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THE STATUS OF THE DIAGNOSTIC SYSTEM AT THE CRYOGENIC STORAGE RING CSR

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Abstract

The cryogenic storage ring (CSR) at MPI für Kernphysik is an electrostatic, cryogenic storage ring for low velocity phase space cooled ion beams. Among other experiments cooling and storage of molecular ions in their rotational ground state is projected. The stored beam current are in the range of 1 nA - 1 μA. The resulting low signal strengths on the beam position pickups, current monitors and Schottky monitor put strong demands on these diagnostics tools. In the paper a summary of the CSR diagnostics tools and diagnosis of the first stored ion beam will be given.

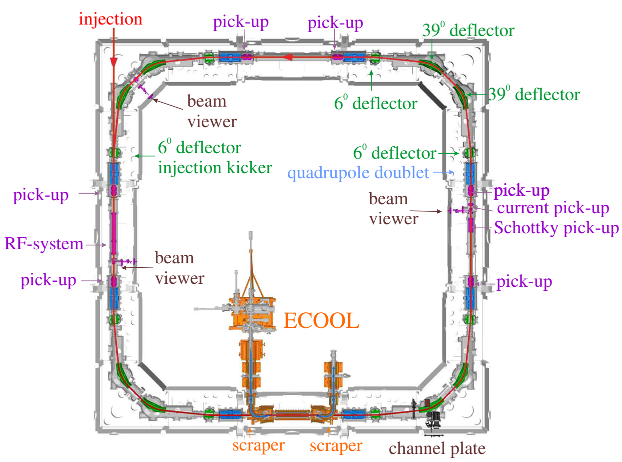

Figure 1: Diagnostics of the cryogenic storage ring CSR.

INTRODUCTION

The CSR is a fully electrostatic storage ring used to store atomic, molecular and cluster ion beams [1] in the energy range of 20-300 q·keV, where q is the charge state of the ions. The whole storage ring can cooled down to temperatures of only a few Kelvin where the stored molecular ion beam reached their lowest quantum mechanical state. The circumference of the storage ring is about 35 m. On March 17, 2014 a 51 keV $^{40}Ar^{+}$ beam was stored for many hundred turns for the first time. Because the complete storage ring could not yet be cooled so far a vacuum in the 10^{-7} mbar range was obtained, resulting in a the storage life times for single charged ions of a few milliseconds. The beam optics consists of quadrupoles, 6° deflectors to separate the ion beam from neutral reaction products and 39° deflectors. It will be possible to merge the ion beam with neutral particles and laser beams. The experimental straight sections contain an electron cooler and a reaction microscope for reaction dynamics investigations. One linear section is uniquely reserved for diagnostics, which will contain a beam viewer for the first turn diagnosis, a Schottky pickup and a current monitor for bunched ion beams (see Fig. 1).

FIRST TURN DIAGNOSTICS

For the first turn diagnostics in the CSR three destructive low intensity beam viewer to detect a low intensity injected ion beam [2] are used. The beam viewer (see Fig. 2) consists of a aluminum plate hit by the beam, producing secondary electrons. Using a grid the electrons are extracted and accelerated before they hit the 40 mm MCP/phosphorous screen combination. The image of the beam is recorded via a CCD camera and analyzed by software. Two rotary feed-troughs are used to move the aluminum plate. The inner feed-through on the experimental vacuum chamber is absolutely vacuum tight and able to operate reliable at temperatures of about 10 K. The outer rotational feed-through on the isolation vacuum chamber is connected via a terminally insulation drive with the inner one. The image of an injected 51 keV $^{40}Ar^{+}$ ion beam measured with the first beam viewer, located in the injection straight section, is shown in figure Fig. 3.

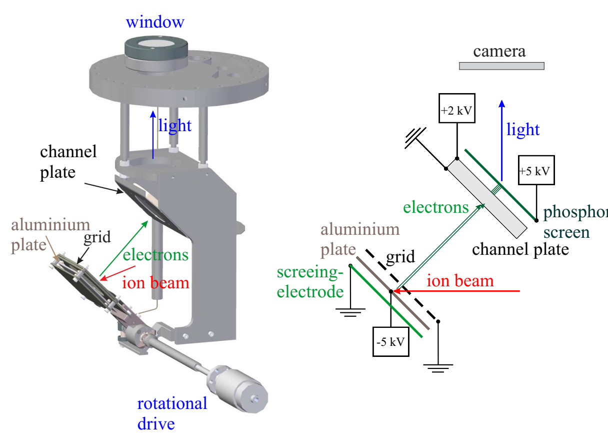

Figure 2: Layout and principle of a CSR beam viewer.

DIAGNOSES OF THE STORED ION BEAM

Directly after the first cycle of the injected $^{40}Ar^{+}$ beam the ion beam could be stored for many hundred turns at the calculated settings based on theoretical models of the storage ring. To detect the stored ion beam the continues current coming from a Penning ion source was pulsed with a chopper located in front of the storage ring. Together with the switched 6^{o} deflector, needed for single turn injection, an injected ion pulse length of approximately half of the revolution time could be realized. With our very sensitive Schottky pick-up, a 35 cm long tube, we were able to detect the stored beam.

