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Estimation of Intrabeam Scattering Effects for RHIC*

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Abstract

The effects of intrabeam scattering on the beam dimensions and energy spread of a 100 GeV/amu gold beam are estimated. After 10 hours, growth of the transverse emittance is about a factor of three, with a similar growth in momentum spread. These findings are in agreement with earlier results of Parzen. Sensitivity of the results to the initial beam conditions is explored. In addition, calculations have been carried out for the case of a high frequency (214 MHz) RF system. In this case the growth is more severe, giving a fivefold increase in transverse emittance. To ensure that the momentum spread after 10 hours does not exceed the RF momentum acceptance, a voltage in excess of 32 MV would be needed.

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INTRODUCTION

The performance of the Relativistic Heavy Ion Collider (RHIC), proposed[1] for construction at Brookhaven National Laboratory, is known[2] to be influenced heavily by the effects of intrabeam scattering (IBS). Because of its importance, it is worthwhile to independently estimate the IBS effects. In this paper we present results based upon a slightly modified version of the LBL accelerator physics code ZAP.[3]

Several different calculations have been performed. First, we investigated the growth under the nominal beam and RF parameter assumptions contained in Ref. 1. Next, we looked at the sensitivity of our results to variations in the starting assumptions. Finally, we briefly explored the ramifications of a change in frequency of the RF system from 26.7 MHz to 214 MHz, thus leading to significantly shorter initial bunch lengths.

Before discussing our results, we first describe the modifications to ZAP required to perform the calculations.

MODIFICATIONS TO ZAP

The code ZAP[3] was initially written to calculate IBS growth rates for either electron, proton, or heavy ion beams, using the formalism derived by Bjorken and Mtingwa.[4] Thus, no major modifications were required to perform the calculations reported here. However, the code was designed to give the growth rates for particular (input) values of the transverse and longitudinal beam emittance. To follow the evolution in time of the beam parameters, it is necessary to integrate numerically the differential equation being solved by the code.

In practice, this is accomplished by taking small time steps and re-evaluating the growth rates in all three planes. The instantaneous growth rate calculated by ZAP is

$$g(\varepsilon) = \frac{1}{\varepsilon}\frac{d\varepsilon}{dt}$$

where ε is the emittance (horizontal, vertical, or longitudinal) and g is the corresponding growth rate, averaged over the lattice, for the specified beam parameters. To ensure that the time steps selected are not too large, we choose increments that are constant in units of emittance growth, rather than time, i.e.,

$$\Delta t = \frac{1}{g(\varepsilon)}\frac{\Delta\varepsilon}{\varepsilon} .$$

By limiting $\Delta\varepsilon/\varepsilon$ to about 1%, we keep the change in $g(\varepsilon)$ small, independently of the magnitude of the growth rate itself. At each step, the new emittance value

$$\varepsilon_1 = \varepsilon_0\left(1 + \frac{\Delta\varepsilon}{\varepsilon}\right)$$

is used to re-evaluate the three growth rates and, thus, the next time step. With this small modification, ZAP was used to evaluate the performance of RHIC.

NOMINAL BEAM PARAMETERS

In the first set of calculations, we consider the parameters taken for the RHIC proposal.[1] A fully stripped Au beam at an energy of 100 GeV/amu is studied, starting from a normalized 95% emittance (in both planes) of 10π mm-mrad and longitudinal parameters of $\sigma_\ell = 0.48$ m and $\sigma_p = (\delta p/p)_{rms} = 3.6 \times 10^{-4}$. The longitudinal values correspond to RF parameters of $f_{RF} = 26.7$ MHz and $V_{RF} = 1.2$ MV. A beam intensity of $N_b = 1.1 \times 10^9$ ions/bunch is assumed. These parameters are referred to as Case A in Table 1.

To look at the dependence of the predicted growth on the assumed starting emittance value, the above calculation was repeated starting from normalized emittance values of both 5π mm-mrad and 20π mm-mrad. These results are denoted Cases B and C, respectively. The time evolution of the transverse emittance is shown for Cases A, B, and C in Fig. 1. Longitudinal growth is shown in Fig. 2.

As can be seen in Figs. 1 and 2, there is some dependence upon the initial transverse emittance, but it is relatively modest. To see how the results change quantitatively, we have summarized the calculated values at t=0, 2 and 10 hours in Table 2. If we define the lifetime of the beam to correspond to the time at which the momentum spread becomes equal to the RF bucket height, then the Case B lifetime would be about 7.5 hours, compared with 10 hours for the nominal parameters (Case A). The final transverse emittances for the three scenarios differ by only about 10-20%.

HIGH-FREQUENCY RF SYSTEM

To achieve a smaller interaction diamond length for the colliding Au beams, it was suggested at the workshop that a high-frequency RF system might be worth considering for use in RHIC. For the purposes of the workshop, it was agreed that a 214 MHz system (corresponding to h = 2736, i.e., 8 times the harmonic number of the "standard" 26.7 MHz system) would serve as a good example case.

