LEP-70/35

31.1.1978

LOW ENERGY CHARACTERISTICS OF LEP-70

A. Hutton

It is well known that the characteristics of an electron beam in a storage ring are energy dependent. It is possible to modify this energy dependence by suitably altering the parameters of the storage ring, notably by altering the tune of the machine or inserting wigglers. For LEP-70 it has been decided to rely primarily on wigglers unless it can be demonstrated that chromaticity correction schemes exist for several different values of the tune. A further decision is to attempt to maintain the emittance of the electron beam constant with energy, implying that the current I in collision mode scales proportionally to the energy E and the peak luminosity $\mathcal{L}$ scales as E^2. This is in contrast to the energy variation of luminosity proposed for the 100 GeV LEP (constant for $E > 750$, $\propto E^2$ for $E < 50$). The effect of wigglers on the beam characteristics has been worked out in some detail [1,2,3] and the formulae previously obtained will be used without derivation.

1. Disposition of wigglers in the ring

Figure 1 shows the layout of LEP-70 near the interaction region. The wigglers should be in a region where the Courant and Snyder Invariant W (also known as $\mathcal{H}$) is the normal lattice value where

$$W = \frac{\eta^2 + (\eta\,\alpha_x + \eta'\,\beta_x)^2}{\beta_x}$$

The most suitable position is the empty cell which serves as dispersion suppressor. It has been shown previously that the best position for the wigglers is next to a horizontally defocussing (D) quadrupole for two reasons. Firstly, the vertical beam size is large which reduces the synchrotron radiation intensity on the vacuum chamber walls. Secondly, the horizontal beam size is small which offsets the sagitta variations in the wigglers. The D quadrupole in the centre of the empty cell is especially favourable for the latter point since the dispersion is also small and by choosing the length of the individual wiggler magnets, ℓ_w, sufficiently small, it will be possible to use the standard vacuum chamber. The space available for the sagitta is 13.6 mm. The wigglers should be more or less equally distributed around the ring, there being 16 possible sites.

2. Emittance and energy spread

The effect of the wigglers on the emittance ε_x compared with the emittance at top energy ε_{x0} (from which the aperture of the machine is calculated) is given by

$$\frac{\varepsilon_x}{\varepsilon_{x0}} = \left(\frac{E}{E_0}\right)^2 \left[\frac{1 + \frac{L_w}{L_0}\left(\frac{\rho_0}{\rho_w}\right)^3 \frac{W_w}{W_0}}{1 + \frac{L_w}{L_0}\left(\frac{\rho_0}{\rho_w}\right)^2}\right]$$

where L_w is the total length of wiggler magnets in the ring, L_0 is the total length of lattice bending magnets (L_0 = 14421.76 m), ρ_w is the bending radius in the wiggler magnets, ρ_0 is the bending radius in the lattice bends (ρ_0 = 2295.29 m), W_w is the average W value in the wiggler magnets, W_0 the average W value in the lattice, E is the energy and E_0 the top energy (E_0 = 70 GeV). The position of the wigglers has been chosen such that $W_w = W_0$ to within 1%.

The effect of the wigglers on the relative energy spread δ compared with the relative energy spread at top energy δ_0 (which determines the range of momentum errors over which chromaticity correction is required) is given by

$$\frac{\delta}{\delta_0} = \frac{E}{E_0}\left[\frac{1 + \frac{L_w}{L_0}\left(\frac{\rho_0}{\rho_w}\right)^3}{1 + \frac{L_w}{L_0}\left(\frac{\rho_0}{\rho_w}\right)^2}\right]^{\frac{1}{2}}$$

In the present case these two equations are identical and if the emittance is kept constant, so is the relative energy spread and therefore the aperture requirement will be the same.

