RHIC-AP-7

APERTURE REQUIREMENTS
AND
PROTON PERFORMANCE IN RHIC

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Aperture Requirements and Proton Perfomance in RHIC

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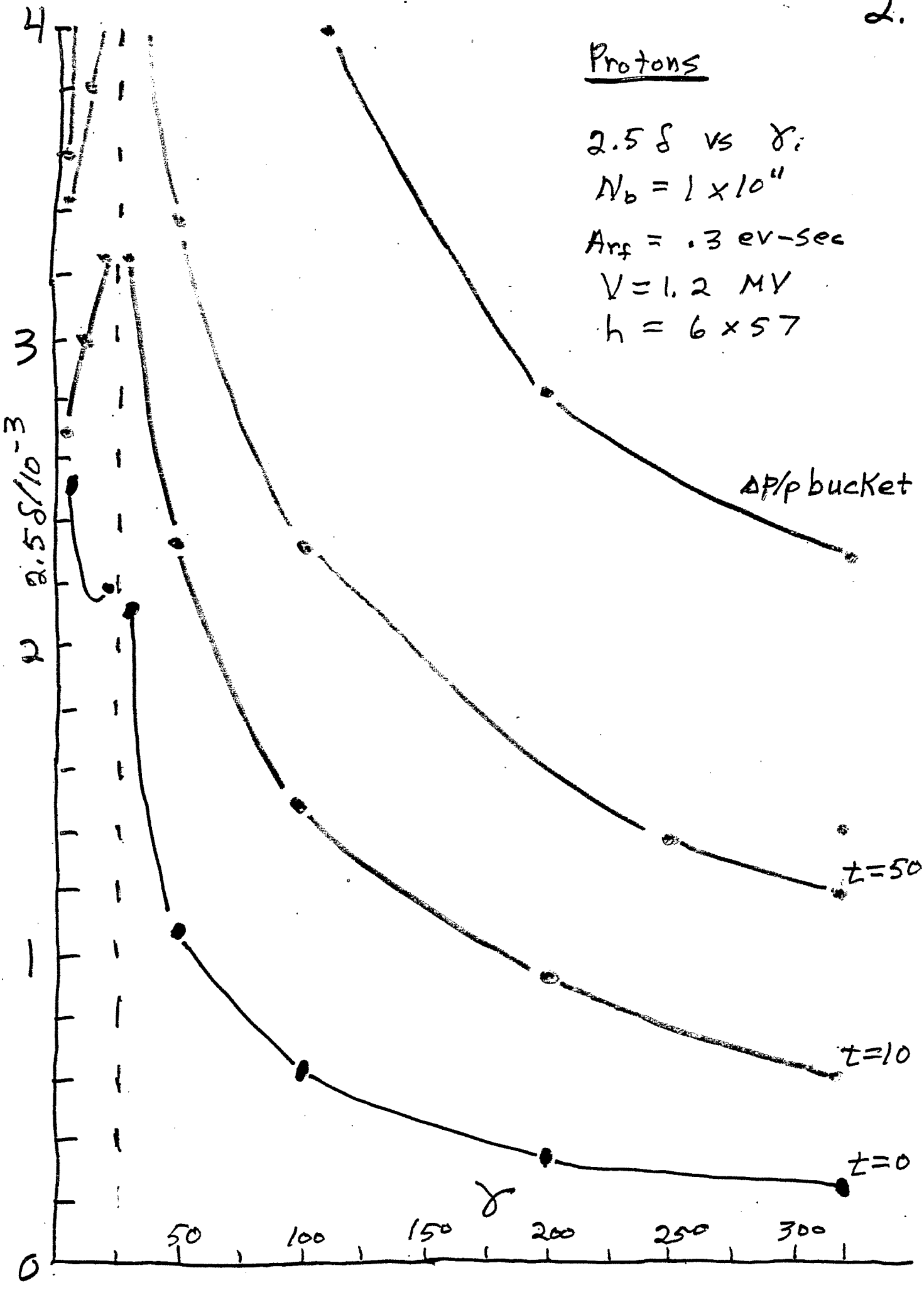
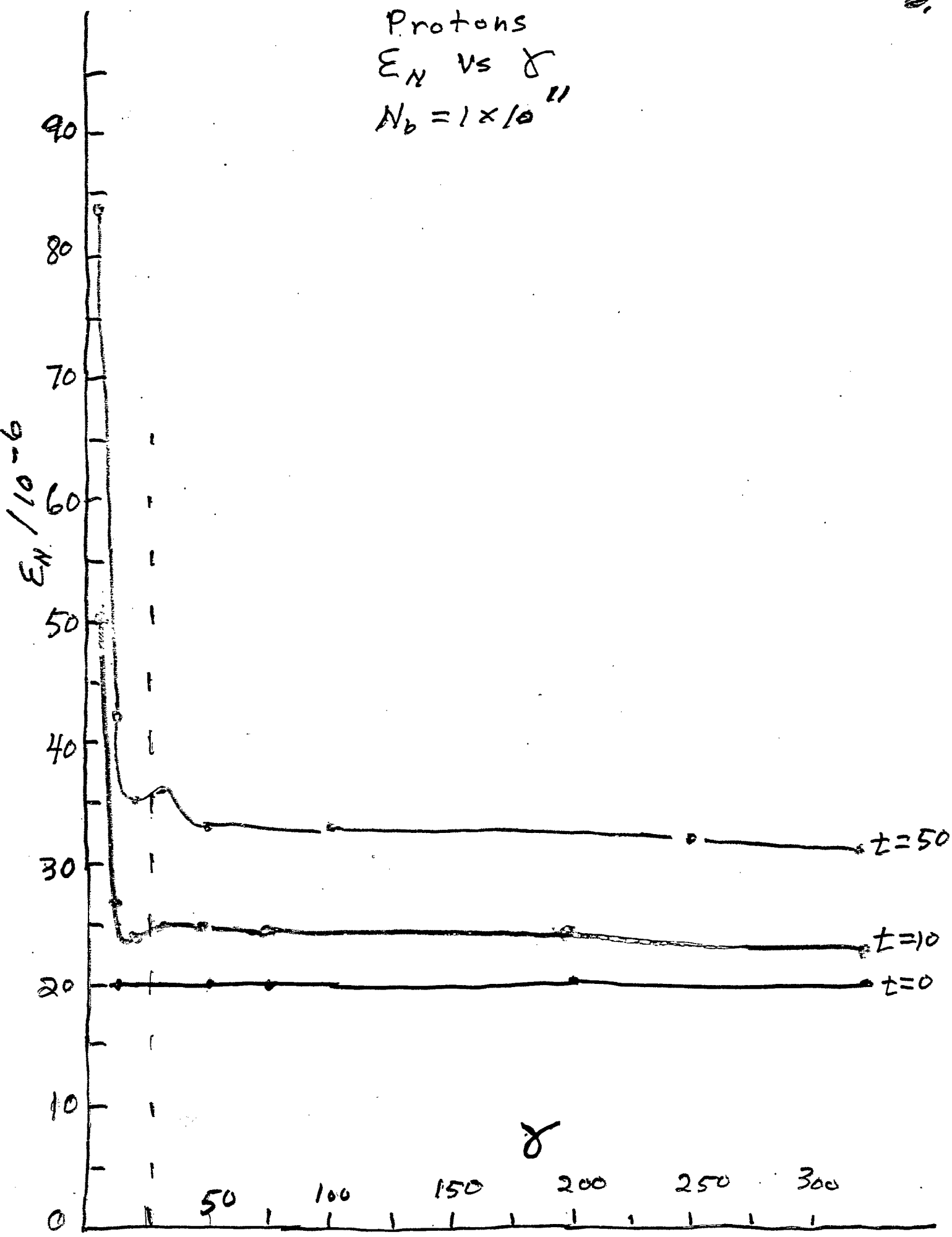
Important Limitations

