Systematic Investigation of Ultra-cold Bunched $^9Be^+$ Beams at the TSR

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At the TSR Heidelberg we presently investigate the dynamics of laser cooled bunched $^9Be^+$ beams over a wide range of especially low particle numbers where the major heating mechanism, intra-beam Coulomb scattering (IBS), is diminished. An elaborate laser cooling scheme including dispersive transverse laser cooling [1] is employed combined with dedicated barrier buckets (sketched in fig. 2) to provide either longitudinal ion confinement as well as a constant slope to counteract the accelerating laser force [2,3]. Furthermore, the complete phase space can now be monitored over the period of many beam lifetimes.

Under these conditions we observed a sudden change in the beam behaviour, when the beam has decayed to about 10^6 ions (corresponding to a mean particle distance of 25 μm). IBS abruptly vanished as reported earlier [3,4] and depicted in fig. 1. The upper curve (a) shows the fluorescence signal proportional to the number of cold ions where the lower (b) represents the number of hot ions having experienced IBS and being re-cooled via rapid adiabatic passage [3]. Connected with the obvious reduction of IBS we observed a dramatic decrease in the longitudinal temperature, similar to the signature reported for the onset of the transition to Coulomb-order observed in heavy ion beams at the ESR [5].

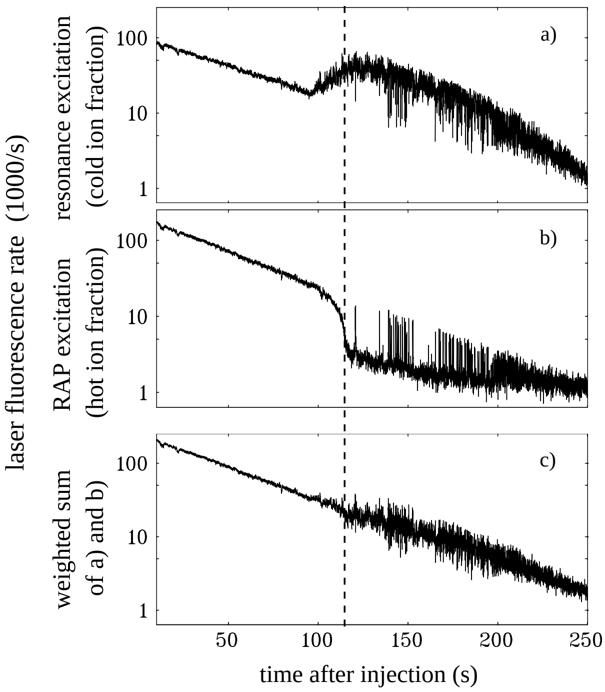

Fig. 1: Temporal evolution of the fluorescence signal of the laser-cooled ion beam proportional to the number of ions interacting with the laser. The dashed line marks the transition discussed in the text. The corresponding longitudinal temperature of the whole ion distribution decreases instantaneously from ≈ 50 K to < 0.5 K.

The beam exhibits a *bistable* behaviour after the transition, the fluorescence rate returning to the extrapolated exponential decay for periods of about 200 ms. Thus, no unexpected particle loss is observed during the transition.

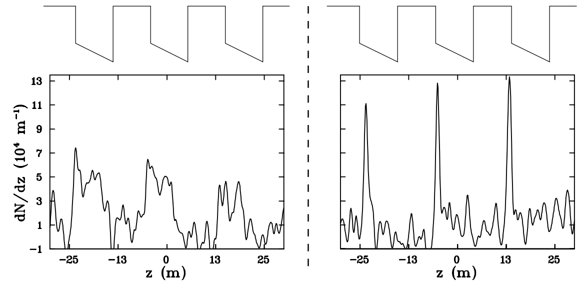

Fig. 2: Longitudinal spatial ion distribution (recorded with an electrostatic pick-up) in the confining pseudo-potential sketched above before and after the transition. The shape of the bunch changes from the well adjusted constant linear density to a sharp peak at the bucket edge.

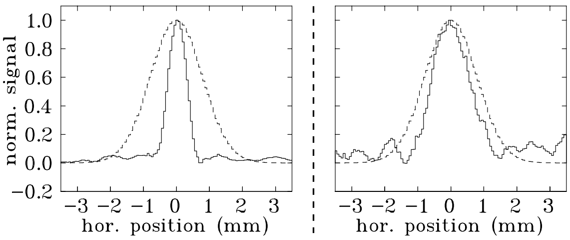

Fig. 3: Corresponding increase in the horizontal beam profile. The dashed line indicates the intensity profile of the cooling-laser (as it would appear at the position of the beam profile monitor).

However, careful monitoring of the whole phase space revealed a striking change in the longitudinal ion density after the transition (fig. 2). Apparently, the mean laser force is increased, overcoming the given counterforce after the transition. This effect can be regarded as a direct consequence of the temperature reduction, leading to an increased laser-ion interaction. It indicates a severe complication inherent to the use of barrier buckets with a constant counterforce, originally invented to provide constant linear density. Furthermore, a limited, yet significant increase of the beam emittance (fig. 3) was observed. The ion beam always stays within the geometric overlap with the cooling laser, assuring the strong laser-ion interaction observed above (fig. 1(c)). Thus, the transition is accompanied by the change from an elongated, transversally small bunch to a dense and cold, but transversally wider.

Especially the latter observation favours an explanation of the transition by a weak unidentified heating mechanism, where the loss of IBS still resembles the signature of Coulomb-ordering. For the future, the search for unambiguous signatures of ordering in very dilute (coasting) beams ($< 10^5$ ions) is envisaged.

References

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