There is an exact solution to the requirement $\delta = \delta_0$ which can be found from ϕ where

$$\sinh 3\phi = \frac{3}{2}\left(\frac{3}{L_W/L_0}\right)^{\frac{1}{2}}\left(\frac{E}{E_0}\right)^2$$

then

$$\frac{\rho_0}{\rho_W} = \frac{1}{2}\left(\frac{3}{L_W/L_0}\right)^{\frac{1}{2}} \frac{1}{\sinh \phi}$$

The field required in the wiggler magnets is then obtained from ρ_W by the standard formulae. Figure 2 shows the field in the wiggler magnets required for constant emittance and constant relative energy spread as a function of energy for three values of L_W (16, 32 and 64 m). The fields are not high and can be produced by normal magnets.

3. Transverse damping time

The transverse damping time τ_x (= τ_y) compared with the damping time at top energy τ_{x0} = 11.6 ms is given by

$$\frac{\tau_x}{\tau_{x0}} = \left(\frac{E}{E_0}\right)^{-3}\left[1 + \frac{L_W}{L_0}\left(\frac{\rho_0}{\rho_W}\right)^2\right]^{-1}$$

Figure 3 shows the damping time as a function of energy for three values of L_W (16, 32 and 64 m) as well as the natural damping time. Above about 30 GeV there is little difference between the four cases. However, the damping time is particularly important for injection and at low energies there is a considerable difference between the various cases considered. This is better seen in Figure 4 which shows the transverse damping time as a function of the total length of wiggler magnets L_W at various energies (10, 15, 20 and 25). There is a considerable overlap between these curves and reasonable damping times can be obtained at low energies with a rather modest length of wiggler magnets.

4. Length of individual wiggler magnets

For the present, the total length of wiggler magnets in the ring is assumed to be 32 m. This may require modification at a later date when the injection energy has been settled. Then the maximum sagitta difference Δx in the individual wiggler block (consisting of four magnets of length ℓ_w with separation s connected in a + - - + fashion) is given by

$$\Delta x = \frac{\ell_w(\ell_w + s)}{\rho_w}$$

where $\Delta x < 14$ mm and ρ_w has a minimum value of 4.48 m at 10 GeV. Choosing $\ell_w = 0.5$ m and $s = 0.25$ m leads to a sagitta difference of 8.4 mm, well within the aperture of the standard vacuum chamber. In this case all of the 16 possible sites contain one wiggler block of four magnets.

5. Variation of machine parameters with energy

The layout of the wigglers is now determined as is their field and it is possible to use the program BEAMPARAM to calculate the parameters of the beam and the RF system at all energies. The first observation was that the energy spread was constant to better than 1% over the whole energy range. The emittance was less constant due to small differences between W_W and W_0 but the aperture requirement was constant to within ± 1 mm. Two cases must be considered. In collision mode, the current varies proportionally to the energy such that the peak luminosity varies as the square of the energy as shown in Figure 5. The maximum current required is 10.6 mA at 70 GeV and this current must be injected and accelerated. The machine parameters for the two cases are shown in Figures 6 and 7. The synchrotron tune remains below 0.12 over the whole range of energies (10 - 70 GeV) and the natural bunch length is less than 2 cm over the energy range. This will, however, be altered significantly by the higher harmonic cavity. The RF parameters are shown in Figure 7 demonstrating the expected steep dependence of the RF power with energy above about 40 GeV, while at lower energies the higher mode losses predominate and the power is not so strongly dependent on the energy.

An important parameter is the bremsstrahlung lifetime since this will determine how frequently the beams must be replenished $^{4)}$. This is shown in Figure 8 indicating that the worst case is at 70 GeV (6¼ hours) and varies approximately as the reciprocal of the energy. Thus the average luminosity will not vary quite as much as the peak luminosity.

6. Summary

The low energy characteristics of LEP-70 Version 5 have been examined including the effect of wigglers designed to keep the emittance constant. The results shown should remain more or less valid even if the parameters of LEP-70 are altered during the course of the study.

References

1) A. Hutton; Control of the Low Energy Characteristics of the LSR Electron Ring using Wiggler Magnets. Particle Accelerators 7, (1976) 177.

2) A. Hutton; Maintaining Constant Luminosity in Electron Storage Rings using Wiggler Magnets. CERN/ISR-LTD/76-20 (1976).

