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Intra Beam Scattering in RHIC

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Intra Beam Scattering in RHIC

I. Introduction

II. IBS beam growth and beam loss

emittance, intensity, luminosity

III. IBS Scaling laws

emittance growth, below & above transition

beam loss, Fokker - Planck equation

IV. Future

Jie Wei

July 19, 1995

Talk at

"Workshop on Machine Backgrounds at RHIC

I. Introduction

IBS : Intra-beam multiple Coulomb scattering

⇒ main cause of beam growth & loss in RH

* most severe for high charge state ions

  scattering cross section $\sim Z^4/A^2$

* severe for high intensity beam

  $\sim N$ (number of particle per bunch)

* severe for low emittance beam

  $\sim \epsilon_x^{-1} \epsilon_y^{-1} S^{-1}$

* typically slow process

  growth time >> synch. osc. period

* Theoretically approached by many people

  A. Piwinsky (1974)

  J. Bjorken and S. Mtingwa (1983)

  ⋮

* Comparison with experimental study

  within a factor of 2 on growth rate

  (theoretical over-estimate, typical)

II. IBS beam growth and beam loss

Au^{79+} 10^9 per bunch, ~57 bunches

* transverse emittance growth

  ε_N : $10\ \pi$ mm·mr → $40\ \pi$ mm·mr

* longitudinal growth, beam loss

  fill rf bucket in < 1 hour

  then significant beam loss (~40% in 10 h)

* luminosity reduction

  $\beta^* = 2$m : 1.1×10^{27} → 1×10^{26} ($cm^{-2}s^{-1}$)

  $\beta^* = 1$m : 2.2×10^{27} → 2×10^{26} ($cm^{-2}s^{-1}$)