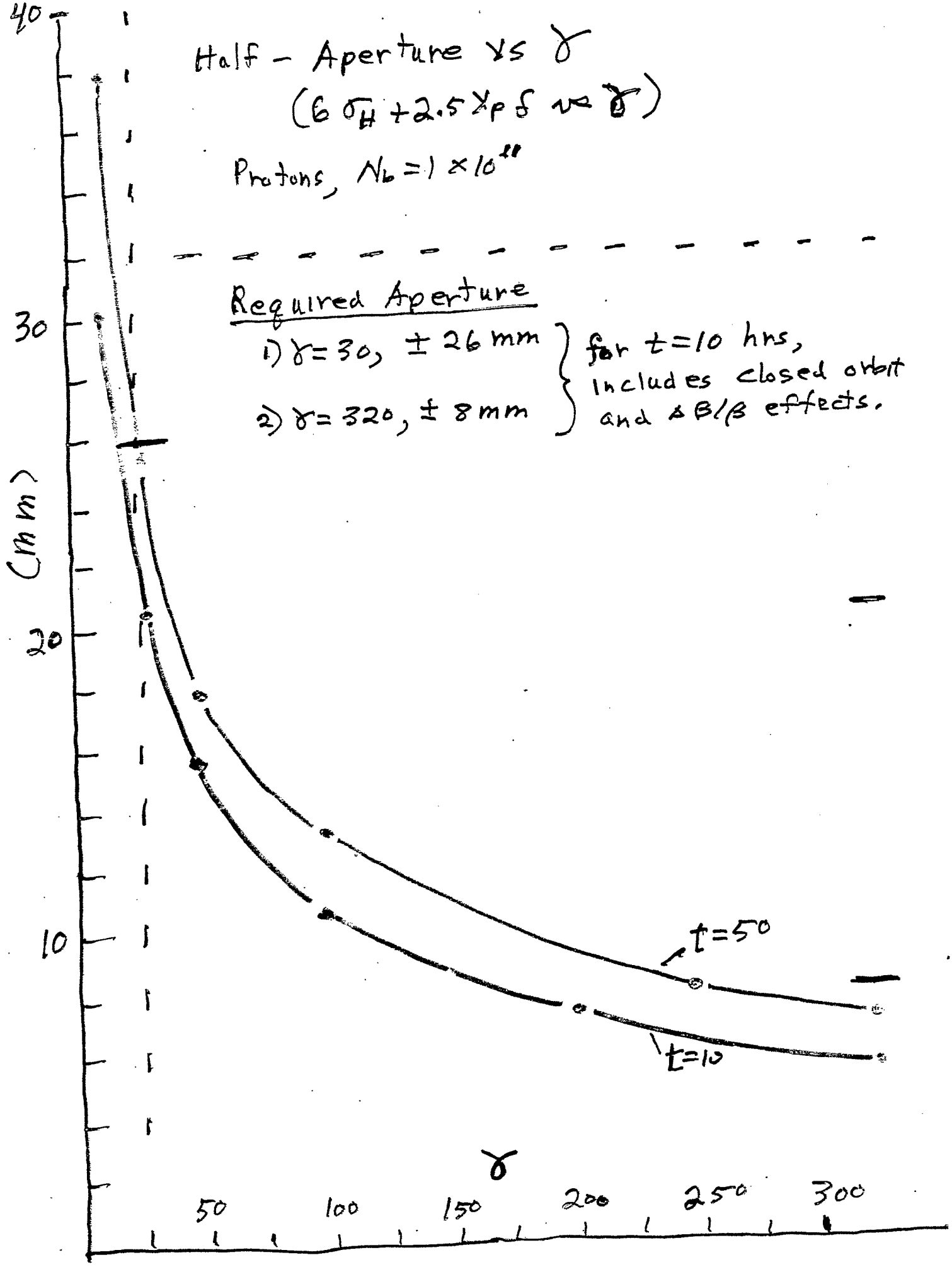
1) Intra beam scattering
2) Beam – Beam interaction
3) Instabilities, $Z_{\parallel}/n$, $Z_{\perp}/n$
4) Aperture (closed orbit errors, random $\Delta B/B$, chromatic $\Delta B/B$)

