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Proton Performance in RHIC

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RHIC-AP-33

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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 $\gamma \simeq 320$ and high intensity, $N_b \simeq 10^{12}$/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 [redacted]

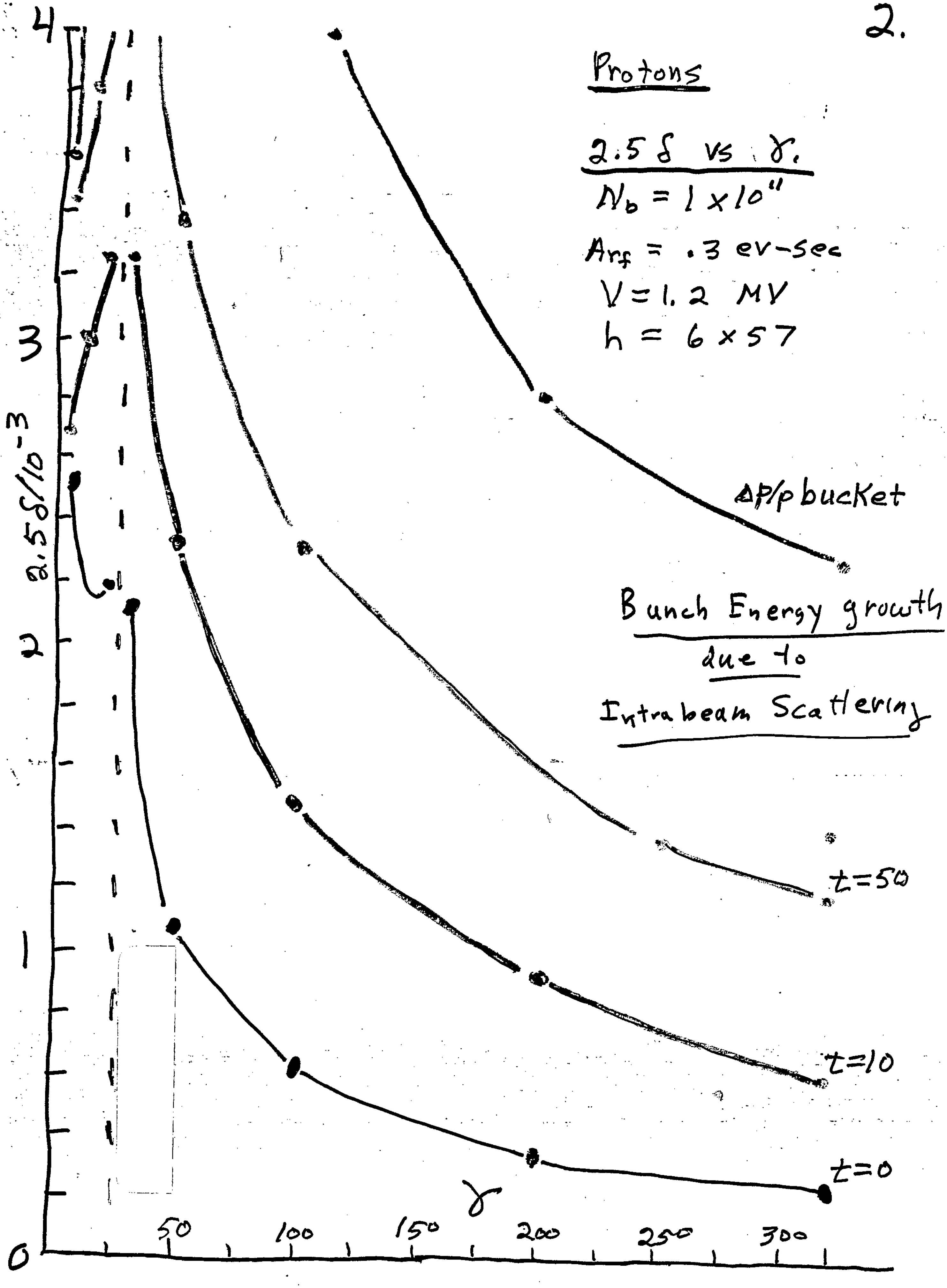
G. Parzen, ~~10/3/84~~
9/17/86

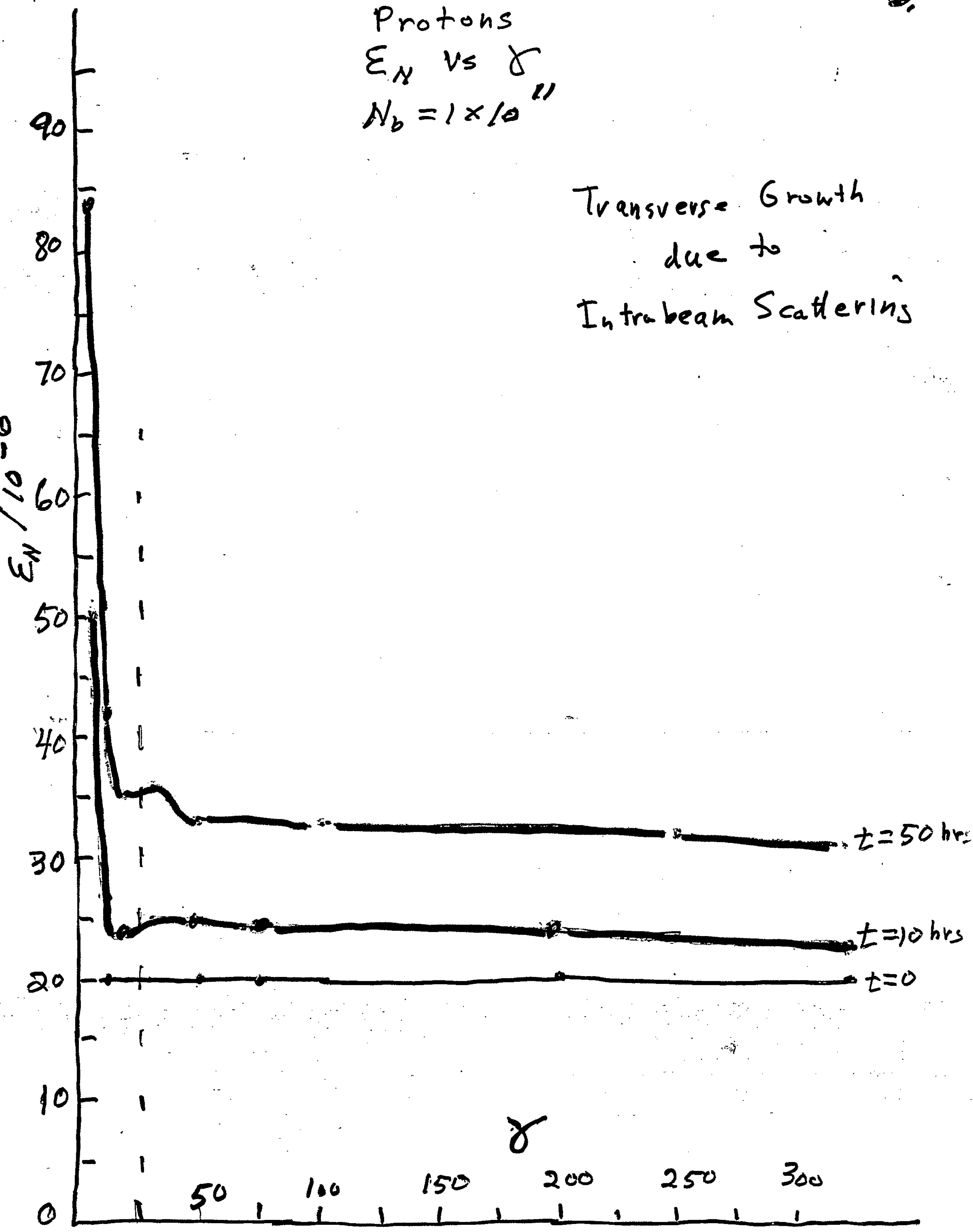
Important Limitations

1) Intra beam scattering
2) Beam – Beam interaction
3) Instabilities, $Z_{\parallel}/n$, $Z_{\perp}/n$
4) Aperture [redacted],
[redacted]
5) Space charge at $\gamma = 30$.

