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Single Bunch Operation in DORIS

by

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Introduction

The electron positron storage ring was completed end of 1973 for first injection. In the following months an instability was found which limits the maximum average positron current to some 170 ma. Although this instability is not yet understood enough it seems that some rf-oscillation modes in the cavities or in some of the vacuumvessels are causing coherent bunch oscillations. Since we have 480 bunches there are 240 oscillation modes and to feed back these coherent oscillations a system is needed with a band width of 250 MHz which is technical not feasible.

It seems difficult to solve these problems very soon. Not to keep up the start of the high energy experiments we want to propose to operate DORIS for some time with only one bunch per beam colliding head on. In this case first the average current is much smaller and by that the excitation of these disturbing rf-modes, and second it is easy to feed back coherent oscillations since now we need only a narrow band feed back system working in the vicinity of 1 MHz which is standard technique. Parallel to the high energy physics experiments we could study the multi bunch instability more thoroughly.

In an unchanged DORIS-structure however, the luminosity for one bunch per beam would be very poor and far below luminosities achieved by SPEAR. Therefore we have to take out the vertical crossing angle and use head on collision. For this we need only to take out the preseptum and replace it by a simple weak bending magnet for both beams as described below.

The injection system needs not to be changed if we use only the two upper half rings for e^+e^- collision and for e^-e^- collision both rings as used now (see fig. 1).

Head on collision has also an optical advantage. With a crossing angle the beam trajectories pass the big quadrupoles adjacent to the interaction points at large distances and slopes with respect to the center of the quadrupoles. This causes kinematical nonlinear terms in the equation of motion which can cause nonlinear resonances and the appearances of satellite resonances. For head on collision only a small part of the quadrupol aperture in the center is used thus reducing the nonlinear effects to a minimum.

Going to head on collision we may also avoid unknown difficulties with the beam beam interaction. It is not known what is the maximum allowable linear tune shift due to the beam beam effect if we have a crossing angle of 24 mrad. It is known however, that for small crossing angles in the order of 2 to 5 mrad the linear tune shift and therefore the luminosity is much smaller than for head on collision. At a $\Delta Q = 0.001$, which is much less than the ΔQ one can reach with head-on collision, we have observed in DORIS already a beam enlargement.

For the experiments a one bunch mode of operation means a smaller duty factor than in the case of 480 bunches. This small duty factor however, seems not to cause unsolvable problems since this is the same duty factor as used at SPEAR. On the other hand the one bunch mode of operation reduces very much the amount of background. The total currents are at most 45 ma per beam at 4 GeV and scale like E^3. This is a factor of 20 less current than needed in the present mode of operation for luminosities of the order of 2 to $5\times10^{30}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$.

Besides this background aspect the reduction of the beam current reduces very much the desorption due to the synchrotron radiation on the walls of the vacuum pipe. As a consequence of this the vacuum with a stored beam can be better by more than one order of magnitude giving a lifetime of the order of 5 to 10 hours according to SPEAR experience.

Optical properties

In the single bunch operation it is not necessary, to localize the interaction of the two beams by a crossing angle, because the two bunches in the machine can meet only at the two interaction points. Therefore we go to head-on collision. But this requires an other focusing of the beam at the interaction point: While with vertical crossing angle ϕ the effective beam height σ_z^{eff}

$$\sigma_z^{eff} \sim \sqrt{(\sigma_z^{nat})^2 + (\sigma_B\cdot\phi)^2}$$

σ_z^{nat} = natural beam height

σ_B = bunch length

is dominated by the term $\sigma_B \cdot \phi$ (which means that the effective beam height is nearly in dependent of the vertical focusing β_o^z) we have with head-on collision (in the beam beam limited regime)

$$L \sim \frac{1}{\beta_o^{z\ 3/2}} \quad .$$

The horizontal beam waste is only restricted by

$$\beta_o^x \leq \frac{\beta_o^z}{K}$$

(with $K = \frac{\varepsilon_z}{\varepsilon_x}$ coupling constant).

