

Proton Performance in RHIC

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BNL

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Proton Performance in RHIC

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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

①

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 ~~for electron cooling, for PIP, for injection, for extraction~~
- 5) Space charge at $\delta = 30$.

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

1) Longitudinal growth

2) Transverse growth

~~Longitudinal growth~~

~~Transverse growth~~

~~Longitudinal growth~~

Protons

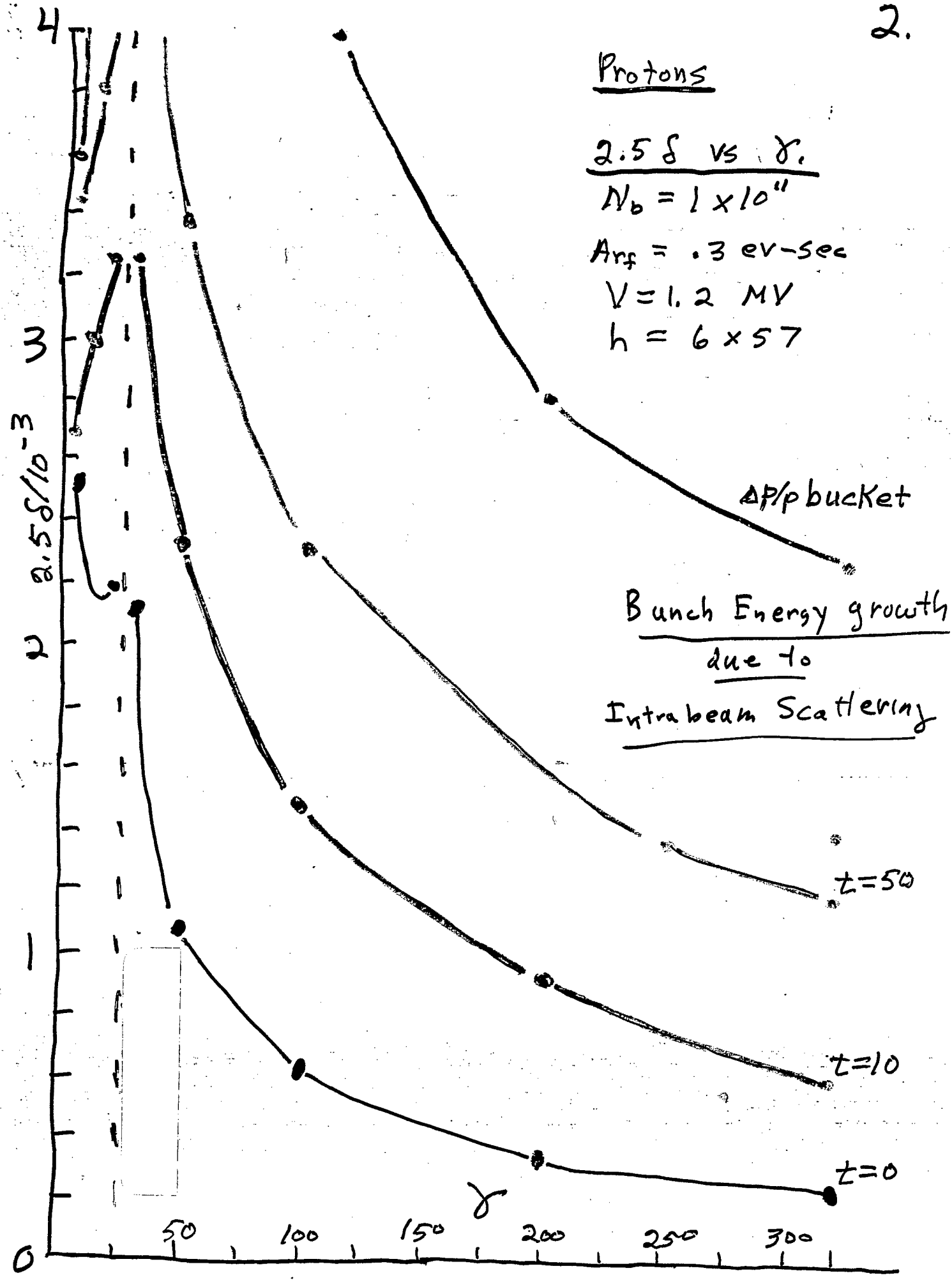
2.5 δ vs γ .

