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Intrabeam Scattering for a Proton Beam in RHIC

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Introduction

The effects of intrabeam scattering have been computed for a proton beam in RHIC. The growth of the beam due to intra beam scattering leads to aperture requirements.

At $\gamma = 30$, the required aperture is $\pm$ 22 mm, for 10 hr. operation and for 1×10^{11} protons/bunch. An additional $\pm$ 5 mm is required for orbit effects, which are regarded as correctable. This orbit effects include

1) random variations in the β-function caused by magnet field errors.
2) random variations in the horizontal dispersion
3) chromatic effects (momentum dependent variations) in the β-function and the horizontal dispersion.

At $\gamma = 250$, the required aperture is $\pm$ 8 mm. An additional $\pm$ 1 mm is needed for correctable orbit effects. At $\gamma = 320$, the required aperture is $\pm$ 7 mm, and an additional $\pm$ 1 mm is needed for correctable orbit effects. These results are for 10 hr operation and for 1×10^{11} protons/bunch.

The intra beam scattering beam growth is weaker for protons than for gold ions, and operation times of the order of 50 hours appear feasible for protons. 50 hour operation requires a few milimeters more of aperture than 10 hour operation.

The beam growth due to intra beam scattering is largely in the energy spread which can increase by a factor of 3 in 10 hours. The transverse size of the beam only changes by about 30% in the same time.

Intra beam Scattering Results

In this study, the proton beam is bunched by an RF system whose peak voltage is 1.2 MV, the harmonic number is $h = 6 \times 57 = 342$, and the initial bunch area is assumed to be A = .3 ev-sec. The lattice used was the RHIC3 lattice, as proposed by J. Claus, with 6 insertions for colliding beams. The actual lattice was used in the calculations, including the variation of β_x, β_y, and X_p around the machine. The initial normalized transverse emittance was assumed to be $\epsilon_x = \epsilon_y = 20\,\pi \times 10^{-6}$ mr for 95% of the beam.

From the above data, one can compute the initial dimensions of the beam. The transverse dimensions are described by ε_x and ε_y and by σ_H and σ_V, $\sigma_H = (\varepsilon_x \beta_x/6\gamma)^{1/2}$, $\sigma_V = (\varepsilon_x \beta_y 16\gamma)^{1/2}$. The bunch dimensions are described by σ_ℓ, the rms bunch length, and δ, the rms energy spread. The initial value of σ_ℓ and δ can be computed from A = .3 ev-sec and the parameters of the RF system.

t = 10 hr Results (Table I)

Table I lists the initial beam state, δ_o, $\sigma_{\ell,o}$, ε_o and the final beam state δ, σ_ℓ, ε after t = 10 hrs for various energies from $\gamma = 5$ to $\gamma = 320$. Also listed are the final rms transverse beam dimensions $\sigma_E = X_p\delta$, $\sigma_H = \sigma_V$, (σ_E and σ_H are given at the focussing quadrupoles in the cells where X_p = 1.39 m and β_x = 51.4 m), and the 95% beam half-width $2.5\ (\sigma_E + \sigma_H)$.

The horizontal and vertical betatron oscillations are assumed to be fully coupled, and thus $\sigma_H = \sigma_V$ throughout the time the beam is growing.

Luminosity results are also listed in Table I. The luminosity decreases with time because of intrabeam scattering. The following luminosity results are listed. L_o, the initial luminosity for head on collisions, L_{AV}/L_o, the average luminosity over 10 hours for head on collisions divided by L_o, $L(\alpha = o)$, the average luminosity for head on collisions, and $L(\alpha = 2 \times 10^{-3})$, the average luminosity for a 2 mr crossing angle.

Figures

The following figures show the growth of the proton beam due to intrabeam scattering. Most of the figures show the beam growth for t = 10 hrs. and t = 50 hrs.