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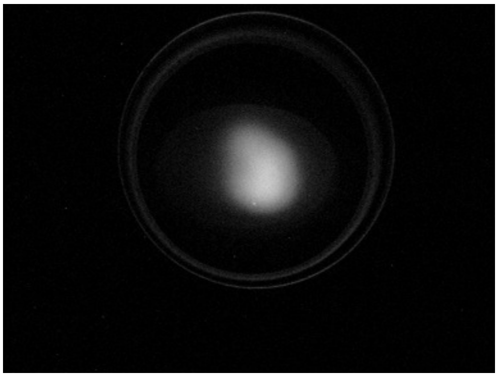

Figure 3: Image of a 51 keV $^{40}Ar^{+}$ beam at the position of the first beam viewer recorded via a CCD camera. The beam intensity was several nA.

Every time the circulating ion pulse is passing the pick-up a voltage signal, discussed in [3], is induced in the pick-up. The measured pick-up signal for the stored $^{40}Ar^{+}$ ion beam is shown in Fig. 4. An absolute measurement of the stored ion number is possible by integration the measured pick-up signal pulses. From the measurement shown in Fig. 4 an injected pulse current of about 100 nA could be derived. In

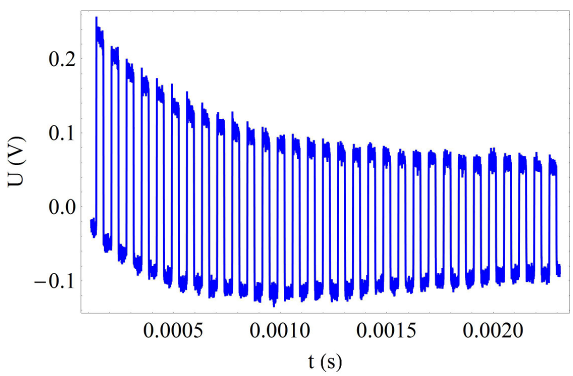

Figure 4: Measured pick-up signal as a function of time for $^{40}Ar^{+}$ ions.

Fig. 5 the measured integral of the pick-up voltage as a function of time is shown. From that measurements a lifetime of 3.0 ms could be derived for the 51 keV $^{40}Ar^{+}$ beam at a vacuum level of about 10^{-7} mbar. This lifetime is mainly determined by single electron capturing in the residual gas. The measured pick-up signal as a function of time allowed an accurate determination of the beam revolution frequency by plotting the center of mass position of each individual pulse as a function of the turn number (see Fig. 6). A fit through the data, shown as a red line in Fig. 6, results in a revolution frequency of f_0=14.112 kHz. With f_0 and the CSR circumference of C_0=35.25 m an energy of E=51.3 keV for the stored $^{40}Ar^{+}$ ion beam could be determined.

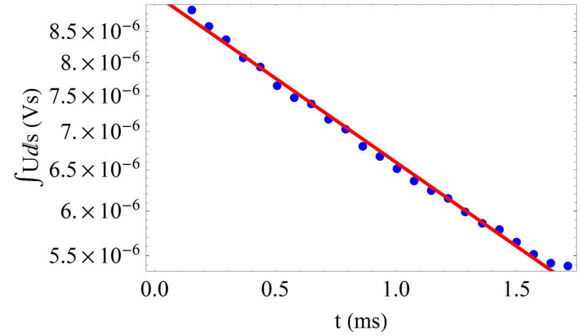

Figure 5: Lifetime measurement of a stored 51 keV $^{40}Ar^{+}$ beam.

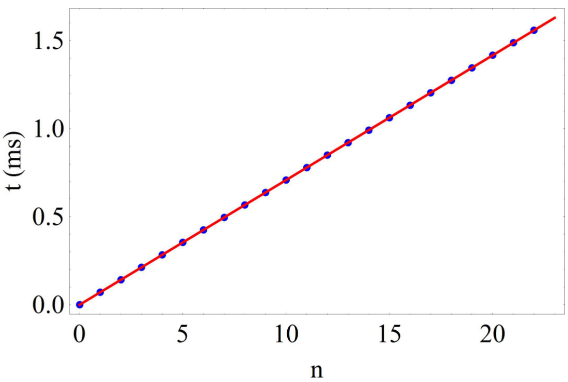

Figure 6: Measurement of the circulation time.