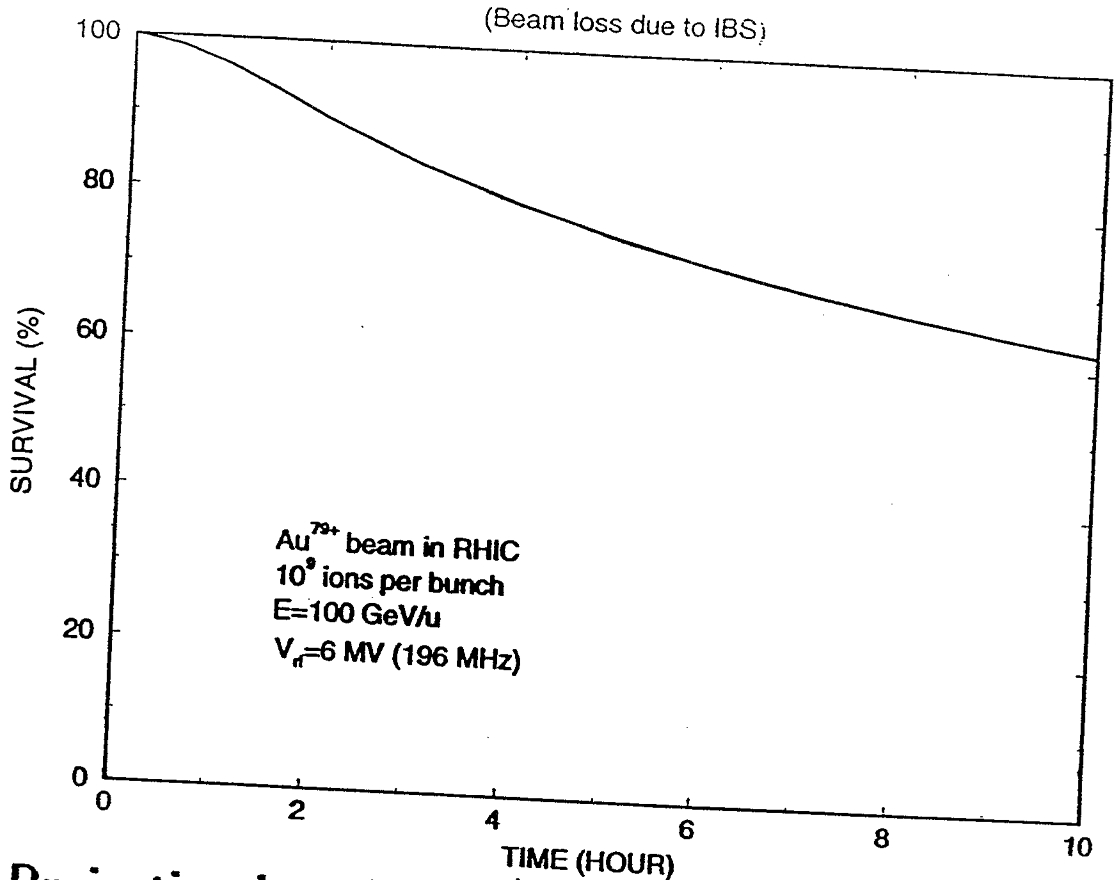
p 10^{11} per bunch, ~57 bunches

* transverse : $20\ \pi$ mm·mr → $30\ \pi$ mm·mr

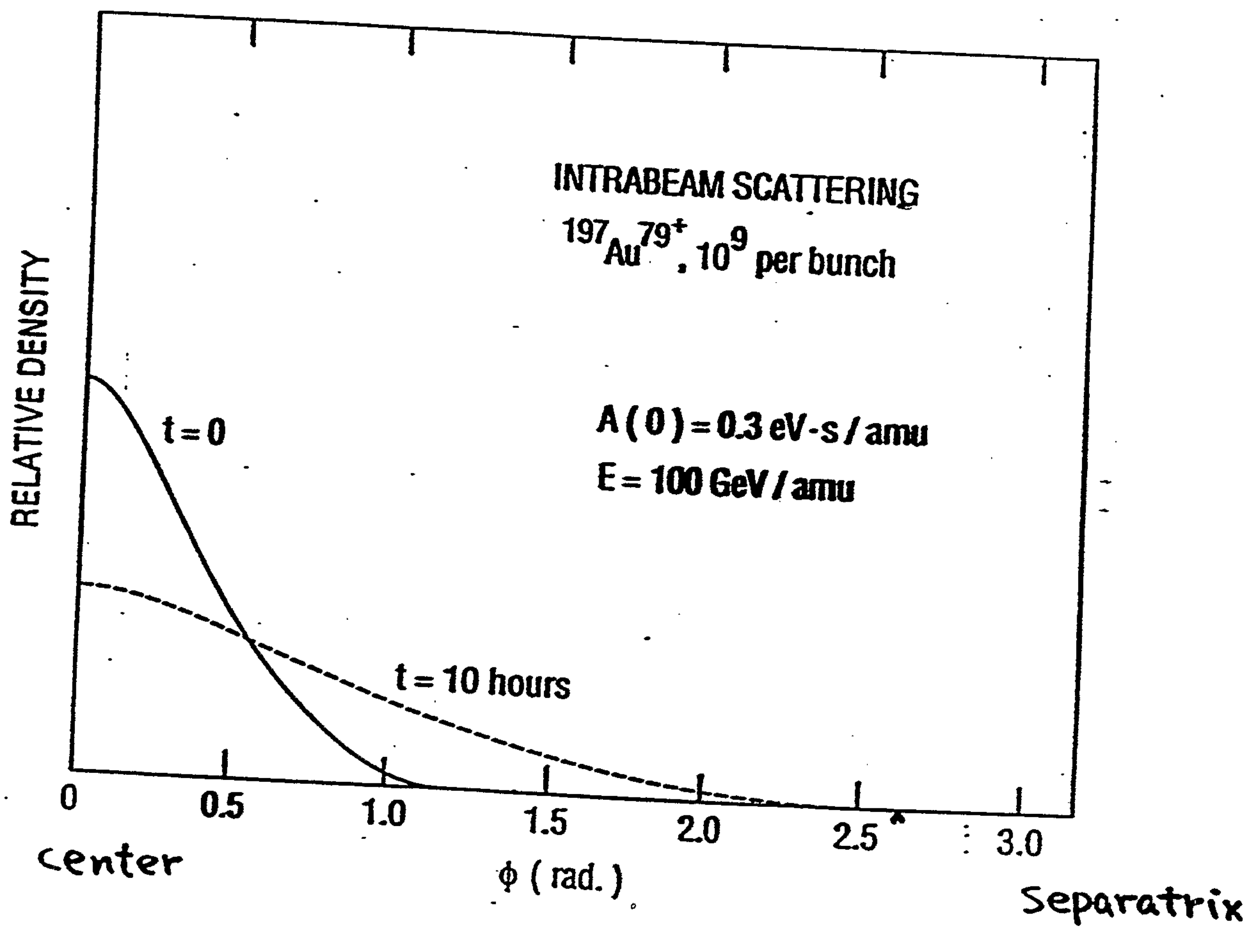
* longitudinal : 0.3 eV·s → 1 eV·s

  (rf bucket area 3.1 eV·s)

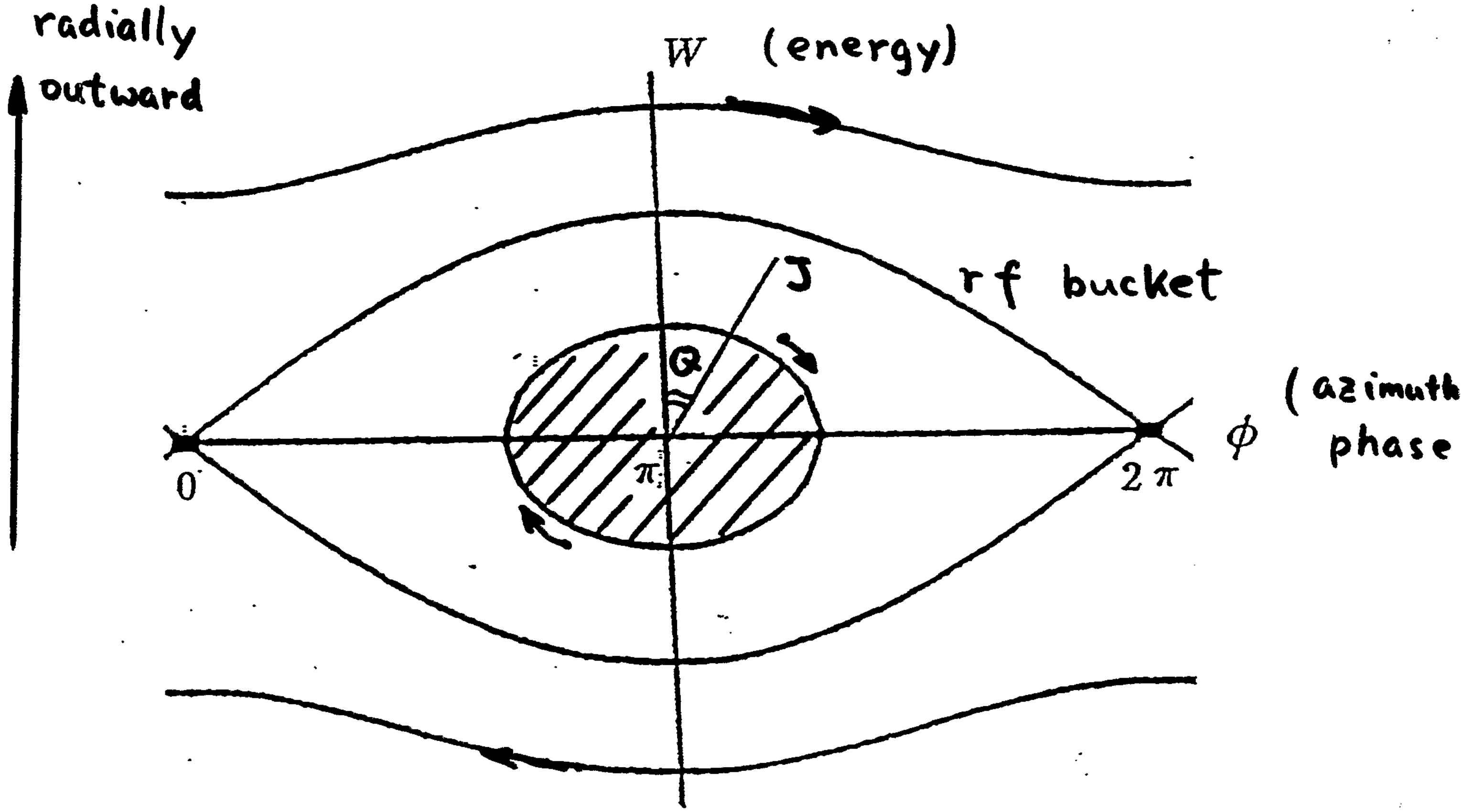
* no beam loss



Projection in azimuthal direction (ϕ):



IBS beam loss



* longitudinal : (mainly)

IBS diffusion

⇒ particles escape out of the bucket

⇒ becomes dc background, beam halo,

or trapped in empty buckets

: transverse : ($\beta^* < 1$ m operation)

particles of large emittance (action) $\epsilon_N \gtrsim 40\pi$ mm·mrad

hit physical aperture

Momentum aperture:

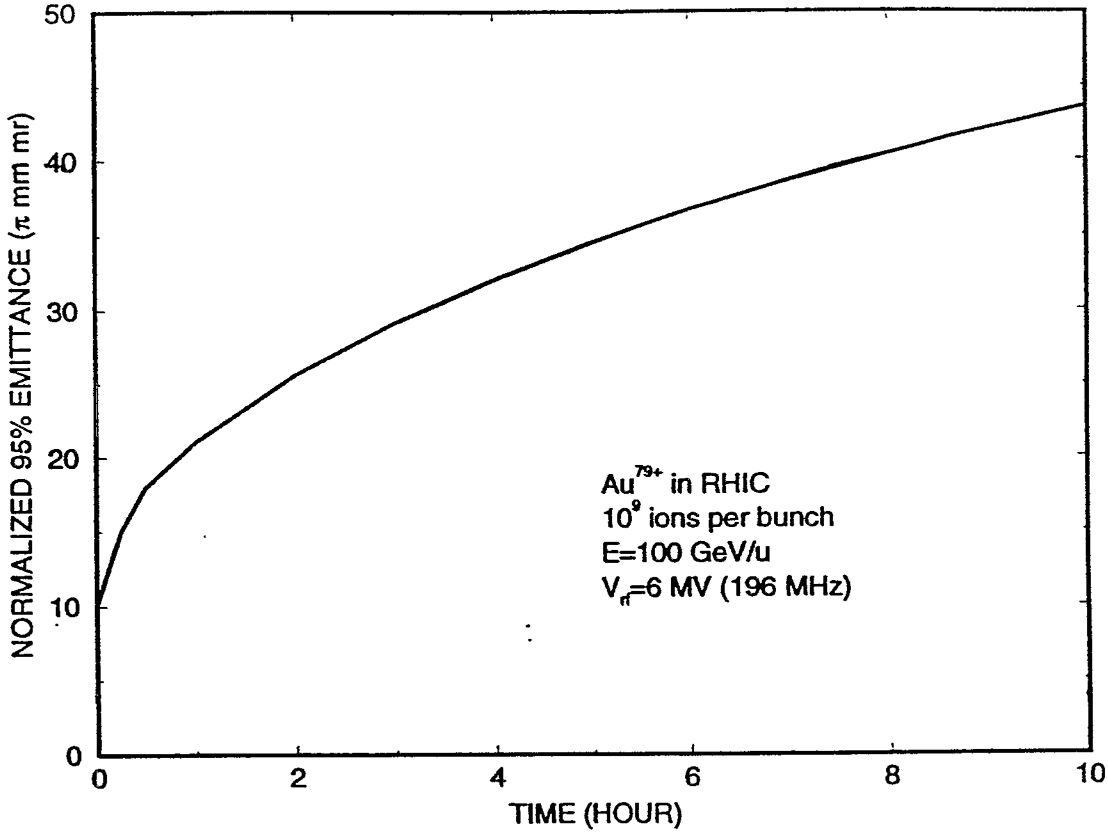
depends on β^* in operation

$\beta^* = 1$ m,

$\frac{\Delta p}{p}$	Dynamic Aperture	
0	5.5 σ	o.k.
0.002 (95%)	4.5 σ	marginal

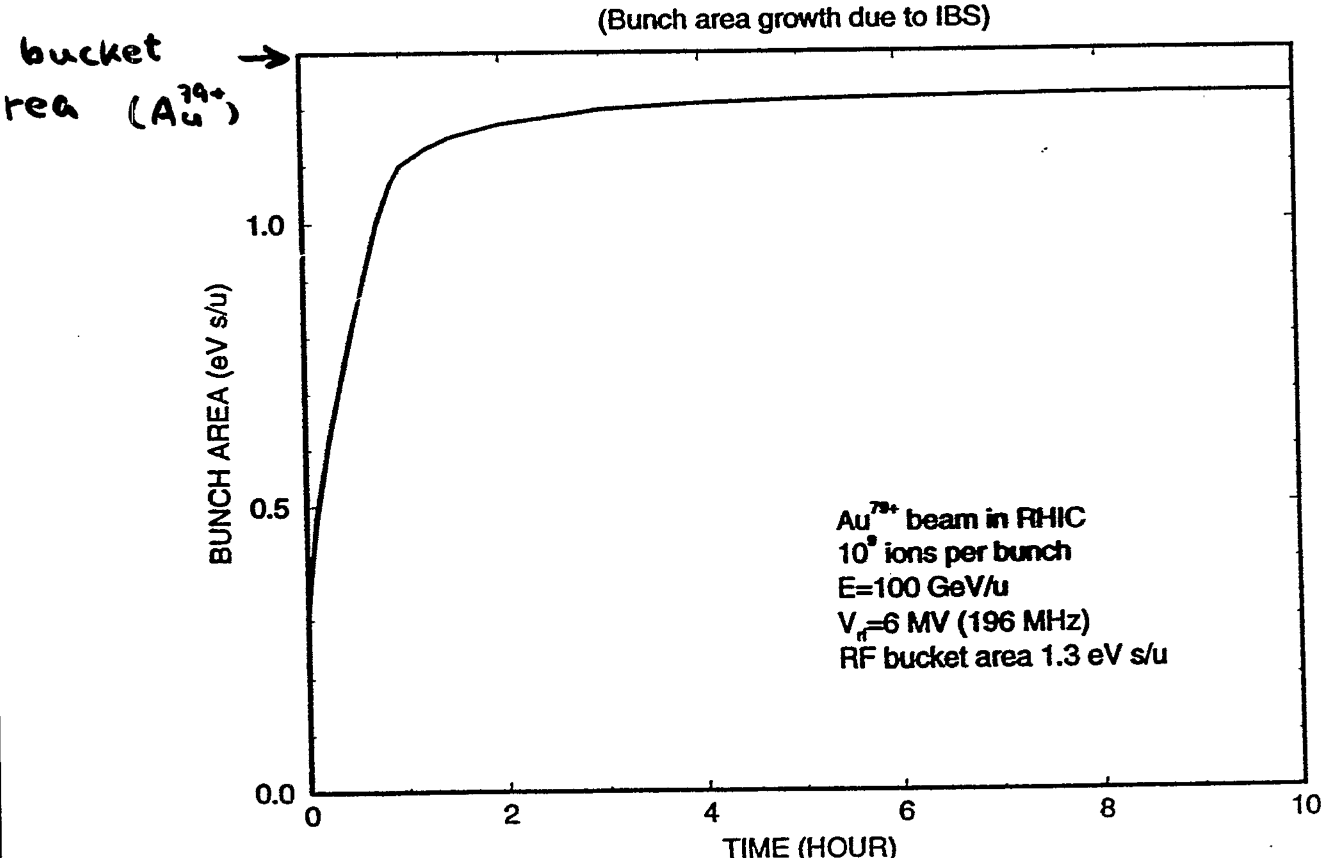
EMITTANCE

(Emittance growth due to IBS)