To avoid large amplitude functions in the quad's adjacent to the interaction point one has to change polarity in the WQ I/II - duplett. Because we don't want to lift the interaction point by 40 cm (i.e. the whole experimental set-up) and to hold the option for e^-e^- open, we keep the vertical deflection.

In the beam beam limited regime the luminosity is proportional to the natural horizontal beam emittance. For maximum luminosity one should choose the lattice as to have the natural horizontal beam emittance equal to the aperture of the machine. As a compromise we show in the following two modes for the lattice:

Mode I: for energies up to 3.8 GeV
Mode II: for higher energies

Both modes have the same amplitude functions at the interaction point:

$$\beta_o^x = 0.75 \text{ m}$$

$$\beta_o^z = 0.06 \text{ m}$$

They are different mainly in the natural beam emittance $\varepsilon_x = \sigma_x^2/\beta_x$

Mode I $\quad \varepsilon_x(\text{rad m}) = 1.0 \cdot 10^{-7} \cdot E^2(\text{GeV})$

Mode II $\quad \varepsilon_x(\text{rad m}) = 3.4 \cdot 10^{-8} \cdot E^2(\text{GeV})$

the momentum compaction factor

Mode I: $\alpha = 0.039$

Mode II: $\alpha = 0.018$

and the chromaticity $\xi = \dfrac{\Delta Q}{\Delta p/p}$

Mode I: $\xi_H = -17$ $\xi_V = -32$

Mode II: $\xi_H = -18$ $\xi_V = -59$

In Mode I the chromaticity can be canceled by sextupoles, while in mode II the chromaticity can only be compensated partly. For the head-tail instability we need therefore a feed back system. A drawing of the envelopes, is shown in figs 2 and 3. The hardware changes, which are needed in the two modes, are discussed in section 4.

Parameters

For the one bunch mode of operation with head on collision we know from ADONE and SPEAR experience that the luminosity is limited only by the beam beam limit for low and medium energies and by the rf-power at the very highest energies. Here we assume that the head tail effect and coherent instabilities are cured by sextupoles and/or by feed back systems as successfully demonstrated at SPEAR.

In the beam beam limited regime the luminosity is given by:

$$L = \frac{1}{4\pi e^2 f} \frac{I^2}{\sigma_x^* \sigma_y^*}$$

where

$$\frac{I}{\sigma_x^* \sigma_y^*} \leq \frac{2\pi \Delta Q e f \cdot \gamma}{r_e \beta_y}$$

or:

$$L = \frac{\pi f \Delta Q^2}{r_e^2} \gamma^2 \frac{\sigma_x^* \sigma_y^*}{\beta_y^{*2}} = 5.7 \cdot 10^{35} \frac{\sigma_x^* \sigma_y^*}{\beta_y^{*2}} E^2$$

$([L] = [cm^{-2} sec^{-1}]$; f: revol. frequency; $\Delta Q = 0.06)$ (fig. 4)

In this regime the beam cross section should be large and the vertical amplitude function very small. For the mode I optics we have $\varepsilon_x = \frac{\sigma_x^2}{\beta_x}$ (rad m) $= 1.0 \cdot 10^{-7} \cdot E^2 (GeV^2)$ $\beta_y^* = 6.4$ cm, and $\beta_x^* = 75$ cm. If we take a coupling of the emittances of $K = \frac{\varepsilon_y}{\varepsilon_z} = 0.0025$ as achieved in SPEAR we get $\sigma_x^* \sigma_y^* = \varepsilon_x \sqrt{K \cdot \beta_x^* \beta_y^*} = 1.1 \cdot 10^{-9} \cdot E^2$ and for the luminosity

$$L_I \; (cm^{-2} sec^{-1}) = 1.5 \cdot 10^{29} \cdot E^4 (GeV^4)$$

The corresponding beam currents are given by

$$I_I \; (ma) = 0.75 \cdot E^3 (GeV^3) \qquad \text{(fig. 5)}$$

In this mode I optic we reach the rf-power limit at 3.8 GeV with a luminosity of $L_{max} = 4.2 \times 10^{31}$ $cm^{-2} sec^{-1}$ and a beam current of $I_{max} = 43$ ma per beam. This bunch current seems not to high if we scale from SPEAR results. We do not know anything about bunch lengthening but if we assume the same bunch-lengtheningfactor for DORIS as for SPEAR,we could scale with the theoretical bunchlength. In SPEAR a bunch current of 200 ma for a theoretical bunchlength of 6.5 cm was achieved. For DORIS the theoretical bunch length is of the order of 2 cm. A bunch current of 43 ma gives a smaller charge density than achieved in SPEAR.