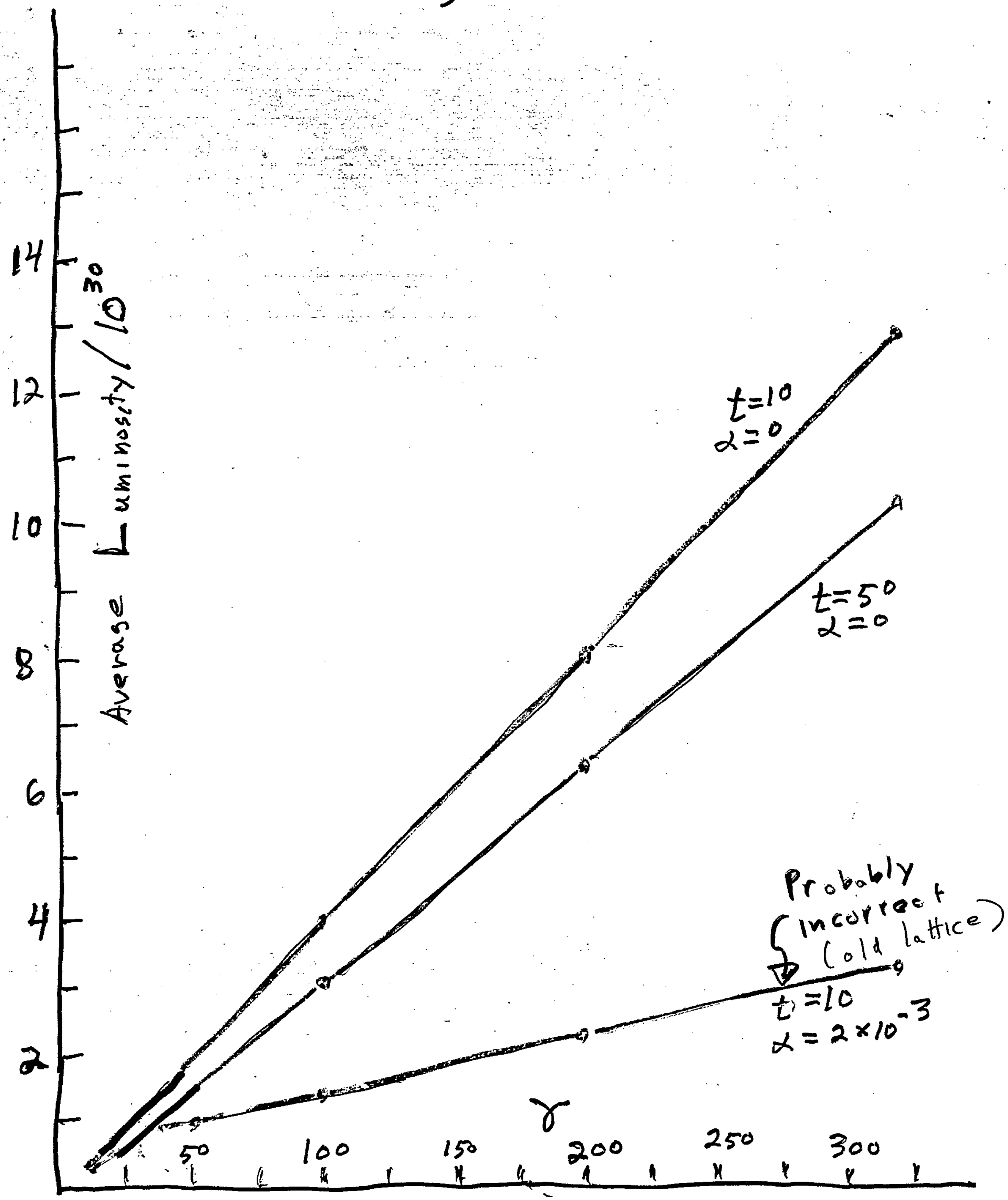
Intra beam Scattering, $N_b = 10^{11}$/bunch