Table 1. Protons
t = 10

γ	5	12	20	30	50	100	250	320
Initial Beam								
$\delta_o/10^{-3}$	1.028	.853	.875	.869	.443	.247	.122	.102
$\sigma_{\ell o}$ (cms)	102.0	50.3	29.4	19.7	23.2	20.8	16.8	15.8
ε_o/π (mm.mr)	20.	20.	20.	20.	20.	20.	20.	20.
σ_H (mm)	5.85	3.78	2.92	2.39	1.85	1.31	.828	.731
$\sigma_E = X_p\ \delta_o$ (mm)	1.43	1.19	1.22	1.21	.616	.343	.170	.142
Final Beam								
t = 10 hrs.								
ε/π (mm.mr)	49.9	26.5	24.2	25.0	25.0	24.8	24.75	22.6
$\delta/10^{-3}$	1.07	1.18	1.30	1.30	.931	.592	.359	.249
σ_ℓ (cms)	107.	69.7	43.8	29.5	48.7	49.8	49.4	38.7
σ_H (mm)	9.25	4.35	3.22	2.67	2.07	1.45	.920	.778
$\sigma_E = X_p\delta$ (mm)	1.50	1.64	1.81	1.81	1.29	.823	.499	.346
Beam Half-Width								
2.5 $(\sigma_H+\sigma_E)$(mm)	26.3	14.7	12.3	11.0	8.25	5.58	3.48	2.75
2.5 σ_V (mm)	23.1	10.9	8.05	6.68	5.18	3.62	2.25	1.94
RF								
2.5 $\delta/10^{-3}$	2.69	2.96	3.26	3.26	2.33	1.48	.880	.622
$(\Delta p/p)/10^{-3}$ bucket)	3.60	6.04	10.6	15.7	6.81	4.24	2.56	2.29
Luminosity								
$L_o/10^{31}$	.0216	.0518	.086	.130	.216	.432	1.08	1.38
L_{AV}/L_o	.529	.858	.900	.878	.864	.880	.877	.935
L $(\gamma=0)/10^{31}$	.0114	.0444	.0774	.114	.187	.380	.947	1.29
L $(\gamma=2\times10^{-3})/10^{31}$	-	-	-	.086	.097	.142	.233	.326
Aperture Needs								
2.5 σ_E + 6 σ_H (mm)	59.2	30.1	23.8	20.5	15.6	10.7	6.74	5.51
6 σ_V (mm)	55.5	26.1	19.3	16.0	12.4	8.7	5.52	4.67

