

RHIC-AP-33

Proton Performance in RHIC

G. Parzen

BNL

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Proton Performance in RHIC

George Parzen

This note considers various effects that limit the performance of RHIC with proton beams, particularly at high energy $\gamma \approx 320$ and high intensity, $N_b \approx 10^{12}$ /bunch. These effects include intrabeam scattering, collective instabilities, and the beam-beam interaction.

The intrabeam scattering after $t = 10$ hours leads to certain requirements for the dynamic aperture. The limit due to the beam-beam interaction appears to give the most trouble. This limit can be avoided by using large enough beam crossing angles. Ways of getting around the limits due to the beam-beam interaction have been further refined and extended by Harald Hahn.

Aperture Requirements and Proton Performance in RHIC

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G. Parzen, 10/3/84
9/17/86

Important Limitations

- 1) Intra beam scattering
- 2) Beam-Beam interaction
- 3) Instabilities, $Z_{||}/h$, Z_{\perp}/h
- 4) Aperture ~~requirements~~
~~requirements~~
- 5) Space charge at $\delta = 30$.

Intra beam Scattering, $N_b = 10^{11}$ /bunch

- 1) Longitudinal growth
- 2) Transverse growth

~~requirements~~

~~requirements~~

~~requirements~~

Protons

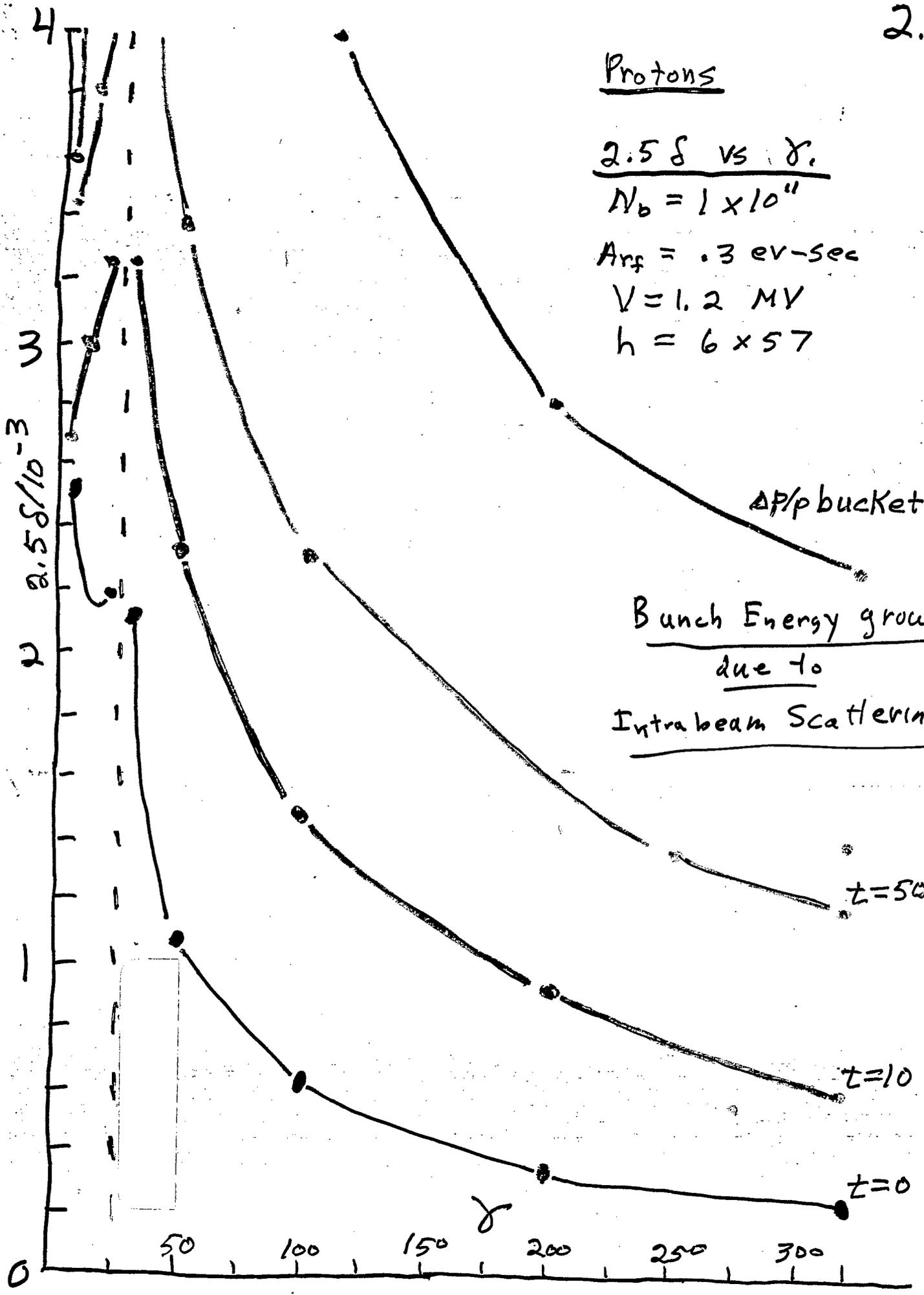
2.5 δ vs γ .