Going to higher energies than 3.8 GeV we use the mode II optics with a smaller momentum compaction factor.

Here the beam emittance is $\varepsilon_x = 3.4 \times 10^{-8} \cdot E^2$ which gives a luminosity of:

$$L_{II} \; (cm^{-2} sec^{-1}) = 5.1 \; 10^{28} \cdot E^4 (GeV^4)$$

with a bunch current of:

$$I_{II}\ (\text{ma}) = 0.26 \cdot E^3(\text{GeV}^3)$$

In this mode II the rf-power limit is reached at 4.4 GeV with a luminosity of $L_{max} = 1.9\times10^{31}\ \text{cm}^{-2}\text{sec}^{-1}$ and a current of $I_{max} = 22$ ma.

To achieve higher energies the rf-power has to be increased or what is much cheaper the cavity losses have to be reduced. This can be done by new and more cavities or by putting all the cavities we have now into one ring. Doing so we reduce the cavity losses by a factor two. In this case we can reach energies up to 5.3 GeV with a luminosity of $L = 3.7\times10^{31}\ \text{cm}^{-2}\text{sec}^{-1}$. The current then is $I = 36$ ma.

The rf-power delivered to one beam which is transformed into synchrotron radiation is given by

$$P_B(\text{kW}) = 7.3\times10^{-3}\ E^4(\text{GeV}^4) \cdot I(\text{ma})$$

In mode I therefore the maximum synchrotron light power is 64 kW per beam at 3.8 GeV and in mode II it is 57.5 kW per beam. Only in the case where we put all the rf-cavities and all the rf-power into one ring (mode III) the synchrotron light power goes up to 140 kW at 5.0 GeV which seems to be the maximum energy for the magnets.

Injection and hardware changes

With the present injection system and by throwing out the not used bunches either in the linac or in the storage ring we expect the following injection times:

For a luminosity of 3×10^{31} at 3.5 GeV we need an average current of 35 mA. With

$$I^{e^+}_{peak} = 250\ \mu\text{A}$$

Injection efficiency = 50 %

rep. rate of injection: 50 c/sec

we have $T^{e^+} = 45$ min ; $T^{e^-} \sim 1$ min. To decrease the injection time for e^+ we propose, to equip the linac II with a triode-gun of coaxial type. This gun should be able to deliver pulses of about 2 nsec width and peak currents of more than 10 A at the converter. With the same beam power at the converter as present it should be possible to increase the analysed e^+ beam by more than a factor of 5. This reduces the e^+ filling time to less than 10 min.

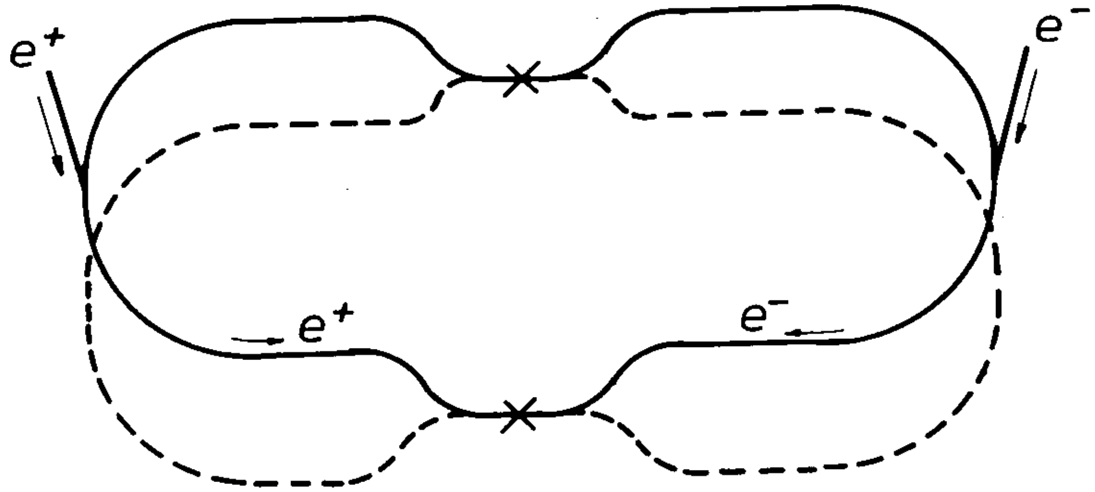
Connected with the single bunch production is the need for a trigger system of linac, synchrotron and storage ring.