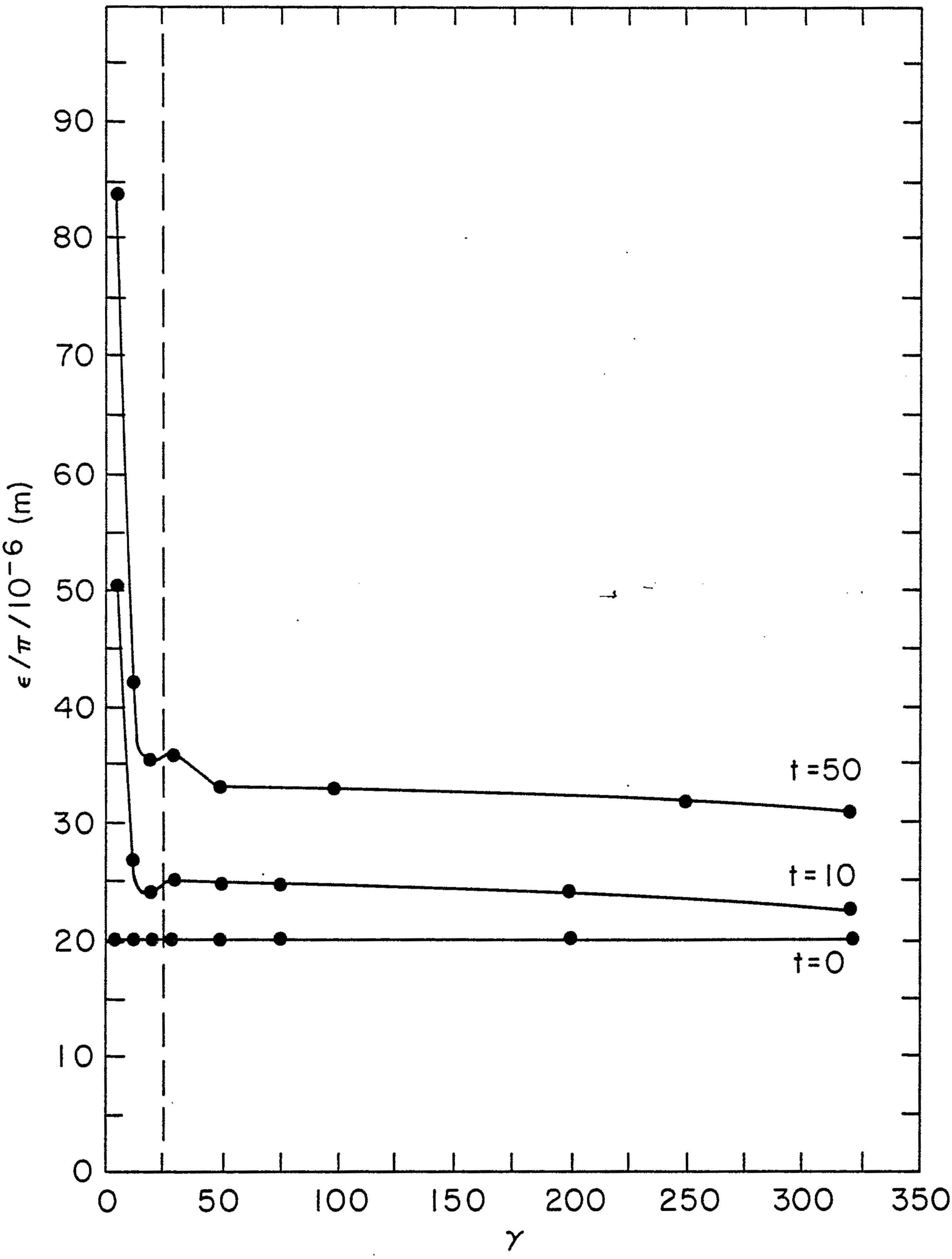

Fig. 1. Beam emittance growth due to intrabeam scattering.

