OBSERVATION OF 2-COMPONENT BUNCHED BEAM SIGNAL WITH LASER COOLING*

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Abstract

Transverse laser cooling with the use of a synchro-betatron coupling is being carried out at S-LSR. Bunched 40 keV $^{24}Mg^+$ beams are cooled by a co-propagating laser with a wavelength of 280 nm. The bunch length was observed during a longitudinal laser cooling with a harmonic number 5. Two components of cooled and uncooled regions are observed in the bunched beam signal. In order to remove the uncooled beam, a scraper was used to cut the uncooled region of the beam [1]. The cooled beam size was measured using the scraper, beam size reduction from 3.3 mm to 1.3 mm in the synchro-betatron resonant coupling condition was observed.

INTRODUCTION

Laser cooling [2] is an efficient cooling method for achieving a ultralow temperature of circulating ion beam. Laser cooling has a strong cooling force in the longitudinal direction, it has no direct cooling effect in the transverse direction. Indirect cooling with use of intra-beam scattering (IBS) [3] was demonstrated but is not effective with a small particle number. In order to achieve an ultralow temperature in the transverse direction, laser cooling with synchro-betatron resonant coupling (SBRC) [4, 5] is considered as the most efficient way. The beam is directly cooled longitudinally with the co-propagating laser and RF voltage [6], then the heat is transferred from the hot transverse direction to cold longitudinal direction through synchro-betatron coupling.

Small laser-equipped storage ring (S-LSR) has a laser cooling system for $^{24}Mg^+$ ions and satisfies necessary conditions [7] for realizing crystalline beams. After the experiment of one-dimensional cooling of coasting beams [8] and bunched beams, laser cooling experiment with resonant coupling has been carried out since 2008. This paper reports present results of the laser cooling experiment.

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EXPERIMENTAL SETUP

The layout and specification of S-LSR is shown in Fig. 1 and Table 1. The beams of 40 keV $^{24}Mg^+$ ions come from an ion source (Danphysik 921A). Betatron tunes are controlled by two series of quadrupole magnets, QM1(QF) and QM2(QD). Excitation currents of the quadrupole magnets are stabilized within 2×10^{-4}.

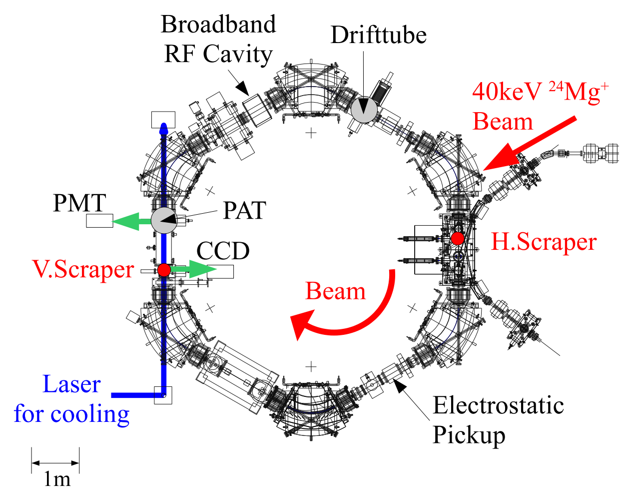

Figure 1: Layout of S-LSR.

A 280 nm ultraviolet(UV) laser is required for the laser cooling of $^{24}Mg^+$. A ring dye laser (Coherent 699-29) is driven by a pumping 532 nm Nd:YVO_4 laser (Coherent Verdi V-10) and provides 300∼500 mW 560 nm frequency controllable laser. A second harmonics generator using LBO crystal (Coherent MBD-200) doubles the frequency and generates the 10∼50 mW UV laser. After passing the transport optics, the UV laser is irradiated co-propagating with the ion beam of a power of 6∼20 mW [9]. Detuning of the dye laser is set to -0.1GHz and its fluctuation is less than 0.01GHz. The laser spot size is 0.3 mm in 1σ.

Two different RF cavities are installed in the ring; one is a broadband cavity (0.1 ∼ 5MHz), used for the bunch length measurement with a harmonic number of 5, the other is a small 2-gap drifttube used for synchro-betatron coupling with a harmonic number of 100. RF voltage is ap-

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plied adiabatically during 0.2 s after injection using amplitude modulation of the signal generator (Agilent E4400B).