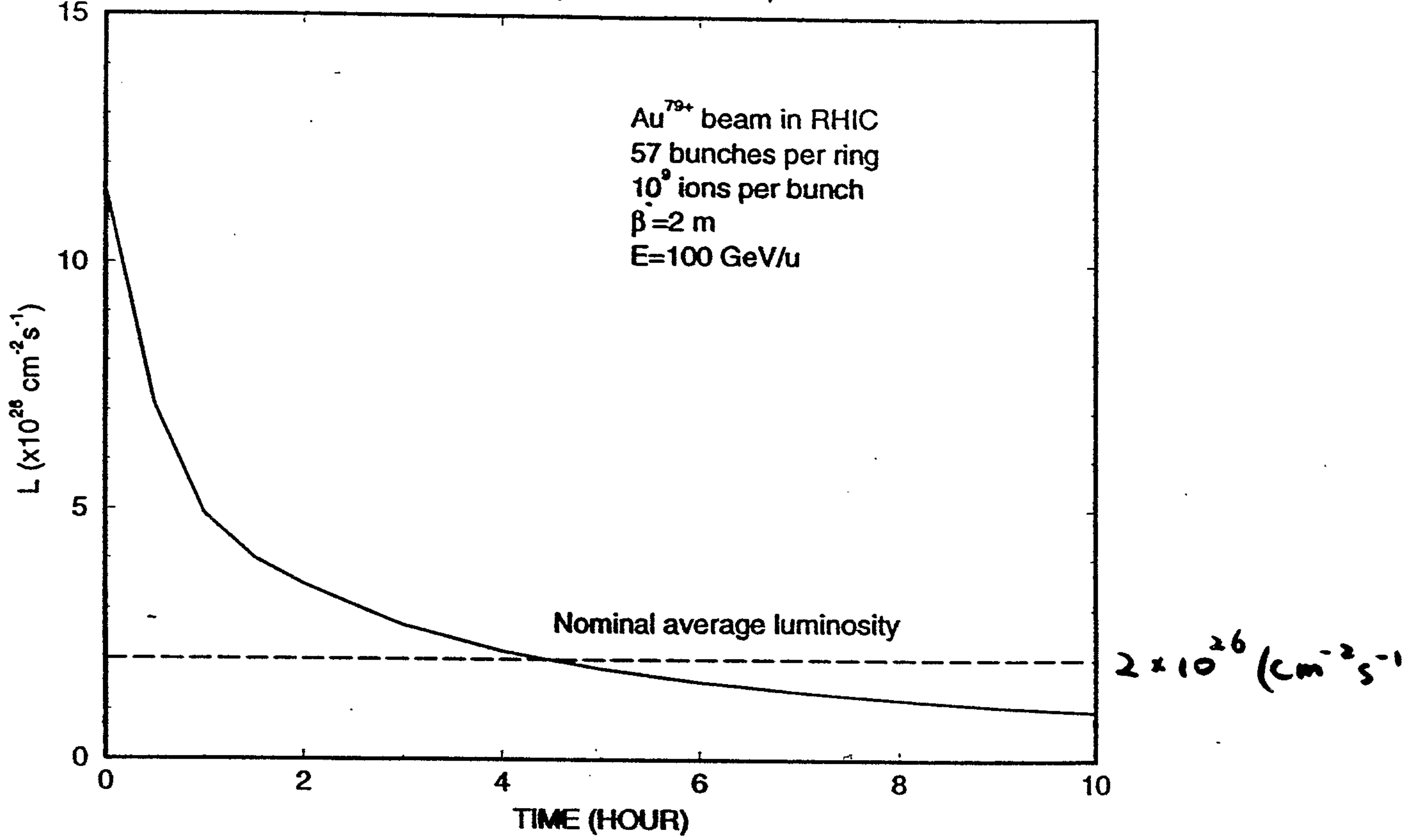
BUNCH AREA

(Bunch area growth due to IBS)



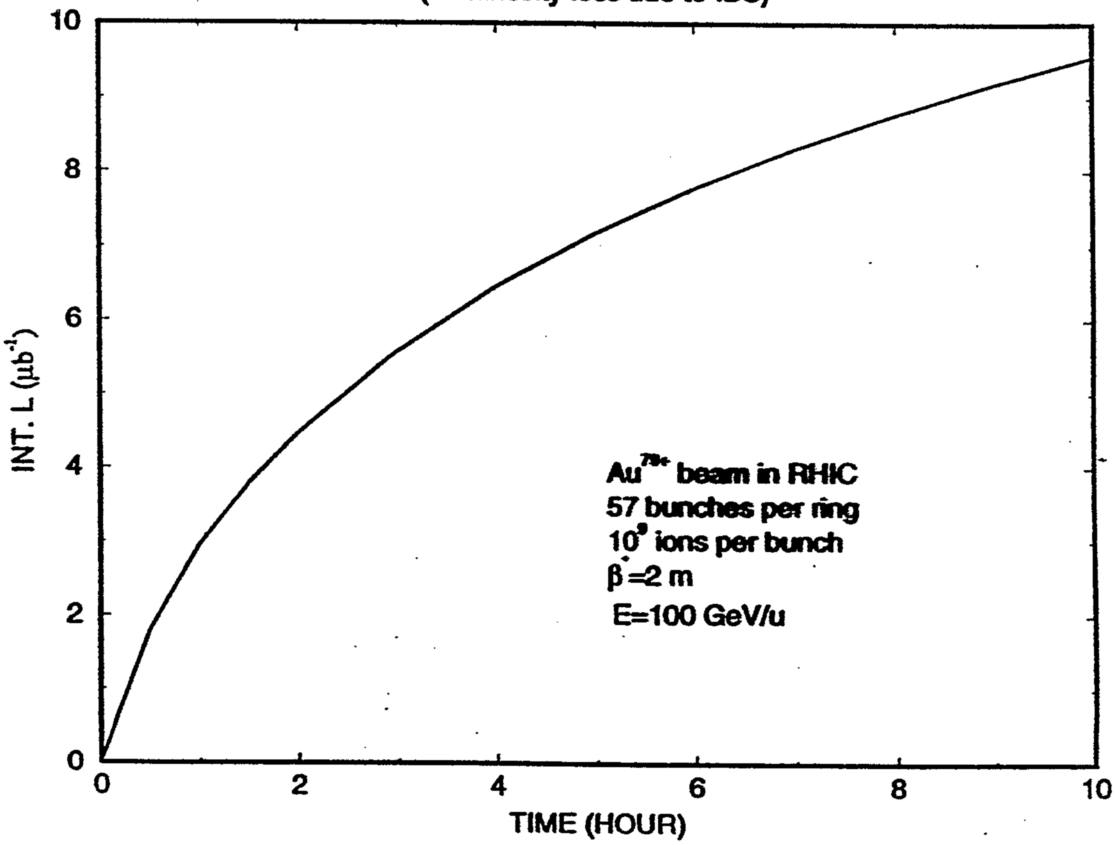
INSTANTANEOUS LUMINOSITY

(Luminosity loss due to IBS)