$N_b = 1 \times 10^{11}$

$A_{rf} = .3 \text{ ev-sec}$

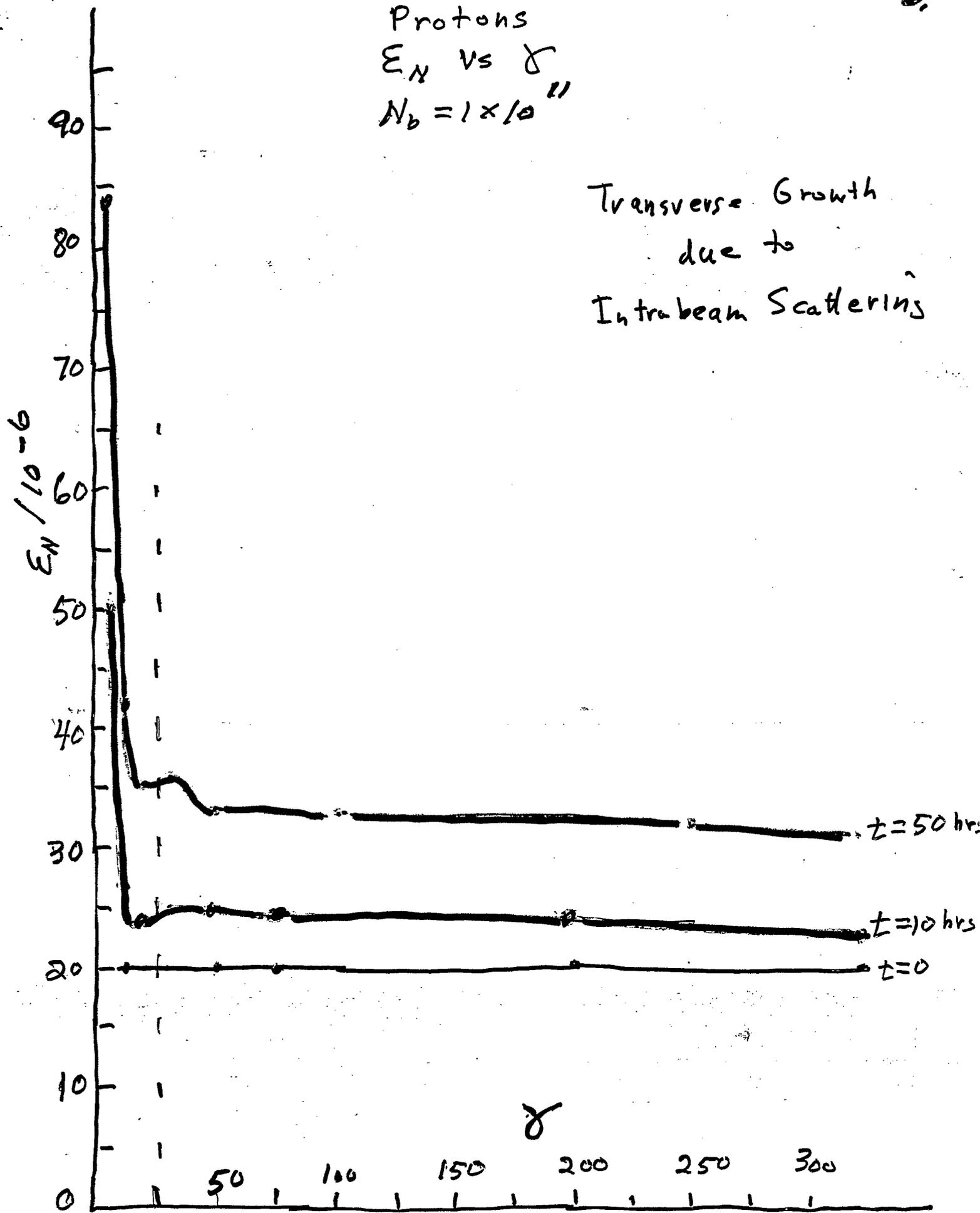
$V = 1.2 \text{ MV}$

$h = 6 \times 57$

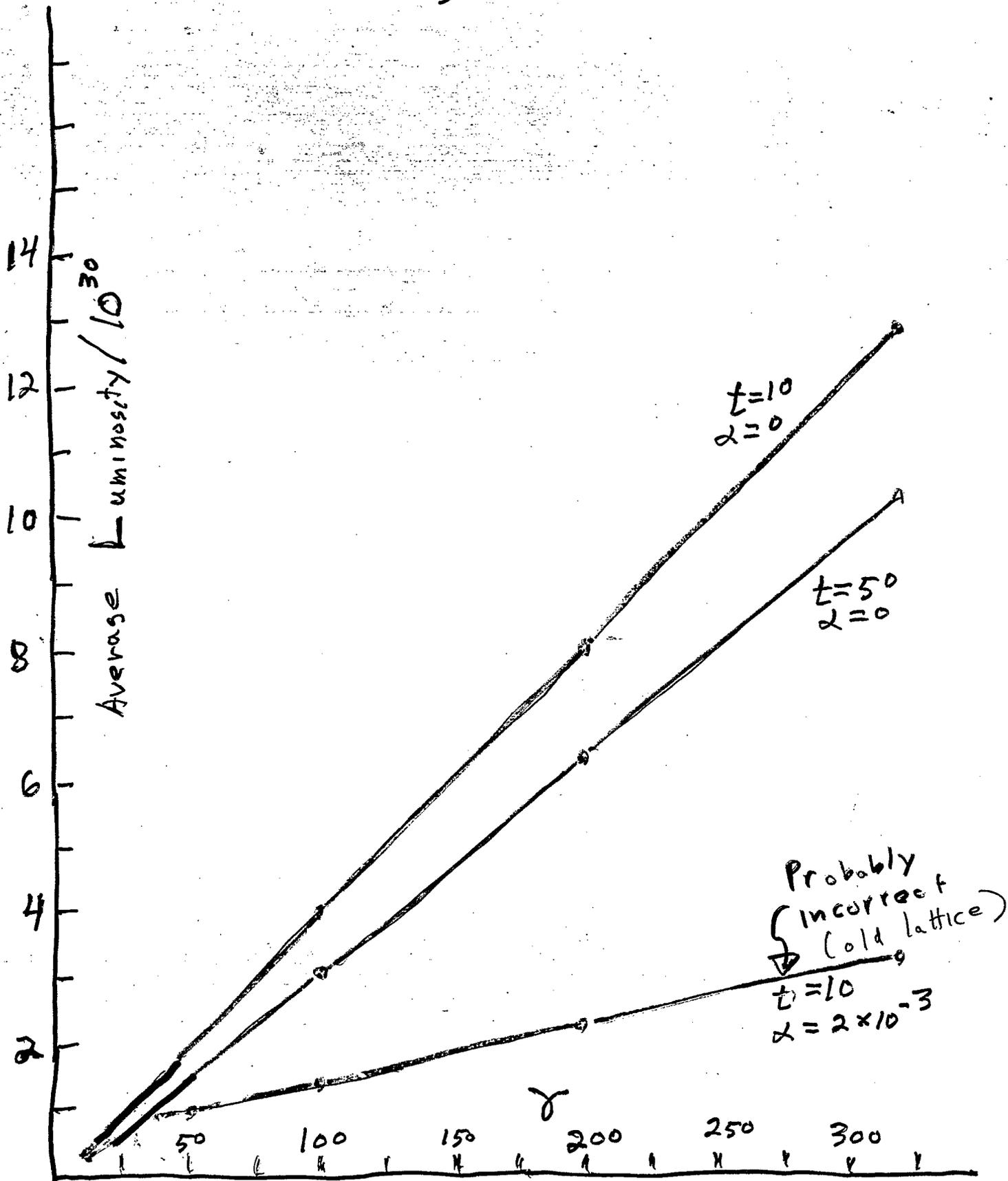


Protons
 ϵ_N vs δ
 $N_b = 1 \times 10^{11}$

Transverse Growth
due to
Intrabeam Scattering

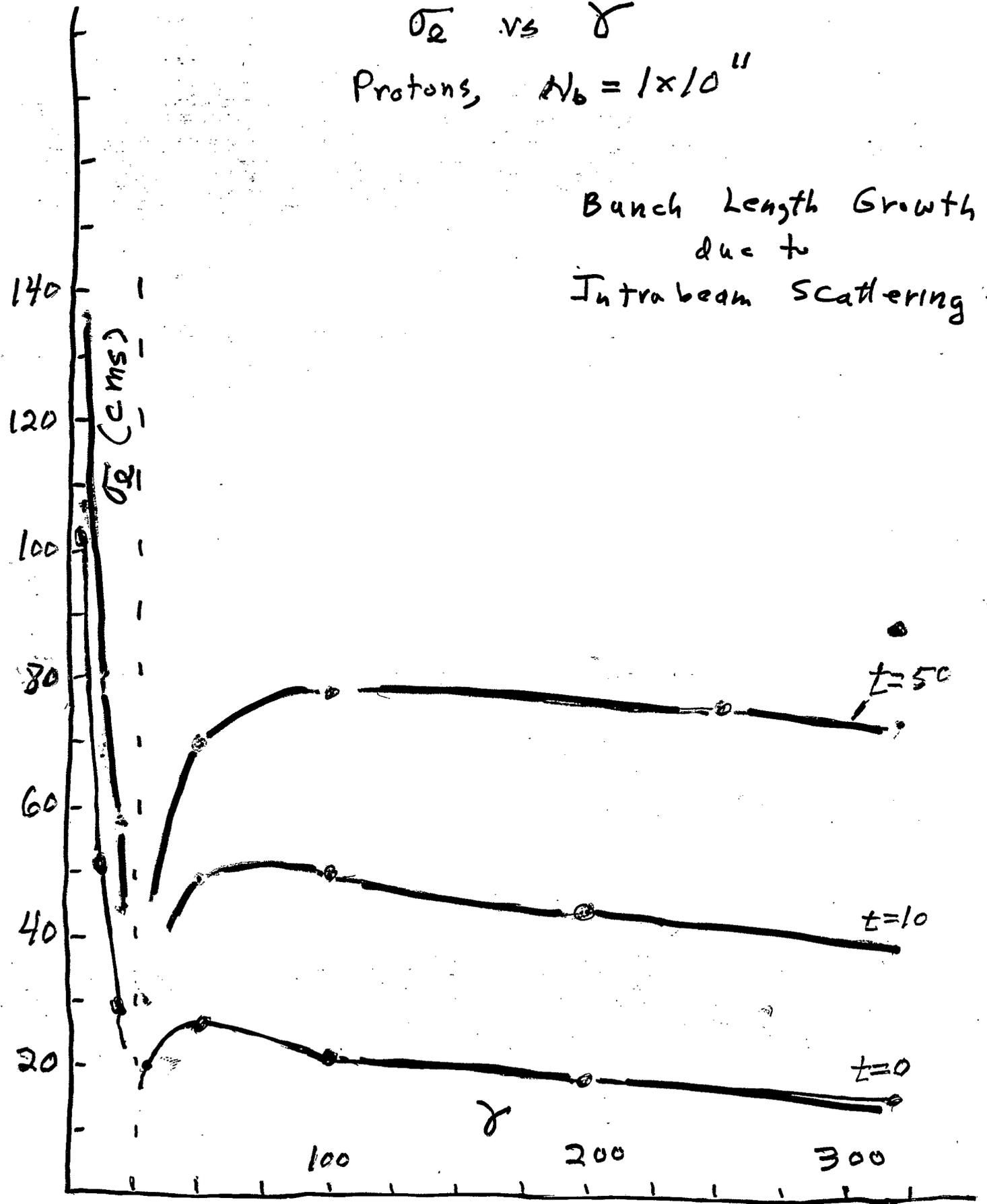


Average Luminosity vs γ
Protons, $N_b = 1 \times 10^{11}$



σ_z vs γ
Protons, $N_b = 1 \times 10^{11}$

Bunch Length Growth
due to
Intra beam Scattering



Aper ture Requirements, $N_b = 10''$ / bunch

$$\underline{\gamma = 30}$$

$$\sigma_H = 2.67 \text{ mm} , 6\sigma_H = 16 \text{ mm} , t = 10 \text{ hrs.}$$

$$A_{SL} = 16 \text{ mm at } \Delta p/p = 0$$

$$\Delta p/p = \pm .0033 , X_p \frac{\Delta p}{p} = \pm 5. \text{ mm}$$

$$\sigma_E = 30 \text{ cms.}$$

$$\text{Maximum } X = 26 \text{ mm at } \Delta p/p = \pm .0033$$