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

1) Longitudinal growth
2) transverse growth
3) aperture required — $\gamma = 30$, ± 26 mm; $\gamma = 320$, ± 320 mm
4) $t = 50$ hr operation
5) Luminosity

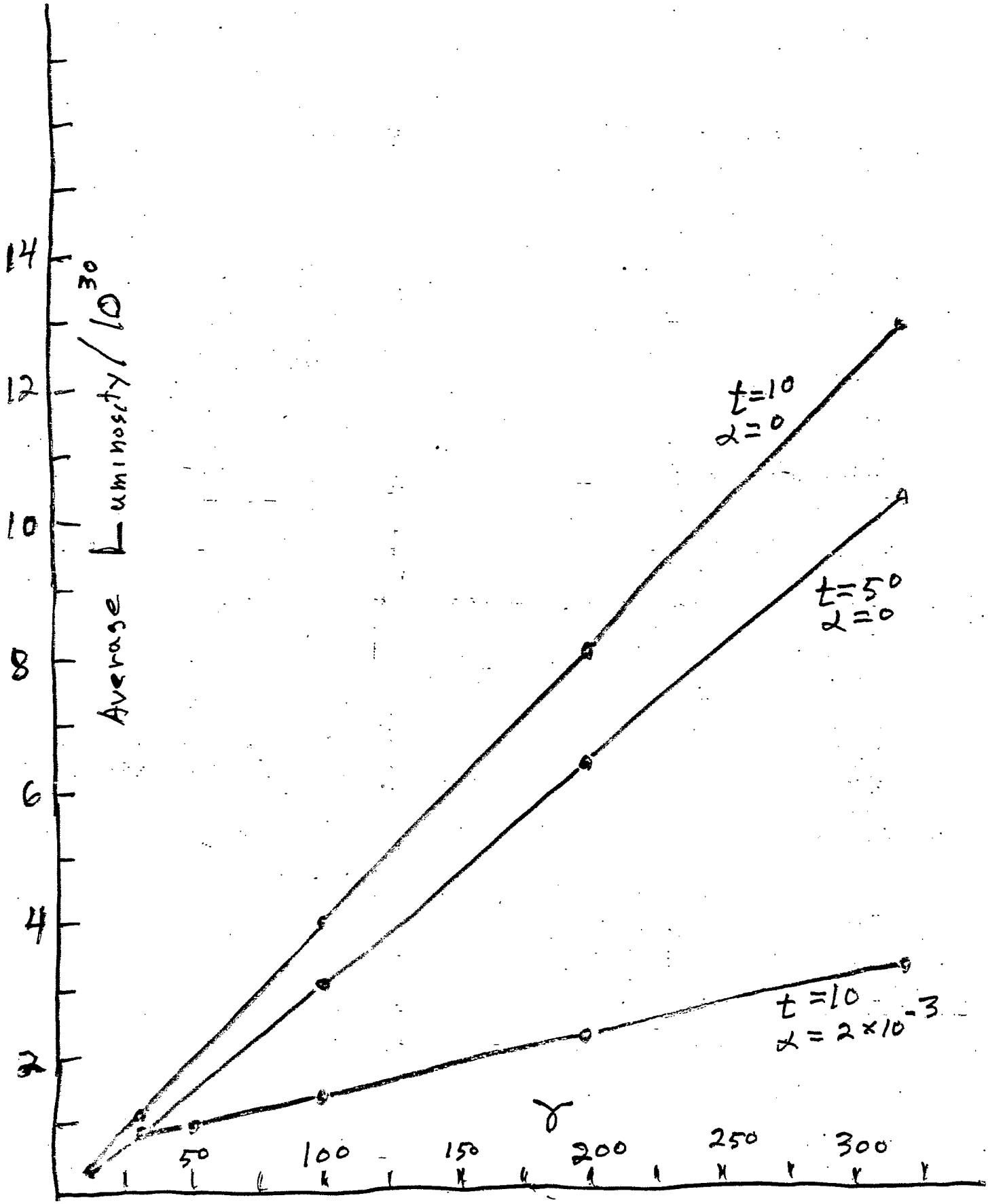

Protons
2.5 δ vs γ_i
N_b = 1 x 10^11
A_rf = .3 ev-sec
V = 1.2 MV
h = 6 x 57
Δp/p bucket
t=50
t=10
t=0
2.5δ/10^-3
γ
0
1
2
3
4
50
100
150
200
250
300

