Towards Crystalline Ion Beams - the PALLAS Ring Trap ◇

T. Schätz, D. Habs, C. Podlech, J. Wei [a], and U. Schramm
[a] Brookhaven National Laboratory, Upton, New York 11973

For heavy ion storage rings like TSR or ASTRID, where a lot of experimental effort has been spent to reach the domain of crystalline ions beams [1], recent molecular dynamics (MD) simulations revealed, that only lower-order crystalline structures like strings can be expected to be stable [2]. This effect has been attributed to the too low symmetry and periodicity of their lattice functions.

To now experimentally elucidate fundamental issues of crystalline ion beams at low velocities, we presently set up PALLAS [3], a table top circular RF quadrupole storage ring for acceleration and laser cooling of $^{24}Mg^{+}$ ions. Described in terms of the synchrotron terminology, PALLAS fully satisfies the required conditions for a smooth lattice [4] as confirmed by the following results of dedicated MD simulations, using the same code as for the storage rings mentioned above.

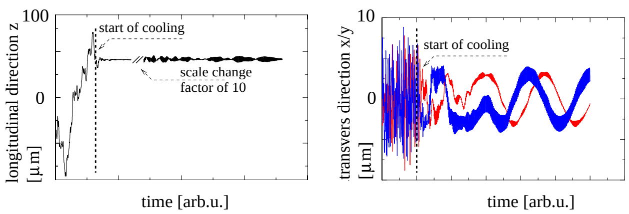

Fig. 1: Longitudinal, respectively transverse position of a test particle in the MD simulation (one out of 10^5 in the whole ring) versus time. While the longitudinal (beam orbit) position coincides with its equilibrium value (co-moving frame) immediately after the beginning of strong longitudinal cooling, the behavior in both transverse degrees of freedom is different: requiring time for the ordering process, the transverse motion is finally described by two phase shifted oscillations corresponding to a twisted helix-like trajectory.

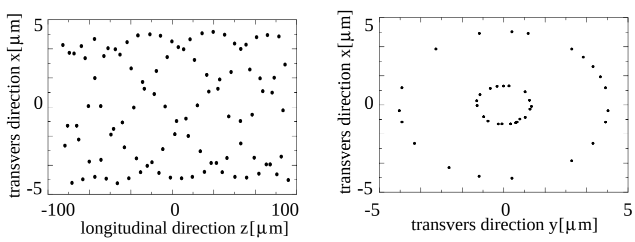

Fig. 2: Snapshot of the ion distribution in the beam after the phase transition demonstrated in fig. 1 has occurred.

Fig. 1 qualitatively shows the behavior of one particle out of the sum of 40 in the MD simulation cell, representing 10^5 ions with an average velocity of 3000 m/s in the PALLAS storage ring. The relation between the trajectories of the ions is shown in fig. 2, where a snapshot of the simulated ion cloud after the ordering process is presented. The left part of the figure shows the longitudinal dimension (for simplicity only those ions belonging to the outer helix are shown). The right part shows the transverse cross section of the resulting crystalline beam structure (both helices). Even though not every possible ion position of the helices comes out to be occupied continuously, the crystalline beam structure remains stable in time. The inter particle distance of about 10 μm is comparable to the one observed for static ion crystals.

Summarizing the upper results, we demonstrated the feasibility of reaching crystalline beams in PALLAS due to the *smoothness* of its lattice.

The idea for the PALLAS storage ring has developed starting from the RF quadrupole ring trap at the MPQ Munich, where the first beam-like ion crystals were reported [3]. PALLAS now stands for a circular RF quadrupole setup, dedicated to the acceleration of stored ions while even improving the established environmental conditions of the ring trap.

We therefore invented an external acceleration mechanism in PALLAS, based on 16 individually biasable drift tubes evenly distributed along the ring circumference, each tube consisting out of six stripe electrodes as sketched in the cross section of fig. 3.

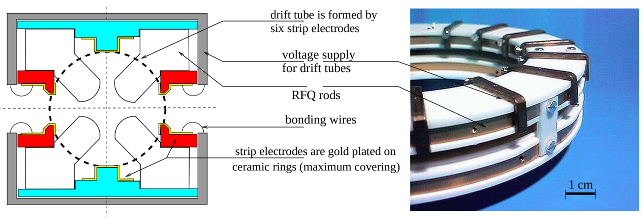

Fig. 3: Schematic cross section and side view of the present status of the partially assembled PALLAS storage ring: It principally consists out of the four circular RFQ rods providing the storage field on axis and the drift tube arrangement for ion acceleration. The latter are segmented into six stripe electrodes metalized in sandwich layers onto precision Al_2O_3 rings which also guarantee the alignment of the main rods to better than 2/100 mm. The yokes provide electric contacting of the segments via bonding wires.

With the stored ions being accelerated [3], their velocity distribution will be reduced by standard longitudinal laser cooling, applying two separate lasers, taking account of the different Doppler-shifts coming from either side. Therefore we presently set up two frequency doubled ring dye lasers [5], pumped by our already existing Argon ion laser system.

Once obtained a crystalline ion beam in PALLAS, we may continuously introduce disturbances with the acceleration electrodes to investigate the limit of smooth lattice deviations. Comparing and scaling anticipated results from PALLAS ($\approx$ 0.4 m circumference) with simulations should enable the detailed study of the properties of beam crystallization in typical ion storage rings ($\approx$ 50 m circumference).

References

[1] U. Schramm *et al.*, this report p. 38 and refs. therein
[2] J. Wei, X.-P. Li, A. Sessler, Phys. Rev. Lett. **73** (1994) 3089
[3] T. Schätz *et al.*, Jahresbericht 1997, p. 97 and refs. therein
[4] T. Schätz *et al.*, Proc. Trap. Char. Part. and Fund. Phys., Monterey, CA, USA, 1998, AIP Press (1999)
[5] U. Schramm *et al.*, Hyp. Int. (1998) 57

◇ partially sup. by DFG under HA 1101/8-1-650/98