Table 1: Specification of S-LSR

Circumference	22.557 m
Average Radius	3.59 m
Curvature Radius	1.05 m
Superperiodicity	6
Ion species	$^{24}Mg^{+}$ (40 keV)
Revolution Frequency	25.192 kHz
Betatron Tune	(2.052,1.118), (2.072,1.124)
RF voltage	11 V(h=5), 10-92 V(h=100)
Transition Level of $^{24}Mg^{+}$	$3s^2S_{1/2} \rightarrow 3p^2P_{3/2}$
Transition wavelength	280 nm
Laser Detuning	-0.1 ± 0.01GHz

2-COMPONENTS OF LASER-COOLED BUNCHED BEAM

The bunch length of the laser cooled Mg^{+} ion beam was measured by a parallel-plate electrostatic pickup. Figures 2 and 3 show the induced signals of the bunched beams with laser cooling. In Fig. 2, the beam signal consists of 2 components, a broad one of 1.45μs (77 cm) and a sharp one of 0.45μs (24 cm), nevertheless almost all of the broad component is lost in Fig. 3. A time evolution of the area

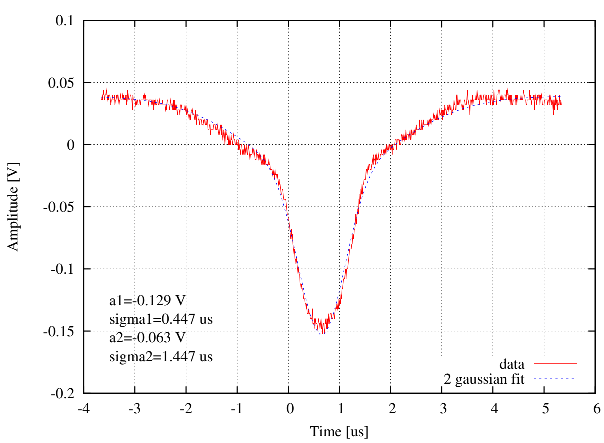

Figure 2: Time domain signal of laser cooled bunched beam observed 30 s after injection. The signal is fitted by two Gaussians.

of each component, which is proportional to the particle numbers, are shown in Fig. 4. Lifetimes of the cooled and uncooled parts are derived from this result as 41.7 s and 25.6 s, respectively. It is considered from this result that there are a significant percentage of uncooled components in the early stage of the laser cooling.

BEAM SIZE MEASUREMENT BY SCRAPER

In order to remove the uncooled part of the beam, A pulse-motor driven screen monitor was used as a scraper. It

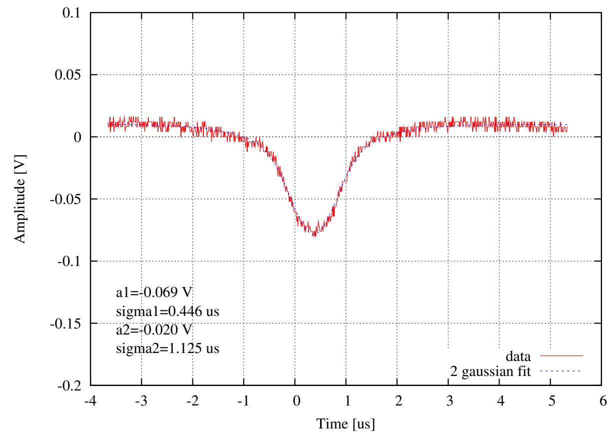

Figure 3: Time domain signal of laser cooled bunched beam observed 60 s after injection. The signal is fitted by two Gaussians. Almost all of the uncooled component was lost, where cooled component still remained.

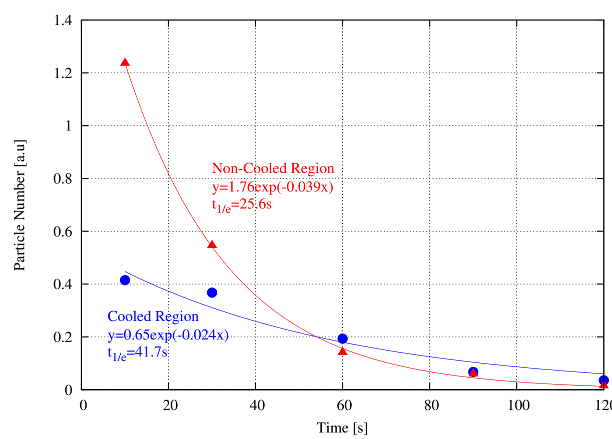

Figure 4: Time evolution of the particle numbers of the cooled and the uncooled region. The lifetime is derived from the reduction rate of particle numbers.

was inserted from the inside of the storage ring toward the beam center, stopped at a certain distance from the beam center, then returns back to the inner side. Amplitudes of the beam signal from the electrostatic pickups are measured during the scraper is approaching and is returning, therefore the survival ratio after the beam was cut by the scraper is obtained by comparing with the amplitude at the same time without inserting the scraper. With changing scraper insertion distance, survival ratio was measured as shown in Fig. 5. The survival ratio shows the percentage of the particles inside the scraper position. Particle distributions were reconstructed from this result as shown in Fig. 6 and the the beam size (1σ) is derived.