Ion Beam Bunching

An alternative and more sensitive method to detect the stored ion beam is to bunch the beam. To bunch the stored ion beam a drift tube with a length of 35 cm can be used. During single turn injection the drift tube voltage U_d is off and after injection a linear increase of U_d, starting at t=0 ms, in several ms to an value of $U_{d,max}$ ≈44 V was chosen in the experiment. In Fig. 7 the bunched beam signal taken

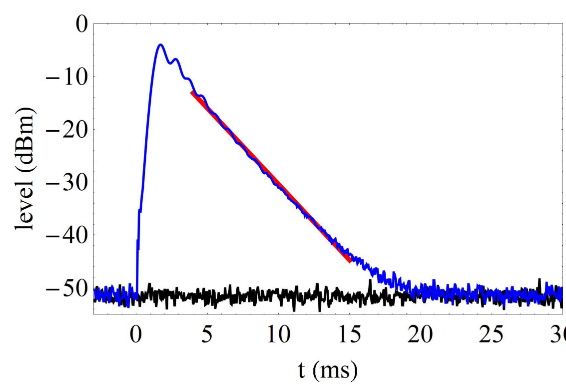

Figure 7: Bunched beam signal determined at the 25^{th} harmonic of the revolution frequency, measured with a spectrum analyzer in span zero mode.

at the 25^{th} harmonic of the revolution frequency is shown, where the spectrum analyzer was used in the span zero mode. The analyzed frequency of the spectrum analyzer was set to

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352 kHz and for the resolution bandwidth an value of 10 kHz was chosen. The black data shown in Fig. 7 is a measurement to determine the background where no beam was injected into the CSR, whereas the red line is a fit through the data. From the fit a beam lifetime of 3.0 ms can be derived, which corresponds to the measured lifetime shown in Fig. 5. The

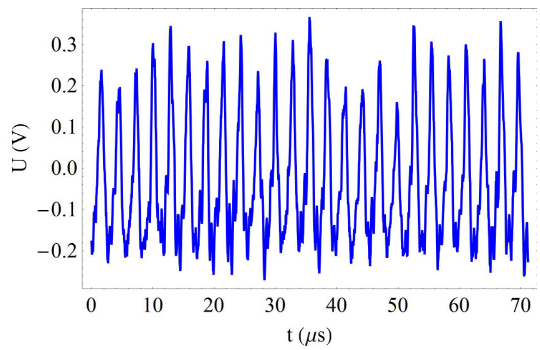

Figure 8: Bunched beam signal as a function of time, measured at $t = 1.75\ ms$ after injection.

bunches obtained at t=1.75 ms after injection and measured with the Schottky pick-up are shown in Fig. 8. Because the beam is bunched at 25^{th} harmonic number of the revolution frequency and the time displayed in Fig. 8 corresponds to the revolution time ($T_0 = 70.85\ \mu s$) 25 bunches are visible. The height of the bunches are not identically since the injected ion pulse, with pulse length $\Delta t \approx T_0$, was fluctuating with time.

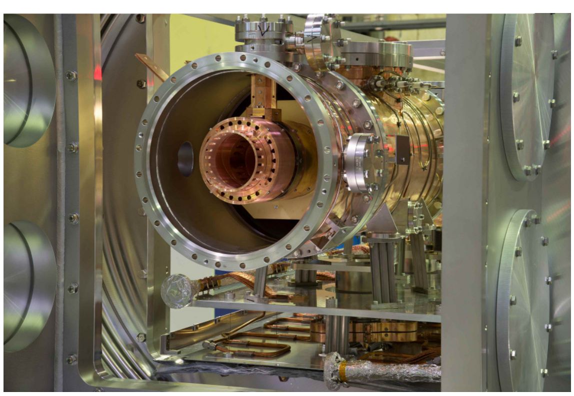

Figure 9: Position pick-up installed in the CSR.

POSITION MEASUREMENTS

The closed orbit of the bunched ion beam can be measured with six beam position monitors, each consisting of a horizontal and vertical position pick-up. All six position pick-ups are installed in the CSR. The diagonal slit type linear pick-ups with a circular aperture are used. The overall beam position monitor length is approximately 25 cm and the diameter of the electrodes is 10 cm. The pick-up itself is mounted in a grounded shielding chamber separating the actual signal from disturbing signals [4]. Fig. 9 shows one capacitive pick-up installed in the CSR. Clearly to see are the pick-up electrodes inside the cylindrically screen tube. The screen tube is electrically isolated from the experimental vacuum chamber. The pick-ups should be able to determine the position of ion beams with intensities down to 10 nA with an accuracy of 0.5 mm. Beam position measurements with the pick-up system should be possible when the beam life-time of the stored ion beam will be much larger then 100 ms which is anticipated end of the year 2014 when the complete storage ring will be cooled to temperatures below 10 K.

OUTLOOK

When the whole storage ring will be operated at cryogenic temperatures the residual gas pressure must not exceed 10^{-13} mbar and lifetimes for single charged ions in the 1000 s range are expected. At this condition measurements of the momentum spread of the stored ion beam using Schottky noise analysis will be possible. The large beam lifetime will further allow the determination of the horizontal and vertical tune as well beta functions of the storage ring with BTF measurements. At the anticipated pressure of $p < 10^{-13}$ mbar at the CSR storage ring a conventional residual beam profile monitor is not usable to measure the profile of the stored ion beam. The beam profile of stored singly charged molecules can be determined by using the dissociative recombination process between the positive singly charged molecules and free electrons of the electron cooler. The neutral fragments from this process are detected with a position sensitive detector. The profile of the stored ion beam can be calculated from the distribution of the center of mass positions of the neutral fragments created in the DR process [5] [6]. The channel plate detector, which is important for the beam profile measurements was already successfully tested in the first CSR experiments.

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