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## Crude Estimate Of $\langle 1 \rangle$ vs. Lattice Choice =Loss Rates Only=

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CRUDE ESTIMATE OF  $\langle 1 \rangle$

vs Lattice Choice

= Loss Rates Only =

G. R. Young

(BNL, December 21, 1983)

We make some "first try" comparisons of luminosity lifetime for some of the different lattices suggested. (see RHIC-PG-10 and RHIC-PG-13).

To greatly simplify this first attempt, we do the following

Fix the following parameters

$$N = 1.87 \times 10^9 / \text{bunch}$$

$$\gamma = 100$$

Au

$$B = 57 \text{ bunches}$$

$$\epsilon_N = 10 \pi \text{ mm-mrad (H \& V)}$$

(AR's "6\sigma emittances")

$$\text{so } \sigma^* = \sqrt{\frac{\epsilon_N}{\beta^*} \cdot \beta^*}$$

$$f_{rev} = 78,197 \text{ Hz}$$

Pick three crossing angles :  $\alpha = 0, 2, 10 \text{ mrad}$ .

Fix  $\sigma_L = 90 \text{ cm}$  (probably too large, but all lattices will be penalized the same factor if  $\sigma_L$  is decreased)

Perhaps this emittance choice is unfair to the stronger focussing lattice, but for this comparison it was felt to be best to concentrate just on the different values of diffusion rates resulting from changing  $\bar{\beta}$ ,  $\bar{\eta}$ .

Clearly, more effort can be expended here. I

suggest at least the following

1) more discussion with experimenters on how long a fill should last. Tom Ludlami's comments on operator tuning and experimenter calibration after each fill at the ISR need to be considered

2) Consideration of smaller emittances  $\epsilon_N \sim 4\pi$  mm mrad? The diffusion rates are not yet catastrophic at this point.

3) Performing a calculation which takes into account the decrease in loss rates with time. The present calculation only uses the initial loss rates, and so is unnecessarily pessimistic in that sense

4) Arguing expense for stronger focussing vs expense for faster kickers to load more bunches into the collider vs expense for a larger booster (or higher peak field) to get better final stripping efficiency for  $A_n$  out of the booster.

# Luminosity

1

$$L = \frac{N^2 B f_{\text{rev}}}{4\pi \sigma_v^* \sigma_H^* f}$$

$$f = \sqrt{1 + \rho^2}$$

$$\rho = \frac{\alpha \sigma_L}{2 \sigma_H^*}$$

Use  $N = 1.87 \times 10^9$  / bunch ( $\gamma = 108.35$  100 GeV/A Au)

$\sigma_L = 90$  cm booster limited and IBS limited

$$\sigma_{v,H}^* = \sqrt{\frac{\epsilon_{N_{H,v}} \beta_{H,v}^*}{\beta \gamma} \frac{\beta_{H,v}^*}{6\pi}}$$

$$B = 57$$

$$f_{\text{rev}} = 78,197 \text{ Hz}$$

Compare cases for  $\alpha = 0$  mrad head on  
2 mrad small angle, A vs A'  
10 mrad small diamond

Compare  $L_0$  and  $\langle L \rangle$  for 1 hour, using

$$L = L_0 e^{-t/\tau_L} \quad \tau_L^{-1} = \text{luminosity loss rate}$$

Effect of different lattices  $\bar{\beta}, \bar{\eta}$   $\gamma_{\pm} \sim \sqrt{R/\bar{\eta}}$

$\gamma_{\pm} \lesssim 25$  GeV avoids transition for protons  $\therefore$  Unbunched protons not limited by passing thru  $\gamma_{\pm}$   
 $R \sim 610.17$  meters