Compared with the standard RF scenario, the high-frequency RF system produces bunch lengths shorter by a factor of three to four, but with a momentum spread increase of the same amount. The various parameters for the two cases studied, corresponding to RF voltages of 15 MV (Case D) and 32 MV (Case E), respectively, are summarized in Table 1.

For ease of comparison with the earlier calculations, we have again assumed an intensity of

1.1×10^9 particles per bunch. It is recognized, of course, that the higher frequency RF system would permit a reoptimization of the bunch structure (in the sense of permitting trade-offs between the number of bunches and the current per bunch to achieve the same luminosity). However, such alternative scenarios have not yet been explored.

Due to the higher initial bunch density, the growth in emittance (see Table 3) is considerably greater than was true for the low frequency cases. Indeed, as shown in Fig. 3, the growth in normalized emittance after 10 hours is more than a factor of five. The growth in longitudinal emittance is also severe (see Fig. 4). For Case D, with V_{RF} = 15 MV, the beam momentum spread reaches the RF bucket acceptance in only one hour. At a voltage of 32 MV, the bucket limit is reached after about 8 hours. Thus, a very high RF voltage would be required to give lifetimes comparable to those for the 26.7-MHz system.

Although producing more than 30 MV of RF voltage is straightforward, it does require a large amount of hardware in the ring and may lead to a large contribution to the ring impedance. Coupled-bunch instabilities are a potential problem with such a scenario, although higher-order mode dampers can be employed—in principle—to mitigate this difficulty. Estimates of coupled-bunch growth rates appear elsewhere in these proceedings.[5]

SUMMARY

In this note we have calculated the growth in longitudinal and transverse emittance for a beam of 100 GeV/amu Au ions. For the nominal operating parameters, we find a transverse emittance growth of about a factor of three, in good agreement with the calculations of Parzen.[2]

The sensitivity toward changes in the initially assumed emittance of 10 π mm-mrad has also been studied. After 10 hours, the final beam parameters are within about ±20% of each other for initial emittance values that vary from the nominal case by a factor of 2. If a higher frequency RF system were selected, the growth (for the same bunch current) would be more severe, about a factor of five. To achieve a 10-hour lifetime in this case would require a voltage in excess of 32 MV.

Alternative scenarios for reaching the required luminosity whereby more RF buckets were filled, with fewer particles per bunch, have not yet been explored. Such an approach would clearly mitigate the increased growth found here for the high-frequency case.

REFERENCES

1) *Conceptual Design of the Relativistic Heavy Ion Collider RHIC*, Brookhaven National Laboratory Report No. BNL-51932, May, 1986.

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3) M.S. Zisman, S. Chattopadhyay, and J. Bisognano, *ZAP User's Manual*, Lawrence Berkeley Laboratory Report No. LBL-21270, December, 1986.

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Table 1

Input Parameters for ZAP IBS Calculations[a)]

Case	f_{RF} (MHz)	V_{RF} (MV)	ε_n (π mm-mrad)	σ_ℓ (cm)	σ_p (10^{-3})
A	26.7	1.2	10	47.7	0.36
B	26.7	1.2	5	47.7	0.36
C	26.7	1.2	20	47.7	0.36
D	213.9	15.0	10	15.1	1.04
E	213.9	32.0	10	12.5	1.26

[a)] Au ions; 100 GeV/amu; $N_b = 1.1 \times 10^9$/bunch; full emittance coupling assumed.

Table 2
Results of ZAP IBS Calculations[a)]

		Case A	Case B	Case C
ε_n (π mm-mrad)				
t = 0	hr	10	5	20
t = 2	hr	16.3	13.2	24.4
t = 10	hr	29.9	26.9	36.2
σ_p (10^{-3})				
t = 0	hr	0.36	0.36	0.36
t = 2	hr	0.63	0.69	0.56
t = 10	hr	0.99	1.03	0.90
σ_ℓ (cm)				
t = 0	hr	47.7	47.7	47.7
t = 2	hr	83.6	91.6	74.6
t = 10	hr	130.9	136.4	120.2

a) Au ions; 100 GeV/amu; N_b = 1.1 x 10^9/bunch; full emittance coupling assumed. Input parameters are summarized in Table 1.

Table 3

Results of ZAP IBS Calculations[a)]

		Case D	Case E
ε_n (π mm-mrad)			
t = 0	hr	10	10
t = 2	hr	28.0	29.7
t = 10	hr	50.7	54.9
σ_p (10^{-3})			
t = 0	hr	1.04	1.26
t = 2	hr	1.35	1.55
t = 10	hr	1.67	1.85
σ_ℓ (cm)			
t = 0	hr	15.1	12.5
t = 2	hr	19.6	15.3
t = 10	hr	24.2	18.4

a) Au ions; 100 GeV/amu; $N_b = 1.1 \times 10^9$/bunch; full emittance coupling assumed. Input parameters are summarized in Table 1.