3) A Hutton; CHEEP Polarization Kinks. CERN/ISR-TH/77-48 (1977).

4) E. Keil; Optimization of the Average Luminosity in LEP-70. LEP-70/13 (1977).

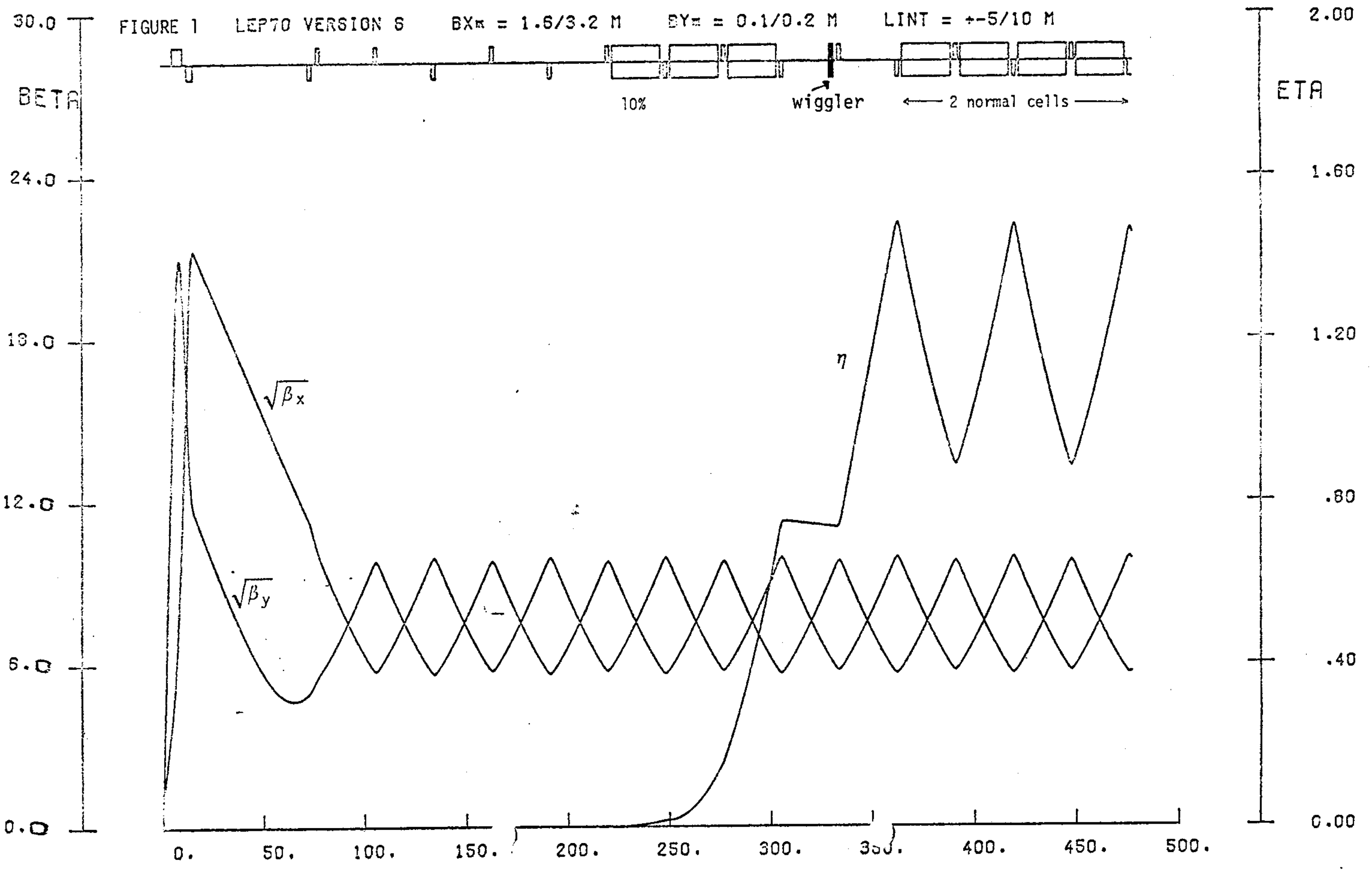

FIGURE 1 LEP70 VERSION 6 BX* = 1.6/3.2 M BY* = 0.1/0.2 M LINT = +-5/10 M

