ANOMALOUS, INTENSITY DEPENDENT LOSSES IN Au(32+) BEAMS

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Abstract

Anomalous, intensity dependent losses in Au(32+) beams have been observed in the AGS Booster. No collective signal is expected, or observed, but increasing the number of injected ions decreases the beam lifetime. The loss rates for Au(32+) are compared with those for Au(15+) .

1 INTRODUCTION

The AGS Booster is a rapid cycling proton and heavy ion synchrotron. The beam pipe has an average radius of 7 cm and the Booster's circumference is $C = 202$ m with betatron tunes ≈ 4.8. When accelerating gold the pressure of the backround gas is $P \approx 2 \times 10^{-11}$ Torr. The injection momentum of the ions is 9 GeV/c and the extraction momentum of 70 GeV/c was reached in 0.55 s for Au(15+) and 0.10 s for Au(32+) . A strongly intensity dependent loss in the Au(15+) beam has been reported previously[1]. In this note we report a qualitatively similar behavior for the Au(32+) .

Machine studies with Au(15+) were conducted in September 1994 and with Au(32+) in January 1997. In both cases the Booster magnet cycle was modified to include porches of constant field, so that data could be collected at a fixed beam energy. The data consisted of digitized current transformer traces taken under various conditions. During the magnetic porch the number of ions in the ring as a function of time $N(t)$ was fitted by an exponential $N(t) \approx N_0 \exp(-\alpha t)$ where α is the inverse life time or loss rate. For some of the data there was clear evidence that the losses were not a simple exponential, but without a theory we had no reasonable parameterization.

2 REVIEW OF Au(15+) DATA AND Au(32+) DATA

Figure 1 shows the equilibrium loss rate as a function of the number of injected Au(15+) ions.

The low intensity loss rates $\approx 0.1 s^{-1}$ are roughly consistent with scattering off residual gas at a pressure of 2×10^{-11} Torr. The lack of a coherent signal, and the insensitivity of the loss rate to the presence of rf suggests that the intensity dependent loss rates are due to the beam creating targets with which it subsequently scatters. This hypotheses is also consistent with the observation that the instantaneous loss rate depends on the intensity earlier in the cycle and on previous cycles.

The dependence of the loss rate on machine history was observed in two ways. In equilibrium, where the same
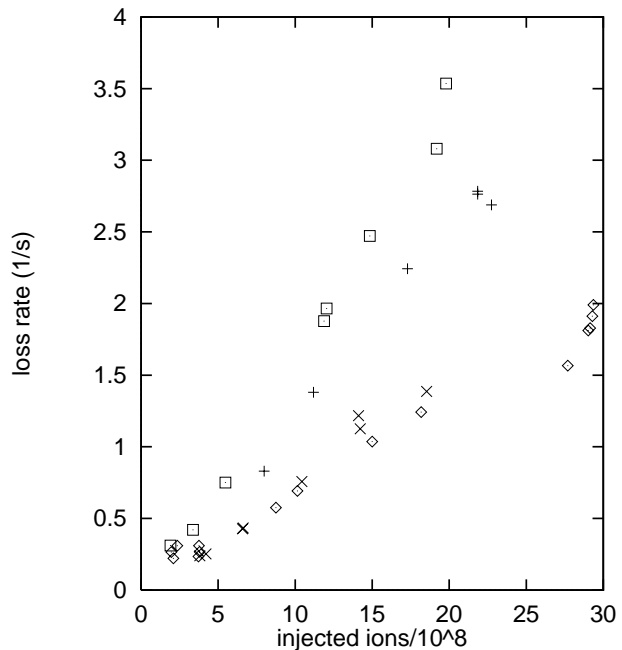
Figure 1: Au(15+) loss rate versus number of injected ions for momenta of: 9 GeV/c (diamonds), 15 Gev/c (crosses), 30GeV/c (squares), and 60 GeV/c (Xs)

number of Au(15+) ions were injected every cycle, the average loss rates are as shown in Figure 1. What is not obvious from the figure is that the number of ions at the end of the Booster cycle was not monotonic with the number of injected ions. For example, with a momentum of $p = 30$ GeV/c with 2×10^9 ions injected there were 1×10^7 ions remaining after 1.5s, while for 1×10^9 ions injected there were 2×10^8 ions remaining after 1.5s.

The history dependence of the loss rates was observed when the beam was turned off for several cycles and the machine was allowed to "cool". The loss rate for the first cycle after cooling was $\approx 50\%$ smaller than the equilibrium value, and loss rates on subsequent cycles monotonically approached the equilibrium value.

Taken together these observations provide compelling evidence that the Au(15+) beam influences the background gas. We also note that the background gas is affected before a significant fraction of the beam is lost, since enhanced loss rates are apparent very early in the cycle.