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

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

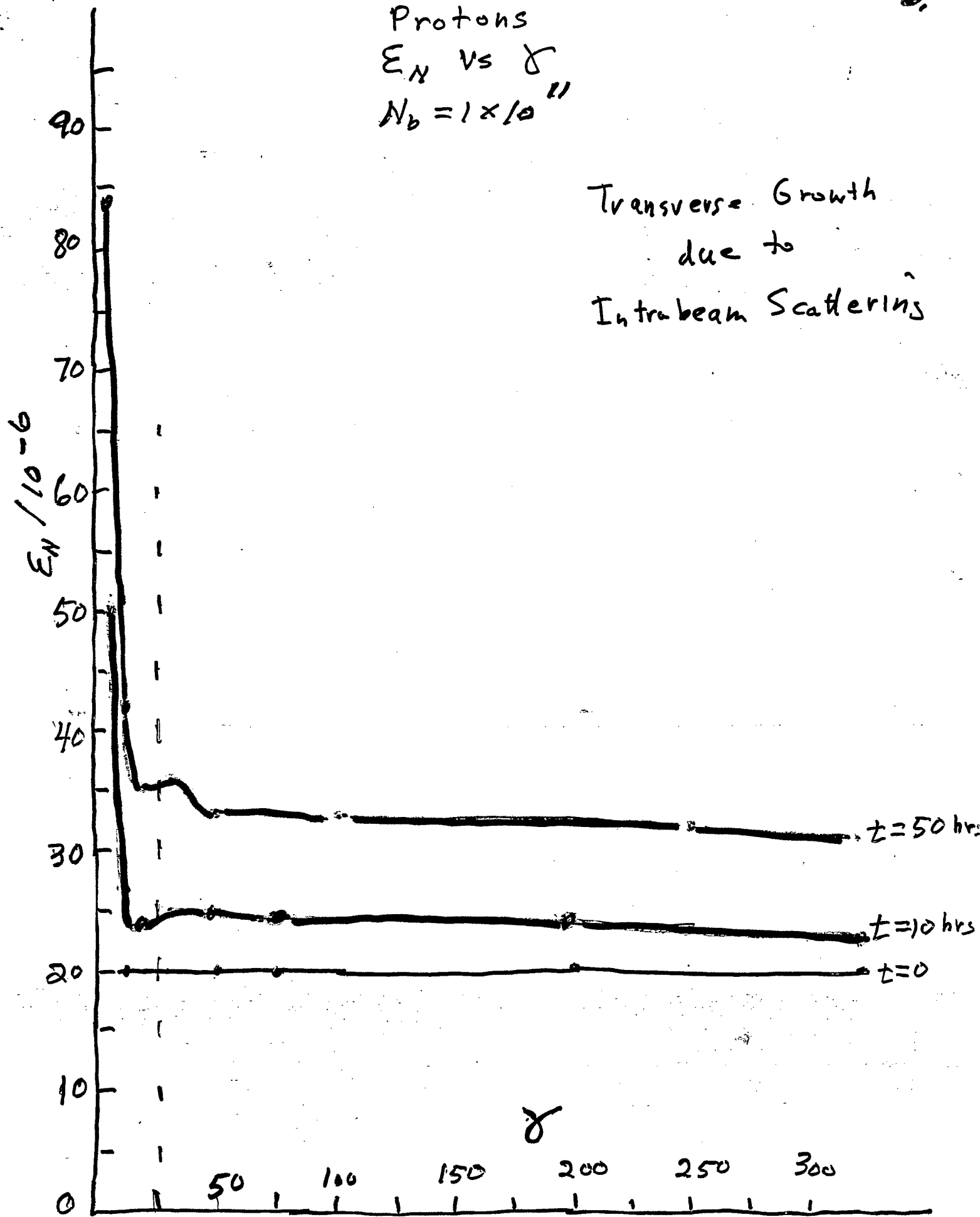
