Experimental Approaches to Crystalline Ion Beams in PALLAS ◇

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Facing the difficulties associated with the preparation of crystalline ion beams in heavy ion storage rings we propose a table top scheme to elucidate fundamental issues of moving ion crystals at low velocities. The setup is principally based on a small radio-frequency quadrupole (RFQ) storage ring of the MPQ, where by laser cooling ion crystals were observed at rest [1], but conceptionally modified with additional acceleration electrodes and manufactured with highest mechanical precision [2].

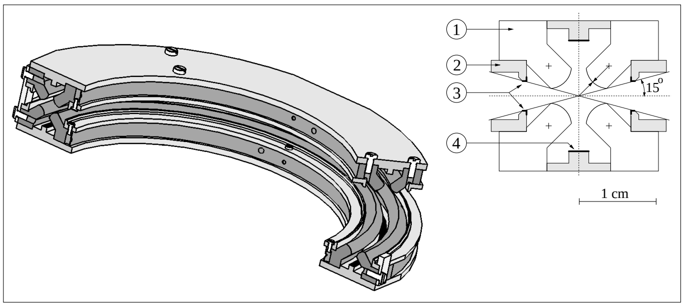

Fig. 1: Construction of the RFQ storage ring PALLAS with a central diameter of 115 mm. The cross section shows the four Ti-rods (1) forming the quadrupole field on axis and illustrates the segmentation of each drift tube into six electrodes (3 and 4) metalized onto precise Al_2O_3 rings (2). These additionally guarantee an alignment of the rods to better than 2/100 mm.

Within the "smooth approximation" an equivalent description of the PALLAS◇ ring and a synchrotron can be written using the following parameters: tune $Q_x=2\pi R_o \nu_\beta / v_o$, momentum compaction factor $\alpha = 1/Q_x^2$, transition energy $E_t=Q_x M_o c^2$ and average dispersion of the ring $D_o=R_o/Q_x^2$ with an average beta function of $\beta_o=R_o/Q_x$. The secular frequency ν_β of typically 500 kHz (for 250V, 5MHz RFQ voltage)thereby corresponds to the betatron frequency of the synchrotron, R_o to the radius of PALLAS and v_o to the average velocity of the circulating ions. Regarding the parameters of PALLAS for the ion velocity v_o=3500m/s received in the simulation of fig 2 results in a tune of Q_x=60 and a dispersion of only 15μm with a kinetic energy far below $E_t=10^6$MeV. According to this equivalence it is possible to transfer results from storage rings to PALLAS (and v.v.), leading to a strongly reduced dispersive heating because of the small dispersion (cp. TSR with $D_o \approx$ 1m) and omitting instabilities because of the large tune (cp. TSR with $Q_x \approx 2$).

Furthermore comparison with theory reaches a new dimension in such a small setup since it is for the first time possible to simulate the experiment not only in periodic cells but completely. Independent of the size of simulation cells it should now be possible to test theoretical models describing the heating mechanisms and sophisticated cooling techniques.

For this aim and to optimize the parameters of the acceleration system we perform Molecular Dynamics (MD) simulations in collaboration with W.Hasse (GSI Darmstadt). E.g. the number of accelerator tubes (see fig. 1), acceleration frequency and shape of the acceleration potential have been optimized, as it can be seen in the inlay of fig. 2, where eleven tubes cause potential steps up and a twelfth one big step down to the potential of the first one. These potential stairs then propagate, accelerated with the ions over the electrodes around the ring. A preliminary result with 1000 ions starting at room temperature with an average velocity of 500m/s can be seen in fig. 2, where 75% of the initial particles have a velocity of 3500±1000m/s. The resulting beam displacement from the center of the ring (due to the centrifugal force) is of the order of some μm and therefore negligible.

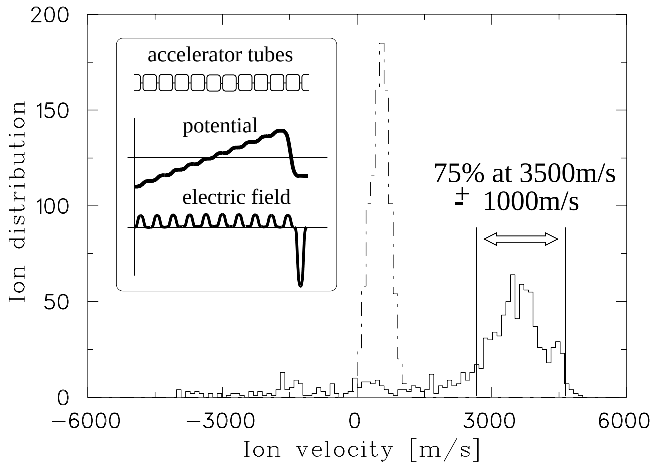

Fig. 2: Preliminary result of MD simulations with 1000 ions starting at room temperature, proving efficient acceleration of more than 70% of the initial particles to a velocity of 3500±1000m/s within a fraction of a millisecond. The dotted line shows the initial thermal velocity distribution of the ions.

With the particles moving the temperature of the beam will be reduced by standard longitudinal laser cooling (at this low ion velocities even transverse laser cooling might be applicable) possibly down to a crystalline state [3].

An advantage compared to regular storage ring laser cooling can be found in the segmented accelerator tubes, where even the stripe electrodes can be biased separately. One may therefore think of a counteracting force dependent on the radius of the ion path, allowing gradient laser cooling for a favored constant angular velocity.

Concerning the status of the experiment the quadrupole rods are manufactured with the necessary precision and surface treatment and Au-sputtering, the Al_2O_3 insulators fixing the stripe electrodes are still under construction.

Besides the fundamental interest even with the low energy beam itself, fascinating development in other domains of physics, like high resolution Ramsey spectroscopy could be performed [2].

References

[1] G. Birkl, S. Kassner and H. Walther, Nature **357** (1992) 310
[2] T. Schätz *et al.*, 3^{rd} Euroconf., submiited to Hyperfine Int.
[3] U. Schramm *et al.*, this report p. 40
[4] Hesiod, Theogony (700 B.C.) p. 376-389

◇ PALLAS here: **PA**u**L** **L**asercooling **A**cceleration **S**ystem; in greek mythology: A Titan, husband of Styx, goddess of the icecold stream of the underworld [4];