a, b, effects corrected by shuffling
and correctors if necessary.

Closed orbit effect $\leq 1 \text{ mm}$ after correction.

$$\underline{\gamma = 320 , N_b = 10''}$$

$$\sigma_H = .78 \text{ mm} , 6\sigma_H = 4.7 \text{ mm} , \sigma_E = 39 \text{ cms}$$

$$A_{SL} = 4.7 \text{ mm at } \Delta p/p = 0 ,$$

$$\Delta p/p = \pm 6.3 \times 10^{-4} , X_p \frac{\Delta p}{p} = \pm .98 \text{ mm}$$

$$\text{Maximum } X = 7.2 \text{ mm at } \Delta p/p = \pm 6.3 \times 10^{-4}$$

Add 1 mm for closed orbit

Add 1 mm for a, b, effects.

$$\text{Maximum } X \approx 9 \text{ mm.}$$

Beam Beam Interaction ($N_b = 10^{11}$)

$$N_b = 1 \times 10^{11}, \quad \epsilon = 2.0 \times 10^{-6}$$

$\Delta V_{BB} = \frac{10037}{10052}$, head on collisions, $t=0$ initial.
 $\rightarrow 10030$ after 10 hrs.

$\Delta V \sim N_b / \epsilon_N$ independent of energy

