Capturing highly charged ions in the SpecTrap penning trap*

T. Murböck[1], *G. Birkl*[1], *A. Martin*[1], *K. König*[2], *W. Nörtershäuser*[2], *S. Schmidt*[2], *Z. Andelkovic*[3], *M. Vogel*[3], *V. Hannen*[4], *J. Vollbrecht*[4], *C. Weinheimer*[4], *D. Segal*[5], *and R. Thompson*[5]

[1]IAP, TU Darmstadt; [2]IKP, TU Darmstadt; [3]GSI, Darmstadt; [4]Westfälische Wilhems-Universität, Münster; [5]Imperial College London

The SpecTrap collaboration aims to perform high precision laser spectroscopy of forbidden transitions in highly charged ions (HCIs). Similar experiments performed to date with ions stored in an EBIT or in a storage ring still suffer from Doppler broadening or the difficulties in wavelength conversion between the laboratory frame and the rest frame [1, 2]. Therefore, the SpecTrap experiment employs a cryogenic Penning trap suitable for trapping externally produced ions and sympathetically cooling them with laser cooled Mg^+ ions [3]. Cooling of HCI to the mK-regime will dramatically reduce the Doppler broadening of the fluorescence signal and allow the measurement of the hyperfine splitting of the HCI with an expected relative accuracy of up to 10^{-8} for a stringent test of bound state QED.

In 2014 we have investigated and optimized the transport properties of the low-energy beamline connecting the SpecTrap Penning trap with an electron beam ion source (EBIS). This EBIS is used for production of argon ions with any desired charge state up to bare Ar. The desired charge state can be selected by adjusting the breeding time of argon in the EBIS and the magnetic field of the multi passage spectrometer (MPS). By adjusting the timing of a pulsed drift tube to the time of flight of the desired charge state the ion energy can be reduced for trapping. It has been demonstrated that transport and trapping of any charge state from Ar^{3+} to Ar^{16+} can be selected within a few seconds.

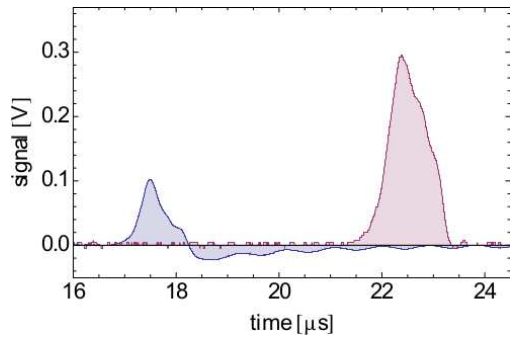

Figure 1: Averaged Ar^{13+} signals at the non-destructive ion detector ($t \approx 17\ \mu$s) and the MCP ($t \approx 23\ \mu$s).

Another method used for ion detection along the beamline is based on low-noise charge amplification in a newly developed detection system. It is formed by a hollow cylinder electrode of the Penning trap and a dedicated cryogenic amplification stage. The detector amplifies the AC voltage signal at the input stage created on the effective input capacitance from ions passing the electrode. Thus the system is used for non-destructive single-pass electronic detection and serves both as a counter and for timing information.

In Fig. 1 an Ar^{13+} ion signal detected with the cryogenic amplifier and with a multi channel plate is shown. The total number of ions of the detected signal amounts to (46000 ± 1000) ions per bunch and is slightly smaller for the multi channel plate measurement due to transport losses. The lowest detectable signal with the detector corresponds to 4000 elementary charges when the detector is operated at room temperature.

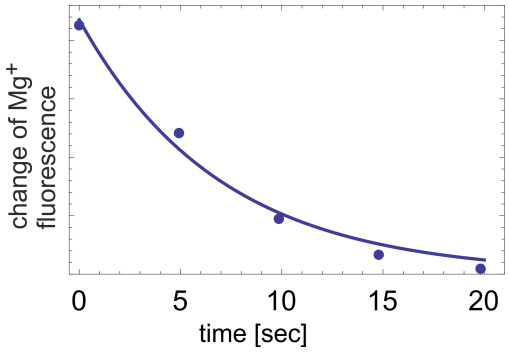

Figure 2: Change of Mg^+ fluorescence intensity after cyclotron excitation of Ar^{3+} as a function of storage time.

For sympathetic cooling the HCI were mixed with a cloud of laser cooled Mg^+ ions. For non-destructive detection the mass dependent cyclotron motion of the HCI was excited with an irradiated radio frequency, while monitoring a change in the Mg^+ fluorescence. The intensity of this change in fluorescence is plotted as a function of storage time in figure 2. Temperature dependent collisions with residual gas limit the HCI storage time, which can be used to estimate the HCI temperature. The exponential decay fitted in Fig. 2 with a time constant of 7 s, is in agreement with the assumption of sympathetically cooled argon ions.

References

[1] Mäckel et al., Phys. Rev. Lett. 107, 143002 (2011)

[2] Lochmann et al., Phys. Rev. A 90, 030501(R) (2014)

[3] Murböck et al., Phys. Scr. T156 (2013)

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