The storage ring itself has to be changed only in the area of the vertical bending:

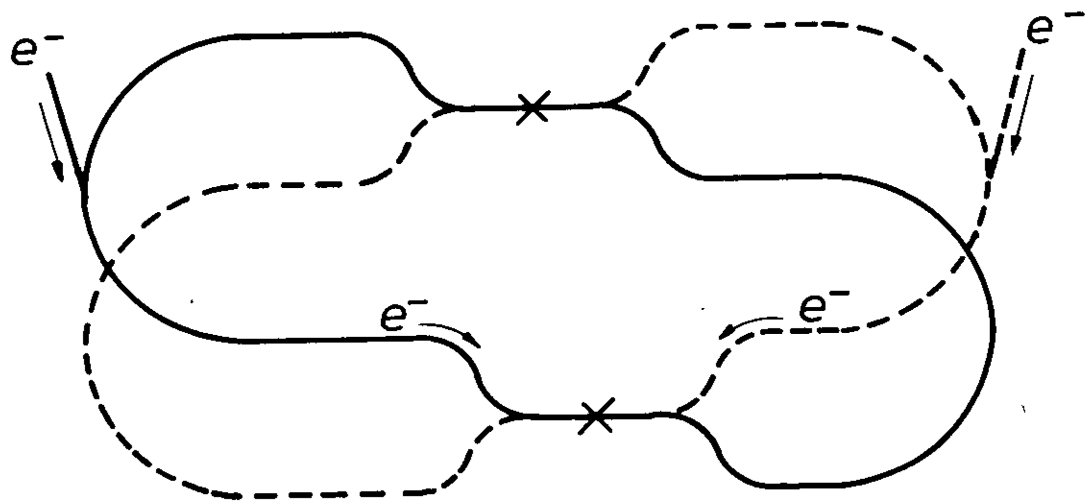
For mode I the strength of the VS has to be increased by 40 % (ρ = 127 m) and the vertical position of the magnet has to be changed by 8 cm or the VS should be replaced by a dipole magnet (Θ = 19 mrad). The vacuum chamber associated with the VS has to be rebuild.

For mode II there is additional to the changes of mode I a change in position of the large quadrupoles adjacent to the interaction point by 0.8 m. (This means a 180° turn on the present support.) By that the experimental area is increased to a total of 7 m. The vacuum connecting the WQ I/II with the VS has to be rebuild. A feed back system with narrow band width must be prepared.

Probably one has to integrate in the existing absorber system for synchrotron light some additional spot-absorbers, because now in every vacuum chamber there are two counter rotating beams. But the maximum synchrotron light power is less than 65 kW which is a factor of 10 less than the maximum design synchrotron light power.