$V = 1.2 \text{ MV}$

$h = 6 \times 57$



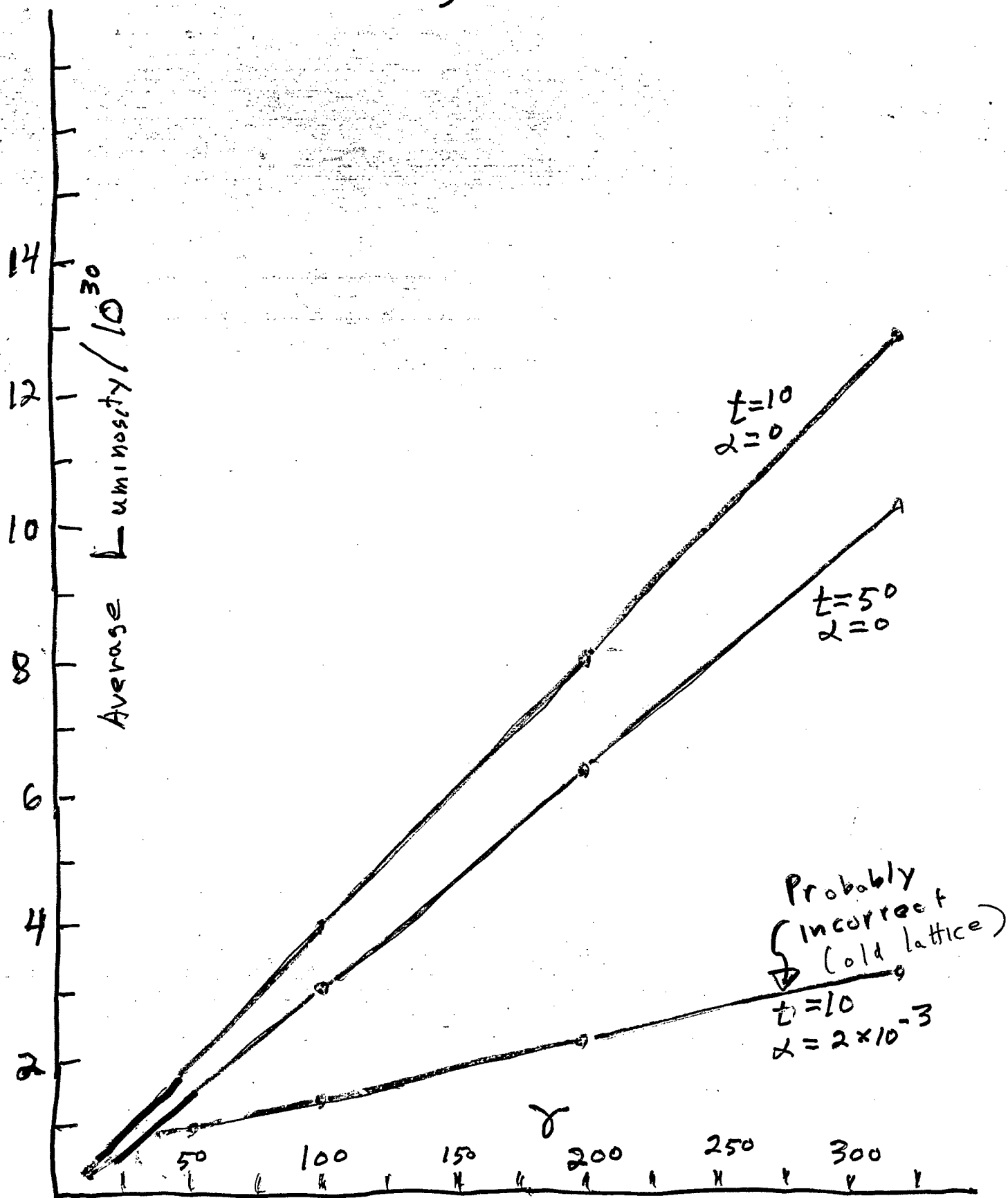
Protons
 ϵ_N vs δ
 $N_b = 1 \times 10^{11}$