FIGURE 2 WIGGLER FIELD FOR CONSTANT EMITTANCE

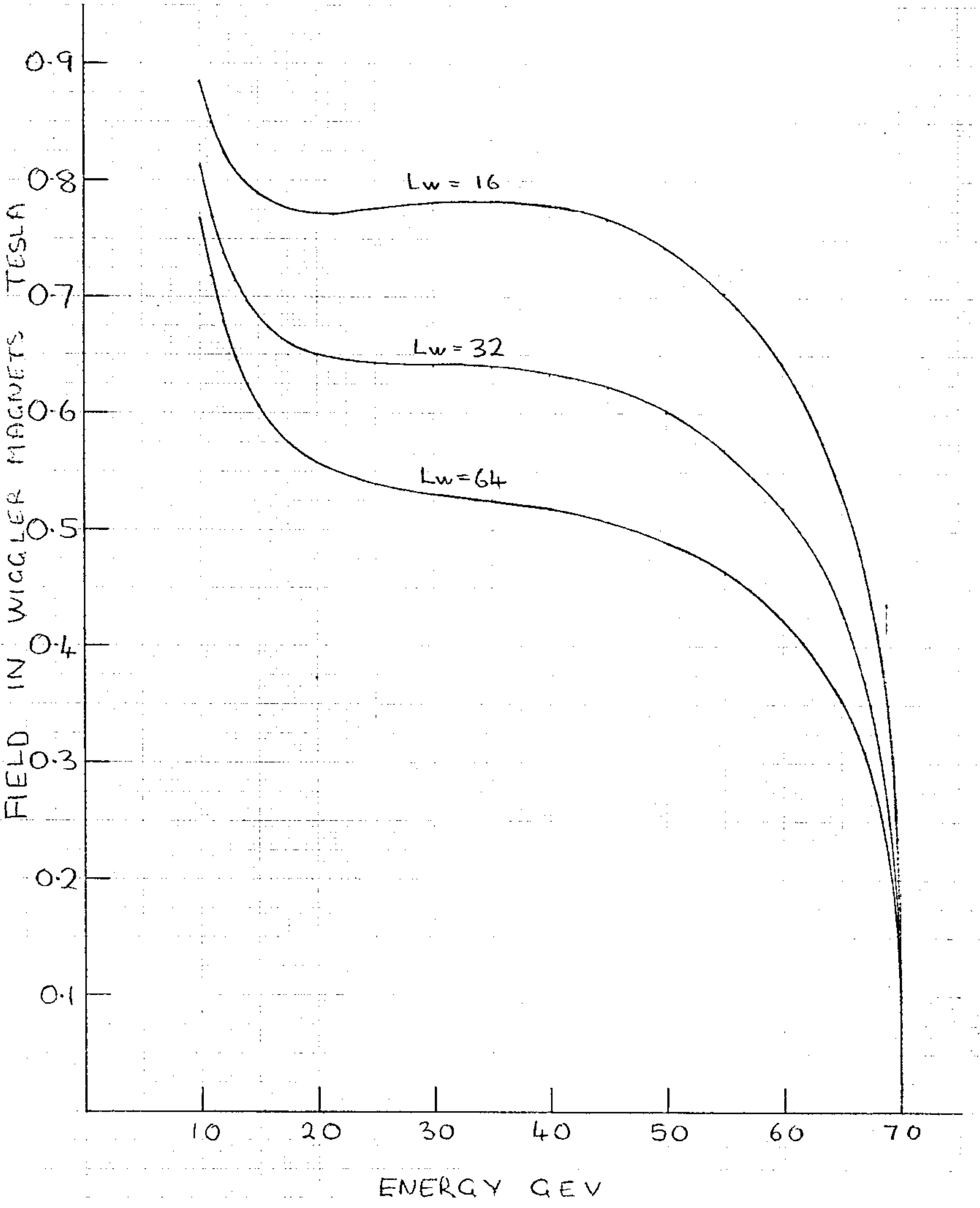

FIGURE 3 DAMPING TIME VERSUS ENERGY

