## Collider Accelerator Department

## Brookhaven National Laboratory

## U.S. Department of Energy <br> USDOE Office of Science (SC)

[^0]
## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

```
            High Energy Facilities
                                    RHIC-9
            Advanced Projects
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
            Upton, New York 11973
RHIC Technical Note No. 9
```


# Intrabeam Scattering for a Proton Beam in RHIC 

## G. Parzen

January 21, 1985

The effects of intrabeam scattering have been computed for a proton beam in RHIC. The growth of the beam due to intra beam scattering leads to aperture requirements.

At $\gamma=30$, the required aperture is $\pm 22 \mathrm{~mm}$, for 10 hr . operation and for $1 \times 10^{11}$ protons/bunch. An additional $\pm 5 \mathrm{~mm}$ is required for orbit effects, which are regarded as correctable. This orbit effects include

1) random variations in the $\beta$-function caused by magnet field errors.
2) random variations in the horizontal dispersion
3) chromatic effects (momentum dependent variations) in the $\beta$-function and the horizontal dispersion.

At $\gamma=250$, the required aperture is $\pm 8 \mathrm{~mm}$. An additional $\pm 1 \mathrm{~mm}$ is needed for correctable orbit effects. At $\gamma=320$, the required aperture is $\pm 7 \mathrm{~mm}$, and an additional $\pm 1 \mathrm{~mm}$ is needed for correctable orbit effects. These results are for 10 hr operation and for $1 \times 10^{11}$ protons/bunch.

The intra beam scattering beam growth is weaker for protons than for gold ions, and operation times of the order of 50 hours appear feasible for protons. 50 hour operation requires a few milimeters more of aperture than 10 hour operation.

The beam growth due to intra beam scattering is largely in the energy spread which can increase by a factor of 3 in 10 hours. The transverse size of the beam only changes by about $30 \%$ in the same time.

## Intra beam Scattering Results

In this study, the proton beam is bunched by an RF system whose peak voltage is 1.2 MV , the harmonic number is $\mathrm{h}=6 \times 57=342$, and the initial bunch area is assumed to be $A=.3 \mathrm{ev}-\mathrm{sec}$. The lattice used was the RHIC3 lattice, as proposed by J. Claus, with 6 insertions for colliding beams. The actual lattice was used in the calculations, including the variation of $\beta_{x}$, $\beta_{y}$, and $X_{p}$ around the machine. The initial normalized transverse emittance was assumed to be $\varepsilon_{x}=\varepsilon_{y}=20 \pi \times 10^{-6}$ mr for $95 \%$ of the beam.

From the above data, one can compute the initial dimensions of the beam. The transverse dimensions are described by $\varepsilon_{x}$ and $\varepsilon_{y}$ and by $\sigma_{H}$ and $\sigma_{V}$, $\sigma_{H}=\left(\varepsilon_{x} \beta_{x} / 6 \gamma\right)^{1 / 2}, \sigma_{V}=\left(\varepsilon_{x} \beta_{y} 16 \gamma\right)^{1 / 2}$. The bunch dimensions are described by $\sigma_{\ell}$, the ${ }^{x}$ rms bunch length, and $\delta$, the rms energy spread. The initial value of $\sigma_{\ell}$ and $\delta$ can be computed from $A=.3 \mathrm{ev}-\mathrm{sec}$ and the parameters of the $R F$ system.
$t=10 \mathrm{hr}$ Results (Table I)
Table $I$ lists the initial beam state, $\delta_{0}, \sigma_{\ell, 0}, \varepsilon_{0}$ and the final beam state $\delta, \sigma_{\ell}, \varepsilon$ after $t=10 \mathrm{hrs}$ for various energies from $\gamma=5$ to $\gamma=320$. Also listed are the final rms transverse beam dimensions $\sigma_{E}=X_{p} \delta, \sigma_{H}=\sigma_{V}$, ( $\sigma_{E}$ and $\sigma_{H}$ are given at the focussing quadrupoles in the cells where $X_{p}=1.39 \mathrm{~m}$ and $\left.\beta_{x}=51.4 \mathrm{~m}\right)$, and the $95 \%$ beam half-width $2.5\left(\sigma_{E}+\sigma_{H}\right)$.

The horizontal and vertical betatron oscillations are assumed to be fully coupled, and thus $\sigma_{H}=\sigma_{V}$ throughout the time the beam is growing.