Transverse Growth
 due to
 Intra beam Scattering



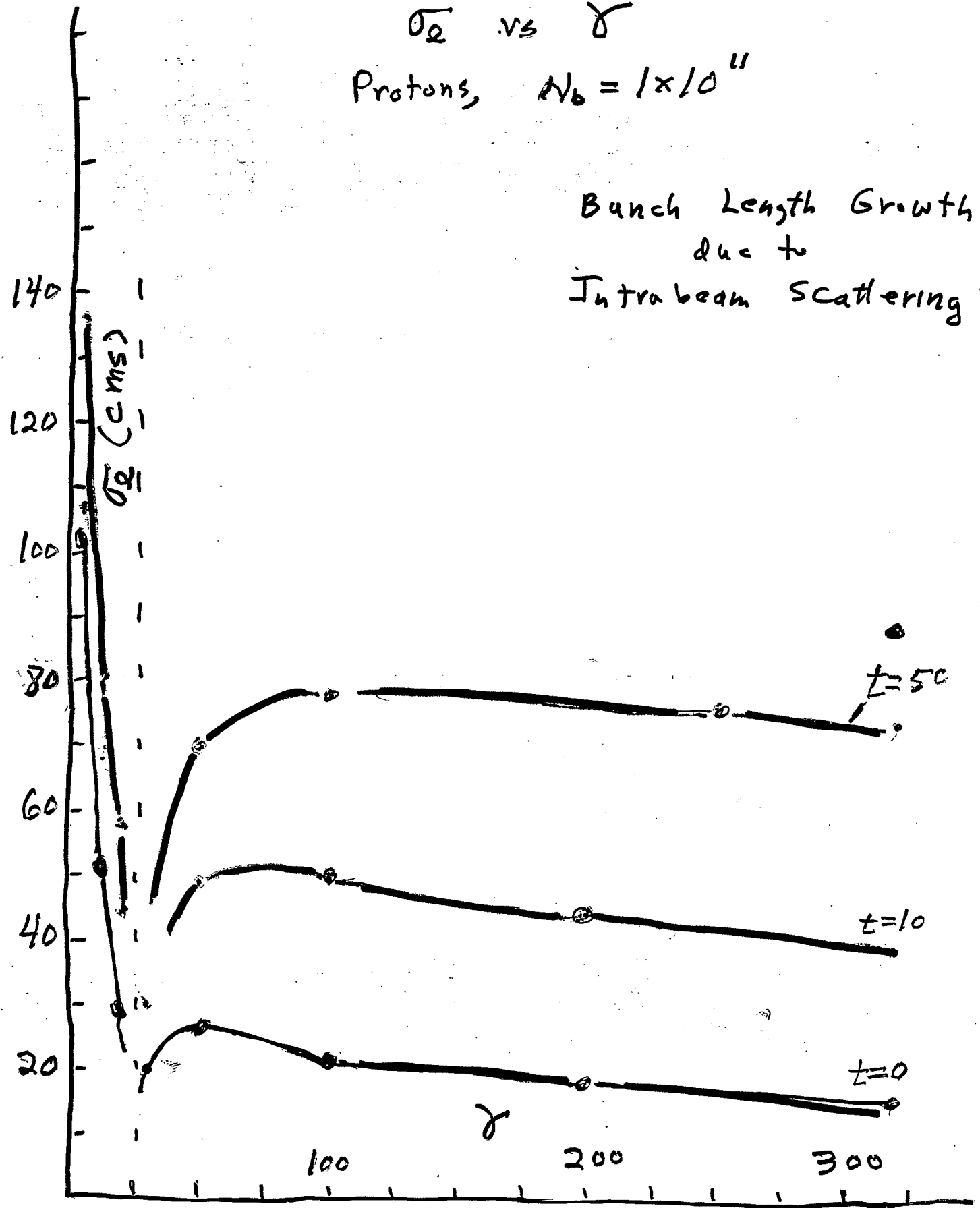
Average Luminosity vs γ
Protons, $N_b = 1 \times 10^{11}$

4.



