First trapped and laser-cooled ions in SPECTRAP

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The development of electron beam ion sources and ion storage rings about two decades ago, allowed spectroscopy experiments with highly charged ions for the first time. Their relative accuracy was limited to around 10^{-4} due to a large energy dispersion of the produced ions, and it was soon realized that a combination of ion traps with laser cooling and spectroscopy could bring an improvement of several orders of magnitude. After several years of development, the SPECTRAP experiment [1] made in 2011 the first steps towards that goal: magnesium ions were produced externally, transported into the trap and cooled to sub-Kelvin temperatures by means of laser cooling.

An overview of the experimental setup is shown in Fig. 1. Situated in a laser laboratory is a frequency-quadrupled fibre laser [2], producing up to 5 mW of 279 nm laser light used for laser cooling on the resonance transition in Mg^+. After shaping and stabilizing, the beam is directed upwards, through the experimental platform, and aligned with a Penning trap on the upper level. The trap itself is located inside a Helmholtz superconducting magnet, which produces a magnetic field up to 6 T. Fluorescence is picked-up radially, directly from the trap centre. $^{24}Mg^+$ ions are produced locally, as indicated in Fig. 1, but the system can also accept ions through the other branch of the beamline from the right. It is foreseen for the future connection with HITRAP, in order to get access to highly charged ions up to hydrogenlike U^{91+}.

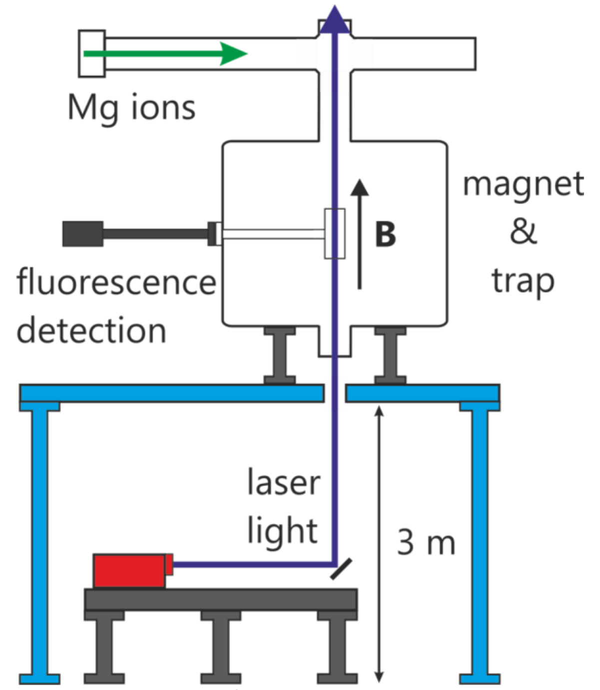

Figure 1: Overview of the SPECTRAP laser laboratory and experimental platform with the magnet and the beamline.

$^{24}Mg^+$ ions were produced with a thermal source, electron impact and pulsed extraction, and then transported through the beamline into the trap. Because of the in-flight ion capture technique and the strong cooling power available with laser cooling, it was possible to store several consecutive ion source shots and accumulate up to 2500 Mg ions in the trap. After ion stacking, the trap was kept permanently closed, while the laser was scanned from approx. 1-2 GHz red detuning towards the Zeeman-shifted frequency of the resonant transition. This was sufficient to cool the stored ion cloud to approx. 0.1 K, as can be seen in Fig. 2, by evaluating the Doppler width from the measured asymmetrical profile taking into account also the $^{24}Mg^+$ natural transition linewidth of 42 MHz.

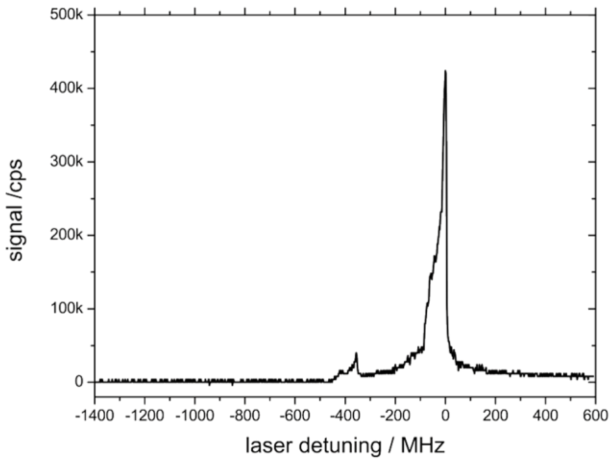

Figure 2: Fluorescence signal as a function of laser detuning. The transition width is proportional to the ion temperature.

Fluorescence was detected using a channel-photo-multiplier, with the detection setup designed at Münster University. Its high detection efficiency and low dark count rate allowed detection of even a single trapped ion. This offered a unique opportunity to detect ions non-destructively, either by means of fluorescence detection or by electronic pick-up of the induced image charge.

The cloud of Mg+ ions will in future experiments serve for sympathetic cooling of highly charged ions. Hence, the achievements are an important step towards the spectroscopy of highly charged ions, but also serve as a proof of principle for the SPECTRAP experiment.

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References

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