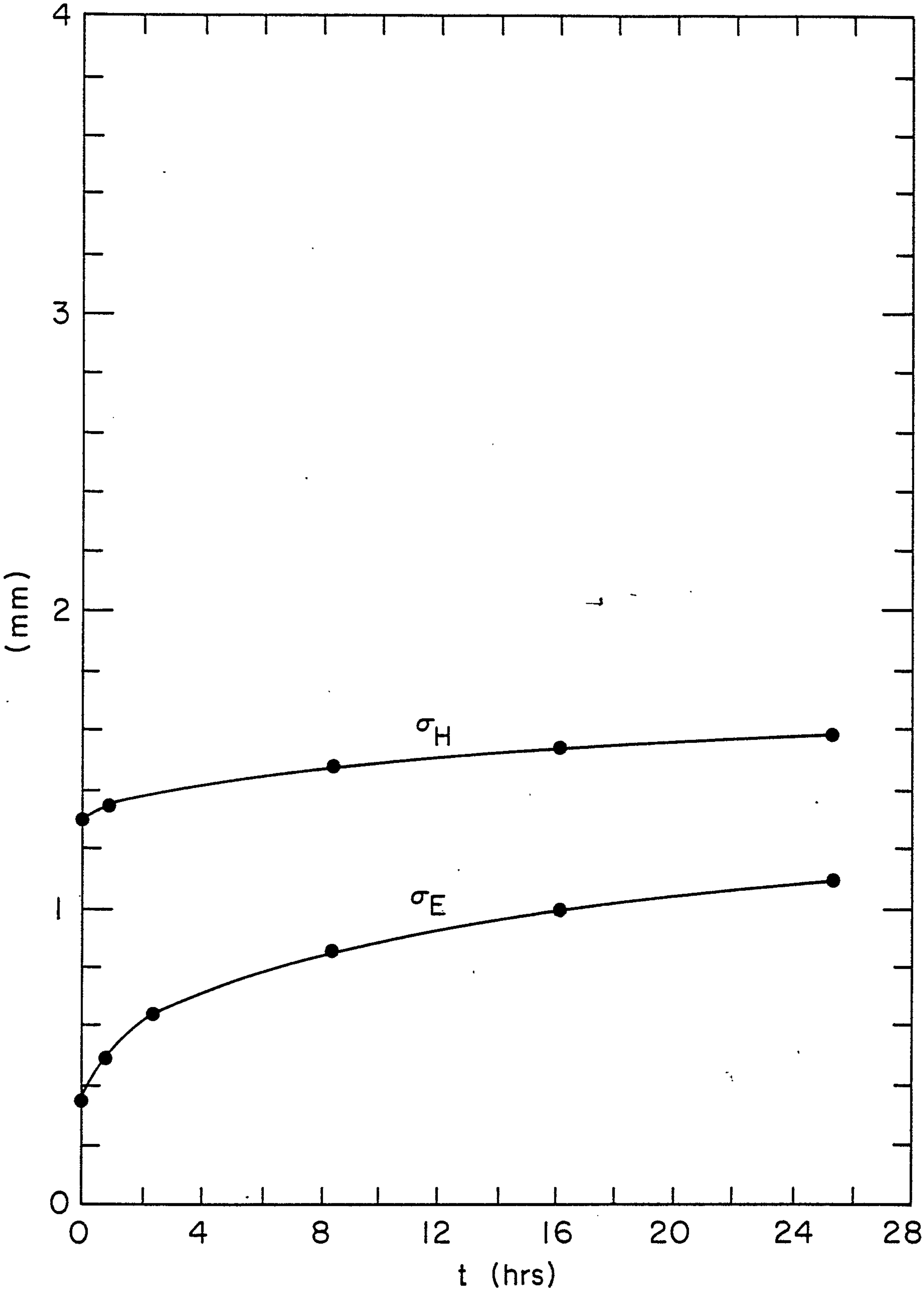

Fig. 2. Beam dimensions versus time at γ = 100.