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

$\gamma = 30$ $\sigma_H = 2.67 \text{ mm}$, $6\sigma_H = 16 \text{ mm}$, $t = 10 \text{ hrs}$

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

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

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

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.

$\gamma = 320$, $N_b = 10''$

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

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

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

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.

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

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

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

$$\Delta V_{BB} = \frac{10037}{10052}, \text{ head on collisions, } t=0 \text{ initial.}$$

$$\rightarrow 10030 \text{ after 10 hrs.}$$

$$\Delta V \sim N_b / \epsilon_N \text{ independent of energy}$$

Collective

Instabilities, $N_b = 10^{11}$

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

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

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

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

$$N_{b,T} \sim \delta^3$$

$$\left(\begin{array}{l} I_p < \frac{2 \pi E}{e} |\eta| \frac{\delta^2}{(Z_{||}/n)} \\ I_p = N_b e \beta c / \sqrt{2\pi} \sigma_z \end{array} \right)$$

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

takes 1/3 hour due to TBS.

(8)

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

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

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

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

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

May require δ increase by other means.

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

Intra beam Scattering (t=10 hrs)

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

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

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

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

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

Beam Beam Interaction

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

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

Use ϵ_N to reduce ΔV_0

$$\epsilon_N = 10 \times 20 = 200$$

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

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

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

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

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

Use α to reduce ΔV

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

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

$p = \overset{11.5}{\cancel{20}}$ needed to reduce ΔV
by factor 10

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

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

Note initial p is smaller
by factor 3.2

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

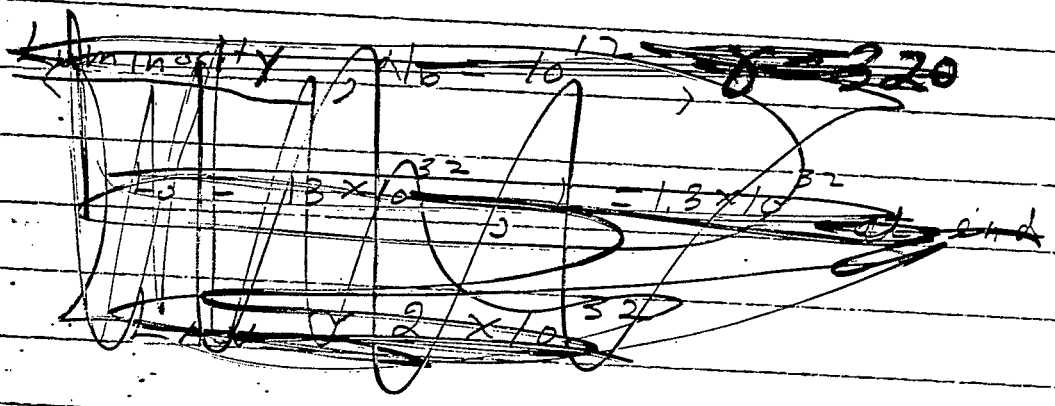
$N_b = 10^{12}$, Instabilities

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

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

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

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



~~Beam Regeneration for Au, $\delta = 13\sigma$ (bunch)~~
~~1.5 mm~~

~~Space Charge ΔV~~
~~Protons, $\gamma = 30$, $N_b = 10^{12}$ bunch, $I_{\text{beam}} = 57 \text{ A}$~~
 ~~$\Delta V_x \approx \Delta V_y \approx 27$~~

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

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

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

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

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

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

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