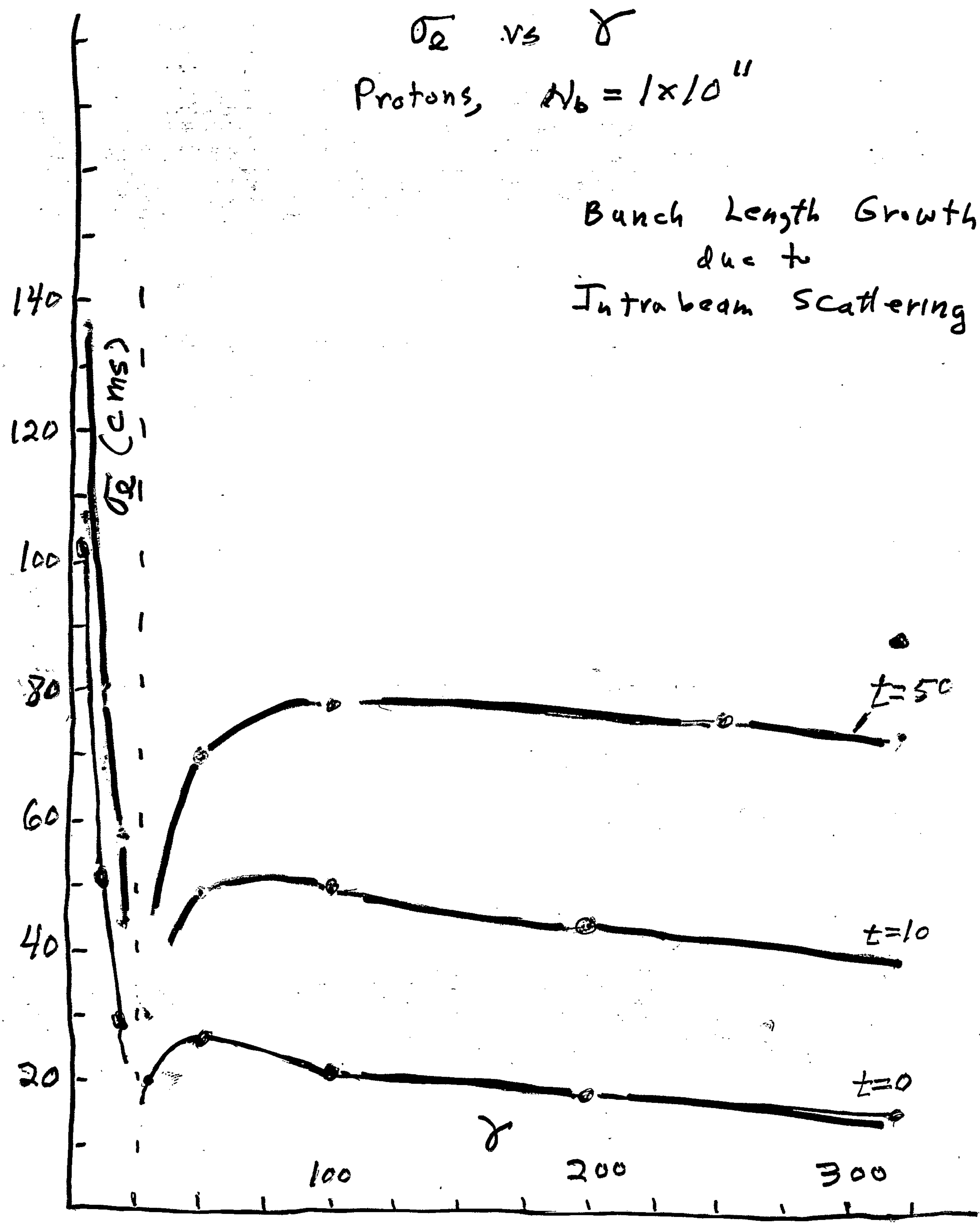
1) Longitudinal growth
2) transvers growth
~~3) aperture required~~ [redacted]
[redacted]


Protons
2.5 δ vs γ.
$N_b = 1 \times 10^{11}$
A_{rf} = .3 ev-sec
V = 1.2 MV
h = 6 × 57
Δp/p bucket
Bunch Energy growth due to Intrabeam Scattering
t=50
t=10
t=0
2.5δ/10^-3
γ
0
1
2
3
4
50
100
150
200
250
300


Protons
ε_N vs γ
$N_b = 1 \times 10^{11}$
Transverse Growth due to Intrabeam Scattering
$\varepsilon_N / 10^{-6}$
0
10
20
30
40
50
60
70
80
90
γ
50
100
150
200
250
300
t = 50 hrs
t = 10 hrs
t = 0

Average Luminosity vs γ
Protons, $N_b = 1\times10^{11}$




σ_ℓ vs γ
Protons, N_b = 1×10^11
Bunch Length Growth due to Intrabeam Scattering
σ_ℓ (cms)
140
120
100
80
60
40
20
γ
100
200
300
t=50
t=10
t=0

Aperture Requirments, $N_b = 10^{11}$/bunch

$\gamma = 30$

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

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

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

$\sigma_\ell = 30$ cms,

Maximun X = 26 mm at $\Delta p/p = \pm .0033$

a, b, effects corrected by shuffling and Correctors if necessory.

Closed orbit effect $\lesssim 1$ mm after correction.