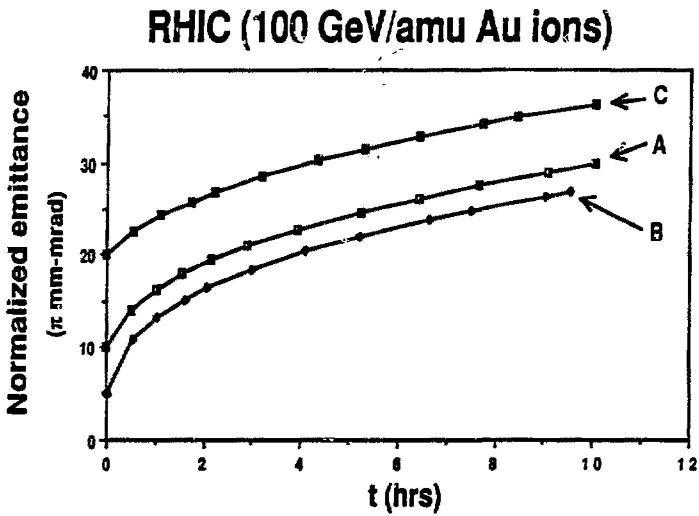

Fig. 1 IBS growth of normalized emittance for a 100 GeV/amu Au beam for various initial emittance values; full emittance coupling is assumed. Parameter values for the three cases are given in Table 1.

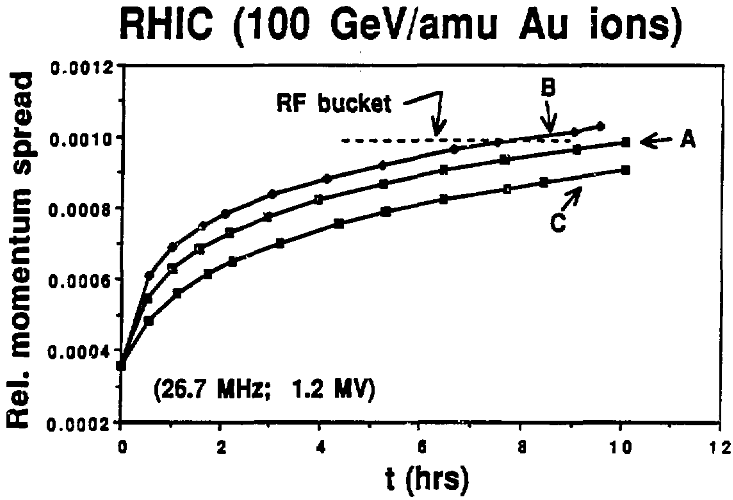

Fig. 2 IBS growth of relative momentum spread for a 100 GeV/amu Au beam for various initial emittance values. Parameter values for the three cases are given in Table 1. The dashed line represents the RF bucket height.

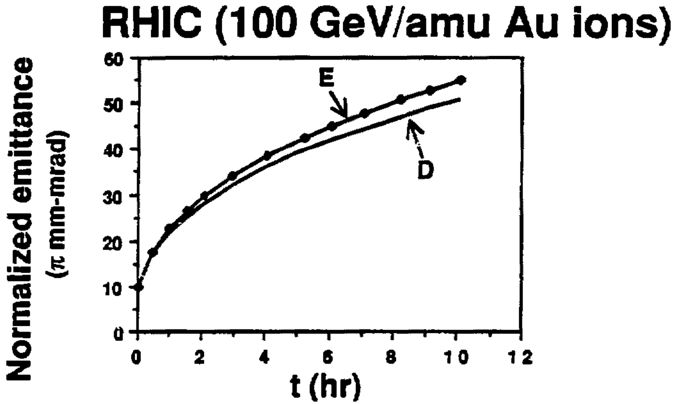

Fig. 3 IBS growth of normalized emittance for a 100 GeV/amu Au beam for two RF voltage values; full emittance coupling is assumed. Parameter values are given in Table 1.

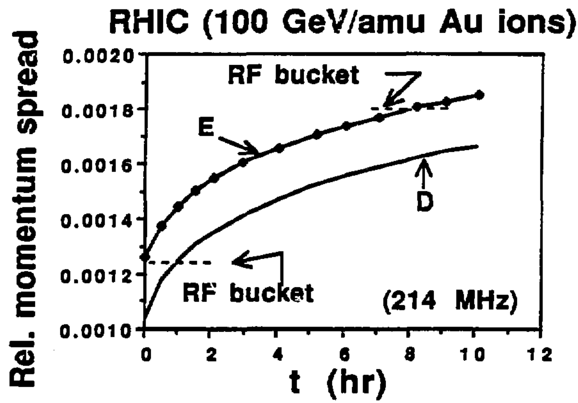

Fig. 4 IBS growth of relative momentum spread for a 100 GeV/amu Au beam for two RF voltage values. Parameter values for the three cases are given in Table 1. The lower dashed line represents the RF bucket height for Case D; the bucket height for Case E is represented by the upper dashed line.