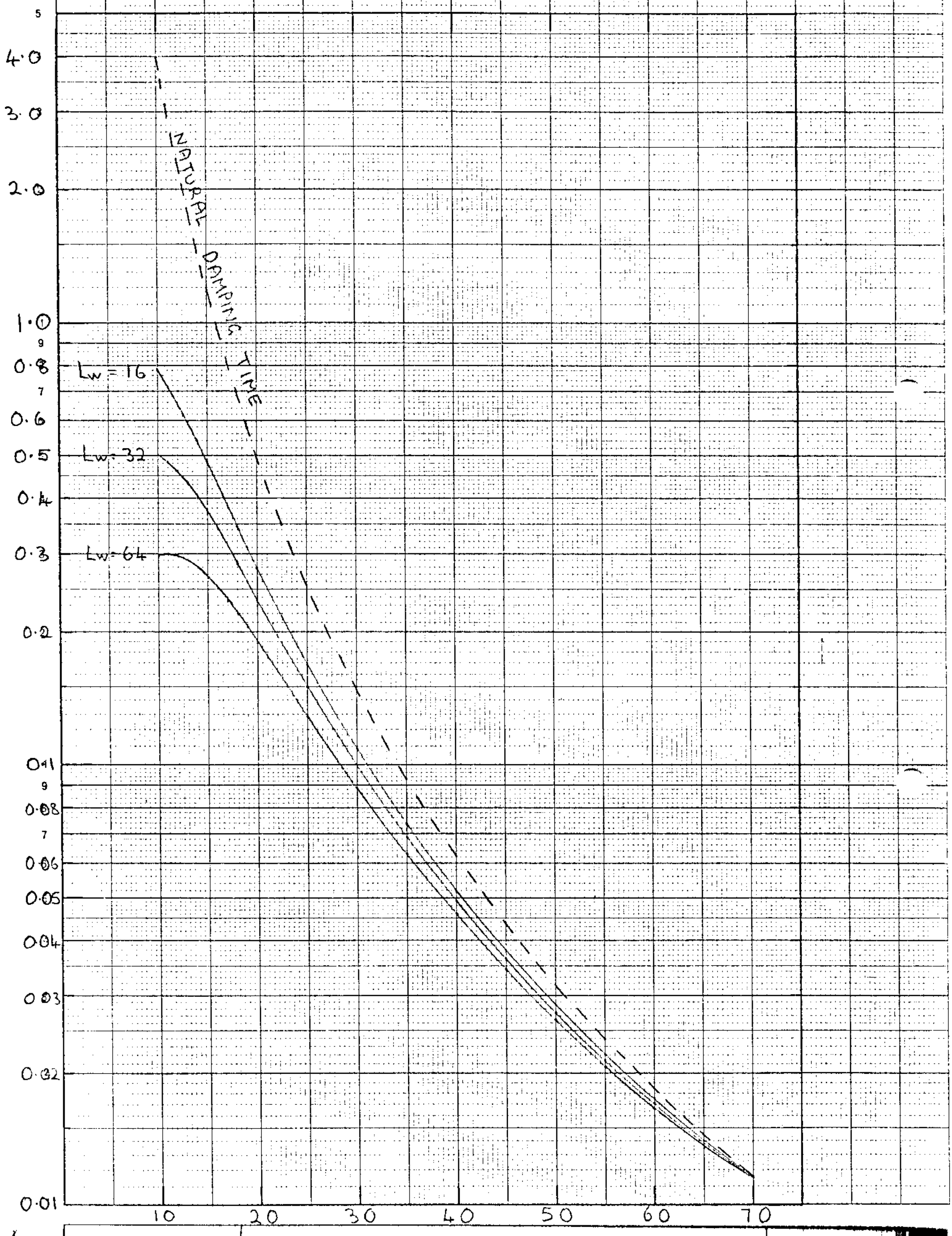

FIGURE 4 DAMPING TIME VERSUS WIGGLER LENGTH

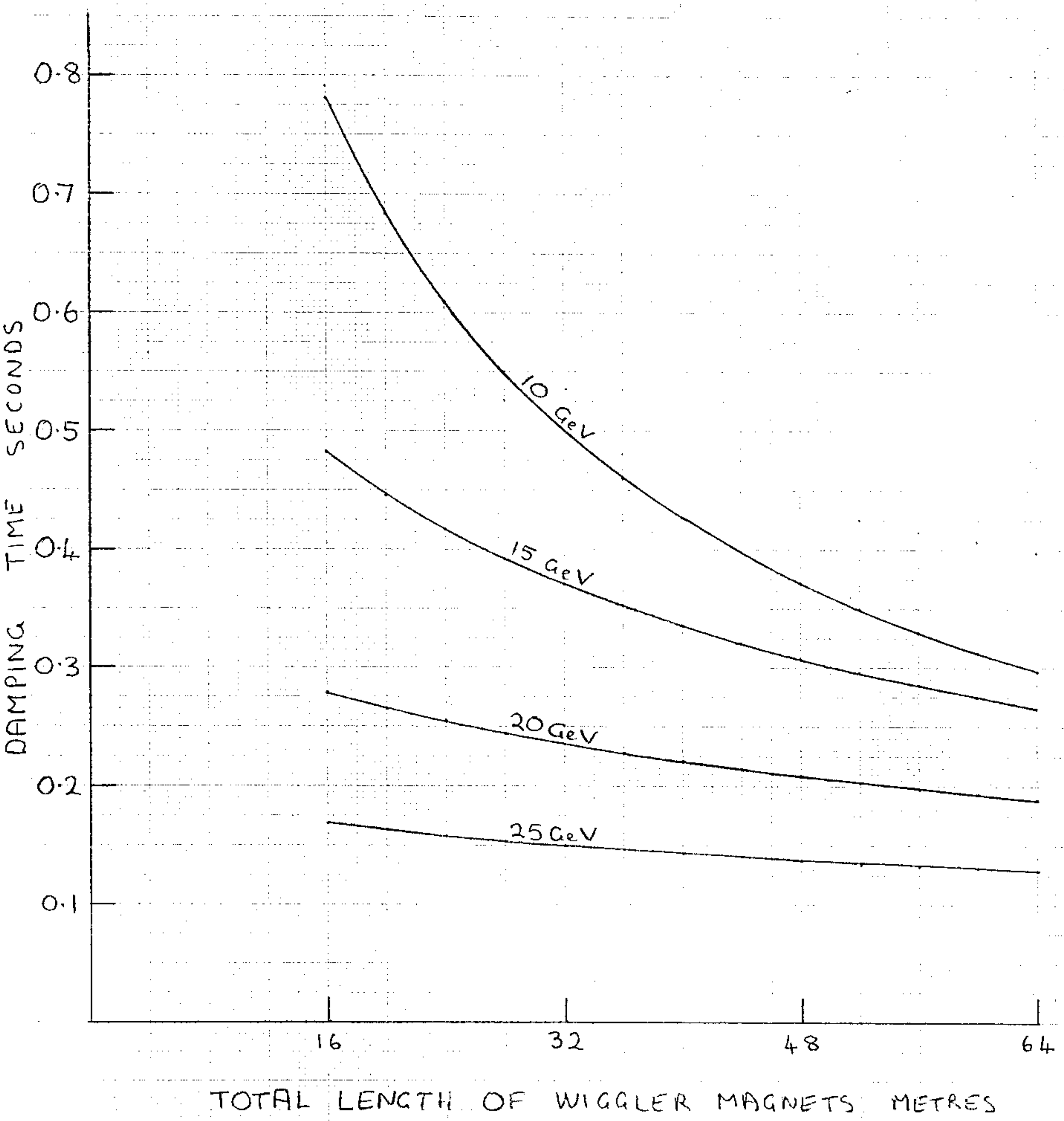