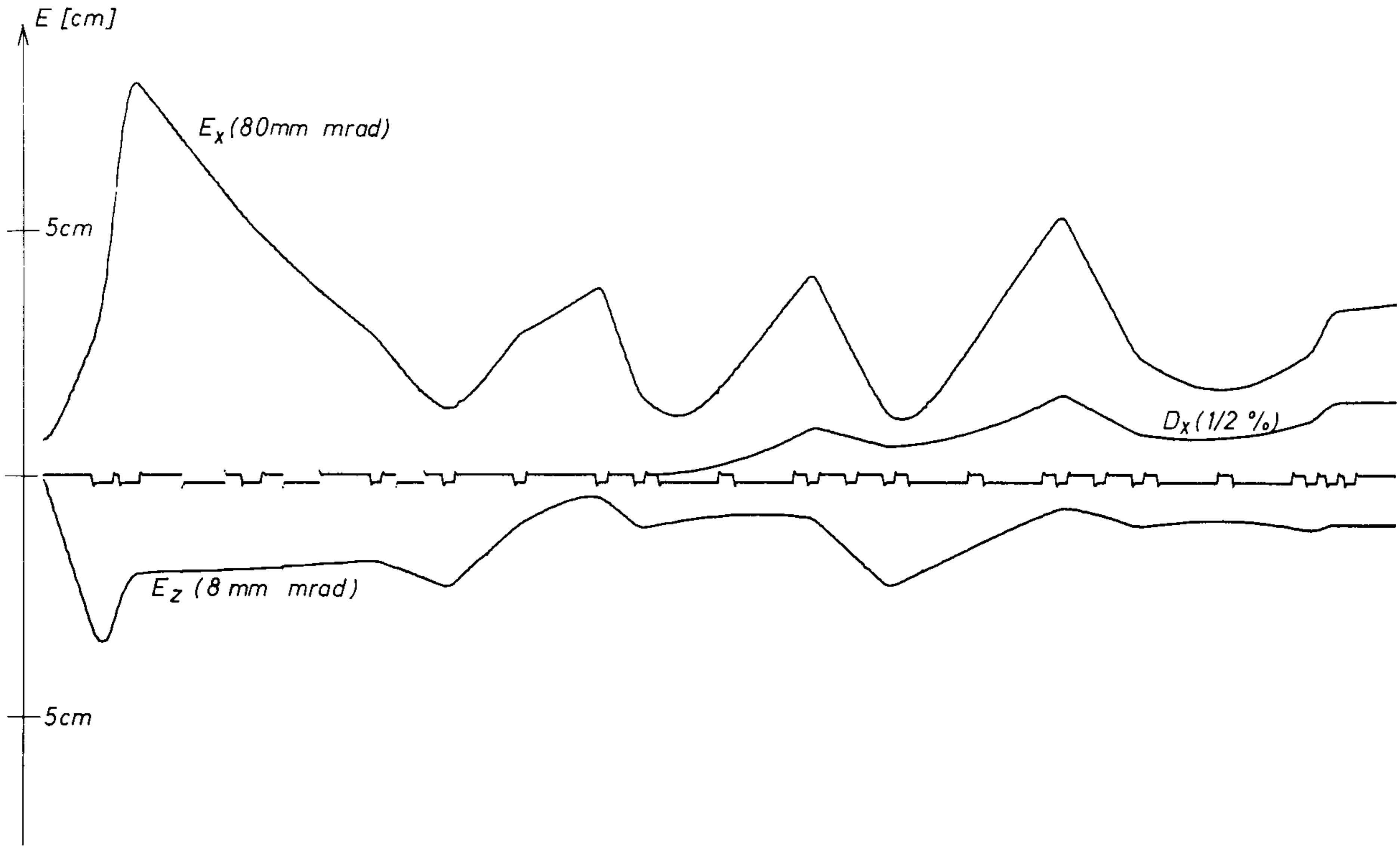


$e^+ e^-$-operation



$e^- e^-$ - operation

FIG. 1



Mode I : Beam size and dispersion function

FIG. 2

Mode II : Beam size and dispersion function

FIG. 3

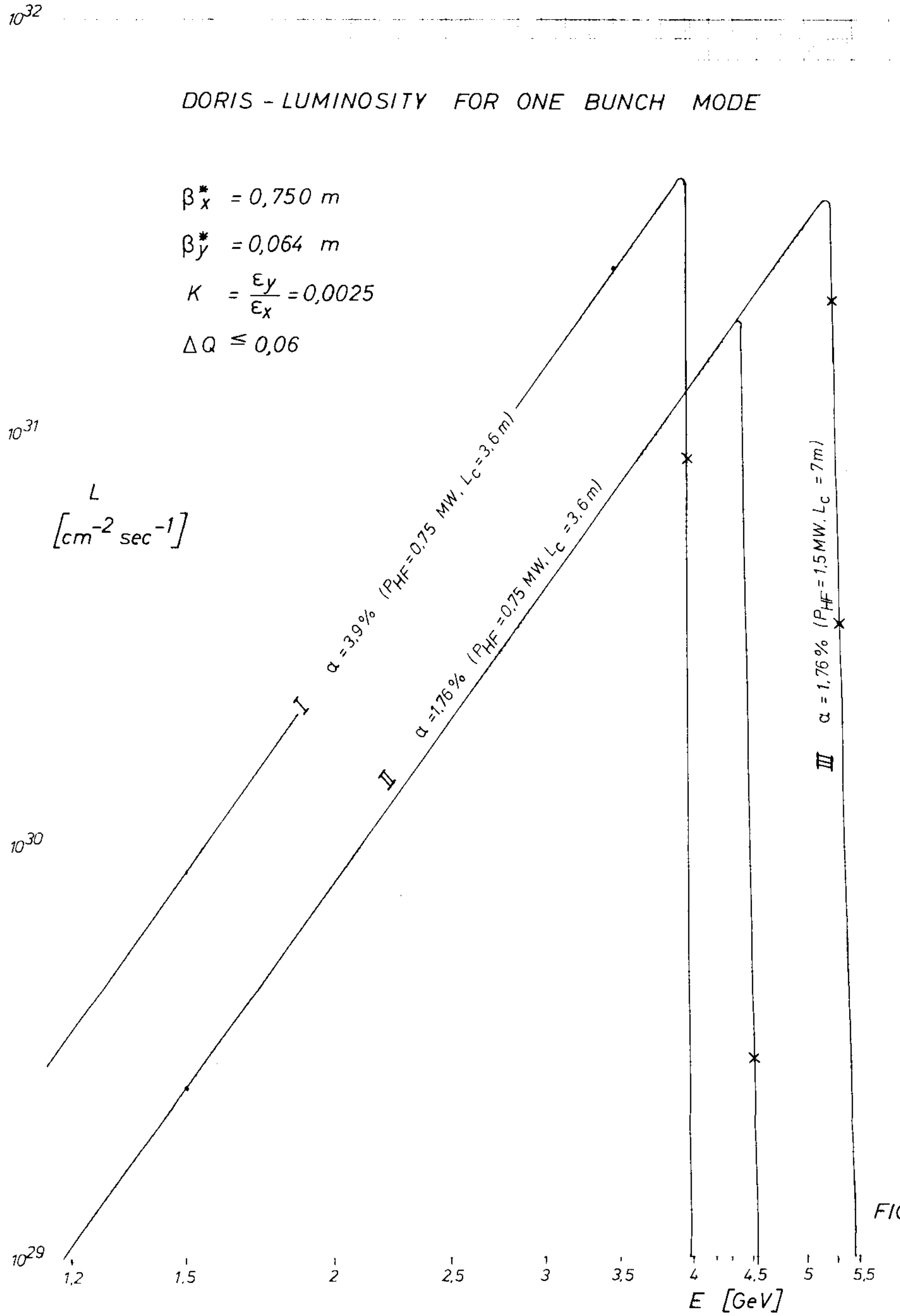

DORIS - LUMINOSITY FOR ONE BUNCH MODE
$\beta_x^* = 0,750$ m
$\beta_y^* = 0,064$ m
$K = \frac{\varepsilon_y}{\varepsilon_x} = 0,0025$
$\Delta Q \leq 0,06$
10^{32}
10^{31}
10^{30}
10^{29}
L
[cm^{-2} sec^{-1}]
I $\alpha = 3,9\%$ ($P_{HF} = 0,75$ MW, $L_c = 3,6$ m)
II $\alpha = 1,76\%$ ($P_{HF} = 0,75$ MW, $L_c = 3,6$ m)
III $\alpha = 1,76\%$ ($P_{HF} = 1,5$ MW, $L_c = 7$ m)
1,2
1,5
2
2,5
3
3,5
4
4,5
5
5,5
E [GeV]

