The Gas Stopping Cell and Extraction RFQ for SHIPTRAP ◊

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In order to determine the absolute stopping and extraction efficiency of the gas cell/extraction RFQ set-up, on-line measurements using stable and radioactive ions were performed at the accelerator facilities of the MLL and at GSI. In contrast to the measurements under SHIPTRAP conditions at GSI with an almost perpendicular ion injection, the experiments at the MLL were performed with a longitudinal injection into the gas cell [1].

For the on-line measurements using radioactive ions at the MLL the $^{121}Sb(^{35}Cl,4n)$ reaction was used to produce the α-emitter ^{152}Er (branching ratio 90 %, $t_{1/2} = 10.3$ s, E(α) = 4.8 MeV). For the production, the separation and the detection of the recoil ions the Munich test set-up [2] was used. The absolute efficiency was determined by the relation between the number of detected α decays of ^{152}Er in front of the cell and behind the extraction chamber. The energy of 150 MeV of the primary beam resulted in a recoil energy of 28.4 MeV $\pm$ 3.6 MeV for the ^{152}Er ions including all energy losses in the target (260 $\mu g/cm^2$) and the carbon charge reset foil (25 $\mu g/cm^2$) in front of the dipole magnet. The measurements were done at He buffer gas pressures of 20 - 60 mbar and a Ti entrance window with a thickness of 4 μm. A maximum stopping and extraction efficiency of 8.4 % $\pm$ 1.5 % was determined for the parameters displayed in Fig. 1 that shows the characteristic α ground state decay energies of ^{152}Er, ^{153}Er, ^{151}Ho and ^{152}Ho detected behind the extraction RFQ.

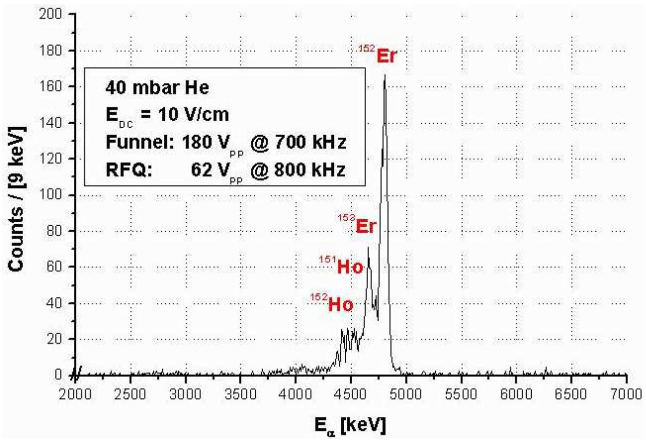

Fig. 1: Plot of α energies detected behind the extraction RFQ during the measurements at the MLL.

In addition measurements with stable ^{107}Ag ions were performed at the MLL in collaboration with the Gießen group and their Ortho-TOF spectrometer [3]. Figure 2 schematically shows the Ortho-TOF connected to the SHIPTRAP extraction RFQ. The ion mass is determined via the measurement of the time of flight at a fixed kinetic energy. In order to improve the accuracy of the measurement without an enlargement of the set-up, the spectrometer is designed as a so-called multi-TOF spectrometer, where the working section is traversed several times by the ions. The naming of the Ortho-TOF is based on the working area attached perpendicular to the longitudinal axis of the incoming ions. The Gießen Ortho-TOF typically has a mass resolution of $\delta m/m \sim 10^{-4}$ and an overall transmission efficiency of about 1 - 3 % [4].

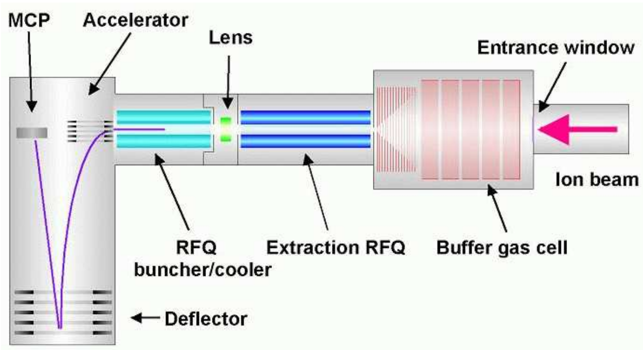

Fig. 2: Schematic view of the set-up used for the on-line measurements with stable ions at the MLL. Following the extraction chamber the Gießen Ortho-TOF spectrometer was connected to the system.