Figure 2 shows the equilibrium loss rate as a function of the number of injected Au(32+) ions. A clear trend in the Au(32+) loss rate with intensity is apparent. The Au(32+) data were not as good as the Au(15+) data because of intensity limitations and generally smaller loss rates. At-

tempts to measure memory affects and variations in the loss rate during a given Booster cycle were inconclusive. On the other hand, we see no reason to believe a qualitatively different loss mechanism for the two cases.
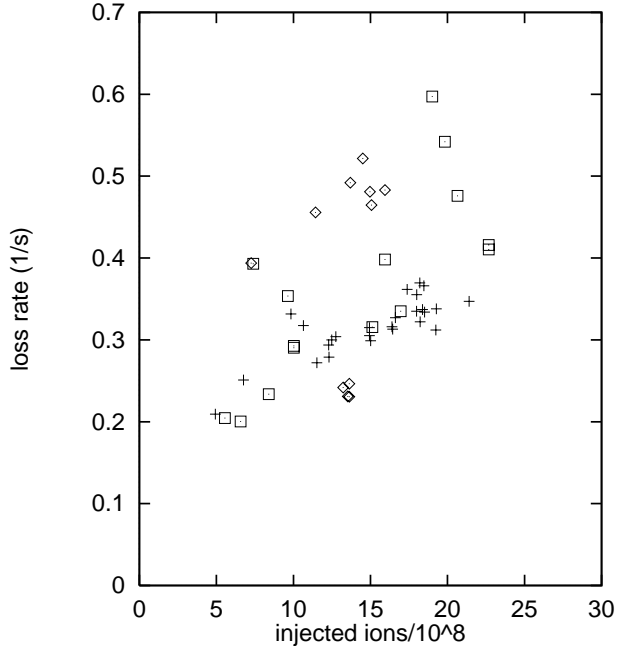
Figure 2: Au(32+) loss rate versus number of injected ions for momenta of: 20 GeV/c (diamonds), 27 Gev/c (crosses), 40 GeV/c (squares)

3 DISCUSSION

Straight lines were fit to the loss rates in Figures 1 and 2, yielding the change in loss rate with the number of injected ions as a function of momentum. These derivatives are shown in Figure 3. For scattering off residual gas the loss rate is given by

$$\alpha = \sum_j v n_j \sigma_j(v)$$

where v is the beam velocity and n_j and $\sigma_j(v)$ are the density and total charge changing cross section for scatterers of the jth type. Only n_j would vary with beam intensity. Assume that any scatterers are uniformly distributed within the vacuum chamber and that only one species is responsible for the change in loss rate with intensity. Then the change in the number of scatterers N_s with the number of injected ions N_b is given by

$$\frac{dN_s}{dN_b} = \frac{V_r}{\sigma v} \frac{d\alpha}{dN_b}$$

where $V_r = 3.1m^3$ is the total vacuum volume in the ring. Set $\sigma = \sigma_{16} 10^{-16} cm^2$, $p = p_9 GeV/c$, and $d\alpha/dN_b = \alpha' 10^{-8} s^{-1}$. The beams are non-relativistic so $dN_s/dN_b = 1.9 \times 10^6 \alpha'/(p_9 \sigma_{16})$, and for Au(15+) at $p = 30$ GeV/c, $dN_s/dN_b = 1 \times 10^4/\sigma_{16}$. For Au(32+) at $p = 20$ GeV/c,

$dN_s/dN_b = 7 \times 10^3/\sigma_{16}$. For $\sigma_{16} = 10$ there are several hundred scatterers generated by each Au(15+) ion.
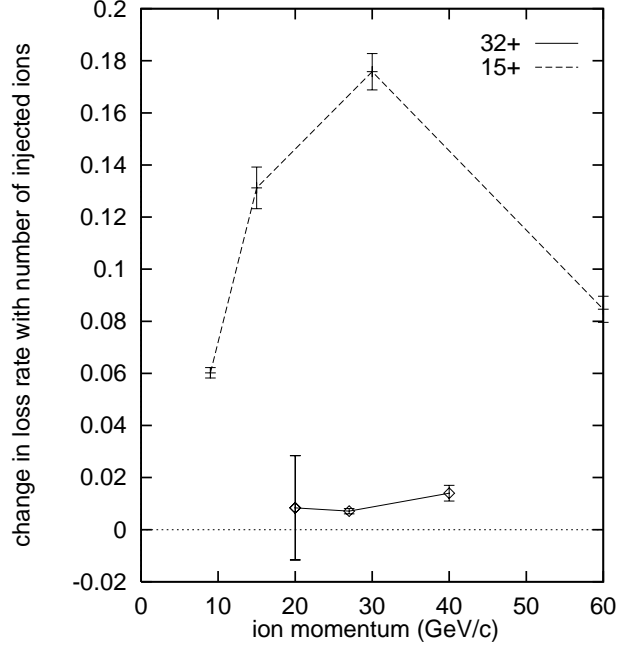
Figure 3: change in loss rate with the number of injected ions, $d\alpha/dN_b$ ($s^{-1}10^{-8}$) versus ion momentum, p (GeV/c). The error bars are one standard deviation.

