Towards Crystalline Ion Beams in PALLAS ◇

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For heavy ion storage rings like TSR [1] or ASTRID molecular dynamics simulations revealed that, mainly due to the too low symmetry and periodicity of their lattice structure, the formation of crystalline ion beams is restricted to lowest order structures [2]. To experimentally elucidate fundamental issues of crystalline ion beams at low velocities, we therefore set up PALLAS, a table top circular RF-quadrupole storage ring [3].

To gain experience in operating PALLAS, we first investigated the cooling dynamics of an ion ensemble at rest in a well-defined region of the ring-trap. The axial confinement is provided by DC-voltages on four (see fig. 1) of the 16 drift tubes, uniformly distributed along the ring circumference [3]. One tunable laser beam was used for probing or cooling of the ion velocity distribution, for cooling counter-acted by an adjustable potential wall. The velocity dependent (Doppler-effect) resonance fluorescence was first detected by a photo-multiplier, results shown in fig. 2. Tuning the laser quickly (2 GHz/s) and far below saturation over the resonance reveals the undisturbed initial velocity distribution (upper fig.), where for high intensities and slow scan rates of about 300 MHz/s (lower fig.) the ion distribution is collected in velocity space and finally cooled close to the Doppler-limit. Further crossing the atomic resonance (to positive detuning) strongly heats the ions causing the instantaneous loss of fluorescence. The cooling mechanism has to overcome different heating mechanisms, in our trap in particular caused by ion oscillations driven by dipole terms of the RF-field and subsequent inter-particle scattering. Eliminating any dipole component in the storage potential by carefully matching the capacitance of the storage rods or by applying additional DC-potentials, the modulation of the fluorescence rate with the RF-frequency vanishes, as shown in the inset of fig. 2.

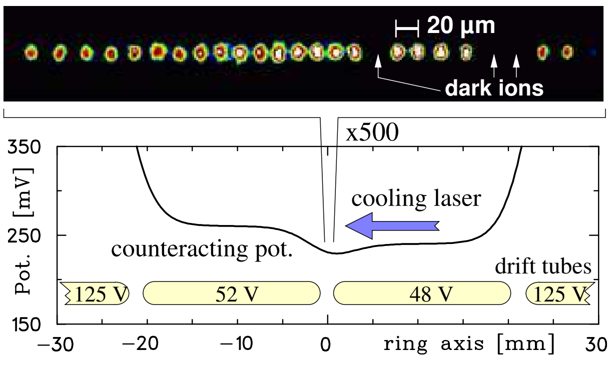

Fig. 1: CCD-camera image of the lowest order ion crystal, the linear chain (25 ions). The ions are axially confined by the static potential sketched below, also counter-acting the laser force.

The PM-signal of the ions (thick line) then suddenly decreases (arrow) crossing a phase-transition as reported in [5]. With the ions forming a crystalline structure, the inter-particle scattering is diminished finally leading to a sharp line close to the resonance.

With the laser frequency kept slightly below resonance, the crystalline structure was observed by an image intensified CCD camera, fig. 1 showing the image of a linear ion chain built up from 25 ions. The inter-particle distance amounts to about 20 μm, varying with the position of the ions in the unharmonic axial potential shown. Those positions where no light is detected are occupied by dark ions beeing cooled sympathetically by the Mg^+ ions.

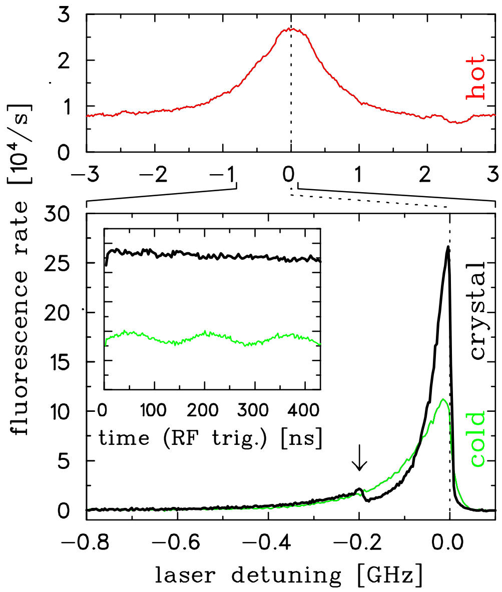

Fig. 2: Resonance fluorescence rate as a function of the laser detuning. In the upper plot the initial ion velocity distribution is probed via the Doppler-effect (σ=720 MHz corresponding to ≈200 m/s) for laser intensities far below saturation. For high intensities (≈ 2000 mW/cm^2) and a slow (300 MHz/s) scan rate the distribution is strongly affected by the scanning laser, finally cooling the distribution of about 100 ions close to the Doppler-limit (σ=40 MHz corresponding to ≈10 m/s). The anticipated drop in the rate due to the phase transition (arrow) occurs when heating due to the RF-field, as visualized by the RF-modulation in the fluorescence rate (inset), is diminished.

Summarizing, we demonstrated the feasibility of ion crystallization in PALLAS for ions at rest up to 3D-structures. Furthermore, first evidence for ion acceleration of ions cooled in a buffer-gas atmosphere (10^{-4}mbar He) was seen. We thus prepare to accelerate the stored ions (up to 5000m/s) in UHV (10^{-11}mbar) and reduce their velocity spread by Doppler- cooling, applying two slightly detuned lasers from either side. Once the goal of a crystalline ion beam is reached in PALLAS, we plan to continuously introduce disturbances to investigate the influence of lattice effects. Comparing and scaling anticipated results from PALLAS (≈ 0.4 m circumference) with simulations will allow the detailed study of the properties of beam crystallization in typical ion storage rings (≈ 50 m circumference).

References

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