB facility CERN ISOLDE (Isotope Separator On-Line DEvice) [1] beamtime for machine development (MD) is very limited. For quality control of targets and ion source units the Offline 1 facility has been established. MD is in competition between beam delivery at ISOLDE and target production at offline 1. Without interrupting beamtime shifts the targets and new equipment can be tested offline. The newly built Offline 2 facility [2] aims to resemble the on-line facility in order to have an equivalent testing environment — specifically in respect of the Frontend and the RFQcb (Isolde Cooler ISCOOL [3–6]). Without the drawbacks of radiation and demanding on-line beam times, any new developments are supposed to be realized and tested offline prior to implementing at ISOLDE on-line. Offline 2 will facilitate systematic studies for new targets and ion source developments including RILIS [7], the research of molecular beams [8], as well as technical projects as HV switching and gating studies on the RFQcb. In addition, both the Frontend and the RFQcb serve as a test bench for any modifications and as spare parts for the on-line facility, which can be replaced in a reasonable amount of time without the need of constructing new parts to ensure on-line operation.

2. Beamline simulations

The layout of the Offline 2 facility is shown in Fig. 1. The target including the ion source is mounted on the Frontend and kept on HV up to 60 kV which in return determines the ion energy. The Frontend contains an electrostatic quadrupole triplet as well as a double x/y steerer. In the first section after the Frontend, a Allison-type scanner [9] (see Fig. 2) has been installed to verify the emittance after extraction of the target. A 90° dipole with a resolution of $R \approx 500$ and a radius of $\rho = 373.5$ mm is embedded between two diagnostic sections at the horizontal focal points consisting of wire scanners and Faraday cups. Besides the magnet's focusing effect in the horizontal plane into a slit located at the focal point, the dipole edges have a vertical focusing effect due to positive end angles of $\alpha = 28.2°$:

$$\Delta y = -\tan\alpha/\rho \cdot y \tag{1}$$

A second quadrupole triplet after the dipole is used to focus the beam into the Radio Frequency Quadrupole Cooler-Buncher (RFQcb). The section downstream the RFQ is currently in the design phase consisting of beam diagnostics (Faraday cup + wire scanner), a Wien filter, an

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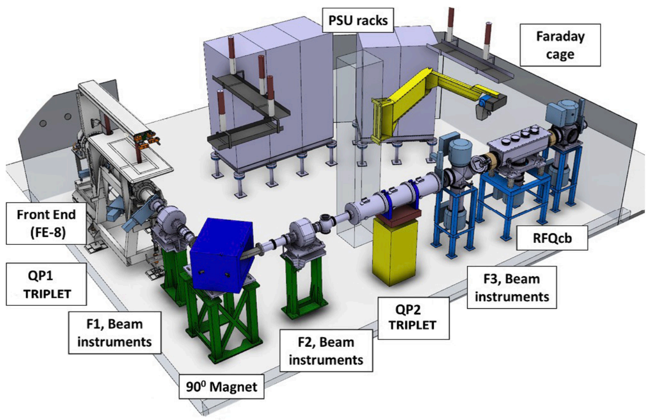

Fig. 1. Digital Mockup of the Offline 2 facility [10].

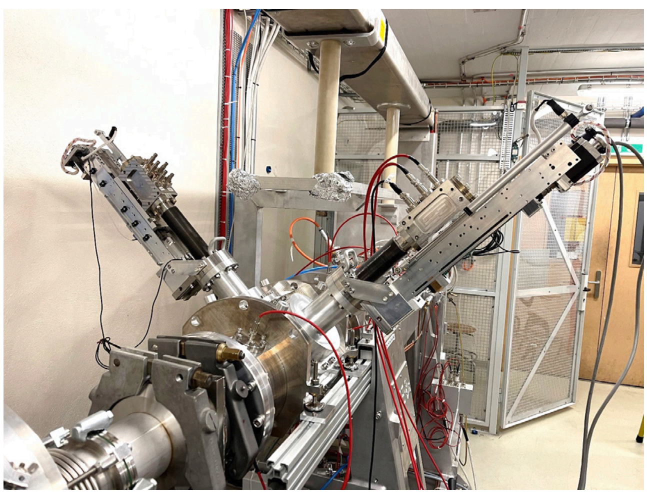

Fig. 2. Allison type emittance meter installed at Offline 2.

Einzel lens and a single ion detector (MagneToF). Through windows in the magnet a laser can both be sent into the ion source to ionize specific atoms as well as into the RFQcb.