$\gamma = 320$, $N_b = 10^{11}$

$\sigma_H = .78$ mm, $6\sigma_H = 4.7$ mm, $\sigma_\ell = 39$ cms

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

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

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

Add 1 mm for closed ORBit

Add 1 mm for a, b, effects.

Maximun X $\simeq$ 9 mm.

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

$N_b = 1 \times 10^{11}$, $\mathcal{E} = 20 \times 10^{-6}$

$\Delta\nu_{BB} =$ ~~.0052~~ .0037, head on collisions, $t=0$ initial.
→ .0030 after 10 hrs.

$\Delta\nu \sim N_b / \mathcal{E}_N$ independent of energy

Collective Instabilities, $N_b = 10^{11}$

$\gamma = 320$, $\sigma_{\ell o} = 15.8$ cms, $\delta_o = .102 \times 10^{-3}$ (initial)
$A_{rf} = .3$ ev-sec, $I_{PK} = 12$ A, $I_{av} = .43$ A

$Z/n = 10$ ohms
$N_{b,T} = .25 \times 10^{11}$ (Threshold)

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

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

$\delta = .1 \times 10^{-3} \longrightarrow .16 \times 10^{-3}$
takes 1/3 hour due to IBS.

$N_b = 10^{11}$ use

$N_{b,T}$ (Transverse) $= 4.7 \times 10^{11}$ for $\delta = .16 \times 10^{-3}$

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

Transverse $I_p < \frac{10\,E}{e} \; |\eta| \; \frac{\delta}{\beta} \; \frac{1}{(Z_\perp/n)}$

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

May require δ increase by other means.

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

Intrabeam Scattering ($t = 10$ hrs)

$\sigma_H = .98$ mm $\quad 6\sigma_H = 6$ mm

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

$\frac{\Delta p}{p} \pm 1.4\times10^{-3}$, $(\Delta p/p)_{bucket} = 2.3\times10^{-3}$

X_p $\Delta p/p$ = ± 2.2 mm

Maximum $X = 10$ mm

Beam Beam Interaction

$\Delta\nu_0 \simeq \frac{N_b}{\varepsilon_N}$, $L_0 \sim \frac{N_b^2}{\varepsilon_N \beta^*}$, Head-on collisions

$\Delta\nu_0$ too large by factor 10, $\Delta\nu_0 \simeq .04$

Use ε_N to reduce $\Delta\nu_0$

$\varepsilon_N = 10\times20 = 200$

$\sigma_H = 2.3$ mm, $6\sigma_H = 13.7$ mm

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

X_p $\Delta p/p$ = 2.2 mm

Maximum $X = 20.4$ mm at $\Delta p/p = \pm 1.4\times10^{-3}$

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

Use α to reduce $\Delta\nu$

$$\Delta\nu = \frac{\Delta\nu_0 \; 2}{1+\sqrt{1+p^2}} \quad , \quad L = \frac{L_0}{\sqrt{1+p^2}}$$

$$p = \frac{\alpha \; \sigma_z}{2 \; \sigma_H^*}$$

$p =$ ~~20~~ 11.5 needed to reduce $\Delta\nu$ by factor 10

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

$\alpha =$ ~~10.8~~ 6×10^{-3} required

<u>Note</u> initial p is smaller by factor 3.2

initial $\Delta\nu \simeq .004 \times 2.8 \simeq .011$

$N_b = 10^{12}$, Instabilities

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

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

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

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

Luminosity, $N_b = 10^{12}$, $\delta = 320$

$\mathcal{L} = 1.3 \times 10^{32}$ $= 1.3 \times 10^{32}$ end

N_b 2×10^{32}

Aperture Required δ, Δu $\delta = 15\sigma$

~ 16 mm

Space Charge $\Delta\nu$

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

$\Delta\nu_x \approx \Delta\nu_y \approx .27$

Space Charge $\Delta\nu$, $\gamma = 30$, $N_b = 10^{12}$/bunch

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

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

$$\Delta\nu_x \simeq \Delta\nu_y \simeq -.27$$

which is close to space charge limit.

Note

RHIC ; $\sigma_\ell = 20$ cms, $\gamma = 30$

AGS $\sigma_\ell \sim 8$ m $= 800$ cms at injection

$\sigma_\ell \sim 1$ m at $\gamma = 30$

Space charge $\Delta\nu$ can be reduced by keeping σ_ℓ large, $\sigma_\ell \sim 1$m, at $\gamma = 30$