INTEGRATED LUMINOSITY

(Luminosity loss due to IBS)



Luminosity for a round beam

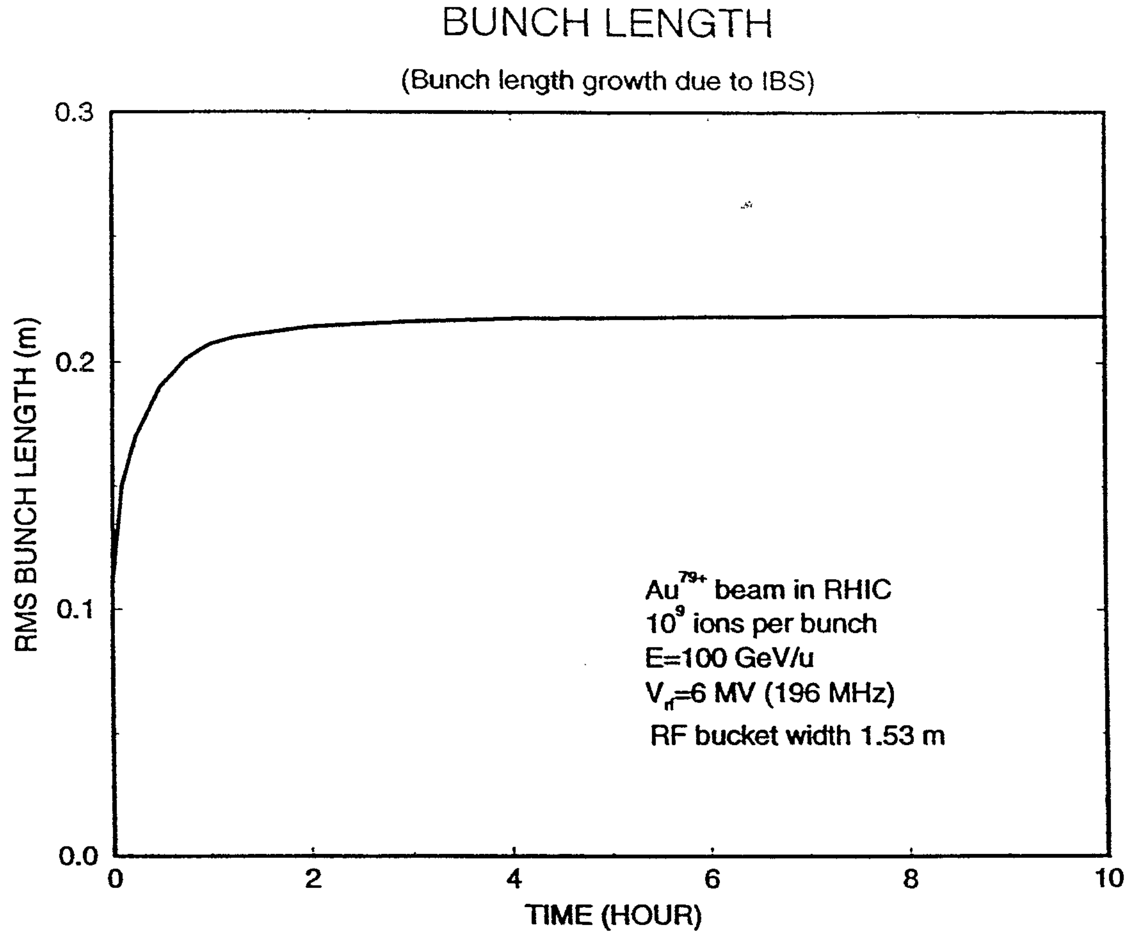
$$\mathcal{L} = \frac{3}{2\pi} f_{rev} \cdot N_B \cdot N^2 \cdot \frac{\beta\gamma}{\varepsilon_N \cdot \beta^*}$$