In order to find a suitable beam dynamics solution the following constraints have to be considered: To increase mass separation, a slit with a width of 4 mm is integrated at the second focal point (F2) 624 mm behind the dipole. The RFQ has an entrance aperture of 4 mm. Therefore, the quadrupoles have to be adjusted in both horizontal and vertical planes, to focus the beam into the RFQ. The beamline simulations are calculated with the PIC code Tracewin [11] including space charge. The input beam is ^{40}Ar with an norm. RMS emittance of $0.01\,\pi$ mm mrad and a current of 1 μA. The Twiss parameters have been adjusted according to the worst assumption of a beam fitting through the extraction electrode of the ion source being defocused. The smallest aperture at the beginning of the extraction electrode is $x_{max} = 3$ mm and therefore limits the spatial limits of the distribution:

$$x_{max} > \sqrt{\epsilon_{edge}\beta} = \sqrt{6 \cdot \epsilon_{rms}\beta} \tag{2}$$

Therefore, $\beta_{max} = 0.2$ mm/mrad. The maximum angle is determined by the exit aperture of the steerers, which results in a maximum angle of 35 mrad and $\alpha_{max} = -2$, respectively:

$$x'_{max} > \sqrt{\epsilon_{edge}\gamma} = \sqrt{6 \cdot \epsilon_{rms}\frac{\alpha^2 + 1}{\beta}} \tag{3}$$

The values are valid in both planes. The energy spread is given by 3 eV emerging from the exact position of the ionization within the line

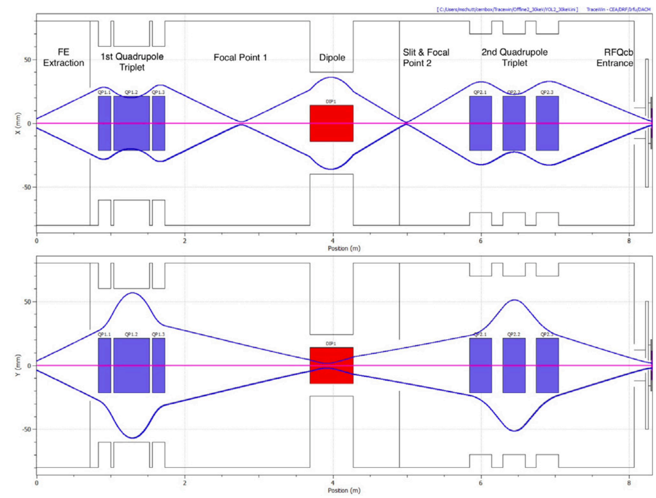

Fig. 3. Tracewin beamline envelopes in the horizontal and vertical plane of the Offline 2 facility from the ion extraction electrode to the entrance of the RFQ.

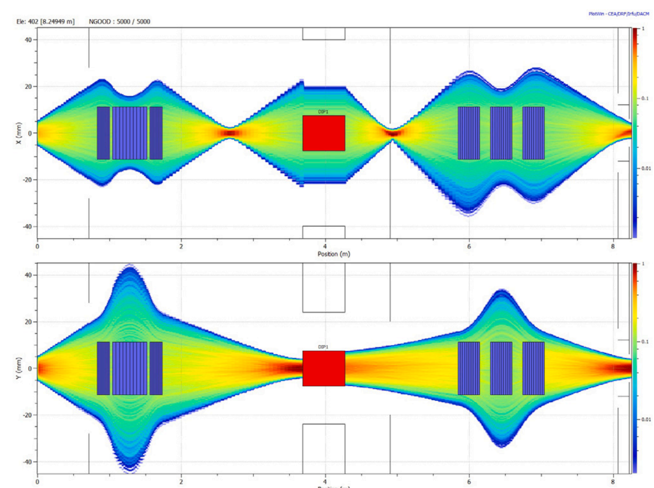

Fig. 4. Tracewin density plot for corresponding results of Fig. 3. The elements of the beamline in the order as shown above are: A drift from the ion source within the Frontend to the first quadrupole (834 mm), the first quadrupole triplet, a drift of 1955 mm, the separator dipole, a drift of 1570 mm with the slit inbetween and the second quadrupole triplet followed by a drift of 1.247 mm to the smallest entrance aperture of the RFQcb (2 mm).

which has a potential difference of that value. The emittance has been measured and confirmed after the first quadrupole triplet [12]. The results of the simulation are shown in Fig. 3 in case of the aperture and Fig. 4 for the corresponding density plot.

3. RFQcb

The RFQcb (cooler and buncher) is shown in Fig. 5. The whole RFQ is lifted to the same HV potential as the Frontend minus a small voltage difference of up to ≈ 200 V max. The entrance acts as an Einzel lens and the ions are decelerated at the entrance of the RFQ drifting with an energy of the chosen voltage difference through the RF fields. The inner aperture of the RFQ is filled with a buffer gas (Helium) to reduce transverse momentum and emittance [13,14]. The longitudinal potential along the beam axis is shown in Fig. 6. At the entrance the potential rises to the energy of the particle and is slightly ramped from 80 V to 0 V and the end of the RFQcb. To transversally confine the ions the longitudinal DC potential is overlaid with a quadrupole

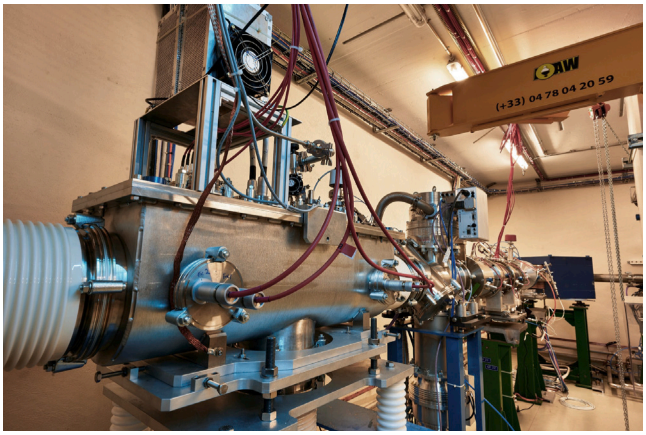

Fig. 5. The RFQcb installed at the Offline 2 facility (looking upstream to the separator magnet) [Cern Document Server 2690229].