FIGURE 5 : LUMINOSITY AND CURRENT VERSUS ENERGY

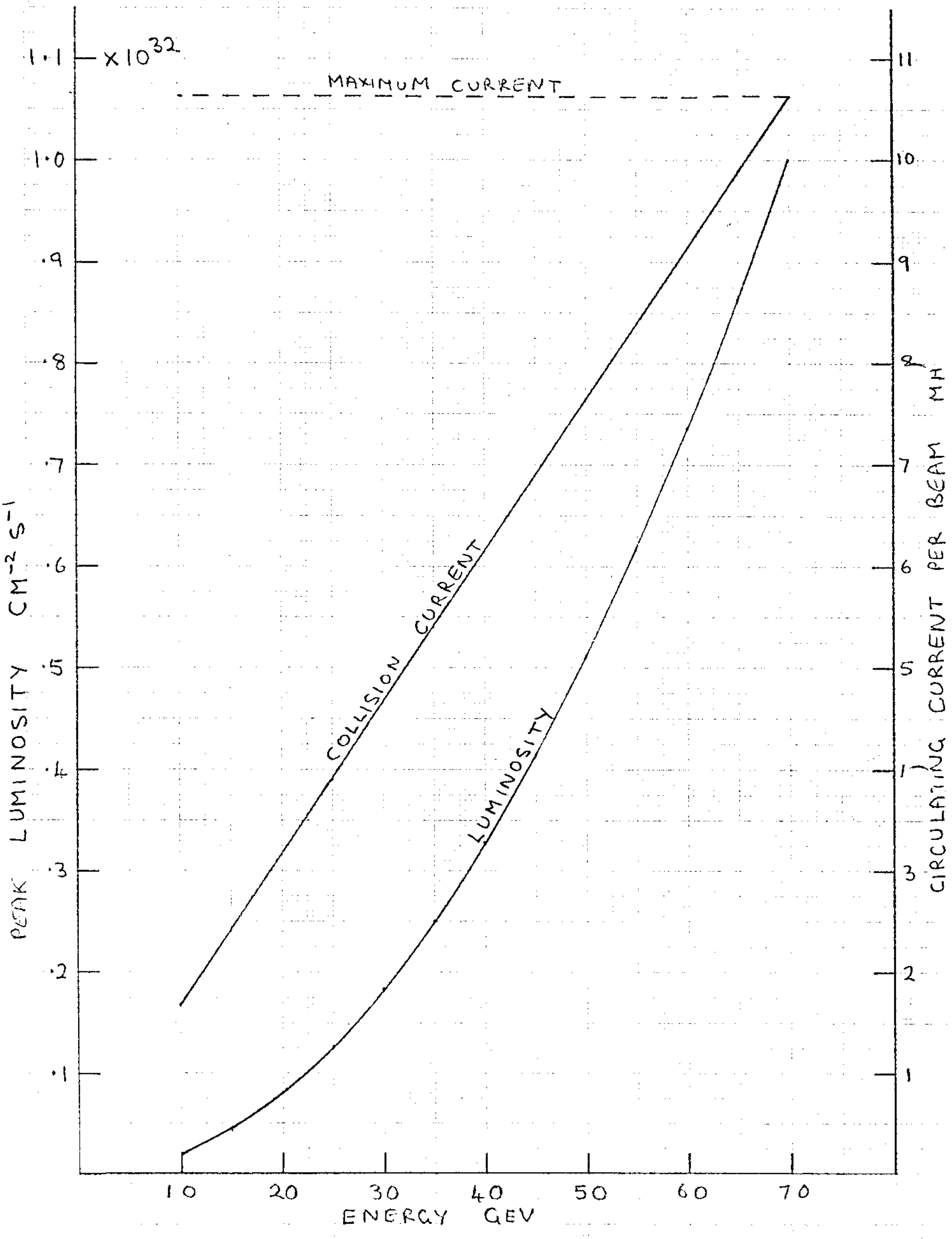