## Luminosity decay time

(RHIC-PG-21)

$$L = \frac{N^2 B f_{rev}}{4\pi \sigma_v^* \sigma_H^* f}$$

$$\text{Calculus} \rightarrow -\frac{1}{L} \frac{dL}{dt} = \frac{1}{\sigma_v^*} \frac{d\sigma_v^*}{dt} + \frac{1}{\sigma_H^*} \frac{d\sigma_H^*}{dt} + \frac{1}{f} \frac{df}{dt}$$

$$\text{where } \frac{1}{f} \frac{df}{dt} = \frac{f^2}{f^2} \left[ \frac{1}{\sigma_L} \frac{d\sigma_L}{dt} - \frac{1}{\sigma_H^*} \frac{d\sigma_H^*}{dt} \right]$$

Assume ① bunch length  $\propto$  energy spread

$$\text{so } \frac{1}{\sigma_L} \frac{d\sigma_L}{dt} = \tau_E^{-1}$$

② full H, V coupling (seconds, i.e.  $\sim 10^5$  revolutions)

$$\text{so } \frac{1}{\sigma_v^*} \frac{d\sigma_v^*}{dt} \approx \frac{1}{\sigma_H^*} \frac{d\sigma_H^*}{dt} = (\tau_H^{-1} + \tau_V^{-1})$$

Then

$$-\frac{1}{L} \frac{dL}{dt} \equiv \tau_L^{-1} = \frac{f^2}{f^2} \tau_E^{-1} + \left(2 - \frac{f^2}{f^2}\right) (\tau_H^{-1} + \tau_V^{-1})$$

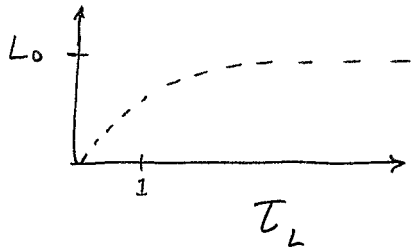
Thenon,  $f=0, f=1$

$$\tau_L^{-1} = 2(\tau_H^{-1} + \tau_V^{-1})$$

# Time average Luminosity

$$-\frac{1}{L} \frac{dL}{dt} = \tau_L^{-1} \quad \text{or} \quad L = L_0 e^{-t/\tau_L}$$

Then  $\langle L \rangle_{1 \text{ hour}} = \frac{\int_0^1 L_0 e^{-t/\tau_L} dt}{\int_0^1 dt} = L_0 \tau_L (1 - e^{-1/\tau_L}) \quad \tau_L \text{ [hours]}$



$\tau_L = .1 \text{ hr}$	$\langle L \rangle = .1 L_0$
$1 \text{ hr}$	$.63 L_0$
$5 \text{ hr}$	$.91 L_0$

3 cases  $\delta = 100$  (see RHIC-P4-10, RHIC-P6-13) For now,  $\epsilon_N = 10\pi \text{ mm mrad (H}^{\pm}/\text{V)}$

$\beta_{H,V}^* = 2 \text{ m}$   
 $\sigma_{H,V}^* = .01826 \text{ cm}$   
 $\sigma_L = 90 \text{ cm}$   
 $\alpha = 2 \text{ mrad} \quad p = 4.93$   
 $f = 5.03$   
 $\frac{p^2}{f^2} = .96$   
 $\alpha = 10 \text{ mrad} \quad p = 24.64$   
 $f = 24.66$   
 $\frac{p^2}{f^2} = .998$

$\bar{\beta}$	30 m	45 m	40 m
$\bar{\eta}$	0.5 m	1.5 m	2 m
$\sim \delta_{\pm}$	35	20.2	17.5
$\tau_E^{-1} (\text{h}^{-1})$	.0816	.0502	.0483
$\tau_H^{-1} (\text{h}^{-1})$	.0669	.2875	.5681
$\tau_V^{-1} (\text{h}^{-1})$	-.0147	-.0135	-.0116
$\tau_L^{-1} (\text{h}^{-1})$	.1044	.548	1.113
$\times = 0$		<del>.333</del>	<del>.625</del>
$\times = 2$	.1326	.333	.625
$\times = 10$	.1337	.3246	.6058