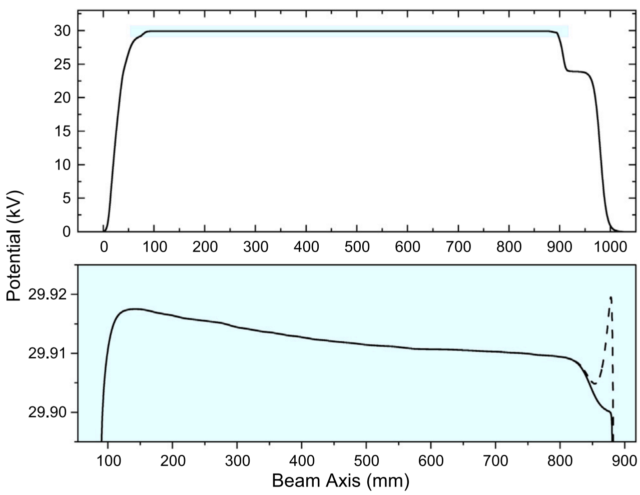

Fig. 6. Longitudinal DC potential along the full RFQcb beam axis in transmission mode (solid) and bunching mode (dashed). The graph below shows a zoom on the inner ramped DC field where the RF field is present.

are RF field (s. Fig. 7) and the ions are gathered at the end of the quadrupole channel. The exact timing for the release of the bunches is controlled by the extraction plate potential, which can be switched between a positive potential for trapping the ions in the RFQ and ground for extraction, respectively. The extraction electrodes reaccelerate the bunches after extraction to the corresponding HV and additionally have the effect of an Einzel lens. The Offline 2 RFQ is an identical copy of the ISCOOL RFQcb with an improved differential pumping system up- and downstream the RFQcb, which may allow more flexible buffer gas pressures. The RF power was increased up to 800 W and is, together with the DC power supplies, controlled via a Labview PXI system allowing to use arbitrary RF signals as well as an adjustable DC offset to control cooling times and the extraction of cooled ion bunches [15]. The 3D DC and RF field of the RFQcb have been calculated with CST Mikrowave Studio [16]. The beam transport through the exported fieldmaps have been simulated with Tracewin. The simulations have confirmed that without a buffer gas the transmission through the RFQcb will not be able to be increased above 10%, which is in accordance with the measurements.

4. Conclusion & outlook

With the beam dynamics simulation of the Offline 2 beamline, an optimum ion optics for the beam transfer from the target to the RFQcb including entrance beam matching has been found. Together with the emittance measurement [N. Bidault, to be published] as well as matching wire scanner measurements the results of the simulations could be confirmed. The DC and RF fields of the RFQcb have been simulated being the basis for future field map PIC simulations. Those also have to include the interaction with a buffer gas to show bunching and cooling of the RFQ. Finally, the RFQ has to be optimized and adjusted for full transmission. The emittance will additionally be measured after the RFQ. Offline 2 will be used for testing HV switches as a preparation for a beam switching project on-line as well as timing and gating the extraction out of the RFQ. The diagnose section detector section downstream the RFQ is subject for planning its layout including focusing elements, mass filter and ion detectors.

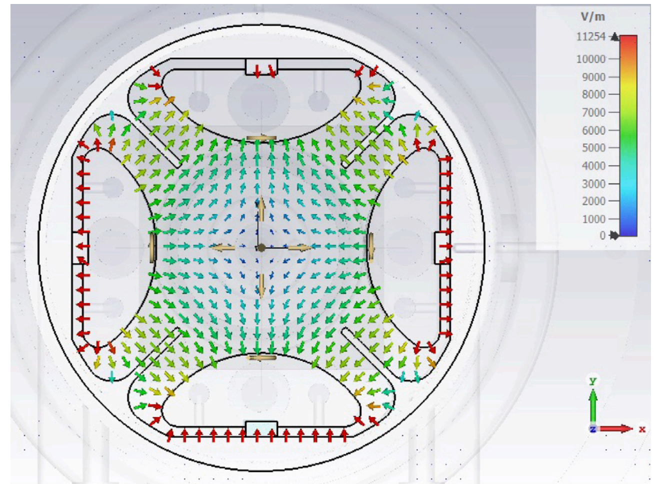

Fig. 7. Transverse RF quadrupole field of the RFQcb.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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