Besides the determination of the absolute stopping and extraction efficiency the combination of the buffer gas cell and the spectrometer allowed for a study of chemical processes inside the cell, especially concerning the molecule formation of the Ag ions with impurities in the buffer gas. A gas-cell stopping and extraction efficiency of about 4 % was obtained under rather unfavourable vacuum conditions, leaving room for increased efficiency values under optimised conditions.

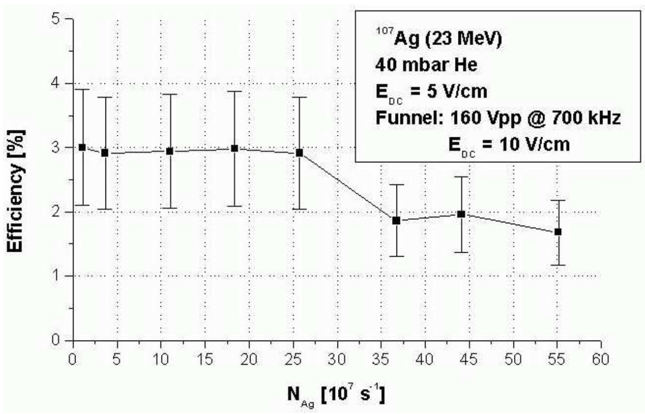

Fig. 3: Plot of the absolute extraction efficiency for ^{107}Ag ions as a function of the intensity of the incoming ion beam, measured with the Gießen Ortho-TOF spectrometer [5].

In order to study the influence of space charge effects, the efficiency of the gas cell set-up was measured as a function of the number of incoming ions as shown in Fig. 3. While up to an intensity of around $2.5 \cdot 10^8$ $^{107}Ag^{17+}$ ions per second the stopping and extraction efficiency is nearly constant, it decreases at higher beam intensities.

◊ work supported by BMBF under contract number 06 LM 973

For the measurements at GSI the same isotope ^{152}Er, produced via the reaction $^{116}Sn(^{40}Ar$,4n) and injected transversely into the buffer gas cell after the separation in SHIP was used. The measurements were performed in a configuration that corresponds to a similar set-up as used for the measurements at the MLL, while in the second configuration the SHIPTRAP RFQ buncher was added behind the extraction chamber. With a primary beam energy of 168 MeV and a target thickness of 440 $\mu g/cm^2$ the recoil energy in front of the buffer gas cell was calculated to be 32.2 MeV ± 5.5 MeV, including a Mylar degrader foil with a thickness of 0.5 μm.

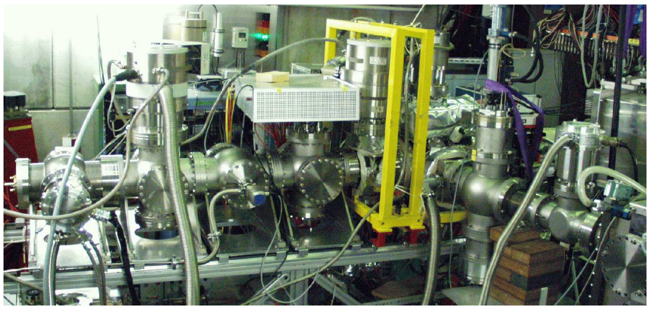

Fig. 4: Photograph of the set-up used at GSI. On the right-hand side the SHIP beam line connected to the SHIPTRAP buffer gas cell is visible. Following the extraction chamber the RFQ buncher and the last beam line section containing the Si-detector are visible.

A maximum value of 4.8 % ± 0.7 % for the absolute stopping and extraction efficiency for ^{152}Er of the set-up without RFQ buncher was measured at a buffer gas pressure of 47 mbar and a field strength of 10 V/cm at the DC electrode and 5 V/cm at the funnel, while an RF amplitude of 190 V_{pp} at 800 kHz was applied at the funnel electrodes. The extraction RFQ was operated at an RF frequency of 1100 kHz and an RF amplitude of 275 V_{pp}. These optimised settings for the gas cell were used for the measurements with the RFQ buncher. The buncher was operated in a pure transmission mode of the extracted ions and in the bunch mode, with an ion accumulation in a trap potential prior to the extraction. For the ion transmission the efficiency was measured for two buffer gas pressures inside the buncher, resulting in 3.2 % ± 0.4 % for $<10^{-5}$ mbar and 2.7 % ± 0.4 % for $\sim10^{-3}$ mbar. In bunch mode with an accumulation time of 20 ms and a pressure of 10^{-3} mbar the measured absolute efficiency for ^{152}Er was 2.7 % ± 0.4 %.