$\delta_t$	35	20,2	17.5
$\alpha=0$			
$L_0$	$3.7 \cdot 10^{27}$	$3.7 \cdot 10^{27}$	$3.7 \cdot 10^{27}$
<u><math>\langle L \rangle</math></u>	$3.5 \cdot 10^{27}$	$2.8 \cdot 10^{27}$	$2.2 \cdot 10^{27}$
$\alpha=2 \text{ mrad}$			
$L_0$	$7.4 \cdot 10^{26}$	$7.4 \cdot 10^{26}$	$7.4 \cdot 10^{26}$
$\langle L \rangle$	$6.9 \cdot 10^{26}$	$6.3 \cdot 10^{26}$	$5.5 \cdot 10^{26}$
$\alpha=10 \text{ mrad}$			
$L_0$	$1.5 \cdot 10^{26}$	$1.5 \cdot 10^{26}$	$1.5 \cdot 10^{26}$
$\langle L \rangle$	$1.4 \cdot 10^{26}$	$1.3 \cdot 10^{26}$	$1.1 \cdot 10^{26}$

1 hour run with collides assumed

→ For 1 hour runs, little difference

$\sim \delta_t$	35	20.2	17.5	<u>5</u>
$\alpha=0$				
$L_0$	3.7	3.7	3.7	
$\langle L \rangle$	2.9 $10^{27}$	1.3 $10^{27}$	6.6 $10^{26}$	
$\theta=2 \text{ mrad}$				
$L_0$	7.4	7.4	7.4	
$\langle L \rangle$	5.4 $10^{26}$	3.6 $10^{26}$	2.3 $10^{26}$	
$\theta=10 \text{ mrad}$				
$L_0$	1.5	1.5	1.5	
$\langle L \rangle$	1.1 $10^{26}$	7.4 $10^{25}$	4.7 $10^{25}$	

**5 hour run** with collider assumed marked dependence, esp. for head on

What happens if we blow up the emittance by  $\times 2$  to  $\epsilon_{N, H, V} = 20 \pi$  mm mrad?

Compare Head-on ~~case~~, 10 mrad cases

Rule of Thumb (see RHIC-PG-13) (leave  $\frac{\sigma_E}{E}$  at  $10^{-3}$ )

$\tau_E^{-1} \sim \frac{1}{\epsilon_N}$        $\tau_Y^{-1} ? \frac{1}{\epsilon_N}$  (small, anyway)  
 $\tau_H^{-1} \sim \frac{1}{\epsilon_N^2}$

$\sigma_{H,V}^* = .0258$  cm       $\alpha = 10$  mrad  
 $\sigma_L = 90$  cm       $f = 17.44$

$\sim \gamma_t$	35	20.2	17.5
$\tau_E^{-1}$	.0408	.0251	.0242
$\tau_H^{-1}$	<del>.0167</del>	.0719	.1420
$\tau_Y^{-1}$	-.0074	-.0068	-.0058
$\alpha=0 \tau_L^{-1}$	.0186	.1302	.2724
$\alpha=10 \text{ mrad } \tau_L^{-1}$	.04998	.0902	.1608

$f = 17.47$   
 $\frac{f^2}{f^2} = .996$

$\sim \gamma_t$	35		20.2		17.5		
$\lambda=0$	$L_0$	1.9	$10^{27}$	1.9	$10^{27}$	1.9	$10^{27}$
	$\langle L \rangle_{1\text{hour}}$	1.88	$10^{27}$	1.78	$10^{27}$	1.66	$10^{27}$
	$\langle L \rangle_{5\text{hour}}$	1.81	$10^{27}$	1.40	$10^{27}$	1.04	$10^{27}$
$\lambda=10\text{mrad}$	$L_0$	1.1	$10^{26}$	1.1	$10^{26}$	1.1	$10^{26}$
	$\langle L \rangle_{1\text{hour}}$	1.07	$10^{26}$	1.05	$10^{26}$	1.02	$10^{26}$
	$\langle L \rangle_{5\text{hour}}$	9.7	$10^{25}$	8.8	$10^{25}$	7.6	$10^{25}$

At 1 hour, ~ no difference

At 5 hours, ~ 40% difference