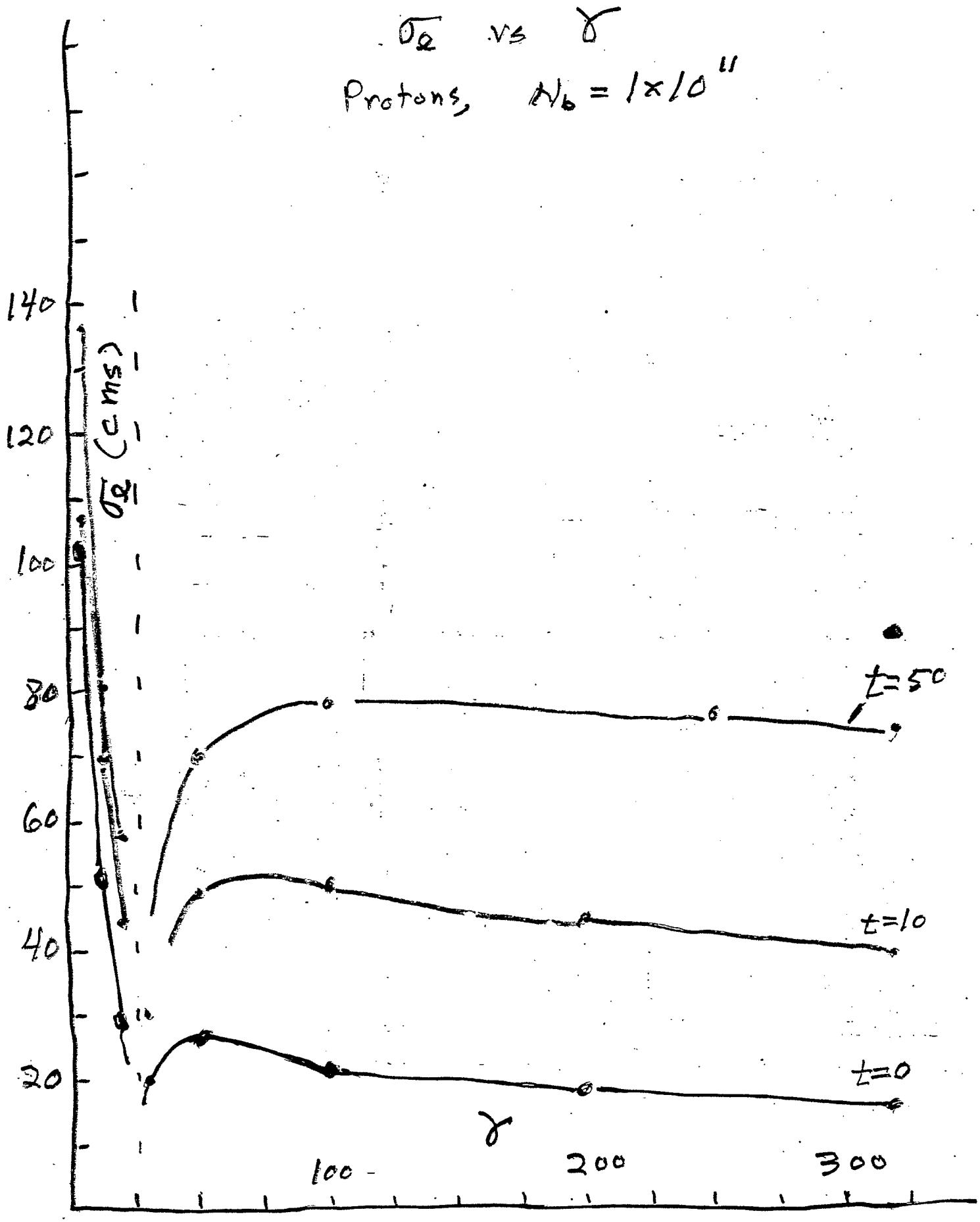

Protons
ε_N vs γ
$N_b = 1 \times 10^{11}$
$\varepsilon_N / 10^{-6}$
90
80
70
60
50
40
30
20
10
0
γ
50
100
150
200
250
300
t=50
t=10
t=0


