

# OBSERVATION OF INTENSITY DEPENDENT LOSSES IN Au(15+) BEAMS\*

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Abstract

During the 1994 heavy ion run at Brookhaven a strongly intensity dependent loss for the Au(15+) beam in the AGS Booster was encountered. Coherent instabilities or space charge induced stopband losses were neither expected nor consistent with the data. It was found that the beam lifetime was an order of magnitude shorter for normal operating conditions than in the low intensity limit with the inverse lifetime increasing monotonically with the injected number of particles. Studies data are presented and the Au(15+) situation is compared with that for Au(33+). Various hypothetical mechanisms are considered.

## I. INTRODUCTION

The AGS Booster is a fast cycling proton and heavy ion synchrotron. The beam pipe has an average radius of  $r_p = 7$  cm and the Booster's circumference is  $C = 202$  m with betatron tunes  $\approx 4.8$ . When accelerating gold, the pressure of the background gas is  $P \approx 2 \times 10^{-11}$  Torr. The injection momentum of the ions is 9 GeV/c and the final momentum of 70 GeV/c was reached in 0.55 s for Au(15+) and 0.10 s for Au(33+).

During 1992 and 1993, the BNL Tandem Van de Graff delivered Au(33+) to the Booster. This required a low energy stripping foil between the Tandem and the Booster and resulted in a small fraction of Au(33+). For 1994, the foil was removed with the intent of using the more plentiful Au(15+) as the primary beam. The number of ions delivered to the Booster increased by a factor of two but losses in the Booster resulted in a lower extracted intensity than was obtained with Au(33+).

It was found that the losses depended strongly on the injected intensity and the peak extraction intensity was reached at less than peak injected intensity. The Laslett tune shift was estimated to be  $\lesssim 0.01$  and instability growth rates were expected to be  $\lesssim 0.01$  s<sup>-1</sup>, well below the values normally needed for collective effects.

## II. STUDIES WITH Au(15+)

Two machine studies were conducted in September 1994. The Booster magnet cycle was modified to include intervals of constant field, so that data could be collected at a fixed beam energy. The rf was turned off at the end of the flat top and the beam was lost as the magnetic field ramped down. The data consisted of normalized current transformer traces taken under various conditions. It was found that the instantaneous loss rate  $\alpha(t) \equiv -d \ln N / dt$  depended on the particle momentum, the number of particles in the ring  $N$ , and the intensity on previous cycles.

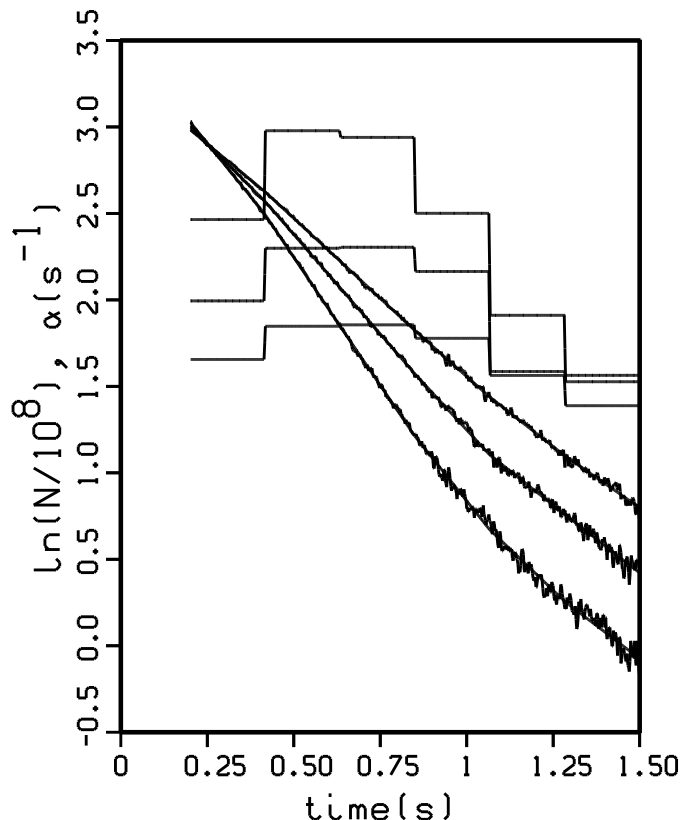


Figure 1. Typical data for the number of particles and loss rate in the Booster. The largest loss rate and smallest final intensity correspond to equilibrium conditions. The smallest loss rate and largest final intensity correspond to the first cycle after cooling. The intermediate state is for the second cycle after cooling.

Figure 1. shows  $\ln N$  and  $\alpha$  for a momentum of 15 GeV/c and different machine histories. The initial number of particles were comparable in all three cases but the loss rate varied dramatically. The smallest losses occurred after the machine had been allowed to “cool” for about a minute and intermediate losses occurred on the second cycle after a cool down. The cooling was accomplished by turning off the inflector and allowing the injected beam to crash in the ring without spiraling. Comparable results were obtained when the injected beam was killed farther upstream in the transfer line. This memory effect strongly suggests that the accelerating beam is affecting the residual gas in the ring. Additionally, it was observed that the number of Booster cycles required to reach equilibrium after a cool down increased when the vacuum was intentionally spoiled.