Collective

Instabilities, $N_b = 10^{11}$

$$\gamma = 320, \quad \sigma_{z0} = 15.8 \text{ cms}, \quad \delta_0 = .102 \times 10^{-3} \text{ (initial)}$$

$$A_{\text{eff}} = .3 \text{ ev-sec}, \quad I_{\text{pk}} = 12 \text{ A}, \quad I_{\text{av}} = .43 \text{ A}$$

$$Z/n = 10 \text{ ohms}$$

$$N_{b,T} = .25 \times 10^{11} \text{ (Threshold)}$$

$$N_{b,T} \sim \delta^3 \left(\begin{array}{l} I_p < \frac{2 \pi E}{e} \frac{|n|}{(Z_{\text{eff}}/n)} \delta^2 \\ I_p = N_b e \beta c / \sqrt{2\pi} \sigma_z \end{array} \right)$$

$$\delta = .1 \times 10^{-3} \rightarrow .16 \times 10^{-3}$$

takes 1/3 hour due to FBS.

(8)

$N_b = 10'' \text{ use}$

$N_{b,T} (\text{transverse}) = 4.7 \times 10'' \text{ for } \delta = .16 \times 10^{-3}$

Problem if $N_b > N_{b,T} (\text{Transverse})$

Transverse $I_P < \frac{10 E}{\rho} \frac{|\eta| \delta}{B} \frac{1}{(Z_I/n)}$

$N_{b,T} \sim \delta^2$

May require δ increase by other means.

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$$N_b = 10^{12} / \text{bunch}, \quad \gamma = 320 \text{ operation}$$

Intra beam Scattering (t=10 hrs)

$$\sigma_H = .98 \text{ mm} \quad 6\sigma_H = 6 \text{ mm}$$

$$A_{SL} = 6 \text{ mm} \text{ at } \Delta p/p = 0, \quad \sigma_x = 88 \text{ cm}$$

$$\Delta p/p \pm 1.4 \times 10^{-3}, \quad (\Delta p/p)_{\text{bucket}} = 2.3 \times 10^{-3}$$

$x_p \text{ or } p \pm \pm 2.2 \text{ mm}$

$$\text{Maximum } X = \underline{10 \text{ mm}}$$

Beam Beam Interaction

$$\Delta V_0 \approx \frac{N_b}{E_N}, \quad L_0 \sim \frac{N_b^2}{E_N \beta^{*2}} \text{ Head-on collisions}$$

$$\Delta V_0 \text{ too large by factor } 10, \quad \Delta V_0 \approx .04$$

Use E_N to reduce ΔV_0 .