In both measurements at the MLL and at GSI the extraction efficiency depended mainly on the DC potentials applied inside the gas cell. Especially the voltage difference between the last funnel electrode and the nozzle showed a strong influence, since the ions have to be decelerated there in order to allow for an efficient transition of the ion transport from electrical guiding fields to the gas flow. A deceleration voltage of 2 V resulted in the optimum ion extraction. Another crucial transition is given between the nozzle and the extraction RFQ, where the voltage difference had to be optimised, while the efficiency was not affected by the DC gradient applied at the extraction RFQ. It should be noted the gas-cell extraction efficiency of about 3 - 5 % for the measurements at GSI was obtained under rather unfavourable vacuum conditions (evacuated pressure 10^{-6} mbar), leaving room for further improvements.

The measured value of 8.4 % of the stopping and extraction efficiency of the SHIPTRAP gas cell set-up has to be compared to the performance of the presently leading facility at Argonne, where 45 % for the extraction efficiency of Cs and Ba ions were reported [6]. TRIM calculations resulted in an estimate of 30 % for the stopping efficiency at the SHIPTRAP gas cell, while an efficiency of about 85 % for the extraction RFQ can be estimated. Thus the 8.4 % overall efficiency can be converted into about 32 % when comparing with the Argonne efficiency on the same basis as used there. For the GSI measurements an extraction efficiency of about 23 % can be deduced. In view of the gain potential under optimised operational conditions (including tests with thinner Kapton entrance windows) efficiency values comparable to the Argonne gas cell are within reach. This goal will be pursued in Munich with a next-generation gas cell/extraction-RFQ set-up, shown in Fig. 5. Moreover, results and improvements originating from the tests with the new Munich installation will directly be transferred to SHIPTRAP, eventually resulting in modifications of the existing set-up.

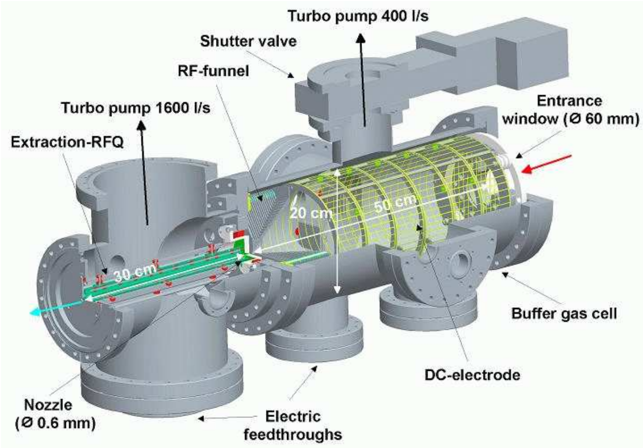

Fig. 5: Schematic view of the new Munich gas cell/extraction RFQ set-up. The buffer gas cell has a length of 50 cm and a diameter of 20 cm, while the extraction chamber has a length of 30 cm.

The main difference of the new gas cell compared to the SHIPTRAP cell is the absence of the radial entrance window and the modified overall dimensions of the cell. With the ions entering the cell on its longitudinal symmetry axis, the radius of the cell can be reduced to 20 cm compared to SHIPTRAP, while the requested flexibility in stopping ranges leads to an increase of the gas cell length to 50 cm. In order to improve the pumping conditions the new extraction chamber will be larger compared to the present one. By enlarging the flange diameter of the connection to the 1600 l/s turbomolecular pump at the extraction chamber the full pumping speed of this pump can be exploited, thus avoiding the present reduction of the conductance. The resulting increase in size of the extraction chamber will be compensated by an increased length of the extraction-RFQ from presently 18 cm to 30 cm, while the number of 12 segments will be kept constant.

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