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RHIC PROJECT
Brookhaven National Laboratory

**Intrabeam Scattering and RHIC Performance
at Low Energies**

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1. Introduction

The performance of RHIC gets worse at low γ , $\gamma \simeq 7$ to $\gamma \simeq 12$ for several reasons. The transverse growth due to intrabeam scattering becomes stronger at low γ . Also the RF bucket becomes smaller at low γ and may be too small to contain the beam. For gold ions at $\gamma = 7$ using the 160 MHz RF system, the transverse aperture limit is reached at $t = 7$ minutes due to intrabeam scattering, and the RF bucket height is at the start only $1.3 \sigma_p$, where σ_p is the rms beam energy spread. Nevertheless, some operation at lower γ may still be possible. This may require using the 25 MHz RF system which gives a larger bunch length $\sigma_\ell \simeq 1$ to 2 meters. There may also be large beam losses due to the small RF bucket size.

The possible performance of RHIC at low γ , as determined by the effect of intrabeam scattering and the RF bucket size, may be summarized as follows:

$\gamma = 12$ Operation

One can operate with either the $f = 26.7$ MHz or the $f = 160$ MHz RF. At $f = 26.7$ MHz, the beam of Au ions can survive 10 hours with about a 15% beam loss. However, the σ_ℓ is large and will grow from $\sigma_\ell = 80$ cm to $\sigma_\ell = 180$ cm. With $f = 160$ MHz, operation for 2.8 hours is possible with about a 35% beam loss. σ_ℓ will grow from 29 cm to about 32 cm.

$\gamma = 7$ Operation

Operation with $f = 160$ MHz may not be possible. The transverse aperture limit is reached in $t = 0.12$ hours and the RF bucket is small with a bucket height that is only 1.3

σ_p at $t = 0$. With $f = 26.7$ MHz, operation for about 1.5 hours appears possible with a beam loss of about 30%. The σ_ℓ will grow from 129 cm to 210 cm.

Other effects that may limit the performance at lower γ include the larger ν spread in the beam due to the larger beam size, and the ν -spread due to space charge forces. The space charge ν -spread gets particularly large, about $\Delta\nu \simeq 0.05$ at $\gamma = 12$ for $f = 26.7$ MHz at $t = 0$, and may be a problem.

2. Computed Results

The effects of intrabeam scattering are more difficult to compute at low γ because of possible beam losses at the transverse aperture limit, and the RF bucket limit. The transverse aperture limit was taken to be at $\epsilon_t = 6$ mm mrad (J. Claus¹). The calculation was done as follows: The beam growth was first computed using the intrabeam scattering program (G. Parzen) based on the intrabeam scattering theory for no aperture limit (Piwinski, Sacherer and Martini²). This result was used to determine the transverse growth, and when the transverse aperture limit is reached. The longitudinal growth and beam losses in the presence of the RF bucket limit were then computed using the results found previously for the transverse growth and using the beam growth program for the longitudinal growth in the presence of the RF bucket limit (Wei and Ruggiero³). This program also gives the beam losses due to longitudinal growth and the RF bucket limit.

The transverse losses are held to a low level by limiting the useful lifetime of the beam to that time when the edge of the beam reaches the transverse aperture limit, $\epsilon_t = 6$ mm mrad. One may note that in computing the useful lifetime of the beam, we have given up the 6σ aperture requirement and its implied safety factor. The useful lifetime due to transverse growth is determined by when the 95% total emittance of the beam just reaches the transverse aperture limit. This corresponds to when $3.2 \sigma_x$ reaches the horizontal aperture limit when $y = y' = 0$.

The transverse growth at low γ , $\gamma < \gamma_t$ when γ_t is the transition energy γ , behaves quite differently than the growth at high γ , $\gamma > \gamma_t$. At low γ , there is little longitudinal growth in RHIC, while the transverse beam size grows rapidly in both the horizontal and

vertical directions. The final σ_x levels off according to the rough empirical rule

$$\sigma_x \longrightarrow \left(\frac{\gamma_t}{\gamma} \right) \sigma_E,$$

where $\sigma_E = X_p \sigma_p$, and where σ_x and σ_E are measured at a QF in a normal cell.

The computed results for Au ions at $\gamma = 7$ and $\gamma = 12$ and for 25 MHz and 160 MHz RF systems are summarized in Table 1. The beam lifetime is determined by when the transverse growth causes the transverse beam size to reach the transverse aperture limit. The beam losses are due to beam loss from the RF bucket. Δ_B is the height of the RF bucket, $\Delta E/E$. L_{av}/L_o is the ratio of the average luminosity to the initial luminosity due to transverse growth of the beam. For $f = 26.7$ MHz, $V = 0.4$ MV, $h = 342$ and for $f = 160$ MHz $V = 4.5$ MV, $h = 2052$.

Table 1: A summary of the computed results for RHIC performance at $\gamma = 12$ and $\gamma = 7$, as limited by beam growth due to intrabeam scattering and by beam losses from the RF bucket.

γ	12	12	7	7
RF Frequency (MHz)	160	26.7	160	26.7
Beam Lifetime (h)	2.8	10	0.12	1.5
Beam Losses (%)	35	15	large	30
Δ_B/σ_p at $t = 0$	2.1	4.3	1.3	2.8
L_{av}/L_o	0.6	0.5	–	0.6
σ_ℓ (cm)	30	80→180	–	129→170

References

1. J. Claus, private communication.
2. A. Piwinski, Proc. 9th Int. Conf. on High Energy Accelerators (1974), p. 405.
M. Martini, CERN PS/84-9 (AA) 1984.
3. J. Wei and A.G. Ruggiero, AD/RHIC-81 (1990).