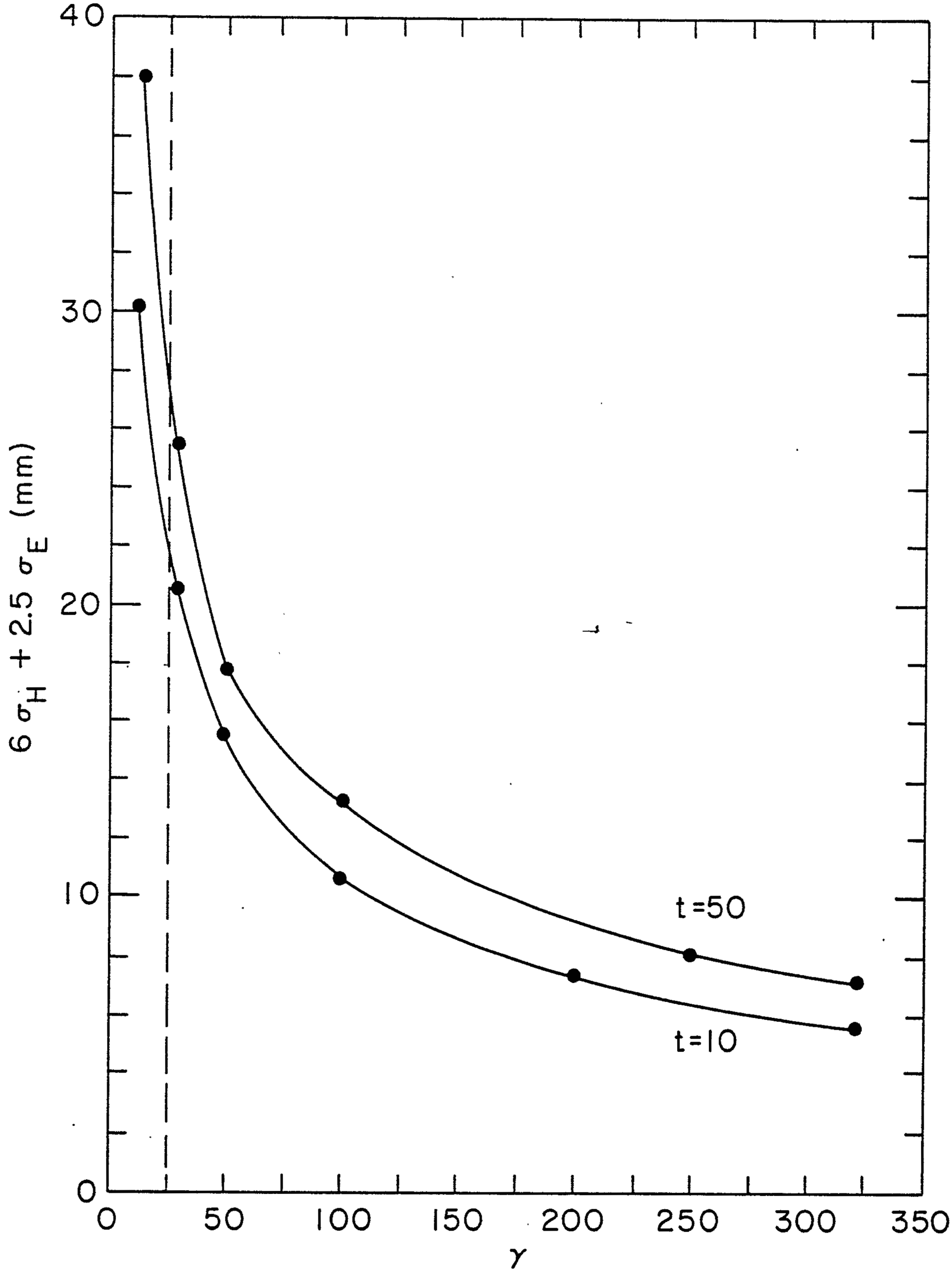

Fig. 3. Aperture half-width required due to intrabeam scattering.