For a beam velocity $v = 0.15c$, a gas pressure of $P = 2\times10^{-11}$Torr, and a low intensity loss rate of $\alpha = 0.25s^{-1}$ the data predict a loss cross section of $\sigma_\ell = 0.87\text{Å}^2$. This is a rather large cross section and to model the intensity dependent losses even larger cross sections appear necessary.

To model the losses, assume that hydrogen (H_2) is the main vacuum component at low beam intensity. After the beam is injected it interacts with the hydrogen via a total cross section σ_t^H which can result in charge exchange σ_ℓ^H or just momentum transfer. When the hydrogen molecule hits the wall, with an energy large compared to kT, it desorbs M molecules of type A. Molecules of type A remain in the beam pipe for a time τ_A before sticking on the wall. Since no significant rise in pressure is noted, assume that the amount of hydrogen is essentially constant. Then,

$$\frac{dN_b}{dt} = -\frac{vN_b}{V_r}\left(\sigma_\ell^A N_A + \sigma_\ell^H N_H\right), \qquad (1)$$

$$\frac{dN_A}{dt} = +\frac{MN_b v}{V_r}\left(N_H \sigma_t^H + N_A \sigma_t^A\right) - \frac{N_A}{\tau_A}. \qquad (2)$$

In equation (1) N_b is the number of gold ions in the beam, N_A is the number of molecules of type A, N_H is the number of molecules of H_2 and σ_ℓ^H and σ_ℓ^A are the charge exchange cross sections for H_2 and molecules of type A, respectively. It is assumed that molecules of both types are distributed uniformly throughout the entire volume of the vacuum chamber V_r. In equation (2) there are M molecules of type A liberated by each molecule that is

scattered by the beam, and σ_t^A is the cross section for momentum transfer between the beam ions and molecules of type A. These equations were numerically integrated using a 4s repetition period with beam present for 2s each cycle, as was done during the Au(15+) study. The calculation was continued until a nearly periodic solution was obtained and average loss rates were calculated.

If we assume that the molecule in question is CO and that the stripping cross sections vary as the square of the target atomic numbers[3] then $\sigma_\ell^A \approx 50\text{Å}^2$. Assume that two CO molecules are liberated per energetic molecular impact and that the CO lifetime is $\tau_A = 20$ s. Additionally, assume that the total cross sections for momentum transfer are ten times the cross sections for charge transfer; $\sigma_t^H = 10\text{Å}^2$ and $\sigma_t^A = 500\text{Å}^2$. With these assumptions the modeled Au(15+) loss rates as a function of the injected number of ions are shown in Figure 4. The loss rate is monotonic in the cross sections and significantly smaller cross sections did not accurately model the Au(15+) data.
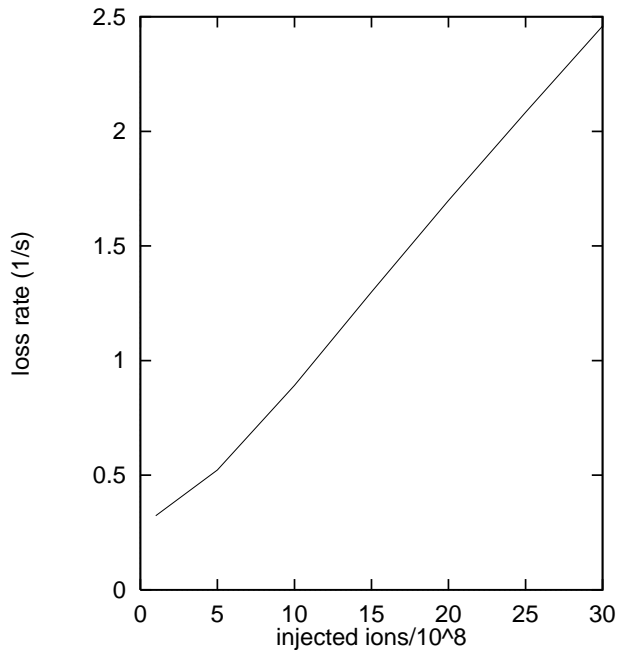

Figure 4: Modeled Au(15+) loss rate s^{-1} versus number of injected ions.

The change in gas composition with beam intensity should be measurable using mass spectroscopy. Such a measurement will provide additional constraints on any model. Since the Au(32+) Coulomb field is significantly greater than the field of Au(15+) we expect any change in backround gas composition to be present when accelerating significant amounts of Au(32+) . Hence, this model can be tested without returning to Au(15+) running.

For the Au(32+) data significantly smaller values of σ_ℓ^A are indicated. On the other hand, if the far field Coulomb force is responsible for the momentum transfer cross section σ_t^A, then σ_t^A should be larger for Au(32+) than for Au(15+) . If this is the case the charge exchange cross

sections for Au(15+) are much greater than simple scaling laws would indicate.

5   REFERENCES

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