FIGURE 7 : R.F POWER AND VOLTAGE VERSUS ENERGY

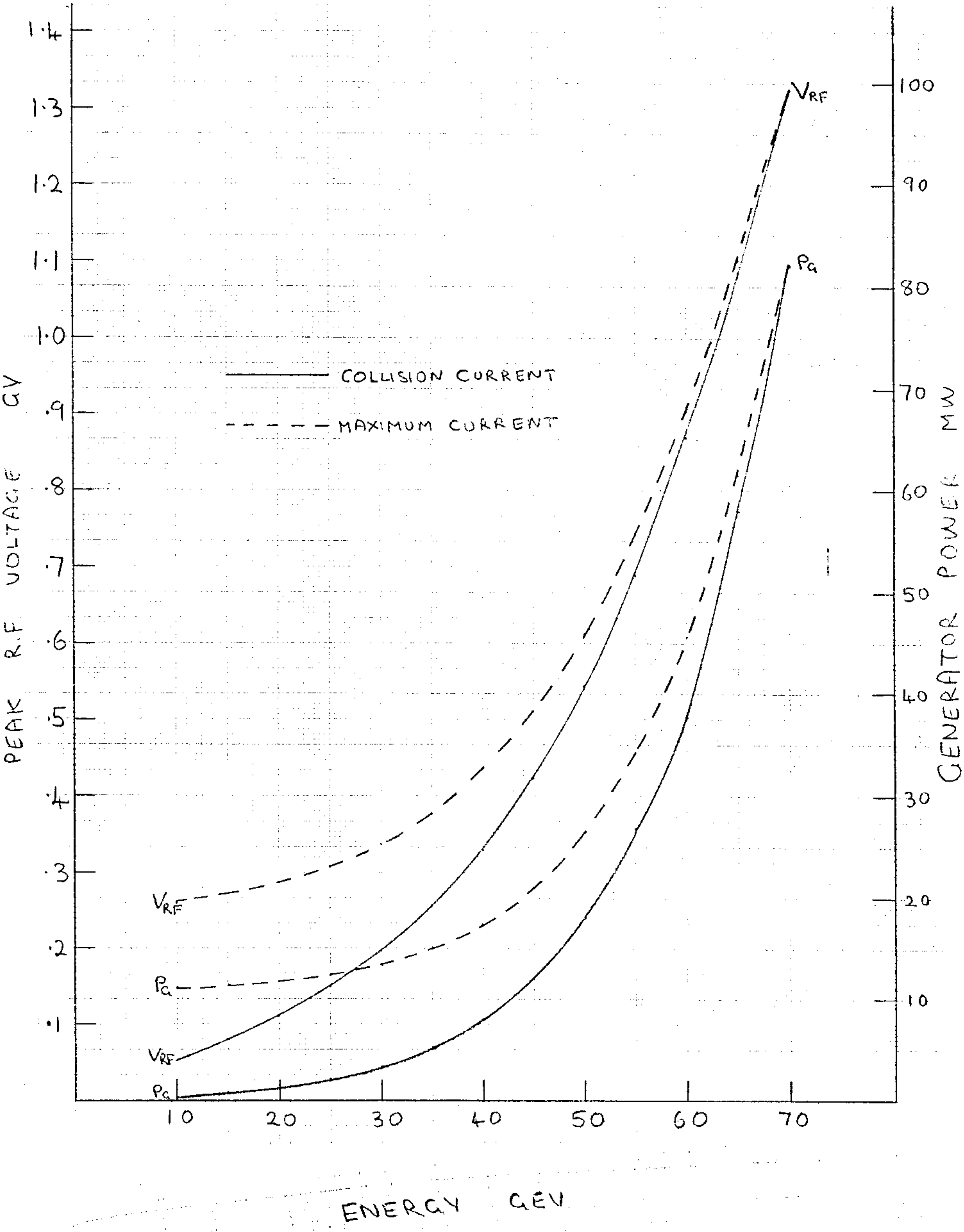

FIGURE 8 BREMSSTRAHLUNG LIFETIME VERSUS ENERGY