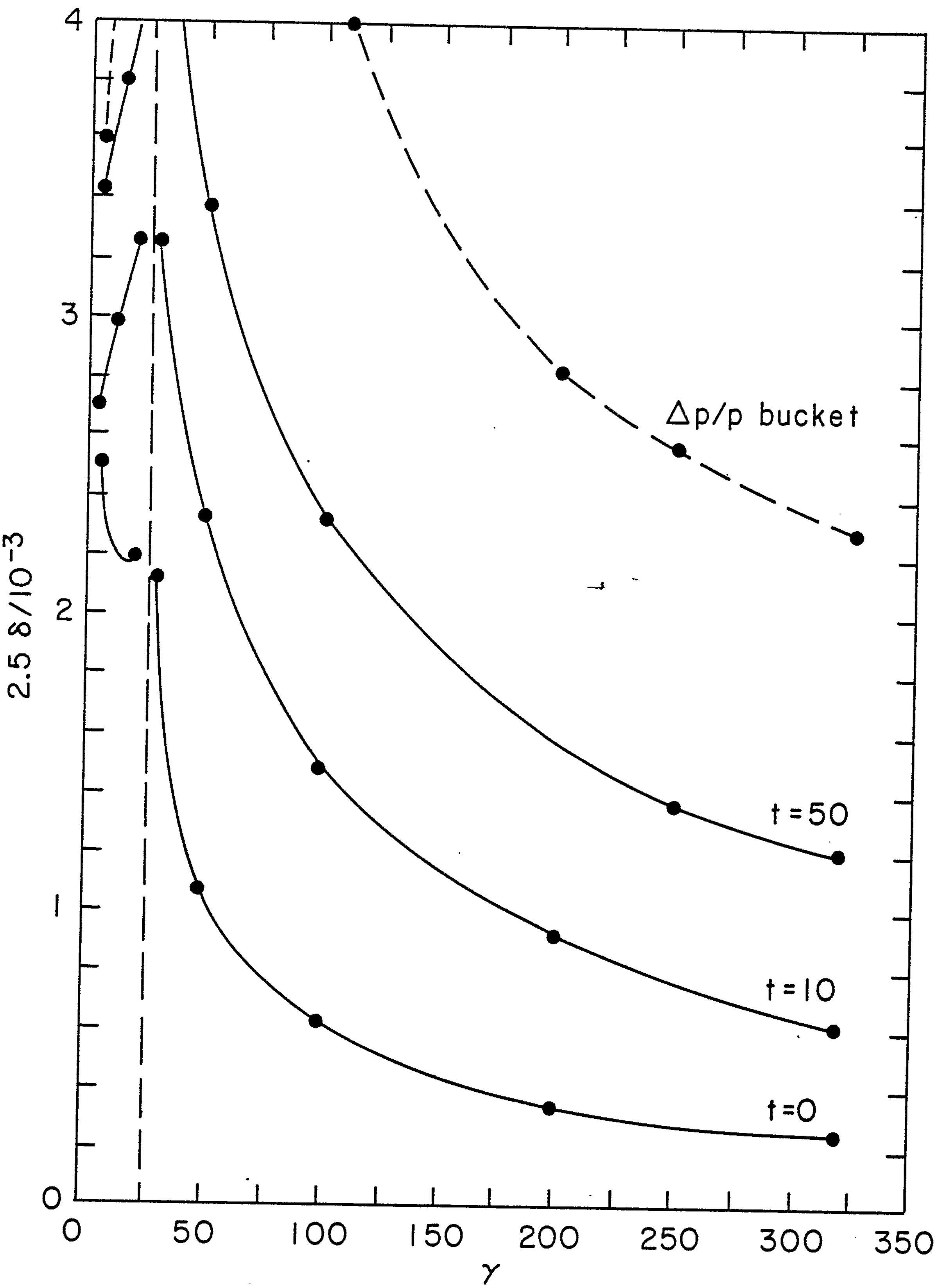

Fig. 4. Beam bunch height growth due to intrabeam scattering.

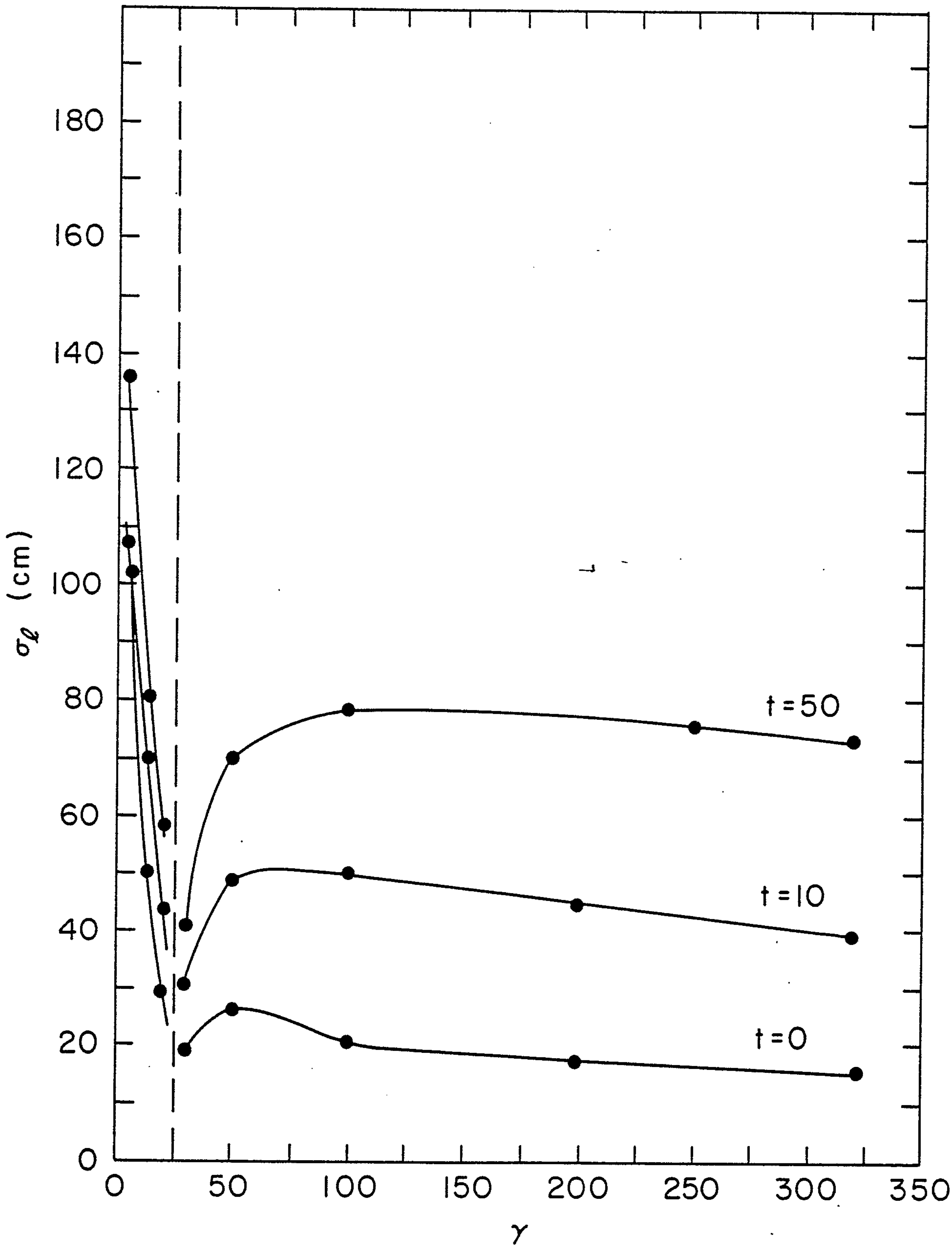

Fig. 5. Bunch length growth due to intra beam scattering.