A first pass at parameterizing the data fitted an exponential to the current yielding an average loss rate,  $\langle \alpha \rangle$ . Figure 2 shows the average loss rate for equilibrium conditions as a function of

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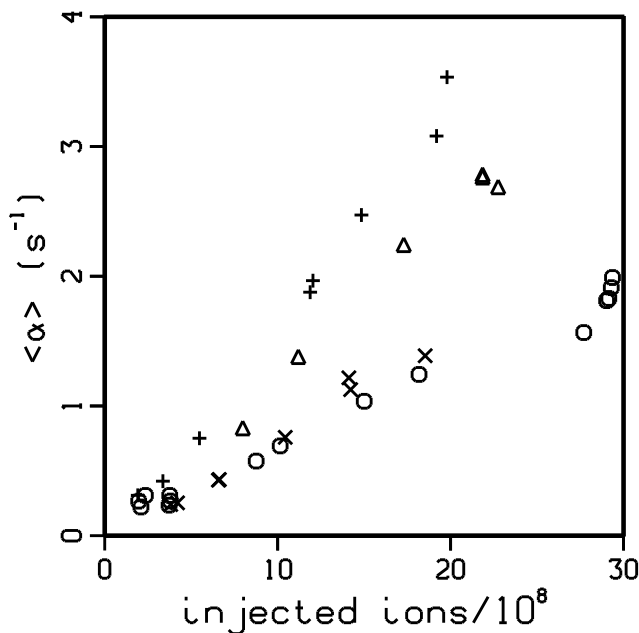


Figure 2. Average loss rate versus the number of injected ions for momenta of 9 GeV/c (circles), 15 GeV/c (triangles), 30 GeV/c (crosses), and 60 GeV/c (Xs).

the number of injected particles and beam momentum. The loss rate rises monotonically with the number of injected particles and peaks for a beam momentum around 30 GeV/c. Loss rates for normal operating conditions are about an order of magnitude larger than loss rates at low intensity and the low intensity loss rates of  $\sim 0.1 s^{-1}$  are comparable to the expected stripping losses due to residual gas at a pressure of  $2 \times 10^{-11}$  Torr.

There were other notable observations. As is apparent from Figure 1 the loss rate is not constant even at constant beam energy. Both increases and decreases in loss rate can occur during a single machine cycle. In most cases any increase in loss rate during a machine cycle occurred before a decrease in loss rate, but not always. When the rf was turned off after reaching the magnetic plateau, the losses were identical to those observed when the beam remained bunched. Radial steering of the beam by changing the rf frequency had little effect on losses.

### III. COMPARISON WITH Au(33+) AND POSSIBLE LOSS MECHANISMS

Given the amount of time that had been lost with Au(15+) no dedicated studies were performed using Au(33+). Data on Au(33+) loss rates were obtained using current transformer data over the whole machine cycle. For Au(33+) the peak number of injected ions was  $10^9$ , about a factor of two smaller than was available as Au(15+). The net loss rate for  $10^9$  injected ions was  $\approx 1.7 s^{-1}$ , and this rate did not decrease substantially as the number of injected ions decreased by a factor of two. From Figure 2, the loss rate for  $10^9$  Au(15+) ions was  $\lesssim 1 s^{-1} < 1.7 s^{-1}$  so it is difficult to say whether intensity dependent losses, at the level seen with Au(15+), were present with Au(33+). We go on to consider possible mechanisms for the Au(15+) losses.

With a pressure of  $P = 2 \times 10^{-11}$  Torr and temperature of  $T = 300$  K, the number density of molecules is  $6.4 \times 10^5 cm^{-3}$ . For a cross section  $\sigma = 10^{-16} cm^2$  with a gold momentum of 9 GeV/c the interaction rate is  $0.1 s^{-1}$  which is consistent with the loss rate in the limit of very low intensity.

The increase in loss rate with intensity suggests that the beam is creating targets with which it subsequently scatters. One possible mechanism is beam induced gas desorption [1]. However, the time scale for desorption must be very fast  $\lesssim 0.1$  s since the loss rates can change significantly over that time. Additionally, the number of desorbed molecules would need to be a factor of  $\sim 100$  larger than those normally in the pipe. The increase in equilibration time with pressure is also a consideration, though the number of adsorbed molecules probably varies with average pressure.

As a second process, consider the possibility that the beam is creating a background of electrons. Given the temperature and pressure any ionization present would be caused by the beam, in accord with the increase in loss rate with intensity. In the case of complete charge neutralization of  $10^9$  ions by electrons, the electron density within the beam is  $2.4 \times 10^5 cm^{-3}$ . This is less than half the number density of gas molecules. If the intensity dependent loss is due to ambient electrons, then the density of electrons is higher than required for complete charge neutralization or the relevant cross section is  $\gg 10^{-16} cm^2$ . Additionally, we know of no process which would generate such a number of electrons. Other processes we have considered are even less likely.

Since the loss rates did not change when the beam was debunched, charge exchange between the ions in the beam (*eg.*  $Au(15+) + Au(15+) \rightarrow Au(14+) + Au(16+)$ ) appears to be ruled out. Space charge induced stopbands and coherent instabilities, which are estimated to be nil, would also be reduced by debunching. Also, these processes would have no ‘‘memory’’, as shown in Figure 1.

### References

- [1] O. Gröbner, R.S. Calder CERN/ISR-VA/73-15 (1973).