$$E_N = 10 \times 20 = 200$$

$$\sigma_H = 2.3 \text{ mm}, \quad 6\sigma_H = 13.7 \text{ mm}$$

$$A_{SL} = 13.7 \text{ mm} \text{ at } \Delta p/p = 0$$

$$x_p \text{ or } p = 2.2 \text{ mm}$$

$$\text{Maximum } X = 20.4 \text{ mm} \text{ at } \Delta p/p = \pm 1.4 \times 10^{-3}$$

$$N_b = 10^{12} \text{ / bunch (continued)}$$

Use α to reduce ΔV

$$\Delta V = \frac{\Delta V_0 \cdot 2}{1 + \sqrt{1+p^2}}, \quad L = \frac{L_0}{\sqrt{1+p^2}}$$

$$p = \frac{\alpha \sqrt{e}}{2 \sigma_H^*}$$

$p = \frac{11.5}{2.0}$ needed to reduce ΔV
by factor 10

L increases by 5 when $N_b = 10^{11} \rightarrow 10^{12}$

$$\alpha = \frac{6}{10.8} \times 10^{-3} \text{ required}$$

Note initial p is smaller
by factor 3.2

$$\text{initial } \Delta V = .004 \times 2.8 \approx .011$$

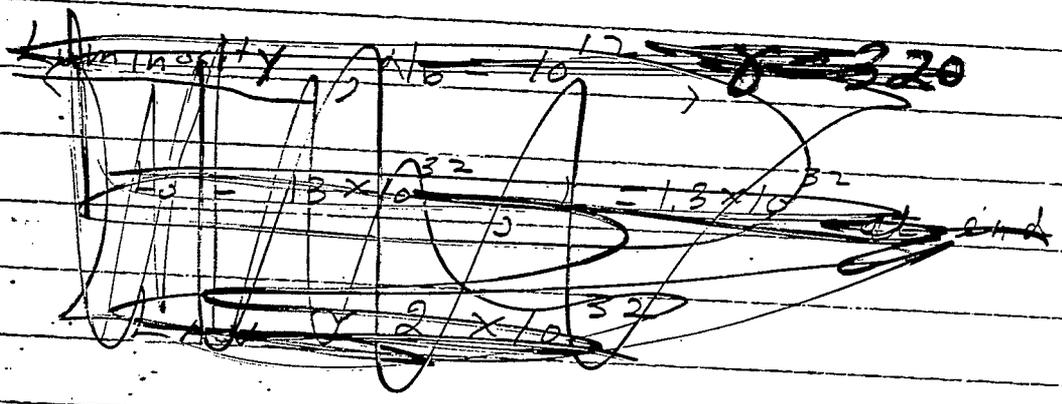
$N_b = 10^{12}$, Instabilities

$z/h = 10$, $N_{b,T} = .25 \times 10^{11}$

$\delta = .1 \times 10^{-3} \rightarrow .34 \times 10^{-3}$

$\sigma_{\text{bucket}} = .9 \times 10^{-3}$

$N_{b,T} (\text{transverse}) = 2.1 \times 10^{12}$ for $\delta = .34 \times 10^{-3}$



~~Beam size required for Au $\delta = 1.3 \times 10^{-3}$~~
~~at 10 mm~~

~~Space charge ΔV~~
~~Protons $z = 10$, $N_b = 10^{12}$ bunch, $I_{\text{beam}} = 57 \text{ A}$~~
 ~~$\Delta V_x \approx \Delta V_y \approx 27$~~

11.
Space Charge ΔV , $\gamma = 30$, $N_b = 10^{12}$ /bunch

Protons, $\gamma = 30$, $N_b = 10^{12}$ /bunch

$$I_{\text{peak}} = 97 \text{ A}$$

$$\Delta V_x \approx \Delta V_y \approx -0.27$$

Which is close to
Space charge limit.

Note

RHIC ; $\sigma_z = 20 \text{ cm}$, $\gamma = 30$

AGS

$\sigma_z \sim 8 \text{ m} = 800 \text{ cm}$
at injection

$\sigma_z \sim 1 \text{ m}$ at $\gamma = 30$

Space charge ΔV can be reduced
by keeping σ_z large, $\sigma_z \sim 1 \text{ m}$, at $\gamma = 30$