Measured beam sizes with 4×10^7 and 5×10^6 initial particles are shown in Fig. 7. The betatron tune is $(\nu_x, \nu_y) = (2.052, 1.118)$. For particle numbers of 5×10^6

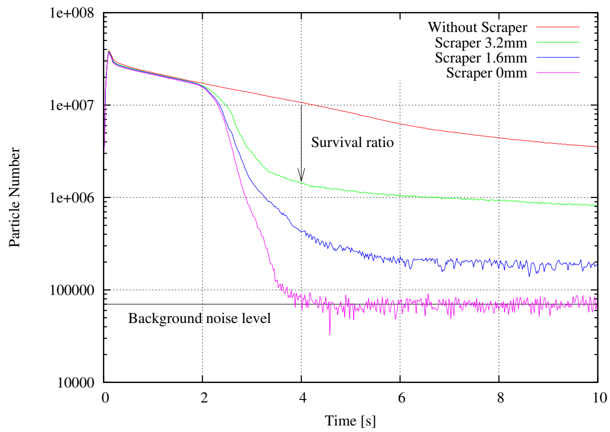

Figure 5: Time evolution of particle number measured by electrostatic pickups. The scraper approaches the beam center within 3.3 s after injection.

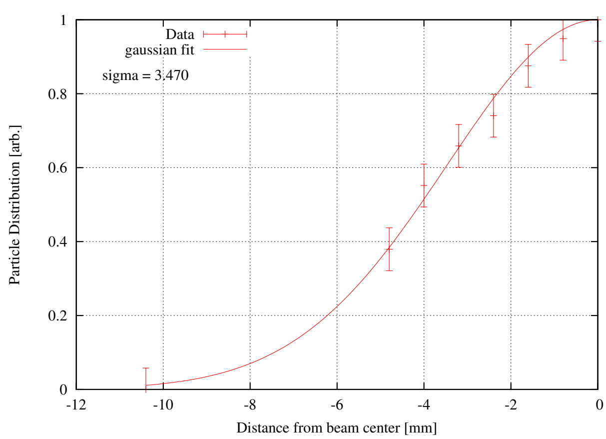

Figure 6: Particle distribution reconstructed from the survival ration measured using the scraper.

and 4×10^7, the beam size is decreased to 1.3$\sim$1.8 mm with the synchrotron tunes of 0.047$\sim$0.055, which satisfies the resonant condition. Without laser cooling, the beam size was 3.3mm at this resonant condition. With non-resonant condition $\nu_s < 0.045$ and $0.055 < \nu_s$, the beam sizes are 3$\sim$4 mm with a particle number of 4×10^7. It should be noted that there is a significant beam size enlargement at $\nu_s = 0.067$ with 4×10^7 particles, for both with and without laser cooling. This phenomena is not observed with 5×10^6 particles and the beam size is decreased to 2.5mm with the synchrotron tune of $\nu_s = 0.067$. The reason of the beam size blowup is not clear, more precise and quantitative measurement with various particle number will be performed.

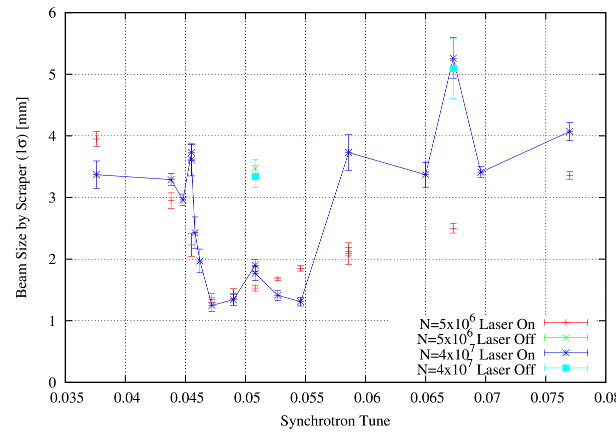

Figure 7: Beam size measurement with a scraper. The betatron tune is (2.052, 1.118).

SUMMARY

Transverse laser cooling with the use of a synchro-betatron coupling was applied to bunched 40 keV $^{24}Mg^+$ beams. Two components of cooled and uncooled regions are observed in the bunch length measurement with laser cooling at a harmonic number of 5. The cooled beam size was measured using the scraper, beam size reduction from 3.3 mm to 1.3 mm in the synchro-betatron resonant coupling condition was observed.

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