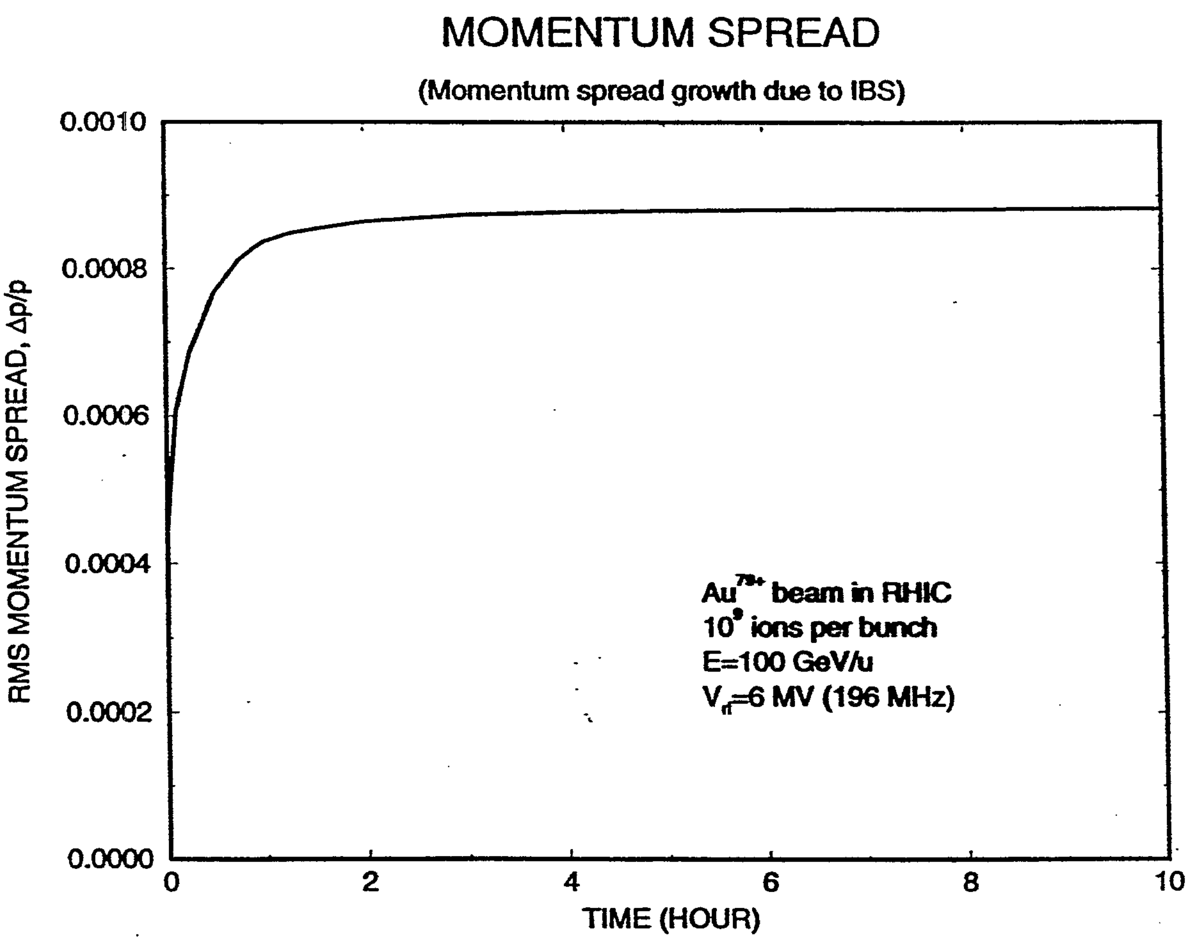
N_B: number of bunches

N: number of ions per bunch

ε_N: $\frac{6 \cdot \beta\gamma \, \sigma_x \sigma_y}{\beta^*}$

f_{rev}: revolution frequency


BUNCH LENGTH
(Bunch length growth due to IBS)
RMS BUNCH LENGTH (m)
0.3
0.2
0.1
0.0
0
2
4
6
8
10
TIME (HOUR)
Au79+ beam in RHIC
10⁹ ions per bunch
E=100 GeV/u
Vrf=6 MV (196 MHz)
RF bucket width 1.53 m


MOMENTUM SPREAD
(Momentum spread growth due to IBS)
RMS MOMENTUM SPREAD, Δp/p
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0
2
4
6
8
10
TIME (HOUR)
Au79+ beam in RHIC
10⁹ ions per bunch
E=100 GeV/u
Vrf=6 MV (196 MHz)

III. IBS scaling laws

* below transition energy :

similar to gas scattering

⇒ asymptotically approaches isotropic state

$$\langle \frac{\sigma_x}{\beta_x} \rangle \sim \langle \frac{\sigma_y}{\beta_y} \rangle \sim \frac{\sigma_p}{\gamma}$$

growth due to machine lattice variation

heat absorption in a time-dependent syste

* above transition energy :

no equilibrium due to negative mass

⇒ asymptotically dispersion related horizontal

and longitudinal dimension

$$n_c \cdot \langle \sigma_x^2 \rangle \sim \langle x_p \rangle^2 \ \sigma_p^2 \qquad n_c = \begin{cases} 1 & \text{uncoupled} \\ 2 & \text{coupled} \end{cases}$$

continuous growth in both horizontal and longitudinal dimension

Beam growth at high energy $\gamma \gg \gamma_T$

$$\begin{bmatrix} \frac{1}{\sigma_p}\frac{d\sigma_p}{dt} \\ \\ \frac{1}{\sigma_x}\frac{d\sigma_x}{dt} \end{bmatrix} = \frac{Z^4 N}{A^2} \frac{C_0}{\gamma_T \epsilon_x \epsilon_y S} \cdot \begin{bmatrix} (1-d^2)/d \\ \\ d/n_c \end{bmatrix}$$

$$C_0 \equiv \frac{\pi r_0^2 m_0 c^2 L_c}{16}$$

$$d = \langle x_p \rangle \sigma_p \Big/ \left(\sigma_x^2 + \langle x_p^2 \rangle \sigma_p^2\right)^{1/2} ; \qquad 0 < d < 1$$