Half - Aperture vs γ
(6 σH + 2.5 Xp δ vs γ)
Protons, Nb = 1 × 10^11
Required Aperture
1) γ = 30, ± 26 mm
2) γ = 320, ± 8 mm
for t = 10 hrs, Includes closed orbit and ΔB/B effects.
(mm)
40
30
20
10
t = 50
t = 10
γ
50
100
150
200
250
300

Average Luminosity vs γ

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




σ_α vs γ
Protons, $N_b = 1\times10^{11}$
140
120
100
80
60
40
20
σ_α (cms)
t=50
t=10
t=0
γ
100
200
300

Beam Beam Interaction

$N_b = 1\times10^{11}$, $\varepsilon \simeq 20\times10^{-6}$

$\Delta\nu_{BB} = .0052$, head on collisions, $t=0$

$\Delta\nu \sim N_b/\varepsilon_N$ independent of energy

Instabilities, $N_b = 10^{11}$

$\gamma = 320$, $\sigma_{\ell o} = 15.8$ cms, $\delta_0 = .102\times10^{-3}$

$A_{rf} = .3$ ev-sec, $I_{PK} = 12$ A, $I_{av} = .43$ A

$Z/n = 10$ ohms

$N_{b,T} = .5\times10^{11}$ (Threshold)

(AGR says 1×10^{11})

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

$$\left(\begin{array}{l} I_p < \dfrac{4\pi E}{e}\,|\eta|\,\dfrac{\delta^2}{(Z_{\parallel}/n)} \\ I_p = N_b e \beta c / \sqrt{2\pi}\,\sigma_\ell \end{array} \right)$$

$\delta = .1\times10^{-3} \longrightarrow .13\times10^{-3}$

takes 1/3 hour due to IBS

$N_{b,T}$ (Transverse) $= 2.9 \times 10^{11}$ for $\delta = .13 \times 10^{-3}$

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

<u>Transverse</u> $I_p < \frac{10\,E}{e} |\eta| \frac{\delta}{\beta} \sqrt{(Z_\perp/\eta)}$

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

May require δ increase by other means.

$N_b = 10^{12}$

Intrabeam Scattering

$\delta \rightarrow .476 \times 10^{-3}$ ($t = 10$ hrs) , $\gamma = 320$

$2.5\,\delta = 1.4 \times 10^{-3}$, $\left(\frac{\Delta p}{p}\right)_{bucket} = 2.3 \times 10^{-3}$

Aperture required $= 7.8$ mm $+ 2.5$ mm
$= 10.3$ mm

Beam-Beam Interaction

$$\Delta\nu \sim \frac{N_b}{\varepsilon_N} \quad L_0 \sim \frac{N_b^2 \gamma}{\varepsilon_N}$$

To keep, $\Delta\nu = .0052$, $\varepsilon_N \rightarrow 10 \times 20 = 200 \times 10^{-6}$

$\sigma_H = 2.3$ mm

$\delta = .48 \times 10^{-3}$, $X_p\,\delta = .78$ mm

Aperture Required $= 6\,\sigma_H + 2.5\,X_p\,\delta = 16$ mm

With closed orbit and $\Delta\beta/\beta$ effect

Aperture Required $= \pm 20.5$ mm

$N_b = 10^{12}$, Instabilities

$z/h = 10$, $N_{b,T} = .5 \times 10^{11}$

$\delta = .1 \times 10^{-3} \longrightarrow .27 \times 10^{-3}$

(would take $\frac{1}{2}$ hr due to IBS)

$N_{b,T}$ (transverse) $= 1.3 \times 10^{12}$ for $\delta = .27 \times 10^{-3}$

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

$L_0 = 13 \times 10^{32}$, $L = 1.3 \times 10^{32}$ at end.

$L_{AV} \simeq 2 \times 10^{32}$

Added Notes

1) The result used for the threshold current for the longitudinal Instability is in error by a factor of 2. This was pointed out by Harald Hahn. The result should read

$$I_p < \frac{2\pi E}{e} |\eta| \frac{\delta^2}{(Z_{\parallel}/n)},$$

and the numerical results should be modified by this factor of 2.

2) One possibly important effect has not yet been looked at in regard to operating RHIC with $N_b = 1 \times 10^{12}$ protons/bunch. This is the incoherent space charge effect, which is the ν-shift caused by the charge and current of the beam.