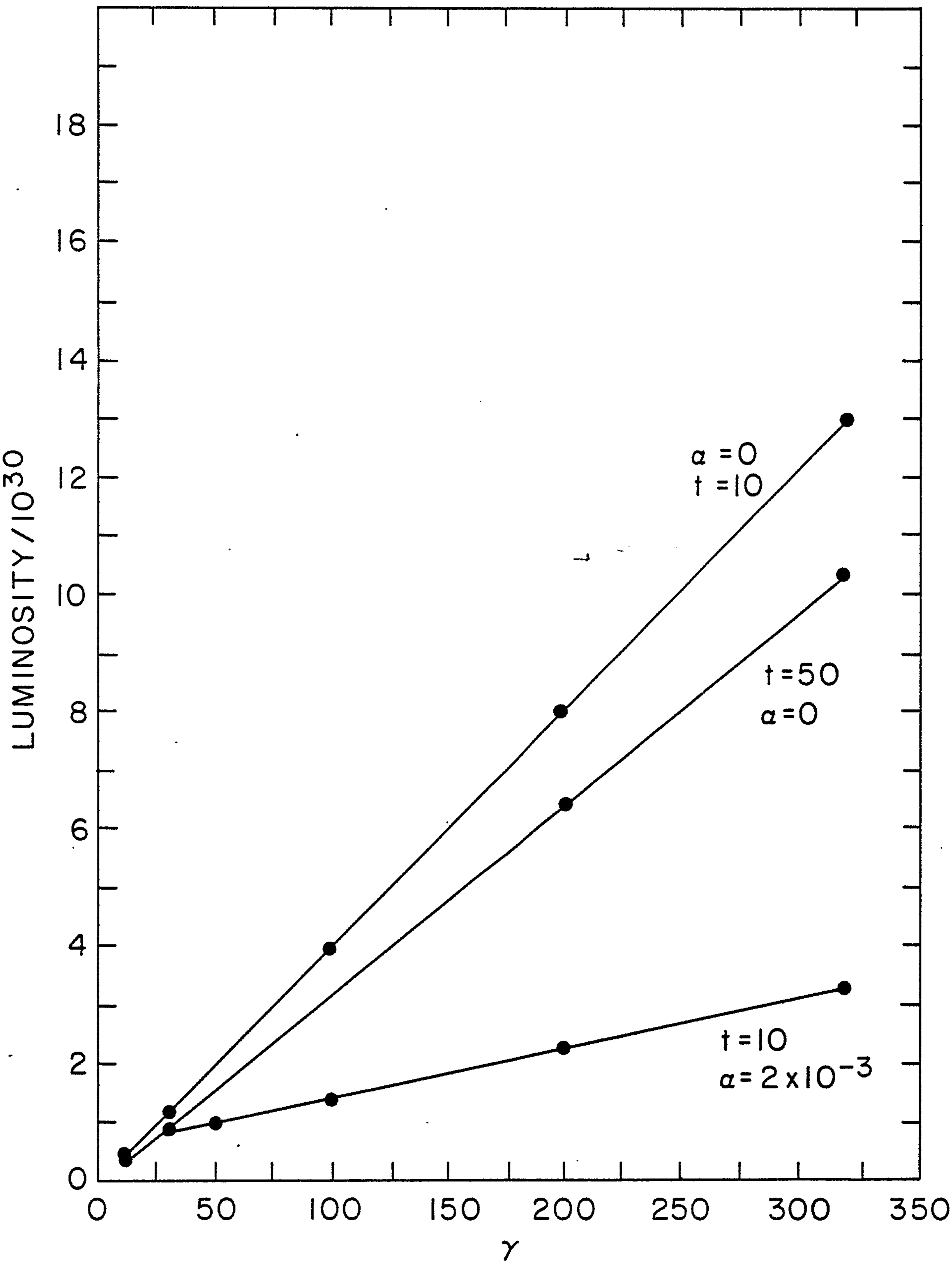

Fig. 6. Average Luminosity vs. γ.