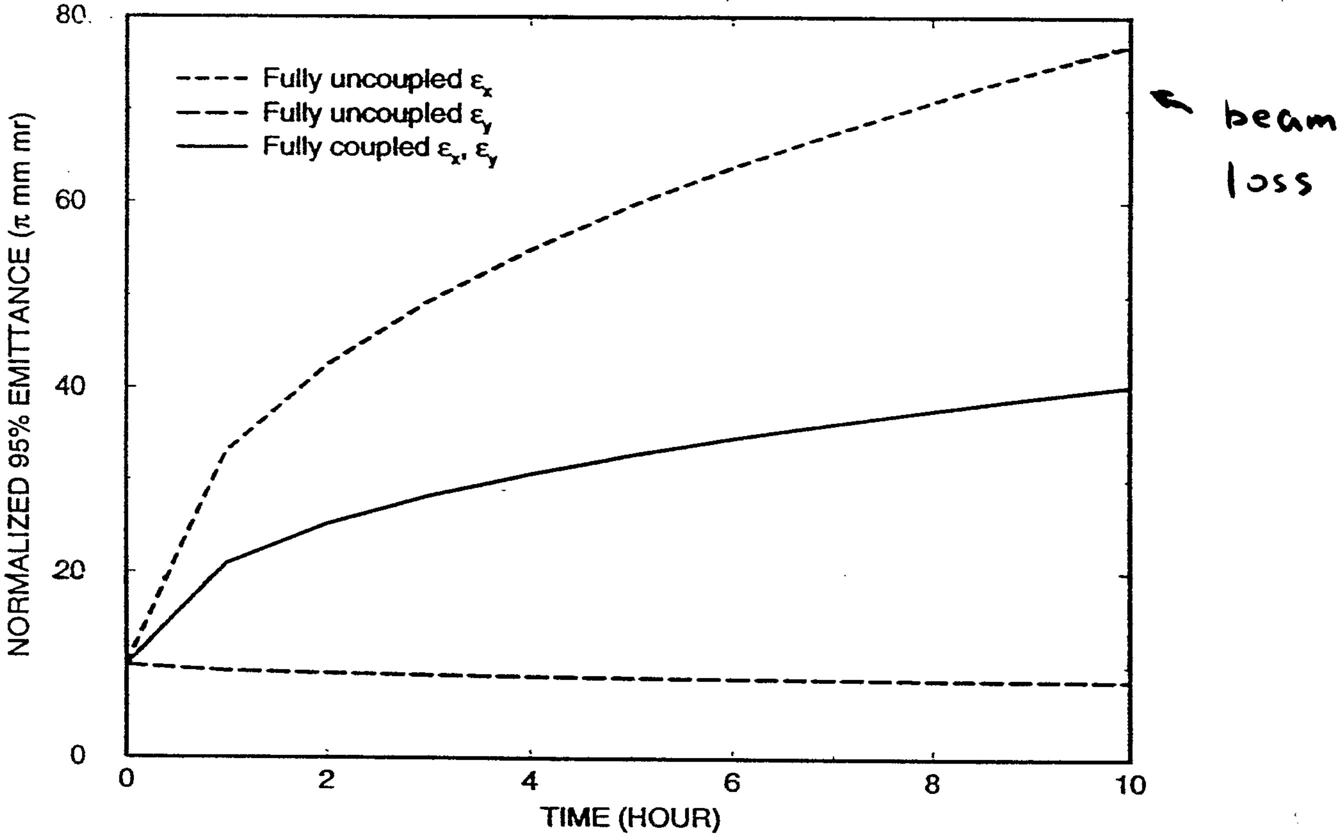
* not sensitive to energy

* $\tau^{-1} \sim \frac{Z^4}{A^2} \frac{N}{\epsilon_x \epsilon_y S}$

* transverse growth sensitive to coupling

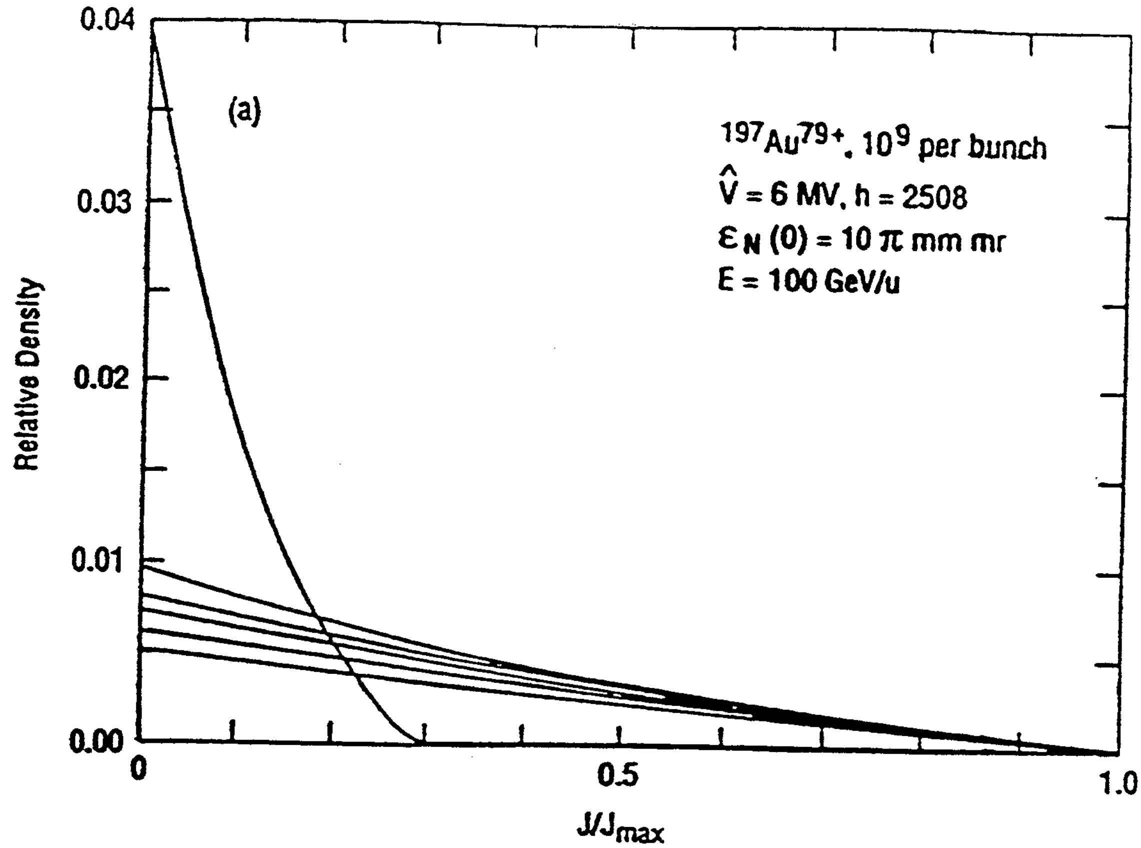
EFFECTS OF COUPLING ON IBS

Au^{79+} beam in RHIC. E=100 GeV/u



For $\beta^* = 1$ m operation :

dynamic aperture limit $\Rightarrow$ $\epsilon_{x,y} \sim 40\ \pi$ mm·m



Use Fokker - Planck equation to evaluate beam evolution and beam loss

$$\frac{\partial \psi}{\partial t} = -\frac{\partial}{\partial J}\left(F(J)\,\psi\right) + \frac{1}{2}\frac{\partial}{\partial J}\left(D(J)\,\frac{\partial \psi}{\partial J}\right)$$