FIG. 4

TOTAL BEAM CURRENT IN THE ONE BUNCH MODE

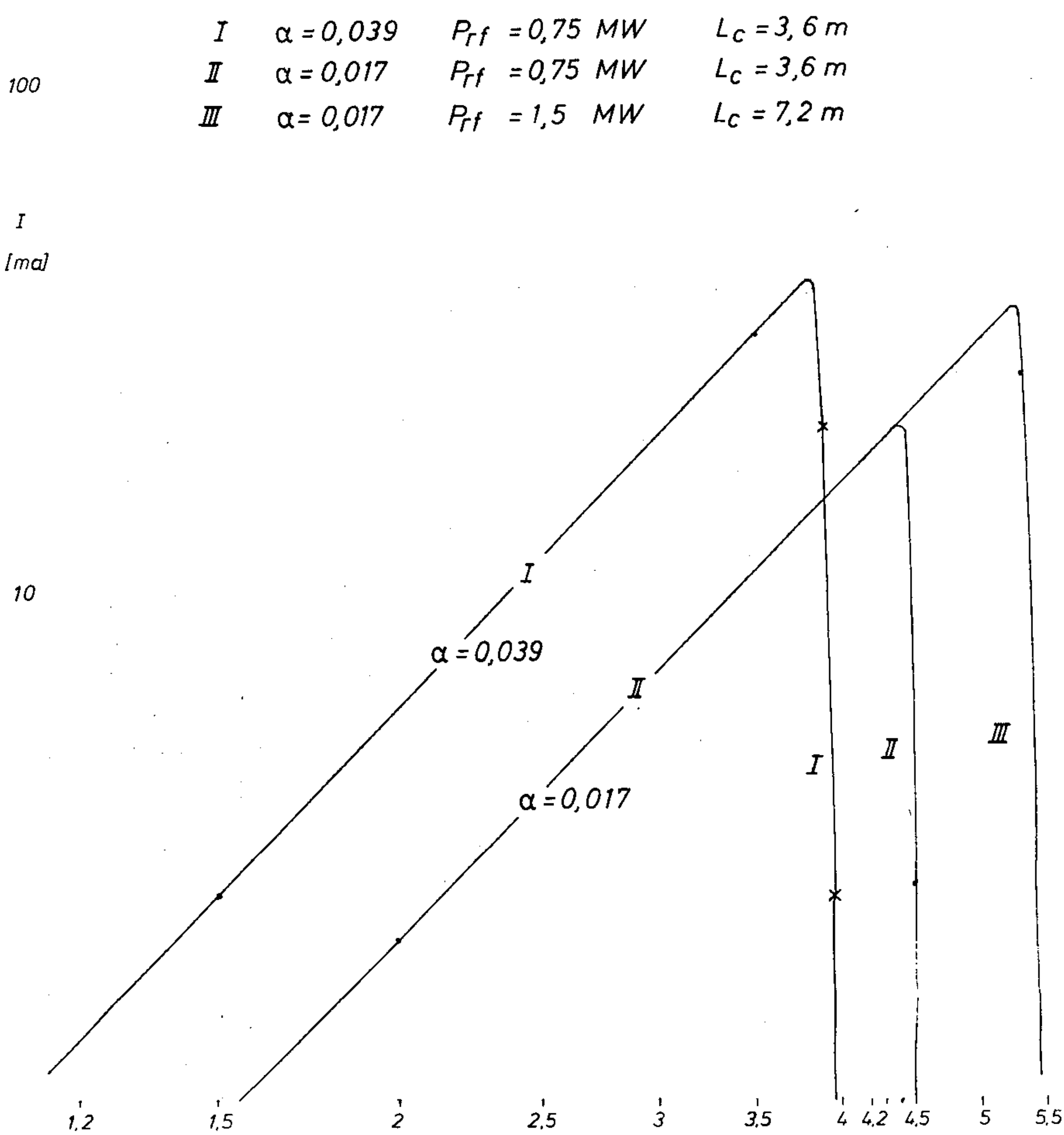


FIG. 5