Luminosity results are also listed in Table I. The luminosity decreases with time because of intrabeam scattering. The following luminosity results are listed. $L_{0}$, the initial luminosity for head on collisions, $L_{A V} / L_{0}$, the average luminosity over 10 hours for head on collisions divided by $L_{0}$, $L(\alpha=0)$, the average luminosity for head on collisions, and $L\left(\alpha=2 \times 10^{-3}\right)$, the average luminosity for a 2 mr crossing angle.

## Figures

The following figures show the growth of the proton beam due to intrabeam scattering. Most of the figures show the beam growth for $t=10 \mathrm{hrs}$. and $t=50 \mathrm{hrs}$.

Table 1. Protons
$t=10$

| $\gamma$ | 5 | 12 | 20 | 30 | 50 | 100 | 250 | 320 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Initial Beam |  |  |  |  |  |  |  |  |
| $\delta_{0} / 10^{-3}$ | 1.028 | . 853 | . 875 | . 869 | . 443 | . 247 | . 122 | . 102 |
| $\sigma_{\ell 0}$ (cms) | 102.0 | 50.3 | 29.4 | 19.7 | 23.2 | 20.8 | 16.8 | 15.8 |
| $\varepsilon_{0} / \pi$ (mm.mr) | 20. | 20. | 20. | 20. | 20. | 20. | 20. | 20. |
| $\sigma_{\mathrm{H}}$ (mm) | 5.85 | 3.78 | 2.92 | 2.39 | 1.85 | 1.31 | . 828 | . 731 |
| $\sigma_{E}=X_{p} \delta_{0}$ (mm) | 1.43 | 1.19 | 1.22 | 1.21 | . 616 | . 343 | . 170 | . 142 |

Final Beam
$\mathrm{t}=10 \mathrm{hrs}$.
$\varepsilon / \pi$ (mm.mr)
49.9
$\delta / 10^{-3}$
$\sigma_{Q} \quad(\mathrm{cms})$
$\sigma_{H}(\mathrm{~mm})$
$\sigma_{E}=X_{p} \delta \quad(\mathrm{~mm})$
1.07
$26.5 \quad 24.2$

| 25.0 | 25.0 | 24.8 | 24.75 | 22.6 |
| ---: | ---: | ---: | ---: | ---: |
| 1.30 | .931 | .592 | .359 | .249 |
| 29.5 | 48.7 | 49.8 | 49.4 | 38.7 |
| 2.67 | 2.07 | 1.45 | .920 | .778 |
| 1.81 | 1.29 | .823 | .499 | .346 |

Beam Half-Width
$2.5\left(\sigma_{H}+\sigma_{E}\right)(\mathrm{mm})$
$2.5 \sigma_{V}(\mathrm{~mm})$
26.3
14.7
12.3
$11 . \overrightarrow{0}$
8.25
$5.58 \quad 3.48$
2.75
23.1
$10.9 \quad 8.05 \quad 6.68$
5.18
$3.62 \quad 2.25$
1.94
$\frac{R F}{2.5 \delta / 10^{-3}}$
$(\Delta \mathrm{p} / \mathrm{p}) / 10^{-3}$
Luminosity

| $L_{o} / 10^{31}$ | .0216 | .0518 | .086 | .130 | .216 | .432 | 1.08 | 1.38 |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $L_{A V} / L_{O}$ | .529 | .858 | .900 | .878 | .864 | .880 | .877 | .935 |
| $L_{\mathrm{O}}(\gamma=0) / 10^{31}$ | .0114 | .0444 | .0774 | .114 | .187 | .380 | .947 | 1.29 |
| $L^{\left(\gamma=2 \times 10^{-3}\right) / 10^{31}}$ | - | - | - | .086 | .097 | .142 | .233 | .326 |

## Aperture Needs

| $2.5 \sigma_{\mathrm{E}}+6 \sigma_{\mathrm{H}}(\mathrm{mm})$ | 59.2 | 30.1 | 23.8 | 20.5 | 15.6 | 10.7 | 6.74 | 5.51 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| $6 \sigma_{V}(\mathrm{~mm})$ | 55.5 | 26.1 | 19.3 | 16.0 | 12.4 | 8.7 | 5.52 | 4.67 |



Fig. 1. Beam emittance growth due to intrabeam scattering.


Fig. 2. Beam dimensions versus time at $\gamma=100$.


Fig. 3. Aperture half-width required due to intrabeam scattering.


Fig. 4. Beam bunch height growth due to intrabeam scattering.


Fig. 5. Bunch length growth due to intra beam scattering.


Fig. 6. Average Luminosity vs. $\gamma$.


[^0]:    Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-AC02-76CH00016 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