J : action

ψ : density distribution function

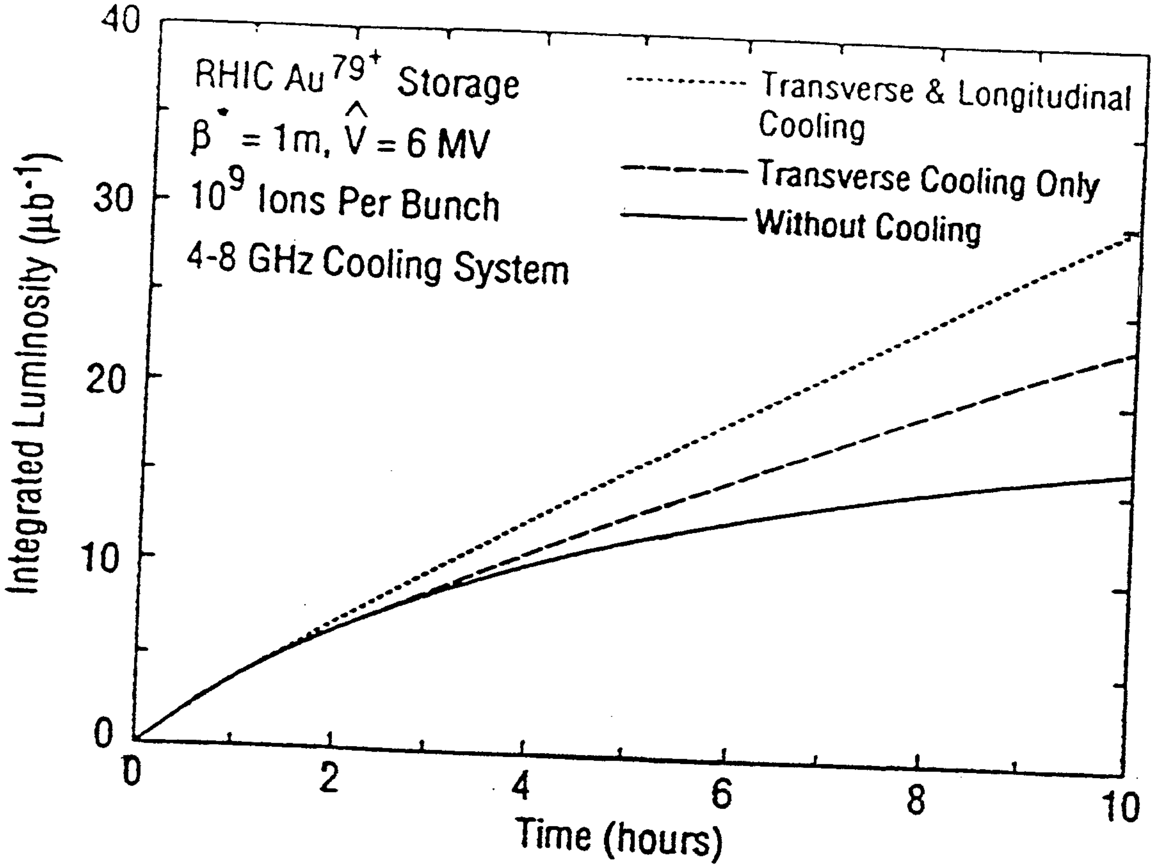
IV. Future

* Increase the number of bunches per ring
* An upgrade in rf system (to 16 MV) can reduce beam loss to 2 %.

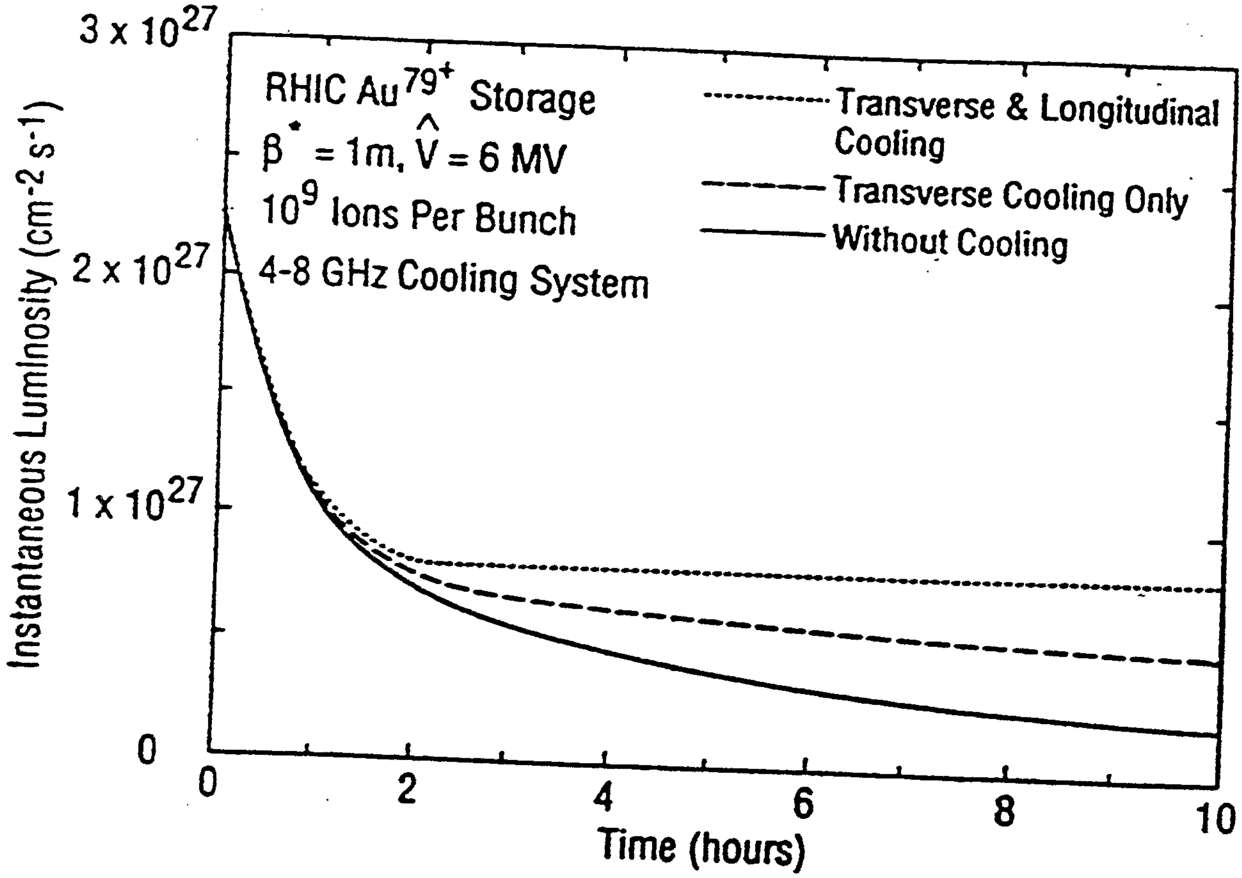
  The gain in luminosity is ~ 30 %.

  may have aperture problem with $\beta^* = 1\,m$ operation and $\epsilon_N \sim 48\,\pi$ mm·mr

* Methods like stochastic cooling are desirable to preserve beam quality, alleviate dynamic aperture requirement, and increase luminosity.



RHIC Au79+ Storage
β* = 1m, V̂ = 6 MV
10^9 Ions Per Bunch
4-8 GHz Cooling System
Transverse & Longitudinal Cooling
Transverse Cooling Only
Without Cooling
Integrated Luminosity (μb-1)
Time (hours)
0
10
20
30
40
0
2
4
6
8
10



RHIC Au79+ Storage
β* = 1m, V̂ = 6 MV
10^9 Ions Per Bunch
4-8 GHz Cooling System
Transverse & Longitudinal Cooling
Transverse Cooling Only
Without Cooling
Instantaneous Luminosity (cm-2 s-1)
Time (hours)
0
1 x 10^27
2 x 10^27
3 x 10^27
0
2
4
6
8
10