Combined Laser and Electron Cooling of Bunched C^{3+} Beams at the ESR ◇

U. Schramm, M. Bussmann, D. Habs, M. Steck [a], T. Kühl [a], P. Beller [a], B. Franzke [a], F. Nolden [a], G. Saathoff [b], S. Reinhardt [b], and S. Karpuk [c]

[a] GSI, 64291 Darmstadt [b] MPI-K, 69029 Heidelberg [c] Inst. f. Physik, Univ. Mainz, 65128 Mainz

Laser cooling of bunched relativistic ion beams at the FAIR synchrotrons is expected to provide fast cooling of Li-like ions to unprecedented low momentum spread [1,2]. Yet, the steep momentum gradient of the resonant force comes at the expense of a narrow momentum acceptance range and predominantly collinear action. An increase in the momentum acceptance can be achieved by adapted tuning of the momentum distribution, as recently demonstrated for laser cooled C^{3+} beams at the ESR [3,4] or by direct tuning or broadening of the laser force, planned for an upcoming ESR beamtime.

Here, we report complementary results of the recent ESR C^{3+} test beam time. The phase space density of the 1.4 GeV ion beam was measured as a function of the continuously decreasing beam current for a fixed tuning of the laser force close to the bucket center that corresponds to a relative momentum deviation of only $\Delta p/p \sim 10^{-6}$. Still, every ion in the bucket experiences the laser force at least once per synchrotron period.

In Figs. 1 and 2 the spatial bunch length, the momentum spread and the transverse width of electron-cooled beams, following the expected phase space dominated intra-beam scattering scaling (dashed lines) [1,4], are plotted for reference (filled symbols). Regarding the bunch length below ion currents of 10 μA, laser cooling (open symbols) leads to a reduction by a factor of two. Bunches are longitudinally space-charge dominated [4] matching the expected equilibrium length (solid line). For higher currents it seems that only a fraction of the ions is efficiently laser-cooled as larger detuning provides longer bunches. For the momentum spread (derived from Schottky spectra for electron cooled reference beams) a momentum dependent measurement of the laser fluorescence (marked HV) yields a reduction of $\Delta p/p$ by about one order of magnitude - far below the solid line that corresponds to the constant equilibrium bunch length. Indirect transverse laser cooling cannot be observed above ion currents of 10 μA. For lower currents, an onset might be visible. Yet, with very little additional electron cooling the behaviour changes (stars). Though the momentum spread slightly increases, the beam becomes transversally as cold as for strong electron cooling.

Summarizing, combined cooling of low current C^{3+} beams leads to unprecedented phase space densities at a plasma parameter of the order of unity. Broad-band laser cooling is presently prepared for an increased momentum acceptance as well as complementary optical methods for the detection of the momentum spread, the bunch length and Schottky noise for a better understanding of space-charge and potential ordering phenomena.

◇ supported by BMBF (06ML183) and MLL

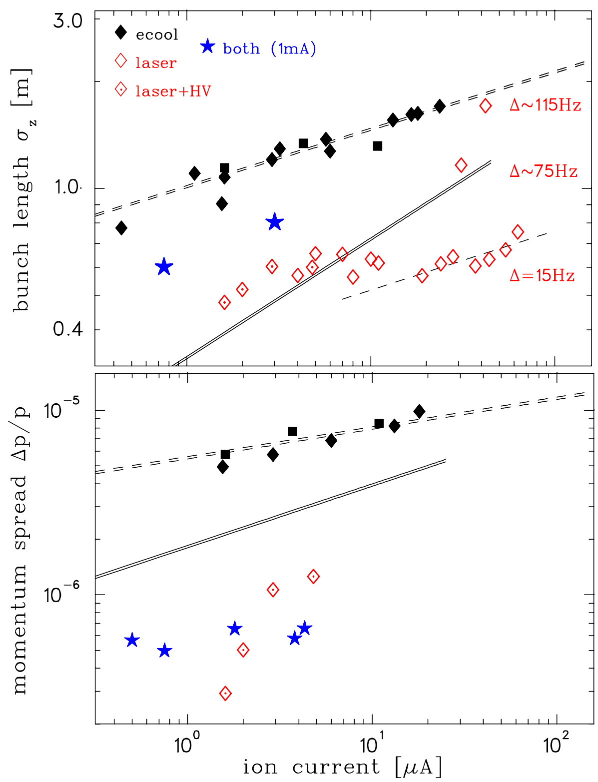

Fig. 1: Spatial bunch length (pick-up measurement) and mometum spread (Schottky signal and fluorescence diagnostics) for electron- and laser-cooled ion beams of decreasing current.

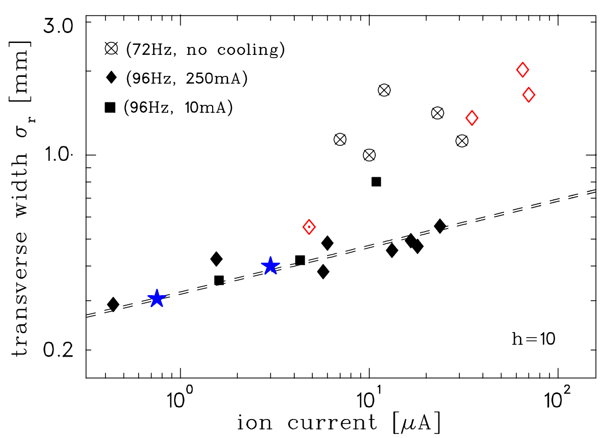

Fig. 2: Transverse width (beam-profile-monitor) as above (σ_r = 0.4 mm corresponds to $\varepsilon = 4 \times 10^{-3}\pi$ mm mrad).

References

[1] U. Schramm, D. Habs, Prog. Part. Nucl. Phys. **53** (2004) 583
[2] U. Schramm, *et al.*, LoI#18 FAIR APPA–PAC (2004) and GSI annual report (2004) 275
[3] U. Schramm *et al.*, Annual report 2004, p. 56
[4] U. Schramm, *et al.*, Proc. PAC05, JACoW (2005) FOAD004 and Proc. COOL05 (2005) AIP Proc. in press